A Prospective Study of Twin Block Appliance Therapy in Children with Class II Division1 Malocclusions Assessed by MRI, 3D-Cephalometry and Muscle Testing

A thesis submitted for the degree of Doctor of Philosophy
by

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Abstract

Functional appliances have been used to correct skeletal Class II malocclusions by repositioning the mandible anteriorly, with favourable changes around the temporomandibular joint (TMJ) being reported. Stimulation of lateral pterygoid activity leading to increased condylar growth at its muscular attachment has been proposed as a mandibular growth controlling mechanism. Varying degrees of skeletal and dento-alveolar change have been noted and the response to functional appliance therapy remains controversial.

Seventy-one children with Class II division 1 malocclusions were investigated over a period of six months. Thirty-four children were treated with Clark Twin Block appliances (CTB) while 37 children received no treatment and served as controls. The main objective of this study was to assess changes in the dento-facial structures, including the TMJ, between the experimental and control groups. Hard and soft tissue changes in the TMJ were investigated using Magnetic Resonance Imaging (MRI). Three-dimensional cephalometry was used to assess skeletal and dento-alveolar changes. Adaptation of protrusive musculature was also assessed.

CTB therapy was associated with significant reductions in overbite and overjet, correction of Class II canine and molar relationships, and an increase in the range of mandibular movement. The correction of the malocclusions included a combination of dento-alveolar changes, demonstrated by upper incisor retroclination and lower incisor proclination, as well as skeletal changes demonstrated by anterior downward rotation of the maxilla, increased mandibular length and gonial angle. The condylar head that was positioned anteriorly on the crest of the articular eminence when the CTB was inserted had repositioned back into the articular fossa with a normal disc-condyle relationship after six months of treatment. However, the position of the condyle was more anteriorly positioned in the fossa. Fatiguing of the protrusive musculature did not change this corrected mandibular position. A reduction in condylar axial angle and an increase in maximum protrusive force found in the controls could not be demonstrated in the CTB group. It is hypothesised that condylar and muscular growth were modified by CTB therapy. Treatment with the CTB had neither positive nor negative effects on the condition of disc displacement.

Signed Statement

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Kanoknart Chintakanon

30 March 1999

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Chapter 1 Introduction & Objectives

1.1 Introduction:

Many different types of functional appliances have been used to correct skeletal discrepancies by changing the posture of the mandible in growing children. In the correction of Class II skeletal patterns in patients with retrognathic mandibles, the components of functional appliances guide the mandible to a pre-determined anterior position for a certain period of time. At the end of treatment, improved clinical appearances such as reduction of overbite and overjet, attainment of competent lips, increased lower facial height, and straighter facial profile are achieved. However, the mechanisms of Class II correction with functional appliances remain unclear. Varying degrees of skeletal and dento-alveolar changes have been reported. Controversy has focused on whether functional appliances can stimulate greater mandibular growth than normal or than other forms of orthodontic treatment. Justification for the use of functional appliances has been questioned from a cost-benefit perspective (Gianelly, 1995; Livieratos & Johnston, 1995; Tulloch *et al*, 1998).

The role of muscle activity, the lateral pterygoid muscle in particular, has been proposed as a control mechanism of mandibular growth. As the mandible is repositioned anteriorly during treatment, adaptation at the temporomandibular joint (TMJ) is also an area of interest. The relationship between functional appliance therapy and temporomandibular disorders (TMD) has been a controversial topic. Functional appliances have been reported to provide a more appropriate condylar position than fixed appliance therapy (Witzig & Spahl, 1986); to correct disc displacement (Clark, 1995); to induce internal derangement of the TMJ (Foucart *et al*, 1998) or to have no effect on temporomandibular disorders (Ruf & Pancherz, 1999).

Previous studies examining skeletal and dento-alveolar changes following the use of functional appliances have been based mainly on conventional lateral radiographic cephalometry, occasionally with the addition of frontal cephalometry. The disadvantage of these studies is that they only provide two-dimensional projection measurements of complex three-dimensional structures. Measurements are subject to projection error (head position) and magnification error (object-film distance). Moreover, conventional lateral cephalometry does not differentiate right or left sides. The average of the lateral structures has been used and treated as though all the structures lie in the mid-sagittal plane. Three-dimensional cephalometry is considered superior as it overcomes many of the problems of conventional cephalometry and it provides more realistic measurements of the structures investigated.

Studies of the TMJ based on radiographic techniques only provide information about the bony structures. The role of soft tissue adaptation, such as changes in the articular disc and retrodiscal tissue, has been considered to be an important factor to compensate for hard tissue remodelling and maintaining normal function of the TMJ. Magnetic Resonance Imaging (MRI) has recently been used to investigate both the hard and soft tissue of the TMJ. It is non-invasive and provides information in three dimensions.

The "lateral pterygoid hypothesis" has been used to explain the mechanism of growth stimulation of the mandible resulting from treatment with functional appliances. It has been hypothesised that functional appliances increase lateral pterygoid activity and consequently increase condylar growth at the muscular attachment. It is difficult to access the lateral pterygoid directly and direct investigation is usually invasive and painful. In the correction of mandibular retrognathism, the mandible is repositioned anteriorly, involving protrusive muscle function of both lateral pterygoid and anterior masseter muscles. The role of protrusive muscles in maintaining the new position of the mandible after functional appliance therapy has not been reported clearly in the literature to date.

1.2 Objectives:

This research was designed as a **prospective study** to examine skeletal, dento-alveolar and muscular adaptations to forward repositioning of the mandible as a result of treatment with a functional appliance (Clark Twin Block - CTB) superimposed on normal growth and development. The results were compared with a matched sample of non-treated children to assess the effects of growth and development alone. The observation period was six months as substantial changes had occurred during this period of time.

Previous studies of CTB therapy have shown significant reduction in overbite and overjet, and a straighter facial profile after relatively short periods of treatment. Furthermore, removal of the CTB does not lead to a repositioning of the mandible back to its pre-treatment position. Several mechanisms have been hypothesised to explain how correction of mandibular position might occur, including alterations in protrusive muscle activity, skeletal changes including remodelling of the glenoid fossa, and dento-alveolar effects.

This study aimed to develop new approaches to test these hypotheses, as well as to investigate whether any adverse effects might occur in the TMJ. The research was divided into four parts with objectives as follows:

Part 1 Clinical assessment:

1. To quantify the amount of Class II correction as a result of CTB therapy compared with spontaneous growth changes in a matched non-treated sample.
2. To assess whether the range of mandibular movement was altered by CTB therapy.
3. To investigate whether CTB therapy affected clinical signs and symptoms of temporomandibular disorders (TMD).

4. To assess whether the timing for commencement of treatment, indicated by growth and development indicators, influenced the magnitude of clinical changes.

Part 2 Muscle testing:

1. To develop a new technique for studying the protrusive masticatory musculature by measuring maximum protrusive force and time to fatigue the muscles.

2. To test whether on removal of the appliance, the anterior position of the mandible was maintained by hyperactivity of protrusive muscles. It was hypothesised that if muscular hyperactivity was the mechanism maintaining the forward mandibular position, deliberate fatiguing of protrusive muscle would result in a relapse of mandibular position.

3. To describe the effects of normal growth and development on the patterns of maximum protrusive force and time to fatigue protrusive muscles in Class II division 1 children, and to test whether CTB therapy altered these patterns.

Part 3 Magnetic Resonance Imaging (MRI):

1. To develop a new technique to transfer reference landmarks from cephalograms to MRI so that changes in the TMJ region could be related to craniofacial structures that were not apparent on the MRI.

2. To describe the effects of normal growth and development on condyle-disc-fossa relationships in axial, sagittal and coronal planes in Class II division1 children and to test whether CTB therapy altered these relationships.

3. To investigate whether remodelling of the condyle and mandibular fossa associated with CTB therapy could be demonstrated by MRI.

Part 4 Three-dimensional cephalometry:

1. To develop a new three-dimensional radiographic cephalometric system for investigation of skeletal and dento-alveolar changes in three dimensions.

2. To describe the skeletal and dento-alveolar growth patterns of Class II division1 children.

3. To assess whether CTB therapy led to increased mandibular length or was limited to dento-alveolar changes only.

As it was claimed by Clark (1995) that the Twin Block appliance can achieve rapid response as early as six months, this research focussed on early treatment effects with an observation period of six months. Future research is needed to investigate long-term effects and to refine the new techniques developed in this project. Three-dimensional cephalometric measurements of untreated Class II children obtained in this study could serve as control data in future research.

Chapter 2 Literature Review

Topics:

2.1 Class II Malocclusion

2.1.1 Classification

Edward H. Angle (1907) classified dental malocclusion into three classes indicated by interdigitation of the first permanent molars. Class II division1 was described as the relationship in which the mesio-buccal cusp of the maxillary first permanent molar occluded mesial to the mesio-buccal groove of the mandibular first permanent molar, together with protrusion of upper incisors. Although Angle classification is universally used in sub-grouping different types of malocclusion, it is based only on antero-posterior dental relationships and does not take into account discrepancies in vertical or lateral planes. It also does not quantify the elements of occlusal disharmony.

Class II malocclusion is not a single entity and not homogenous, comprising several subgroups with numerous skeletal components. Skeletal Class II relationships may result from a prognathic maxilla with an orthognathic mandible, an orthognathic maxilla with a retrognathic mandible or a combination of both prognathic maxilla and retrognathic mandible. Several studies agree that mandibular retrusion, either reduced mandibular length or posterior position of the mandible, is the most common finding in Class II samples (Hitchcock, 1973; Moyers *et al*, 1980; McNamara, 1981; Carter, 1987; Ferrario *et al*, 1994b; Karlsen, 1994; Pancherz *et al*, 1997). However, Rosenblum (1995) noted that a prognathic maxilla and orthognathic mandible is the dominant type. Rosenblum (1995) suggested the contradiction could be ascribed to the reliability of the cephalometric analyses which are particularly dependent upon the reference planes chosen.

Unlike the wide agreement about the most common horizontal Class II type, studies of vertical discrepancies in Class II patients do not concur. McNamara (1981) reported long lower facial height as the most common type (46%) while Pancherz *et al* (1997) reported 97% –100% frequency of short lower face height in their Class II sample. The authors (Pancherz *et al*, 1997) also concluded that except for the position of the maxillary incisors, no basic difference in dentoskeletal morphology exists between Class II division 1 and Class II division 2 malocclusions. Karlsen (1994) described Class II patients with deep overbite as having shorter than normal total anterior facial height. The maxillary and mandibular molar heights were also shorter than normal. In the Class II group without deep overbite, a steep mandibular plane, upward tilted palatal plane, and larger maxillary and mandibular incisal height were characteristic features. Angelillo and Dolan (1982) reported that Class II malocclusion is the most common type of malocclusion in patients with long face syndrome.

Cranial base angle (Ba-S-N) and the lengths of anterior cranial base (N-S) or posterior cranial base (S-Ba) are believed to be the fundamental determinants of jaw relation rather than the size of the mandible. It has been found that in Class II groups, the cranial base angle is significantly larger with shorter anterior and posterior cranial base lengths than Class I or Class III patterns, resulting in a more posterior position of the mandible (Anderson & Popovich, 1983; Kerr & Hirst, 1987; Dibbets, 1996).

Class II malocclusion in the primary dentition is characterised by a distal step relationship of the primary second molars, Class II deciduous canine relationship, and excessive overjet. This type of occlusion usually persists or becomes exaggerated later during the transitional period through to the permanent dentition (Ingelsson-Dahlstrom & Hagberg, 1994; Baccetti *et al*, 1997; Bishara, 1998). The skeletal pattern of Class II malocclusion in the deciduous dentition typically is characterised by significant mandibular skeletal retrusion and mandibular size deficiency. Cephalometric changes consist of significantly greater maxillary growth increments and smaller increments in mandibular dimensions in the Class II sample. Moreover, a greater downward and backward inclination of the condylar axis relative to the mandibular line, with consequent smaller decrements in the gonial angle, indicates a posterior morphogenetic rotation of the mandible (Baccetti *et al*, 1997).

It is important to differentiate Class II malocclusions for clinical applications, as treatment planning differs depending on aetiologic sites. For instance, a treatment plan for children with skeletal Class II with prognathic maxilla should aim to inhibit maxillary growth while a treatment plan for skeletal Class II with retrognathic mandible should aim to stimulate mandibular growth. Therefore, caution should be exercised when comparing treatment effects of Class II malocclusions.

2.1.2 Epidemiology

Class II malocclusion is the second largest subgroup of malocclusions in most populations. An extensive review of 44 studies in 18 countries by Jago (1974) showed that the prevalence of Class II malocclusion ranges from 0% (Greenland – very small sample size) to 32.4% (USA). The prevalence in other populations not included in Jago's review (1974) is shown in Table 1. Differences in prevalence are likely to be due to several factors such as ethnicity, age group, sample selection, sample size and diagnostic criteria.

Table 1 ▪ The prevalence of Class II malocclusion in different populations

Authors	Population	Prevalence (%)
Homan & Davies, 1973	Aborigines and Torres Strait Islanders	Less than 5
Haavikko & Helle, 1974	Finnish	22
Freer & Olive, 1976	Australian (Qld)	31.4
Steigman *et al*, 1983	Israeli Arab	10.2
McLain and Proffit, 1985	American	15 – 20
De Muniz, 1986	Argentinean	10
Jones, 1987	Saudi Arabian	27.5
Woon *et al*, 1989	Chinese – Malaysian	18.12
	Indian – Malaysian	6.48
	Malay – Malaysian	12.5
Burgersdijk *et al*, 1991	Dutch	28
Spencer *et al*, 1992	Australian (SA)	47.9

Because a significant proportion of orthodontic patients present with Class II malocclusions, studying Class II developmental patterns and treatment changes is of considerable interest as results may in turn be applied to many different populations.

2.1.3 Class II malocclusion and temporomandibular joint

Abnormal temporomandibular joint (TMJ) morphology and a high prevalence of temporomandibular disorders (TMD) have been reported in patients with Class II malocclusions characterised by large overjet, deep overbite and retrognathic mandible (Solberg *et al*, 1986; Pullinger *et al*, 1988b; Seligman & Pullinger, 1989; al Hadi, 1993; Schellhas *et al*, 1993; De Boever *et al*, 1996; Burke *et al*, 1998). Class II patients have also been found to have steeper articular eminence inclination (Savastano & Craca, 1991). Associations between bilateral disc displacement and mandibular retrognathia have also been reported (Bosio *et al*, 1998).

Peltola *et al* (1995b; 1995c) reported an association of Class II malocclusion in children with condylar changes such as flattening of the articular surface, subcortical sclerosis, marginal erosion and other changes including deformities. Although Dibbets & Van der Weele (1991b) have also reported "deformed or flattened" appearances of condyles in children with a steep mandibular plane angle, short mandibular corpus and retrognathic chin. This "deformed appearance" appeared to come and go in an unpredictable manner. This phenomenon was hypothesised as a seasonal growth change which reflected a temporarily active growth vector rather than pathology.

Witzig and coworkers (Witzig & Yerkes, 1985; Witzig & Spahl, 1986) have suggested that mandibular retrusion and forward head posture are predisposing conditions of TMD. These factors result in a distally positioned condyle that consequently causes pain from compression of retrodiscal tissue. Treatment of a retrognathic mandible by forward repositioning of the condyle is then considered to be justifiable to prevent TMD. This forward position of the condyle is considered to be the optimal condylar position (Gelb, 1985). This hypothesis of Witzig and coworkers (Witzig & Yerkes, 1985; Witzig & Spahl, 1986) is not supported by any scientific studies. In fact, contradictory findings have been reported. Pullinger *et al* (1987) reported that non-concentric condylar position was a feature of their Class II malocclusion sample with significantly more anterior positions in Class II, division 1 subjects than in Class

I subjects. Posteriorly positioned condyles were found in only 4% of Class II division 1 patients (Gianelly *et al*, 1991a).

On the other hand, several investigations have not found significant differences in condylar position between Class II malocclusion and Class I occlusions (Demisch *et al*, 1992; Utt *et al*, 1995; Cohlmia *et al*, 1996). Moreover, several studies have failed to identify any specific type of occlusion or occlusal characteristics to be associated with TMD (reviewed by Simmons & Gibbs, 1997).

2.1.4 Class II malocclusions and muscular function

Muscular function is hypothesised to be a controlling factor in craniofacial growth and development of the dentition. Variations in muscular activity are believed to influence the expression of craniofacial features including types of occlusion (Strodel, 1987). The functional activities of the muscles of mastication, such as postural activity, maximum bite force and swallowing activity, have been found to vary between subjects with different craniofacial characteristics (Proffit *et al*, 1983; Hannam & Wood, 1989; Kiliaridis *et al*, 1993; Braun *et al*, 1995b; Ingervall & Minder, 1997; Raadsheer *et al*, 1999). Correlations between different muscular activities and different malocclusion types have also been reported (Lowe *et al*, 1983; Lowe & Takada, 1984; Weijs & Hillen, 1984; Wood, 1987; Miralles *et al*, 1991; Honicke *et al*, 1995).

The functional matrix hypothesis (Moss & Rankow, 1968; Moss & Salentijn, 1969; Moss, 1972; Moss, 1979) proposes that growth of cartilage and bone is a compensatory response to functional demands of matrix growth including muscles, nerves, glands and teeth. According to this hypothesis, growth of the mandible is not genetically predetermined but reflects the growth of muscles and other adjacent soft tissues. This also implies that the clinical presentation of malocclusion reflects the product of abnormal soft tissue function. Changes in the activity of masticatory muscles can theoretically influence the growth of the craniofacial structures (Melsen *et al*, 1986; Petrovic *et al*, 1988; Graber *et al*, 1997).

Although several studies have indicated that muscular activity in Class II malocclusions differs from Class I and Class III malocclusions, the results are inconclusive. While Class II division 1 patients have been reported in some studies to have lower activity of masseter, temporalis and orbicularis oris muscles than those with normal occlusions (Pancherz, 1980; Lowe & Takada, 1984; Harper *et al*, 1997), others have reported high activity of masseter and temporal muscles in Class II malocclusions (Ishida *et al*, 1988; Antonini *et al*, 1990; Honicke *et al*, 1995;). The differences may be due to variation in vertical facial characteristics of the Class II subgroups. Correlations have also been reported between high anterior temporalis activity and flat palatal plane and large ramus height, low orbicularis oris activity and high lower facial height, and low anterior temporalis activity during clenching in Class II division 1 patients (Lowe *et al*, 1983; Lowe & Takada, 1984).

Mandibular masticatory patterns in Class II malocclusion have also been found to differ from those in Class I and Class III malocclusions (Pancherz, 1980; Deguchi *et al*, 1994). Harper *et al* (1987) have reported that Class II patients with a retrognathic mandible demonstrate a wide variation in EMG activity and abnormal recruitment of the lateral pterygoid muscle during border movements of the mandible. This abnormal recruitment pattern is rectified to normal levels after mandibular advancement surgery (Harper *et al*, 1997). Zimmer *et al* (1991) have studied the physiological differences in mandibular mobility between groups of patients with Class I, II or III dental relationships using an axiographic recording device. Clinical measurements showed that Class II patients were able to protrude their mandibles further than Class I patients. Class II patients could also move their mandibles significantly further forward and laterally than Class III patients. However, the results did not elucidate whether specific functional findings were mainly correlated to skeletal (ANB angle) or dental parameters (overjet). Zimmer *et al* (1991) have stated that no single dental or skeletal parameter correlates to or is responsible for the typical functional findings.

2.2 Functional Appliances

Functional appliances include a variety of devices designed to alter skeletal jaw relationships. Some functional appliances such as headgear attached to an Activator exert force on the maxilla but functional appliances typically alter mandibular position sagittally and vertically, thus generating forces on dental and skeletal structures from the orofacial musculature. This process leads to both orthodontic and orthopaedic changes. Functional appliances work through an interaction between three basic systems (Woodside, 1998):

1. Craniofacial growth: modification of growth, retardation or stimulation of maxillary or mandibular growth, redirection of maxillary or mandibular growth.

2. Development of the dentition: differential eruption of teeth.

3. Neuromuscular function: adaptation, reorientation or reattachment of muscles.

All functional appliances produce some degree of dento-alveolar effect. However, a controversial topic is to identify which functional appliance produces a higher proportion of orthopaedic to dento-alveolar effects. Long-term effects of functional appliances are also questionable.

2.2.1 Classifications

Functional appliances can be classified in different ways as follows:

1. **One plate (Monobloc type)**: e.g. Activator, Bionator, functional regulator-FR, or **Two plates**: e.g. Herbst appliance, Twin Block appliance

2. **Tooth-borne**: e.g. Activator, Herbst, Twin block, or **Tissue-borne**: e.g. functional regulator-FR

3. **Fixed**: e.g. Herbst appliance, or **Removable**: e.g. Activator, functional regulator-FR, Twin Block

4. **Class II correction**: e.g. Class II Activator, FR-1, FR-2, Twin Block
Class III correction: e.g. Class III Activator, FR-3, reverse Twin Block
Open-bite, bimaxillary protrusion correction; e.g. FR-4

Theoretically, a tooth-borne appliance is likely to produce more dento-alveolar effects than a tissue-borne appliance because the force is directly transferred to the tooth (McNamara *et al*, 1990). However, this has never been demonstrated scientifically. Generally, the reduction of large overjets by tooth movement will limit the advancement of the mandible and may occur before the desired skeletal changes have been achieved. These phenomena can occur with both tooth-borne and tissue-borne appliances depending on the appliance design and clinical manipulation. Functional appliances have been used in various types of malocclusion. However, treatment seems to be most successful in individuals displaying Class II malocclusion, predominantly due to a retrognathic mandible, who constitute a high percentage of the entire Class II malocclusion population (Woodside, 1998). This review focuses mainly on the correction of Class II malocclusions.

2.2.2 Mode of action

The proposed mechanisms of functional appliance action can be summarised as follows:

1. Alteration of musculature
2. Transduction of viscoelastic force
3. Feedback control system
4. Unloading of the TMJ
5. Differential tooth eruption

➢ *Alteration of musculature*

This mode of action is based on the functional matrix hypothesis (Moss & Rankow, 1968; Moss & Salentijn, 1969; Moss, 1972; Moss, 1979). As has been previously mentioned in the section (2.1.4), this concept hypothesises that growth of the mandible is secondary to growth of muscles and other adjacent soft tissues. In Class II malocclusions with retrognathic mandibles, it has been proposed that there is an imbalance between mandibular retractive and mandibular protrusive muscles. Hyper-function of retrusive muscles, such as the posterior temporalis, and hypo-function of protrusive muscles, such as the lateral pterygoid, result in retardation of mandibular growth (McNamara, 1973; McNamara, 1974b). Stimulation of the lateral pterygoid muscle, therefore, is thought to enhance mandibular growth. This concept is known as the ***"lateral pterygoid hypothesis"***.

❖ **"Lateral pterygoid hypothesis":**

The lateral pterygoid muscle has been thought to have a special role in the regulation of condylar growth. Several studies have suggested that its activity is essential for normal condylar growth and that increased activity is a prerequisite to increased condylar growth (McNamara, 1973; McNamara, 1974b; Petrovic, 1974; McNamara *et al*, 1975; Petrovic *et al*, 1975; Petrovic *et al*, 1982). To test this hypothesis, studies have been designed to assess the effects of the lateral pterygoid muscle on condylar growth and to determine whether functional appliances alter function of the muscle.

Various animal models have been used to study the influence of the lateral pterygoid muscle activity on the condylar growth. Myectomy of the muscle has been reported to result in decreased condylar growth in several studies (Whetten & Johnston, 1985; Hinton, 1990; Stutzmann & Petrovic, 1990; Hinton, 1991). However, other studies have not demonstrated any significant differences in condylar growth in the presence or absence of the lateral pterygoid muscle (Whetten & Johnston, 1985; Awn *et al*, 1987). The results of these studies are not conclusive as other factors such as damage to blood circulation from the surgical procedure, significant post-operative loss of body weight, incisal supra-eruption indicative of feeding difficulties, and lack of normal functional loading make interpretation difficult. Hyperfunction of the lateral pterygoid muscles in rats induced by electrical stimulation has also been shown to play an important role in the differentiation of progenitor cells and in the maturation and calcification of chondrocytes in mandibular condyles (Takahashi *et al*, 1995).

The effects of functional appliances on lateral pterygoid activity are also unclear. An increase in muscle activity associated with an increase in the proliferation of condylar cartilage after the use of functional appliances has been reported in monkeys (McNamara, 1973; McNamara, 1974b; McNamara *et al*, 1975; Burke & McNamara, 1979a; Burke & McNamara, 1979b), in rats (Petrovic, 1974; Oudet & Petrovic, 1978; Petrovic *et al*, 1982; Oudet *et al*, 1988; Easton & Carlson, 1990) and in humans (Auf der Maur, 1980; Hiyama, 1996). However, Sessle (1990) and Yamin-Lacouture (1997) found that muscle activity was decreased with the use of a functional appliance in monkeys. It is unclear whether this altered muscle function is a transient phenomenon with no long-term effect or whether it results in structural and functional adaptation of the involved musculature.

Although the observed pattern of changes conflicted, Auf der Maur (1980), Hiyama (1996), Sessle *et al* (1990) and Yamin-Lacouture *et al* (1997) have agreed that the change in lateral pterygoid activity diminishes shortly after appliance insertion and before any correction of jaw relationship is achieved. Therefore, the morphological change in jaw relationship does not appear to depend only on functional stimulation from the lateral pterygoid muscle. Moreover, Sessle *et al* (1990) have demonstrated that progressive mandibular advancement of 1.5 to 2 mm every 10 to 15 days does not prevent a decrease in lateral pterygoid postural EMG activity. Therefore, progressive mandibular advancement of the mandible, as a method to 'reactivate lateral pterygoid muscle activity' and thereby maximise mandibular growth, is not supported by their study. The lateral pterygoid hypothesis is therefore rejected.

Alteration in activity of other masticatory muscles associated with functional appliance therapy has also been reported. A decrease in postural (rest) activity of retractor muscles, such as the posterior temporalis muscle, has been described as a sign of forward displacement of the mandible during treatment with a functional appliance. Treatment of Class II patients with a functional appliance has been found to produce no change in elevator muscle activity at rest but a decrease in muscular activity during maximum biting, chewing and swallowing has been reported (Ingervall & Thuer, 1991; Thuer *et al*, 1992; Bermudez *et al*, 1993). However, a decrease in muscular activity during maximum biting, chewing and swallowing is commonly found during orthodontic treatment as a result of discomfort, pain or occlusal instability (Pancherz, 1980; Ingervall & Thuer, 1991; Thuer *et al*, 1992; Miyamoto *et al*, 1996).

The superficial part of the masseter muscle, which has anteroposterior orientation of its fibres and also functions as a protrusive muscle, is hypothesised to play a part in the regulation of condylar growth. However, this hypothesis has not been supported by any study. Moreover, myectomy of the muscle does not seem to affect mandibular growth in rats (Hinton, 1991).

Hyperactive buccinator, mentalis and inferior orbicularis muscles are believed to retard forward growth of the mandible (Fränkel & Fränkel, 1989) and the Function Regulator (FR-1) has been designed to re-educate these muscles. Stretching these muscles together with periosteum away from the alveolar process is believed to stimulate bone apposition and allow forward mandibular growth. However, there is no scientific evidence to support this hypothesis.

Although many studies have been undertaken on muscle function related to functional appliances, interpretation of their results should be made cautiously. This is because great variation exists between the different muscles examined, accuracy and accessibility of electrode placement, interference of the electrode position in the function of the muscle, between-day or within-day sessions, and individual variations (Dahan & Boitte, 1986; Koole *et al*, 1990).

➢ ***Transduction of viscoelastic force***

Viscoelastic forces are generated by passive tension from stretched soft tissue. An increase in muscle length alters muscle contractile properties by changing viscous elements of the connective tissue, resulting in an increase muscle function (Lindauer *et al*, 1991; Lindauer *et al*, 1993; Noro *et al*, 1994; Taylor *et al*, 1997). Although viscoelastic stress decreases with time, it is not correlated with a decrease in muscle force (McHugh *et al*, 1992). Unlike the "lateral pterygoid hypothesis" which places emphasis on protrusive muscle action, the "transduction of viscoelastic force hypothesis" emphasises the jaw closing muscles. It is hypothesised that some functional appliances such as Activators increase facial vertical dimension beyond the neutral position and consequently create viscoelastic forces from stretched jaw-closing muscles. These forces are then transferred through the appliance and play an important role in initiating tissue and cellular reactions (Woodside *et al*, 1975; Kuster & Ingervall, 1992). Activators with a high construction bite not only generate high forces but also alter the direction of muscle force (Ahlgren & Bendeus, 1982; Noro *et al*, 1994). Studies that reject the "lateral pterygoid hypothesis" often support this "viscoelastic force hypothesis" (Sessle *et al*, 1990; Yamin-Lacouture *et al*, 1997).

➢ ***Feedback control system***

Petrovic and co-workers (Petrovic *et al*, 1975; Stutzmann & Petrovic, 1979; Petrovic & Stutzmann, 1997) have surmised that mandibular growth derives from a periosteal contribution and a cartilaginous contribution. The cartilaginous contribution (condylar, coronoid and angular processes) is easily modifiable and subject to local control systems through a feedback loop. Cybernetic models for controlling mandibular growth have been proposed. Control mechanisms from different types of functional appliances and Class II elastics are postulated to be involved in negative feedback loops.

In the cybernetic model, the retrodiscal tissue is also thought to play an important role in condylar growth. It serves as a major supplier of the blood circulation and biochemical substances. Resection of the retrodiscal tissue has been shown to diminish condylar growth (Stutzmann & Petrovic, 1990). Retraction of the mandibular condyle away from the fossa may increase iterative activity of the retrodiscal tissue which results in increased condylar cartilage growth and endochondral bone ossification. It also controls bone apposition at the posterior margin of the ramus resulting in concavity of the ramus and alteration in growth direction (Petrovic & Stutzmann, 1997).

➢ ***Unloading of the TMJ***

The mandibular condyle is normally subjected to pressure during function. The condylar cartilage has been shown to be responsive to alterations in load pressures, and this secondary type of cartilage is also able to increase its proliferative activity to a limited extent when load pressure is altered (Pirttiniemi *et al*, 1991). It has been proposed that during mandibular movement, synovial fluid is displaced and deformation of the joint capsule occurs with reduction of joint space. This results in an increase of synovial fluid pressure and causes local homeostasis which is believed to be one of the controlling mechanisms of mandibular growth. Unloading of the mandibular condyle with a functional appliance is hypothesised as a mechanism for facilitating an increased rate of condylar growth (Roberts, 1985).

This hypothesis is highly questionable. Several studies have demonstrated that a decrease in occlusal load is associated with reduced mitotic activity of the TMJ (Nickel *et al*, 1988a; Shaw & Molyneux, 1994; Tuominen *et al*, 1996). An area of stress from loading has also been found at the antero-superior part of the condylar head (Hu *et al*, 1997). If unloading of the TMJ by a functional appliance leads to an increase in growth of the condyle, then significant change should be found at the antero-superior part of the condyle. However, histological investigations in animals have demonstrated significant changes at the posterior superior part of the condyle (McNamara, 1973; Petrovic *et al*, 1975; Oudet & Petrovic, 1978; Hinton & McNamara, 1984; McNamara & Bryan, 1987; Pirttiniemi *et al*, 1993).

Moreover, the study by Ward *et al* (1990) provides no support for the hypothesis that functional appliances reduce pressure in the TMJ. Ward *et al*

(1990) described the synovial fluid pressure response within the superior aspect of the temporomandibular joint space to altered mandibular positions in growing pigs. Both anterior and posterior positioning of the mandible caused an increase in synovial fluid pressure that gradually decayed within two hours. No "unloading" of the joint by anterior positioning of the mandible was noted. The fact that the synovial organ has the capacity to quickly adjust to a regional change in protrusive position shows the lack of continuing long term signals from synovial fluid pressure to incite growth. Although animals wearing the protrusion appliance showed a relative increase in mandibular growth and animals wearing the mandibular retrusion appliance showed a relative decrease in mandibular growth, the mechanism for the changes in growth was not explained.

➢ ***Differential tooth eruption***

The eruption pattern of molars and incisors and its association with development of malocclusion has been described by Harvold (1974). Harmonious eruption between the maxillary and mandibular teeth results in a Class I dental relationship. Over-eruption of maxillary molars and incisors tends to develop into Class II malocclusions while over-eruption of mandibular molars and incisors develops into Class III malocclusions. These eruption patterns can be altered by functional appliances via differential eruption or guidance of eruption (Fränkel, 1971; Harvold, 1974). The basic design of functional appliances for correction of Class II malocclusion includes components that arrest eruption of maxillary molars (and/or incisors) while allowing for the eruption of mandibular molars (and/or incisors). With this mode of action, a Class I occlusal relationship can be achieved from dento-alveolar changes rather than skeletal changes.

2.2.3 Functional Appliance and TMJ interactions

➢ ***Histological studies***

Histological changes in the TMJ associated with the use of protrusive appliances have been demonstrated in rats (Petrovic *et al*, 1975; Oudet & Petrovic, 1978; Buchner, 1982; Petrovic *et al*, 1982; Oudet *et al*, 1984; Oudet *et al*, 1988) monkeys (McNamara, 1973; McNamara *et al*, 1982; Hinton & McNamara, 1984; McNamara & Bryan, 1987) and rabbits (Pirttiniemi *et al*, 1993; Kantomaa *et al*, 1994;). These studies have shown an increase in the rate and amount of condylar growth associated with increased mitotic activity in the chondroblasts at the distal surface of the condyle. Stutzmann & Petrovic (1997) have also demonstrated that the hyperpropulsor not only increases the mitotic activity of the condylar cartilage but also changes the direction of condylar growth (Figure 1). Reorientation of the condylar trabeculae and an increase in subperiosteal ossification have also been demonstrated. An increase in the rate of bone and cartilage remodelling in rats wearing a hyperpropulsor device has also been verified by an increase in radioactive bone marker (99mTc). However, this increased rate appears to be temporary (Nicolay *et al*, 1991).

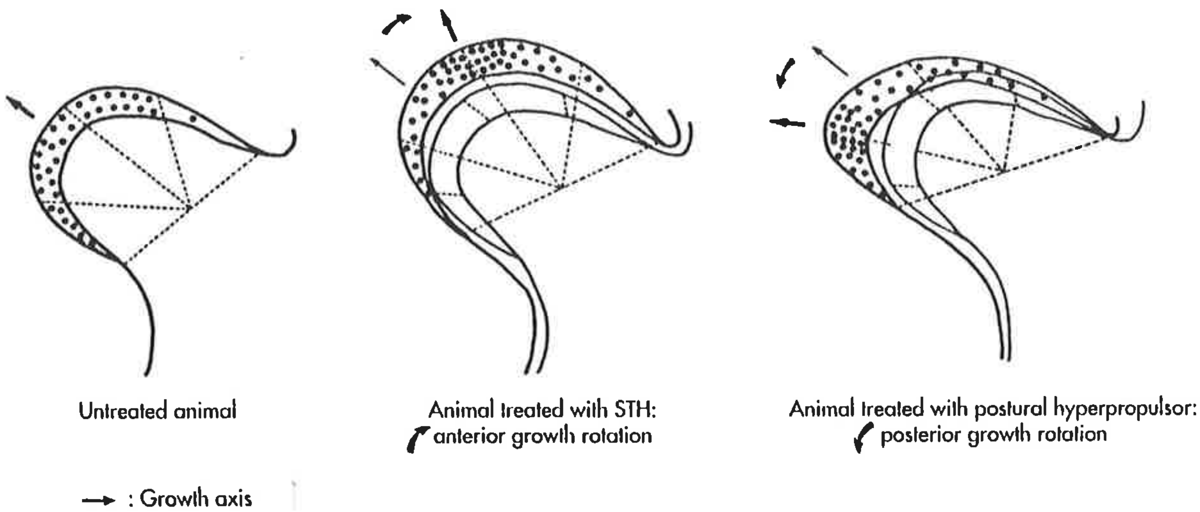


Figure 1 ▪ Mitosis distribution and area of concentration in a sagittal section of condylar cartilage (Stutzmann & Petrovic, 1997).

Although these researchers have clearly demonstrated an increased proliferation of chondroblasts at the condyle, the regulation of the increased growth is not fully understood.

➢ *Radiographic studies*

Only a few studies have reported changes in the human TMJ as a result of functional appliances. This may be because the methodology available at the time, such as using tomograms or CT-scan imaging, has involved an increased radiological risk to subjects. These methods are also limited in that they only allow observation of changes in the bony structures.

Birkebaek *et al* (1984) has applied implants combined with laminagraphy of the TMJ to illustrate a slight forward and downward displacement of the glenoid fossa in children treated with an Activator, and downward but backward displacement of the fossa in the untreated Class II children. No change in the angle of the articular eminence was found. Similar tomographic changes, both in the relocation of the fossa and the growth of the condyle, have been reported in three patients with pathologic condyles treated with the Harvold Activator (Melsen *et al*, 1986). Conversely, a tomographic study of Fränkel therapy has failed to show any significant changes in the shape or position of glenoid fossa and condylar position (Hamilton *et al*, 1987).

Changes in condylar position associated with Activator treatment have been demonstrated by Cobo *et al* (1993) using transcranial radiographs. Their study has shown that the condyle displaces anteriorly at the beginning of the treatment but appears to relocate back in the fossa at the end of treatment. However, their study did not differentiate whether the changes were due to condylar growth, anterior relocation of the fossa, or repositioning of the condyle in the fossa during the treatment. Similar changes in condylar position associated with Twin Block therapy have also been demonstrated using tomograms (Clark, 1997).

With CT-scanning, Paulsen *et al* (1995) have shown a double contour image in the articular fossa and on the posterior part of the condylar process in a child undergoing Herbst treatment in late puberty. They stated that the images represented adaptive bone remodelling and the image of the condylar head returned to "normal" appearance after two and a half years of observation.

Using tomograms, Major *et al* (1997) have reported an increase in anterior joint space in a group of patients treated with non-extraction orthodontic procedures. Although this is not a result associated with treatment with a functional appliance, it is noted here due to the reported possibility that Class II elastics used in non-extraction treatment can produce similar "functional effects" (Petrovic & Stutzmann, 1997).

Owen (Owen, 1988; Owen, 1989) reported three cases of unexpected TMJ responses to functional jaw orthopaedic therapy. All the patients had Class II division 1 malocclusions with a retrognathic mandible. Pre-treatment transcranial radiographs demonstrated posterior displacement of the condyles in their fossae. Two patients had undergone treatment with Bionators and the other was treated with a Fränkel appliance. Although the condyles were positioned anteriorly during the functional appliance treatment, posterior condylar displacements were still present in post-treatment transcranial radiographs. The author stated that only 2% to 3% of his patients responded in this manner and no physiologic mechanism was suggested. Those patients who completed treatment with posterior condylar displacement included both growing persons and adults.

> ***Clinical studies***

Assessment of the treatment effects of different types of functional appliances has mainly involved lateral cephalometric analyses, with results varying among investigators and appliance types. Interpretation of results from these types of studies depends on the reliability of locating landmarks and the types of analyses used. Some analyses show greater changes than others. The changes are also mainly the result of 2-dimensional projections of 3-dimensional structures in the sagittal plane. A summary of clinical studies based on different appliance types is shown in Table 2.

Table 2 ▪ Summary of the results of studies using different types of functional appliances

Functional regulator (FR)	
Gianelly *et al*, 1984; Owen, 1981	• Stimulation of mandibular growth • Restriction of maxillary growth
Freeland, 1979; McNamara *et al*, 1985; Haynes, 1986a; Falck & Frankel, 1989; Kerr *et al*, 1989; McNamara *et al*, 1990; Pangrazio-Kulbersh & Berger, 1993	• Stimulation of mandibular growth • Little effects on the maxilla
Gianelly *et al*, 1983	• Inconclusive • 40% showed forward posturing of the mandible • Varying degrees of mandibular growth
Courtney *et al*, 1996	• Reduce cranial base flexure • No effect on the maxilla
Adenwalla & Kronman, 1985; Haynes, 1986b; Hamilton *et al*, 1987; Battagel, 1990; Nelson *et al*, 1993	• Dento-alveolar changes only

Activator or Bionator	
Vargervik & Harvold, 1985	• Stimulation of mandibular growth • Restriction of maxillary growth • Forward relocation of glenoid fossa
Birkebaek *et al*, 1984; Melsen *et al*, 1986; Op Heij *et al*, 1989	• Stimulation of mandibular growth • Forward relocation of the glenoid fossa
Pancherz, 1984; Hashim, 1991	• Inhibit maxillary growth • No stimulation of mandibular growth

Jakobsson & Paulin, 1990	• Restriction of maxillary growth in girls • Stimulation of mandibular growth in boys
Courtney *et al*, 1996; McNamara, 1989; Drage & Hunt, 1990; Dermaut *et al*, 1992; Nelson *et al*, 1993	• Dento-alveolar changes only
Knight, 1988	• Dento-alveolar changes with temporary mandibular stimulation
Mamandras & Allen, 1990	• Inconclusive and depends on facial type

Headgear with and without Activator	
Deguchi, 1991; Keeling *et al*, 1998; Baumrind *et al*, 1983a	• Stimulation of mandibular growth • Restriction of maxillary growth
Caldwell *et al*, 1984; Ozturk & Tankuter, 1994; Tulloch *et al*, 1997	• Restriction of maxillary growth • No stimulation of mandibular growth
Knight, 1988	• Dento-alveolar changes with temporary maxillary restriction and temporary mandibular stimulation
Levin, 1985; Mair & Hunter, 1992	• Inconclusive and depends on facial type
Malmgren *et al*, 1987	• Restriction of maxillary growth with stimulation of mandibular growth in boys

Herbst appliance	
Pancherz, 1982; Wieslander, 1984; Woodside *et al*, 1987	• Stimulation of mandibular growth • Restriction of maxillary growth • Forward relocation of glenoid fossa
Pangrazio-Kulbersh & Berger, 1993; McNamara *et al*, 1990; Omblus *et al*, 1997; Konik *et al*, 1997; Pancherz, 1979; Windmiller, 1993	• Stimulation of mandibular growth • Restriction of maxillary growth
Hägg & Pancherz, 1988; Pancherz & Hägg, 1985; Valant & Sinclair, 1989; Paulsen *et al*, 1995; Hiyama, 1996; Ruf & Pancherz, 1998	• Stimulation of mandibular growth • Little effects on the maxilla
Long-term studies:	
Pancherz & Fackel, 1990; Hansen *et al*, 1991; Hägg, 1992; Wieslander, 1993	• Temporary stimulation of mandibular growth (not significant from untreated control values after 5 years)

Based on a review of previous research studies and reports, Woodside (1998) summarised how functional appliance therapy can achieve correction of Class II malocclusion as follows:

1. Dento-alveolar changes
2. Restriction of forward growth of the midface
3. Stimulation of mandibular growth beyond that which would normally occur in growing children
4. Redirection of condylar growth from an upward and forward-directed growth to a posterior direction
5. Deflection of ramal form

6. Horizontal expression of mandibular growth from downward and forward to horizontal

7. Changes in neuromuscular anatomy and function that would induce bone remodelling

8. Adaptive changes in glenoid fossa location to a more anterior and vertical position

The net result of functional appliance treatment may reflect a combination of some or all of the factors but the contribution from each factor is hard to verify. Some apparent Class II correction may be from the anterior displacement of the mandibular condyle to a more anterior and inferior position in the glenoid fossa (Nelson *et al*, 1993).

❖ Long-term studies

Long-term studies of the effects of functional appliances have shown that initial orthopaedic effects, especially the increase in mandibular growth, have only a temporary impact on the existing skeletofacial growth pattern. Except for the study by DeVincenzo (1991), most of the long-term studies report results based on the Herbst appliance (Table 2). The findings of these studies indicate that the stimulation of mandibular growth achieved at the end of active treatment appears to be only temporary. After a period of four to five years post-treatment, mandibular growth fails to continue and mandibular length does not differ significantly from untreated control values. Hansen *et al* (1991) have suggested that a stable occlusion after Herbst therapy could be of greater importance for long-term stability than either the post-treatment growth pattern or the growth period during which patients were treated. The ideal period for treatment would appear to be in the permanent dentition period, at or just after peak height velocity, as this would promote occlusal stability after treatment and reduce retention time. Although his findings are consistent with others on the effect of mandibular growth, Wieslander (1993) has found that the effect on the maxilla continued during the five-year observation period. Consequently, maxillary sutural remodelling might be more receptive long-term to orthopaedic treatment than the mandibular condylar growth process.

Comparisons between two-stage treatments (functional appliance initially then fixed appliance later) and one-stage treatment (fixed appliance) have revealed no significant differences in the correction of the skeletal relationship (Gianelly, 1995; Livieratos & Johnston, 1995; Tulloch *et al*, 1998). This implies that early treatment with a functional appliance does not encourage greater mandibular growth than fixed appliance treatment (Livieratos & Johnston, 1995). Concerning cost-benefit and total treatment time, one-stage treatment is preferred as all treatment goals can be accomplished in one phase in the late mixed dentition (Gianelly, 1995; Tulloch *et al*, 1998).

2.3 The Twin Block Appliance

The Twin Block is a functional appliance introduced by William J. Clark in 1977. It is a development of Pierre Robin's monobloc and the Schwarz double plates (Clark, 1982). As a functional appliance therapy, it aims to improve the functional relationship of the dentofacial structures by eliminating unfavourable developmental factors and improving the muscle environment that envelops the developing occlusion. By altering the position of the teeth and supporting tissues, a new behaviour pattern is established that can support a new position of equilibrium (Clark, 1997).

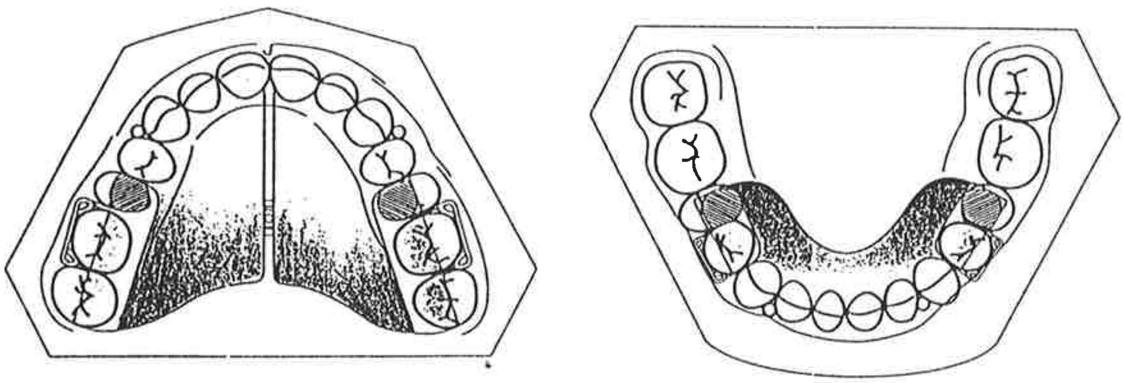
The appliance consists of double plates with occlusal bite blocks and inclined planes that guide the mandible to displace downward and forward. When the Twin Block was first used in 1977, the interlocking between the inclined plane was 90° (Clark, 1990). In 1982, the upper and lower bite block interlocking was recommended to be at a 45° angle in order to establish an equal downward and forward component of force when engaged in full closure (Clark, 1982). But following further clinical experience, it was recommended that the interlocking angle should be 70° to produce a more horizontal component of force and to encourage more forward mandibular growth (Clark, 1990; Clark, 1997).

The Twin Block is designed to be worn 24 hours per day including meal times to utilise all functional forces applied to the dentition, including masticatory forces. Estimated average duration of treatment is 18 months, including retention.

2.3.1 Treatment stages

➢ ***Stage 1: Active phase***

The objective of Twin Block therapy is to achieve rapid functional correction of mandibular position from retruded Class II to Class I occlusion, and to establish the correct vertical dimension.



Upper plate **Lower plate**

Figure 2 ▪ Standard Twin Block design for correction of Class II division 1 malocclusion in the permanent dentition (Clark, 1995)

Upper Plate:

1. Retentive part: delta clasps on molars and ball clasps mesial to first premolars

2. Occlusal bite block: cover first and second molars with inclined plane on the second premolars

3. Palatal jackscrew: for midline expansion

Lower Plate:

1. Retentive part: delta clasps on lower first premolars and ball clasps mesial to lower canines

2. Occlusal bite block: cover first premolars with inclined plane on the second premolars

❖ **Bite construction**

Bite construction is a term used for registration of the relationship of the mandible to the maxilla in the desired forward position. The amount of mandibular protrusion depends on the ease with which the patient can protrude. The amount of forward and downward mandibular positioning is referred to as the "activation" of the appliance. Generally, the construction bite is obtained with the mandible protruded to an edge-to-edge incisor relationship and with a 2-mm interincisal clearance. Re-activation may be required for some patients who have extreme overjet where achieving an edge-to-edge posture is initially not possible. Posterior inter-occlusal clearance should be approximately 5-6 mm in the first premolar region. Inadequate vertical opening allows the mandible to drop back posteriorly and a correct mandibular relationship cannot be maintained.

During this phase, the patient should be seen periodically. Initial bonding of the appliance to the teeth is sometimes recommended to overcome co-operation problems (Clark, 1995; Rondeau, 1996). The vertical dimension is controlled by incremental adjustment of the occlusal bite blocks to allow the eruption of the lower posterior teeth and intrusion of upper posterior teeth (Figure 3). At the end of this stage the distal occlusion, overbite and overjet should be fully corrected with three-point occlusal contacts at the incisal and molar regions. Average time of active treatment is six to nine months.

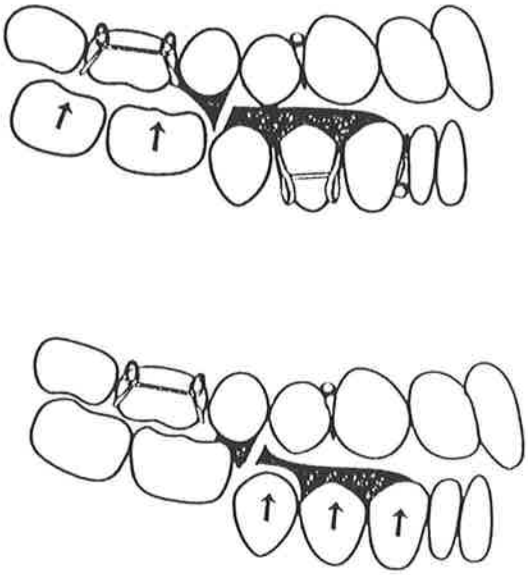


Figure 3 ▪ Adjustment of the occlusal bite blocks to allow the eruption of lower posterior teeth (Clark, 1995)

➢ ***Stage 2: Support phase***

The objective is to maintain the corrected antero-posterior relationship and allow settling of the buccal segment into full interdigitation. The average treatment time is 3 to 6 months, which depends greatly on the eruption process. Full-time wearing of the appliance is required.

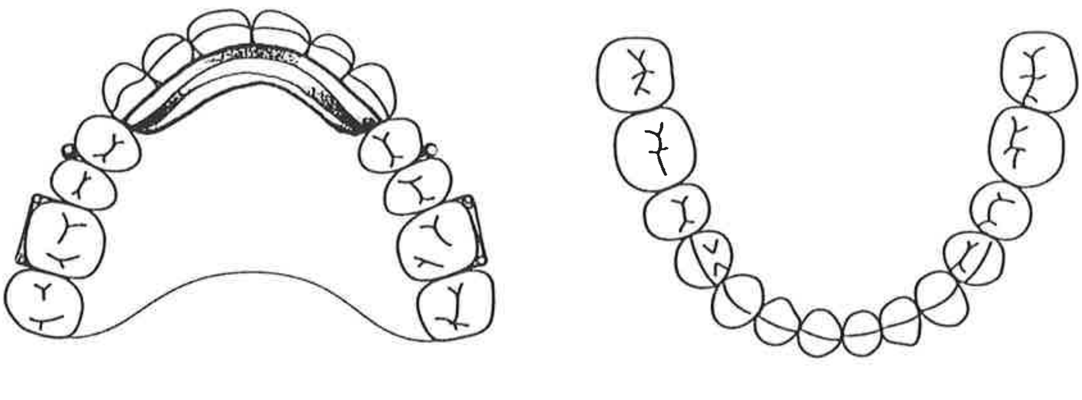


Figure 4 ▪ Appliance for the Support Phase (Clark, 1995)

Upper Plate:

1. Retentive part: delta clasps on upper first molars and ball clasps between first and second premolars

2. Anterior inclined plane to engage the lower incisors and canines

Lower Plate: none

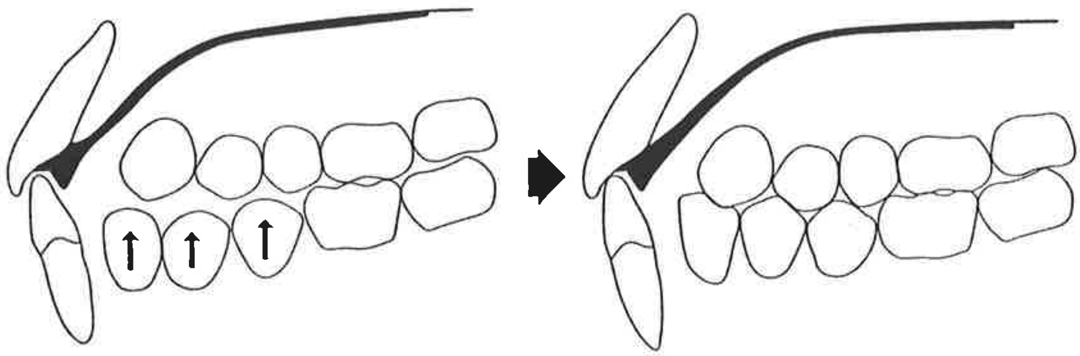


Figure 5 ▪ Settling of buccal segment during the support phase (Clark, 1995)

Other types of appliances such as, the *Waveney Goal Post Appliance,* which is a Hawley retainer with palatal wire framework to engage the lower incisors (Stratford & Scott, 1988), or the *Rick-A-Nator Appliance,* which is a form of fixed inclined plane (Rondeau, 1996), are also recommended as alternative appliances for the support phase.

➢ ***Stage 3: Retention***

The upper appliance used in stage 2 is worn only at night times when the occlusion is fully established. The recommended time for this stage is 9 months. At the end of the treatment, improvement of facial appearance and lip seal should be achieved.

2.3.2 Case selection

The ideal criteria for simple treatment with the Twin Block appliance are:

- Full unit Angle Class II division 1 malocclusion with 10–12 mm. overjet.
- Uncrowded dentitions with good arch form. Adjustment of posterior arch width and dental alignment are recommended before Twin Block treatment (Trenouth, 1989).
- Deep overbite with short or normal lower anterior facial height.
- Improved facial profile when the mandible is in forward position.
- Coincidence with the pubertal growth spurt.

2.3.3 Advantages of the Twin Block appliance

1. The Twin Block appliance is less bulky and easier to wear than most other functional appliances, such as the Function Regulator (FR) or the Harvold Activator, which are bulky and take a few days for patients to adjust and wear them comfortably.
2. The Twin Block appliance improves patient appearance as soon as after the appliance is fitted. Although other types of functional appliances also change the mandibular position anteriorly, their bulkiness often makes the patient look "too full or fat" with the appliance in the mouth.
3. The Twin Block appliance interferes minimally with speech and eating, and is comfortable to wear, so it can be worn 24 hours per day. However, practice is needed at the beginning of treatment.
4. The Twin Block appliance allows the mandible to move laterally while most functional appliances do not.

5. The Twin Block has minimal anterior-wire so it is less visible during speaking or smiling.

6. Integration with fixed appliances or extraoral traction is convenient (Clark, 1988).

7. Reactivation of the appliance is simple and can be carried out at the chair side.

2.3.4 Disadvantages of the Twin Block appliance

1. The Twin Block is a tooth-borne appliance which is believed to generate more dento-alveolar changes than tissue-borne appliances (Fränkel & Fränkel, 1989; McNamara *et al*, 1990).

2. The appliance requires retention from teeth. Adequate retention may not be possible for short, partially erupted or mobile teeth.

3. The lower plate is small which can lead to retention problems especially during the transitional dentition. More recently, the lower plate has been modified with an extension back to the lingual side of the first molars to improve retention (Clark, 1992a; Clark, 1992b).

4. The lower plate can be broken easily in the midline region.

5. The posterior open-bite occurring during the active phase usually requires a fixed appliance for full interdigitation of the posterior teeth.

The Twin Block is widely used for the correction of Class II division 1 or Class II division 2 malocclusions in growing children. However, Clark (1995) has also reported success in using the appliance to correct complex malocclusions such as Class III malocclusions, facial asymmetry, TMJ dysfunction or even severe Class II malocclusions in non-growing patients.

Although the Twin Block appliance is ideal for treatment of deep overbite cases with short lower anterior facial height, Orton (1990) has recommended the Clark Twin Block to treat moderate Class II division 1 malocclusions with anterior open-bite. Orton (1990) has stated that the appliance induces posterior open-bite and is less appropriate for deep-bite cases.

2.3.5 Twin Block studies

Using cephalometric analysis, Clark (1982) has shown changes in the first stage of treatment with the Twin Block to be predominantly retardation of maxillary growth, lingual inclination of maxillary incisors, and downward and backward rotation of the mandible with 5° to 10° of proclination of the mandibular incisors. During the second stage, mandibular rotation reversed to an upward and forward rotation and the lower incisors were reported to upright. Reduction of the ANB angle was a result of forward mandibular rotation and reduction in forward maxillary growth. The most favourable and sustained mandibular response occurred in boys when treatment coincided with the pubertal growth spurt. No description of subjects or sample size was indicated in this report.

Although data on the magnitude of changes are not given, Clark (1988) has reported significant craniofacial changes in a study of 70 consecutively treated cases, including:

1. Reduction of ANB angle
2. Increase in effective mandibular length (Articulare to Gnathion)
3. Increase in length of the facial axis (CC to Gnathion)
4. Increase in facial height (Nasion to Menton)
5. Reduction in facial convexity
6. Reduction of the distance between upper first molar to the pterygoid vertical
7. Proclination of lower incisors in the active phase with uprighting during the support phase

8. After 18 months of retention, growth changes during the active phase remain stable.

A so-called "pterygoid response", described as TMJ pain when the appliance is removed, has also been reported to be a common feature in the initial stages of treatment. It has been hypothesised that muscle balance has been altered and that a "tension zone" has formed distal to the condyle. Upon removal of the appliance, the mandible retracts back and the TMJ becomes painful due to the increase of pressure in the "tension zone".

DeVincenzo and Winn (1989) have reported that the annual rate of increase of mandibular length (Ar-Pg) in girls approximates 5 mm with Twin Block treatment. However, data on mandibular growth rates in untreated children were not available for comparison. Significantly different orthopaedic or orthodontic effects were not found among groups of children treated with different amounts of protrusive activation. This study rejects the hypothesis that a greater amount of appliance activation results in greater dental changes.

Trenouth (1992) has reported that there is no significant difference in the improvement of the dental base relationship (reduction of ANB angle) when the Twin Block and Andresen Activator are compared. However, the treatment time for Twin Block therapy was significantly less, consistent with the findings of Yang (1996).

Clark (1995) has compared the growth response to Twin Block treatment in 74 children with Class II division 1malocclusions with control groups studied by Riolo *et al* (1979 – Michigan series, Class I cases) and Prahl Anderson *et al* (1979 – Nijmegen series, Class II non-treated cases). A series of six cephalograms obtained before treatment up until 18 months out of retention, was analysed. Compared with the Michigan series (Class I cases), the significant changes were:

- Correction of sagittal discrepancies by maxillary retraction (A-point) and minor mandibular advancement.

- Increase in mandibular length (Ar-Gn) and increase in ramus height, (inconclusive depending on age group)
- Increase in face height (N-Me)
- Retraction of upper incisors, retraction of upper molars, advancement of lower incisors, increase in the inter-incisor angle

When compared with the Nijmegen series (Class II non-treated cases) the changes were similar except for an increase in gonial angle in some age groups. Sexual dimorphism in treatment response was found, with greater mandibular growth in boys. During treatment, the rate of mandibular growth (Ar-Gn) in the Twin Block group was greater than in the control group (2.45 mm for boys, 2.17 mm for girls). However, assessment two years post-treatment revealed similar annual rates of growth between control and Twin Block groups. Clark (1995) also hypothesised that in the slow growing patient, retraction of the maxilla was more likely to occur than advancement of mandible.

Stangl (1997) has reported significant increases in ramus height and mandibular body length after Twin Block therapy in a series of six patients. Due to the small number of children investigated and the lack of comparison with control data, it is difficult to conclude whether the Twin Block appliance actually stimulates greater mandibular growth than normal.

Neuromuscular responses to the Twin Block appliance have been reported in monkeys (Yamin-Lacouture *et al*, 1997). It was found that both postural and functional activity of the masticatory muscles decreased during treatment with the Herbst, Fränkel and Twin Block appliances. Progressive activation of appliances did not enhance muscle activity. Nonetheless, proliferation of pre-chondroblastic condylar tissue and forward modelling of the glenoid fossa were found. This study fails to support the lateral pterygoid hypothesis and concludes that an increase in lateral pterygoid activity is not a prerequisite for the stimulation of mandibular growth.

A prospective, controlled clinical study of the effects of Twin Block by Lund & Sandler (1998) has shown similar results to previous studies. Slow maxillary expansion was also incorporated in the treatment. Significant skeletal changes found (Table 3) were; an increase in effective mandibular length (Ar-Pog), an increase in ramal height (Ar-Go) and an increase in lower anterior facial height (ANS-Me). The study failed to specify whether the changes were due to growth of the mandible alone or combined with anterior repositioning of the fossa. In contrast to previous reports, no restriction of maxillary growth was found. The design of the Twin Block appliance included an upper labial bow and may have encouraged retraction of maxillary incisors.

Table 3 ▪ Significant changes from Twin Block treatment (Lund & Sandler, 1998)

Variables	Mean difference ± SD CTB	Mean difference ± SD Control	Net Difference
Ar-Pog (mm)	5.1 ± 2.3	2.7 ± 1.5	2.4
Ar-Go (mm)	4.0 ± 2.9	1.8 ± 1.5	2.2
N-Me (mm)	4.9 ± 2.6	2.3 ± 1.8	2.6
SNB (deg.)	1.9 ± 2.0	0.4 ± 1.0	1.5
ANB (deg.)	-2.0 ± 1.9	-0.1 ± 0.8	-1.9
Ui-Max (deg.)	-11.0 ± 7.6	-0.2 ± 2.4	-10.8
Li-Mand (deg.)	8.2± 7.1	0.3 ± 2.6	7.9

Another clinical study of Twin Block treatment by Mills & McCulloch (1998) has also demonstrated similar results in mandibular growth. Slow maxillary expansion and vertical elastics at night were also applied. This study used Condylion (Co) instead of Articulare (Ar) to demonstrate changes at the mandibular condyle. Mandibular growth changes were more pronounced but there was only minor restriction of the maxillary growth. The increase in effective mandibular length (Co-Gn) represented a combination of increased ramus height (Co-Go) and mandibular body length (Go-Gn). Mandibular growth change in the treatment group was on average 4.2 mm greater than in the control group over the 14-month treatment period. Although the nature of the changes was similar, dento-alveolar changes reported in this study were notably less than in the study by Lund & Sandler (1998). Significant reduction of cranial base angle (N-S-Ar) in the Twin Block group was also reported.

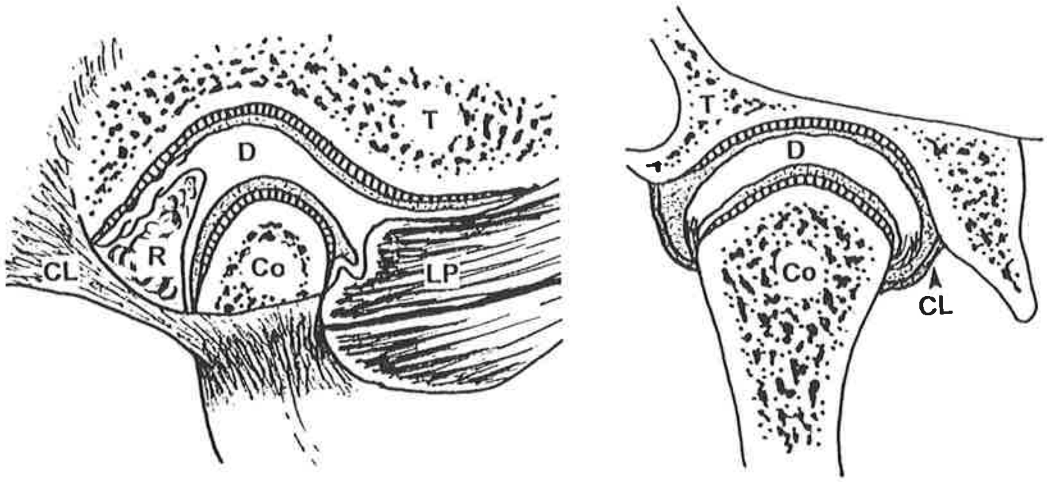
Apart from a shorter treatment time, results of studies involving Twin Block treatment have not demonstrated any superior outcomes compared with those involving other functional appliances.

2.4 Temporomandibular Joint (TMJ)

2.4.1 TMJ anatomy

The temporomandibular joint (TMJ) comprises a complex articulation between the mandibular condyle and the opposing surface of the temporal bone. It has unique anatomical and bilateral functional characteristics that are associated with dental occlusion. Movement of the TMJ includes a hinge movement, which predominantly occurs in the inferior compartment, and a translatory movement, which includes the movement of the articular disc along the articular eminence of the temporal bone and occurs predominantly in the superior compartment. Histologically, the TMJ differs from other synovial joints in that the articulating surfaces are covered by connective tissue which is better adapted to withstand shearing forces and has greater ability to repair than hyaline cartilage. The components of the TMJ (Figure 6) are:

1. **Temporal bony surfaces**: These are the glenoid fossa, anterior articular eminence and the articular tubercle on the lateral aspect. The bony roof of the glenoid fossa is thin and does not seem to be a load-bearing area (Mohl, 1988). The orientation of the articular eminence and the articular tubercle influences movement of the mandible during translatory and lateral movements. This also helps in disclusion of potential occlusal interferences during protrusion and lateral excursions, the so-called Christensen phenomenon (Mohl, 1988).



Lateral view **Frontal view**

T: temporal bone, D: disc, Co: condyle, CL: capsular ligament, R: retrodiscal tissue, LP: lateral pterygoid

Figure 6 ▪ Components of the TMJ (modified from Okeson, 1993)

2. **Mandibular condyle**: The shape of the condylar head is described as having medial and lateral poles which are not symmetrical. The lines projected through the horizontal axes of the condyles intersect medioposteriorly at an obtuse angle with the medial poles located more posteriorly. The pterygoid fovea represents the insertion of the lateral pterygoid muscle and is located on the anteromedial aspect of the neck of the condyle. In centric occlusion, the articular surface of the condyle faces the posterior slope of the articular eminence rather than the deepest part of the glenoid fossa (Christiansen & Thompson, 1990b).

3. **Articular disc**: The articular disc, or meniscus, consists of a noninnervated, nonvascular dense fibrous connective tissue (Moffett, 1966; Carlson *et al*, 1978; Hylander, 1979) which changes its shape during condylar movement. It is divided into three bands, the posterior band being the thickest and the intermediate band being the thinnest. The anterior band connects to the fibrous capsule that partially joins the superior part of the lateral pterygoid muscle

(Wilkinson & Chan, 1989). Posterior to the disc is loosely organised connective tissue referred to as the bilaminar area, or retrodiscal tissue, where the loose upper layer attaches to the temporal bone and the lower layer connects to the posterior surface of the condylar process. The articular disc and bilaminar zone divide the TMJ space into lower and upper compartments.

4. **Fibrous capsule**: The capsule consists of loose fibrous connective tissue lined by a thin layer of synovial membrane on its inner surface. The area of greatest synovial covering is found on the superior and inferior surfaces of the retrodiscal tissue. The main functions of the synovial membrane are secretion, phagocytosis and regulation of the movement of solutes, electrolytes and proteins. The inner surface of the synovial membrane has an abundant blood supply but is poorly innervated. Movement of the joint is lubricated by synovial fluid which also acts as a medium for transporting nutrients to, and waste products from the articular surfaces and the disc.

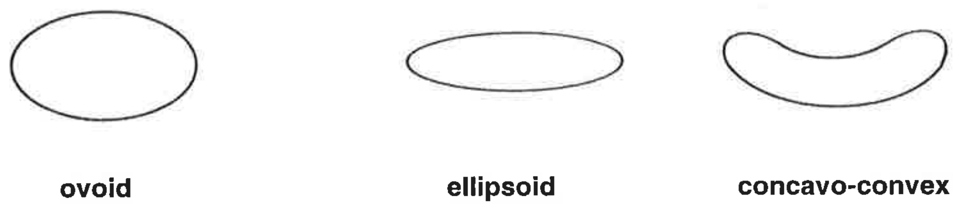
5. **Ligaments**: The temporomandibular ligament, which represents a thickening of the capsule on its lateral side, serves as a restraining device to prevent condylar displacement from the fossa during extreme movements (Mohl, 1988).

2.4.2 Anatomical variations of the TMJ

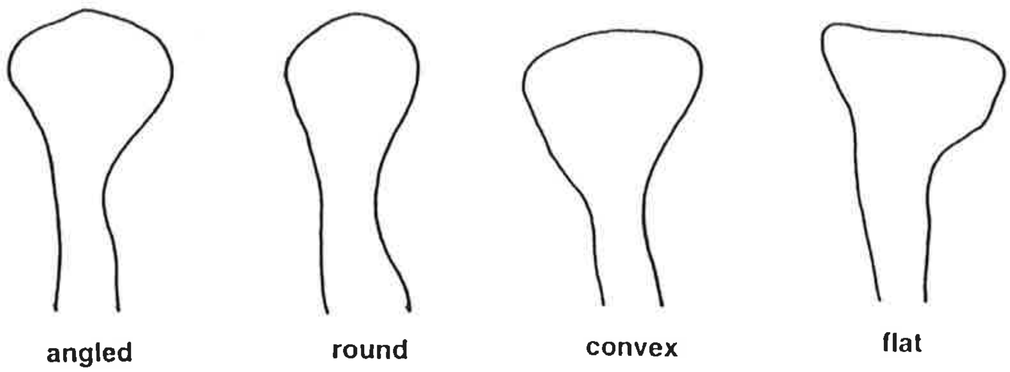
➢ ***Condylar morphology***

Condylar head shape varies considerably. The shape (Figure 7) has been classified as ovoid, ellipsoid and concavo-convex in the axial view (Christiansen *et al*, 1987), and as angled, round, convex or flat in the coronal view (Yale *et al*, 1963). The medial pole is generally more prominent than the lateral pole (Okeson, 1993). Classification of sagittal condylar head shape is less definitive. However, there is no reported functional implication in these morphological differences. No relationship between condylar head shape and disc displacement has been found (Solberg *et al*, 1985). Average dimensions of the condyle and intercondylar distances have been found to be greater in males than in females (Christiansen & Thompson, 1990b).

Dibbets & Van der Weele (1991b) have investigated condylar shapes in 161 children and found that 16% of the subjects showed 'deformed or flattened' condyles radiographically. They suggested that flattened condylar projections in children exhibit a seasonal variation and may be interpreted as a reflection of a temporarily active growth vector. The results coincide with Oudet and Petrovic's (1978) study that has demonstrated a circadian and seasonal variation in growth rate of the condylar cartilage in young rats.



A. Axial condylar head shape



B. Coronal condylar head shape

Figure 7 ▪ Axial and coronal condylar head shape

➢ *Condylar position*

"Concentricity" or condylar positioning in the centre of the fossa has been proposed to be the normal condylar position (Pullinger *et al*, 1985; Pullinger & Hollender, 1985; Zhao, 1993). However, obvious variations in condylar position can be seen and the concentric position is not the only normal physiological position of the condyle (Zhao, 1993). Nonconcentricity and mild asymmetry of the condyle-fossa relationship have been observed commonly in patients who require orthodontic treatment (Cohlmia *et al*, 1996). Posterior condylar position has been found in less than 10% of subjects (Pullinger *et al*, 1987; Gianelly *et al*, 1991) and has been observed more often in patients with TMJ clicking than in those without (Artun *et al*, 1992).

The results of studies on the relationship between condylar position and facial skeletal relationship are inconclusive. Artun (1992) has reported a higher frequency of anteriorly positioned condyles in Class I cases. Other studies (Pullinger *et al*, 1987; Gianelly *et al*, 1991) have reported a higher prevalence of anterior condylar position in Class II than in Class I malocclusion. However, Cohlmia *et al* (1996) have found no significant differences in condylar position between class I and Class II groups. Skeletal Class III patients demonstrate a higher frequency of anteriorly positioned condyles than Class I and Class II patients (Seren *et al*, 1994; Cohlmia *et al*, 1996).

An extensive review by Christiansen & Thompson (1990b) cast doubt on the value of recording the condyle/fossa concentricity because of:

1. Relative differences in the shape and size of the condyle and the fossa,
2. Variation of the joint space envelope moving from lateral to medial,
3. The limitations of methods used to determine the concentricity,
4. Variation in the morphology of the articular disc.

There is little discussion in the literature about the concentricity of the condyle in a coronal view. With the advent of improved imaging systems, it is now possible to visualise the hard and soft tissue of the TMJ in three dimensions. Future studies should consider three-dimensional "concentricity" when relating joint structure to function.

➢ ***Articular eminence***

The articular eminence is relatively flat at birth and does not fully develop until after the first decade of life. Therefore, condylar inclination is relatively shallow in the primary and early mixed dentition (Thilander *et al*, 1976; Nickel *et al*, 1988b). Inclination of the articular eminence varies with age but does not directly relate to specific occlusal relationships (Nickel *et al*, 1988a; Pullinger *et al*, 1993b; Matsumoto & Bolognese, 1994; Nickel & McLachlan, 1994; Sato *et al*, 1996; Nickel *et al*, 1997).

Kantomaa (1989) has studied the relationship between mandibular configuration and the shape of the glenoid fossa in humans and found that glenoid fossa shape affected growth of the mandible. A vertically oriented articular eminence seemed to direct condylar growth more vertically than an articulating surface oriented more horizontally. Conversely, alteration in growth direction can affect the configuration of the articular eminence (Pirttiniemi *et al*, 1991). It has been shown that loading is necessary for the development of the eminence (Solberg *et al*, 1986; Nickel *et al*, 1988a; Tuominen *et al*, 1993; Poikela *et al*, 1995; Trainor *et al*, 1995; Osborn, 1996; Tuominen *et al*, 1996).

There is still controversy regarding an association between steepness of the eminence and temporomandibular disorders (TMD). Some studies have suggested a steep articular eminence to be an aetiological factor in internal derangement of the TMJ (Atkinson & Bates, 1983; Hall *et al*, 1985). Other studies have suggested the opposite (Solberg *et al*, 1986; Carano & Keller, 1990; Keller & Carano, 1991; Ren *et al*, 1995b). Recent studies have failed to detect any correlation between steep articular eminence and anterior disc displacement (Panmekiate *et al*, 1991a; Pullinger *et al*, 1993a; Pullinger *et al*, 1993b; Galante *et al*, 1995) or between articular morphology and occlusal characteristics (Pullinger & Seligman, 1993a; Pullinger *et al*, 1993b; Matsumoto & Bolognese, 1994; Sato *et al*, 1996). Furthermore, the steepness of the articular eminence has been proposed to be less in patients with TMD due to remodelling or degenerative bony changes resulting from internal derangement (Ren *et al*, 1995b). An increase in articular soft tissue thickness to compensate for flatter eminence slopes and osseous irregularities, and to maintain an intact surface, has also been described (Pullinger *et al*, 1993a; Pullinger *et al*, 1993b). Therefore, investigations of the soft tissue structures of the TMJ are also important.

➢ *Articular disc position*

A range of articular disc positions in the sagittal plane has been described by Drace & Enzmann (1990) for asymptomatic subjects, including those with and without a history of orthodontic treatment. These researchers have proposed using the position of the posterior band to categorise disc displacement cases. Normal disc position is defined as being in the range of two standard deviations from the "twelve o'clock point". Greater variation in disc position was found in the group of asymptomatic subjects with a history of trauma or with previous orthodontic treatment.

Reported prevalences of disc displacement in asymptomatic volunteers range from 2% to 35% (Kircos *et al*, 1987; Dijkgraaf *et al*, 1992; Stefanoff *et al*, 1992; Davant *et al*, 1993; Morrow *et al*, 1996). Differences in the prevalence may be due to the method of diagnosis and characteristics of volunteers including age, sex and previous history of trauma. Diagnosis by ultrasound imaging has shown the lowest prevalence (Stefanoff *et al*, 1992) which may be due to inferior image quality. Dijkgraaf *et al* (1992) have reported the presence of a biconcave configuration of the disc in most "disc displacement" cases. It was suggested that anatomical and physiological variability should be considered in these cases with so-called "abnormal" disc position.

Agreement in diagnosis of disc displacement between clinical and MRI assessments is only about 75% (Davant *et al*, 1993). Therefore, 25% of patients with symptoms of internal derangement diagnosed by clinical procedures are likely to have a different pathological basis. Moreover, 75% of patients diagnosed as having unilateral disc displacement were found to have bilateral disc displacement when assessed by MRI. Evidence derived from clinical observations, autopsy material, imaging studies and surgical findings have failed to establish strong support for the central role of disc displacement in internal derangements of the TMJ (Dolwick & Dimitroulis, 1996).

2.4.3 TMJ imaging

Various radiographic techniques have been used in TMJ imaging. As a minimum, two positions are recommended, one when the mouth is closed with the teeth in centric occlusion, and the other when the mouth is open at some point of clinical interest, e.g. a point just prior to clicking, onset of pain, or maximum opening (Christiansen & Thompson, 1995). The disadvantages of radiographic techniques are their inability to depict soft tissue and the problem of radiological risk to adjacent vital organs such as eyes and brain. Recently, imaging of both soft tissue and hard tissue, with a high degree of accuracy, has become possible with the use of Magnetic Resonance Imaging (MRI).

➢ ***Plain film radiographs***

Plain film radiographs can be obtained easily using an ordinary dental x-ray machine and thus the practising dentist is able to retrieve radiographic information without the need to refer patients. The cost is relatively low but superimposition is inherent in any plain film projection. Images can be obtained at specific angles to minimise the superimposition from adjacent structures. Inaccurate positioning of patients can lead to distorted images of the bony structures as well as the joint space. Understanding how the image has been obtained is important when interpreting radiographs. Non-mineralised cartilaginous structures are not visible in plain radiographs.

Table 4 ▪ Plain film radiographic techniques and their limitations.

Technique	Area seen	Limitations
Transcranial (lateral view)	• glenoid fossa • lateral one third of the condyle	• Osseous disease occurring centrally and/or medially may not be detected
Transpharyngeal (lateral view)	• anterolateral part of the condyle	• Condyle may be superimposed on the articular eminence if the mouth is not adequately open. • High radiation dose is used due to short target to film distance.
Transorbital (frontal view)	• posterior surface of the condyle	• Only information about the non-functional surface of the TMJ
Transmaxillary (frontal view)	• superior surfaces of the condyle	• Superimposed by articular eminence, hard palate or teeth • Distorted and low reproducibility
Submento-vertex (inferior view)	• inclination of the condylar axes	• Deviation from the ideal position will cause possible error in evaluation of condyle shape and size and condylar axial orientation.
Cephalometric (lateral and frontal view)	• gross form of TMJ	• Superimposed by lateral cranial structures • inadequate for details of the TMJ.

➢ *Tomography*

Tomography is a specialised technique for producing radiographs of only a section of a patient. During the exposure the x-ray source moves in one direction around the object while the film moves in the opposite direction. Only the structures in the focal plane are sharply defined and in focus. Structures outside the section are blurred and out of focus. This technique provides images that are relatively free of the superimposition of structures that occurs with plain radiography. The thickness of section is determined by the arc of X-ray source movement. Small tomographic arcs produce relatively thick sections while larger tomographic arcs produce relatively thin sections.

Linear tomography is the simplest with the tube and film moving in one direction only. Linear tomography is superior to plain film radiography in that it can isolate joint structures without angular distortion. Bony structures oriented perpendicular to the tomographic plane of motion generally are visualised better than those parallel to the plane of motion because of the inherent streaking effects of the linear tomograms. More complex movements such as hypocycloidal and trispiral movement create less ambiguous images and usually a consistent layer thickness. However, because of the cost and size of the equipment, they are generally not used in dental practice. Tomography gives reliable information about the position of the bony parts of the joint but non-calcified cartilage is not visible. Lateral corrected tomography is commonly used with occasional addition of frontal corrected tomography to give three-dimensional information. Frontal corrected tomography should be obtained when the patient's mandible is protruded so that the condyle is below the articular eminence, and the superior functional surface should be at right angles to the tomographic plane.

➢ *Pantomography:*

Pantomography (OPG) is a form of tomography with a horseshoe-shaped focal trough. Typically, the mandible is slightly protruded at exposure. Imaging of the TMJ takes place during the first and the last parts of the exposure. The angulation of the radiation varies among different machines and is also dependent on the position of the patient's head in the apparatus. Usually the image of the condyle is clearly visible but the image of the articular eminence is sometimes obscured by the middle cranial fossa. The view of the condyle is a compromise between lateral and anteroposterior views. The most posterior border on the OPG represents the medial posterior border while the anterior border of the image represents the lateral slope of the condyle, which often seems much steeper than it is in reality because the radiation is directed from below (about seven degrees). The OPG tends to serve as a primary screening tool to decide whether more complex imaging techniques are needed. Vertical magnification is inherent in the OPG, resulting in image asymmetry. Less than 6% asymmetry between the right and left condyles is considered to be acceptable and is attributed usually to head position. Asymmetry greater than 6% usually is thought to indicate a true morphologic difference (Christiansen & Thompson, 1990a).

➢ *Arthrography*

This method involves injection of an aqueous medium into the joint space with the aid of fluoroscopy for accurate positioning of the needle. Video-recorded fluorography allows imaging of the joint during movement. As a transcranial projection is usually used, only the lateral aspects of the joint are seen. Arthrography provides the most reliable information about the configuration, position and function of the disc (Hollender, 1994). It reveals the speed of movement, irregularities on opening or closing, possible disc dislocation, translatory versus rotational movement of the condyle, and subluxation. It does not allow detailed analysis of structure because of the relatively poor resolution. The radiation dosage is similar to that for a single tomographic image.

➢ *Computed Tomography (CT)*

Computed tomography provides a series of sectional images of the TMJ. High-resolution thin-section CT is capable of demonstrating both hard and soft tissue joint structures but because the TMJ soft tissues are relatively scant and closely surrounded by bone, their resolution is generally poor (Benoit & Razook, 1994). Axial scans are common and sagittal, frontal or 3D images are created from a series of axial CT sections. Direct sagittal CT scanning requires an additional stretcher to position the patient in the direct sagittal CT scanning plane (Figure 8). Katzberg & Westesson (1994) believe that the diagnostic accuracy of this method is higher than using reconstructed images from axial scans as there is some loss of anatomical detail during the reconstruction procedure. A single CT slice involves less radiation exposure than conventional tomography but is more sensitive in detecting changes in bone density (Benoit & Razook, 1994). Finer slice thickness of axial scans improves the 3D reconstructed image quality but accumulative radiation dosage becomes greater.

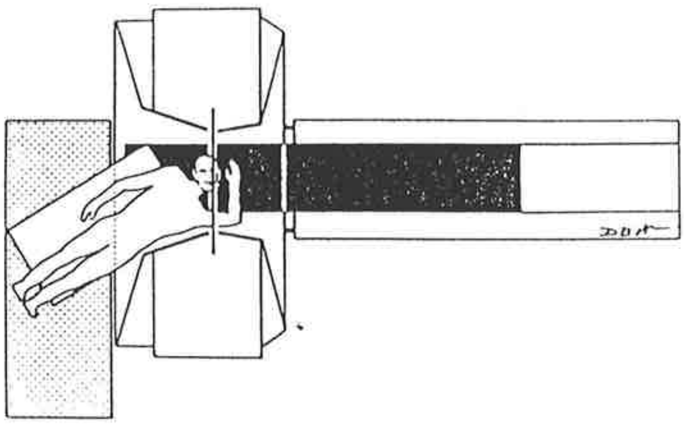


Figure 8 ▪ Diagram of patient positioning for direct sagittal CT scanning of TMJ (Katzberg & Westesson, 1994).

Selection of section thickness is critical in reconstructing images. Small structures such as the TMJ disc that is too thin to fill the section will appear blurred or the outline will be obliterated. Therefore, CT is not sensitive for diagnosis of disc displacement. Scanning of soft tissues with thin sections requires a high resolution technique. High radiation levels are potentially damaging to vital tissues such as eyes, bone marrow, brain, pituitary gland and thyroid gland (Wilson, 1990; Katzberg & Westesson, 1994).

2.4.4 Malocclusion, orthodontic treatment and TMJ

> ***Occlusion and TMJ function***

The relationship between dental occlusion and function of the TMJ is a complex and controversial topic. The dental profession has viewed malocclusion historically as a primary aetiologic factor for temporomandibular disorders (TMD). Skeletal and dental characteristics that are frequently mentioned as causes include: occlusal disharmony, skeletal anterior open-bite, large overjet, large discrepancies between centric relation and centric occlusion position, unilateral posterior crossbite, and loss of vertical dimension due to missing several teeth. Raustia *et al* (1995b) found that disturbances of occlusal relationships were often found in subjects with clinically evident joint signs associated with pathological MRI findings. Reported results by the same authors in other studies are sometimes contradictory (Pullinger *et al*, 1988a; Pullinger *et al*, 1988b; Seligman & Pullinger, 1989; Pullinger & Seligman, 1991; Seligman & Pullinger, 1991a; Seligman & Pullinger, 1991b; Pullinger & Seligman, 1993a; Seligman & Pullinger, 1996). This is thought to reflect the multifactorial origin of TMD. Different types of TMD have different combinations of aetiologic factors. Moreover, a definitive diagnosis is difficult due to overlapping of signs and symptoms. Despite extensive literature reviews by several authors, no consistent occlusal, structural, functional skeletal or dental factors have been found in TMD patients (Seligman & Pullinger, 1991a; Seligman & Pullinger, 1991b; Tallents *et al*, 1991; McNamara *et al*, 1995; McNamara, 1997; McNamara & Turp, 1997; Turp & McNamara, 1997). Occlusion is considered to play a limited role in the cause of TMD. Skeletal anterior open-bite, overjets greater than 6 to 7 mm and retruded cuspal position/intercuspal position slides greater than 4 mm are though to be the result of TMD rather than its cause. The role of unilateral posterior crossbite needs further investigation. The correction of unilateral posterior crossbite has been recommended to eliminate occlusal disturbances and prevent development of facial asymmetry during growth (De Boer & Steenks, 1997). There have been no convincing correlations noted among any of the cephalometric variables and the Craniomandibular Index, the Dysfunction index, or Muscle index scores (De Boever *et al*, 1996).

The symptoms of TMD are common in samples requiring orthodontic treatment (Heikinheimo *et al*, 1989; Olsson & Lindqvist, 1992; Pilley *et al*, 1992; Barone *et al*, 1997). Common symptoms include muscle pain, headache, joint sounds, and locking of the joint. Some researchers have claimed that patients with retrognathic mandibles display a higher prevalence of TMD and that their symptoms are more severe (Olsson & Lindqvist, 1992; Le Bell *et al*, 1993). However, symptoms tend to be occasional, inconsistent, unstable and impossible to predict from earlier symptoms and signs (Dibbets & Van der Weele, 1989; Heikinheimo *et al*, 1989). Because of the inconsistent nature of TMD, it should not be used as an indicator of the need for orthodontic treatment (Heikinheimo *et al*, 1989; Barone *et al*, 1997).

➢ ***Orthodontic treatment and temporomandibular disorders (TMD)***

Orthodontic treatment has been mentioned as either a cause, a management method, or as having no effects on TMD at all. Reynders (1990) has reviewed the literature on the topic of orthodontics and TMD from 1966 to 1988 and found that a high percentage (60%) of the published articles merely reflected the belief of the author(s) who wrote them (so-called viewpoint publication). Only 6% of the articles were clinically controlled studies. Of the 91 articles reviewed, 40 stated that orthodontics could both cause and cure TMD. Thirty-five publications stated that orthodontics cured TMD; eight articles showed that orthodontics did not influence TMD; and the remaining eight articles, based solely on the authors beliefs, stated that orthodontics caused TMD. Reynders (1990) has stated that viewpoint publications and case reports have little or no value in the assessment of the relationship between orthodontics and TMD. From six clinical studies, four studies showed that orthodontics had no effects on TMD and two studies showed that orthodontics cured TMD. Based on clinically controlled studies, Reynders (1990) has concluded that orthodontic treatment should not be considered responsible for creating TMD, regardless of the types of appliance used (fixed or functional appliances).

Sadowsky (1992) has published a similar review of associations between orthodontic treatment and TMD up to 1991. Fourteen clinical studies were used to draw conclusions about the relationship between orthodontics and TMD. Sadowsky (1992) has found that objective signs increase with age rather than with orthodontic treatment, and that TMJ sounds, often present in the absence of symptoms, are a common finding occurring in approximately 20% to 30% of the population. Also orthodontic treatment performed on children and adolescents does not generally seem to be a risk for the development of TMD many years later. Sadowsky (1992) has explained these findings by noting that the cause of TMD is multifactorial and that orthodontic mechanotherapy produces gradual changes in an environment that is generally quite adaptive.

The present review of the literature from 1992 to 1998 has revealed similar inconclusive findings. The majority of the papers have indicated that orthodontic treatment neither increases nor decreases the prevalence of signs of TMD. (Hirata *et al*, 1992; Kremenak *et al*, 1992a; Kremenak *et al*, 1992b; Rendell *et al*, 1992; Dibbets *et al*, 1993; Wadhwa *et al*, 1993; Dibbets & Carlson, 1995; De Boever *et al*, 1996; Katzberg *et al*, 1996). Some studies have reported that orthodontic treatment has positive effects on the symptoms of TMD. Improvement is indicated by a lower craniomandibular dysfunction index which includes the occlusal irregularity index (Egermark & Thilander, 1992; Kremenak *et al*, 1992a; Kremenak *et al*, 1992b; Deng & Fu, 1995). Some studies have used the lack of joint sounds or pain symptoms as an indication of improvement (Tyler, 1992; Keeling *et al*, 1994). Given that occlusal characteristics show little association with TMD (reviewed by Seligman & Pullinger, 1991a; Seligman & Pullinger, 1991b; Tallents *et al*, 1991; McNamara *et al*, 1995; McNamara, 1997; McNamara & Turp, 1997; Turp & McNamara, 1997), the occlusal irregularity index is not considered to be a valid indicator of improvement. Only a few articles have shown negative effects of orthodontic treatment on the TMJ (Peltola *et al*, 1995a; Peltola *et al*, 1995c). These studies have reported a higher prevalence of condylar flattening observed on panoramic radiographs as well as joint crepitation in orthodontically treated subjects (Peltola *et al*, 1995a).

The prevalence of TMD symptoms appears to consistently increase with age (Dibbets & Van der Weele, 1989; Pilley *et al*, 1992; Keeling *et al*, 1995; Olsson & Lindqvist, 1995; Pilley *et al*, 1997). This is probably due to several factors including hormonal changes, growth, trauma and stress. In investigations of orthodontic treatment as a possible TMD risk factor, studies extending over more than four years may lead to less rather than more conclusive findings as non-orthodontic factors may have influenced TMJ status over time (Kremenak *et al*, 1992b).

➢ ***Extraction vs. functional appliance therapy***

The extraction of first premolars to correct large overjets in Class II patients has been hypothesised as a possible cause of TMD (Farrar & McCarty, 1979; Levy, 1979; Witzig & Spahl, 1986; Keller, 1993). This type of TMD is reportedly characterised by posterior displacement of the condyle due to excessive incisal retraction and loss of vertical dimension. Therefore, a functional appliance with a non-extraction approach is often a preferred option in the treatment of Class II malocclusions. O'Connor (1993) has found that the extraction rate has declined by approximately 8% over the five years of his study and this was influenced by medico-legal factors following a court case which associated TMD with orthodontic treatment.

However, this hypothesis has never been supported by any scientific clinical research. In fact, the majority of the studies refute this hypothesis. Studies have found that there are no clinically important TMD differences in patients treated with or without premolar extractions (Dibbets & Van der Weele, 1991a; Gianelly *et al*, 1991a; Gianelly *et al*, 1991b; Artun *et al*, 1992; Dibbets & Van der Weele, 1992; Kremenak *et al*, 1992a; Luecke & Johnston, 1992; Sadowsky, 1992; Dibbets *et al*, 1993; O'Reilly *et al*, 1993; Staggers, 1994; Major *et al*, 1997). The correction of Class II malocclusion with a fixed appliance, either by extraction or non-extraction, does not only occur by means of incisal retraction. Some degree of "functional appliance effect", such as an increase of condylar growth, and forward mandibular movement, is also found with the use of Class II elastics (Petrovic & Stutzmann, 1997). The decision for either extraction or non-extraction should be based on the correct diagnosis of aetiologic factors.

2.5 Magnetic Resonance Imaging (MRI)

Damadian (1971) has claimed to be the first to use MRI scanning (then called Nuclear Magnetic Resonance – NMR) for medical diagnosis. The first functional body scanning machine was developed in 1977 with a scanning time of approximately five hours (Damadian *et al*, 1981). Contemporary magnetic field strength has increased ten times or more, thus reducing the scanning time and offering better images. The MRI signal is derived mainly from the hydrogen nuclei of water and lipid molecules. Signal intensity varies from tissue to tissue, and between normal and abnormal tissue. Protons in fat give out a strong signal (seen as a white area) as do those in water (although these areas appear different in intensity). Cortical bone does not give out a signal, therefore, it is seen as a black area while cancellous bone gives out a strong signal due to its marrow content. Teeth also appear black. Even within tissue types such as the brain it is possible to differentiate between grey and white matter. MRIs obtained can be presented in the same planar format as CT scan images. In the region of the head and neck these are usually produced and presented in the coronal and sagittal plane rather than the axial. Section thickness varies from 3 to 10 mm. Examination time varies from six to 27 minutes (Hall, 1994).

2.5.1 How MRI works

Understanding how MRI works is important in selecting suitable radiofrequency sequences for structures under investigation and the interpretation of the images. MRI is a type of computer-reconstructed image mathematically derived from electromagnetic signals emitted from tissues. The signal is generated by protons in the tissues which react to three different types of magnetic fields (reviewed from Schild, 1990).

1. **A static magnetic field** is generated by a superconducting magnet. This type of magnet gives a high magnetic field strength and excellent magnetic field homogeneity. However, the disadvantages include high cost and use of an expensive cryogen to cool down to superconducting temperature (about 4°K or –269°C). The strength of a magnet is given in Tesla or Gauss, where 1 Tesla = 10,000 Gauss. Magnets used for imaging mostly have field strengths between 0.5 to 1.5 Tesla. Although 4.0 Tesla is available, it is not recommended for medical imaging due to the questionable safety margin.

2. Radiofrequency coils are used to send a **radiofrequency pulse** (RF) to excite protons and to receive the signal.

3. To select a slice to be examined, a **gradient magnetic field** is superimposed on the main magnetic field created by the superconducting magnet.

The patient is placed in high static magnetic field
(**Effect**: - realigning of protons)

⇩

Radiofrequency pulse sent in
(**Effects**: - exciting the protons, changing of magnetisation)

⇩

Gradient magnetic field is superimposed on main magnetic field
(**Effect**: - enable the selection of slice to be examined)

⇩

Radiofrequency pulse turned off
(**Effects**: - relaxation of protons, emission of signals)

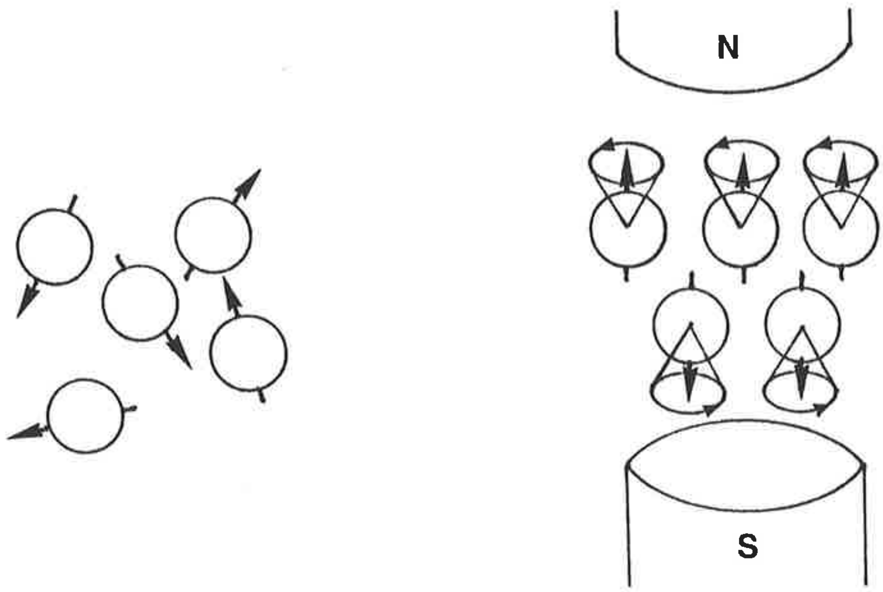
⇩

Computer reconstruction of the image (MRI)

Figure 9 ▪ Steps in MRI examination

> ***Steps in MRI examination***

1. The patient is placed in a high static magnetic field.
   Effects: The protons align themselves and spin (or "precess") along the same plane (parallel or anti-parallel) to the static magnetic field (Figure 10). Therefore, the patient's magnetic field is longitudinal to the external magnetic field (longitudinal magnetisation).

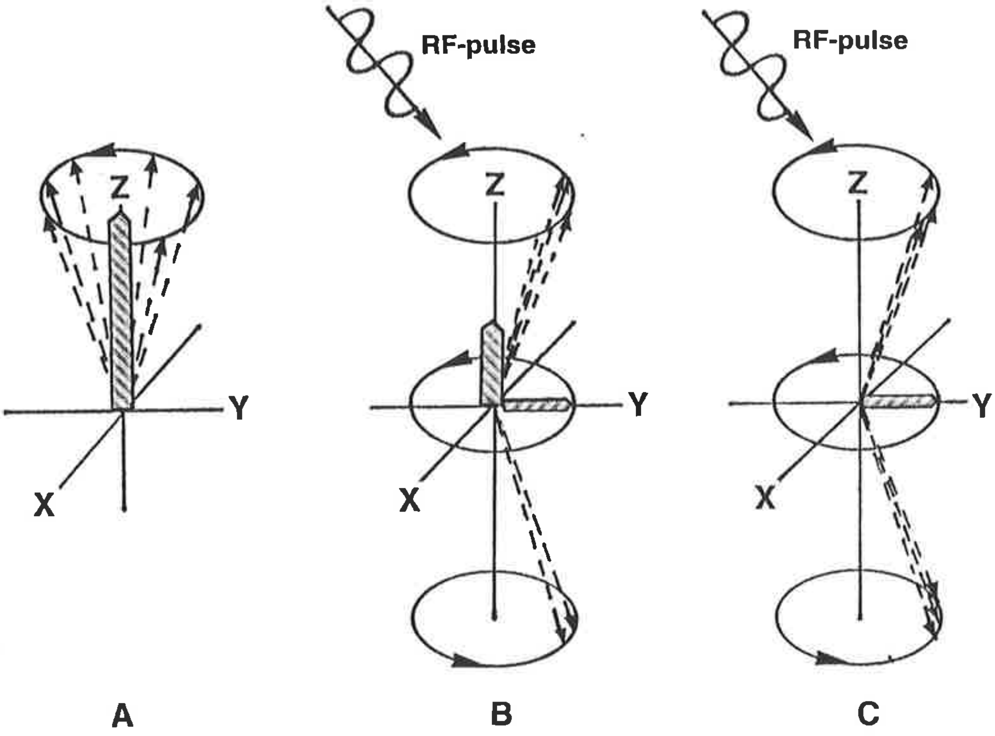


A. Normally protons are aligned in a random fashion

B. When they are exposed to a strong external magnetic field, they are aligned either parallel or anti-parallel to the external magnetic field

Figure 10 ▪ Precession of protons in a strong magnetic field

2. A sequence of electromagnetic waves, referred to as a radio frequency (RF) pulse, is applied.
   Effects: Protons with the same frequency as the RF pulse pick up the energy from the RF pulse causing "resonance". The RF pulse also causes the protons to precess in phase. These effects result in the reduction of the longitudinal magnetisation and establishment of a new transverse magnetisation (Figure 11).



A. When the protons align along the external magnetic field, a longitudinal magnetic field is established in the patient (thick grey arrow). This magnetic field is not possible to measure as it is in the same direction of the main magnetic field.

B. When the RF-pulse is sent in, a new transverse magnetisation (thin grey arrow) is established while longitudinal magnetisation decreases.

C. With a certain RF-pulse, longitudinal magnetisation may totally disappear.

Figure 11 ▪ Changing magnetisation after the RF-pulse is sent in

3. Magnetic gradient fields are superimposed on the external or main magnetic field.

   Effects: Protons along this gradient magnetic field are exposed to different magnetic field strengths thus they have different precession frequencies. The RF pulse with the corresponding frequency is then generated to excite the protons in the slice that is imaging. This helps in determining the different signals from different slices of tissue examined.

4. RF pulse is turned off.

   Effects: As protons lose their phase, there is a reduction and disappearance of the transverse magnetisation. The reduction of transverse magnetisation is described by a time constant **T2**, transverse relaxation time (Figure 12).

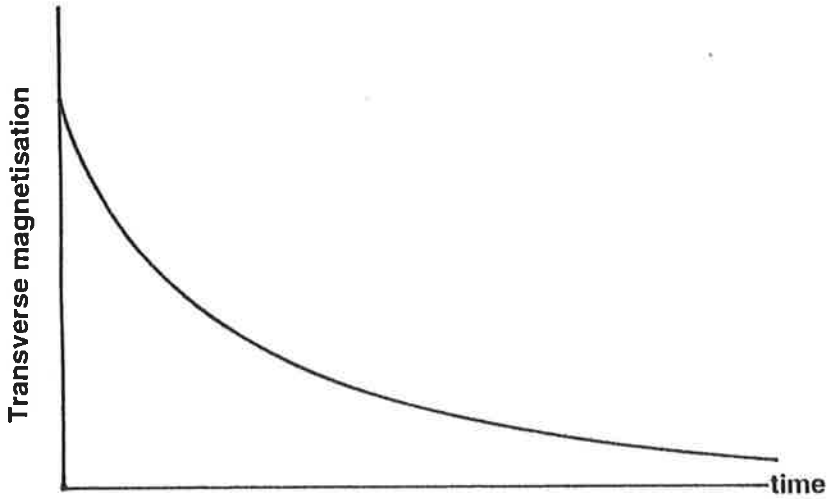


Figure 12 ▪ Transverse magnetisation curve (T2-curve) after the RF-pulse is switched off.

5. While the transverse magnetisation decreases, more protons realign with the external magnetic field again. The longitudinal magnetisation then increases. The increase in longitudinal magnetisation is described by a time constant **T1**, longitudinal relaxation time (Figure 13).

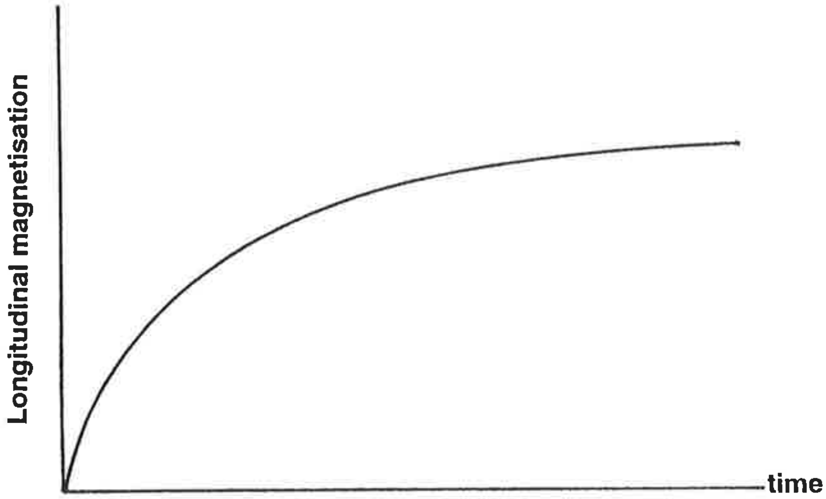
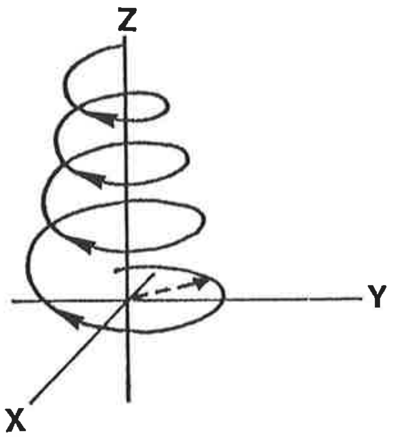
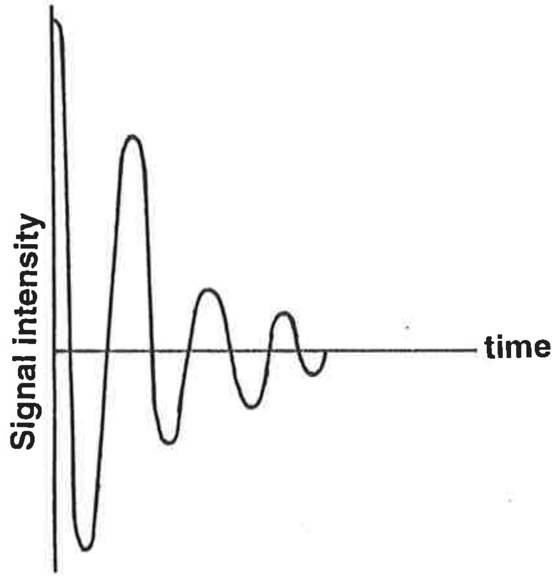


Figure 13 ▪ Longitudinal magnetisation curve (T1-curve) after the RF-pulse is switched off.

6. The patient emits a signal.
   This signal comes from the electrical current induced by the changing in magnetic force/moment, from transverse magnetisation back to longitudinal magnetisation, after the RF pulse is turned off (Figure 14).



A. Changing of sum vector (direction and magnitude) from longitudinal and transverse magnetisation is in spiral motion. The sum vector induces an electrical current in the signal receiver.



B. The magnitude of the signal is the greatest immediately after the RF-pulse is switched off and then disappears with time.

Figure 14 ▪ Changing magnetisation and emission of signal after the RF-pulse is switched off.

7. Receiving the signal and reconstruction of the image.
   The signal is received by receiver coils. The computer reconstructs an image according to the RF pulse and the gradient magnetic field sequence used during the imaging process.

➢ ***Selection of RF sequence***

Each tissue has different T1 and T2 characteristics, which depend on its internal magnetic field. The internal magnetic field is influenced by the distribution of protons contained in the tissue, precession frequencies of the protons and the interaction with the magnetic fields from neighbouring nuclei, which are not evenly distributed. By choosing the specific pulse sequences and imaging parameters, such as varying the time to repeat (TR) and time to echo (TE) of the RF pulses, different types of images can be obtained. The choice of pulse sequence will determine the signal emission (Figure 15).

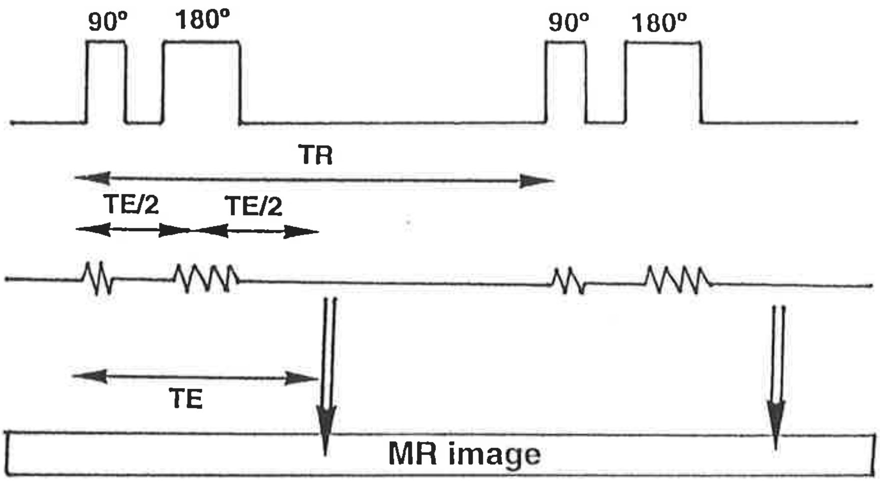


Figure 15 ▪ Schematic illustration of and RF-pulse sequence and the construction of the image.

TR, time to repeat, is the time between successive RF pulses which tilt the longitudinal magnetisation to transverse magnetisation (90° pulse). For T1-weighted images, the differences in signal intensity between tissues (or tissue contrast) are more pronounced when using a short TR (Figure 16). With a long TR the difference between the two tissues is low and would appear the same on a MR picture. A TR of less than 500 msec is considered to be short, while a TR greater than 1500 msec is considered to be long.

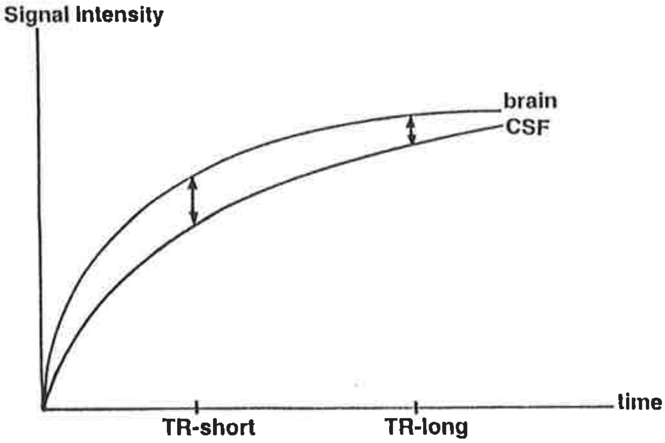


Figure 16 ▪ The differences in longitudinal (T1)-relaxation time between brain and CSF. With short TR, the differences in signals between the two tissues are more evident.

To obtain the T2-weighted images, a 180° RF pulse is used to echo the de-phasing protons to become in-phase again. This increases the transverse magnetisation and the spin echo signal is received. **TE**, time to echo, is the time between the 90° pulse and the spin echo. The shorter the TE the stronger the signal intensity. However, the tissue contrast is small and hard to distinguish with a short TE. The longer TE will give better T2 tissue contrast (Figure 17). But a longer TE also results in lower signal intensity and smaller signal-to-noise ratio. The image appears grainy. A TE of less than 30 msec is considered to be short, a TE greater than 80 msec is considered to be long.

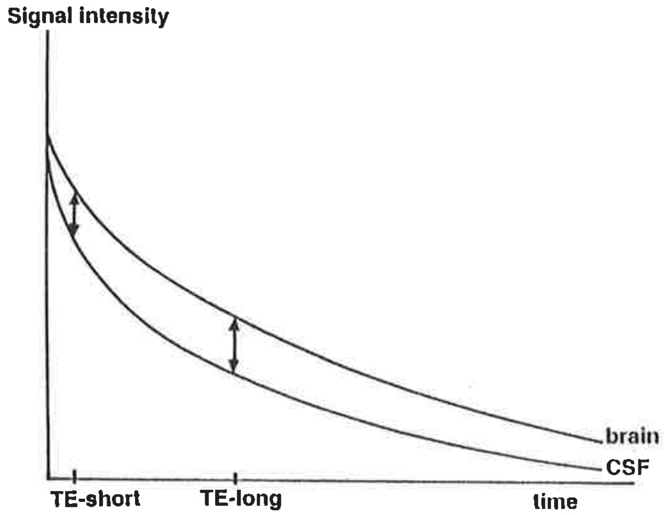


Figure 17 ▪ The differences in transverse (T2)-relaxation time between brain and CSF. With long TE, the differences in signals between the two tissues are more evident.

To maximise the T1 effect, RF sequences with short TR and short TE are used. The result is called the **T1-weighted image** (Figure 18). Due to the relatively short time used, this gives the strongest signal. To obtain the **T2-weighted image**, a long TR is used to minimise the T1 effect and a long TE is used to produce greater T2 tissue contrast (Figure 19). T2-weighted images give darker and more grainy appearances than T1-weighted images as a longer time is needed before receiving the signal thereby reducing the signal intensity. Proton density (also called spin density) images are obtained by using a long TR and a short TE (Figure 20). This minimises both the T1 and T2 effects, i.e. both T1 and T2 relaxation are completed. The difference in signals depends only on the density of the protons in the different tissues. Proton density images are somewhat similar to T1-weighted images but the signal from the proton density sequence is weaker than T1 as it takes longer than T1 to receive the signal. Water or liquid has a long T1 and long T2 while fat has a short T1 and short T2.

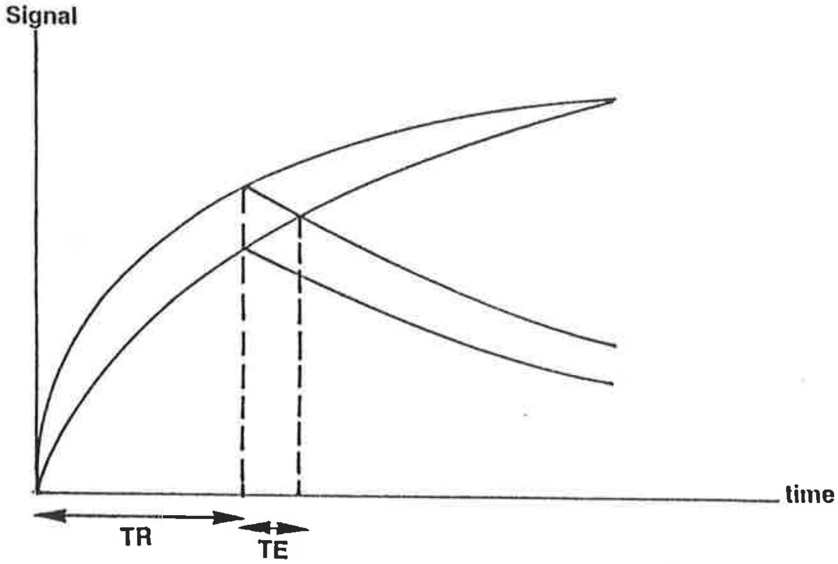


Figure 18 ▪ T1-image is obtained by using short TR, where the difference between the two tissues on the T1-curve is more evident, and short TE, where the difference between the two tissues on the T2-curve is less evident.

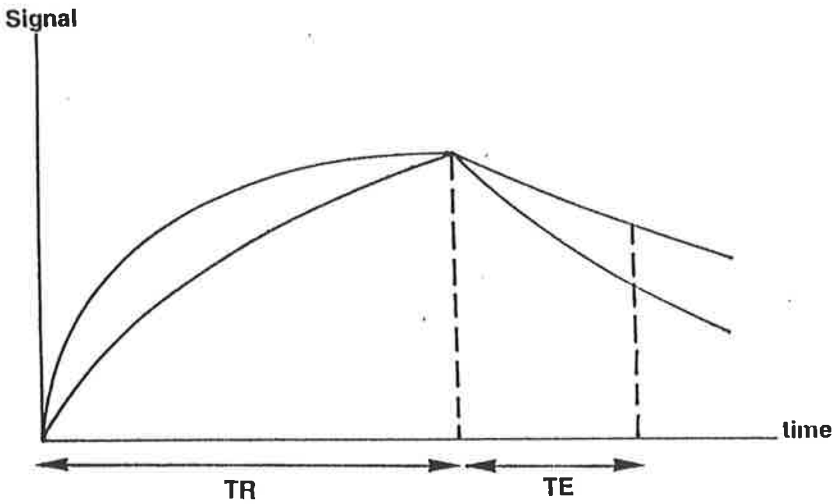


Figure 19 ▪ T2-image is obtained by using long TR, where the difference between the two tissues is the least on the T1-curve as the two tissues have completed T1-relaxation, and long TE, where the difference between the two tissue on the T2-curve is more evident. However, using very long TE results in reduction of signal intensity and increasing of signal-to-noise ratio thus producing a poor image.

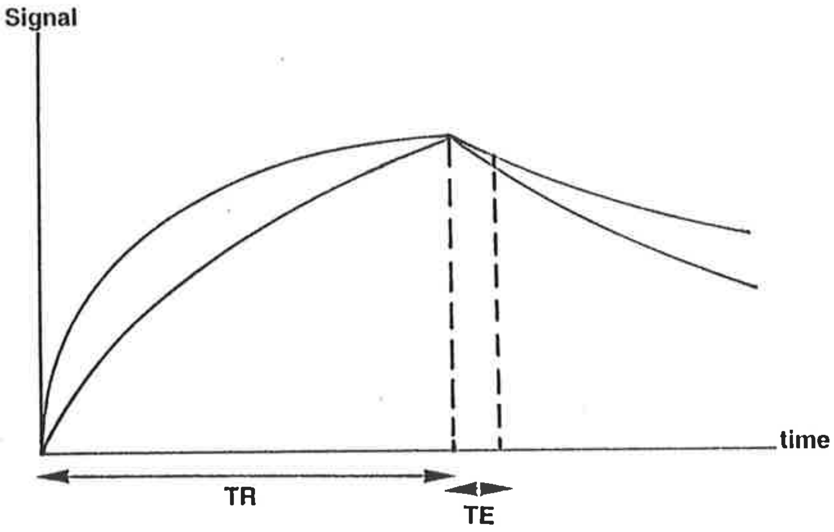


Figure 20 ▪ Proton density image is obtained by using a long TR, where the two tissues have completed T1-relaxation, and short TE (ideally zero), where the difference between the two tissues on the T2-curve is the least evident. This RF-pulse minimises both T1 and T2 effects. The signal emitted is then determined by the differences in the density of the protons in the tissues.

Image quality can be improved by increasing the number of excitation (NEX) which represents the number of repeat measurements. This adds up the signals from several measurements thus giving better signal-to-noise ratios. Because imaging time increases with every additional measurement, it is harder for the patient to keep still for a lengthy period of time.

2.5.2 Biological effects of MRI scanning

MRI scanning involves three different types of magnetic fields, which are:

- Static magnetic fields
- Gradient or switched magnetic fields
- Radiofrequency electromagnetic fields

There is no conclusive evidence for irreversible or hazardous biological effects related to acute, short-term exposures of humans to clinical MRI. However, potential health hazards of the MRI are as follows:

- Physical damage from the collision hazards (or projectile effect) of ferromagnetic objects, or the movement of metal internal prostheses attracted by the field.
- Thermal effects from current induction resulting in heat deposition within the tissue or electrically conductive material in the tissue (such as intraorbital metallic foreign body, intracranial aneurysm clips, permanent tattoo eye liner).
- Nerve and muscle excitation if the electromagnetic field is strong enough to reach the threshold of neuromuscular stimulation.
- Interference with magnetically sensitive equipment such as cardiac pacemakers.
- Hearing loss resulting from motion and vibration of gradient coils which produce banging noises.

A static magnetic field of 4 Tesla has been reported as causing dizziness and nausea related to the force on circulating inner ear fluids (Hardy *et al*, 1988). Alteration in the shape of normal red blood cells and in the alignment of sickled red blood cells *in vitro* have also been reported (Leitmannova *et al*, 1977; Brody *et al*, 1985; Murayama *et al*, 1991). The amplitude of the noise is between 65 and 95 dB and temporary or even permanent hearing loss as a result of the MR examination has been reported (Brummett *et al*, 1988).

The National Radiological Protection Board of the United Kingdom (1992) has recommended that the exposure of humans to static magnetic fields below about 2.5 T is unlikely to have any adverse effect on health. Exposure to gradient magnetic fields should be such as to avoid the stimulation of nerves and muscles by restricting the induced current density to less than 400 mA/m^2. And the exposure to radiofrequency fields should be such as to avoid a rise of more than 0.5°C in body temperature by limiting time of exposure to less than 30 minutes. Hearing–protective devices such as headphones or earplugs are recommended during examination.

2.5.3 MRI of the TMJ

MRI has been extensively used in the head and neck region for investigations of the brain and spine. More recently, it has been used for studying morphology, position and function of the temporomandibular joint (TMJ). MRI has been found to be very suitable for visualising internal morphology, interpreting the pathology, and observing disc behaviour in different functional positions. It can also be used for postoperative evaluation, trauma, inflammatory arthritis and neoplasia of the TMJ.

➢ ***Advantages and disadvantages***

The advantages of this technique are that it is non-invasive, has no associated radiological risk and can enable visualisation of both hard and soft tissue components such as disc and capsule. With the cine loop method, MRI also offers the ability to image the joint throughout its range of motion (Bell *et al*, 1992; Quemar *et al*, 1993; Yustin *et al*, 1993). This technique offers more than 95% accuracy (sensitivity and specificity) in identifying the menisco-ligamentous complex (Bell *et al*, 1992). Furthermore, because signal intensity varies between normal and abnormal tissues, pathologic conditions can be diagnosed (Jih *et al*, 1992). Multiplanar imaging or three-dimensional reconstruction of MRI is also obtainable and anatomical details can be enhanced with intravenous administration of contrast agents (Takebayashi *et al*, 1997). The drawbacks of MRI are that it is time-consuming and expensive (Bauer *et al*, 1994), requires patients to remain immobile for an extended period, and some patients may feel claustrophobic during the procedure (Santler *et al*, 1993).

➢ ***Techniques for TMJ imaging***

- An axial scout image is routinely used for localising the condyle and programming the imaging angles for the sagittal and coronal scans (Figure 21).

Figure 21 ▪ Axial scout image for localising the condyle.

- The sagittal plane is the standard orientation of imaging. Oblique images perpendicular to the horizontal (medio-lateral) long axis of the condyle (corrected sagittal plane) are preferable to straight sagittal images. Normally, images are obtained in closed and open-mouth positions (Figure 22).

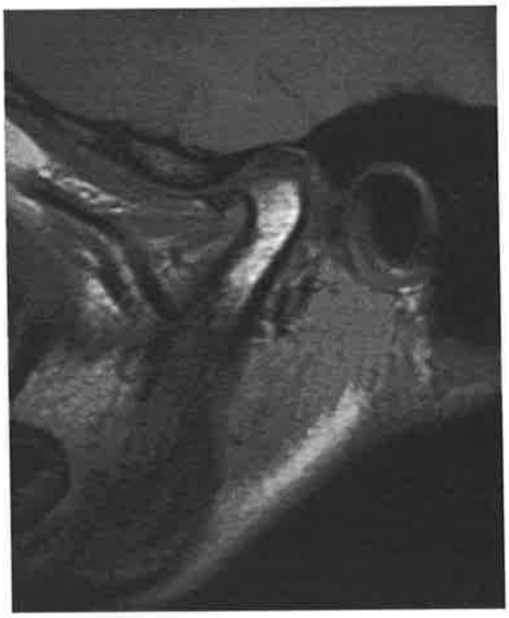


Figure 22 ▪ T1-sagittal image of a normal TMJ (closed-mouth position)

- Coronal images are important for studying medial and lateral disc displacement. Coronal images should be parallel to the horizontal long axis of the condyle. They are usually obtained only in the closed-mouth position (Figure 23).

Figure 23 ▪ T1-coronal image of a normal TMJ

- A slice thickness of 3 mm is desirable. A thin slice provides better anatomic detail but it gives a lower signal-to-noise ratio.

- Matrix size, defined as number of picture elements (pixels) x number of rows, determines the resolution of the image. The finer the matrix, the better the resolution, but the longer the imaging time.

- Increasing the number of excitation (NEX) improves the image quality but requires longer scanning time and increases the risk of motion artefacts.

- T1 weighted and proton density weighted spin echo sequences give similar images that highlight fat (Table 5). T1 images are good for depicting normal structures of the TMJ.

Table 5 ▪ Relative brightness of body tissues seen on a T1- or proton density weighted spin-echo sequence (Katzberg, 1996).

Fat	White
Marrow of condyle	
Brain	
Muscle	Grey
Body fluid	
TMJ disc	
Cortical bone	
Air	Black

- T2 weighted spin echo sequences give an image that highlights water-containing structures. T2 images are best for detecting inflammation and effusions of the joint (Curtin, 1988).
- Bilateral surface coils for TMJ (Figure 24) increase the signal-to-noise ratio and resolution, and thus improve image quality. It is recommended that both joints should be imaged at the same time, as the prevalence of bilateral TMD is high (Katzberg, 1996).

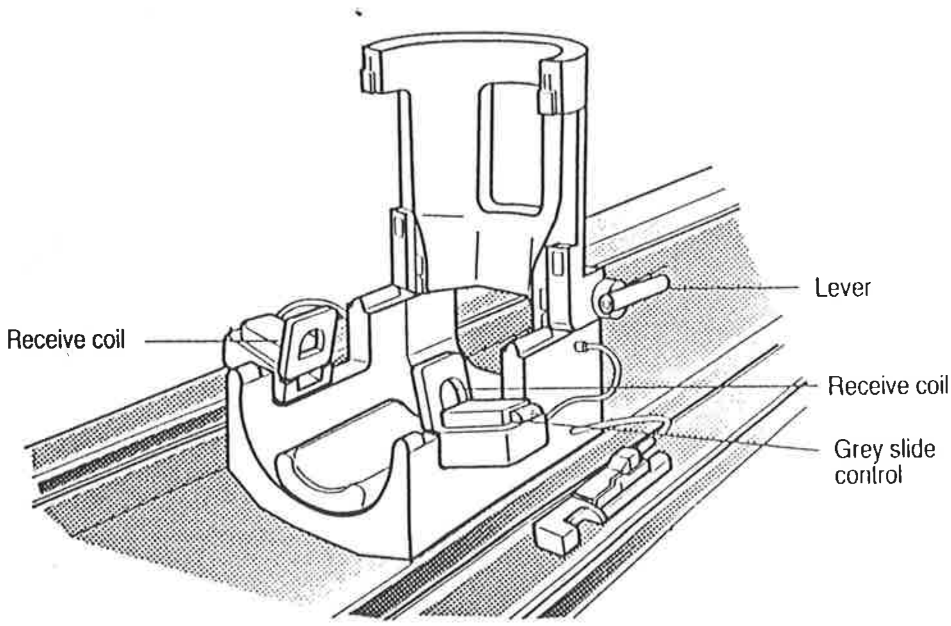


Figure 24 ▪ Bilateral surface coils for TMJ

➢ *MRI vs. other TMJ imaging techniques*

Several techniques such as axiography, radiography, arthrography, computerised tomography, ultrasonography, and lately magnetic resonance imaging (MRI) have been used in studying the morphology, position and function of the TMJ. In their study of cryosections from fresh cadavers, Tasaki and Westesson (1993) have found that MRI was 95% accurate in the assessment of disc position and disc form and 93% accurate in the assessment of osseous changes. Coronal images also help avoid a false-negative diagnosis in 13% of cases. The accuracy of the MRI has been found to be above 95% when compared with other techniques (Bell *et al*, 1992; Brady *et al*, 1993).

Comparing clinical functional analysis, axiography and MRI, Bauer *et al* (1994) have recommended that a valid diagnosis can be made on the basis of MRI alone. In contrast, Piehslinger *et al* (1995) have concluded that computerised axiography determines the dysfunctional dynamics more clearly than MRI.

Raustia *et al* (1995a) have stated that MRI provides the most accurate examination of TMJ soft tissue structures. However, MRI cannot detect changes in the bone of the TMJ as accurately as computed tomography (CT). Moreover, disc perforations were found to be more accurately detected by arthrography than with MRI (Santler *et al*, 1993). Raadsheer *et al* (1994) have found that ultrasonography and MRI produce significant correlations in measuring the thickness of the masseter. Diagnoses of joint effusion, joint degeneration and changes in the retrodiscal tissues have also been found to be accurate with the use of MRI (Takaku *et al*, 1995).

High quality images, suitable training of the observers, and well-defined criteria for interpretation have been expressed as vital ingredients for high diagnostic accuracy and low interobserver and intraobserver variation (Tasaki *et al*, 1993).

➢ *MRI in diagnosis of disc position*

Because of its non-invasive nature and ability to image the soft tissues of the TMJ, MRI provides a useful method to diagnose disc displacement. It has disclosed evidence of disc displacement, ranging from 7% to 35%, in subjects who showed no signs and symptoms of TMD clinically (Kircos *et al*, 1987; Westesson *et al*, 1989; Davant *et al*, 1993; Raustia *et al*, 1994; De Leeuw *et al*, 1995). The accuracy of MRI has been found to be very high in comparison to other techniques for diagnosing various types of disc displacements (Liedberg *et al*, 1990; De Laat *et al*, 1993). However, false positives for disc displacement without reduction have been reported (De Laat *et al*, 1993). The type of imaging technique used, anatomical variations and pathological changes of the joint structure can also affect the visibility of the disc (Raustia *et al*, 1995b).

De Leeuw *et al* (1995, 1996) used MRI to study articular disc position and configuration in TMJs of patients with long histories (30 years) of internal derangement. They found that the degree of disc deformation related to the degree of anterior displacement. However, some patients with internal derangement with reduction could maintain normal disc configuration over long periods of time. A considerable difference existed between disc configuration in the open and closed mouth positions. A small number of TMJs with normal disc position or with reducing disc displacement appeared to deviate from biconcave configuration on the MRI when the mouth was closed but were revealed to be biconcave on the MRI when the mouth was open. De Leeuw *et al* (1995; 1996) have suggested that the presence of altered disc configuration could be best judged in the open mouth position.

Although MRI has high specificity for identification of abnormal condyle to disc relationships, it does not identify patients with potential TMD as a result of other causes. Isolated symptoms of internal derangement diagnosed by MRI alone should not be a significant factor in treatment planning unless the patient demonstrates clinically significant symptoms. History and clinical examination are recommended as the diagnostic tests of choice because they allow for detection of all forms of potential TMD (Hans *et al*, 1992; Davant *et al*, 1993).

➢ *MRI evaluation of functional appliance therapy*

The number of evaluations of functional appliance therapy using MRI is very limited. The effects of the Herbst appliance and headgear Activator have been studied (Foucart *et al*, 1998; Ruf & Pancherz, 1998; Ruf & Pancherz, 1999) but comparisons between studies are complicated due to differences in MRI sequences. However, diagnostic criteria of disc displacement in these studies were all based on Drace & Enzmann's method (Drace & Enzmann, 1990).

Using turbo spin-echo sequence, Foucart *et al* (1998) have reported that 20% (7/30 cases) of the children in their study developed internal derangement after treatment with the Herbst appliances or headgear Activators. The symptoms included anterior disc displacement with reduction, anterior disc displacement without reduction, lateral partial anterior disc displacement with reduction, lateral rotational disc displacement with reduction and restriction of translation. None of the children showed any clinical signs of dysfunction.

Ruf & Pancherz (1998; 1999) have used closed mouth proton-density weighted spin echo sequences and mouth open T2-weighted sequences to demonstrate TMJ changes in children treated with the Herbst appliances. Pre-treatment MRI with the appliance in place showed the condyle situated anteriorly relative to the fossa but post-treatment MRI revealed that the condyle had seated back into the glenoid fossa. The most striking result was the display of increased MRI signal intensity at the posterior-superior region of the condyle in most of the cases. A similar increase of signal intensity was also found at the anterior-inferior aspect of the post-glenoid spine in a smaller number of cases. An increase in signal intensity was found for both proton density and T2 sequences obtained at six to 12 weeks after appliance insertion. These appearances were interpreted as the evidence of remodelling. However, the increase in signal intensity was not evident on the post-treatment MRI. It could be implied that the active remodelling had ceased by seven months after the insertion of the appliance. Condylar position was unaffected by treatment, on average, but varied on an individual basis.

Long-term effects of Herbst appliances (over four years) have also been demonstrated (Ruf & Pancherz, 1999). Moderate to severe signs of TMD were found in 25% of the studied children while mild symptoms of TMD were found in 15%. However, pre-treatment data were not available and so it was not possible to determine whether the internal derangement was caused by the Herbst therapy. The prevalence of TMD in this group of children was compared with reported prevalence in other studies. It was concluded that the children treated with Herbst appliances did not demonstrate higher prevalence of TMD than the general population. Therefore, Herbst appliance therapy seemed not to have any adverse long-term effect on the TMJ.

Several MRI studies have shown that the use of occlusal splints in an attempt to "recapture" displaced discs is ineffective (Chen *et al*, 1995; Moritz *et al*, 1995; Joondeph, 1997). This type of treatment is similar to the use of functional appliances except the "disc-recapture" occlusal splint is used in non-growing patients. Occlusal splints have been shown to be effective in improving jaw movement and reducing pain symptoms. However, no evidence of permanent disc recapture has been found. In a long-term study by Joondeph (1997), mandibular position relapsed in all cases and none of the patients showed improvement in disc displacement.

2.6 Three-dimensional Cephalometry

Cephalometry has long been used to study craniofacial relationships and craniofacial growth, and to assess treatment results in orthodontics. The lateral projection cephalograms are the most commonly used while postero-anterior or frontal cephalograms are only used as an adjunct to assess facial symmetry. Conventional cephalometric analysis is based on 2-dimensional images of 3-dimensional structures. This method has several disadvantages including:

1. The distances or angles measured are projections of 3-dimensional structures on 2-dimensional images; therefore, they are not realistic measurements. Measurements constructed from landmarks that are not on

the same plane can lead to either underestimation (Figure 25) or overestimation depending on the orientation of the structures investigated and head orientation.

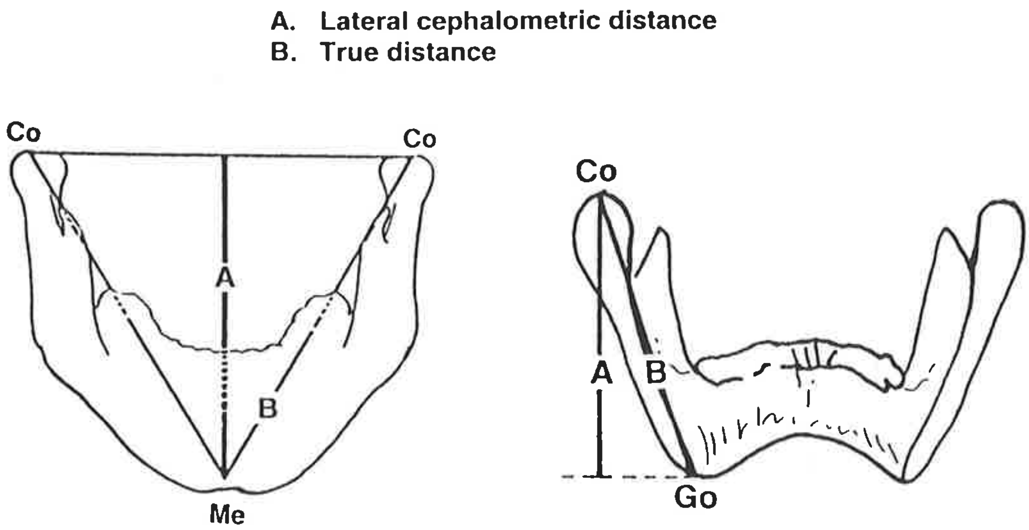


Figure 25 ▪ Underestimation of mandibular length and ramal height when measured from the lateral cephalogram (modified from Grayson *et al* 1988).

2. Conventional lateral cephalometric analysis does not distinguish right and left lateral structures. The average of both sides has been used and treated as though all the structures are in the mid-sagittal plane. This method is not sensitive in detecting asymmetry or differential growth between both sides. Although the frontal cephalograms can be used to help detect asymmetry, it is still not possible to accurately measure the length of a structure that orientates postero-laterally and antero-medially (or vice versa) such as mandibular length (Cc-Me) from frontal cephalograms.

3. Magnification varies between the side closer to the film and the side furthest from the film. Estimation of the true length of a facial structure from a cephalogram involves multiplication of the observed distance by a magnification coefficient. However, the magnification coefficient is used as though both sides have the same degree of magnification.

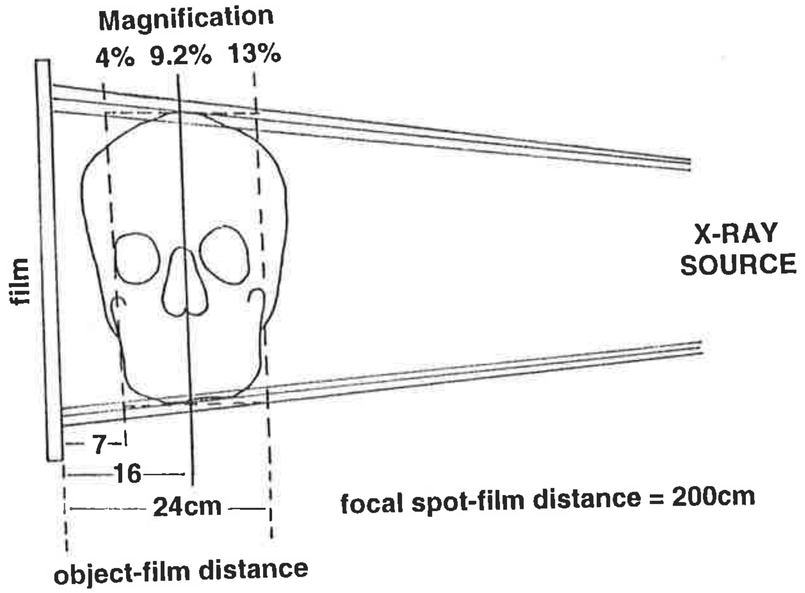


Figure 26 ▪ Variation in magnification from the side closer to the x-ray source, mid sagittal plane, and the side closer to the film.

4. Incorrect head position can affect the measurements such as facial heights obtained from frontal and lateral cephalograms (Figure 27).

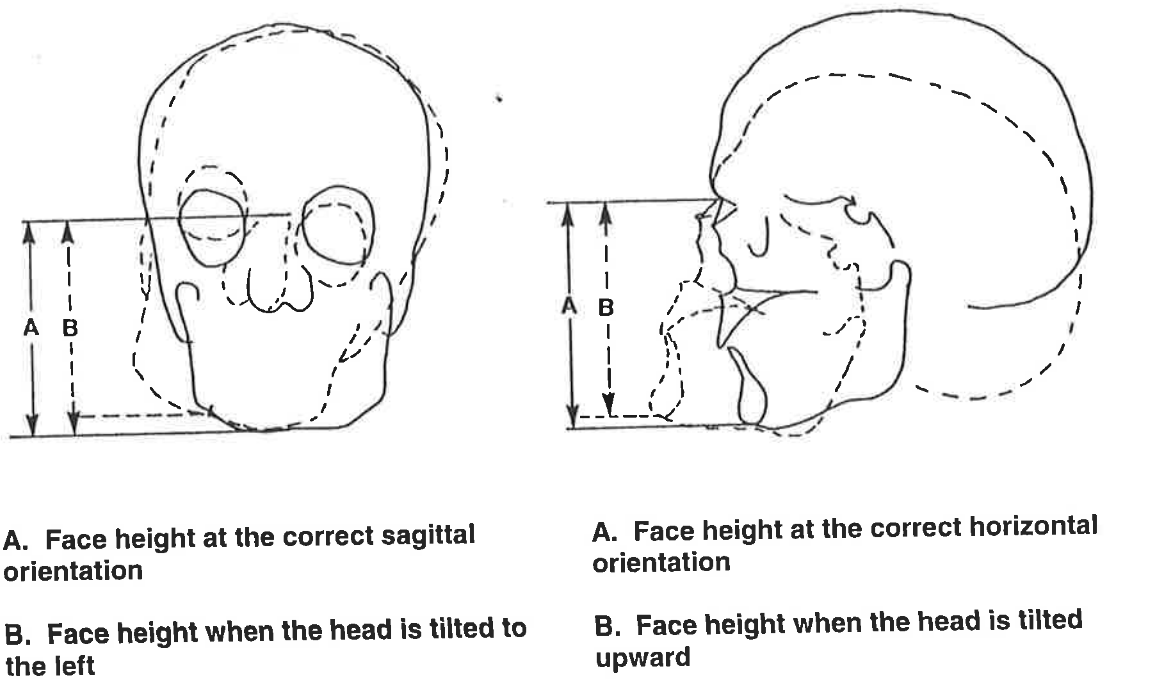


Figure 27 ▪ Effects of head orientation on the measurement of facial height.

2.6.1 Development of methods

The importance of measuring craniofacial structures in 3D has been acknowledged for over 70 years. The "Bolton Orientator" is a pioneering instrument to co-ordinate lateral and frontal films based on the Frankfort Horizontal plane (Figure 28). The patient's head is fixed in the cephalostat and the x-ray source is rotated 90% between the two exposures. This method is not true 3D cephalometry but rather a system that links two types of 2D cephalometry together.

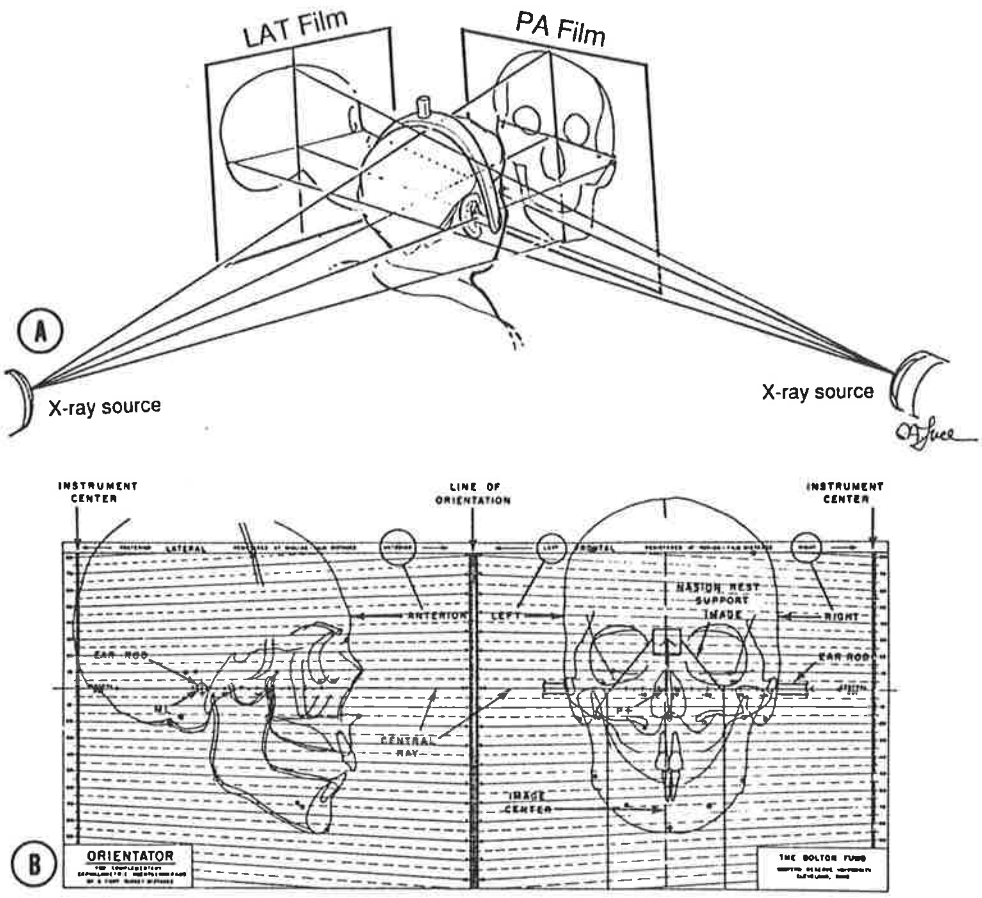


Figure 28 ▪ The Bolton Orientator (Broadbent *et al* 1975)

Most of the 3D cephalometric systems that have been developed have used the same principle as the Bolton Orientator. With the use of computerised three-dimensional reconstruction, it is now possible to perform more realistic 3D measurements. Two cephalograms, lateral and frontal, are commonly used for 3D reconstruction, but additional cephalograms such as basilar views may be used to provide more information for the reconstruction process (Grayson *et al*, 1983; Grayson *et al*, 1985).

Other systems such as coplanar cephalometric stereo pairs use two rotated lateral cephalograms (Baumrind *et al*, 1983b; Baumrind *et al*, 1983c), based on the principle used in stereo-photogrammetry.

Using the same principle, three-dimensional cephalometric measurement of facial soft tissue structures is also available. Because an infrared coupled device (CCD) camera can be used, no radiological risk is involved. Several images can then be obtained from several horizontal and vertical angles for maximum information in the reconstruction process (Ferrario *et al*, 1996). However, structural changes need to be interpreted with caution because soft tissue changes are not directly proportional to bony changes (McCance *et al*, 1993).

2.6.2 Accuracy of 3D cephalometric systems

The accuracy of 3D-cephalometric outputs relies on the input information by operators and mathematical analysis by computer software. Sources of error can occur during the following procedures:

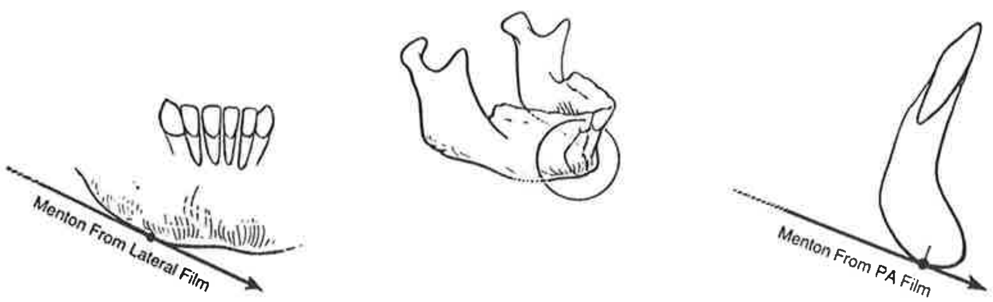
- ***Radiographic method***

The method used to obtain cephalograms is vital to the accuracy of the co-ordinate system for reconstruction. Systems where cephalograms are simultaneously exposed (Savara, 1965; Savara *et al*, 1966) are likely to have less error than those that rotate the head between exposures (Grayson *et al*, 1988; Brown & Abbott, 1989).

Theoretically, the greater the number of cephalograms, the smaller the envelope of errors (Grayson *et al*, 1983). However, increasing the number of cephalograms adds to the complexity of landmark identification and provides more radiation to the patient.

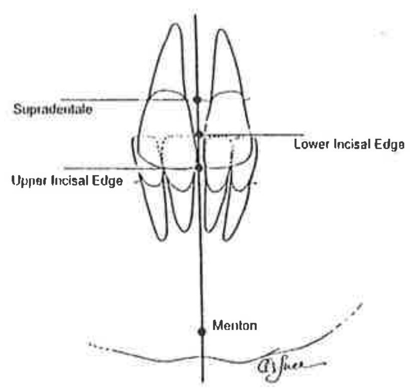
➢ *Landmark location*

Ambiguity in identifying landmarks due to superimposition of overlying structures that is encountered in 2D cephalometry still exists in 3D cephalometry. An additional difficulty includes identifying the same reference point precisely on each of the cephalograms. The best candidates for landmarks are those that can be seen on all cephalograms. Some conventional landmarks such as Zygoma can be located on frontal but not lateral cephalograms. The same problem applies for Porion which is visible on the lateral view but not on frontal cephalograms unless mechanical Porion is used. Modification or deletion of conventional landmarks may then be necessary. For example, Grayson *et al* (1988) have demonstrated the modification of a landmark, Menton, from the conventional cephalograms for use in a 3D system (Figure 29).



Menton projected from lateral cephalogram lies slightly displaced from the mid-sagittal plane on frontal cephalogram.

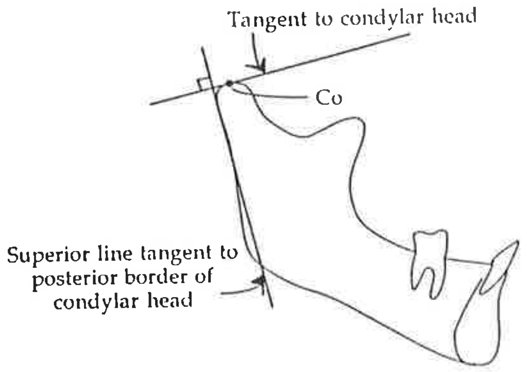
Menton projected from frontal cephalogram lies slightly more posterior on the lateral cephalogram



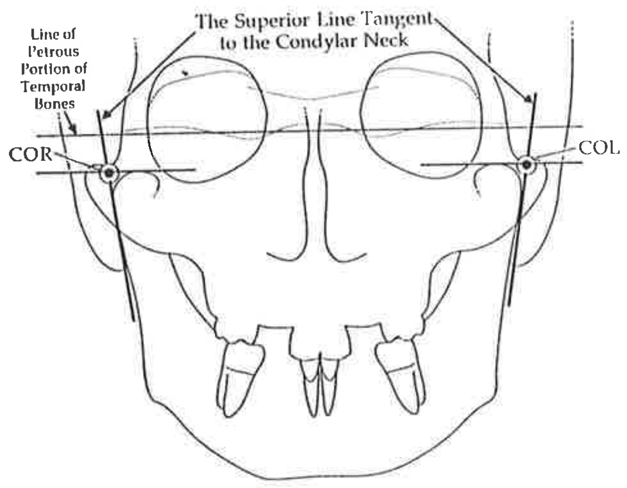
Modified Menton is in a slightly superior position

Figure 29 ▪ Location of landmark Menton in the 3D-system (Grayson *et al*, 1988)

Modified landmarks need to be clearly described. Most 3D systems use data from lateral cephalograms to generate landmark location on the frontal cephalograms. An example is the location of the constructed Condylion described by Bookstein *et al* (1991). The "operational Condylion" does not even appear on the condyle when viewed from a frontal cephalogram (Figure 30).



A. Constructed Condylion on lateral view.



B. Constructed Condylion on frontal view.

Figure 30 ▪ Constructed "operational Condylion" from lateral and frontal cephalogram (Bookstein *et al*, 1991).

With mathematical calculation, it is also possible to obtain a computer assisted estimation line to enable digitisation of the second cephalogram using data from the first (Figure 31).

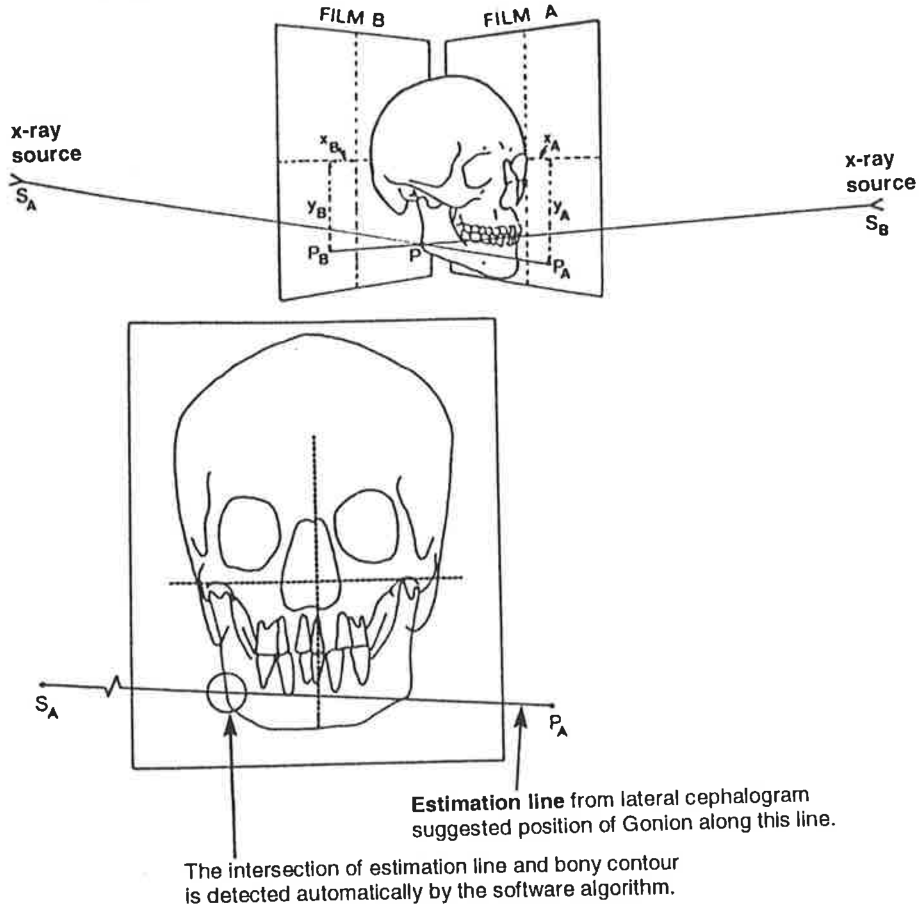


Figure 31 ▪ Computer assisted estimation line for landmark "Gonion" on frontal cephalogram using the data from digitised lateral cephalogram (Brown & Abbot 1989).

➢ ***Digitising procedures***

Digitising procedures in 3D systems are similar to those in 2D. Some systems use a traced cephalogram before digitising (Grayson *et al*, 1988; Brown & Abbott, 1989; Bookstein *et al*, 1991; Haynes & Chau, 1993) while other systems digitise directly from the cephalogram (Major *et al*, 1994). If a digitising tablet is used, errors associated with the digitising tablet need to be considered. It has been shown that various areas of the digitising tablet can yield different degrees of precision with errors tending to increase toward the sides of the tablet (Tourne, 1996).

➢ *Computer software*

The calculation of measurements relies on computational formulae. Construction of these formulae aims to compensate for magnification and projection errors. Computerised measurement should be calibrated with manual measurements from known objects such as dry skulls. Some systematic errors may not be identified readily. For example, using one lateral cephalogram in the system can lead to unequal magnifications with the side closer to the film having less distortion than the side further away. Assessment of random errors reported in the study by Bookstein (1991), indicated that right side measurements had consistently larger errors than the left side. However, the errors were small and may be negligible.

2.6.3 Advantages and disadvantages

➢ *Advantages*

- Three-dimensional cephalometry overcomes the magnification and projection errors inherent in 2D systems. Craniofacial structures can be measured in three different planes simultaneously and 3D-constructed images can be rotated and visualised at different angles.

- Three-dimensional cephalometry has been shown to be valuable in planning for correction of severe facial deformities by surgical procedures (Cutting *et al*, 1986; Fuhrmann *et al*, 1996).

- Although 3D-reconstructed images from CT or MRI offer superior quality, both CT and MRI are several times more expensive, and therefore, cannot be used routinely. Furthermore, Kragskov *et al* (1997) have demonstrated that although CT methods offer advantages in assessment of individuals with severe craniofacial deformities, there is no evidence that 3-D CT is more reliable than conventional cephalometric methods in studying normal skull morphology.

- Radiation used is relatively low in 3D cephalometry when compared with CT scans. A pair of cephalograms involves approximately 26 mrad skin dose to the subject while a closely-spaced series of CT slices totals about 6.5 rad (Grayson *et al*, 1988). Radiation can be reduced further if digital imaging is used (Forsyth *et al*, 1996a).

- More comprehensive measurements such as, shape, vector, area and volume are possible with 3D methods.

➢ ***Disadvantages***

- There is a lack of cross-sectional and longitudinal normative values available for comparison given that obtaining cephalometric images from normal individuals is now unacceptable ethically. Furthermore, generating appropriate normative data is difficult as a large number of individuals of different ethnicity or ages are needed.

- Three-dimensional cephalometric systems tend to be complicated, time consuming, and require technical skill and special armamentarium.

- Three-dimensional cephalometric systems are still in the developmental stage and are often not very user friendly. A certain amount of trial-and-error is often unavoidable.

2.7 Summary and Rationale for the Project

Published findings on the topic of mechanisms and effects of functional appliance therapy remain controversial. Based on the functional matrix hypothesis, it has been claimed that growth of the mandible is not genetically determined and that changes in functional demand can lead to normal development. Increased functional demand has often been associated with increased muscular activity, especially in the lateral pterygoid muscle. It has been hypothesised that functional appliances increase lateral pterygoid activity and consequently increase condylar growth at the muscular attachment. This "lateral pterygoid hypothesis" has been used to explain the mechanism of growth stimulation of the mandible resulting from treatment with functional appliances but lately this belief has come under question. Studies of the lateral pterygoid muscle in humans have inherent limitations. It is difficult to access the muscle directly, and investigations are usually invasive and painful making them unacceptable in children. In the correction of mandibular retrognathism, the mandible is repositioned anteriorly. This involves protrusive muscle function including both lateral pterygoid and anterior masseter muscles. The role of protrusive muscles in maintaining the new position of the mandible after functional appliance therapy has not been reported clearly in the literature to date.

Soft tissue adaptation, such as changes in the articular disc and retrodiscal tissue, has been considered to be an important compensatory factor for hard tissue remodelling and maintaining normal function of the TMJ. However, studies of the TMJ based on conventional radiographic techniques only provide information about the bony structures. Magnetic Resonance Imaging (MRI) has recently been used to investigate both the hard and soft tissues of the TMJ. MRI is non-invasive and provides information in three dimensions. The number of MRI studies on the effect of functional appliances is limited. Only the Herbst appliance and headgear Activator have been investigated. An association between functional appliance therapy and internal derangement of the TMJ has been shown in two studies, but the results from these two studies are contradictory.

Previous studies examining skeletal and dento-alveolar changes following the use of functional appliances have been based mainly on conventional lateral cephalometry and, occasionally, with the addition of frontal cephalometry. The disadvantage of these studies is that they provide only two-dimensional projection measurements of three-dimensional structures. The measurements are subjected to projection errors (head position) and magnification errors (object-film distance). Moreover, conventional lateral cephalometry does not distinguish left or right sides. An average of the lateral structures is used and treated as though all the structures are in the mid-sagittal plane. Three-dimensional cephalometry is considered superior as it overcomes many of the problems of conventional cephalometry and provides more realistic measurements of the structures investigated. However, further development of three-dimensional cephalometric systems is needed to provide better identification of bilateral structures, especially at the TMJ. No three-dimensional cephalometric assessments of treatment with functional appliances have been reported to date.

This present research involves a prospective study of treatment with the Twin Block appliance compared with untreated controls. The comprehensive design of the study aims to describe and associate changes in three different areas i.e., muscular adaptation, TMJ adaptation and dento-alveolar changes.

Chapter 3 Subjects and Methods

Topics:

3.1 Sample Selection

3.1.1 Referral procedures

Information about the research project and a letter requesting referral were sent to dentists working in the school dental clinics around Adelaide (South Australian Dental Service - SADS). The research procedures and criteria for selection were also presented at two SADS regional meetings and to interested school dentists invited to an information session at the Adelaide Dental Hospital. The initial criteria for selection were:

1. Class II division 1 malocclusion characterised by an overjet of more than 5 mm and mandibular deficiency.
2. Age 9-13 years for females and 10-14 years for males.
3. Caucasian ethnicity.

The referred children were telephoned by the researcher, then an information letter including an appointment for clinical examination was posted to each child.

3.1.2 Clinical selection

At the appointment for initial examination and consultation, the final selection was based on:

1. Angle Class II molar and Class II canine relationship.
2. Age between 9-13 years for females and 10-14 years for males.
3. Caucasian ethnicity.
4. Overjet equal to or greater than 4 mm.
5. Convex profile with retrognathic mandible.
6. Normal or short lower anterior facial height.

7. Improved facial profile when the child postured anteriorly to an edge-to-edge position.

8. No signs or symptoms of temporomandibular disorders.

9. No history of orthodontic treatment.

10. Ability to attend appointments.

Diagnostic records (see section 2.2) were obtained for children who matched the criteria. Children who did not match the criteria were referred back to their school dentist.

3.1.3 Sample size

One hundred and thirty-nine children were referred from 37 school dental clinics. Eighty-one children, 32 girls and 49 boys, were deemed to be suitable for the project. Fifty-eight children, 24 girls and 34 boys, who did not meet the selection criteria were referred back to the school dentist.

Of all the suitable cases, 17 girls and 23 boys were randomly assigned according to the order of presentation to be treated with the Twin Block appliance, while 15 girls and 26 boys were randomly assigned to be in the control group. Because of co-operation problems, such as failure to attend appointments, refusal to wear the appliance full-time, and poor oral hygiene, two girls and four boys later withdrew from the experimental group and three girls and one boy withdrew from the control group. Therefore, over the experimental period of 6 months, there were 34 children (15 girls and 19 boys) treated with the Twin Block appliance and 37 children (12 girls and 25 boys) who served as controls.

A complete set of records, including cephalograms, MRIs and muscle testing could not be obtained for every child involved in the project due to the following problems:

- Because of the high expense, MRIs were obtained for approximately half of the children (see section 2.5.2).

- There were three children, one girl and two boys, from the control group who had muscle co-ordination problems and could not correctly perform the muscle test.
- Follow-up cephalograms from two children could not be obtained because they had moved interstate but they did have complete MRI records.

Table 6 ▪ Summary of sample sizes for each type of experimental record

	Hand wrist / OPG	Cephalogram	Muscle test	MRI
Control/female	12	12	11	8
Control/male	25	25	23	13
Control/total	37	37	34	21
Experiment/female	15	14	14	5
Experiment/male	19	18	18	14
Experiment total	34	32	32	19

3.2 *Clinical Procedures*

The clinical procedures were conducted in the Orthodontic Clinic, Adelaide Dental Hospital. Cephalograms were obtained in the Radiology Department, Adelaide Dental Hospital. The MRI was performed at the Medical Imaging Department, Flinders Medical Centre.

3.2.1 Initial examination and consultation (visit 1)

Both the children and parents were given careful explanation about the orthodontic problems, specifically, the need for interceptive treatment to correct skeletal discrepancies (retrognathic mandible) in order to improve function, aesthetics, and to maintain healthy oral tissues. The Twin Block appliance was shown and the child was informed that compliance was crucial for successful results. It was pointed out that the appliance must be worn 24 hours per day, 7 days per week. Although significant changes should occur in the first six months, patient was expected to wear the appliance for approximately one year for better treatment stability. Treatment results would be re-evaluated after 12 months for further treatment needs such as full banding.

Informed Consent: Explanations were given verbally and in writing to those children who matched the criteria and their parents so that they fully understood that they were participating in a research project, according to the guidelines approved by the University of Adelaide Human Ethics Research Committee (see section 2.8). All clinical procedures used in this research were the same as those normally used for orthodontic treatment except for the use of MRI and the muscle testing. They were also informed that although these additional procedures required extra time, they were not invasive and the researcher would be with the children at every session. The children were able to withdraw from any additional procedures which they found uncomfortable. Once the children and their parents or guardian agreed to be involved in the project, consent forms were signed by the children (Appendix 1) and their parents or guardians (Appendix 2). A set of the signed consent forms together with an Information Sheet (Appendix 3) was given to the parents or guardians.

The examination procedure included collection of general information, medical and dental histories, intra- and extra-oral assessment, and a functional analysis of the masticatory system (Appendix 4). **The Helkimo Index** was used to evaluate function and dysfunction of the masticatory system.

The Helkimo Index (1974) consists of three parts:

- Clinical dysfunction index (Di): an evaluation by symptoms, i.e., impaired range of movement of the mandible, impaired function of the TMJ, pain on movement of the mandible, pain in the TMJ and pain in the masticatory muscles.
  - Di0 clinically symptom-free
  - Di1 mild symptoms
  - Di2 moderate symptoms
  - Di3 severe symptoms
- Anamnestic dysfunction index (Ai): based on data from an interview
  - Ai0 subjective symptom-free

- Ai1 mild symptoms
- Ai2 severe symptoms

- Index for occlusal stage (Oi): an evaluation of dental occlusion, i.e., number of teeth, number of occluding teeth, interferences on occlusion and articulation.
    - Oi0 no occlusal disturbances
    - Oi1 moderate occlusal disturbances
    - Oi2 severe occlusal disturbances

According to recent studies (Seligman & Pullinger, 1991a; Seligman & Pullinger, 1991b; Tallents *et al*, 1991; McNamara *et al*, 1995; McNamara, 1997; McNamara & Turp, 1997; Turp & McNamara, 1997), occlusion is considered as having a limited role as a cause of TMD. Therefore, selection of children free of TMD was based on Di and Ai only.

Diagnostic records obtained in this session were:

1. Impressions and bite registration for making study models.
2. Extraoral 35-mm slides, including a frontal view in mandibular rest position, frontal view while smiling, a profile view in mandibular rest position, and a profile view with the mandible in the forward position.
3. Intraoral 35-mm slides including frontal occlusion, right side occlusion, left side occlusion, upper arch and lower arch.
4. Radiographs including an orthopantomogram and a hand-wrist radiograph.

At this stage, all the diagnostic records were analysed for treatment planning. An attempt was made to randomise the selection of children into either the control or experimental groups. However, stage of dental development was a major factor in the allocation of children into these groups. For example, children were placed in the control group when the teeth where the clasps of the Twin Block appliance would be placed were mobile or missing.

Children with doubtful co-operation or inadequate oral hygiene were also placed in the control group.

All of the children selected for the experimental group were treated with the Twin Block functional appliance by the same operator (Kanoknart Chintakanon). The rest of the children served as controls. The children in the control group were placed on a waiting list to be treated at a later stage by other operators.

3.2.2 Pre-treatment records

Treatment plans were fully explained to children and their parents or guardians. They were also informed whether they were in the experimental group or in the control group. Treatment procedures were then applied differently between the two groups.

➢ ***Experimental group:***

❖ **Visit 2: Twin Block construction, muscle test and cephalometric records**

1. Impressions were made from which working models for the Twin Block appliance were obtained. Bite registrations were made using Formasil®-II (Heraeus Kulzer, Germany) and a plastic bitefork (Great Lakes Orthodontics Ltd., New York, USA). These were obtained with the mandible postured forward to an edge-to-edge position (Figure 32). The vertical inter-incisal clearance was 2 mm or 5 mm depending on the thickness of the bitefork used. The selection of the bitefork thickness was made to achieve a posterior interocclusal distance of at least 6 mm. In a few cases, if children could not move the mandible to edge-to-edge position, the registration bite was performed at the child's maximum protrusive position.

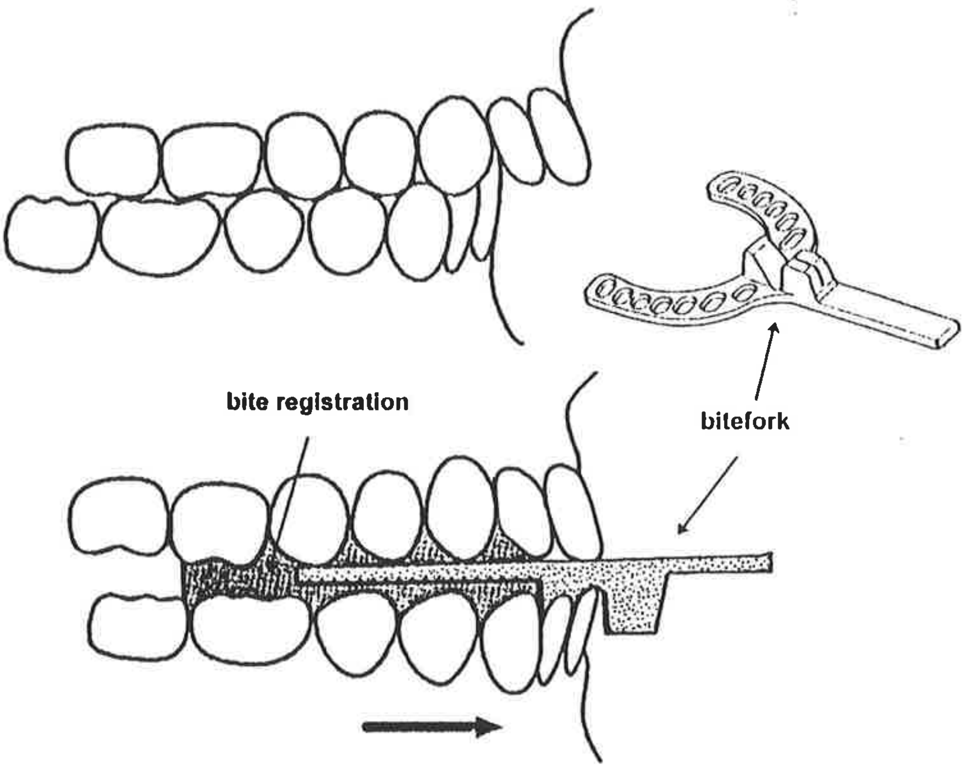


Figure 32 ▪ Bite registration using a bitefork at the edge-to-edge position with a 6-mm posterior interocclusal clearance.

2. Bite registration at maximum intercuspation was made using Formasil®. This bite registration was also used when cephalograms and MRIs were obtained, ensuring that the child occluded in the same position at both visits.

3. A calibration head frame (see section 2.5.1) with markers was selected to fit the child's head. Formasil® was use to make an individual nosepiece to support the head frame (Figure 33). This was to ensure proper seating such that the head frame was in the same position when the cephalograms and the MRIs were obtained.

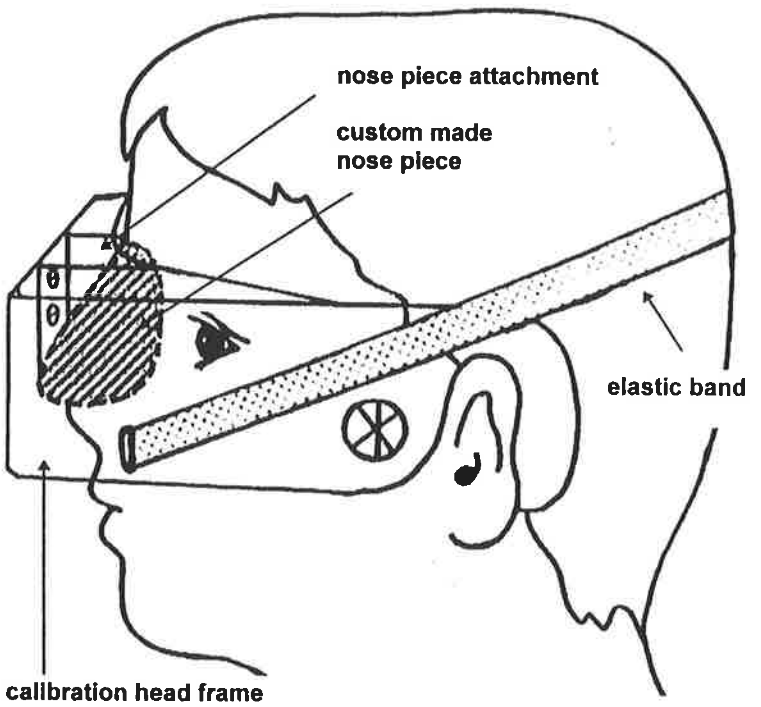


Figure 33 ▪ Position of the head frame supported by the nosepiece

4. Three cephalograms; a standard postero-anterior, a 10° right rotated lateral and a 10° left rotated lateral, were obtained with the children occluding onto the bite registration in maximum intercuspation position and wearing the calibration head frame (see section 2.6.1).

5. Muscle tests were performed to measure maximum protrusive force and fatigue time (see section 2.4).

❖ **Visit 3: Magnetic resonance imaging** (see section 2.5.2)

1. Sagittal and coronal MRIs were performed only on the right side TMJ to reduce total scanning time. The children were wearing the calibration head frame and occluding on a Formasil® bite registration made at maximum intercuspation during the second visit.

2. Without moving the child from the previous position, the Formasil® bite registration at maximum intercuspation was replaced by the

bite registration made for the Twin Block appliance at the second visit. Sagittal MRIs were then performed.

❖ **Visit 4: Twin Block insertion**

1. The Twin Block appliance was inserted. Children were instructed to wear the appliance 24 hours per day including during eating. They were informed that they would experience some discomfort for the first few days. They were advised to practise eating slowly and reading aloud to help in adjusting to the new environment. Children were asked to keep records of the number of hours they wore the appliance each day and report any problems as soon as possible.

2. Muscle tests were repeated on five girls and five boys selected at random to enable an assessment of recording errors (see section 2.4.6).

❖ **Visit 5, 6, and 7: Treatment progress**

1. Treatment progress was assessed every 6 weeks by recording the change in overbite, overjet, canine relationship and molar relationship. A functional analysis of the mandible, including assessment of mandibular movements and pain or clicking of the TMJs, was also performed.

2. Height and weight were recorded at each visit to monitor incremental growth of the children.

3. No attempt was made to adjust the Twin Block except to ensure adequate retention.

> ***Control group:***

❖ **Visit 2: Muscle test and cephalometric records**

The procedures were managed identically to the experimental group except for the construction of the CTB.

❖ **Visit 3: Magnetic resonance imaging**

Sagittal and coronal MRIs were performed on the right side TMJ while the children were wearing the calibration head frame and occluding in maximum intercuspation on a Formasil® bite registration made at the second visit.

3.2.3 Six-month records

> ***Experimental group:***

❖ **Visit 8: Study models, intra- and extra-oral 35-mm slides, muscle tests and cephalometric records**

1. Height and weight were recorded and intra- and extra-oral 35-mm slides were obtained.
2. The Helkimo Index was used to evaluate function and dysfunction of the masticatory system after use of the Twin Block appliance for six months.
3. Impressions were obtained to assess treatment progress. The occlusal relationship at the most reproducible retrusive position was registered using Formasil® when the children were relaxed and the operator guided the mandible to its most retrusive position. This bite registration was used when the cephalograms and MRIs were taken to ensure that the children occluded in the same position on those sessions.

4. The calibration head frame and Formasil® nosepiece made during the second visit were tried to determine whether proper seating could be achieved. In three cases where the children had grown and the previous head frame no longer fitted, a larger head frame was used and a new individual Formasil® nosepiece was constructed.

5. Three cephalograms; a postero-anterior, a 10° right rotated lateral and a 10° left rotated lateral, were obtained with the children occluding on a bite registration at the most retruded position and wearing a calibration head frame.

6. Muscle tests were performed to measure maximum protrusive force and fatigue time.

7. Treatment was re-evaluated and further treatment procedures were verified for each individual.

❖ **Visit 9: Magnetic resonance imaging**

Sagittal and coronal MRIs of the right TMJ were obtained with the children wearing the calibration head frame and occluding at the most retruded position on the Formasil® bite registration made during the previous visit.

➢ ***Control group:***

❖ **Visit 4: Study models, intra- and extra-oral 35-mm slides, muscle tests and cephalometric records.**

All the procedures were similar to those of the experimental group. The children were then transferred for treatment as appropriate.

❖ **Visit 5: Magnetic resonance imaging**

Sagittal and coronal MRIs were performed on the right side TMJs with the children wearing the calibration head frame and occluding on the Formasil® bite registration at maximum intercuspation made during the fourth visit.

Table 7 ▪ Summary of clinical procedures

visit	Experiment group	Control group
1	• Consultation • Consent form signed • Clinical examination • Impressions for study models • Intra-and extra-oral 35-mm slides • OPG and hand wrist	• Consultation • Consent form signed • Clinical examination • Impressions for study models • Intra-and extra-oral 35-mm slides • OPG and hand wrist
2	• Formasil® bite (maximum intercuspation) and nosepiece • Formasil® construction bite for CTB • Impression for working models • Muscle test • Frontal, 10° right and 10° left lateral cephalograms	• Formasil® bite (maximum intercuspation) and nosepiece • Muscle test • Frontal, 10° right and 10° left lateral cephalograms
3	• MRI - sagittal and coronal at maximum intercuspation position • MRI -sagittal at CTB position	• MRI - sagittal and coronal at maximum intercuspation position
4	• CTB insertion • (2nd muscle test - to assess errors of method)	
5 6 7	• CTB treatment progress records • Height and weight records • Mandibular movement records	
8	• CTB treatment progress records • Height and weight records • Mandibular movement records • Impressions for progress models • Intra-and extra-oral 35-mm slides • Formasil® bite (most retruded position) and nosepiece • Muscle test • Frontal, 10° right and 10° left lateral cephalograms • Re-evaluation for further treatment	• Height and weight records • Mandibular movement records • Impressions for study models • Intra-and extra-oral 35-mm slides • Formasil® bite (maximum intercuspation) and nosepiece • Muscle test • Frontal, 10° right and 10° left lateral cephalograms • Transfer for appropriate treatment
9	• MRI - sagittal and coronal at most retruded position	• MRI - sagittal and coronal at maximum intercuspation position

3.3 Growth and Development Analysis

Analysis of children's development was based on the following data:

1. **Chronological age**

2. **Statural growth**
   Height and weight of the children were recorded every visit, approximately 6 weeks apart. The height and weight records of each child were plotted against growth curves for Australian boys and girls produced by the National Health and Medical Research Council (NHMRC – Appendix 5 - 8).

3. **Dental age**
   Orthopantomograms obtained at the initial consultation were used to assess dental emergence age using South Australian data (Diamanti, 1991 - Appendix 9).

4. **Skeletal maturation**
   Skeletal age was assessed from hand wrist radiographs according to Fishman's Skeletal Maturity Indicators (SMI, Fishman, 1982 – Appendix 10).

3.4 Muscle Testing

The main objective was to develop and implement a reliable method of studying protrusive muscle function and the adaptation of these protrusive muscles after treatment with the Twin Block appliance. Another aim was to examine whether fatiguing the protrusive muscles would affect mandibular position especially after the Twin Block treatment. The muscle testing consisted of measurements of maximum protrusive force and fatigue time.

3.4.1 Components of the muscle testing apparatus

The objective of the apparatus was to measure isometric protrusive force and to measure the time to fatigue protrusive muscles. The apparatus needed to be non-invasive, not demanding, and acceptable for young children. The initial design involved a biteplate connected to headgear but this was rejected because the apparatus was too heavy and extra effort was needed for the children to hold it in the mouth. A non-rigid form also made it hard to control the direction of the force and reproducibility was poor. Measuring protrusive force using an appliance attached to the anterior teeth was considered but was later rejected, as it was more likely to cause pain than measuring from the chin. The final design of the muscle testing apparatus consisted of the following:

1. **Back plate:** A wooden back plate was attached to a chair to provide a solid frame for the head. It also supported the weight of other parts of the apparatus connected to the back plate including, biteplate supporting frames, pulley system, electronic device and calibration load (Figure 34).

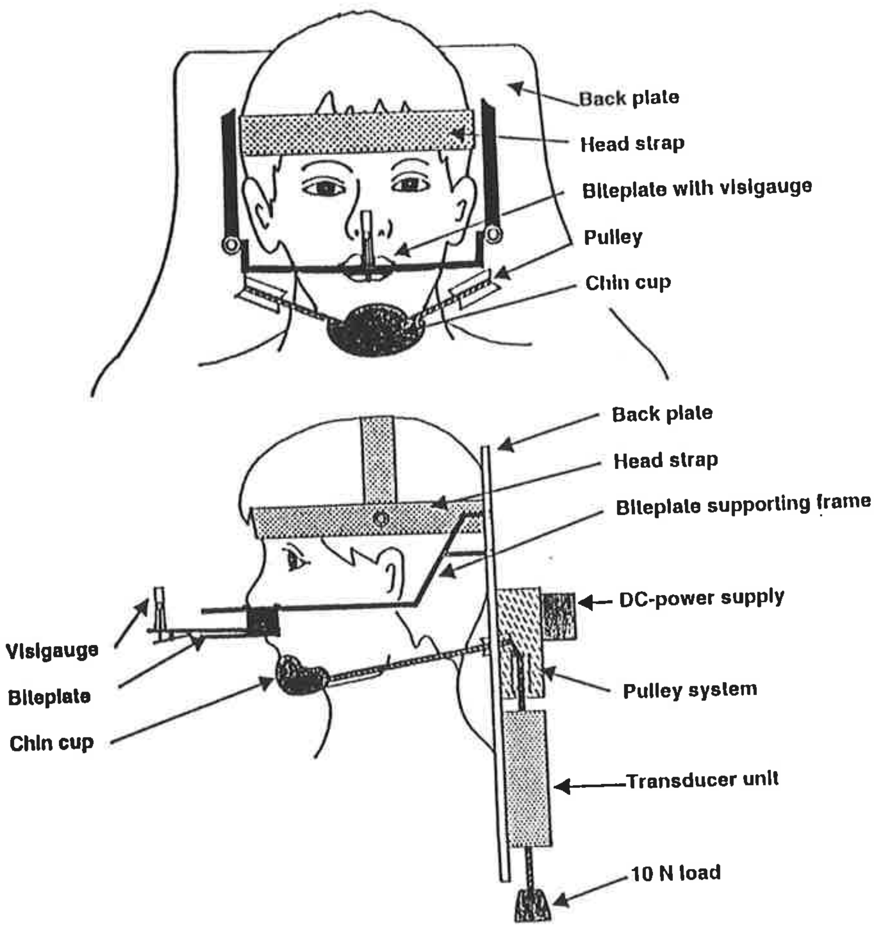


Figure 34 ▪ Diagram of muscle testing apparatus, front view and side view.

2. **Head strap:** A plastic strap with an adjustable knob was used to secure the head to the rigid back plate so that movement of the head was minimised.

3. **Biteplate:** A stainless steel biteplate consisted of an intra-oral part and an extra-oral part. The intra-oral part could be removed from a sliding slot on the extra-oral part so that it could be sterilised. The extra-oral part was connected to the back plate with biteplate supporting frames that could be adjusted vertically. A millimetre scale with a sliding plate was included on the extra-oral plate for measurement of overjets (Figure 35).

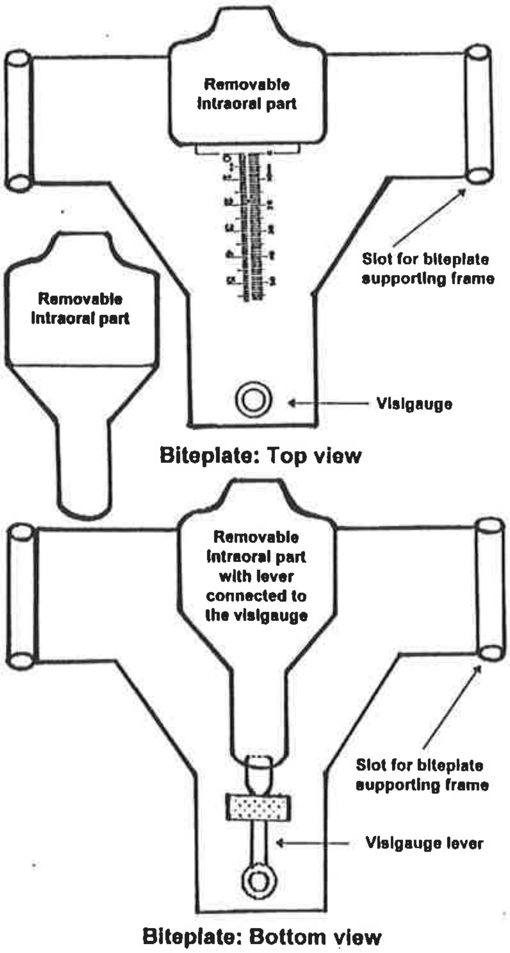


Figure 35 ▪ Reference biteplate with "visigauge". The biteplate consists of extra-oral and intra-oral plates. The intra-oral plate can be removed from the extra-oral plate for sterilisation.

4. **Visigauge:** The "visigauge" was used to train the children to protrude the mandible without biting on the biteplate. It was connected to the extra-oral end of the biteplate. The intra-oral plate of the biteplate also engaged on the lever connected to the visigauge. If the children bit on the biteplate, the lever dropped and the ball inside the visigauge dropped down below the marked line (Figure 36). The children were instructed to watch the level of the ball in the "visigauge" while protruding the mandible. If the ball was below the marked line, it was an indication that the children were biting on the biteplate and the record was abandoned. The use of the visigauge helped in providing a true anterior protrusive force rather than a combination of vertical and protrusive forces.

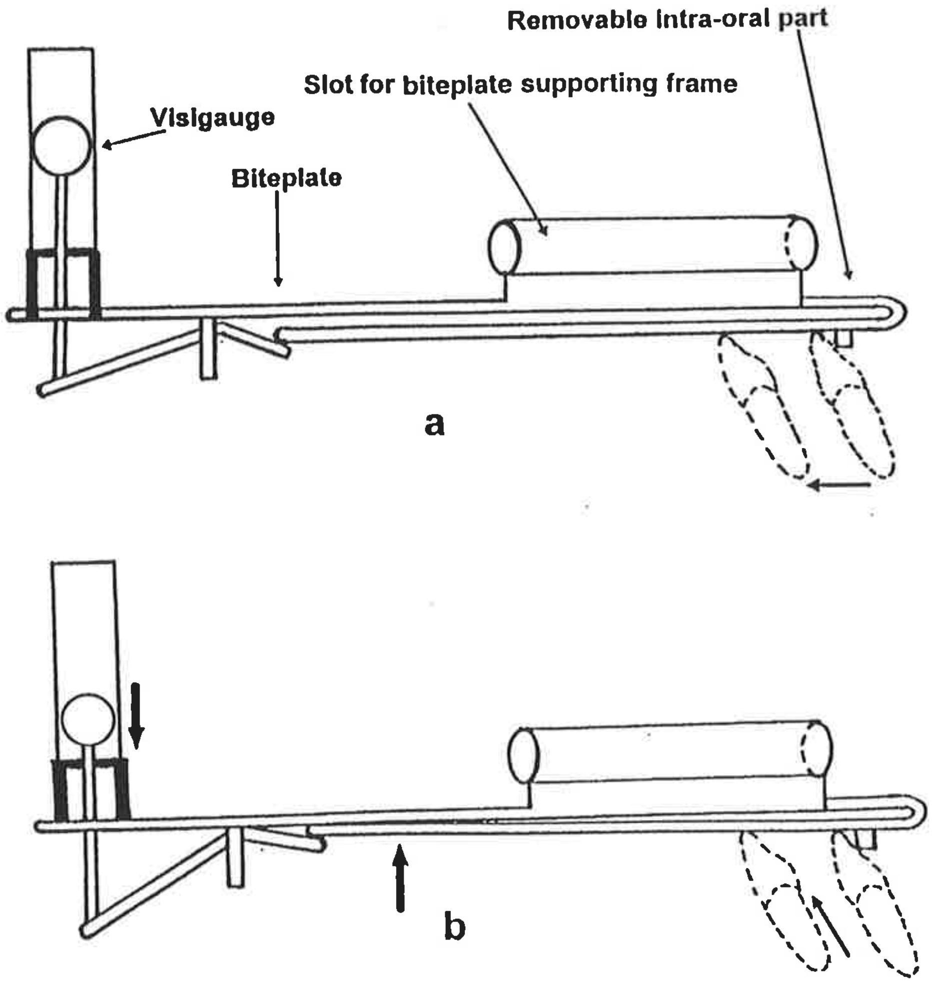


Figure 36 ▪ Reference biteplate with "visiguage", side views: The lower part of the removable intraoral plate is engaged on the lever connecting to the "visigauge". Note the position of the ball in the visiguage while the child only protrudes along the biteplate (a) and while the child protrudes and bites on the biteplate (b).

5. **Chin cup:** A leather chin cup was hooked to a pulley system through a metal cord. The pulley system was used to direct the protrusive force from the chin through the metal cord to the transducer unit at the back of the back plate (Figure 37). Formasil® was sometimes used to mould the shape of the chin inside the chin cup for better adaptation and stabilisation.

6. **DC-power supply:** The transducer was connected to a DC-power supply which transferred the electrical output to a pen recorder.

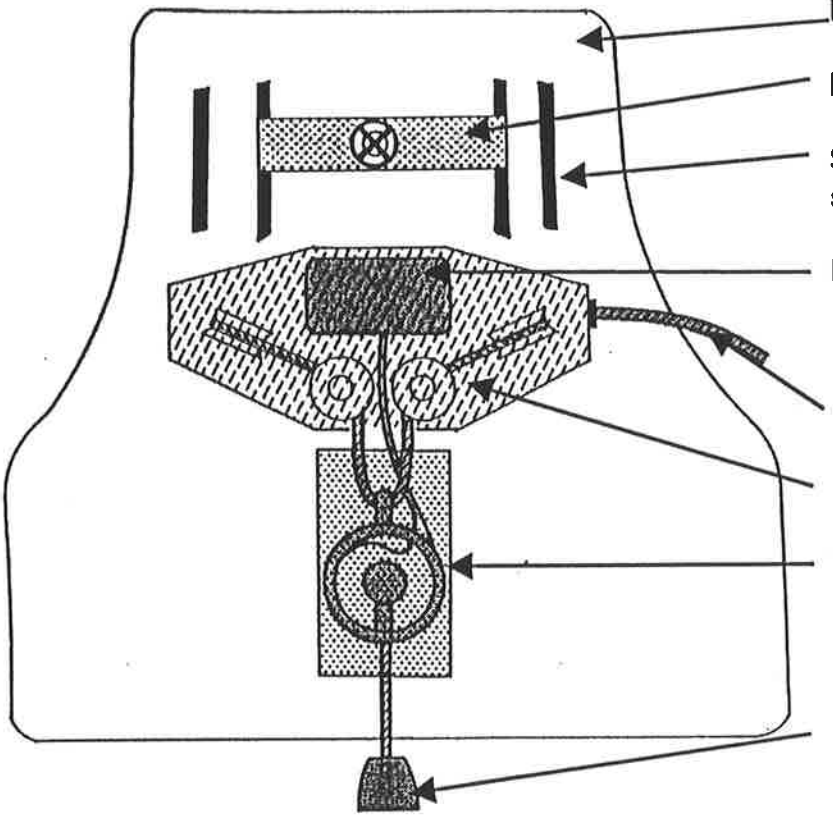


Figure 37 ▪ Diagram of muscle test apparatus, back view, showing the pulley system and the connection with transducers.

3.4.2 Preparation of the children for protrusive force recording

1. The children were positioned carefully in a rigid frame apparatus that kept the head and shoulders in a fixed position relative to the protrusive force-recording device. This procedure in limiting movement of the children was necessary to obtain reproducible force data. The operator manipulated each child's mandible several times to achieve the most reproducible retruded position. Overjet was recorded with a millimetre ruler on the biteplate and this position was set as the starting position.

2. The biteplate was placed on the biteplate supporting frame and then slid into the child's mouth to stabilise the anteroposterior maxillary position. The biteplate vertical position was adjusted at the biteplate supporting frame so that the occlusal line of the maxillary teeth was parallel to the horizontal plane. The children were asked to bite gently on the biteplate with the mandible in the most retruded position.

3. The rigid chin cup that was connected to the transducer through a pulley system was then placed around the child's chin. The direction of pull was either parallel to or steeper than the lower border of the mandible. The protrusive force was displayed by a pen recorder. A fixed amount of preload or tension, 10 N (Newton), was applied on the chin cup through the pulley system in order to take up the slack in the system and to use this level as a reference baseline. The displacement of the pen recorder to the 10 N load also served as a calibration.

3.4.3 Measurement of maximum isometric protrusive force

Maximum isometric protrusive force was recorded on the pen recorder. Children were asked to move the mandible forward (protruded position) by sliding along the biteplate as far as possible while pushing against the rigid chin cup. The position of the ball in the visigauge was monitored during the protrusion. The measurement of protrusive force was accepted only when the ball in the visigauge was in the correct position.

The children were asked to keep the mandible in the forward position for three seconds then drop the mandible back to its original position. This protrusive movement was done with 30-second intervals for a minimum of four times or until the force generated during attempted maximum protrusion was relatively stable. The highest force produced during the test was selected for statistical analysis. A one-minute rest period was then given for the child to relax before the fatigue test (Figure 38).

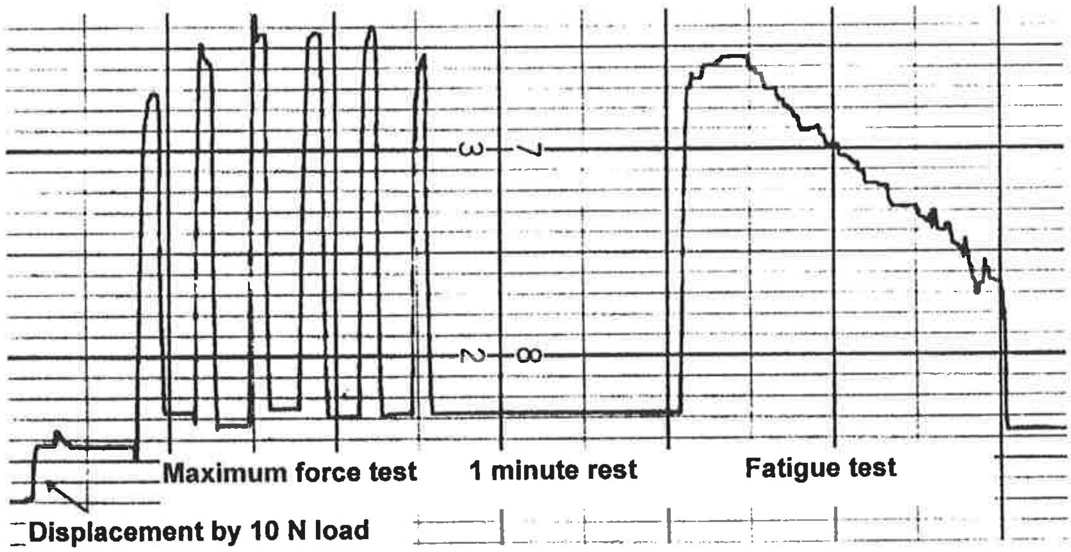


Figure 38 ▪ Example of a pen recorder graph generated during maximum protrusion and fatigue test. Maximum force was calculated from the highest amplitude.

3.4.4 Fatigue test

After the rest period, the children were asked to perform maximum protrusion again, but this time holding the mandible in the forward position until they tired, after which the mandible was allowed to drop back. This assumed that fatigue of the protrusive muscles had occurred. After the test, the chin cup and the biteplate were immediately removed. Incisal overjet was recorded with a millimetre rule at the most retruded mandibular position under the guidance of the operator. The pre- and post- muscle test overjets were then compared to evaluate any change in mandibular position.

3.4.5 Data analysis

Muscle tests were carried out for the initial and 6-month recordings in both experimental and control groups. The combined results from the experimental and control groups at the initial record were analysed cross-sectionally to describe the characteristics of protrusive and fatigue time in children displaying Class II division 1 malocclusions. The associations of protrusive force and fatigue time relative to gender, age, skeletal maturity, height, weight, overjet, facial widths and facial heights were also assessed. Protrusive force and fatigue time between the control and experimental groups were then compared.

Longitudinal analysis between the pre-treatment and 6-month records was performed to evaluate the effects of the Twin Block treatment and growth, and the effects of growth alone on the protrusive force and fatigue time. The effect of fatiguing the protrusive muscles on the stability of mandibular position in children treated with the Twin Block appliance was also assessed. In essence, the fatigue test checked for mandibular forward posturing as a consequence of muscle training by the Twin Block appliance.

3.4.6 Error study

The maximum protrusive force and the fatigue test were performed twice in a group of ten children (5 females and 5 males) selected randomly from the experimental group. Children in the control group were not selected for the error study because this would have required an extra visit. However, an extra visit was not required for the experimental group, as the muscle tests were performed just before the insertion of the Twin Block appliance. The tests were carried out approximately four weeks apart. The error study was performed to enable assessment of variations in measurement and responses from children with previous experience of the test. The means for the difference between the first and the second investigations were 5% for the maximum protrusive force (Figure 39) and 2% for the fatigue test (Figure 40).

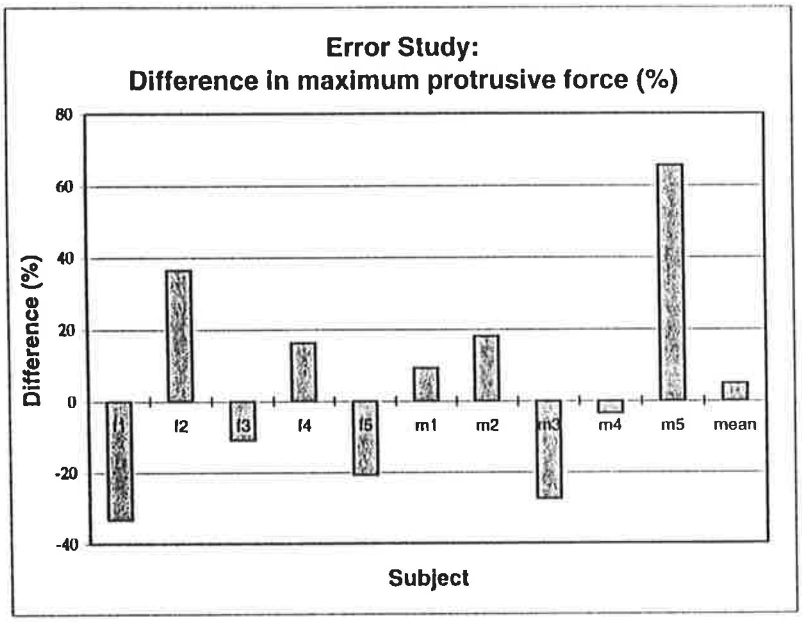


Figure 39 ▪ Differences in maximum protrusive force between the first and the second test for 5 female and 5 male children.

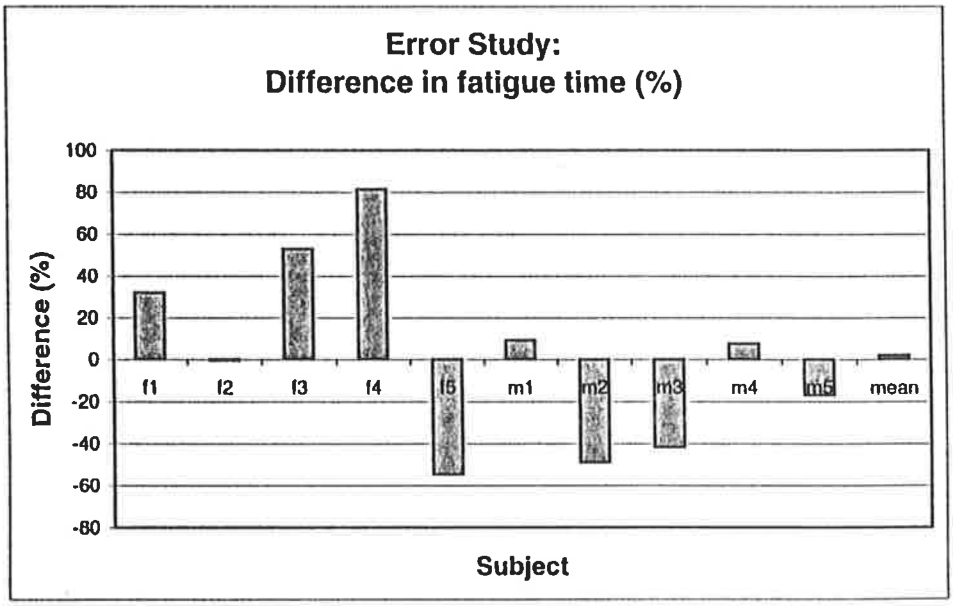


Figure 40 ▪ Differences in fatigue time between the first and the second test for 5 female and 5 male children.

3.5 Magnetic Resonance Imaging (MRI)

3.5.1 Construction of calibration head frame

Cephalograms were obtained in a standing position while MRIs were obtained in a supine position. In order to relate the craniofacial structures on the cephalogram to the TMJ structures on the MRI, a calibration head frame with markers was designed to be worn when both types of images were obtained. Lead markers visible on the cephalograms and lipid markers visible on the MRIs were incorporated into the head frame. Adjustable glasses (Figure 41) were constructed as part of a pilot study. The glasses helped in measuring the facial width and facial depth, and also locating the TMJ for placement of lipid markers. Facial width and facial depth were measured clinically in ten children with varying head sizes using the adjustable glasses. The locations of the TMJs in these children were also marked on the arms of the glasses.

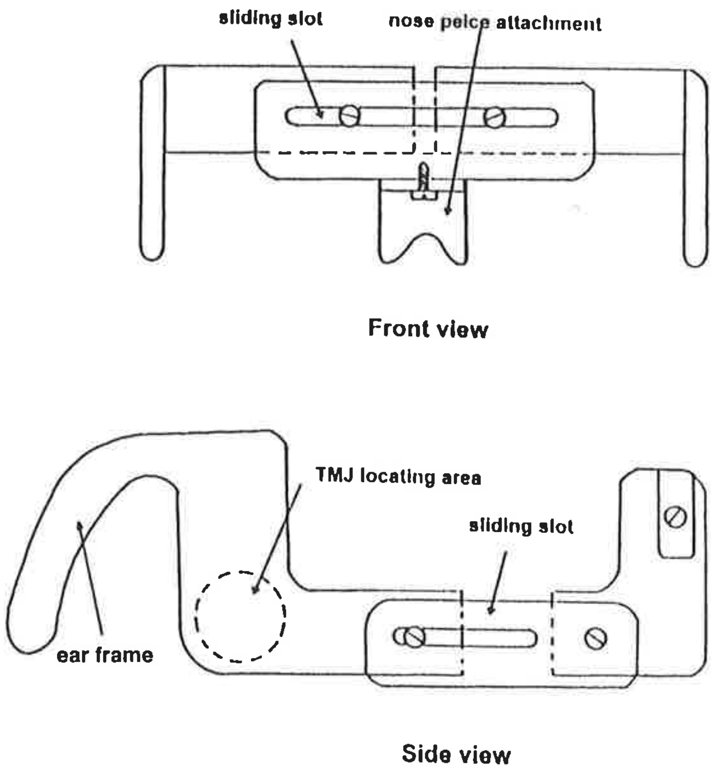


Figure 41 ▪ Adjustable glasses used as a prototype for calibration head frames. The glasses could be adjusted in width and length.

Two different head frames, large and small, were constructed using the maximum and mean facial dimensions measured from the pilot study. Non-ferromagnetic material was used to avoid movement of the head frame under the strong magnetic field of the MRI scanner. The head frame incorporated seven lead markers and two lipid markers (Figure 42). The relationship of known distances and angles among the markers served as three-dimensional calibrations for cephalometric and MRI measurements. These data provided input to a software program (Sculptor, Acuscape Inc.) for three-dimensional cephalometric reconstruction (see section 3.6.3).

The position of the head frame was secured by an elastic headband and supported by an individual nosepiece made from Formasil®. This enabled proper seating and ensured that the head frame was in the same position relative to the head when the cephalograms and the MRIs were obtained. The positions of the children in the cephalostat and MRI scanner were then less critical, as the calibration was performed relative to the head frame.

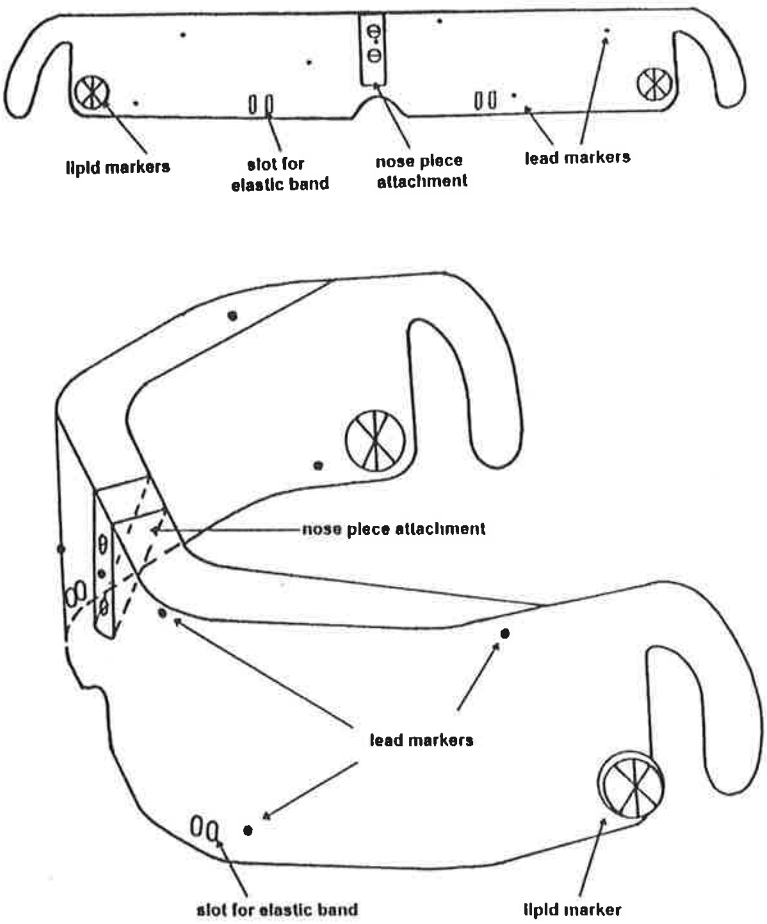


Figure 42 ▪ A calibration head frame with lead markers and lipid markers

3.5.2 Imaging procedures

Both written information and verbal explanation about MRI scanning (Appendix 11) were given to the children and their parents before the MRI session. Magnetic resonance imaging was performed at the Medical Imaging Department, Flinders Medical Centre using a 1.0 Tesla MAGNETOM IMPACT EXPERT system (Siemens, Erlangen, Germany) with bilateral TMJ coils (Figure 43).

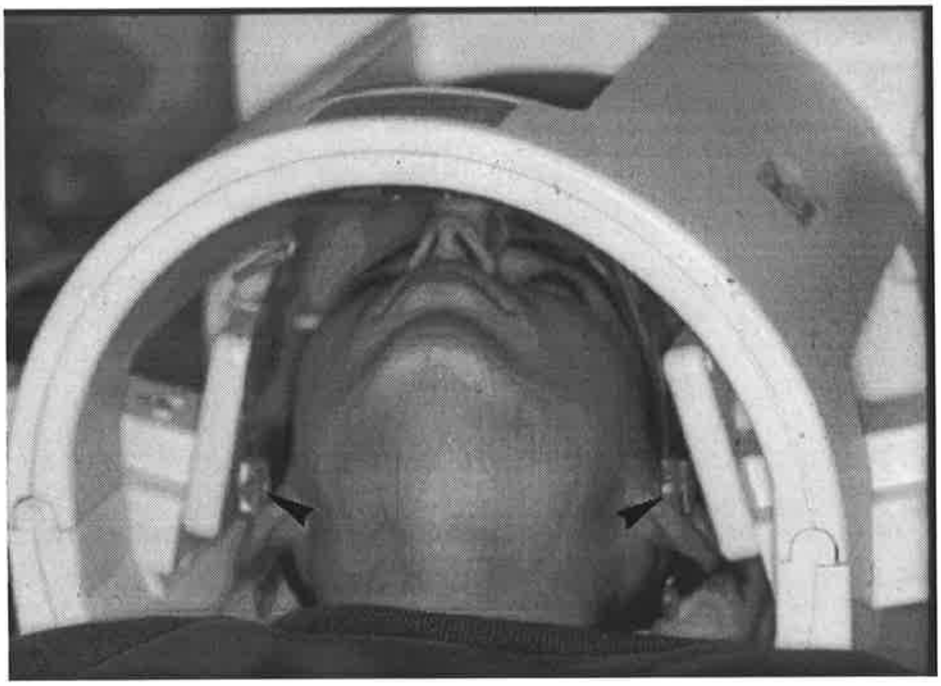


Figure 43 ▪ Position of TMJ surface coils lateral to the lipid markers (arrow) on the calibration head frame.

At the MRI session, the children and the parents were asked to remove all metallic material before entering the MRI suite. A series of questions was asked concerning metal materials in the body. A consent form (Appendix 12) was signed. Only one person was allowed to accompany the child into the MRI scanning room. The calibration head frame and a pair of earplugs were worn during the scanning which was performed with the child in the supine position. To reduce the scanning time, the MRI was performed on the right TMJ only. Protocol for MRI is shown in Table 8.

Table 8 ▪ Protocol for MRIs in control and experimental children

Pre-treatment MRIs		6-month MRIs	
Control	**Experimental**	**Control**	**Experimental**
Sagittal image at maximum intercuspation	Sagittal image at maximum intercuspation	Sagittal image at maximum intercuspation	Sagittal image at the most retruded position
Coronal image at maximum intercuspation	Coronal image at maximum intercuspation	Coronal image at maximum intercuspation	Coronal image at the most retruded position
	Sagittal image at CTB position		

➢ *Scout images*

Using fast gradient echo sequence, a short sagittal scan was performed initially to obtain a sagittal image of the head. This sagittal scout image (Figure 44) was used for localising the level of the condyle. The next short axial scan was performed for an axial scout image. This axial scout image was used to localise the condyle and program the imaging angles for the sagittal (Figure 45) and coronal scans (Figure 46). The fast scannings and programming process lasted approximately three minutes. During the time of each scanning, the children had to remain still to obtain sharp images. However, scout images were usually of low quality due to relatively short scanning time.

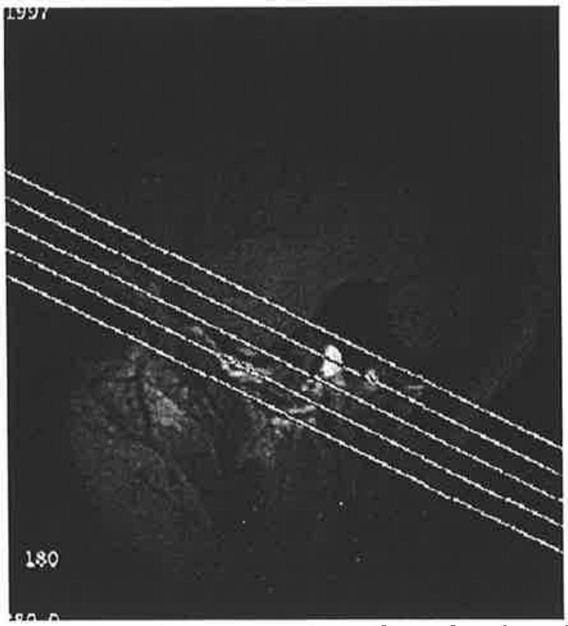


Figure 44 ▪ Sagittal scout image to localise the level of the condyle for axial scan.

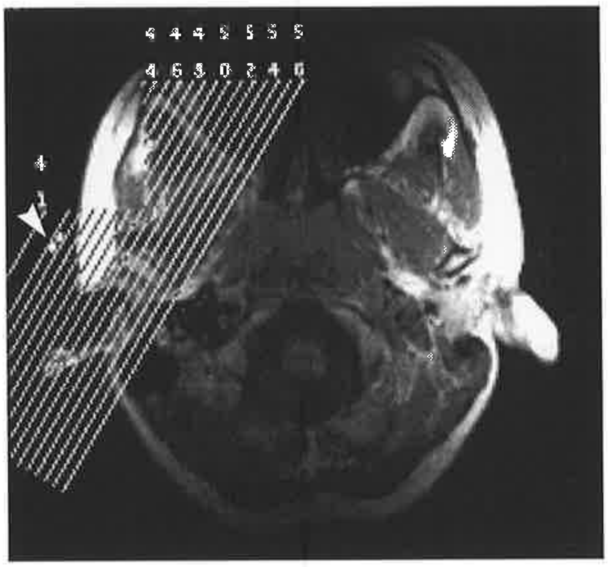


Figure 45 ▪ Axial scout image used to assign the angle for corrected sagittal images. Sixteen slices were planned. Note the position of the lipid markers lateral to the TMJ (arrow).

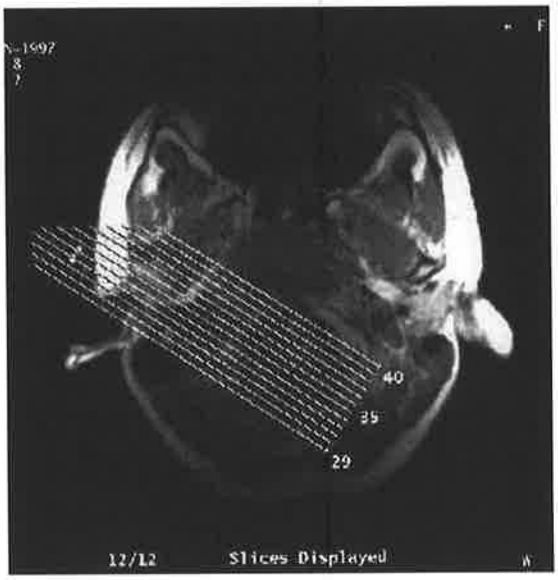


Figure 46 ▪ Axial scout image used to assign the angle for corrected coronal images. Twelve slices were planned.

➢ ***Sagittal images***

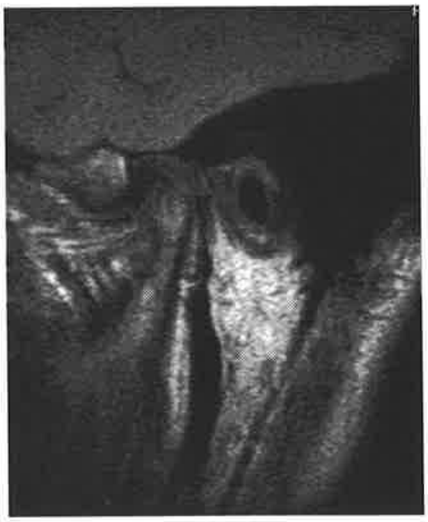
The sagittal scan was planned from the axial scout image. The angle of the sections was at right angles to the medio-lateral axis of the condyle but not the true sagittal plane of the children. This plane was referred to as the "corrected sagittal plane". Sixteen slices were performed from lateral to medial pole. The duration of this scan was approximately eight minutes.

➢ *Coronal images*

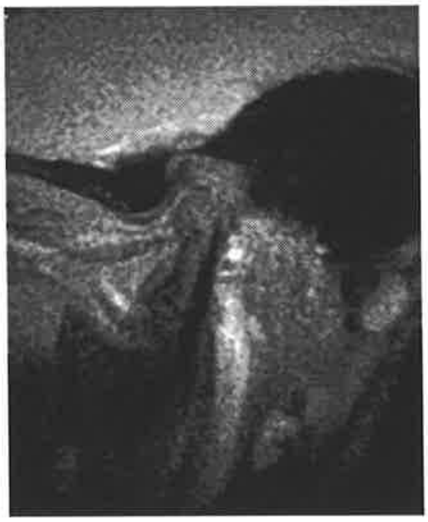
The angle of sections for coronal images was planned to be perpendicular to the "corrected sagittal plane". Twelve slices from the anterior to the posterior part of the joint were obtained. The time for this scan was approximately six minutes.

➢ *Selection of MR sequences*

A series of MR sequences was performed as a pilot study in a volunteer boy to help in selection of a sequence that produced good quality images. The series tested were T1 and T2* (flash gradient echo). The use of a finer matrix (number of pixels in a row x number of rows) with a relatively small field of view (FoV - area of investigation under the defined matrix size) and high number of excitation (NEX) provided superior image quality. However, the total scanning time was over 25 minutes and it was not possible for children to remain still during that length of time. Therefore, it was decided to obtain images of the right TMJ only. Images from the T1 sequence provided superior detail of structures while the T2* image was dark, grainy and less defined (Figure 47). T1 images with an increased number of excitations (NEX = 3) were selected for analysis.



T1 image



T2* image

Figure 47 ▪ Comparison between T1 and T2* images (NEX =1) from pilot study

The parameters used in the scanning process for sagittal and coronal images are shown in Table 9. Total scanning time was approximately 20 - 25 minutes. Scanning was repeated if the image quality was poor due to movement.

Table 9 ▪ Parameters used for Magnetic Resonance Imaging

	Sagittal image	Coronal image
Number of slices	16	12
Time to repeat (TR- msec)	608.0	456.0
Time to echo (TE- msec)	20.0/1	20.0/1
Time of acquisition (TA - min)	8:06	5:28
Field of view (FoV)	120 x 160 mm^2	100 x 160 mm^2
Matrix size	192 x 512	160 x 512
Number of excitation (NEX)	3	3
Magnification	1.75	1.75
Slice thickness	3 mm	3 mm
distance between slice	0.3 mm	0.3 mm

3.5.3 Measurements and analysis

➢ ***Axial images***

The shape of the condylar head and the angle of the condylar head axis relative to the cranial midline were examined from the T1 axial scout images. The shape of the condylar head was classified into three categories, i.e. ovoid, concavo-convex or ellipsoidal as described by Christiansen *et al* (1987, Figure 48).

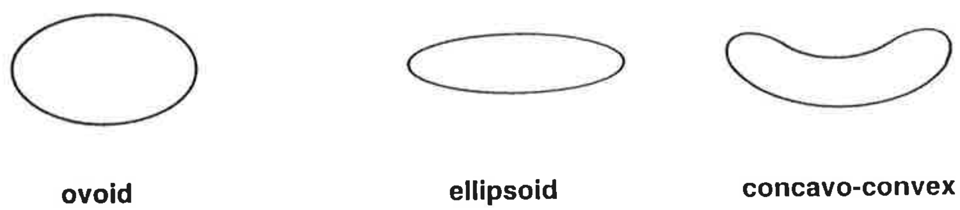


Figure 48 ▪ Classification of condylar axial image into three types: ovoid, ellipsoid and concavo-convex

The midline of the cranium was estimated, based on medial cranial structures, including crista galli, Sella and foramen magnum. The condylar axis was constructed across the longitudinal axis of the condylar head. The angle between the two constructed lines was defined as the condylar axial angle (Figure 49).

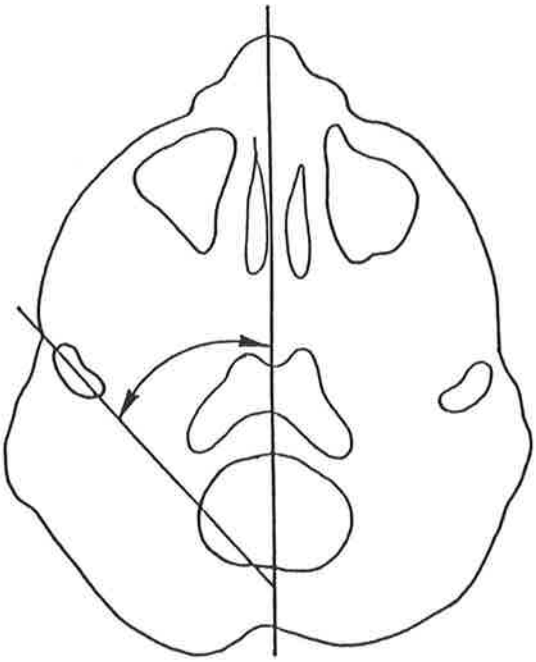


Figure 49 ▪ Condylar axial angle relative to the cranial midline

➢ *Coronal images*

A slice exhibiting the widest image of the TMJ was selected from the corrected coronal series for measurements. The features of interest were:

- Coronal condylar shape
- Maximum condylar width
- Articular disc position.

❖ Coronal condylar shape

The shape of the condyle from the coronal plane was classified into four types using Yale's classification (Yale *et al*, 1963). The four types were angled, round, convex and flat (Figure 50).

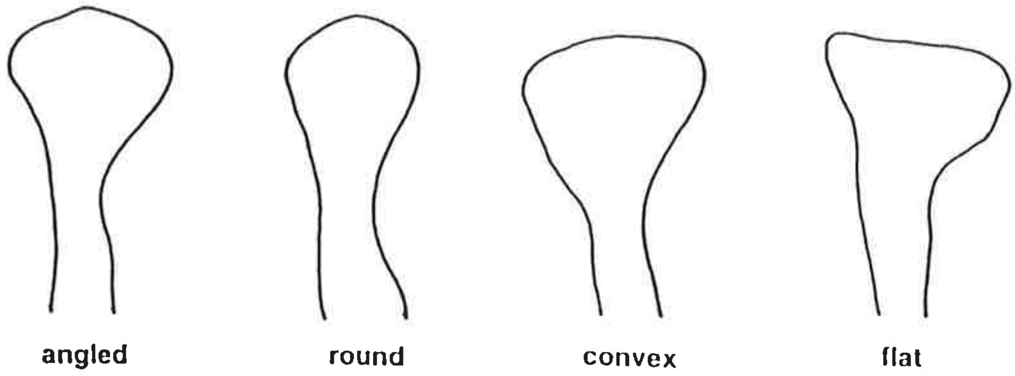


Figure 50 ▪ Classification of coronal condylar head shape (Yale *et al*, 1963)

❖ Maximum condylar width

A long axis reference line was constructed along the condylar head and neck. Lines parallel to the long axis were constructed tangential to the medial and lateral side of the condyle. The maximum condylar width was measured from the points where the constructed lines on the medial and lateral side contacted the condyle (Figure 51).

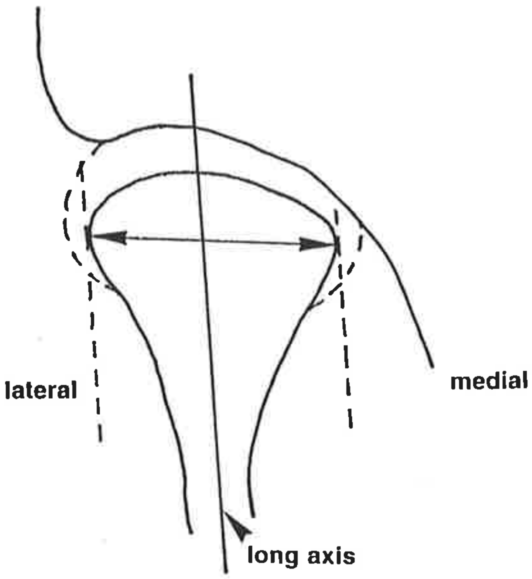


Figure 51 ▪ Method of measuring maximum condylar width

❖ The articular disc position

The construction reference lines and points were similar to those for measuring the maximum condylar width. The line across the maximum width was then divided into tenths. The position of the disc was recorded in relation to the 1/10 divisions of the condylar width. Negative values represented the lateral side while positive values represented the medial side. This method was preferred for measurement, rather than using absolute values, to overcome the differences in sizes of individual condyles.

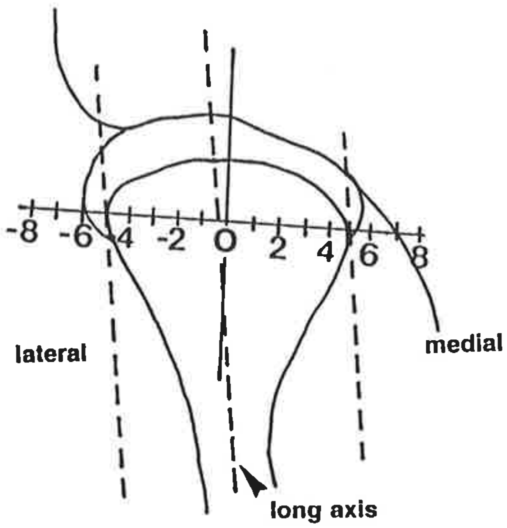


Figure 52 ▪ Method of measuring coronal articular disc position

➢ ***Sagittal images***

A T1-corrected sagittal image section through the central part of the condyle that displayed maximum length of the posterior border of the condyle and ramus was chosen for measurements. The features observed were:

- The angle of the articular eminence
- The articular disc position relative to condylar head and the glenoid fossa
- The concentricity of the condylar head in the glenoid fossa

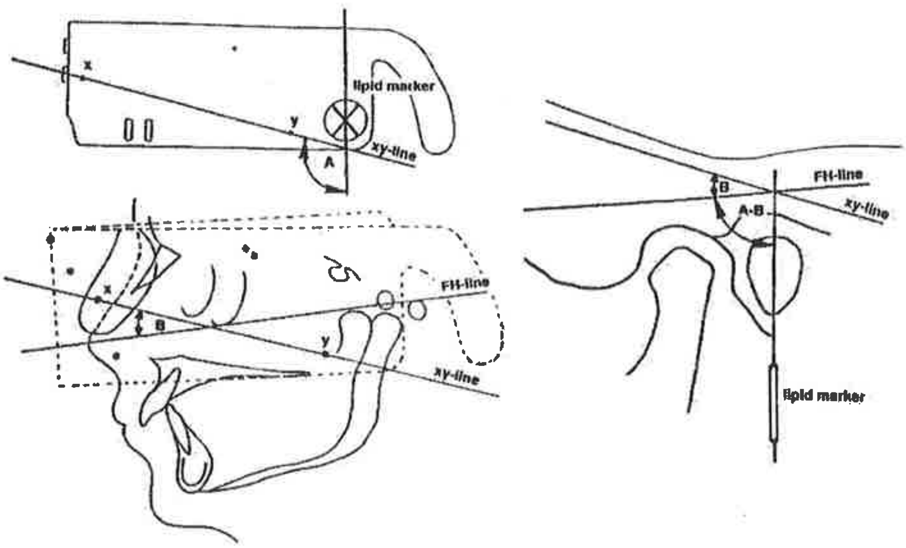
Two reference lines were used for the measurement of articular eminence angle and articular disc position.

1. **Posterior condylar reference line (PC-line)**

   This method aimed to use a reference structure that was displayed directly on the MR image. A posterior condylar reference line (PC-line) was constructed as the tangent along the length of the posterior border of the condyle and ramus.

2. **Frankfort Horizontal plane (FH)**

   The Frankfort Horizontal plane is commonly used as a reference plane for measuring the slope of the articular eminence both in cephalometry and when using an articulator. However, this plane is not visible in the MRI field of view used in this study. Using the calibration head frame, it was possible to transfer the FH-plane from the cephalogram onto the MRI. The two right side lead landmarks nearest to Orbitale and Porion, which form the FH-plane, were selected. The angle of the line between these landmarks was measured relative to each lipid marker on the right hand side. The angle of FH to the lead landmark line was measured from the cephalogram. The difference between these two angles represented the angle between FH plane and the lipid marker. Figure 53 shows an example of transferring the FH-plane onto the MRI using the central lipid landmark.

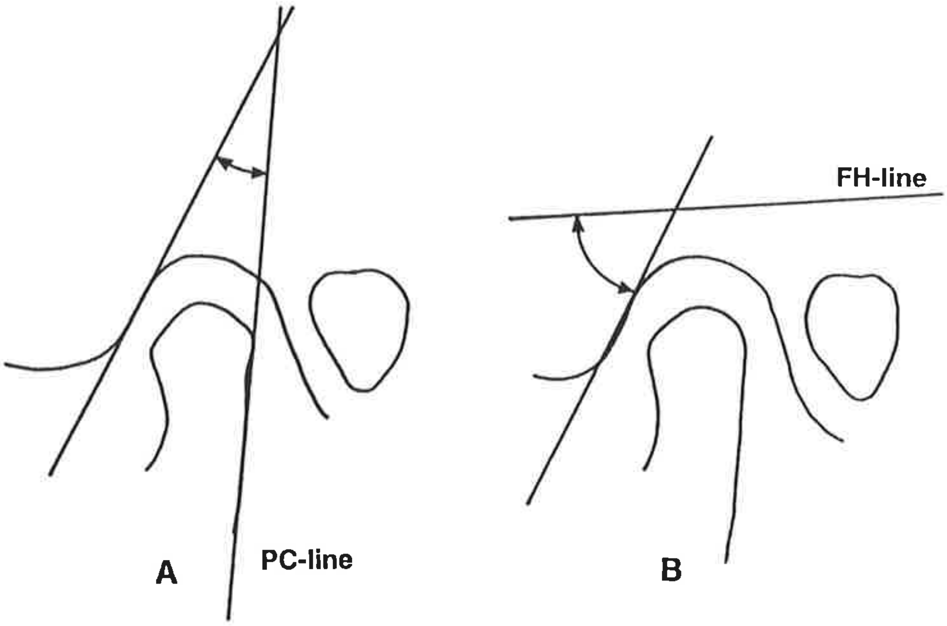


"A" = angle between the reference line from lead markers (X-Y) to the central lipid marker
"B" = angle between the reference line from lead markers (X-Y) to the FH plane
"A-B" = angle between the FH plane and the central lipid marker

Figure 53 ▪ Method of transferring the FH plane from the cephalogram onto the MRI.

❖ Articular eminence angle

The steepness of the articular eminence was measured as the angle formed by a line tangential to the posterior slope of the articular eminence and related to the two reference lines (Figure 54). Angles more than one standard deviation below the mean were classified as "steep" while the angles more than one standard deviation above the mean were classified as "shallow".



A: eminence angle relative to PC-line **B: eminence angle relative to FH-plane**

Figure 54 ▪ Method of measuring articular eminence angles

❖ Articular disc position

The method of defining disc position was a variation of that used by Drace and Enzmann (1990) who defined a so-called "12 o'clock" position in determining disc position relative to the condylar head. The centre of a "circle of best fit" on the condylar head was determined on the chosen sagittal image and used as a reference point representing the geometric centre of the condylar head.

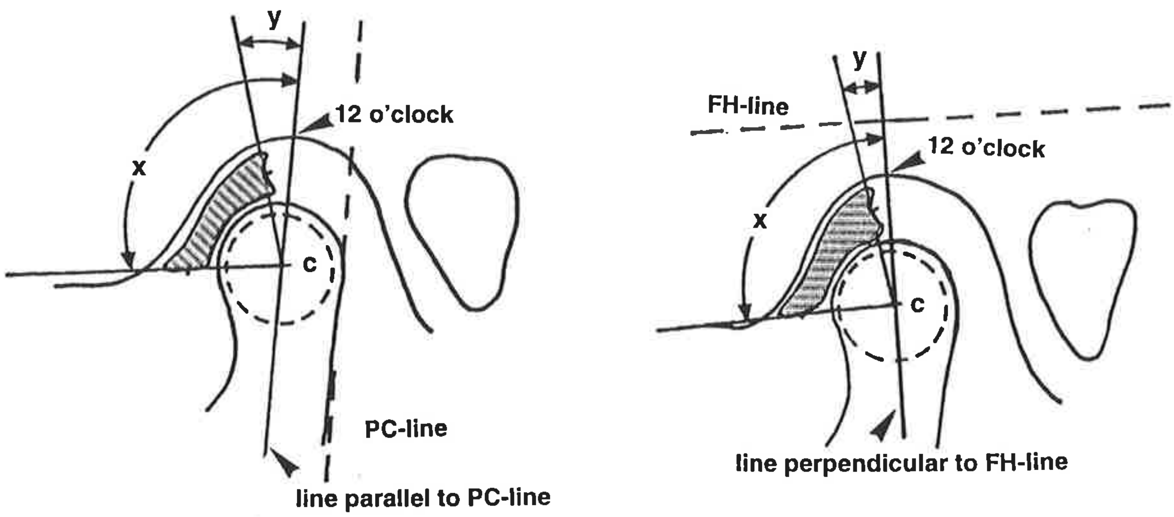
Using the PC-line: The intersecting point between a line parallel to the PC-line passing through the condylar centre and the roof of the fossa was constructed and referred to as the "12 o'clock" position in the glenoid fossa.

Using the FH-plane: The "12 o'clock" position was constructed by the line perpendicular to the FH-plane through the condylar centre and the roof of the articular fossa.

The positions of the anterior and posterior bands of the disc were then measured as angles relative to the 12 o'clock position (Figure 55). The position of the posterior band was used to classify the disc position into three categories: anterior displacement, normal and posterior displacement. One standard deviation above the mean was taken to represent the anterior limit of normality and one standard deviation below the mean was used to define the posterior limit of normality.

Note: Although the terms "anterior displacement" and "posterior displacement" were used in the present study, this should not be interpreted as necessarily indicating any abnormality.

X = angle of the anterior band of the disc,
Y = angle of the posterior band of the disc,
C = centre of the condylar head



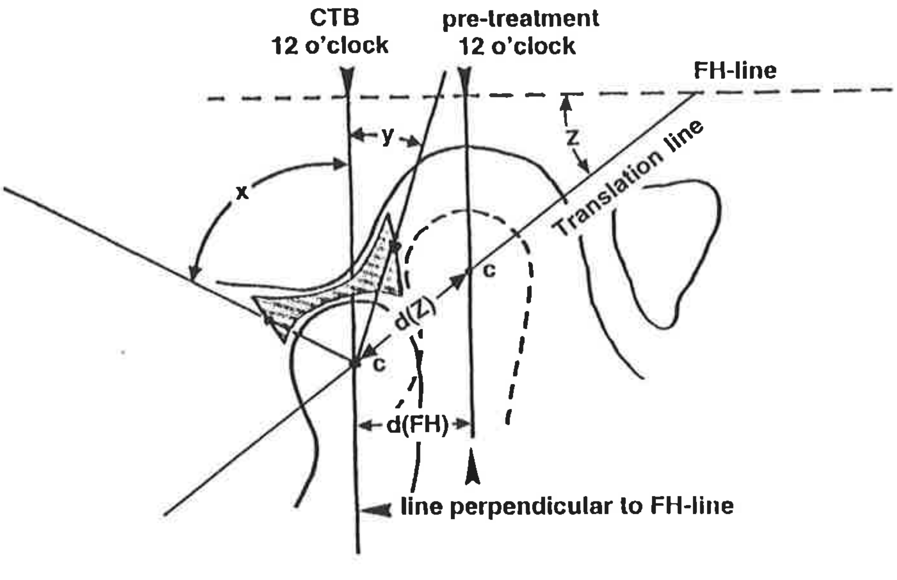
A: using a line parallel to the PC-line drawn through the centre of the condyle

B: using a line perpendicular to the FH-plane drawn through the centre of the condyle

Figure 55 ▪ Constructed 12 o'clock points at the roof of the articular fossa

❖ Translation of condyle and disc in the CTB group

Translation of the condyle when the children were wearing the Twin Block appliance was assessed by comparing tracings of the initial sagittal MRI with the appliance position MRI, superimposing on the lipid landmarks. Translation of the condyle in the CTB group was measured relative to the FH-line. The reference 12 o'clock position was constructed from the line perpendicular to the FH-line through the centre of the condylar head. The line joining condylar centres was referred to as the translation line. The angle between the translation line and FH-line was referred to as the translation angle. The translation of the condyle was also measured along the FH-line.



X, angle of the anterior margin of the disc
y, angle of the posterior margin of the disc
z, translation angle
d(FH), translation distance along FH-line
d(Z), translation distance alone translation angle

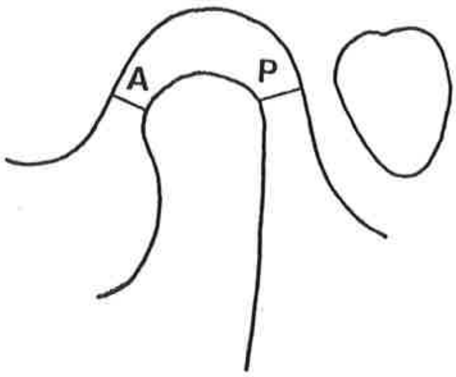
Figure 56 ▪ Method of measuring disc position and translation distance along the FH-line when the children were wearing the CTB.

❖ Condylar concentricity

Concentricity of the condyle was evaluated using the method described by Pullinger *et al* (1987). The condylar position was calculated from the narrowest anterior and posterior inter-articular joint spaces (Figure 57) using the formula:

[(P-A)/(P+A)] x 100 = % displacement

Positive values indicated an anterior position, negative values indicated a posterior position, and a zero value was referred as "concentric".



A is the narrowest anterior inter-articular joint space
P is the narrowest posterior inter-articular joint space

Concentricity is calculated from the formula:
[(P-A)/(P+A)] x 100 = % displacement

Figure 57 ▪ The method of evaluating condylar position in the glenoid fossa (Pullinger *et al* 1987).

3.5.4 Error study

MRIs from ten randomly selected children, five from the control group and five from the experimental group, were used for a study of the errors of the method. The MRIs were traced and measured twice on two separate occasions. Paired t-tests were used for detection of systematic errors. Statistical significance was set at $p<0.05$. The calculation of t-values was as follows:

$$t = \frac{\bar{d}}{SE_{\bar{d}}} \quad (\textit{with degrees of freedom} = n-1)$$

where, $\bar{d}$ = *mean of the differences between pairs*

$SE_{\bar{d}}$ = *standard error of the mean of the differences between pairs*

n = *number of pairs*

Estimation of random error was quantified using Dahlberg's (1940) formula:

$$Se = \sqrt{\frac{\sum d^2}{2n}}$$

where, Se = standard deviation of a single determination
d = differences between pairs
n = number of pairs

Reliability of each variable was determined from error variance (Se^2) and observed variance (So^2) using the formula:

$$Reliability = \left(1 - \frac{Se^2}{So^2}\right) \times 100$$

where, Se = standard deviation of a single determination calculated from Dahlberg's formula
So = observed standard deviation of the whole sample

Table 10 ▪ Analysis of systematic errors and random errors in MRI variables

Variables	t value	p value	Se	Se^2	So^2	Reliability %
Axial angle	0.58	0.57	0.93	0.86	81.18	98.9
Coronal width	1.00	0.34	0.22	0.05	5.29	99.0
Medial disc position	1.41	0.19	0.25	0.06	3.61	98.3
Lateral disc position	0.56	0.59	0.19	0.04	1.44	97.4
Eminence angle relative to PC-line	1.08	0.31	1.04	1.07	98.01	98.9
Eminence angle relative to FH-line	0.31	0.77	1.04	1.08	169.00	99.4
Anterior margin (PC)	0.17	0.87	1.27	1.63	79.21	97.9
Posterior margin (PC)	1.59	0.15	1.89	3.56	207.36	98.3
Anterior margin (FH)	0.94	0.37	1.66	2.75	112.36	97.6
Posterior margin (FH)	0.83	0.43	1.99	3.96	179.56	97.8
Translation angle	0.51	0.62	0.55	0.30	77.44	99.6
Translation distance along FH [d(FH)]	0.39	0.70	0.71	0.50	2.89	82.7
Translation distance along Z [d(Z)]	0.63	0.68	0.95	0.35	2.56	86.2

No systematic errors were found for any of the variables. The random errors were greatest for the measurement of anterior and posterior disc position variables, most possibly because of variability in the construction of the reference lines. Simple measurements such as coronal width, medial and lateral disc positions were associated with small random errors. Overall, random errors were relatively small and unlikely to bias subsequent analyses. Reliability ranged from 82.7% to 99.4%.

3.6 Three-dimensional Cephalometry

3.6.1 Development of three-dimensional cephalometry

To measure the craniofacial structures in three dimensions, the software "Sculptor version 1.0" (Acuscape Inc., copyright 1996-1998 HM Associates, LLC) required three cephalogram views. Originally, this program used lateral view, frontal view and frontal-up view (where the subject tilted the head anteriorly upward). Because this project was focused on mandibular growth, the cephalograms chosen were based on the ability to identify the condylar heads on both the left and right sides. Condylar heads were easier to identify on lateral cephalograms than on a frontal cephalogram. Therefore, two views of lateral cephalograms and one frontal cephalogram were used.

To avoid condylar superimposition on the lateral cephalograms, some degree of head rotation was considered to be necessary. A pilot study was performed to identify an appropriate amount of head rotation for the lateral cephalograms. A series of cephalograms of a dry skull, with metal landmarks attached, was obtained to investigate the reliability of locating cephalometric landmarks from cephalograms taken at different angles. The objective was also to find a head rotation angle that separated the two condylar heads enough to identify which side was the right or the left while still being able to recognise the anatomical landmarks. Metal pellets were placed on a dry skull at Nasion (N), Orbitale (Or), Porion (Po), floor of the Sella Turcica (S), Anterior Nasal Spine (ANS), Posterior Nasal Spine (PNS), point A, point B, Pogonion (Pg), Menton (Me), Gonion (Go), Condylion (Co), and Basion (Ba). Thin wire was placed around the midline of the symphysis and the mandibular condyle. The cephalograms were obtained at 0°, 5°, 10°, 15°, 20° and 35°, with the right side of the skull closest to the film. Each cephalogram was traced on an acetate sheet by three experienced operators. The landmarks were digitised later after the tracing was removed from the cephalograms. The location of the landmarks and variables from the tracing were then compared with the landmarks on the cephalogram (Table 11).

Table 11 ▪ Differences in landmark locations and variables in a series of rotated lateral cephalograms

LANDMARKS	Mean differences in mm					
	0°	5°	10°	15°	20°	35°
Nasion	0.0	0.0	0.0	0.0	0.8	1.5
Orbitale (right)	0.3	0.3	0.3	1.0	2.0	3.0
Orbitale (left)	1.7	0	0.8	1.0	2.3	3.0
Porion (right)	1.3	2.0	2.0	?	?	?
Porion (left)	1.3	2.2	2.0	?	?	?
Sella	0.0	0.0	0.0	1.0	1.3	1.7
ANS	0.0	0.0	0.0	0.0	1.0	3.0
PNS	0.0	0.0	0.0	0.0	1.0	1.0
point A	0.0	0.0	0.0	0.0	0.0	1.8
point B	0.0	0.0	0.0	0.0	1.0	2.0
Pogonion	0.0	1.0	0.3	0.0	1.0	2.0
Menton	0.3	0.7	0.8	1.0	2.2	3.0
Gonion (right)	0.7	0.7	1.0	1.8	2.0	2.0
Gonion (left)	0.3	0.7	0.3	1.7	1.8	3.0
Condylion (right)	0.3	0.7	0.7	1.0	?	1.0
Condylion (left)	0.7	0.7	0.8	3.0	?	?
Basion	0.0	0.0	0.0	0.3	?	?

"?" means that at least two of the operators could not locate the landmark.

As expected, the results showed that anatomical landmarks situated along the midline were the least affected by head rotation. The 10° rotated cephalogram was suitable in separating the two condyles while the anatomical landmarks were minimally distorted compared with a standard lateral cephalogram. Porion was the critical anatomical landmark. It was not possible to locate Porion once rotation of the head was more than 10°.

Three views of cephalograms, frontal (postero-anterior), 10° right lateral and 10° left lateral, were chosen to provide data that would enable three-dimensional reconstructions to be obtained (Figure 58). All the cephalograms were obtained under supervision of the researcher using the same radiographic machine and cephalostat. Double emulsion Kodak rapid films and fast screens were used to reduce the radiation dose for the children. The focal spot to film distance was 2.02 m and the object (mid-sagittal plane) to film distance was

16.5 cm. The focal spot to object (mid-sagittal plane) distance was 1.855 m. The voltage used was 80 kv and the current used was 15-19 mAs. The effective radiation dosages were calculated and approved by radiation safety officer, Physics and Radiation Safety Section, Royal Adelaide Hospital (Appendix 15). The total radiation burden for the research component of this project was 31 μSv.

The children were positioned so that the cantho-meatal line was parallel to the horizontal plane for the postero-anterior view, while the Frankfort plane was parallel to the horizontal plane for the lateral views.

The children wore a calibration head frame and occluded on a bite registration at maximum intercuspation while the cephalograms were obtained, with the exception that the Twin Block subjects occluded on a bite registration at the most retruded position when the 6-month records were obtained.

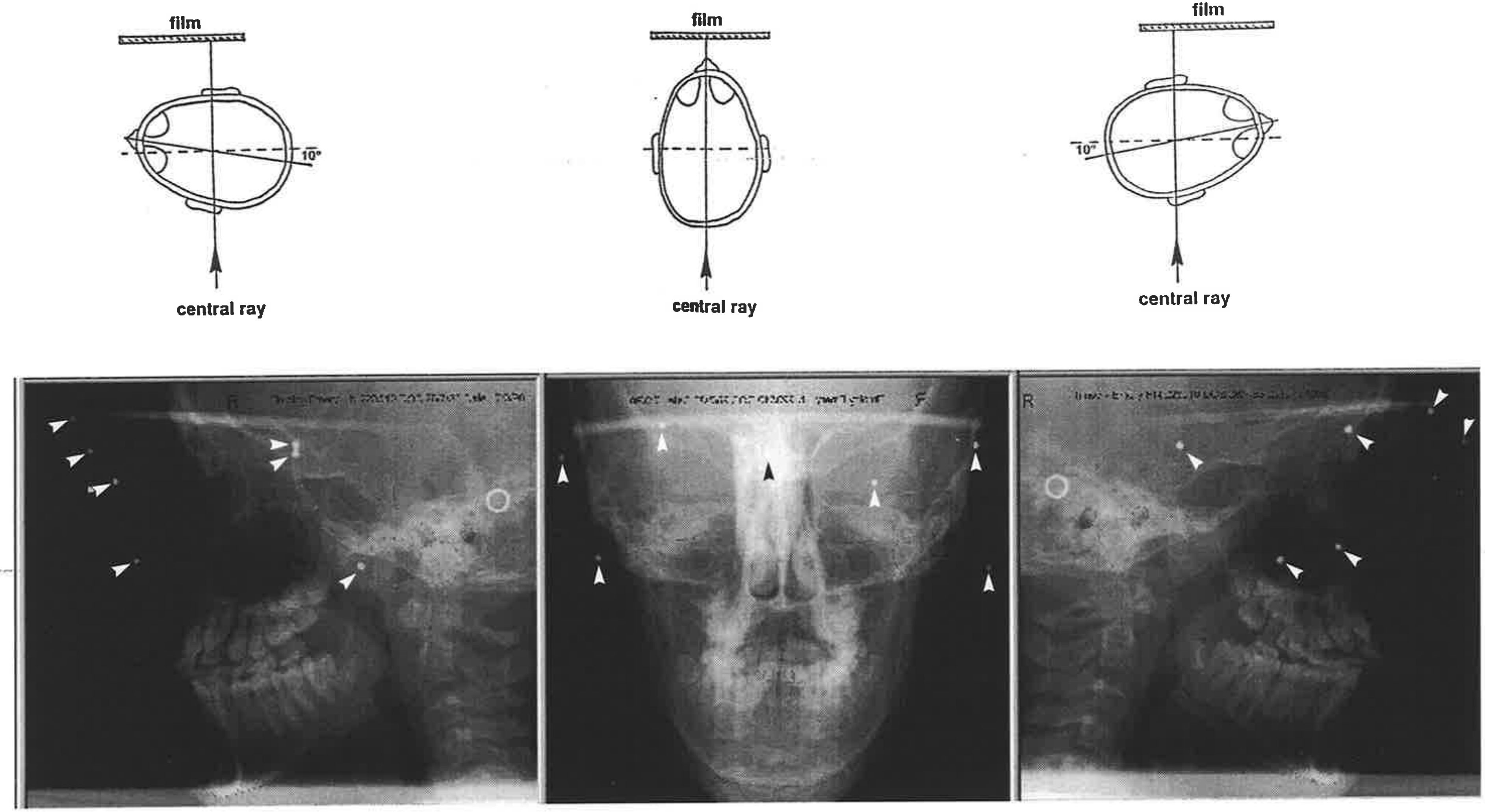


Figure 58 ▪ Three views of cephalograms used in 3-D cephalometry showing seven lead markers (arrows) on each cephalogram.

3.6.2 Landmarks

Landmarks for 3D-cephaolmetric analysis included seven naso-maxillary landmarks, four dental landmarks and four mandibular landmarks (Table 12).

Table 12 ▪ 3D-Cephalometric landmarks

Naso-maxillary landmarks	Definitions
ANS	Anterior nasal spine
PNS	Posterior nasal spine
A	A point: anterior limit of the maxillary denture base
S	Sella: the constructed midpoint of the sella turcica
N	Nasion: the most anterior point of the frontonasal suture
Po (r), (l)	Porion: the most superior point on the external auditory meatus (right side and left side)
Or (r), (l)	Orbitale: the lowest point on the infraorbital margin (right side and left side)
Dental landmarks	**Definitions**
U1 tip	Upper incisor tip
L1 tip	Lower incisor tip
U1 root	Upper incisor root apex
L1 root	Lower incisor root apex
Mandibular landmarks	**Definitions**
Me	Menton: the most inferior point on the mandibular symphysis
B	B point: anterior limit of mandibular denture base
Go (r), (l)	Gonion: (right side and left side)
Cc (r), (l)	Condylar centre (right side and left side)

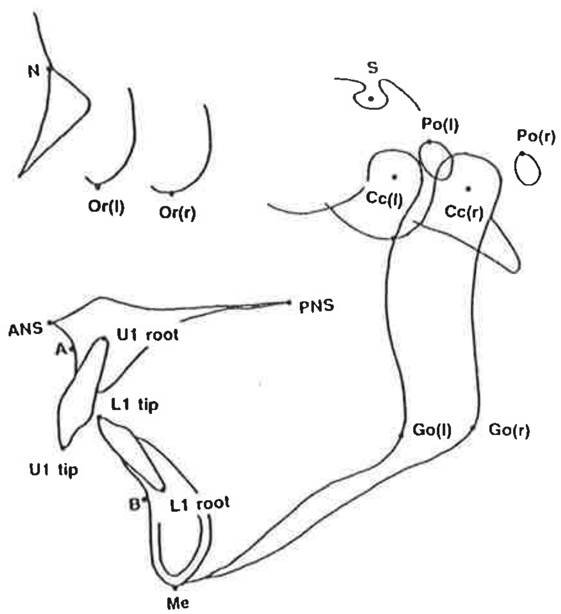


Figure 59 ▪ Cephalometric landmarks for digitisation (right lateral view).

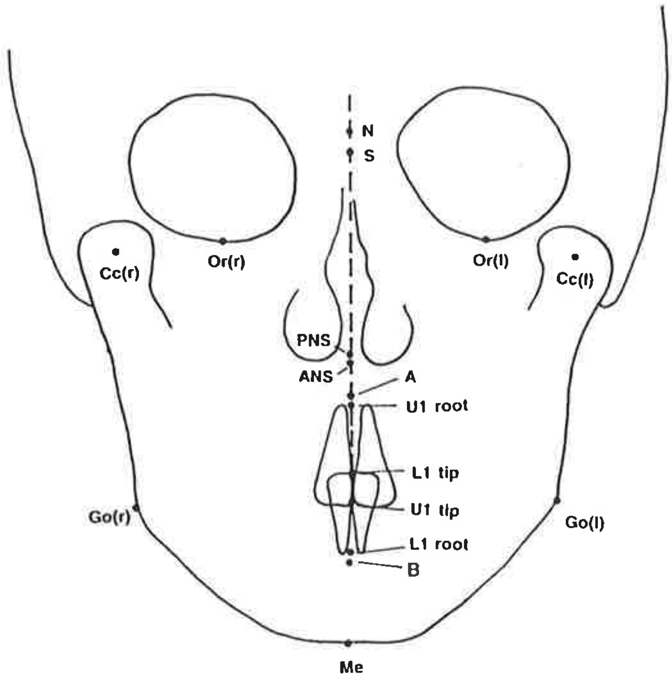


Figure 60 ▪ Cephalometric landmarks for digitisation (frontal view).

3.6.3 Calibration and digitisation procedures

Cephalograms were scanned with a resolution of 150 dpi using "Jasc Paint Shop Pro version 3" software (copyright© 1995, JASC Software Inc., USA) and stored as JPEG files. Software "Sculptor version 1.0" (Acuscape Inc., copyright© 1996-1998, HM Associates, LLC, USA) was used to calibrate the three cephalograms based on the co-ordinate markers on the calibration head frame, and to measure the dento-facial variables. The procedures were as follows:

➢ ***Calibration***

The three-dimensioned co-ordinates of the seven lead landmarks from the different sized head frames were stored in the program as "calibration frames". A scanned cephalogram was imported into the program and the seven lead markers were digitised according to the calibration frame. The "calibrate" function was then used to match the digitised landmarks with the calibration frame. The landmarks were re-digitised several times until all the digitised landmarks matched well with the calibration frame. The process was repeated for the other two cephalograms. At the end of the calibration, all the cephalograms were correlated in three dimensions according to the calibration frame.

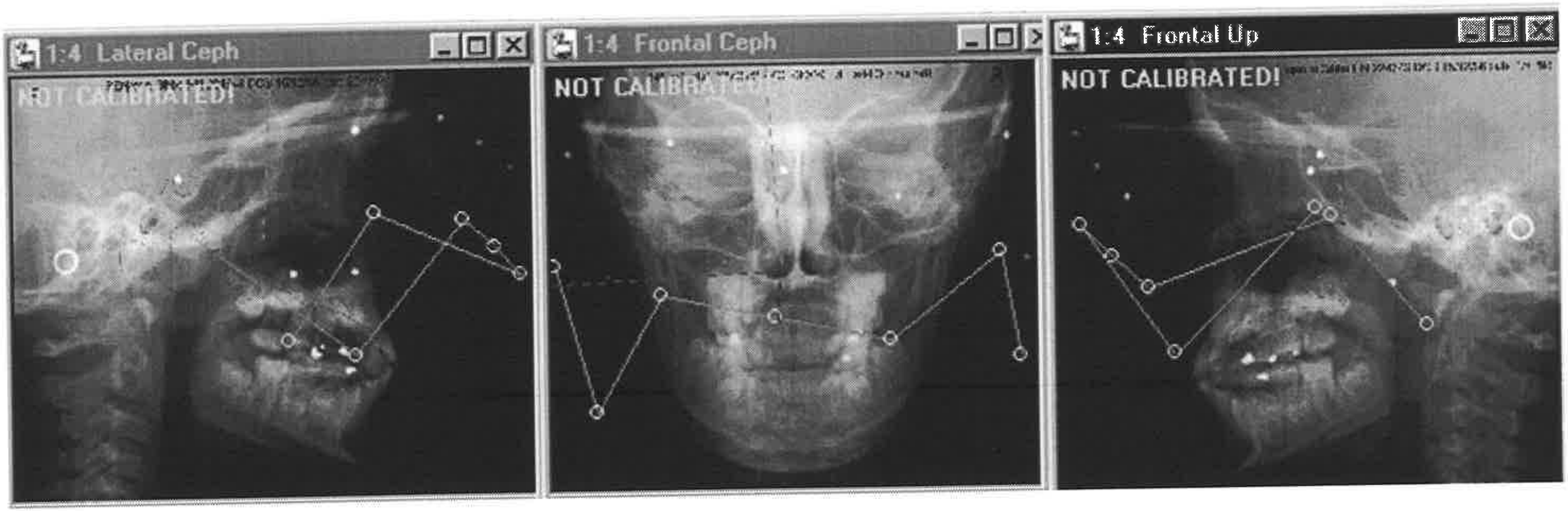


Figure 61 ▪ Images from three cephalograms and their corresponding calibration frames before calibration.

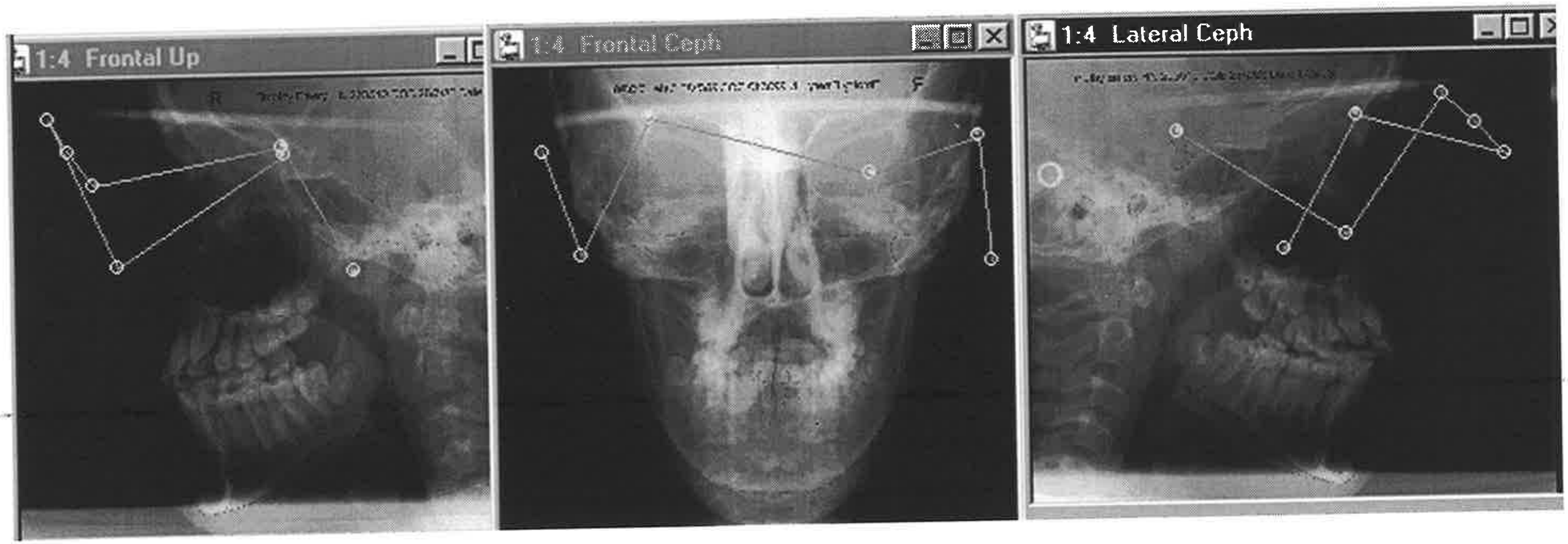


Figure 62 ▪ Images of the three cephalograms after calibration.

> ***Set reference plane***

The mid-sagittal reference plane was set on the frontal cephalogram and all the midline landmarks of the naso-maxillary complex were consistently related back to this reference line by the computer software to reduce variability in locating the landmarks.

Figure 63 ▪ Position of mid-sagittal reference line on a frontal cephalogram.

> ***Landmark digitising***

Three calibrated cephalograms were tiled vertically together on the screen for comparison during the digitising. A landmark was digitised first on the lateral cephalogram where that landmark could be clearly identified. The corresponding landmark was then digitised on the second lateral cephalogram. The frontal cephalogram was digitised last with the help of computer prompted epipolar lines from the two previously digitised cephalograms (Figure 64). An epipolar line was a computer constructed reference line based on the co-ordinates relative to the calibration frame. This line used the information from the previous cephalogram to indicate along which horizontal line the same landmark would be expected to lie on the current image.

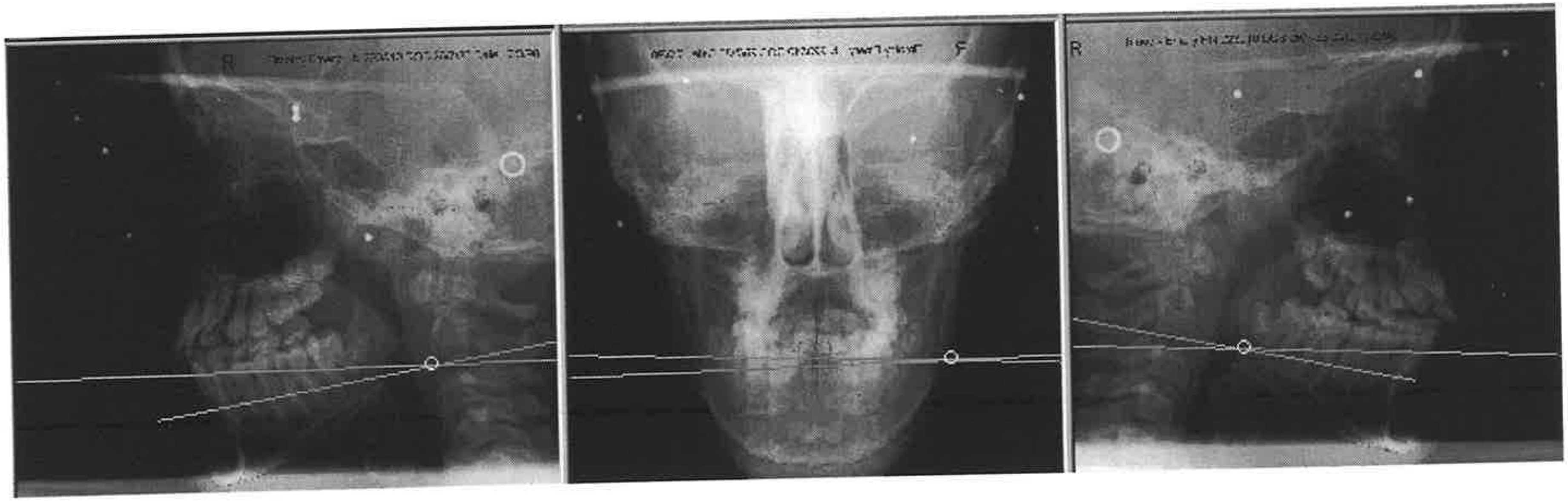


Figure 64 ▪ Epipolar lines for Gonion landmark relate vertical distance from one cephalogram to the others according to the calibrated co-ordinates.

After the landmark was digitised on all three cephalograms, the function "triangulate" was then performed. The triangulation function determined the average position of the digitised landmark relative to the calibrated co-ordinates from the three cephalograms. If the location of the triangulated landmark was unacceptable, the process was repeated.

Rules for digitising landmarks were set for consistency of digitisation (Table 13). Some landmarks such as Porion, PNS, and sella were visible on lateral cephalograms but not on frontal cephalograms. Modification of location of these landmarks was then applied according to these rules.

Table 13 ▪ Rules for 3D- cephalometric digitisation.

Landmarks	Rules
S, A, N, ANS, PNS U1-tip, and U1-root	• Digitise from the two lateral views first. • Use the vertical level suggested by the epipolar lines from the lateral views and locate the landmarks at the central line (computer assisted) on the frontal view.
Orbitale (Or)	• Digitise from the two lateral views first. • Digitise on the frontal view as seen.
Porion (Po)	• Digitise from the two lateral views first. • Use the vertical level suggested by the epipolar lines from the lateral views and locate the landmarks at the most lateral aspects of the skull on the frontal view.
Gonion (Go)	• Digitise from the two lateral views first. • Use the vertical level suggested by the epipolar lines from the lateral views and locate the landmarks at the most lateral aspects of the mandible on the frontal view.
Condylar centre (Cc)	• Digitise from the two lateral views first. • Use the vertical level suggested by the epipolar lines from the lateral views and locate the landmarks at the centre of the condyle on the frontal view.

Menton (Me)	•	Digitise from the two lateral views first.
	•	Use the vertical level suggested by the epipolar lines from the lateral views and locate the landmarks at the deepest depression of the chin on the frontal view.
	•	Construct the vertical line from this Menton to use as the central line for the mandible.
B, L1-tip, L1-root	•	Digitise from the two lateral views first.
	•	Use the vertical level suggested by the epipolar lines from the lateral views and locate the landmarks at the constructed lower central line on the frontal view.

After digitisation of all the landmarks, the information of the co-ordinates were generated and stored in a data base file ready for measurement in three dimensions.

3.6.4 Measurements

The Acuscape™ macro program was used to process the programmed queries and transport all of the measurements into a spreadsheet file. The measurements included 24 distance variables and 33 angular variables (Table 14, Figure 65).

Due to the complexity of the 3D-cephalometry, data from only ten boys from the control group and ten boys from the experimental group were generated for analysis. All these boys had participated in the MRI study. None displayed evidence of disc displacement on their MRIs.

Table 14 ▪ 3D-Cephalometric variables (to be read with Figure 65)

Distances	Angles	
S - ANS	SNA	(1)
ANS – Me	SNB	(2)
Or(r) - Or(l)	ANB	(3)
A – Or(r)	ANS-PNS to SN	(4)
A – Or(l)	SN to FH(r)	(5)
A – Cc(r)	SN to FH(l)	(6)
A – Cc(l)	ANS-PNS to FH(r)	(7)
Or(r) - U1tip	ANS-PNS to FH(l)	(8)
Or(l) - U1tip	A to Or(r) to Po(r)	(9)
ANS - U1tip	A to Or(l) to Po(l)	(10)
A - B	U1 to SN	(11)
Me - L1tip	U1 to FH(r)	(12)
L1tip - Cc(r)	U1 to FH(l)	(13)
L1tip - Cc(l)	U1 to ANS-PNS	(14)
Me - Cc(r)	U1 to L1	(15)
Me - Cc(l)	L1 to SN	(16)
Me - Go(r)	L1 to FH(r)	(17)
Me - Go(l)	L1 to FH(l)	(18)
Me - Or(r)	L1 to Me-Go(r)	(19)
Me - Or(l)	L1 to Me-Go(l)	(20)
Cc(r) - Go(r)	Me to Go(r) to Cc(r)	(21)
Cc(l) - Go(l)	Me to Go(l) to Cc(l)	(22)
Cc(r) - Cc(l)	Me-Go(r) to FH(r)	(23)
Go(r) - Go(l)	Me-Go(l) to FH(l)	(24)
	Me-Go(r) to SN	(25)
	Me-Go(l) to SN	(26)
	Or(r) to A to Or(l)	(27)
	Cc(r) to A to Cc(l)	(28)
	Or(r) to U1tip to Or(l)	(29)
	Or(r) to Me to Or(l)	(30)
	Cc(r) to L1tip to Cc(l)	(31)
	Cc(r) to Me to Cc(l)	(32)
	Go(r) to Me to Go(l)	(33)

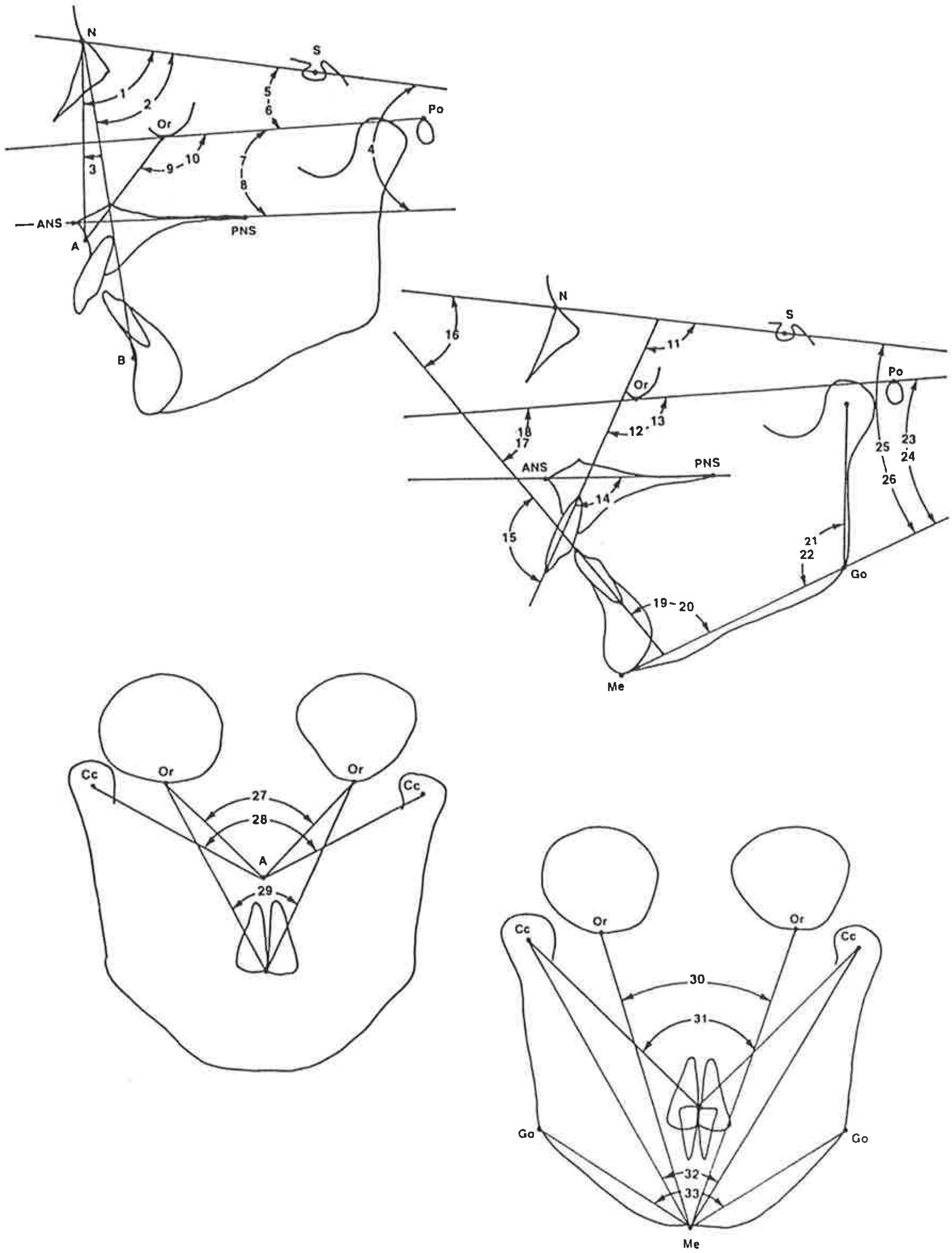


Figure 65 ▪ Measurement of angles in 3D-cephalometry

3.6.5 Error studies

➢ ***Program accuracy***

Accuracy of the computerised 3D-cephalometric program was tested by comparing the measurement of distances generated by the program against direct measurements on a dry skull with metal landmarks (Figure 66). Cephalograms of the dry skull were digitised three times to compare the error of measurements between each session. Variability in the measurement was low with the maximum difference being 0.16 mm. The average of these three measurements was used for comparison with direct measurements.

A digital calliper with sharp ends was used for direct measurements of the skull which were also performed three times. The maximum difference between measurements was 0.13 mm, the average of the three measurements being used for comparison. Paired t-tests were used to analyse systematic error. It was shown that the measurements from both direct and computerised data were not statistically significant. The mean difference (± SD) was 0.2 ± 1.5 mm. Differences in the measurements associated with the right side Porion were found to be higher than other measurements (Table 15).

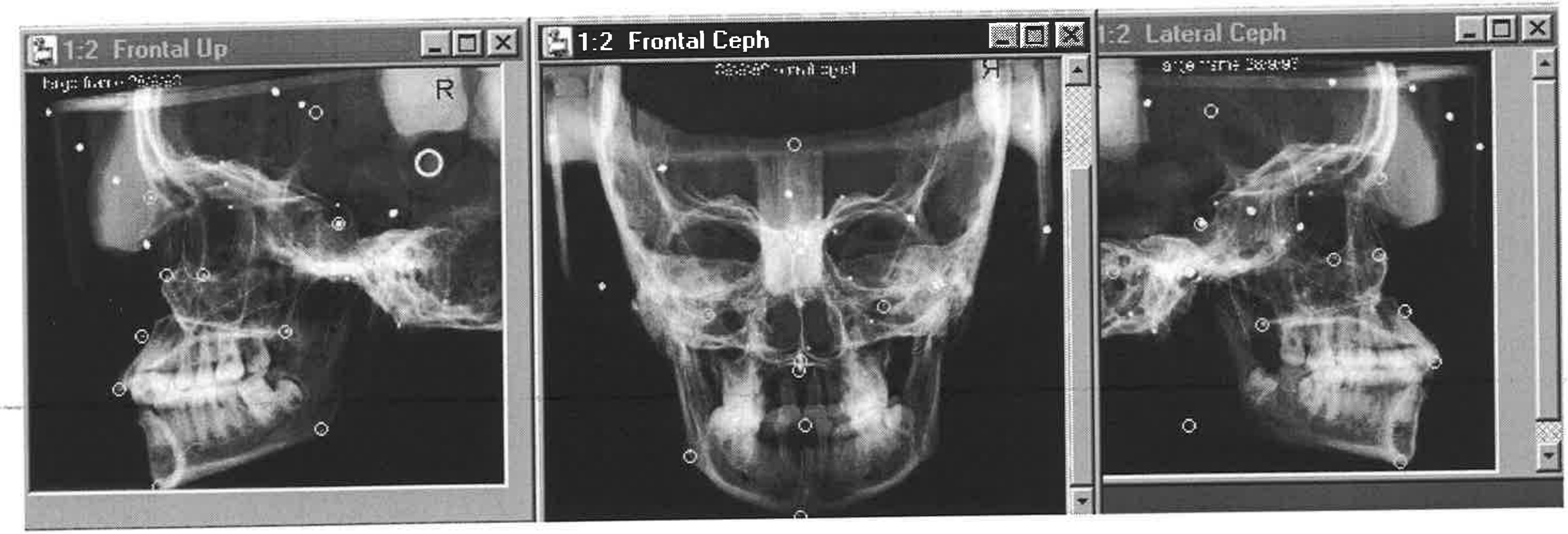


Figure 66 ▪ Three cephalograms of a digitised dry skull with metal landmarks.

Table 15 ▪ Comparison of distances (mm) between manual and computer methods.

Distances		Manual	Computer	Differences
A to	Me	49.6	49.7	-0.2
	N	44.6	45.0	-0.4
	Or(r)	37.3	37.6	-0.3
	Or(l)	38.2	38.6	-0.5
	Po(r)	97.7	94.5	3.1
	Po(l)	98.7	99.2	-0.6
	Go(l)	82.6	83.7	-1.2
	U1 tip	18.6	19.1	-0.5
Me to	N	93.9	94.2	-0.3
	Or(r)	75.0	75.9	-0.9
	Or(l)	73.5	74.2	-0.7
	Po(r)	114.3	112.6	1.6
	Po(l)	113.2	114.7	-1.6
	Go(l)	73.2	73.8	-0.6
	U1 tip	34.6	34.8	-0.3
N to	Or(r)	40.6	40.4	0.2
	Or(l)	39.5	40.7	-1.2
	Po(r)	95.8	92.4	3.3
	Po(l)	94.9	96.0	-1.2
	Go(l)	104.1	105.9	-1.8
	U1 tip	62.8	63.4	-0.7
Or(r) to	Or(l)	58.1	58.8	-0.8
	Po(r)	71.4	68.5	2.8
	Go(l)	98.2	99.4	-1.2
	U1 tip	50.3	51.3	-1.1
Or(l) to	Po(l)	71.8	72.8	-1.0
	Go(l)	72.0	72.8	-0.8
	U1 tip	51.9	52.9	-1.0
Go(l) to	U1 tip	84.4	86.0	-1.7
Go(l) to	Po(r)	100.0	98.3	1.7
Po(r) to	U1 tip	109.6	105.9	3.6
Po(l) to	Go(l)	56.3	55.7	0.5
Po(l) to	U1 tip	109.6	111.2	-1.6

➢ *Intra-operator variations*

Five sets of frontal, right lateral and left lateral cephalograms were randomly selected from five children to assess intra-observer reliability. The cephalograms comprised two from children in the pre-treatment experimental group, one initial record of a boy in the control group, one post-treatment record of a boy from the experimental group and one 6-month record from a boy in the control group. Cephalometric landmarks were digitised and measured twice by one operator on separate days. For detecting systematic errors, paired t-tests were used to assess the mean differences between the two sets of measurements. According to the formulae provided in section 2.5.4, Dahlberg statistics and reliability estimates were also obtained.

Paired t-tests revealed significant mean differences between observations for two distance variables (Table 16) and two angular variables (Table 17). For the distance variables, the largest random error was associated with variable Me - Go(r) and the smallest random error was associated with variable S-ANS. For the angular variables, the largest random error was related to variable Go(r) to Me to Go(l) and the smallest random error was related to variable Or(r) to Me to Or(l). All of the errors were considered to be within an acceptable range and unlikely to bias results. Reliability ranged from 80.4% to 99.6% for the distances and from 95.5% to 99.9% for the angles.

Table 16 ▪ Analysis of intra-operator systematic errors and random errors of 3D distance measurements.

Distances	$\overline{d}$	SD	$SE_{\overline{d}}$	Se	Reliability (%)
S-ANS	-0.1	0.4	0.2	0.26	99.5
ANS – Me	-0.4	0.3	0.2	0.36	99.6
Or(r) - Or(l)	-0.1	0.8	0.3	0.50	98.6
A – Or(r)	0.3	0.6	0.3	0.43	97.3
A – Or(l)	-0.4	1.0	0.5	0.71	94.0
A – Cc(r)	-0.6	0.7	0.3	0.62	97.6
A – Cc(l)	-0.3	0.4	0.2	0.32	98.7
Or(r) - U1tip	**0.8***	0.6	0.3	0.70	91.0
Or(l) - U1tip	0.1	0.7	0.3	0.44	97.5
ANS - U1tip	0.5	0.7	0.3	0.58	87.1
A - B	0.6	1.5	0.7	1.03	91.0
Me - L1tip	-0.7	1.1	0.5	0.86	92.2
L1tip - Cc(r)	-0.5	0.6	0.3	0.53	98.5
L1tip - Cc(l)	-0.2	0.4	0.2	0.28	99.5
Me - Cc(r)	0.0	0.6	0.3	0.41	99.0
Me - Cc(l)	0.3	0.9	0.4	0.57	97.7
Me - Go(r)	-0.2	2.3	1.0	1.43	80.3
Me - Go(l)	0.0	1.6	0.7	1.03	87.6
Me - Or(r)	0.4	1.0	0.4	0.69	97.8
Me - Or(l)	0.0	1.0	0.5	0.65	98.3
Cc(r) - Go(r)	0.2	1.8	0.8	1.18	82.2
Cc(l) - Go(l)	0.1	1.6	0.7	0.99	89.1
Cc(r) - Cc(l)	-0.1	1.2	0.5	0.74	95.9
Go(r) - Go(l)	**-1.4***	0.8	0.4	1.14	91.4

** Significantly different from zero at p<0.05*

Table 17 ▪ Analysis of intra-operator systematic errors and random errors of 3D angular measurements.

Angles	$\bar{d}$	SD	$SE_{\bar{d}}$	Se	Reliability (%)
SNA	-0.4	0.6	0.3	0.49	98.0
SNB	-0.3	0.7	0.3	0.51	97.8
ANB	0.2	0.6	0.3	0.40	95.9
ANS-PNS to SN	**0.5***	0.4	0.2	0.42	97.3
SN to FH(r)	0.2	0.6	0.3	0.43	97.4
SN to FH(l)	0.0	0.7	0.3	0.45	96.5
ANS-PNS to FH(r)	0.7	0.6	0.3	0.65	95.5
ANS-PNS to FH(l)	0.5	0.4	0.2	0.42	97.5
A to Or(r) to Po(r)	1.3	1.0	0.5	1.12	95.9
A to Or(l) to Po(l)	0.6	1.0	0.4	0.75	98.6
U1 to SN	-0.4	1.5	0.7	1.01	96.9
U1 to FH(r)	-0.2	1.1	0.5	0.72	97.9
U1 to FH(l)	-0.5	1.1	0.5	0.74	97.5
U1 to ANS-PNS	-0.9	1.4	0.6	1.09	96.3
U1 to L1	-0.4	1.4	0.6	0.91	98.4
L1 to SN	0.0	1.3	0.6	0.85	98.6
L1 to FH(r)	0.2	1.0	0.4	0.64	99.0
L1 to FH(l)	-0.1	1.5	0.7	0.94	97.9
L1 to Me-Go(r)	0.2	0.7	0.3	0.45	98.9
L1 to Me-Go(l)	0.4	0.9	0.4	0.60	98.4
Me to Go(r) to Cc(r)	-0.2	0.9	0.4	0.61	98.6
Me to Go(l) to Cc(l)	**-0.9***	0.6	0.2	0.74	97.8
Me-Go(r) to FH(r)	0.0	0.9	0.4	0.59	98.4
Me-Go(l) to FH(l)	-0.4	1.1	0.5	0.77	97.7
Me-Go(r) to SN	-0.2	0.9	0.4	0.62	98.8
Me-Go(l) to SN	-0.4	0.8	0.3	0.57	99.0
Or(r) to A to Or(l)	-0.3	1.0	0.4	0.68	99.1
Cc(r) to A to Cc(l)	0.3	0.8	0.3	0.53	99.8
Or(r) to U1tip to Or(l)	-0.7	1.2	0.5	0.90	97.1
Or(r) to Me to Or(l)	-0.2	0.5	0.2	0.35	99.2
Cc(r) to L1tip to Cc(l)	-0.3	1.3	0.6	0.87	97.9
Cc(r) to Me to Cc(l)	0.1	0.6	0.3	0.38	99.4
Go(r) to Me to Go(l)	-0.8	2.4	1.1	1.60	96.8

** Significantly different from zero at $p<0.05$*

➢ *Inter-operator variations*

A set of good quality cephalograms was selected for a study of inter-operator variations. Both operators had the same understanding of the rules for digitisation (Table 13) and had practised using the same program together for three weeks. The cephalograms were digitised four times by each operator independently and measurements from the last digitisation episode were compared.

Paired t-tests did not reveal any significant differences between the two sets of distance (Table 18) and angular measurements (Table 19), although inter-operator differences were generally greater than intra-operator differences. There were two distance variables and five angular variables for which the differences were larger than 5 mm or 5 degrees. Landmarks commonly associated with large discrepancies were A point, condylar centre (Cc) and Gonion (Go).

Table 18 ▪ Comparison of distance measurements (mm) between two operators.

Distances	Operator 1	Operator 2	differences
S - ANS	77.2	78.4	-1.2
ANS – Me	70.0	68.8	1.2
Or(r) - Or(l)	65.3	65.5	-0.2
A – Or(r)	39.7	44.4	-4.8
A – Or(l)	46.7	47.8	-1.1
A – Cc(r)	92.0	93.6	-1.6
A – Cc(l)	90.8	92.8	-2.0
Or(r) - U1tip	59.8	59.7	0.1
Or(l) - U1tip	63.9	62.5	1.4
ANS - U1tip	24.4	20.3	4.2
A - B	42.7	37.5	5.2
Me - L1tip	42.5	40.3	2.2
L1tip - Cc(r)	100.7	97.2	3.5
L1tip - Cc(l)	98.2	95.7	2.5
Me - Cc(r)	115.9	112.4	3.5
Me - Cc(l)	113.2	111.2	2.0
Me - Go(r)	81.7	77.7	3.9
Me - Go(l)	78.8	77.5	1.4
Me - Or(r)	92.7	90.6	2.1
Me - Or(l)	94.5	91.1	3.4
Cc(r) - Go(r)	48.4	47.1	1.3
Cc(l) - Go(l)	49.4	48.6	0.8
Cc(r) - Cc(l)	93.4	88.8	4.6
Go(r) - Go(l)	87.2	77.4	9.9

Table 19 ▪ Comparison of angular measurements (degrees) between two operators.

Angles	Operator 1	Operator 2	differences
SNA	73.3	77.3	-4.0
SNB	72.2	71.0	1.2
ANB	-1.2	-6.4	5.2
ANS-PNS to SN	10.5	9.0	1.6
SN to FH(r)	-16.6	-16.2	-0.5
SN to FH(l)	-16.7	-16.2	-0.5
ANS-PNS to FH(r)	-6.1	-7.2	1.1
ANS-PNS to FH(l)	-6.2	-7.2	1.0
A to Or(r) to Po(r)	58.5	55.4	3.1
A to Or(l) to Po(l)	64.1	57.0	7.1
U1 to SN	81.8	82.4	-0.6
U1 to FH(r)	65.2	66.3	-1.1
U1 to FH(l)	65.1	66.3	-1.1
U1 to ANS-PNS	71.3	73.4	-2.2
U1 to L1	-48.5	-47.9	-0.7
L1 to SN	-49.6	-49.7	0.1
L1 to FH(r)	-66.3	-65.9	-0.4
L1 to FH(l)	-66.3	-65.9	-0.5
L1 to Me-Go(r)	86.1	88.9	-2.8
L1 to Me-Go(l)	86.9	88.5	-1.6
Me to Go(r) to Cc(r)	-51.6	-53.5	1.9
Me to Go(l) to Cc(l)	-53.1	-54.5	1.5
Me-Go(r) to FH(r)	27.6	25.3	2.4
Me-Go(l) to FH(l)	26.7	25.6	1.1
Me-Go(r) to SN	44.2	41.4	2.8
Me-Go(l) to SN	43.4	41.8	1.7
Or(r) to A to Or(l)	-77.4	-83.9	6.6
Cc(r) to A to Cc(l)	-52.2	-67.9	15.7
Or(r) to U1tip to Or(l)	66.9	66.7	0.1
Or(r) to Me to Or(l)	40.8	42.3	-1.5
Cc(r) to L1tip to Cc(l)	87.8	86.3	1.5
Cc(r) to Me to Cc(l)	57.6	55.1	2.5
Go(r) to Me to Go(l)	-79.4	-88.6	9.1

3.7 Statistical Analysis

Tests of normality were performed using the estimation of skewness and kurtosis. Means and standard deviations were used to describe parametric variables, such as, chronological age, age of dental emergence, height, weight, overbite, overjet, jaw movement distances, protrusive force, fatigue time, MRI and cephalometric measurements. Median values were used to describe skeletal maturity index (SMI; Fishman, 1982). F-tests were used to compare the variances of parametric variables between groups. Student's t-tests were used to assess the differences of the parametric variables between control and experimental groups; and between males and females. When significant differences in variances were found, modified t-tests were used. Paired t-tests were used to assess differences in parametric variables between the pre-treatment and 6-month records. One-way analysis of variance (ANOVA) was performed when comparing disc positions among the three categories of condylar positions.

Comparisons of the frequency of non-parametric variables, such as, severity of class II, SMI, condylar axial shapes, condylar coronal shape, condylar concentricity, coronal disc position between control and CTB groups were made using chi-square tests.

Pearson's product-moment correlation coefficient was used to quantify the strength of the relationships between parametric variables, such as: age and protrusive force; age and fatigue time; protrusive force and stature; age and eminence angle; age and condylar coronal width.

Statistical significance was reported at the 0.05 (*), 0.01(**) and 0.001(***) probability levels.

3.8 Ethical considerations

All procedures in this research project were conducted in accordance with the NHMRC statement on Human Experimentation and Supplementary Notes. All children together with their parents or guardians were provided with an information sheet (Appendix 3) and clear verbal explanations in lay terms concerning the purpose and the procedures of the experiment. The consent forms were signed by the children and their parents or guardian (Appendix 1, 2). The children were free to withdraw consent to further participation at any time.

All clinical procedures used in this research were the same as conventional orthodontic treatment except for the use of MRIs and muscle tests. However, the extra muscle test and Magnetic Resonance Image (MRI) were not harmful to the children. The muscle test was not demanding and was tolerated well by most children. The MRI technique was non-invasive in nature and has no known associated risk. The children were free to refuse to participate in any of these procedures.

The research project was approved by The University of Adelaide, Committee on the Ethics of Human Experimentation (Appendix 13) and the South Australian Dental Service Board of Directors (Appendix 14). Radiation doses were evaluated by the Physics and Radiation Safety Section, Royal Adelaide Hospital (Appendix 15).

Chapter 4 RESULTS

Topics:

Introduction

The clinical findings and assessments of growth and development were derived from records obtained at the beginning of the investigation. Other analyses were based on the following:

1. **R1 - Control & CTB combined:** The data from the **initial records (R1)** of both the control and CTB groups were combined to provide a cross-sectional analysis of the characteristics of a group of Australian children displaying Class II division 1 malocclusions. Relationships of study variables with genders and developmental indicators were also investigated using **R1 - Control & CTB combined** data.

2. **R1-Control *vs.* CTB:** Data from the initial records (R1) of the control and CTB groups were also analysed separately. Unpaired t-tests were used to analyse whether there were any significant differences between the two groups at the beginning of the study.

3. **R1 *vs.* R2:** Data from the initial records (R1) were compared to the data obtained six months later (R2). This enabled a longitudinal analysis of changes in the features investigated over the study period. Changes in the control group represented the outcome of growth, while changes in the CTB group resulted from growth together with the effects of the Twin Block appliance. Paired t-tests were used to determine whether the changes in each group were statistically significant.

    - **Control group** refers to the group of children who received no treatment during the investigation period.

    - **CTB group** refers to the group of children who were treated with Twin Block appliances during the investigation period.

    - **R1** refers to the data collected from the initial records at the beginning of the investigation.

    - **R2** refers to the data collected from the 6-month records at the end of the investigation.

4.1 Clinical Examination

➢ *History of facial trauma*

The children studied had a high prevalence of facial trauma with 42% demonstrating a positive history. Of these, 73% involved the fracture of one or more upper anterior teeth. Although some of the children had scars on the forehead, nose or lower lip, none of the children had broken facial bones. The distribution of facial trauma according to groups studied is shown in Table 20.

Table 20 ▪ Prevalence of children with history of facial trauma

	Prevalence (person)
Control/females (n = 12)	4 (3 involved teeth)
Control/males (n = 25)	10 (9 involved teeth)
CTB/females (n = 15)	4 (2 involved teeth)
CTB/males (n = 19)	12 (8 involved teeth)
Total (n = 71)	30 (22 involved teeth)

➢ *Stage of dental development*

The dentition was classified into early mixed dentition, late mixed dentition and permanent dentition. The early mixed dentition stage referred to the stage when all primary molars and primary canines were present; the late mixed dentition stage referred to the stage when only some primary molars and primary canines were present; the permanent dentition stage referred to the stage when none of the primary teeth were present. Most of the children in the control group were in the late mixed dentition stage while more of the children in the CTB group had all their permanent teeth. The stage of dental development in each group is shown in Table 21.

Table 21 ▪ Stages of dental development in the study groups	Early mixed dentition	Late mixed dentition	Permanent dentition
Control/females (n = 12)	5	6	1
Control/males (n = 25)	12	12	1
CTB/females (n = 15)	2	6	7
CTB/males (n = 19)	7	4	8
Total (n = 71)	26	28	17

➢ *Severity of Class II malocclusion*

The severity of malocclusion in the sagittal plane was evaluated by molar relationship, canine relationship and incisal overjet. Although the molar relationships were similar between the control and CTB groups, the children in the CTB group demonstrated more severe Class II malocclusions, with more cases of Class II full unit canine relationships and larger overjets. The overbite was also deeper on average in the CTB group. The boys in the CTB group had the most severe degree of Class II malocclusion. Chi-square analysis did not demonstrate any significant differences in molar and canine relationships among the four groups of children ($\chi^2 = 0.29$, df = 3). Although t-tests failed to disclose any significant differences in overbite and overjet between girls in the control and CTB groups, overbite and overjet of the boys in the CTB group were significantly greater than those of boys in the control group ($p<0.05$).

Table 22 ▪ Severity of Class II malocclusions between groups	CTB/Female	Control/Female	CTB/Male	Control/Male
Molar full unit (%)	53	50	63	52
Canine full unit (%)	27	25	32	24
Mean overjet ± SD (mm)	8.9 ± 2.1	8.9 ± 1.9	**10.6* ± 2.0**	**8.9 ± 2.4**
Mean overbite ± SD (mm)	4.0 ± 1.6	4.0 ± 2.0	**6.2* ± 1.7**	**4.7 ± 1.9**

** Mean value for CTB/male differed significantly from mean value for control/male at p<0.05.*

Class II subdivision malocclusions were found in two girls and three boys in the control group but none of the children in the CTB group had Class II subdivision malocclusions.

➢ *Other abnormalities*

Apart from Class II malocclusion, other dental anomalies included congenitally missing teeth, microdontia, taurodontism, posterior crossbite and anterior openbite (Table 23). Two boys in the control group who had skeletal posterior crossbite were treated with a slow maxillary expansion appliance while for two girls in the CTB group a midpalatal screw was incorporated in the design of the Twin Block appliance. Slow maxillary expansion was also performed during the observation period.

Table 23 ▪ Distribution of dental anomalies

CTB group	**Female (person)**	**Male (person)**
Congenitally missing	1 (tooth number 35)	2 (tooth number 15, 35, 45)
Microdontia	1 (tooth number 12, 22)	none
Taurodontia	none	1 (tooth number 37,47)
Posterior crossbite	4 (2 skeletal, 2 dental)	5 (dental)
Openbite	none	None

Control group	**Female (person)**	**Male (person)**
Congenitally missing	1 (tooth number 35, 45)	2 (tooth number 45, 25)
Microdontia	1 (tooth number 12, 22)	2 (tooth number 12, 22, 31, 41)
Posterior crossbite	3 (dental)	5 (3 skeletal, 2 dental)
Openbite	1 (1.5 mm)	none

Two boys in the CTB group were diagnosed with Attention Deficit Disorders (ADD). These boys had difficulty keeping still during the MRI scanning. However, this did not affect their co-operation during the study period and results of treatment with the Twin Block were excellent for both boys. Another boy in the CTB group had mild speech and learning problems. His treatment result was poor with minimal correction of overbite, overjet, or molar and canine relationships.

4.2 Growth and Development Analysis

➢ *Chronological age*

Chronological ages of the children in the CTB group ranged from 8.4 to 14.2 years while the ages of the children in the control group ranged from 9.2 to 13.5 years. Mean chronological age of children in the CTB group was slightly greater than in the control group and this trend was also found when male and female subgroups were compared (Table 24). However, t-tests did not demonstrate any significant differences in mean ages between the CTB and control groups, or between male and female subgroups.

Table 24 ▪ Average chronological age (years) in the study groups.

	Age (mean ± SD)
Control/females (n = 12)	10.8 ± 0.8
Control/males (n = 25)	10.7 ± 1.0
CTB/females (n = 15)	11.1 ± 1.0
CTB/males (n = 19)	11.2 ± 1.4
Control/males & females (n= 37)	10.7 ± 1.0
CTB/males & females (n = 34)	11.2 ± 1.2

➢ *Dental emergence age*

Dental emergence ages of the children in the CTB group ranged from 8.2 to 13.5 years while those of the children in the control group ranged from 8.2 to 12.3 years. Although the ranges for the CTB and the control groups were similar, t-tests revealed that the mean dental emergence age of the children in the CTB group was significantly greater than that of the control group ($p < 0.01$). Although the mean dental emergence age of the girls in the CTB group was also significantly greater than that of the control group ($p < 0.05$), the mean values for males did not differ significantly.

Table 25 ▪ Pre-treatment means of dental emergence age (years).

	Age (mean ± SD)
Control/females (n = 12)	**9.8 ± 1.4**
Control/males (n = 25)	10.2 ± 1.2
CTB/females (n = 15)	**11.0* ± 1.2**
CTB/males (n = 19)	10.9 ± 1.9
Control/males & females (n= 37)	**10.0 ± 1.2**
CTB/males & females (n = 34)	**10.9** ± 1.6**

**Mean value for CTB/females differed significantly from mean value for control/females at p<0.05.*
***Mean value for CTB/males and females differed significantly from mean value for control/males and females at p<0.01.*

➢ ***Stature (height and weight)***

Pre-treatment heights (Figure 67) and weights (Figure 68) of the children were plotted against National Health and Medical Research Council (NHMRC) standard curves for Australian children. The height and weight of all the girls in control and CTB groups were above the 10th percentile while 5% of the boys were below the 10th percentile for height and weight. Caution needs to be exercised in using these growth standards given that they were generated in 1960s. It is likely that secular trends in height and weight have occurred during the past 30 years.

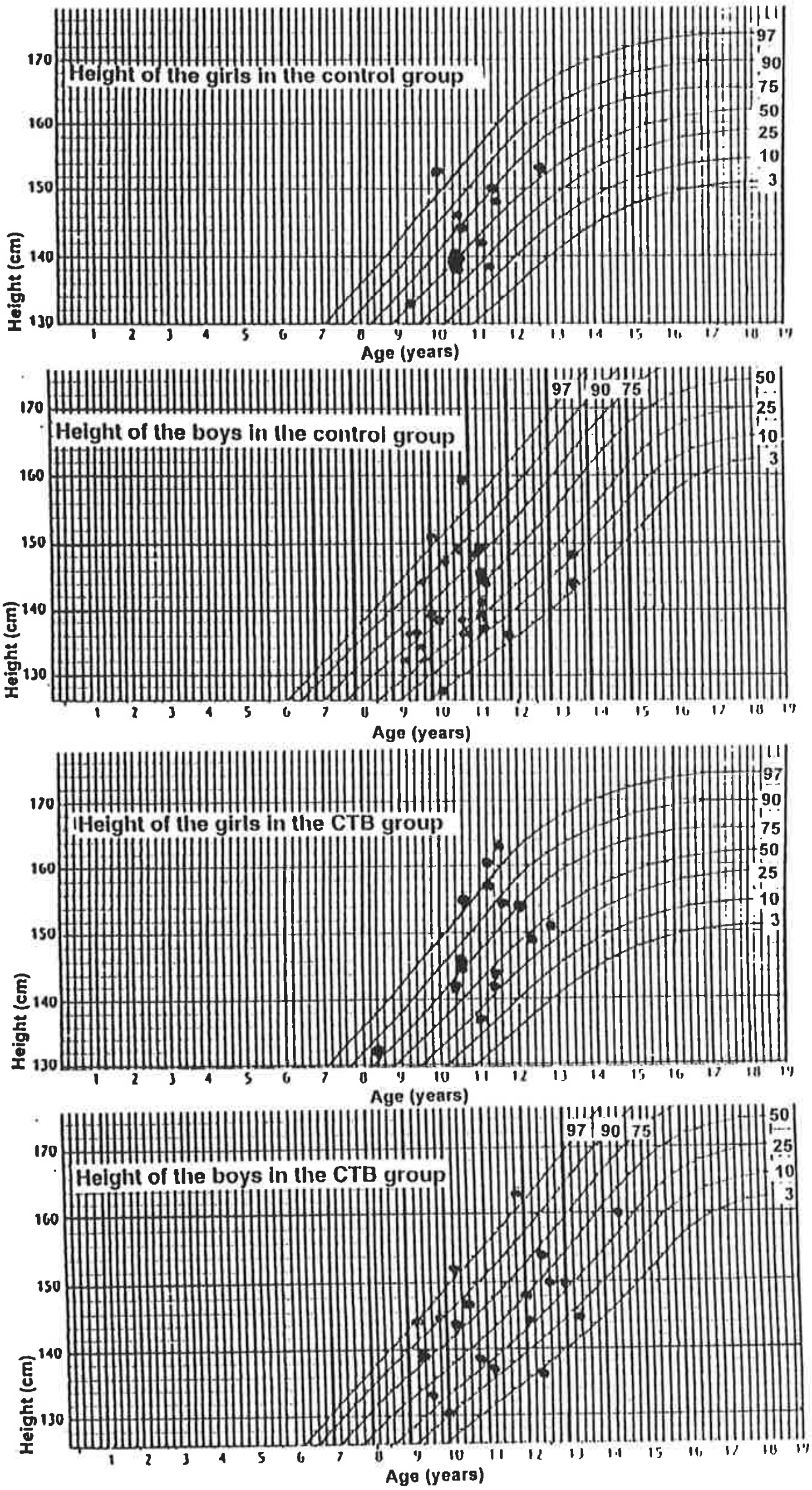


Figure 67 ▪ Heights of boys and girls in the study plotted against standard curves for Australian children

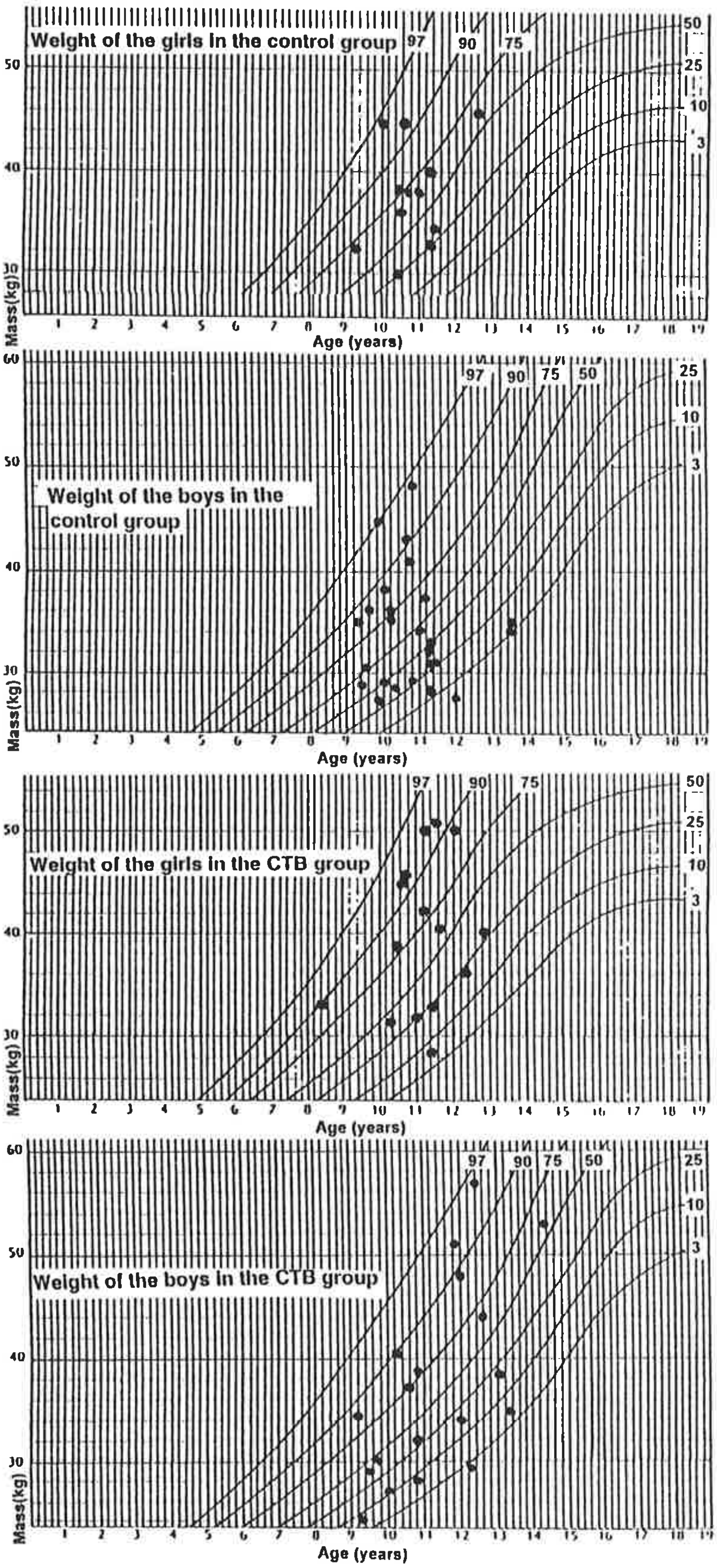


Figure 68 ▪ Weights of boys and girls in the study plotted against standard curves for Australian children

The mean heights and weights of children in the CTB group (combined boys and girls) were significantly greater than those for the control group (Table 26, $p<0.05$). Although a similar trend was also found when comparisons were made for boys and girls separately, it did not reach significant levels.

Table 26 ▪ Pre-treatment mean height (cm) and weight (kg).

	Height (mean ± SD)	Weight (mean ± SD)
Control/females (n = 12)	143.6 ± 6.4	38.2 ± 5.3
Control/males (n = 25)	141.2 ± 7.3	34.3 ± 5.7
CTB/females (n = 15)	148.8 ± 8.8	40.0 ± 7.5
CTB/males (n = 19)	145.3 ± 8.5	37.5 ± 9.5
Control/males & females (n= 37)	**142.0 ± 7.0**	**35.5 ± 5.8**
CTB/males & females (n = 34)	**146.9* ± 8.7**	**38.6* ± 8.6**

**Mean value for CTB/males and females differed significantly from mean value for control/males and females at $p<0.05$.*

The mean incremental growth over the 6-month period (expressed as units/year) of the children in the CTB group was 8.2 ± 3.6 cm/year for height and 6.8 ± 4.8 kg/year for weight. The mean rates of growth of children in the control group were 8.0 ± 3.6 cm/year for height and 8.0 ± 5.0 kg/year for weight (Table 27). No significant differences were found in the average rates of growth between children in CTB and control groups or between male and female subgroups.

Table 27 ▪ Mean changes of height (cm/year) and weight (kg/year) between pre-treatment and 6-month records.

	Height (mean ± SD)	Weight (mean ± SD)
Control/females	8.2 ± 4.0	8.2 ± 3.8
Control/males	7.8 ± 3.6	8.0 ± 5.6
CTB/females	8.4 ± 3.4	7.2 ± 5.8
CTB/males	8.2 ± 3.6	6.6 ± 4.0
Control/males & females	8.0 ± 3.6	8.0 ± 5.0
CTB/males & females	8.2 ± 3.6	6.8 ± 4.8

➢ *Skeletal maturity indicator (SMI)*

SMI values of the children in the CTB group ranged from SMI-1 to SMI-7 while those of the children in the control group ranged from SMI-1 to SMI-6 (Table 28). The median of the SMI was similar in control and CTB groups, being 2 in control and 2.5 in the CTB group. It appeared that more of the males were in the lower SMI categories, however, because of the small sample size in many categories, no statistical analysis was performed.

Table 28 ▪ Distribution of children according to Skeletal Maturity Indicator (SMI)

	SMI							
	1	2	3	4	5	6	7	median
Control/females	0	1	5	1	1	4	0	3.5
Control/males	15	5	3	1	1	0	0	1
CTB/females	1	2	1	0	3	4	4	6
CTB/males	6	8	3	1	0	0	1	2
Control/males & females	15	6	8	2	2	4	0	2
CTB/males & females	7	19	4	1	3	4	5	2.5

➢ *Relationship among growth and development indicators*

Correlation analysis showed that the rate of growth in height correlated poorly with SMI values for females (r = 0.09) and males (r = 0.38), and for females and males combined (r = 0.13).

The correlation coefficients between SMI values and dental emergence age; SMI values and chronological age; and dental emergence age and chronological age are shown in Table 29. The correlations were significant and indicated moderate strengths of relationships. The strongest associations were between SMI values and dental emergence age for females (r = 0.61) and between dental emergence age and chronological age for males (r = 0.66).

Table 29 ▪ Correlation coefficients between growth and development indicators in males and females

Relationship	female	male
SMI and dental emergence age	r = 0.61***	r = 0.57***
SMI and chronological age	r = 0.41*	r = 0.55***
Dental emergence age and chronological age	r = 0.47*	r = 0.66***

** p<0.05, **p<0.01, ***p<0.001*

4.3 Clinical Results

➢ ***Change of overbite and overjet (R1* vs. *R2)***

Control group: The initial (R1) mean **overbite** of the control group was 4.4 ± 1.9 mm and the mean overbite at the 6-month follow-up (R2) was 5.9 ± 1.9 mm. The mean increase was 1.5 ± 1.5 mm (paired t-test, p<0.001) and reflected increases in the majority of the children. Only approximately 25% of the children displayed no change or a reduction in overbite at R2 compared with R1 (Table 30).

Mean **overjet** of the children in the control group at R1 was 8.9 ± 2.2 mm compared with 8.1 ± 1.9 mm at R2. Although the magnitude of change was small in clinical terms, a paired t-test revealed that the reduction in overjet was statistically significant (p<0.001). Spontaneous reduction of overjet occurred in the majority of children. Some children displayed no change in overjet while only a few displayed an increase.

Table 30 ▪ Changes of overbite and overjet in the control group

	Overbite	Overjet
Reduction (% of cases)	8.1	54.0
No change (% of cases)	16.2	37.8
Increase (% of cases)	75.7	8.1
Mean change (mm)	1.5 ± 1.5	-0.8 ± 1.2

CTB group: Mean **overbite** of the children in the CTB group was 5.2 ± 2.0 mm at R1 and 2.8 ± 1.6 mm at R2. The mean reduction in the overbite was 2.3 ± 1.6 mm (paired t-test, p < 0.001).

A significant reduction in **overjet** was also found ($p<0.001$). The average overjet was 9.9 ± 2.2 mm at R1 and 3.5 ± 2.2 mm at R2. The mean overjet reduction was 6.2 ± 2.4 mm.

A range of one standard deviation was used to provide an indication of whether treatment could be considered to be successful or not. Therefore, those children with overjet reductions of less than 3.8 mm (more than one standard deviation below the mean) could be considered to be treatment failures, according to this criterion. Five children fell into this category, four being in the permanent dentition stage of development. The percentage reductions in overjet of these children were all less than 35% (Table 31) while for the rest of the children they were more than 40%. All of the five children had problems wearing the appliance full-time, especially during eating. Over all, the rate of success of treatment with the CTB in this study was estimated to be around 85%.

Table 31 ▪ Changes of overjet in failure cases.

Patient ID	Overjet at R1 (mm)	Overjet at R2 (mm)	% reduction
B.R. / male	13	11.5	13.0
L.H. / female	9.4	8.2	14.6
H.D. / male	10.6	8.3	27.7
A.H. / male	14.5	11	31.8
J.R. / male	12	9	33.3

➢ *Mandibular movements*

Mandibular movements investigated included maximum movements during opening, protrusion, retrusion, and lateral excursions.

❖ R1 - control *vs.* CTB:

Mandibular movements of the children in the control and the CTB groups are shown in Table 32. Unpaired t-tests revealed that the children in the control group could perform greater protrusive movements, on average, than those in the CTB group ($p<0.05$). Only 10.8 % of the children in the control group could not protrude their mandibles beyond the edge-to-edge position, while 32.3 % of the children in the CTB group were unable to achieve this movement.

Table 32 ▪ Pre-treatment maximum jaw movements (mm).

Maximum jaw movement	**CTB** (n=34) (mean ± SD)	**Control** (n=37) (mean ± SD)
Opening	45.3 ± 6.2	43.1 ± 4.6
Protrusion (past edge-to-edge)	**0.0* ± 2.1**	**1.2 ± 2.0**
Retrusion	0.2 ± 0.6	0.4 ± 0.6
Right lateral	9.5 ± 2.4	9.5 ± 2.4
Left lateral	9.8 ± 2.4	10.1 ± 2.6

**Mean value for CTB differed significantly from mean value for control at p<0.05.*

❖ R1 *vs.* R2

For the control group, the only significant change in jaw movements between R1 and R2 was an increase in the average amount of protrusive movement past edge-to-edge position ($p < 0.05$). The mean change was 0.6 ± 1.4 mm.

For the CTB group, highly significant increases in all types of jaw movement were noted (Table 33, $p < 0.001$). The most clinically obvious result was that all of the children in this group were able to protrude their mandibles more than 2 mm beyond the edge-to-edge position.

Table 33 ▪ Change in jaw movements of children treated with CTB for 6 months.

Type of movement	**Changes (mm)** mean ± SD
Maximum opening	6.6*** ± 2.4
Maximum protrusion (past edge-to-edge)	5.1*** ± 2.8
Maximum retrusion	0.1*** ± 0.7
Maximum right lateral excursion	1.1*** ± 2.5
Maximum left lateral excursion	0.8*** ± 2.7

**** p<0.001, n = 34*

4.4 Muscle Testing

➢ Maximum protrusive force

❖ R1 - control & CTB combined:

Maximum protrusive force in this group of children displaying Class II division 1 malocclusion showed a wide variation, as indicated by large standard deviations (Table 34). Tests of normality revealed slight positive skewness where a few children performed with a high magnitude of force. Maximum protrusive force ranged from 18.5 N to 160 N with a mean force of 80.3 ± 30.7 N. Student's t-test revealed that the maximum protrusive force in males was significantly higher than that in females ($p < 0.001$, Figure 69).

Table 34 ▪ Maximum protrusive force at R1

	Maximum protrusive force (N)	
	Range	**Mean ± SD**
Females (n = 25)	18.5 - 143.3	**65.0 ± 26.4**
Males (n = 41)	36.4 - 160.0	**89.6*** ± 29.7**
Males & females (n = 66)	18.5 - 160.0	80.3 ± 30.7

****Mean value for males differed significantly from mean value for females at p<0.001.*

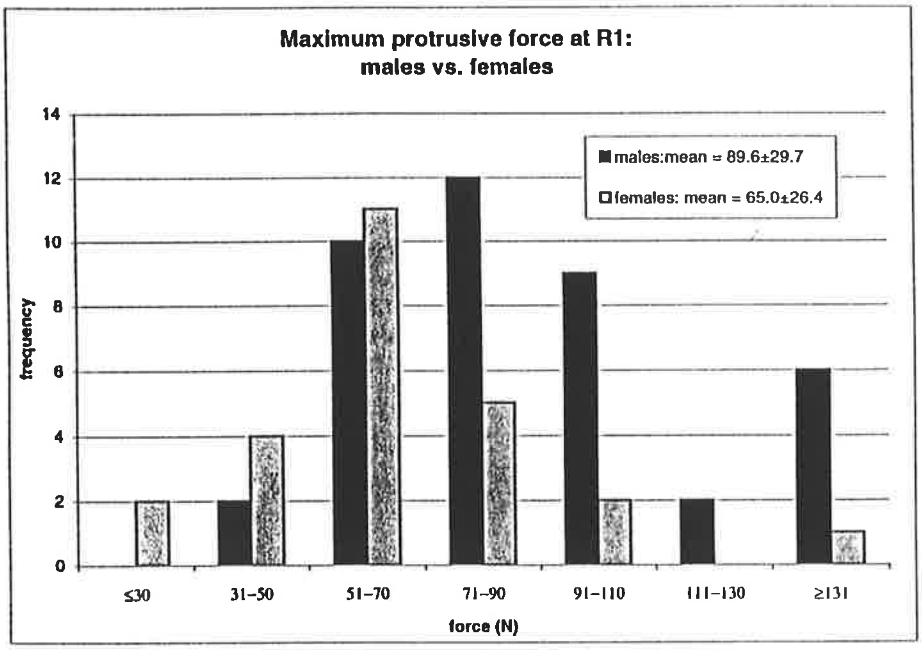


Figure 69 ▪ Distribution of maximum protrusive force in males and females (t-test: p<0.001)

❖ R1 - control *vs.* CTB

There was a tendency for the mean maximum protrusive force for both males and females in the CTB group to exceed those in the control group. However, no significant differences were found when comparing maximum protrusive force between children in the CTB and control groups for males, females and male-female combined (Table 35).

Table 35 ▪ Comparison of maximum protrusive force (N) in control and CTB groups at R1

	Mean ± SD
Control/females (n = 11)	58.4 ± 18.2
Control/males (n = 23)	87.1 ± 25.3
Control/total (n = 34)	74.4 ± 23.5
CTB/females (n = 14)	70.2 ± 31.0
CTB/males (n = 18)	92.8 ± 35.1
CTB/total (n = 32)	82.9 ± 34.7

❖ R1 *vs.* R2

Control group: Maximum protrusive force at R2 was significantly higher than that at R1 (p<0.001). Significant increases in average maximum protrusive force were also found within male (p<0.01) and female subgroups (p<0.01).

CTB group: Although the maximum protrusive force was also found to have increased in the CTB group, the change did not reach a statistically significant level.

Table 36 ▪ Comparison of maximum protrusive force (N) at R1 and R2 in control and CTB groups

	R1 mean ± SD	R2 mean ± SD	R2-R1 mean ± SD
Control/females (n = 11)	**58.4 ± 18.2**	**87.1 ± 32.1**	**28.7** ± 27.9**
Control/males (n = 23)	**87.1 ± 25.3**	**110.5 ± 37.9**	**23.4** ± 42.3**
Control/total (n = 34)	**77.8 ± 26.7**	**102.9 ± 37.3**	**25.1*** ± 37.9**
CTB/females (n = 14)	70.2 ± 31.0	73.5 ± 25.9	3.2 ± 20.0
CTB/males (n = 18)	92.8 ± 35.1	98.2 ± 27.0	5.4 ± 38.3
CTB/total (n = 32)	82.9 ± 34.7	87.4 ± 28.9	4.5 ± 31.2

*Paired t-test **Mean difference between R1 and R2 differed significantly from zero at p<0.01*
****Mean difference between R1 and R2 differed significantly from zero at p<0.001*

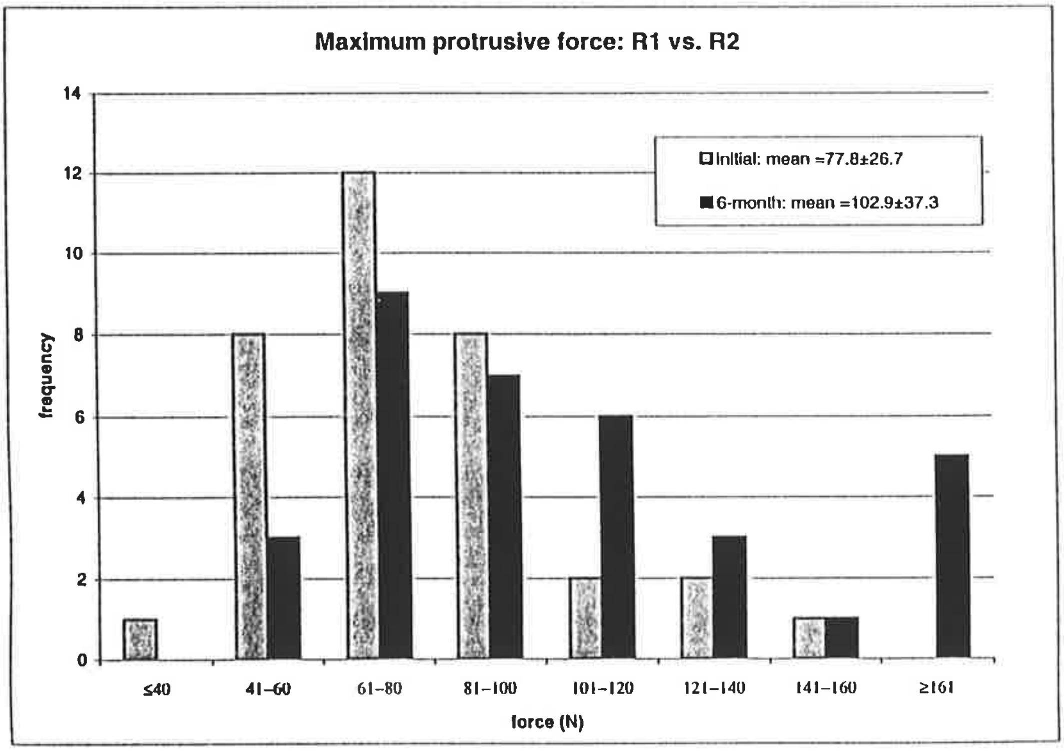


Figure 70 ▪ Comparison of maximum protrusive force (N) between R1 and R2 in the control group, male-female combined (t-test: p<0.001).

➢ *Fatigue time*

❖ R1 - control & CTB combined:

Fatigue time ranged from 17 seconds to 206 seconds with a mean of 69.1 ± 36.4 seconds (Table 37). Tests of normality also showed evidence of positive skewness for the distribution of fatigue time in the study. Although there was a tendency for the mean fatigue time in the male group to be greater than the mean in the female group, the difference was not statistically significant. The value of the correlation between the maximum protrusive force and fatigue time was low in both groups (boys: r = 0.14; girls: r = 0.10) and did not reach significance.

Table 37 ▪ Fatigue time at R1 (sec).

	Range	Mean ± SD
Females (n = 25)	22.0 - 170.0	67.6 ± 33.6
Males (n = 41)	17.0 - 206.0	70.0 ± 38.5
Males & females (n = 66)	17.0 - 206.0	69.1 ± 36.4

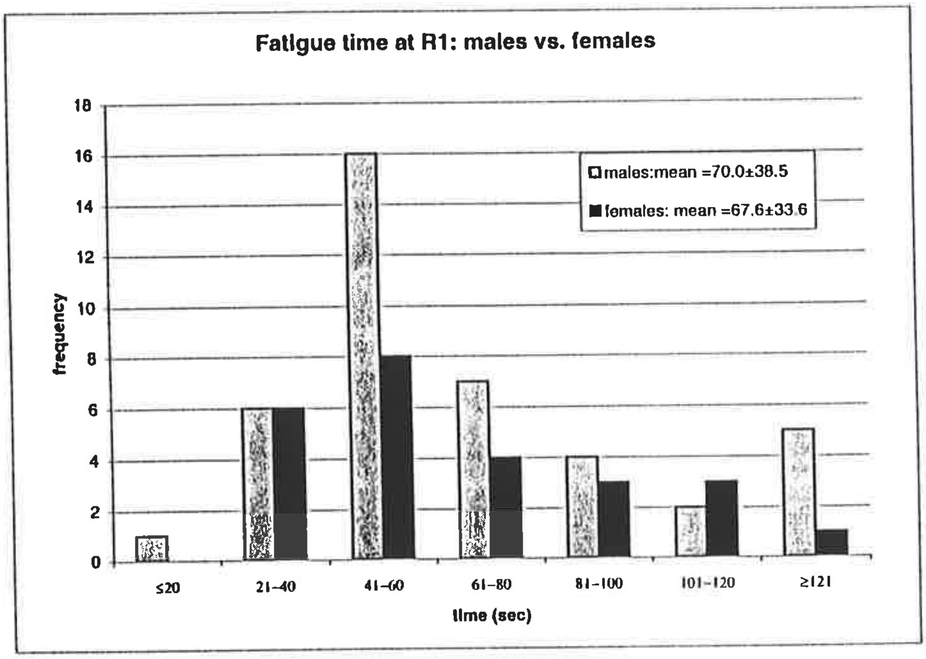


Figure 71 ▪ Distribution of fatigue time (sec) in males and females at R1 (t-test: p>0.05)

❖ R1 - control *vs.* CTB

No significant differences were found when comparing fatigue time of control and CTB groups for males, females and male-females combined.

Table 38 ▪ Comparison of fatigue time (sec) between control and CTB groups at R1.

	Mean ± SD
Control/females (n = 11)	54.2 ± 22.1
Control/males (n = 23)	72.7 ± 41.5
Control/total (n = 34)	66.7 ± 37.0
CTB/females (n = 14)	78.2 ± 37.9
CTB/males (n = 18)	66.6 ± 35.1
CTB/total (n = 32)	71.7 ± 36.2

❖ R1 *vs.* R2

Control group: A reduction in fatigue time at R2 was found in male and male-female combined subgroups, but in the female subgroup fatigue time was slightly increased at R2. However, none of these changes reached significant levels.

CTB group: Although a tendency for reduction in fatigue time between R1 and R2 was also found in all CTB subgroups, paired t-tests did not reveal any significant differences in those changes.

Table 39 ▪ Comparison of fatigue time (sec) between R1 and R2 in control and CTB groups

	R1	R2	R2-R1
	mean ± SD	mean ± SD	mean ± SD
Control/females (n = 11)	54.2 ± 22.1	56.6 ± 28.3	2.4 ± 29.1
Control/males (n = 23)	72.7 ± 41.5	62.4 ± 37.1	-8.7 ± 50.5
Control/total (n = 34)	66.7 ± 37.0	60.5 ± 34.0	-5.1 ± 44.6
CTB/females (n = 14)	78.2 ± 37.9	67.6 ± 41.4	-10.5 ± 50.4
CTB/males (n = 18)	66.6 ± 35.1	59.2 ± 24.6	-8.0 ± 39.0
CTB/total (n = 32)	71.7 ± 36.2	63.0 ± 32.9	-9.1 ± 40.6

Paired t-test, p>0.05

➢ *Mandibular position*

After the fatigue test at R1, it was possible to guide the mandible to a more retruded position in 12 of the 66 children (18.2%). These 12 children were four females (16.0%) and eight males (19.5%). The change in mandibular position was demonstrated by an increase in overjet after the fatigue test. The increase in overjet ranged from 0.5 to 3.0 mm (mean = 1.2 mm). The children in this group had overjets ≥ 7 mm. Chi-square analysis revealed no significant differences in the number of children with changed mandibular position between males and females, or between control and CTB groups.

Comparison of the number of children with altered mandibular position after the fatigue test between R1 and R2 in the control group is shown in Table 40. The number of children with altered mandibular position at R2 was lower than those at R1. The majority of the children (76%) displayed unaltered mandibular position both at R1 and R2. Only one girl showed an altered mandibular position both at R1 and R2.

Table 40 ▪ Number of children with altered mandibular position after the fatigue test in the control group.

			R1		
	Control		Unaltered n (%)	Altered n (%)	Total n (%)
R2	Unaltered	n (%)	26 (76)	5 (15)	31 (91)
	Altered	n (%)	2 (6)	1 (3)	3 (9)
	Total	n (%)	28 (82)	6 (18)	34 (100)

The number of children with altered mandibular position after the fatigue test between R1 and R2 in the CTB group showed a similar trend to the control group (Table 41). There was no evidence that CTB therapy had any effects in forward posturing of the mandible.

Table 41 ▪ Number of children with altered mandibular position after the fatigue test in the CTB group.

			R1		
	CTB		Unaltered n (%)	Altered n (%)	Total n (%)
R2	Unaltered	n (%)	22 (69)	4 (13)	26 (81)
	Altered	n (%)	4 (13)	2 (6)	6 (19)
	Total	n (%)	26 (81)	6 (19)	32 (100)

➢ *Associations between maximum protrusive force and developmental indicators*

Correlation analyses were used to assess the relationship between maximum protrusive force and developmental indicators such as chronological age, dental emergence age and SMI, based on **R1 - Control & CTB combined** data. Generally, weak negative correlations were found in girls while weak positive correlations were found in boys. The correlation coefficients reached significance (p<0.05) for the relationship between maximum protrusive force and chronological age in boys, between maximum protrusive force and SMI in girls, and for boys and girls combined (Table 42). Given the different pattern of correlations in females and males, values for both sexes combined were not computed.

Table 42 ▪ Correlation coefficients (r) between maximum protrusive force and developmental indicators

	Females	Males	Males & females
Force and dental emergence age	-0.28	0.28	0.07
Force and chronological age	-0.15	**0.37***	0.20
Force and SMI	**-0.43***	0.12	**-0.37***

**Pearson's product-moment correlation significantly different from zero at p < 0.05.*

➢ *Maximum protrusive force and body measures*

Correlation analyses were performed to evaluate the relationship between maximum protrusive force and body measures, i.e., height, weight and weight/height ratio based on **R1 - Control & CTB combined** data. The correlation coefficients were low for both sexes and did not reach significance (Table 43).

Table 43 ▪ Correlation coefficients (r) between maximum protrusive force and body measures

	Females	Males	Males & females
Force and height	-0.30	-0.01	-0.18
Force and weight	-0.34	-0.03	-0.18
Force and weight/height	-0.28	-0.03	-0.15

4.5 MRI

Forty-six children were selected by order of enrolment in the study for MRI scanning. Five children failed to provide successful MRI scannings. Because four boys failed to stay still during the time of scanning, the images were too poor to be analysed. Two of these boys were diagnosed as having attention deficit disorders. One girl refused to enter the MRI scanner because of claustrophobia. One boy withdrew from the project, so the 6-month records could not be obtained. The final sample size is shown below.

Sample size	Females	Males
Control	8	13
CTB	5	14

The average age of the CTB group was 11.7 ± 1.3 years and the average age of the control group was 11.5 ± 1.3 years. Student's t-test did not show significant differences in mean age between the groups.

4.5.1 Axial MRI

➢ ***Condylar axial shapes***

❖ **R1 - control & CTB combined:**

Axial images from one boy in the CTB group and one girl in the control group were unclear and could not be included in the analyses. MRI at R1 showed that the axial condylar head shape in the majority of the children examined was concavo-convex, followed by ellipsoid. Ovoid shapes were least common in both male and female groups (Table 44). Chi-square tests revealed no significant differences between sexes.

Table 44 ▪ Distribution of axial condylar head shape at R1

Axial shape	Males	Females	Total
	n (%)	n (%)	n (%)
Concavo-convex	11 (42)	7 (58)	18 (47)
Ellipsoid	8 (31)	4 (33)	12 (32)
Ovoid	7 (27)	1 (8)	8 (21)

❖ **R1 - control *vs.* CTB**

The distribution of condylar head shapes at R1 was similar when compared between control and CTB groups. Concavo-convex condylar shape was most common and ovoid shapes were least common (Table 45).

Table 45 ▪ Comparison of axial condylar head shape between control and CTB groups at R1.

	R1 - control	R1 - CTB
	n (%)	n (%)
Concavo-convex	9 (45)	9 (50)
Ellipsoid	6 (30)	6 (33)
Ovoid	5 (25)	3 (17)

❖ R1 *vs.* R2

Control & CTB combined: Classification of condylar head shape differed between R1 and R2 in four cases. Condylar shape of two boys in the CTB group changed from concavo-convex to ellipsoid. Condylar shape of one boy from the control group changed from ovoid to concavo-convex, and condylar shape of one girl from the control group changed from ellipsoid to ovoid shape. However, the concavo-convex shape was still the dominant type at R2, followed by ellipsoid and ovoid respectively (Table 46).

Table 46 ▪ Distribution of axial condylar head shape at R2

Axial shape	Males	Females	Total
	n (%)	n (%)	n (%)
Concavo-convex	11 (41)	8 (62)	19 (48)
Ellipsoid	10 (37)	3 (23)	13 (32)
Ovoid	6 (22)	2 (15)	8 (20)

Control *vs.* CTB: Comparing condylar shape at R2 between the control and CTB groups disclosed slight differences. For the CTB group, the number of children with concavo-convex and ellipsoid condyles was equally distributed. For the control group, the numbers of ellipsoid and ovoid types were equal but were fewer than concavo-convex shapes which represented the majority (Table 47).

Table 47 ▪ Comparison of axial condylar head shape between control and CTB groups.

	R2 - control	R2 - CTB
	n (%)	n (%)
Concavo-convex	11 (52)	8 (42)
Ellipsoid	5 (24)	8 (42)
Ovoid	5 (24)	3 (16)

Neither normal growth nor the Twin Block appliance therapy seemed to have much effect on the axial shape of the condyle. The differences appeared to depend on variability in level of the MRI slice selected.

➢ *Axial condylar angle*

❖ R1 - control & CTB combined:

At R1, the axial condylar angle relative to the midline ranged from 40° to 72° with a mean of 55.5 ± 9.0°. T-tests did not reveal any differences in mean condylar angles between males and females. Correlation analysis failed to demonstrate any significant relationship between age and axial angle for males, females, or the male-female combined group.

Table 48 ▪ Axial condylar angle relative to the midline at R1

	Range	Mean ± SD
Females (n = 13)	40° - 70°	56.3° ± 9.5°
Males (n = 27)	40° - 72°	55.2° ± 9.0°
Males & females (n = 40)	40° - 72°	55.5° ± 9.0°

❖ R1 - control *vs.* CTB

At R1, axial condylar angles were similar for both control and CTB groups. T-tests revealed no significant differences between the two groups.

Table 49 ▪ Axial condylar angle relative to the midline in CTB and control groups at R1

	Range	Mean ± SD
Control/females (n = 8)	48° - 70°	60.0° ± 8.7°
Control/males (n = 13)	40° - 73°	56.2° ± 9.6°
Control/males & females (n = 21)	40° - 73°	57.5° ± 9.2°
CTB/females (n = 5)	40° - 62°	51.0° ± 8.6°
CTB/males (n = 14)	42° - 72°	54.2° ± 8.6°
CTB/males & females (n = 19)	40° - 72°	53.3° ± 8.5°

❖ R1 *vs.* R2

Control group: Mean axial angle in the control group was found to be reduced when compared between R1 and R2. This trend was found in both males and females in the control group. However, paired t-tests did not disclose a significant difference when comparing males and females separately. When males and females were combined together, paired t-test showed that the mean value at R2 was significantly lower than that at R1 ($p<0.05$, Table 50).

CTB group: A reduction of axial angles was found in females only but the difference did not a reach significant level.

Table 50 ▪ Comparison of axial condylar angle between R1 and R2

	R1	R2	R2-R1
	Mean ± SD	Mean ± SD	Mean ± SD
Control/females (n = 8)	60.0° ± 8.7°	56.3° ± 8.3°	-6.2° ± 8.6°
Control/males (n = 13)	56.2° ± 9.6°	53.2° ± 9.5°	-3.0° ± 8.7°
Control/males & females (n = 21)	**57.5° ± 9.2°**	**54.4° ± 8.9°**	**-4.1°* ± 8.6°**
CTB/females (n = 5)	51.0° ± 8.6°	48.7° ± 11.0°	-2.3° ± 10.2°
CTB/males (n = 14)	54.2° ± 8.6°	57.0° ± 12.2°	1.7° ± 9.6°
CTB/males & females (n = 19)	53.3° ± 8.5°	54.8° ± 12.2°	0.6° ± 9.6°

*Paired t-test: *Mean difference between R1 and R2 differed significantly from zero at $p<0.05$.*

It was apparent that axial condylar angle continued to reduce with growth as demonstrated in the control group. The Twin Block therapy may have altered this direction of condylar growth axially as illustrated in the CTB group where the reduction of axial condylar angle did not reach significance.

4.5.2 Coronal MRI

➢ ***Condylar coronal shape***

❖ **R1 - control & CTB combined:**

Three types of coronal condylar shape, i.e., convex, round and flat were found, with convex being the most common type. Round and flat types were found in only a small number of males.

Table 51 ▪ Distribution of coronal condylar shape at R1.	Convex	Round	Flat
	n (%)	n (%)	n (%)
Females (n = 13)	13 (100)	0 (0)	0 (0)
Males (n = 27)	23 (85)	1 (4)	3 (11)
Males & females (n = 40)	36 (90)	1 (3)	3 (7)

❖ R1 - control *vs.* CTB

Distributions of coronal condylar shape in the control and CTB groups were similar, with the convex type being most common. Condyles with a flat appearance were only found in the control group.

Table 52 ▪ Comparison of coronal condylar shape between control and CTB at R1

	Convex	Round	Flat
	n (%)	n (%)	n (%)
Control/females (n = 8)	8 (100)	0 (0)	0 (0)
Control/males (n = 13)	10 (77)	0 (0)	3 (23)
Control/males & females (n = 21)	18 (86)	0 (0)	3 (14)
CTB/females (n = 5)	5 (100)	0 (0)	0 (0)
CTB/males (n = 14)	13 (93)	1 (7)	0 (0)
CTB/males & females (n = 19)	18 (95)	1 (5)	0 (0)

❖ R1 *vs.* R2

The frequency of condyles with round and flat shapes was greater at R2 for the control group. The distribution of condylar coronal shape in the CTB group at R2 was similar to that of R1.

Table 53 ▪ Distribution of condylar coronal shape in control and CTB group at R2	**Convex**	**Round**	**Flat**
	n (%)	n (%)	n (%)
Control/females (n = 8)	6 (75)	2 (25)	0 (0)
Control/males (n = 13)	6 (46)	3 (23)	4 (31)
Control/males & females (n = 21)	13 (62)	4 (19)	4 (19)
CTB/females (n = 5)	5 (100)	0 (0)	0 (0)
CTB/males (n = 14)	13 (93)	1 (7)	0 (0)
CTB/males & females (n = 19)	18 (95)	1 (5)	0 (0)

➢ *Coronal width*

❖ R1 - control & CTB combined:

Coronal condylar width ranged from 12.7 - 21.8 mm, with means of 17.0 ± 2.1 mm for girls and 17.4 ± 2.1 mm for boys. There was no significant difference in condylar width between boys and girls. Correlation analysis failed to disclose any significant association between age and coronal condylar width.

Table 54 ▪ Coronal condylar width (mm) at R1	**Range**	**Mean ± SD**
Females (n = 13)	12.7 - 20.0	17.0 ± 2.1
Males (n = 27)	12.7 - 21.8	17.4 ± 2.1
Males & females (n = 40)	12.7 - 21.8	17.3 ± 2.1

❖ R1 - control *vs.* CTB

No significant differences were found when comparing mean condylar widths of the children in the CTB group with those of the control group (Table 55).

Table 55 ▪ Comparison of condylar coronal width (mm) between control and CTB groups at R1	Range	Mean ± SD
Control/females (n = 8)	12.7 - 20.0	16.5 ± 2.5
Control/males (n = 13)	12.7 - 20.9	17.4 ± 1.9
Control/males & females (n = 21)	12.7 - 20.9	17.1 ± 2.1
CTB/females (n = 5)	16.4 - 19.1	17.8 ± 1.0
CTB/males (n = 14)	14.5 - 21.8	17.5 ± 2.3
CTB/males & females (n = 19)	14.5 - 21.8	17.6 ± 2.0

❖ **R1 *vs.* R2**

The change in the coronal condylar width was minimal for both the control and CTB groups. Paired t-tests showed no significant differences between R1 and R2 for both the CTB and control groups (Table 56).

Table 56 ▪ Comparison of condylar coronal width (mm) between R1 and R2

	R1	R2	R2-R1
	Mean ± SD	Mean ± SD	Mean ± SD
Control/females (n = 8)	16.5 ± 2.5	17.2 ± 3.2	0.8 ± 0.9
Control/males (n = 13)	17.4 ± 1.9	16.8 ± 2.0	-0.7 ± 1.3
Control/males & females (n = 21)	17.1 ± 2.1	16.9 ± 2.5	-0.1 ± 1.4
CTB/females (n = 5)	17.8 ± 1.0	18.0 ± 1.1	0.2 ± 0.6
CTB/males (n = 14)	17.5 ± 2.3	17.9 ± 2.4	0.5 ± 1.5
CTB/males & females (n = 19)	17.6 ± 2.0	17.9 ± 2.1	0.4 ± 1.3

➢ ***Coronal disc position***

❖ **R1 - control & CTB combined:**

Coronal disc position was expressed in tenths of the condylar width. Negative values reflected lateral positions and positive values indicated medial positions. For example, a value of -1.5 referred to a disc position with the centre of the disc 1.5 units to the lateral side. The majority of the children displayed a coronal disc position that tended to the lateral side, with a mean of -0.6 ± 1.5 units; i.e. 0.6 units to the lateral (Table 57). No statistically significant difference was found in the coronal disc position between boys and girls (χ^2 = 0.77, df = 2, p>0.05).

Table 57 ▪ Percentage of the distribution of coronal disc position at R1

	Lateral	Centre	Medial
	n (%)	n (%)	n (%)
Females (n=13)	9 (62)	1 (15)	3 (23)
Males (n=27)	16 (59)	4 (15)	7 (26)
Males & females (n=40)	25 (63)	5 (12)	10 (25)

Using one standard deviation either side of the mean to represent a normal range, three boys and two girls were classified as having lateral disc displacement and two boys were classified as having medial disc displacement. Therefore, the prevalence of lateral disc displacement was 12.5 % and the prevalence of medial disc displacement was 5.0 % in this group of children. A bulging appearance of the disc to the lateral side was disclosed in four out of the five children who had been classified as having lateral disc displacement (Figure 72). The two children classified with medial disc displacement also displayed the appearance of the disc bulging to the medial side (Figure 73).

Figure 72 ▪ Coronal disc position classified as lateral disc displacement. The disc appears to bulge toward the lateral aspect.

Figure 73 ▪ Coronal disc position classified as medial disc displacement, with the disc appearing to bulge toward the medial aspect.

❖ **R1 - control *vs.* CTB**

Chi-square tests showed no significant difference in the distribution of coronal disc position between the CTB and control groups (Table 58). However, children in the control group displayed a greater prevalence of coronal disc displacement. One boy and two girls had lateral disc displacement, while two boys had medial disc displacement. In the CTB group, only two boys had lateral disc displacement.

Table 58 ▪ The distribution of coronal disc position between the children in the control and the CTB group at R1

	Lateral	Centre	Medial
	n (%)	n (%)	n (%)
Control (n=21)	13 (62)	2 (10)	6 (29)
CTB (n=19)	12 (63)	3 (16)	4 (21)
CTB and control (n=40)	25 (63)	5 (12)	10 (25)

$\chi^2 = 0.76$, $df = 2$, $p>0.05$

❖ R1 *vs.* R2

Control group: The number of children with medial and central disc positions increased in comparison to lateral disc positions at R2. However, chi-square tests did not demonstrate any difference in the distribution of coronal disc position between R1 and R2. Using a range of one standard deviation above and below the mean as an indication of "normality", those children falling outside the range were classified as displaying disc displacement. Children who were classified as having disc displacement at R1 also displayed disc displacement at R2. However, there was one boy who was classified as having lateral disc displacement at R2 while his disc position at R1 was in the normal range. There was also evidence of disc bulging toward the lateral aspect.

CTB group: Changes in the distribution of coronal disc position were also found in the CTB group with an increasing number of children displaying medial disc position. However, chi-square tests did not demonstrate any significant difference in the distribution of coronal disc position between R1 and R2 (Table 59). All the children who were classified as having disc displacement at R1 were confirmed at R2, with the addition of one boy. His disc position at R1 was near to the threshold of being classified as a lateral disc displacement.

Table 59 ▪ The distribution of coronal disc position between the children in the control and the CTB group at R2

	Lateral	Centre	Medial
	n (%)	n (%)	n (%)
Control (n=21)	8 (38)	5 (24)	8 (38)
CTB (n=19)	9 (47)	3 (16)	7 (37)
CTB and control (n=40)	17 (43)	8 (20)	15 (37)

$\chi^2 = 0.77$, $df = 2$, $p>0.05$

An increased number of children with lateral disc displacement was found in both the control and CTB groups. There was no evidence that Twin Block therapy had any effects on coronal disc position.

4.5.3 Sagittal MRI

➢ ***Condylar sagittal concentricity***

❖ **R1 - control & CTB combined:**

Condylar concentricity was found in only 22.5% of the children investigated. Most of the condyles (50%) were in an anterior position and 27.5% were in a posterior position. The distribution of condylar positions in girls and boys was similar, with anteriorly positioned condyles being most common, and the numbers of concentric and posteriorly positioned condyles were similar. Chi-square tests revealed no significant difference in the distribution of sagittal condylar position between boys and girls (Table 60).

Table 60 ▪ The distribution of sagittal condylar positions at R1

	Anterior	Concentric	Posterior
	n (%)	n (%)	n (%)
Females (n=13)	7 (54)	3 (23)	3 (23)
Males (n=27)	13 (48)	6 (22)	8 (30)
Males & females (n=40)	20 (50)	9 (22)	11 (28)

$\chi^2 = 0.91$, $df = 2$, $p>0.05$

❖ **R1 - control *vs.* CTB**

Anterior condylar positions were most common, followed by posterior positions, then concentric respectively in the control group. Condylar positions of the CTB group were distributed evenly between anterior, concentric and posterior positions. The distribution of sagittal condylar position in the control group differed from the CTB group. However, chi-square tests failed to demonstrate significant differences in the distribution between the two groups (Table 61). It was noted that although classified in the same categories as either anterior or posterior, condylar positions might differ in the degree of displacement.

Table 61 ▪ Comparison of sagittal condylar positions between control and CTB groups at R1.

	Anterior	Concentric	Posterior
	n (%)	n (%)	n (%)
Control (n=21)	14 (67)	2 (10)	5 (23)
CTB (n=19)	6 (32)	7 (37)	6 (32)
CTB and control (n=40)	20 (50)	9 (22)	11 (28)

$\chi^2 = 0.14$, $df = 2$, $p>0.05$

❖ **R1 *vs.* R2**

Control group: The distribution of sagittal condylar position at R2 was similar to that at R1, with anteriorly positioned condyles being most frequent. Condylar positions had changed in eleven children (52%) but remained unchanged in ten children (48%). The direction of change was not uniform, with six children (29%) changing to a more posterior direction and five children (24%) changing to a more anterior position.

Table 62 ▪ Distribution of condylar positions in the control group at R1 and R2.

	Control	R1 Anterior	Concentric	Posterior	Total
	Anterior	9	1	3	13
R2	Concentric	3	1	1	5
	Posterior	2	1	0	3
	Total	14	3	4	21

CTB group: At the beginning of treatment with the Twin Block appliance, it was obvious that the condyle was positioned anteriorly, nearly to the crest of the eminence, when the CTB was in place. After treatment with the Twin Block appliance, it was interesting to observe that the condyles had apparently moved back and repositioned in their glenoid fossae while the occlusion of the treated children had changed from Class II to Class I (Figure 74).

Analysis of condylar positions revealed that the number of condyles in an anterior position increased and became the most frequent type at R2 in the CTB group. Condylar position remained unaltered in eight children (42%) but had changed in 11 children (58%). Of those children with changed condylar position, eight (73%) changed to a more anterior direction while only three (27%) changed to a more posterior direction (Table 63).

Table 63 ▪ Distribution of condylar positions in the CTB group at R1 and R2.

		R1			
	CTB	Anterior	Concentric	Posterior	Total
	Anterior	5	3	4	12
R2	Concentric	0	2	1	3
	Posterior	1	2	1	4
	Total	6	7	6	19

When failure cases were excluded, it was evident that direction of change in condylar positions was towards the more anterior categories (53%). Condylar positions in seven children (47%) remained unchanged. But none of the children changed in condylar position towards the posterior direction. Thus, more condyles were positioned anteriorly at R2 in the CTB group.

Table 64 ▪ Distribution of condylar positions in the CTB group at R1 and R2 when failure cases were excluded.

		R1			
	CTB	Anterior	Concentric	Posterior	Total
	Anterior	5	3	4	12
R2	Concentric	0	2	1	3
	Posterior	0	0	0	0
	Total	5	5	5	15

The MRI demonstrated that condylar position in the CTB group at R2 appeared to be similar to that in the control group, even though condyles in the CTB group had been positioned anteriorly to a considerable distance by the CTB at the commencement of the treatment. Although the condyles in the CTB group appeared to be seated in their fossae, the position of the condyle relative to the fossa had been changed to the more anterior direction by the Twin Block treatment, for the successful cases.

a

b

c

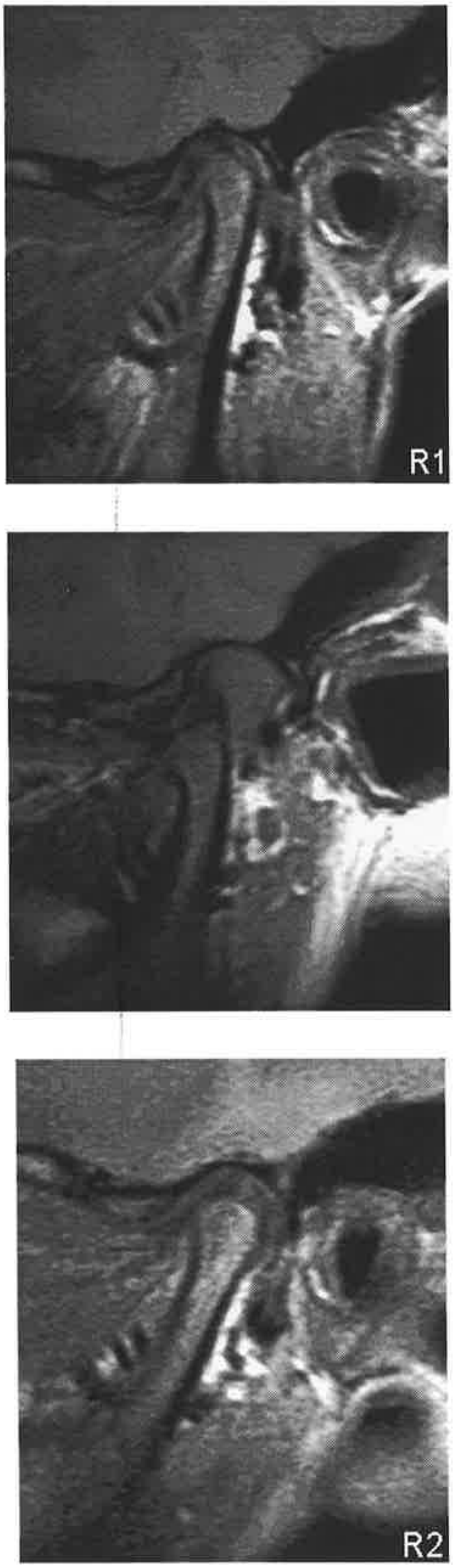


Figure 74 ▪ The position of the condyle (a) before treatment, (b) when wearing CTB and (c) after 6 months of treatment.

➢ *Sagittal eminence angle*

Eminence angle relative to PC-line

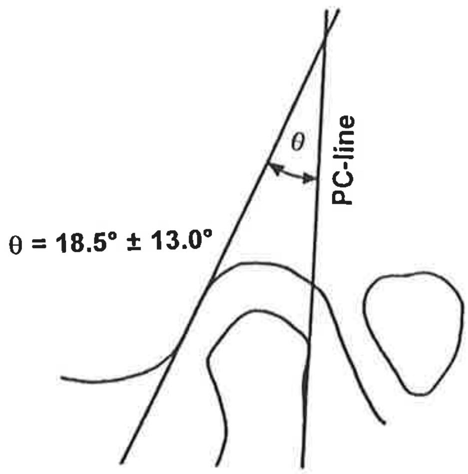


Figure 75 ▪ Articular eminence angle relative to PC-line at R1 - control & CTB combined.

❖ **R1 - control & CTB combined:**

The articular eminence angle relative to the PC-line ranged from -12.5° to 43.0° with a mean of 18.5° ± 13.0° (Table 65). Although mean eminence angle in boys (17.2° ± 12.5°) tended to be steeper than that in girls (21.2° ± 13.9°), the difference was not statistically significant. Using one standard deviation either side of the mean as an indication of a normal range, eminence angles less than 5.6° to the PC-line were classified as steep while angles more than 31.5° to the PC-line were classified as shallow. Four boys and three girls were considered to have steep eminences. Three girls and two boys were considered to have shallow eminences.

Table 65 ▪ Descriptive statistics for eminence angle relative to the PC-line at R1.

	Range	Mean ± SD
Females (n = 13)	3.0° - 43.0°	17.2° ± 12.5°
Males (n = 27)	-12.5° - 38.5°	21.2° ± 13.9°
Males & females (n = 40)	-12.5° - 43.0°	18.5° ± 13.0°

Pearson's product-moment correlation analysis was used to evaluate the relationship between the angle of the eminence to PC-line and the developmental indicators (chronological age, dental emergence age and SMI). Positive correlations were found indicating that the angle of the eminence tended to increase as age or SMI increased. However, none of the correlation coefficients reached statistical significance (Table 66).

Table 66 ▪ Correlations between eminence angle relative to PC-line and developmental indicators

	Correlation coefficient (r)
Eminence to PC-line and chronological age	0.27
Eminence to PC-line and dental emergence age	0.20
Eminence to PC-line and SMI	0.20

❖ **R1 - control *vs.* CTB**

Although the mean eminence angle relative to the PC-line in the CTB group tended to be steeper than that of the control group, t-tests revealed no significant difference (Table 67).

Table 67 ▪ Comparison of the mean eminence angles relative to the PC-line in the control and the CTB groups at R1.

	Control	CTB
Females (n = 13)	23.1° ± 15.6°	18.2° ± 11.7°
Males (n = 27)	17.0° ± 12.4°	17.3° ± 13.2°
Males & females (n = 40)	19.4° ± 13.6°	17.6° ± 12.5°

❖ **R1 *vs.* R2**

Control group: There were trends for mean eminence angle at R2 to be reduced in males, females and male-female combined groups. However, paired t-tests demonstrated no significant difference in mean values between R1 and R2.

CTB group: The changes in eminence angles in the CTB group were not uniform as the angle increased in female and male-female combined groups but reduced in the male group. Paired t-tests failed to demonstrate any significant changes in the eminence angle between R1 and R2.

Values of standard deviations were high in both control and CTB groups reflecting the considerable extent of variation in eminence angle in both groups.

Table 68 ▪ Comparison of mean eminence angles relative to the PC-line between R1 and R2.

	R1	R2	R2-R1
	Mean ± SD	Mean ± SD	Mean ± SD
Control/females (n = 8)	23.1° ± 15.6°	13.5° ± 10.2°	-9.6° ± 9.4°
Control/males (n = 13)	17.0 °± 12.4°	15.7° ± 13.0°	-1.4° ± 10.6°
Control/males & females (n = 21)	19.4 °± 13.6°	14.8° ± 11.8°	-4.5° ± 10.7°
CTB/females (n = 5)	18.2 °± 11.7°	21.9° ± 10.3°	3.7° ± 14.5°
CTB/males (n = 14)	17.3 °± 13.2°	16.8° ± 9.9°	-1.2° ± 13.2°
CTB/males & females (n = 19)	17.6° ± 12.5°	18.2° ± 10.0°	0.2° ±13.3°

Eminence angle relative to FH-line

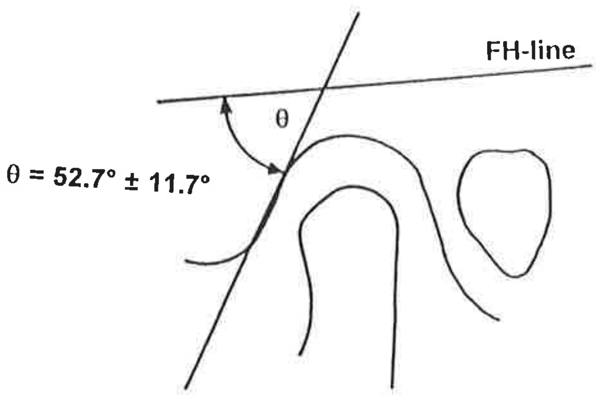


Figure 76 ▪ Articular eminence angle relative to FH-line at R1 - control & CTB combined.

❖ R1 - control & CTB combined:

The eminence angle relative to Frankfort Horizontal plane ranged from 32° to 85.5°with a mean of 52.7° ± 11.7°. The mean eminence angle in boys (53.2° ± 13.4°) was slightly steeper than in girls (51.6° ± 7.6°). The differences between boys and girls, and the variability of eminence angles were less than when the PC-line was used as a reference plane. The difference was also not statistically significant.

Based on a range of one standard deviation either side of the mean to define "normality", the normal range of the eminence angle relative to FH-plane was from 49.0° to 64.4°. Consequently, there were five children who could be considered to have shallow eminence angles and three with steep eminences. All of them were boys.

Correlation analysis was used to evaluate the relationship between the angle of the eminence relative to FH-line and chronological age, dental emergence age, and SMI. Low positive correlations were found (Table 69). The highest correlation was found between chronological age and the angle of the eminence relative to FH-line (Figure 77). However, none of the correlation coefficients reached significance.

Table 69 ▪ Correlations between eminence angle relative to FH-line and developmental indicators.

	Correlation coefficient (r)
Eminence to FH-line and chronological age	0.28
Eminence to FH-line and dental emergence age	0.21
Eminence to FH-line and SMI	0.21

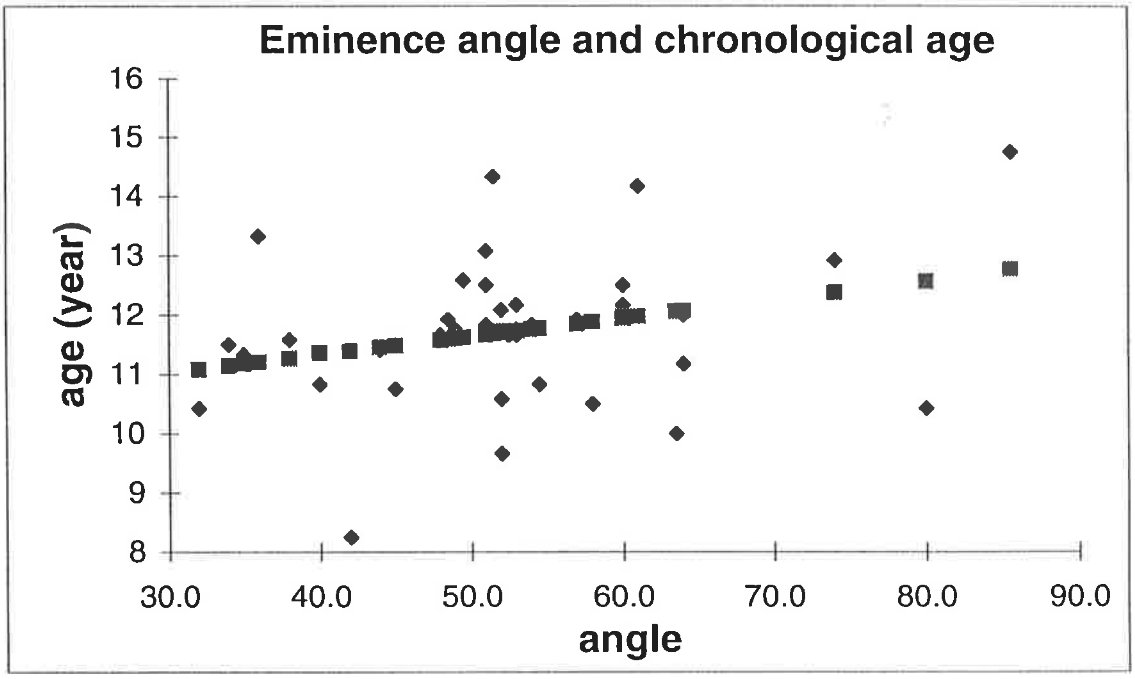


Figure 77 ▪ Relationship between eminence angle relative to FH-line and chronological age (r = 0.28, p>0.05)

❖ **R1 - control *vs.* CTB**

Mean eminence angles relative to the FH-line of the control and CTB groups were similar and t-tests revealed no significant difference between the two groups (Table 70).

Table 70 ▪ Comparison of the mean eminence angles relative to the FH-line in the control and the CTB groups at R1.

	Control	CTB
Females (n = 13)	52.3° ± 9.8°	50.7° ± 3.8°
Males (n = 27)	53.1° ± 11.6°	53.3° ± 15.6°
Males & females (n = 40)	52.8° ± 10.7°	52.6° ± 13.1°

❖ **R1 *vs.* R2**

Control group: Changes in the mean eminence angles were minimal in all subgroups and paired t-test did not reveal any significant differences between R1 and R2.

CTB group: Changes in mean eminence angles in the CTB group were also minimal and non-uniform as demonstrated by the reduction in the female and male-female combined subgroups but an increase in the male subgroup. Paired t-tests revealed no significant differences of mean eminence angle between R1 and R2.

Table 71 ▪ Comparison of mean eminence angles relative to the FH-line between R1 and R2.

	R1	R2	R2-R1
	Mean ± SD	Mean ± SD	Mean ± SD
Control/females (n = 8)	52.3° ± 9.8°	54.1° ± 8.6°	1.1° ± 11.8°
Control/males (n = 13)	53.1° ± 11.6°	53.3° ± 12.1°	0.1° ± 11.8°
Control/males & females (n = 21)	52.8° ± 10.7°	53.6° ± 10.6°	0.5° ± 11.5°
CTB/females (n = 5)	50.7° ± 3.8°	48.0° ± 6.5°	-2.1° ± 7.0°
CTB/males (n = 14)	53.3° ± 15.6°	53.5° ± 10.0°	0.5° ± 12.0°
CTB/males & females (n = 19)	52.6° ± 13.1°	52.1° ± 9.3°	-0.2° ± 10.7°

➢ ***Sagittal disc position***

One of the boys in the control group showed severe antero-lateral disc displacement and the disc could not to be seen in the selected slice in which the maximum condylar length was observed (Figure 78). The disc could only be seen in the more lateral slices of the sagittal MRI and in the coronal MRI (Figure 79). Therefore, this case was excluded from the analysis of disc position. However, it was included when determining the prevalence of disc displacement.

A

B

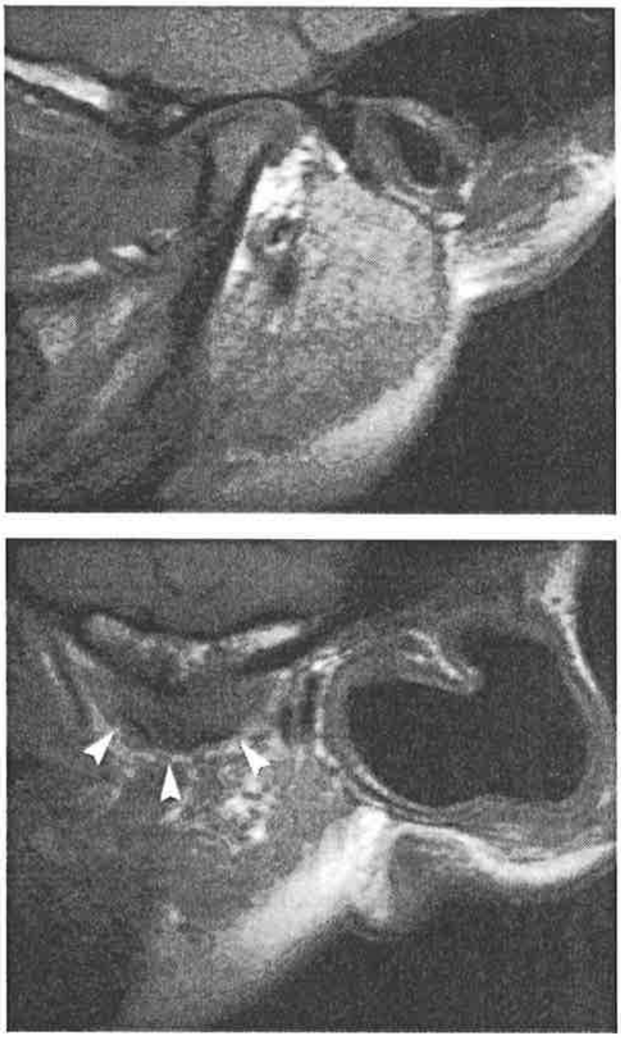
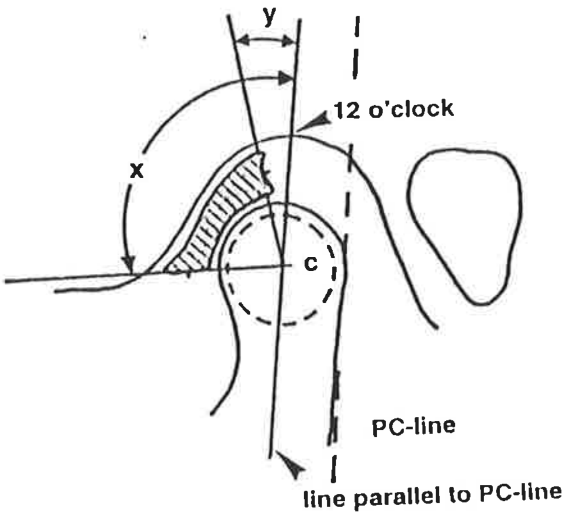


Figure 78 ▪ Sagittal MRI from a boy (T.S.) in the control group with severe disc displacement. The disc is not visible in the mid-sagittal slice (A) but the disc can be seen as a shadow (arrow) in the more lateral slice (B).

Figure 79 ▪ Coronal MRI of a boy (ID: control/male/T.S.) showing lateral disc displacement.

Disc position relative to PC-line



x, angle of the anterior margin of the disc = 116.6° ± 8.9°
y, angle of the posterior margin of the disc = 24.8° ± 14.4°
c, centre of the condylar head

Figure 80 ▪ Mean disc position using construction point relative to PC-line for the combined control and CTB groups at R1.

❖ R1 - control & CTB combined

The position of the anterior margin of the disc ranged from 93° to 136° relative to the constructed 12 o'clock point with an overall mean of 116.6° ± 8.9°. The mean was 118.0° ± 10.3° for girls and 115.9° ± 8.2° for boys.

The position of the posterior margin of the disc ranged from 0° to 65° with a combined mean of 24.8° ± 14.4°. The mean was 24.5° ± 15.9° for girls and 25.0° ± 13.9° for boys.

Student's t-tests showed no significant differences in disc position, at both anterior and posterior margins, between boys and girls. The margin of the anterior band was strongly associated with the crest of the articular eminence while the position of the posterior band varied to a greater degree, as indicated by the larger standard deviations.

❖ **R1 - control *vs.* CTB**

The mean values describing the position of the margin of the disc for children in the control and CTB groups are shown in Table 72. Student's t-test showed no significant differences in the position of either anterior or posterior margins between the control and CTB groups.

Table 72 ▪ Comparison of the disc position relative to the PC-line in the control and the CTB groups at R1.

	Control (Mean ± SD)		CTB (Mean ± SD)	
	Anterior margin	Posterior margin	Anterior margin	Posterior margin
Females (n=13)	115.6° ± 11.3°	19.1° ± 11.9°	121.7° ± 8.0°	33.2° ± 18.9°
Males (n=27)	115.7° ± 9.7°	25.1° ± 13.5°	116.1° ± 7.1°	24.9° ± 14.8°
Males & females	115.7° ± 10.1°	22.7° ± 12.9°	117.6° ± 7.6°	27.1° ± 15.8°

❖ **R1 *vs.* R2**

Control group: Although a reduction in the angles relating anterior and posterior margins of the disc to the 12 o'clock point was found, the differences did not reach significance when analysed by paired t-tests.

CTB group: Paired t-tests revealed that the position of the posterior margin was significantly different ($p < 0.05$) between R1 and R2, with the margin closer to the 12 o'clock point at R2. The margin of the anterior band was also closer to the 12 o'clock point at R2 but the difference in position of the anterior margin did not reach significance ($p = 0.07$).

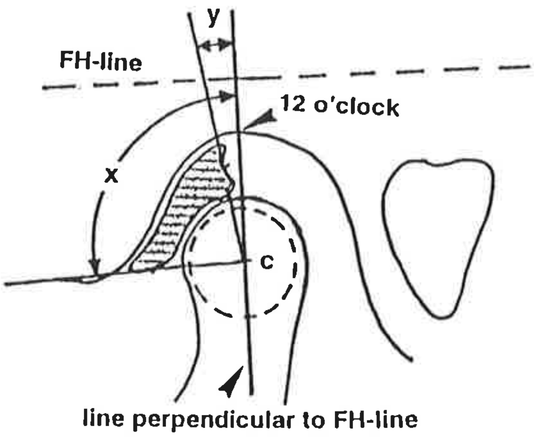
Table 73 ▪ Comparison of the positions of the anterior and posterior margins of the articular disc relative to the PC-line between R1 and R2.

	R1	R2	R2 -R1
Anterior margin	Mean ± SD	Mean ± SD	Mean ± SD
Control	115.7° ± 10.1°	114.0° ± 10.3°	-1.7° ± 6.4
CTB	117.6° ± 7.6°	114.4° ± 7.3°	-3.2° ± 7.3
Posterior margin			
Control	22.7° ± 12.9°	19.2° ± 10.4°	-3.6° ± 12.6
CTB	**27.1° ± 15.8°**	**19.5° ± 11.3°**	**-7.6°* ± 13.4**

*Paired t-test: *Mean difference between R1 and R2 differed significantly from zero at p<0.05.*

The arc between anterior and posterior margins of the disc was used to represent the length of the disc. Student's t-test showed no significant differences in disc length between the CTB and control groups from R1 to R2. Paired t-tests demonstrated no significant differences in disc length between R1 and R2 for both groups.

Disc position relative to FH-line



x, angle of the anterior margin of the disc = 99.5° ± 10.6°
y, angle of the posterior margin of the disc = 4.9° ± 13.4°
c, centre of the condylar head

Figure 81 ▪ Mean disc position using construction point relative to FH-line for the combined control and CTB groups at R1.

❖ **R1 - control & CTB combined**

The position of the anterior margin of the disc ranged from 82.0° to 124.0° relative to the 12 o'clock point, with a mean of 99.5° ± 10.6°, while the posterior margin ranged from -18° to 36° relative to 12 o'clock point with a mean of 4.9° ± 13.4°. Student's t-tests showed no significant differences in the position of the anterior and posterior margins between boys and girls. The variation in the position of the posterior margin was also greater than that of the anterior margin.

❖ R1 - control *vs.* CTB

Positions of the anterior and posterior margin of the disc are shown in Table 74. Variation in the position of the posterior margin for both males and females in the CTB group was larger than that of the control group. No significant differences in disc position, both anterior and posterior margins, were found between control and CTB groups.

Table 74 ▪ Comparison of the positions of the anterior and posterior margins of the disc relative to the FH-line in the control and the CTB groups at R1.

	Control (Mean ± SD)		CTB (Mean ± SD)	
	Anterior margin	Posterior margin	Anterior margin	Posterior margin
Females (n=13)	104.3° ± 13.1°	4.7° ± 12.8°	99.6° ± 10.2°	11.0° ± 15.5°
Males (n=27)	98.2° ± 9.7°	4.8° ± 11.4°	97.9° ± 10.5°	2.7° ± 15.6°
Males & females	100.4° ± 11.1°	4.8° ± 11.6°	98.4° ± 10.1°	5.1° ± 15.5°

❖ R1 *vs.* R2

The anterior and posterior margins of the disc at R2 were located more posteriorly in both the CTB and the control groups. Paired t-tests demonstrated significant differences in the position of the anterior ($p < 0.01$) and posterior ($p < 0.01$) margins in the control group but not in the CTB group. No significant difference was found for the length of the disc represented by the arc between anterior and posterior margins in either control or CTB groups when comparing R1 with R2.

Table 75 ▪ Comparison of the positions of the anterior and posterior margins of the articular disc relative to the FH-line between R1 and R2.

	R1	R2	R2 -R1
Anterior margin	Mean ± SD	Mean ± SD	Mean ± SD
Control (n=21)	**100.4° ± 11.1°**	**93.3° ± 9.1°**	**-7.1°** ± 8.5**
CTB (n=19)	98.4° ± 10.1°	94.5° ± 7.8°	-3.5° ± 9.0
Posterior margin			
Control (n=21)	**4.8° ± 11.6°**	**-1.7° ± 10.7°**	**-6.5°** ± 9.3**
CTB (n=19)	5.1° ± 15.5°	-0.2° ± 13.8°	-3.3° ± 8.7

*Paired t-test: **Mean difference between R1 and R2 differed significantly from zero at p<0.01.*

NOTE: *It appeared that the positions of the disc were more posterior relative to the 12 o'clock point at R2 for both the control and CTB groups. However, statistical analysis using different reference points led to contrasting results regarding level of significance. Using reference points relative to the PC-line, the differences between R1 and R2 reached significance for the CTB group but not for controls. Using the reference points relative to the FH-line, the differences between R1 and R2 reached significance for the control group but not the CTB group. These contrasting results are discussed in Chapter 5.*

➤ ***Diagnosis of disc displacement***

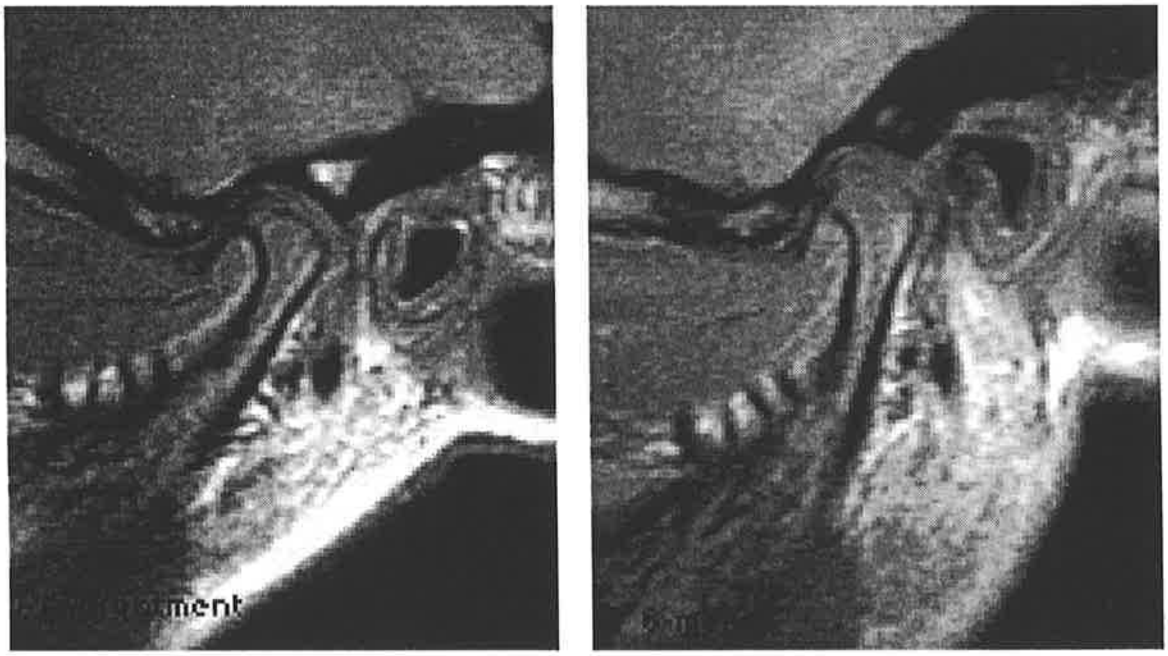
Based on data from asymptomatic adults with no history of trauma or orthodontic treatment, Drace & Enzmann (1990) recommended using the position of the **posterior margin** of the disc to diagnose disc displacement. Two standard deviations either side of the mean from their sample (mean ± 10°) was used to represent the so-called "normal range". In the present study, one standard deviation either side of the mean was used because the range was approximately equal to mean ± 10°.

- **Using reference points relative to PC-line:**
  At R1, eight children, two girls and six boys, were identified as having anterior disc displacement. At R2, only five children, one girl four boys, were diagnosed as having anterior disc displacement. One of these five children was not diagnosed as having anterior disc displacement at R1.

- **Using reference points relative to FH-line:**
  At R1, six children, two girls and four boys, were classified as having anterior disc displacement. At R2, seven children, two girls and five boys, were diagnosed as having anterior disc displacement. Two boys of these seven children were not diagnosed as having anterior disc displacement at R1.

Table 76 ▪ Children diagnosed as having anterior disc displacement at R1 and R2.

Children ID	PC-reference		FH- reference	
	R1	R2	R1	R2
Control/female/A.H.			✓	✓
Control/female/R.V.	✓			
Control/male/A.D.	✓	✓	✓	✓
Control/male/Sc.G.	✓			
Control/male/L.T.	✓			
CTB/female/G.M.	✓	✓	✓	✓
CTB/male/Sk.G.		✓	✓	✓
CTB/male/J.R.	✓	✓	✓	✓
CTB/male/P.S.	✓			
CTB/male/B.R.	✓		✓	
CTB/male/G.S.		✓		✓
CTB/male/J.P.				✓



Pre-treatment Sagittal MRI **6-month Sagittal MRI**

Figure 82 ▪ Sagittal MRI of patient-CTB/female/G.M. who was classified as having anterior disc displacement both at R1 and R2 when using either PC or FH references.

➢ *Disc position and condylar concentricity*

- **Using PC-reference:**

  At R1, analysis of variance (one-way ANOVA) was used to compare the disc position within three groups of children with anteriorly positioned condyles, concentric condyles and posteriorly positioned condyles. The tests showed that the mean position of the **posterior margin** of the disc in the posteriorly positioned condyle group was significantly different from that of the concentric or anteriorly positioned condyle ($p<0.05$, Table 77). At R1, the position of the posterior margin of the disc in the posteriorly positioned condyle group was approximately 19° more anterior than that of the concentric condyle and anteriorly positioned condyle groups. However, no significant differences in the position of the posterior margin of the disc were noted between these three groups at R2.

  No significant difference in the position of the **anterior margin** of the disc was found among the three groups of condylar positions at either R1 or R2.

Table 77 ▪ Comparison of disc position relative to PC-line within three groups of anterior, concentric and posterior condylar positions.

	Anterior margin at R1	Posterior margin at R1
Condylar concentricity	Mean ± SD	Mean ± SD
Anterior	115.3° ± 10.6°	18.4° ± 13.9°
Concentric	112.4° ± 9.5°	18.9° ± 12.1°
Posterior	119.3° ± 9.8°	**37.5°* ± 13.9°**
	Anterior margin at R2	**Posterior margin at R2**
	Mean ± SD	Mean ± SD
Anterior	113.9° ± 7.5°	17.9° ± 11.0°
Concentric	116.1° ± 10.5°	20.0° ± 10.7°
Posterior	112.4° ± 11.3°	22.9° ± 10.0°

*Student-Newman-Keuls test: *Mean value for posteriorly positioned condyle group differed significantly from mean values for anterior and concentric positioned condyle groups at $p<0.05$.*

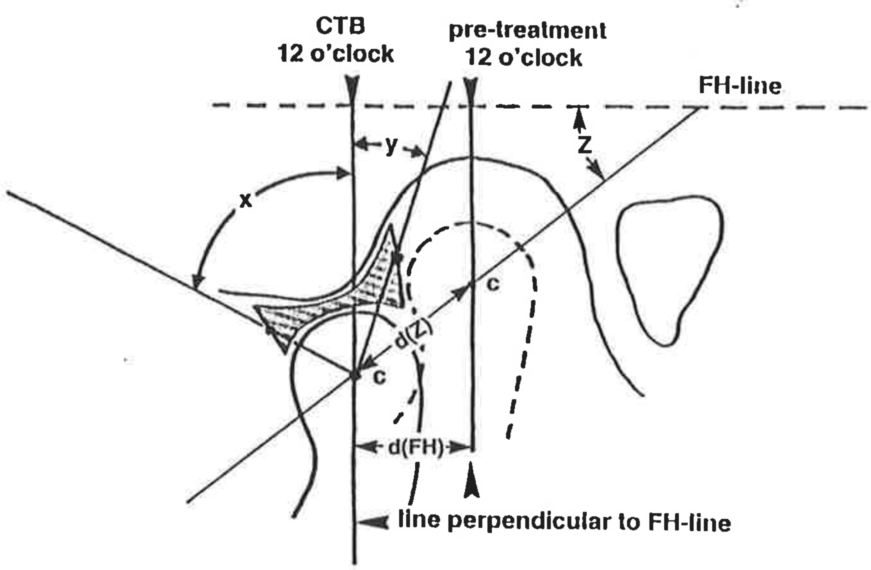
- **Using FH-reference:**

  Comparison of the position of anterior and posterior margins of the disc among the three groups of anterior, concentric and posteriorly located condylar positions showed similar trends to those when using the PC-line. However, the differences did not reach a statistically significant level.

Table 78 ▪ Comparison of disc position relative to FH-line within three groups of anterior, concentric and posterior condylar positions.

	Anterior margin at R1	Posterior margin at R1
Condylar concentricity	Mean ± SD	Mean ± SD
Anterior	99.8° ± 11.1°	2.6° ± 12.6°
Concentric	97.3° ± 10.7°	0.9° ± 13.6°
Posterior	100.7° ± 10.2°	12.5° ± 12.7°
	Anterior margin at R2	**Posterior margin at R2**
	Mean ± SD	Mean ± SD
Anterior	92.6° ± 8.3°	-2.6° ± 13.0°
Concentric	95.4° ± 6.9°	-2.9° ± 8.8°
Posterior	95.2° ± 10.9°	5.3° ± 11.4°

➢ *Translation of condyle and disc in CTB group*

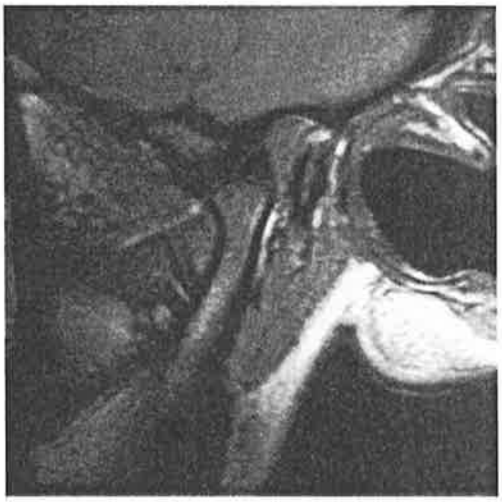


x, angle of the anterior margin of the disc = 60.1° ± 11.9°
y, angle of the posterior margin of the disc = 29.2° ± 12.8°
z, translation angle = 35.6° ± 8.8°
d(FH), translation distance along FH-line = 6.3 ± 1.7 mm
d(Z), translation distance alone translation angle = 7.9 ± 1.6 mm

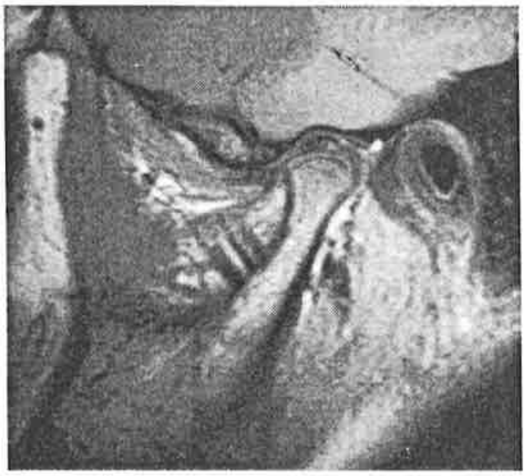
Figure 83 ▪ Mean values for disc position and translation distances relative to the FH-line in children wearing the CTB.

The condyle translated forward and downward when the children began to wear the CTB. The horizontal translation distance along the FH-line ranged from 4 to 9 mm with a mean of 6.3 ± 1.7 mm while the mean vertical translation ranged from 3 to 6.5 mm with a mean of 4.6 ± 1.2 mm. Translation along the translation line ranged from 5.5 to 10.5 mm with a mean of 7.9 ± 1.6 mm. The position of the disc relative to the condyle also changed. All of the children displayed the top of the condyle positioned close to the centre of the disc. The position of the anterior margin ranged from 32° to 84°, with a mean of 60.1° ± 11.9. The position of the posterior margin ranged from 10° to 52°, with a mean of 29.2° ± 12.8°. The variation in position of the anterior and posterior margins was similar. No appearance of disc displacement without reduction was found including those classified as having anterior, lateral or medial disc displacement.

A - Pre-treatment MRI



B - when wearing CTB analogue



C - 6-month MRI

Figure 84 ▪ Sagittal MRIs of patient-CTB/male/B.G. displaying relationship between disc and condyle.

4.6 3D-Cephalometric Analysis

❖ R1 - control *vs.* CTB

Cephalometric data were derived from ten boys from the control and ten boys from the experimental groups. All of these children had participated in MRI assessment. None of these children were classified as having anterior, lateral or medial disc displacement. Preliminary analyses, including the estimation of skewness and kurtosis, indicated that the craniofacial data conformed generally to normal distributions and could therefore be described adequately in terms of mean values and standard deviations.

Three-dimensional cephalometric analysis demonstrated that this group of children had Class II skeletal relationships with a mean ANB angle of 5.2° ± 1.6° (Table 80) which confirmed clinical judgement. Compared with 2D-cephalometric standards (Owen, 1984a; 1984b), it appeared that the Class II skeletal relationship was due to mandibular retrusion rather than maxillary protrusion. The mandibular plane angle was within the normal range. The upper incisors displayed relatively normal angulation while the lower incisors were relatively upright. It was not possible to compare distance measurements such as maxillary length or mandibular length with conventional cephalometric standards as they involved landmarks that lie on lateral structures. Those measurements represent projected lengths and are not compensated for perspective errors as in 3D cephalometric measurements.

Children in the control and CTB group displayed similar 3D-cephalometric characteristics for both linear (Table 79) and angular (Table 80) variables. T-tests revealed no significant differences in the variables between control and CTB groups, except for variable Me-Cc(r) ($p<0.05$). However, this was likely to be a type I error as no significant differences were found for any other associated variables.

Table 79 ▪ Comparison of 3D distances between control and CTB groups at R1.

DISTANCES (mm)	**Control (Mean ± SD)**	**CTB (Mean ± SD)**
S - ANS	78.9 ± 3.3	78.2 ± 4.5
ANS – Me	61.5 ± 7.3	58.0 ± 4.0
Or(r) - Or(l)	65.5 ± 3.0	62.8 ± 4.7
A – Or(r)	44.3 ± 1.8	43.7 ± 2.1
A – Or(l)	45.0 ± 3.0	43.3 ± 3.1
A – Cc(r)	94.0 ± 3.1	93.8 ± 5.0
A – Cc(l)	92.5 ± 2.7	93.1 ± 3.3
Or(r) - U1tip	59.9 ± 1.7	59.3 ± 2.0
Or(l) - U1tip	60.5 ± 2.8	59.2 ± 2.6
ANS - U1tip	21.0 ± 1.3	20.5 ± 1.7
A - B	33.9 ± 3.8	31.0 ± 2.7
Me - L1tip	37.8 ± 3.3	36.9 ± 2.6
L1tip - Cc(r)	95.2 ± 2.4	94.6 ± 4.9
L1tip - Cc(l)	94.1 ± 2.7	95.0 ± 3.5
Me - Cc(r)	**109.5 ± 2.8**	**106.0* ± 3.8**
Me - Cc(l)	108.2 ± 2.7	106.4 ± 4.1
Me - Go(r)	78.4 ± 2.7	76.3 ± 2.2
Me - Go(l)	77.6 ± 2.4	76.5 ± 3.4
Me - Or(r)	84.2 ± 5.3	81.2 ± 3.3
Me - Or(l)	84.7 ± 5.3	81.9 ± 4.7
Cc(r) - Go(r)	46.8 ± 2.2	45.8 ± 3.2
Cc(l) - Go(l)	46.7 ± 2.6	45.7 ± 3.0
Cc(r) - Cc(l)	91.9 ± 3.1	91.0 ± 5.3
Go(r) - Go(l)	84.6 ± 4.4	81.5 ± 3.6

*Student's t-test: *Mean value for CTB group differed significantly from mean value for the control group at $p<0.05$.*

Table 80 ▪ Comparison of 3D angles between control and CTB groups at R1.

ANGLES (degrees)	Control (Mean ± SD)	CTB (Mean ± SD)
SNA	79.0 ± 3.2	77.7 ± 2.8
SNB	72.4 ± 2.5	71.9 ± 4.0
ANB	6.7 ± 1.6	5.8 ± 1.5
ANS-PNS to SN	9.5 ± 1.7	10.2 ± 2.8
SN to FH(r)	15.3 ± 2.4	14.0 ± 3.5
SN to FH(l)	15.0 ± 1.5	14.3 ± 3.3
ANS-PNS to FH(r)	6.0 ± 2.6	4.0 ± 3.6
ANS-PNS to FH(l)	5.5 ± 1.9	4.5 ± 3.3
A to Or(r) to Po(r)	56.3 ± 5.6	60.7 ± 4.5
A to Or(l) to Po(l)	56.3 ± 5.4	58.0 ± 6.5
U1 to SN	101.6 ± 5.7	106.2 ± 6.9
U1 to FH(r)	116.9 ± 5.2	120.3 ± 6.0
U1 to FH(l)	116.6 ± 4.9	120.6 ± 5.8
U1 to ANS-PNS	111.1 ± 6.0	116.5 ± 5.7
U1 to L1	129.1 ± 7.1	123.6 ± 4.9
L1 to SN	50.7 ± 5.4	49.8 ± 7.7
L1 to FH(r)	66.1 ± 5.0	63.8 ± 6.9
L1 to FH(l)	65.7 ± 4.9	64.1 ± 6.7
L1 to Me-Go(r)	85.2 ± 3.5	82.6 ± 2.7
L1 to Me-Go(l)	85.2 ± 3.6	82.7 ± 3.1
Me to Go(r) to Cc(r)	123.5 ± 6.1	120.2 ± 3.4
Me to Go(l) to Cc(l)	122.1± 5.1	121.0 ± 3.9
Me-Go(r) to FH(r)	23.0 ± 4.9	21.2 ± 4.6
Me-Go(l) to FH(l)	22.7 ± 4.8	20.7 ± 5.1
Me-Go(r) to SN	38.3 ± 6.6	35.2 ± 5.0
Me-Go(l) to SN	37.6 ± 5.8	35.0 ± 5.7
Or(r) to A to Or(l)	80.8 ± 5.5	83.2 ± 6.4
Cc(r) to A to Cc(l)	71.7 ± 11.1	71.1 ± 10.7
Or(r) to U1tip to Or(l)	67.8 ± 3.2	66.2 ± 5.7
Or(r) to Me to Or(l)	46.2 ± 3.2	45.8 ± 4.5
Cc(r) to L1tip to Cc(l)	84.4 ± 3.5	84.5 ± 5.1
Cc(r) to Me to Cc(l)	58.1 ± 4.1	59.9 ± 5.0
Go(r) to Me to Go(l)	80.4 ± 8.3	79.2 ± 6.3

❖ R1 *vs.* R2

Control group: Comparison of 3D distances (Table 81) and angles (Table 82) between R1 and R2 revealed significant differences for eight variables as follows:

1. Me-L1 tip: increase in anterior mandibular height.
2. L1tip-Cc(l): increase in lower dental arch length relative to left condyle.
3. Me-Cc(l): increase in effective mandibular length relative to left condyle.
4. Cc(l)-Go(l): increase in left ramal height.
5. ANB angle: reduction of severity in Class II relationship.
6. U1 to FH(r): reduction of upper incisal proclination relative to right Frankfort Horizontal plane.
7. U1 to ANS-PNS: reduction of upper incisal proclination relative to palatal plane.
8. U1 to L1: reduction of inter-incisal procumbency.

The changes in the control group were related mainly to dental changes. Some mandibular growth was observed but the changes were only found on the left side. Changes in the maxilla were minimal and did not reach significance.

Table 81 ▪ Comparison of 3D distances in control group between R1 and R2.

DISTANCES (mm)	R1 (Mean ± SD)	R2 (Mean ± SD)	Mean diff (R2-R1)
S - ANS	78.9 ± 3.3	77.6 ± 3.0	-1.3
ANS – Me	61.5 ± 7.3	61.2 ± 7.1	-0.2
Or(r) - Or(l)	65.5 ± 3.0	64.2 ± 4.3	-1.3
A – Or(r)	44.3 ± 1.8	44.4 ± 3.0	0.1
A – Or(l)	45.0 ± 3.0	43.5 ± 3.4	-1.5
A – Cc(r)	94.0 ± 3.1	93.1 ± 3.6	-0.8
A – Cc(l)	92.5 ± 2.7	93.7 ± 1.8	1.2
Or(r) - U1tip	59.9 ± 1.7	60.7 ± 2.5	0.9
Or(l) - U1tip	60.5 ± 2.8	59.9 ± 4.0	-0.5
ANS - U1tip	21.0 ± 1.3	21.6 ± 2.2	0.6
A - B	33.9 ± 3.8	34.0 ± 4.4	0.1
Me - L1tip	**37.8 ± 3.3**	**38.3 ± 3.5**	**0.5***
L1tip - Cc(r)	95.2 ± 2.4	95.6 ± 3.8	0.4
L1tip - Cc(l)	**94.1 ± 2.7**	**96.2 ± 2.0**	**2.1*****
Me - Cc(r)	109.5 ± 2.8	109.8 ± 4.7	0.3*
Me - Cc(l)	**108.2 ± 2.7**	**111.1 ± 3.0**	**2.9*****
Me - Go(r)	78.4 ± 2.7	78.7 ± 3.4	0.4
Me - Go(l)	77.6 ± 2.4	78.2 ± 3.2	0.6
Me - Or(r)	84.2 ± 5.3	84.9 ± 5.4	0.8
Me - Or(l)	84.7 ± 5.3	84.6 ± 6.4	-0.1
Cc(r) - Go(r)	46.8 ± 2.2	47.2 ± 3.1	0.5
Cc(l) - Go(l)	**46.7 ± 2.6**	**49.2 ± 2.8**	**2.4****
Cc(r) - Cc(l)	91.9 ± 3.1	92.8 ± 2.8	0.9
Go(r) - Go(l)	84.6 ± 4.4	84.2 ± 3.1	-0.4

*Paired t-test: mean values differed significantly at *p<0.05, **p<0.01, ***p<0.001*

Table 82 ▪ Comparison of 3D angles in control group between R1 and R2.

ANGLES (degrees)	R1 (Mean ± SD)	R2 (Mean ± SD)	Mean diff (R2-R1)
SNA	79.0 ± 3.2	77.7 ± 3.9	-1.3
SNB	72.4 ± 2.5	72.4 ± 3.0	0.0
ANB	**6.7 ± 1.6**	**5.4 ± 1.5**	**-1.3***
ANS-PNS to SN	9.5 ± 1.7	9.2 ± 1.6	-0.3
SN to FH(r)	15.3 ± 2.4	14.9 ± 2.3	-0.4
SN to FH(l)	15.0 ± 1.5	15.2 ± 1.6	0.2
ANS-PNS to FH(r)	6.0 ± 2.6	5.7 ± 2.9	-0.3
ANS-PNS to FH(l)	5.5 ± 1.9	6.0 ± 2.3	0.5
A to Or(r) to Po(r)	56.3 ± 5.6	58.1 ± 4.9	1.8
A to Or(l) to Po(l)	56.3 ± 5.4	59.1 ± 4.3	2.9
U1 to SN	101.6 ± 5.7	100.1± 4.6	-1.5
U1 to FH(r)	**116.9 ± 5.2**	**115.1 ± 4.2**	**-1.8***
U1 to FH(l)	116.6 ± 4.9	115.3 ± 3.8	-1.2
U1 to ANS-PNS	**111.1 ± 6.0**	**109.4 ± 5.1**	**-1.7***
U1 to L1	**129.1 ± 7.1**	**131.5 ± 6.8**	**2.3***
L1 to SN	50.7 ± 5.4	51.6 ± 5.3	0.9
L1 to FH(r)	66.1 ± 5.0	66.5 ± 4.4	0.5
L1 to FH(l)	65.7 ± 4.9	66.8 ± 5.1	1.1
L1 to Me-Go(r)	85.2 ± 3.5	85.5 ± 3.4	0.3
L1 to Me-Go(l)	85.2 ± 3.6	85.5 ± 4.0	0.4
Me to Go(r) to Cc(r)	123.5 ± 6.1	122.5 ± 6.8	-1.0
Me to Go(l) to Cc(l)	122.1 ± 5.1	122.3 ± 6.4	0.3
Me-Go(r) to FH(r)	23.0 ± 4.9	22.7 ± 5.6	-0.3
Me-Go(l) to FH(l)	22.7 ± 4.8	22.2 ± 5.8	-0.5
Me-Go(r) to SN	38.3 ± 6.6	37.6 ± 6.9	-0.7
Me-Go(l) to SN	37.6 ± 5.8	37.4 ± 6.2	-0.2
Or(r) to A to Or(l)	80.8 ± 5.5	82.5 ± 4.0	1.7
Cc(r) to A to Cc(l)	71.7 ± 11.1	71.9 ± 11.9	0.2
Or(r) to U1tip to Or(l)	67.8 ± 3.2	65.8 ± 2.9	-2.0
Or(r) to Me to Or(l)	46.2 ± 3.2	44.9 ± 4.3	-1.2
Cc(r) to L1tip to Cc(l)	84.4 ± 3.5	86.0 ± 3.5	1.5
Cc(r) to Me to Cc(l)	58.1 ± 4.1	57.9 ± 2.4	-0.2
Go(r) to Me to Go(l)	80.4 ± 8.3	80.8 ± 5.7	0.4

*Paired t-test: mean values differed significantly at *p<0.05, **p<0.01, ***p<0.001*

CTB group: Paired t-tests revealed significant changes in 11 linear (Table 83) and 15 angular variables (Table 84) between R1 and R2. The changes were interpreted as follows:

1. ANS-Me: increase in lower facial height.

2. A-B: increase in maxillo-mandibular dento-alveolar height.

3. Me-L1 tip: reduction in mandibular dental height.

4. L1 tip-Cc(r): increase in lower dental arch length relative to right condyle.

5. L1 tip-Cc(l): increase in lower dental arch length relative to left condyle.

6. Me-Cc(r): increase in effective mandibular length relative to right condyle.

7. Me-Cc(l): increase in effective mandibular length relative to left condyle

8. Me-Go(r): increase in right mandibular body length.
   (Note: Me-Go(l) also increased with the change almost reaching significance, p=0.06)

9. Me-Or(r): increase in right facial height.

10. Me-Or(l): increase in left facial height.

11. Cc(l)-Go(l): increase in left ramal height.
    (Note: Cc(r)-Go(r) showed minimal change and did not reach significance, p=0.8)

12. ANB angle: reduction of severity in Class II relationship.

13. ANS-PNS to SN: anterior downward rotation of the palatal plane relative to SN.

14. U1 to SN: reduction of upper incisal proclination relative to cranial base.

15. U1 to FH(r): reduction of upper incisal proclination relative to right Frankfort horizontal plane.

16. U1 to FH(l): reduction of upper incisal proclination relative to left Frankfort horizontal plane.

17. U1 to ANS-PNS: reduction of upper incisal proclination relative to palatal plane.

18. U1 to L1: increase in inter-incisal procumbency.

19. L1 to SN: increase in lower incisal proclination relative to cranial base.

20. L1 to FH(r): increase in lower incisal proclination relative to right Frankfort horizontal plane.

21. L1 to FH(l): increase in lower incisal proclination relative to left Frankfort horizontal plane.

22. L1 to Me-Go(r): increase in lower incisal proclination relative to right mandibular body.

23. L1 to Me-Go(l): increase in lower incisal proclination relative to left mandibular body.

24. Me to Go(r) to Cc(r): increase in right Gonial angle.

25. Me to Go(l) to Cc(l): increase in left Gonial angle.

26. Me-Go(r) to SN: increase in mandibular plane angle relative to cranial base. (Note: Me-Go(l) to SN also increased but did not reach significance, $p = 0.08$)

Table 83 ▪ Comparison of 3D distances in CTB group between R1 and R2.

DISTANCES (mm)	R1 (Mean ± SD)	R2 (Mean ± SD)	Mean diff (R2-R1)
S - ANS	78.2 ± 4.5	78.6 ± 4.1	0.4
ANS – Me	**58.0 ± 4.0**	**60.2 ± 4.4**	**2.2****
Or(r) - Or(l)	62.8 ± 4.7	64.7 ± 4.7	2.0
A – Or(r)	43.7 ± 2.1	45.2 ± 3.3	1.5
A – Or(l)	43.3 ± 3.1	44.4 ± 1.9	1.1
A – Cc(r)	93.8 ± 5.0	93.4 ± 4.6	-0.4
A – Cc(l)	93.1 ± 3.3	93.9 ± 3.6	0.9
Or(r) - U1tip	59.3 ± 2.0	60.8 ± 3.0	1.5
Or(l) - U1tip	59.2 ± 2.6	60.3 ± 1.2	1.1
ANS - U1tip	20.5 ± 1.7	20.6 ± 0.9	0.2
A - B	**31.0 ± 2.7**	**33.4 ± 1.7**	**2.4****
Me - L1tip	**36.9 ± 2.6**	**36.1 ± 2.8**	**-0.8****
L1tip - Cc(r)	**94.6 ± 4.9**	**99.8 ± 4.3**	**5.2*****
L1tip - Cc(l)	**95.0 ± 3.5**	**101.0 ± 3.5**	**5.9*****
Me - Cc(r)	**106.0 ± 3.8**	**109.3 ± 4.1**	**3.3****
Me - Cc(l)	**106.4 ± 4.1**	**110.6 ± 3.3**	**4.2*****
Me - Go(r)	**76.3 ± 2.2**	**78.5 ± 4.2**	**2.2***
Me - Go(l)	76.5 ± 3.4	77.8 ± 2.9	1.3
Me - Or(r)	**81.2 ± 3.3**	**85.1 ± 4.1**	**3.9*****
Me - Or(l)	**81.9 ± 4.7**	**85.1 ± 3.6**	**3.2*****
Cc(r) - Go(r)	45.8 ± 3.2	46.0 ± 2.7	0.2
Cc(l) - Go(l)	**45.7 ± 3.0**	**47.9 ± 2.8**	**2.3*****
Cc(r) - Cc(l)	91.0 ± 5.3	93.2 ± 3.0	2.2
Go(r) - Go(l)	81.5 ± 3.6	81.4 ± 3.7	-0.1

*Paired t-test: mean values differed significantly at *p<0.05, **p<0.01, ***p<0.001*

Table 84 ▪ Comparison of 3D angles in CTB group between R1 and R2.

ANGLES (degrees)	R1 (Mean ± SD)	R2 (Mean ± SD)	Mean diff (R2-R1)
SNA	77.7 ± 2.8	76.7 ± 4.1	-1.1
SNB	71.9 ± 4.0	73.3 ± 4.3	1.4
ANB	**5.8 ± 1.5**	**3.3 ± 1.9**	**-2.5*** **
ANS-PNS to SN	**10.2 ± 2.8**	**11.7 ± 3.3**	**1.5** **
SN to FH(r)	14.0 ± 3.5	14.8 ± 2.6	0.8
SN to FH(l)	14.3 ± 3.3	14.9 ± 2.9	0.6
ANS-PNS to FH(r)	4.0 ± 3.6	3.7 ± 2.9	-0.3
ANS-PNS to FH(l)	4.5 ± 3.3	3.7 ± 2.8	-0.8
A to Or(r) to Po(r)	60.7 ± 4.5	58.8 ± 6.9	-1.9
A to Or(l) to Po(l)	58.0 ± 6.5	59.3 ± 8.9	1.3
U1 to SN	**106.2 ± 6.9**	**102.5 ± 4.3**	**-3.8** **
U1 to FH(r)	**120.3 ± 6.0**	**117.3 ± 3.4**	**-3.0** **
U1 to FH(l)	**120.6 ± 5.8**	**117.4 ± 2.7**	**-3.2** **
U1 to ANS-PNS	**116.5 ± 5.7**	**114.2 ± 3.5**	**-2.3***
U1 to L1	**123.6 ± 4.9**	**120.8 ± 5.5**	**-2.8** **
L1 to SN	**49.8 ± 7.7**	**43.2 ± 7.4**	**-6.6*** **
L1 to FH(r)	**63.8 ± 6.9**	**58.1 ± 6.5**	**-5.8*** **
L1 to FH(l)	**64.1 ± 6.7**	**58.1 ± 6.3**	**-6.0*** **
L1 to Me-Go(r)	**82.6 ± 2.7**	**79.1 ± 4.5**	**-3.5** **
L1 to Me-Go(l)	**82.7 ± 3.1**	**79.5 ± 5.5**	**-3.2***
Me to Go(r) to Cc(r)	**120.2 ± 3.4**	**121.9 ± 3.3**	**1.7** **
Me to Go(l) to Cc(l)	**121.0 ± 3.9**	**122.7 ± 4.7**	**1.7** **
Me-Go(r) to FH(r)	21.2 ± 4.6	21.7 ± 3.9	0.5
Me-Go(l) to FH(l)	20.7 ± 5.1	21.5 ± 5.0	0.8
Me-Go(r) to SN	**35.2 ± 5.0**	**36.5 ± 4.6**	**1.3***
Me-Go(l) to SN	35.0 ± 5.7	36.4 ± 6.0	1.4
Or(r) to A to Or(l)	83.2 ± 6.4	80.9 ± 10.8	-2.2
Cc(r) to A to Cc(l)	71.1 ± 10.7	63.3 ± 18.6	-7.7
Or(r) to U1tip to Or(l)	66.2 ± 5.7	67.9 ± 8.2	1.7
Or(r) to Me to Or(l)	45.8 ± 4.5	45.3 ± 4.7	-0.5
Cc(r) to L1tip to Cc(l)	84.5 ± 5.1	78.4 ± 8.0	-6.1
Cc(r) to Me to Cc(l)	59.9 ± 5.0	61.4 ± 7.1	1.4
Go(r) to Me to Go(l)	79.2 ± 6.3	74.8 ± 13.6	-4.4

*Paired t-test: mean values differed significantly at *p<0.05, **p<0.01, ***p<0.001*

Comparisons of the mean change in distances and angles between control and CTB groups using unpaired t-test revealed significant differences in 17 variables. This test aimed to determine whether the mean change in the control group differed significantly from the mean change in the CTB group. Changes in variables that were significantly greater in the CTB group than in the control group were as follows:

1. ANS-Me: increase in lower facial height was greater in the CTB group.

2. A-Or(l): increase in maxillary height was greater in the CTB group.

3. Me-L1 tip: increase in mandibular height was greater in the control group.

4. L1 tip-Cc(r): increase in lower dental arch length relative to right condyle was greater in the CTB group.

5. L1 tip-Cc(l): increase in lower dental arch length relative to left condyle was greater in the CTB group.

6. Me-Cc(r): increase in right effective mandibular length was greater in the CTB group.
   (Note: increase in Me-Cc(l) did not reach significance, p=0.18)

7. Me-Or(r): increase in right facial height was greater in the CTB group.

8. Me-Or(l): increase in left facial height was greater in the CTB group.

9. ANS-PNS to SN: anterior downward rotation was greater in the CTB group.

10. U1 to L1: inter-incisal procumbency was reduced in the controls but increased in the CTB group.

11. L1 to SN: increase in lower incisal proclination relative to cranial base was greater in the CTB group.

12. L1 to FH(r): increase in lower incisal proclination relative to right Frankfort horizontal plane was greater in the CTB group.

13. L1 to FH(l): increase in lower incisal proclination relative to left Frankfort horizontal plane was greater in the CTB group.

14. Me to Go(r) to Cc(r): increase in gonial angle was greater in the CTB group
 (Note: Me to Go(l) to Cc(l) also increased and almost reached significance, p=0.07)

15. Me-Go(r) to SN: increase in right mandibular plane angle relative to cranial base was greater in the CTB group.
 (Note: Me-Go(l) to SN also increased but did not reach significance, p=0.12)

The significant differences in the changes observed over the 6-month period between the control and CTB groups were considered to represent the effects of treatment with Twin Block appliance, above that associated with normal growth. Marked treatment effects included an increase in facial height and proclination of lower incisors which consequently increased lower dental arch length. The maxilla was rotated downward and anteriorly but inhibition of maxillary growth could not be confirmed. Change in effective mandibular length was significantly different between the groups but only on the right side. The increase in gonial angle and mandibular plane angle was also significantly different between the groups only on the right sides.

Table 85 ▪ Comparison of mean changes in distances from R1 and R2 between control and CTB group.

DISTANCES (mm)	**Control (R2-R1)**	**CTB (R2-R1)**
	Mean diff ± SD	**Mean diff ± SD**
S - ANS	-1.3 ± 3.3	0.4 ± 2.5
ANS – Me	**-0.2 ± 2.5**	**2.2* ± 1.8**
Or(r) - Or(l)	-1.3 ± 3.4	2.0 ± 4.8
A – Or(r)	0.1 ± 3.4	1.5 ± 3.5
A – Or(l)	**-1.5 ± 2.1**	**1.1* ± 2.4**
A – Cc(r)	-0.8 ± 3.1	-0.4 ± 3.1
A – Cc(l)	1.2 ± 2.1	0.9 ± 1.8
Or(r) - U1tip	0.9 ± 2.2	1.5 ± 2.7
Or(l) - U1tip	-0.5 ± 2.7	1.1 ± 2.3
ANS - U1tip	0.6 ± 2.6	0.2 ± 2.0
A - B	0.1 ± 2.3	2.4 ± 3.2
Me - L1tip	**0.5 ± 0.6**	**-0.8*** ± 0.8**
L1tip - Cc(r)	**0.4 ± 2.7**	**5.2*** ± 2.4**
L1tip - Cc(l)	**2.1 ± 1.2**	**5.9*** ± 2.1**
Me - Cc(r)	**0.3 ± 3.0**	**3.3* ± 3.2**
Me - Cc(l)	2.9 ± 1.7	4.2 ± 2.4
Me - Go(r)	0.4 ± 3.2	2.2 ± 3.0
Me - Go(l)	0.6 ± 1.8	1.3 ± 2.0
Me - Or(r)	**0.8 ± 1.6**	**3.9** ± 2.4**
Me - Or(l)	**-0.1 ± 2.1**	**3.2** ± 2.1**
Cc(r) - Go(r)	0.5 ± 2.1	0.2 ± 1.9
Cc(l) - Go(l)	2.4 ± 1.7	2.3 ± 1.3
Cc(r) - Cc(l)	0.9 ± 3.3	2.2 ± 4.6
Go(r) - Go(l)	-0.4 ± 3.3	-0.1 ± 1.5

*Unpaired t-test: mean values differed significantly at *$p<0.05$, **$p<0.01$, ***$p<0.001$*

Table 86 ▪ Comparison of mean changes in angles from R1 and R2 between control and CTB group.

ANGLES (degrees)	Control Mean diff ± SD	CTB Mean diff ± SD
SNA	-1.29 ± 1.9	-1.06 ± 2.5
SNB	0.02 ± 1.2	1.42 ± 2.4
ANB	-1.31 ± 1.6	-2.48 ± 1.7
ANS-PNS to SN	**-0.26 ± 1.0**	**1.52** ± 1.5**
SN to FH(r)	-0.37 ± 1.1	0.79 ± 1.6
SN to FH(l)	0.25 ± 1.5	0.58 ± 2.0
ANS-PNS to FH(r)	-0.30 ± 1.5	-0.32 ± 1.3
ANS-PNS to FH(l)	0.50 ± 1.3	-0.77 ± 1.9
A to Or(r) to Po(r)	1.85 ± 3.3	-1.86 ± 6.9
A to Or(l) to Po(l)	2.86 ± 5.6	1.29 ± 5.3
U1 to SN	-1.48 ± 2.6	-3.79 ± 2.8
U1 to FH(r)	-1.84 ± 2.5	-2.99 ± 3.0
U1 to FH(l)	-1.23 ± 2.2	-3.20 ± 3.4
U1 to ANS-PNS	-1.73 ± 2.4	-2.27 ± 2.8
U1 to L1	**2.33 ± 3.2**	**-2.78*** ± 2.5**
L1 to SN	**0.85 ± 1.2**	**-6.57*** ± 3.1**
L1 to FH(r)	**0.49 ± 1.7**	**-5.78*** ± 3.0**
L1 to FH(l)	**1.10 ± 2.3**	**-5.98*** ± 3.4**
L1 to Me-Go(r)	**0.26 ± 1.1**	**-3.48** ± 3.5**
L1 to Me-Go(l)	**0.35 ± 1.4**	**-3.23* ± 4.2**
Me to Go(r) to Cc(r)	**-1.02 ± 2.6**	**1.71* ± 1.4**
Me to Go(l) to Cc(l)	0.25 ± 1.8	1.70 ± 1.6
Me-Go(r) to FH(r)	-0.29 ± 1.8	0.53 ± 1.1
Me-Go(l) to FH(l)	-0.45 ± 2.5	0.82 ± 1.2
Me-Go(r) to SN	**-0.66 ± 1.5**	**1.32* ± 1.8**
Me-Go(l) to SN	-0.20 ± 1.9	1.41 ± 2.3
Or(r) to A to Or(l)	1.70 ± 6.3	-2.24 ± 8.5
Cc(r) to A to Cc(l)	0.17 ± 10.9	-7.71 ± 20.0
Or(r) to U1tip to Or(l)	-2.03 ± 3.1	1.74 ± 5.0
Or(r) to Me to Or(l)	-1.25 ± 2.6	-0.52 ± 2.9
Cc(r) to L1tip to Cc(l)	1.54 ± 5.9	-6.10 ± 10.3
Cc(r) to Me to Cc(l)	-0.25 ± 3.5	1.41 ± 6.1
Go(r) to Me to Go(l)	0.41 ± 6.5	-4.38 ± 11.4

*Unpaired t-test: mean values differed significantly at *p<0.05, **p<0.01, ***p<0.001*

4.7 Summary

The Twin Block appliance was effective in improving Class II malocclusions by a reduction in overbite and overjet, and correction of canine and molar relationships from Class II to Class I occlusion. Mandibular movements, such as maximum opening, maximum protrusion and lateral excursions also increased after six months of treatment.

Maximum protrusive force was greater in males than females and increased with time but treatment with the Twin Block appliance had a limiting effect on the increase. Fatiguing protrusive muscles did not lead to an alteration in the mandibular position which had been corrected by the Twin Block appliance. Therefore, forward posturing of the mandible was not the reason for the improvement in maxillo-mandibular relationships.

Condylar axial angle relative to the midline decreased with time in the control group but the Twin Block appliance altered this direction of change. MRI demonstrated the translation of the mandibular condyle by the Twin Block appliance to the crest of the eminence at the beginning of treatment, but after six months of treatment the mandibular condyle had apparently moved back into the glenoid fossa. However, the condyle was in a more anterior position in the fossa in the CTB group than the controls. The prevalence of disc displacement was high with 27.5% of all the children displaying Class II division 1 malocclusions. It appeared that the disc became more posteriorly positioned relative to the condyle with time and the Twin Block appliance had little effect on disc position. There was no evidence of "disc recapture" in any of the children with disc displacement after treatment with the Twin Block appliance.

Three-dimensional cephalometric analysis demonstrated a significant increase in facial height as a result of treatment with the Twin Block appliance. Class II correction was achieved by retraction of upper incisors, proclination of lower incisors, redirection of maxillary growth and an increase in effective mandibular length, associated with an increase in gonial angle. However, the Twin Block appliance appeared to have limited skeletal effects.

Chapter 5 DISCUSSION

Topics:

5.1 Clinical Aspects

5.1.1 Sample selection and limitations

This thesis presents the findings of a prospective study which was designed to minimise variation in stage of development, severity of malocclusion and craniofacial characteristics of the children under investigation. At the same time, the sample size needed to be sufficient for meaningful statistical analysis. Given the nature of biomedical research, there were certain limitations. Initial selection of the children was dependent upon the judgement of dentists employed by the South Australian Dental Service. Despite verbal and written explanations of the selection criteria, the agreement between referring dentists and the orthodontist researcher about which children represented suitable cases was approximately 60%. This was lower than a previously reported survey (Pietila *et al*, 1992), where agreement on treatment needs for orthodontic patients between general practitioners and orthodontic specialists was approximately 70%. The recruitment of the patients was spread over 16 months. The number of girls involved was less than boys due to the pattern of referrals and this imbalance was more pronounced in the MRI investigation where there were only four girls in the CTB/female subgroup. Therefore, any statistical analyses among subgroups needed to be interpreted with caution. Sexual dimorphism that has been reported in previous studies, such as for condylar width (Tadej *et al*, 1989; Christiansen & Thompson, 1990b) and mandibular growth (Buschang *et al*, 1982; Lewis *et al*, 1982; Buschang *et al*, 1986), could not be demonstrated in this study. This was possibly due to small sample sizes and consequent lack of statistical power.

The fact that no apparent relationships could be established between age and muscle force, condylar width, eminence angle or condylar angle from the cross-sectional data available in this present study may have been due to the limited age range of children under investigation and the short duration of the study.

Assignment of children to the control or CTB groups was made essentially at random. However, given that the Twin Block is a tooth-borne appliance, retention was a problem for some children with transitional dentitions due to lack of suitably retentive teeth. Therefore, these children could not be assigned to the CTB group. Consequently, the number of children with late mixed dentitions was higher in the control group. However, the distributions of chronological age and SMI were similar between the control and CTB groups. It was considered that this slight difference in dental age should not bias the outcome of comparisons between these groups.

5.1.2 Timing of treatment

Successful treatment results using functional appliances rely on favourable growth. It has been proposed that patients with Class II malocclusions should be treated during the acceleration phase of their peak growth velocity so that the maximum stimulation of mandibular growth can be achieved in the shortest treatment time (Hägg & Pancherz, 1988). Most common methods for prediction of growth stages have been based on incremental height and skeletal development of hand and wrist bones (Grave & Brown, 1976; Hägg & Taranger, 1980; Taranger & Hägg, 1980; Fishman, 1982). Other methods include serial cephalometric radiographs, uptake of technetium-99m methylene diphosphonate, and developmental stages of the hyoid bone or cervical vertebrae, (Kaban *et al*, 1982; Mitani & Sato, 1992). Dental development has been found to be a poor predictor of mandibular growth (Liebgott, 1978; Luder, 1985). Some studies have shown that the timing of maximum growth velocity of the mandible varies more widely than that of other growth indicators such as skeletal age, incremental height or secondary sex characteristics (Lewis *et al*, 1982; Sato & Mitani, 1990; Mitani & Sato, 1992; Tulloch *et al*, 1997). Therefore, the use of other growth indicators in predicting the timing of mandibular growth is insufficient for many clinical applications. Other factors such as co-operation, psychological problems, periodontal tissue status, and prevention of dental trauma play an important role in deciding the timing of treatment (Sadowsky, 1998; Tung & Kiyak, 1998).

An early study of the Herbst appliance has recommended that treatment of male patients should commence at the stage of the initial closure of the middle phalanx of the third finger (MP3-FG) because this is the time when patients display the greatest amount of sagittal condylar growth (Hägg & Pancherz, 1988). Later studies (Hansen *et al*, 1991) have concluded that the Herbst appliance is equally efficient in patients treated before and after the pubertal peak of growth. Moreover, the growth period in which treatment was performed did not seem to have any conclusive effect on the long-term results (Konik *et al*, 1997). Several reports on treatment with functional appliances are in agreement that treatment outcome and post-treatment stability are similar whether treatment is commenced at an early or late stage of development (Harris *et al*, 1994; Gianelly, 1995; Livieratos & Johnston, 1995; Tulloch *et al*, 1997). These findings suggest that the optimal timing of treatment may be in the late mixed dentition, thus avoiding a lengthy retention phase before subsequent orthodontic treatment. However, because of the high prevalence of dental trauma noted in the group of children who participated in the present study, early treatment to minimise the risks of damage to incisor teeth may be justified.

Although statistically significant, the correlation coefficients among selected growth and developmental indicators used in the present study were moderate to low in magnitude. Correlations between SMI or chronological age and maximum protrusive force were also weak. Correlations between articular eminence angle and chronological age, dental age or SMI did not reach significance. The effectiveness of treatment with the CTB, reflected by reduction in overbite and overjet, muscular adaptation, and condylar adaptation did not depend on the rate of skeletal growth indicated by incremental height or SMI. Other factors such as stage of dentition, severity of malocclusion, psychological condition (ADD), and physical status were found to have little effect on treatment outcome.

In this present study, co-operation of the children during treatment depended on individual temperament rather than age. Children with unfavourable results often reported an inability to wear the appliance full-time. However, it has been acknowledged that it is not possible to verify the level of co-operation by clinical assessment of compliance alone. In fact, with the use of micro-electronic timing devices, it has been shown that most patients fulfil only 50% to 60% of the orthodontist's requirements even though clinical assessment of compliance may appear to be excellent (Sahm *et al*, 1990). In the present study, there was some evidence that children who displayed favourable results may not have worn the appliance full-time. Therefore, it was not possible to determine the optimal time for wearing the appliance to achieve maximum effect.

5.2 Muscle Testing

5.2.1 Methodology, accuracy and validity

One of the objectives of the present study was to develop a new approach to study mandibular protruding musculature including lateral pterygoid muscle function and to test whether the lateral pterygoid muscle was responsible for mandibular repositioning after Twin Block treatment. Many studies have explored the role of the mandibular protrusive musculature in promoting growth at the condylar cartilage and overall lengthening of the lower jaw, with emphasis on the lateral pterygoid muscle (McNamara, 1973; Petrovic *et al*, 1975; McNamara *et al*, 1982). However, the lateral pterygoid muscle is difficult to access beneath the overlying structures. It is not possible to directly palpate the lateral pterygoid muscle clinically (Wanman & Agerberg, 1986) and any attempt to do so poses the possibility of confusion with the sensitivity of other muscles such as medial pterygoid or temporalis muscles (Johnstone & Templeton, 1980; White, 1985). Moreover, the study of lateral pterygoid function using EMG is generally invasive and may lead to discomfort, muscle soreness, jaw stiffness and occasionally haematomas or infections in human subjects (Koole *et al*, 1990). The method used in this study provided a non-invasive alternative to study the lateral pterygoid together with other protrusive muscles. It was not demanding and was well accepted by most children with the exception of three who had poor muscle co-ordination.

The present method assessed the combined function of the protrusive muscles. Protrusion of the mandible results from contraction of the lateral pterygoid muscle and the superficial part of the masseter muscle which also has an antero-posterior orientation to its muscle fibres (Easton & Carlson, 1990; Uchida, 1990; Hinton, 1991). Although both of these muscles have a protrusive effect on mandibular movements, their controlling mechanisms on mandibular growth appear to be different. Bilateral resection of the superficial portion of the masseter muscle has been shown to result in reduction of ramus height and bone apposition in the muscle attachment area, but did not seem to affect overall mandibular length (Hinton, 1991). On the other hand, myotomy of the lateral pterygoid muscle results in a significant decrease in mitotic activity of the condylar cartilage, and consequently, retardation of mandibular growth (Hinton, 1990). Furthermore, the responses of these muscles to functional appliances also differ. Cephalometrically, the masseter has been shown to increase 5-15% in length whereas the lateral pterygoid decreases 25% in length when a functional appliance is in place (Ahlgren & Bendeus, 1982). Histochemical analysis of muscle fibre types in rats shows that the superficial masseter muscle exhibits a significantly greater percentage of both type IIa and type IIb fibres whereas the lateral pterygoid muscle exhibits a significantly greater area occupied by type I fibres. The lateral pterygoid muscle becomes more active with respect to postural activity, whereas the superficial masseter becomes more active phasically as a result of functional appliance therapy (Easton & Carlson, 1990). It was not possible to differentiate the force and fatigue responses of the different protrusive muscles in this study.

To the best of the author's knowledge, the study of protrusive force has only been reported once in adult females by Marklund & Molin (1972) who have concluded that the maximum protrusive force in females with mandibular pain dysfunction syndrome was only half that produced by normal controls. The maximum protrusive force in asymptomatic control females was approximately 60 kilopond (KP). Maximum protrusive force was also the highest among horizontal forces such as retrusive or laterotrusive forces.

Marklund & Molin (1972) have measured the force via an acrylic splint on the mandibular teeth but the system was not calibrated and the measurement did not eliminate simultaneous biting force during protrusion. In the present study, the methodology was improved giving reliable recordings of protrusive force with minimal interference from jaw closure forces. Measurement of protrusive force was performed at the chin because this area was less susceptible to pain than the teeth. Hence, the maximum protrusive force was not limited or modified by pain receptors in the periodontal ligament. Sexual dimorphism for maximum protrusive force was demonstrated for the first time in the present study.

Although the mean variation in protrusive force due to measurement error was low in the present study, high individual variability was noted. The variation ranged from 65.6% to -33.4%. The random error was high which resulted in low reliability of the measurements (Reliability = 54%). Therefore, careful interpretation of the results was needed. High variation in the measurement of muscle function has been reported frequently. EMG studies of masseter and lateral pterygoid muscles during maximum protrusion in young adults also show variability between the side of recording and between recording sessions (Dahan & Boitte, 1986). Between-day sessions show more variation than within-day sessions. Individual variation has been found to be higher for the lateral pterygoid (65.9%) than for the masseter (31.2%). Alteration in muscle recruitment pattern between sessions has been hypothesised as a contributing factor to this variability. It is also important to note that during maximum protrusion, other muscles such as digastric, medial pterygoid or temporalis may participate in bracing the condylar head against the articular eminence (Wood *et al*, 1986). Therefore, the maximum protrusive force measured in the present study was the result of the collective actions of various muscles in the system. Similar protrusive performances observed on different occasions may derive from different muscle recruit patterns, thus resulting in high variation in the protrusive force produced. This finding agrees with the recent study by Scutter and Türker (1998) who have found that recording muscle recruitment patterns in controlled jaw muscle contractions is very hard to achieve unless the EMG of the muscle of interest is used as feedback.

The present study illustrates the difficulty in controlling muscle recruitment patterns in a restricted jaw movement. Even though head and jaw positions of the subjects were stable and reproducible, the force data for the repeated experiment changed dramatically and illustrated the difficulty in recruiting the protrusive muscles reliably between experiments. Furthermore, maximum protrusive movement requires an unusual contraction and does not have a defined endpoint, such as clenching or biting on a hard substance. Hence it is difficult to perform the task with equal strength each time, especially in young children. Contractile characteristics of protractor muscles may be very variable and subject to fatigue. External factors such as motivation, attention, learning experience, fear and discomfort may also have influenced the force outcome (Lazarus & Todor, 1991; Ingervall & Minder, 1997).

5.2.2 Maximum protrusive force and bite force

The most extensive investigations to date of the force generated by masticatory muscles are those of bite force and the relationship of bite force to craniofacial and physical characteristics. The present study did not aim to compare the function of bite force and protrusive force, as they are generated by different groups of muscles, but to compare their relationship with general factors such as age, gender and physical characteristics.

In the present study, maximum protrusive force (80.3 ± 30.7 N) was found to be approximately 10 times less than previously reported maximum bite force (Linderholm *et al*, 1971; Ingervall & Minder, 1997), with a wide range of individual variation.

Physical characteristics such as gender, age and body size have been found to be related to the force generated by the isometric contraction of skeletal muscles (Backman, 1988a; Backman & Henriksson, 1988b; Backman *et al*, 1989). Julien *et al* (1996) have reported higher masticatory performance in males than in females and in subjects with greater body weight. Yuen *et al* (1989) have demonstrated different EMG power spectra of the masticatory muscles between males and females, and among different age groups. Sexual dimorphism has been reported in several bite force studies (Kiliaridis *et al*, 1993; Braun *et al*, 1995a; Ingervall & Minder, 1997). However, Lindqvist and Rinqvist (1973) and Helle *et al* (1983) have not found any significant difference in bite force between boys and girls. Significant but weak positive correlations between age (Helle *et al*, 1983; Ono *et al*, 1992; Kiliaridis *et al*, 1993; Ingervall & Minder, 1997) and body stature (Linderholm *et al*, 1971; Kiliaridis *et al*, 1993; Braun *et al*, 1995a) with bite force have also been demonstrated.

Using cross-sectional data from the present study, no significant association between age, height or weight and protrusive force was found. Only gender was found to be associated with protrusive force, with boys producing higher maximum protrusive forces than girls.

In this present study, the comparisons between pre-treatment and 6-months follow up revealed contradictory results between control and CTB groups. The significant increase of maximum protrusive force in the control group was considered to be a result of normal growth and development. As inter-individual variation was large, this may explain why no association between protrusive force and age or stature could be demonstrated when using the cross-sectional data. The results from the present study were very similar to those of a longitudinal study by Braun *et al* (1996) who found that bite force increased over a 2-year observation period. However, no association of age or stature was found in a previous cross-sectional study (Braun *et al*, 1995a). The increase in bite force is hypothesised to reflect an increase in muscle mass and the difference between males and females is more obvious after post-pubertal growth. The role of muscle mass in increasing bite force is supported by other studies (Sasaki *et al*, 1989; Van Spronsen *et al*, 1989; Van Spronsen *et al*, 1992).

In the present study, a trend towards an increase in maximum protrusive force was also found in the CTB group but it did not reach a significant level. It was hypothesised that the functional appliance would alter the neuromuscular system. Muscular adaptation can be expressed as alteration in muscle length, reorientation of muscle fibres or relocation of muscle attachment. As previously mentioned, the lateral pterygoid and masseter respond differently to functional appliances so it is possible that the lateral pterygoid may reduce in length as it adapts to a new mandibular position. The net increase in muscle mass due to growth and development in the CTB group could be less than that in the control group. Shortening of the lateral pterygoid muscle as a response to Twin Block appliance therapy has also been demonstrated in monkeys (Yamin-Lacouture *et al*, 1997).

Braun *et al* (1995a) have reported that subjects with TMJ symptoms did not exhibit a significantly different maximum bite force than subjects without symptoms, while Marklund & Molin (1972) have reported a significant reduction of maximum protrusive force in females with TMD symptoms. None of the children in the present study had clinical signs or symptoms of TMD but disc displacement was found in 12 of 40 children during MRI examination. Maximum protrusive force in the group of children with disc displacement was not significantly different from those without disc displacement (Table 87).

Table 87 ▪ Comparison of maximum protrusive force in children with and without disc displacement.

	Maximum protrusive force (N) Mean ± SD
Children with disc displacement (n = 12)	88.7 ± 29.8
Children without disc displacement (n = 28)	87.5 ± 31.9

5.2.3 Lateral pterygoid hypothesis

The lateral pterygoid hypothesis emphasises the significance of this muscle in controlling condylar growth, with stimulation of activity leading to stimulation of condylar growth (Charlier *et al*, 1969; McNamara, 1973; McNamara, 1974b; Petrovic, 1974; Moyers & McNamara, 1975; Petrovic *et al*, 1975; Stutzmann & Petrovic, 1979; Petrovic *et al*, 1981; McNamara & Bryan, 1987; Oudet *et al*, 1988; Stutzmann & Petrovic, 1990). Experiments designed to test this hypothesis have sought to answer the following questions:

Question 1: Does the lateral pterygoid muscle control condylar growth? If it does, then removal of the muscle should result in retardation of mandibular growth.

Question 2: Does an increase of lateral pterygoid activity result in increased mandibular growth? If it does, any treatments aimed at stimulating mandibular growth should be directed at stimulating lateral pterygoid activity. Moreover, an increase in lateral pterygoid activity would be expected to continue throughout the period of increased mandibular growth to maintain long-term stability.

Question 3: What modalities can be used to stimulate lateral pterygoid activity? Does functional appliance therapy increase lateral pterygoid activity? If it does, increased mandibular growth should be expected and the lateral pterygoid hypothesis would be accepted. If it does not, the lateral pterygoid hypothesis would be rejected and other mechanisms would be needed to explain how functional appliances work.

To attempt to answer question 1, the lateral pterygoid muscle has been removed in experimental animals. Surgical resection of the lateral pterygoid muscle has been shown to retard condylar growth (Hinton, 1990; Stutzmann & Petrovic, 1990; Hinton, 1991). However, results of other experiments do not support the alteration of condylar growth after lateral pterygoid myotomy (Goret *et al*, 1983; Whetten & Johnston, 1985; Awn *et al*, 1987). Moreover, myotomy of the lateral pterygoid muscle may not result directly in inhibition of its function in the long-term. Retardation of condylar growth may result from post-operative trauma and feeding difficulties (Burke & McNamara, 1979b).

Experimental protocols aimed at answering question 2 are very limited. This is because the modality to increase muscular activity is unclear. One method of increasing lateral pterygoid activity is to use electrical stimulation (Takahashi *et al*, 1995). Results from this approach suggest that the activity of the lateral pterygoid muscle might play a significant role in the differentiation of progenitor cells and in the maturation and calcification of chondrocytes in mandibular condyles.

More experiments have been designed to answer question 3. Early experiments supported the hypothesis that functional appliances increase lateral pterygoid activity (Charlier *et al*, 1969; McNamara, 1973; McNamara, 1974a; McNamara, 1974b; Auf der Maur, 1980; Oudet *et al*, 1988; Stutzmann & Petrovic, 1990). However, later experiments have demonstrated that, although an increase in lateral pterygoid activity is evident, it is transient and does not parallel the increase in mandibular growth (Hiyama, 1996). These findings do not support the lateral pterygoid hypothesis. Results indicate that mandibular adaptation to functional adaptation is not dependent on the intensity and duration of the muscular activity alone. On the other hand, some researches dispute that functional appliances increase lateral pterygoid activity (Sessle *et al*, 1990; Yamin-Lacouture *et al*, 1997). A transient decrease in lateral pterygoid activity after the use of functional appliances has been explained by the physical shortening of the lateral pterygoid muscle. A reduction of EMG activity associated with shortened muscle length has also been reported (Lindauer *et al*, 1991). Results of these studies have also failed to support the lateral pterygoid hypothesis.

In the present study, the lateral pterygoid hypothesis was tested using a different approach. Based on the hypothesis, it can be assumed that the mandible was held in the new position after CTB treatment by means of hyperactivity or contraction of the lateral pterygoid muscle. It was expected that fatiguing the protrusive muscles by continuous isometric protrusion for a long period of time would result in relaxation of the muscles. Consequently, it would be possible to alter the mandibular position from a muscle-controlled position (forward position achieved by muscle contraction) to a structural-control position (position where the condyle seated in the glenoid fossa). However, the position of the mandible did not change significantly after fatiguing the protrusive muscles in this study. This result could be interpreted in two ways:

Postulation 1: The lateral pterygoid muscle was not responsible for the new position of the mandible after treatment with the CTB and, therefore, the lateral pterygoid hypothesis could be rejected.

Postulation 2: During the 6-month period of treatment with the CTB, structural changes (skeletal or dentoalveolar) had occurred at the same rate as muscular adaptation. Therefore, the muscular control position of the mandible was the same as the structural-control position. This possibility would lead to neither accepting nor rejecting the lateral pterygoid hypothesis.

In this present study, examination of MRIs showed that condyles were in their glenoid fossae after six months of treatment with the CTB. However, assessment of condylar concentricity in clinically successful cases, revealed that the condyles were more anteriorly positioned within the fossa. Therefore, discrepancies between the muscle-control position of the mandible and structural-control position were evident. Moreover, results from fatigue tests conducted periodically in some children in the CTB group did not demonstrate any alteration in mandibular position after fatiguing the protrusive muscles. This present study, therefore, does not provide support for the lateral pterygoid hypothesis. However, it is acknowledged that the results of the present study did not represent the activity of the lateral pterygoid muscle alone, but rather a combination of all the protrusive muscles. In addition, functional appliances have been reported to alter the proportion of muscle fibre types in the lateral pterygoid muscle (Oudet *et al*, 1988), with fast, non-fatigable fibres increased significantly. It is possible that the methodology in the present study failed to completely fatigue all of the protrusive muscles.

It is interesting that the lateral pterygoid hypothesis has been applied only to treatment of Class II malocclusions. If the lateral pterygoid hypothesis is to apply to treatment of Class III malocclusions, inhibition of lateral pterygoid activity would be an objective of treatment to limit mandibular growth. In reality, the treatment of Class III malocclusions with functional appliances focuses on an increase of pressure to the condyle in order to decrease cell proliferation (Van Vuuren, 1991) rather than a reduction of protrusive muscle activity or stimulation of retrusive muscle activity.

5.3 MRI

This study demonstrated the effectiveness of using MRI to visualise the morphologic variations of the TMJ in three different planes, i.e., axial, sagittal and coronal, in children with Class II division 1 malocclusions. Axial condylar shape and axial condylar angle were analysed from axial scout images.

Sagittal concentricity, slope of the articular eminence and sagittal position of the posterior band of the disc were analysed from corrected sagittal images. Coronal condylar shape, coronal width and coronal disc position were analysed from corrected coronal images. No significant differences between boys and girls were found in any of the variables studied, reflecting the wide variation that existed in the whole sample. Moreover, when children were grouped according to gender, the small sample size in the subgroup of girls led to a lack of statistical power.

Different MRI sequences were considered for use in this study. One of the limiting factors was the time used for the scanning, as it was difficult for young children to keep still for a long time. T1-weighted imaging was selected because it required relatively shorter time (short TE and short TR) than proton density (long TE and short TR) or T2-weighted images (long TE and long TR). Because the signal was received within a short time after the RF-pulses were turned off, the high signal to noise ratio resulted in images with better definition for both hard and soft tissue than either T2-weighted or proton density sequences.

Concerns have been expressed about favourable TMJ adaptation during orthodontic treatment using functional appliances to correct the antero-posterior jaw relationship in growing patients with Class II division 1 malocclusions by repositioning the mandible anteriorly (Gianelly, 1995; Livieratos & Johnston, 1995; Tulloch *et al*, 1997; Tulloch *et al*, 1998). Adverse effects such as disc displacement associated with functional appliance therapy has also been reported (Foucart *et al*, 1998). This prospective study has demonstrated favourable changes occurring in the TMJ as a result of growth alone compared with changes resulting from growth and treatment effects from the CTB therapy.

The use of MRI to demonstrate TMJ adaptation during functional appliance therapy (Herbst appliance) has recently been reported by Ruf & Pancherz (1998; 1999). However, their studies do not include a control group for comparison. The present study has demonstrated a similar type of TMJ adaptation to a new mandibular position as that found by Ruf & Pancherz (1998). The condyle that was located anteriorly by functional appliances appeared to move back into the fossa. Ruf & Pancherz (1998) have demonstrated an increase of MRI signal at the posterior-superior border of the condyle and at the anterior surface of the postglenoid spine of the fossa that has not been demonstrated previously. This increase in MRI signal was interpreted as being associated with remodelling and the effects on the condyle were more prominent than on the fossa. The increase in MRI signal was found only after six to 12 weeks of therapy but could not be seen at the end of treatment (seven months). However, Ruf & Pancherz (1998) did not specify whether or when the remodelling process had ceased. To maintain the condyle-fossa relationship, remodelling would also be expected at the articular eminence but this was not demonstrated in their study. In the present study, no increase of MRI signal was seen. It is possible that the MRI obtained in the present study at six months after treatment may have missed this "remodelling process" or that the MRI sequence used was different from Ruf & Pancherz (1998). Periodical MRI at shorter intervals is needed to clarify this phenomenon.

5.3.1 Condylar head shape

Concavo-convex axial condylar shapes were observed most often in the present study, a finding consistent with Christiansen *et al* (1987) based on CT scans. In four cases, the shape of the condyle pre-treatment was different from that six months later. The variation in shape was considered to result from the difference in levels at which the slices were obtained (Figure 85).

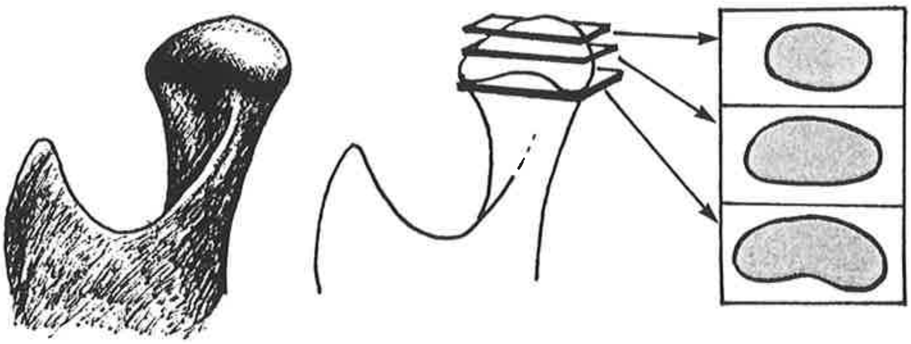


Figure 85 ▪ Variation in axial condylar shape according to the level of MRI slice.

The distribution of axial condylar head shapes viewed from submento-vertex radiographs (Pandis *et al*, 1991) differed from the findings of this present study. The concavo-convex form (named as convex type in their study) was the least common type when viewed from submento-vertex radiographs. Pandis *et al* (1991) have also demonstrated that the variation in anterior joint space seen on sagittal tomograms moving from the medial to lateral pole, is found only in this convex type. The condyle can appear to be positioned posteriorly when viewed from tomograms taken from the centre of the axial concavity while condylar position viewed from more medial or lateral tomograms may appear more concentric. The reliability of using condylar concentricity as an indication of optimum condylar position has been questioned (Pullinger *et al*, 1985; Pullinger & Hollender, 1985; Zhao, 1993). Based on the above hypothesis of Pandis *et al* (1991), it was expected that posteriorly positioned condyles would be found most often because concavo-convex shapes were most often seen in this present study. However, the opposite result was found. Anteriorly positioned condyles were most common in the present study. Comparisons between MRI, CT scans and submento-vertex radiographs need to be made with caution. MRI and CT scans use only one section (slice) from the condylar head and, therefore, the level of cut can affect the appearance of the image. Submento-vertex radiographs (SMV), on the other hand, represent the sum of superimpositions from all levels onto one image. No clinical implication of condylar axial shape has been presented by previous researchers (Christiansen *et al*, 1987).

5.3.2 Coronal condylar width

Coronal or mediolateral condylar width determined in the present study was similar to values reported in previous studies except for the study by Seren *et al* (1994) where condylar width was smaller (Table 88). Mediolateral width of the condylar head has been shown previously to display a positive correlation with age (Tadej *et al*, 1989; Nickel *et al*, 1997). Sexual dimorphism, with males displaying greater mediolateral condylar width than females, has also been reported (Tadej *et al*, 1989; Christiansen & Thompson, 1990b). Class III patients have also been found to have larger mediolateral condylar width than Class I patients (Seren *et al*, 1994).

Table 88 ▪ Mediolateral condylar width from different studies

Authors	Technique	Subject	Width (mm)
Tadej *et al*, 1989	SMV	Adolescent male	19.7 ± 1.8
		Adolescent female	18.7 ± 2.1
Christiansen & Thompson, 1990b	CT	Adult male	19.6
		Adult female	17.7
Seren *et al*, 1994	CT	Adult Class I	16.0 ± 1.0
		Adult Class III	17.2 ± 2.1
Present study	MRI	Children male	19.2 ± 2.3
		Children female	18.7 ± 2.3

Although in the present study, average coronal condylar width in boys tended to be consistently larger than in girls, this difference was not statistically significant reflecting the small sample size for girls. No correlation was found between age and coronal width in either the cross-sectional or longitudinal data. According to Nickel *et al* (1997), rapid changes in mediolateral condylar width tend to be found at a younger age than that of the children in the present study (Figure 86). The present study also included a relatively narrow age group for cross-sectional data and a short period of observation for longitudinal data.

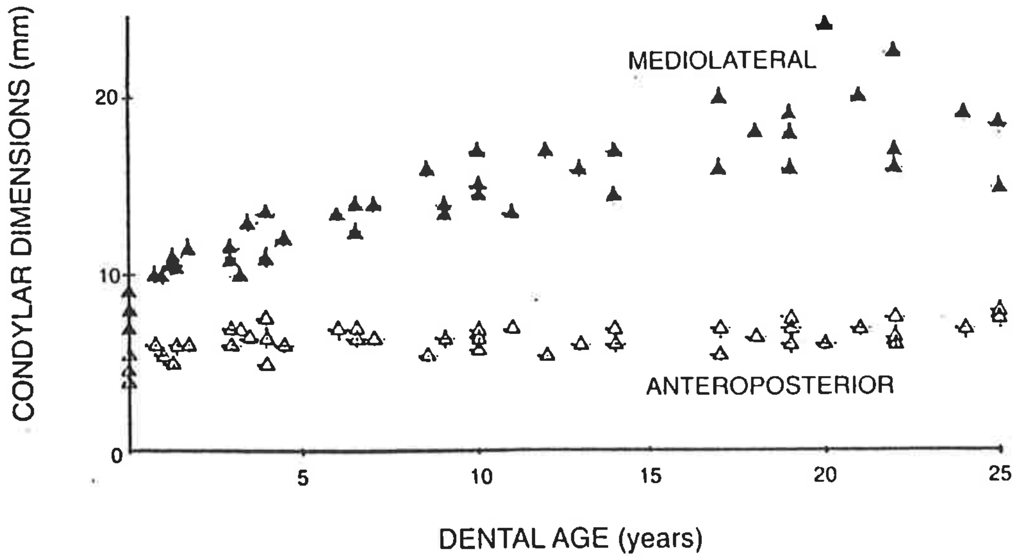


Figure 86 ▪ Condylar dimensions vs. age (Nickel *et al*, 1997).
(Condylar dimensions were measured from osteological remains from Hamman-Todd and Johns Hopkins Osteological Collections, Cleveland Museum of Natural History.)

5.3.3 Axial angle

Axial angles reported from previous studies show wide variation, probably reflecting the different techniques used and subjects investigated. Condylar axial angles derived from MRI in the present study were relatively small (55.5° ± 9.0°) with wider variation than reported in other studies (Table 89). The children in the present study had Class II malocclusions and were juveniles who were undergoing growth and development. Therefore, the results may not be directly comparable to other studies in which more mature subjects were analysed. Future research is needed to clarify whether small axial angles are associated with Class II malocclusions and/or represent a "normal" stage of development. No sexual dimorphism in axial angle was found in this study or in previous studies. Westesson *et al* (1991) have reported progressive reduction of axial angle relative to the midline in groups of patients with disc displacement with reduction, disc displacement without reduction, and degenerative joint disease respectively. It was hypothesised that remodelling associated with internal derangement and degenerative joint disease resulted in this alteration of axial angle. However, Ebner *et al* (1990) have not found any statistically significant differences in axial angles between normal condyles and those displaying osseous abnormalities. In the present study, axial condylar angles of the children with disc displacement were not significantly different from the rest of the children.

Table 89 ▪ Data for axial condylar angles obtained from different studies.

Authors	Subject	Technique	Axial angle
Mohl, 1988	Not stated	Not stated	72° to 80°
Tadej *et al*, 1989	Adolescents (62.5 % were Class II)	SMV	65° ± 6°
Danforth *et al*, 1991	Adults, dry skulls	Photograph	68° to 98°
		SMV	58° to 86°
Westesson *et al*, 1991	Adults	MRI	69°
Seren *et al*, 1994	Adults Class I	CT	68.7° ± 4.0°
	Adults Class III		71.2° ± 3.0°
Present study	Children, Class II	MRI	40° to 72° (55.5° ± 9.0°)

Axial condylar angles of children in the control group were significantly smaller at the 6-month observation period, whereas there was no significant difference between pre-treatment and 6-month records for the children in the CTB group. No clear explanation can be given for this finding. Future research is needed to determine whether reduction of axial angle with age is a characteristic of the growth patterns of children with Class II malocclusions. It is possible that CTB therapy altered the orientation of the condyle from its original growth pattern and consequently no further reduction of condylar axial angle was evident.

5.3.4 Condylar position

TMJ condylar position has been described as the position of the mandibular condyles in their glenoid fossae when the teeth are in maximum intercuspation (McNeill, 1985). Clinicians have tended to base their diagnosis and treatment of temporomandibular joint disorders on concepts of ideal condylar position. However, controversy exists over what constitutes optimal condylar position in the fossa. This controversy is attributed to the inconsistency of research methodology (Abdel Fattah, 1989). Although there are some studies that use lateral cephalograms in assessing condylar position (Luecke & Johnston, 1992; Braun *et al*, 1997; Braun *et al*, 1997), they are considered to be inappropriate for making comparisons with the present study. Firstly, this study used a corrected sagittal plane (sagittal plane relative to TMJ) to analyse the condylar position while cephalometric studies have used true sagittal planes (sagittal plane relative to patient's midline). Secondly, the image of the TMJs and fossae are usually poorly defined on cephalograms. Superimposition of condyles from both sides also contributes to errors in cephalometric analyses. The present study is in agreement with Gilbert *et al* (1994) who have concluded that cephalometric radiographs are inadequate for clinical monitoring of condylar position. Therefore, comparisons of the results in the present study with studies using corrected tomography, CT scans and MRI would seem to be more appropriate.

Condylar concentricity is found in approximately 50% to 65% of normal asymptomatic individuals and this has been suggested to be the "normal" condylar position (Pullinger *et al*, 1985; Pullinger *et al*, 1986; Alexander *et al*, 1993; Zhao, 1993). However, these studies have all shown that there is a wide range of variability. Therefore, non-concentricity cannot be justified as a sign of TMD. On the contrary, other studies have noted that non-concentric condyles are a common finding (Cohlmia *et al*, 1996) and that different condylar positions are often found in individuals with normal TMJs (Ren *et al*, 1995a). Several studies have reported that anteriorly positioned condyles are common in Class II populations (Pullinger *et al*, 1987; Gianelly *et al*, 1991a; Gianelly *et al*, 1991b). Conversely, other studies have reported that anteriorly positioned condyles are common in Class III subjects (Seren *et al*, 1994; Cohlmia *et al*, 1996). Several studies have failed to demonstrate a correlation between specific dental parameters and condylar position (Demisch *et al*, 1992; Gianelly *et al*, 1991a; Gianelly *et al*, 1991b).

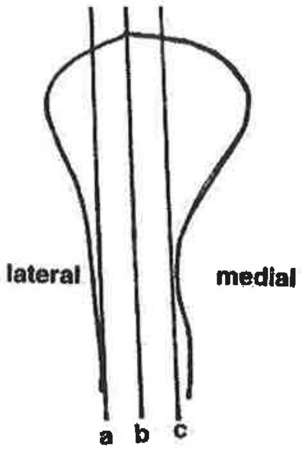
In the present study, initial MRIs showed that most of the condyles were non-concentric with anteriorly positioned condyles observed in the majority of children. This finding did not support the claim by "Functional Orthodontists" who have stated that mandibular retrognathic patients possess distally positioned condyles as a result of forward head posture (Witzig & Yerkes, 1985). However, the frequency of posteriorly positioned condyles in this present study was slightly higher than in previous reports (Pullinger & Hollender, 1985; Gianelly *et al*, 1991). No significant difference was found in the distribution of condylar position between boys and girls which does not agree with Pullinger *et al* (1985) who have reported that the distribution of non-concentric condyles was significantly more anterior in men and more posterior in women. Whether condylar positions in children differ from adults needs to be clarified in the future.

Posterior condyle position is considered to be a predisposing factor to disc displacement (Pullinger *et al*, 1986; Abdel Fattah, 1989; Artun *et al*, 1992). The present study did not find any association between posterior condylar position and anterior disc displacement. Only two of the children with posteriorly positioned condyles displayed anterior disc displacement. Moreover, a boy with anterior disc displacement displayed a condyle in a concentric position while another boy with antero-lateral disc displacement exhibited an anteriorly positioned condyle. The present study supported the finding that condyles may be in anterior, posterior or centric positions in many joints with anteriorly displaced discs. Thus, anterior disc displacement is not influenced by posterior condylar position (Alexander *et al*, 1993; Ren *et al*, 1995a).

Asymmetrical condylar position has been reported in patients with skeletal asymmetry (O'Byrn *et al*, 1995), but this study only examined condylar position on the right side, therefore, comparisons of position between the right and left side were not possible.

The relationship between orthodontic treatment and condylar position is also inconclusive. Some studies have reported changes in condylar position after changes of tooth position by orthodontic treatment (Iijima *et al*, 1990; Luecke & Johnston, 1992; Major *et al*, 1997). Others have found that condylar position was unrelated to tooth position or orthodontic treatment; either extraction or non-extraction (Pullinger *et al*, 1987; Gianelly *et al*, 1991; Gianelly *et al*, 1991a). Hamilton *et al* (1987) have found no significant changes in condylar position during therapy with Fränkel appliances. Gianelly *et al* (1983) have reported that the position of the condyle was forward on the eminence in four out of 10 patients after one year of treatment with Fränkel appliances. Using MRI, Ruf and Pancherz (1998) have found anteriorly positioned condyles in the majority of children they studied. Although Ruf and Pancherz (1998) have concluded that the condyle-fossa relationship was on average unaffected by Herbst therapy, the position of the condyle was more anterior in 53% of the children after treatment. In the present study, a significant difference was found in the distribution of condylar positions in the group of children judged to show a successful result after 6 months of treatment with the CTB. Condylar position was evenly distributed in the pre-treatment MRI but after 6 months of treatment, anterior condylar positions were in the majority. This change was not obvious by visual inspection, as the condyles appeared to be seated normally in their glenoid fossae, but calculation of condylar position based on anterior and posterior joint spaces revealed these subtle changes. None of the children demonstrated "duel bite" or "Sunday bite"(described as forward posturing of the mandible where the condyle is situated outside the fossa) as a result of treatment with the CTB. It would be interesting to investigate condylar position of these children in the future to evaluate its final or permanent position.

On examining consecutive sagittal sections, considerable variation in condylar position was found across the joint (Figure 87). This indicated that condylar position was not uniform from lateral pole through to medial pole and selection of slice for analysis of condylar position was crucial to the outcome. In the present study, the sagittal slice selected was the one that showed the maximum condylar head and neck outline and it was assumed that the selected slice represented the condyle at the mid-sagittal cut.



Slice a: more lateral

Slice b: mid sagittal

Slice c: more medial

Figure 87 ▪ Apparent changes in condylar position of the same patient assessed from different MRI slices.

The present study is in agreement with Christiansen and Thompson (1990b) who questioned the significance of condylar position. Moreover, the analysis of condylar position seems to have little significance for clinical application. This is because condylar position does not correlate well with pain, dysfunction or structural changes of the TMJ (Tallents *et al*, 1991). Therefore, information about condylar position has no effect in confirming or changing clinical diagnosis of TMD (White & Pullinger, 1995). However, evaluation of condylar position may have some value for research purposes in longitudinal studies. The present study was able to demonstrate significant changes in condylar position as a result of CTB treatment. This result partly helps to explain the often reported increase in effective mandibular length after functional appliance therapy.

By changing mandibular position and orientation, the commonly used reference landmark Articulare (Ar) is relocated (Figure 88). This results in longer effective mandibular lengths (Ar-Me) even though the mandibles are exactly the same size. The same effect on mandibular length, to a lesser degree, can also be applied when using Condylion (Co) as a landmark, depending on the condylar head shape. Location of Condylion on a round condylar head may not be affected by the movement of the mandible. However, location of Condylion on a flat condyle can be different when mandibular rotation takes place.

The present study agrees with Buschang & Santos-Pinto (1998) that Ar should not be used to describe either condylar growth or fossa displacement. They have demonstrated that using Ar leads to systematic overestimation of inferior fossa displacement and posterior condylar growth but underestimation of vertical condylar growth. Furthermore, Ar cannot be used in three-dimensional measurements, as the mandibular ramus does not in fact intersect the occipital bone.

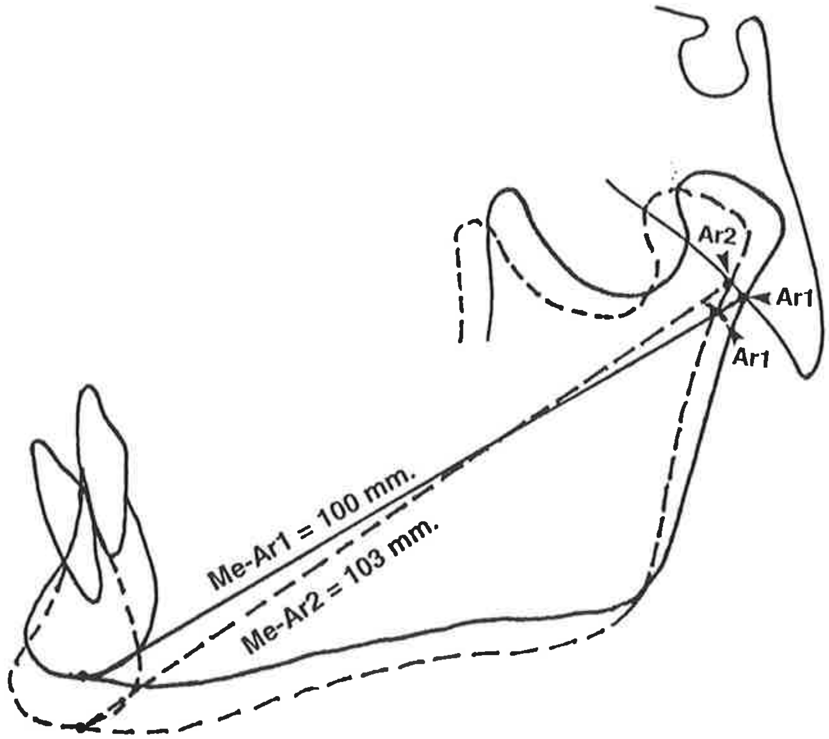


Figure 88 ▪ Effect of changing condylar position on the location of the landmark, Articulare, and the apparent increase of effective mandibular length.

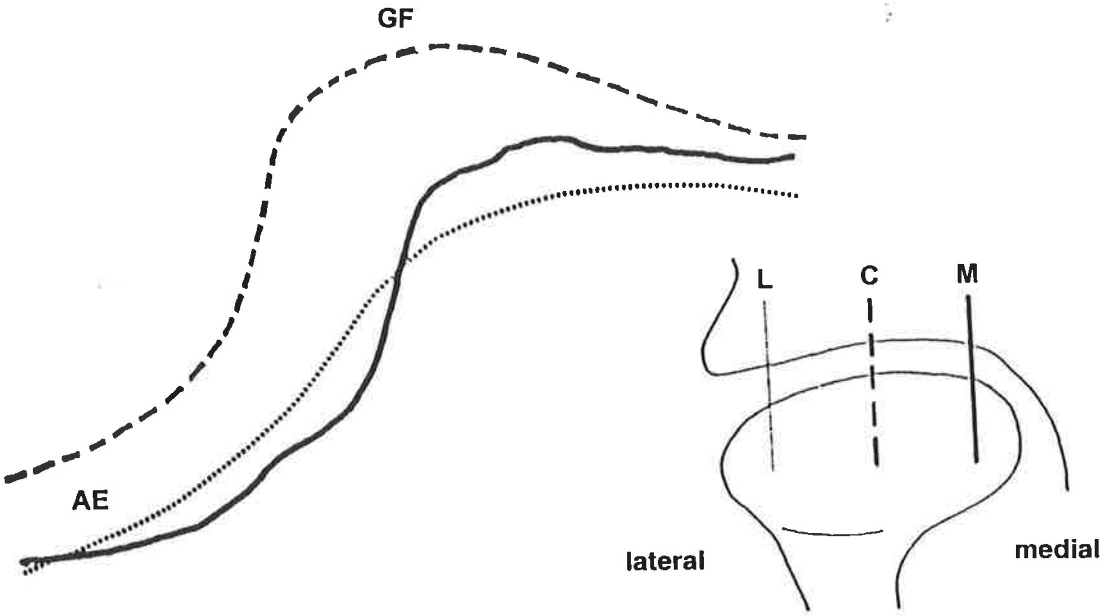
5.3.5 Articular eminence

Various reference lines have been used to measure articular structures such as: occlusal plane (Nickel *et al*, 1988a; Carano & Keller, 1990; Keller & Carano, 1991; Nickel & McLachlan, 1994; Nickel *et al*, 1997); palatal plane or cranial base (Kantomaa, 1988; Kantomaa, 1989); Frankfort horizontal plane (Christiansen *et al*, 1987; Christiansen & Thompson, 1990b; Ikai *et al*, 1997); a line parallel to the edge of the film (Panmekiate *et al*, 1991a; Panmekiate *et al*, 1995b) or even a visual horizontal line (Pullinger *et al*, 1985). Selection of stable anatomical landmarks for construction of reference lines on the MRI is difficult, as the field of view for investigation is limited. Reference lines such as occlusal plane, palatal plane, cranial base or Frankfort Horizontal plane are not readily available. Anatomical landmarks shown on the MRI also vary depending on the slice selection. Use of the edge of the film or a visual horizontal line relies on patient positioning which can vary between MRI sessions and therefore give questionable reproducibility for longitudinal comparison.

In the present study, use of the PC-line was selected because it was readily available on the MRI and did not rely on head position in the scanner. Although Murakami *et al* (1993) have used anatomical landmarks, such as the most inferior point on the articular eminence and the most inferior point on the post-glenoid process, the location of the inferior point on the post-glenoid process was not consistently found in chosen MRI slices. The disadvantage of the PC-line is that it based on the mandible which is movable. Mandibular rotation by growth or treatment can affect the orientation of the reference line. Remodelling of the posterior part of the ramus may also alter the orientation of the PC-line. This effect was demonstrated in this study. The change in the PC-line orientation is discussed in further detail in the "disc position" section (section 4.3.6).

For longitudinal studies, the use of craniofacial structures to determine reference lines such as the Frankfort Horizontal line (FH-line) is preferred. The use of a special head frame with lead and lipid markers in the present study allowed the reference plane to be transferred from cephalograms onto the MRIs. This reference FH-line is based on more stable structures. However, for the study of growing children, the FH-line is also influenced by growth remodelling. Additional steps to transfer the reference line can also increase the random error of the study. The present study has reported results relative to both the PC-line and FH-line. The FH-line was the reference line based on upper facial structures while the PC-line was based on the mandible. The relationship between both reference lines demonstrated the change between the upper and lower jaws in the longitudinal study. The change in the relationship between the two reference lines is discussed in the "disc position" section (section 4.3.6).

Variation in the steepness of the articular eminence from medial to lateral regions in the sagittal plane has been demonstrated previously (Christiansen & Thompson, 1990b; Ichikawa *et al*, 1990; Ren *et al*, 1995b; Ikai *et al*, 1997). These studies indicate a consistent trend for the steepness to be least laterally and greatest centrally (Figure 89).



AE = articular eminence, GF = glenoid fossa,

L = lateral, C = central, M = medial

Figure 89 ▪ Variation of the steepness of articular eminence from lateral slice to medial slice from the study by Christiansen & Thompson (1990b). The steepness of the eminence is least laterally and greatest centrally.

In contrast to Christiansen & Thompson (1990b), the present study found inconsistent variation in the steepness of the eminence from the lateral slice through to the medial slice (Figure 90). Selection of the slice from medial, mid-sagittal or lateral regions for measurement could consequently affect the results.

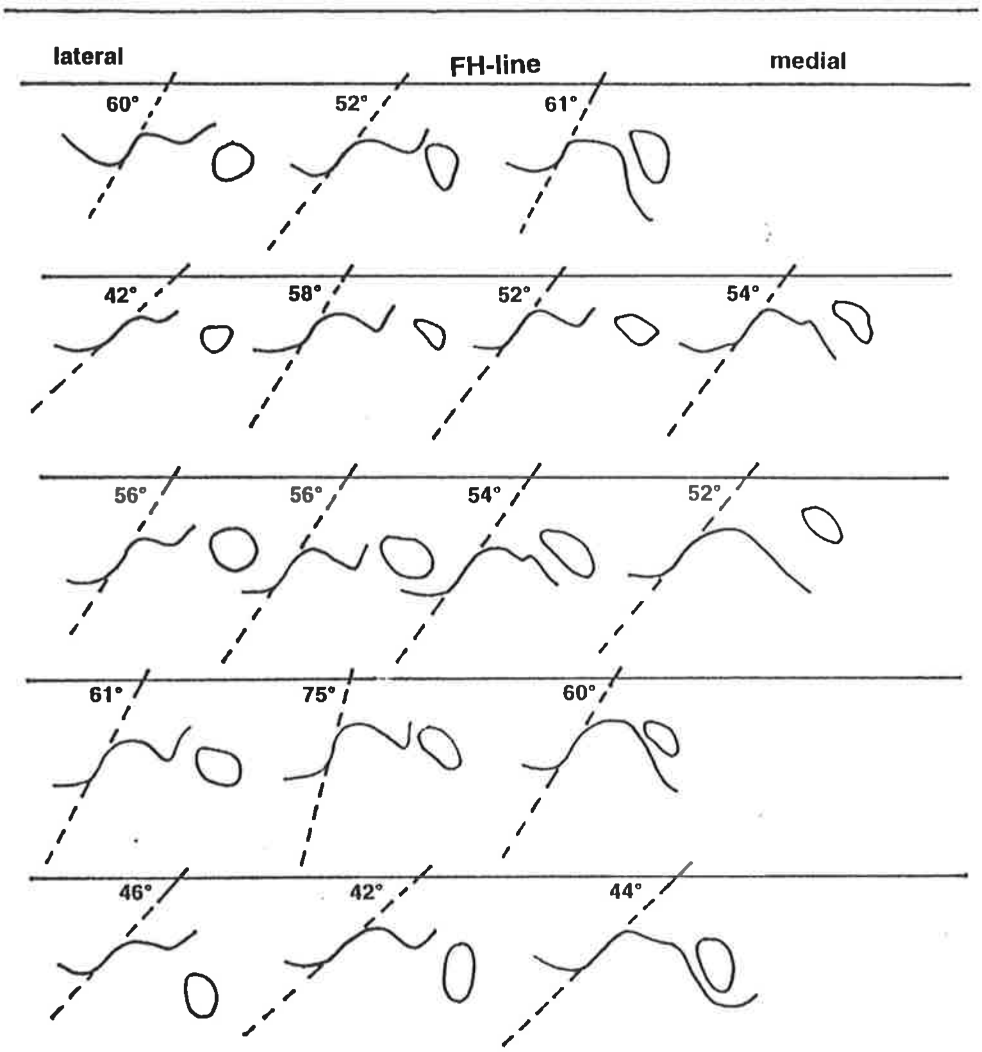


Figure 90 ▪ Variation of the steepness of articular eminence from lateral slice to medial slice of five children from this study

The steepness of the articular eminence has been shown to increase with age, with a strong relationship to functional loading of the TMJ (Thilander *et al*, 1976; Nickel *et al*, 1988a; Nickel & McLachlan, 1994; Poikela *et al*, 1995; Osborn, 1996; Nickel *et al*, 1997). In the present study, although a positive relationship between age and the steepness of the eminence was found, it did not reach significance. In a previous cross-sectional study (Nickel *et al*, 1997), a strong relationship between age and articular eminence angle has been found from birth to approximately 10 years of age. The correlation is weaker and approaching zero in the older age range (Figure 92). The age of the children in the present study ranged from 8 to 14 years and this may explain why the calculated correlation was low and did not reach significance.

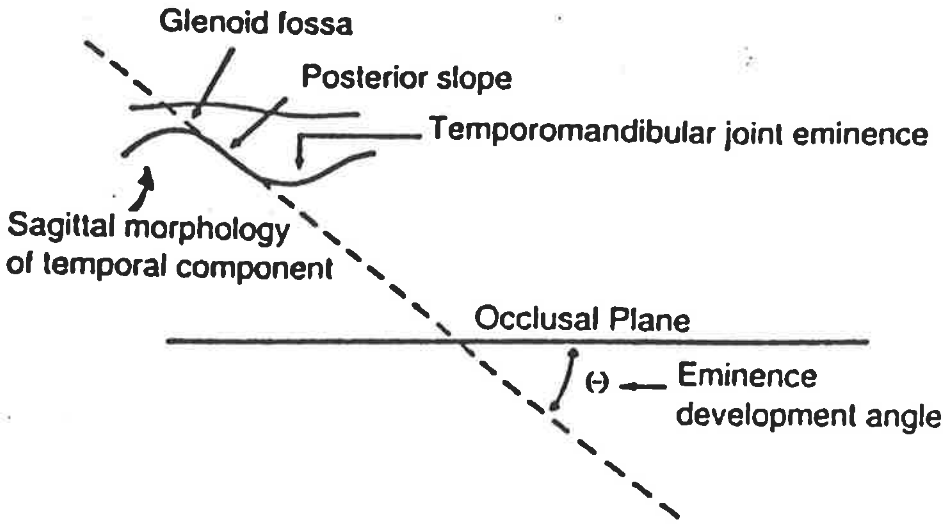


Figure 91 ▪ Method of measuring eminence angle by Nickel *et al* (1997). The eminence angle is a measurement of the steepness of the posterior slope of the eminence relative to occlusal plane in the sagittal view

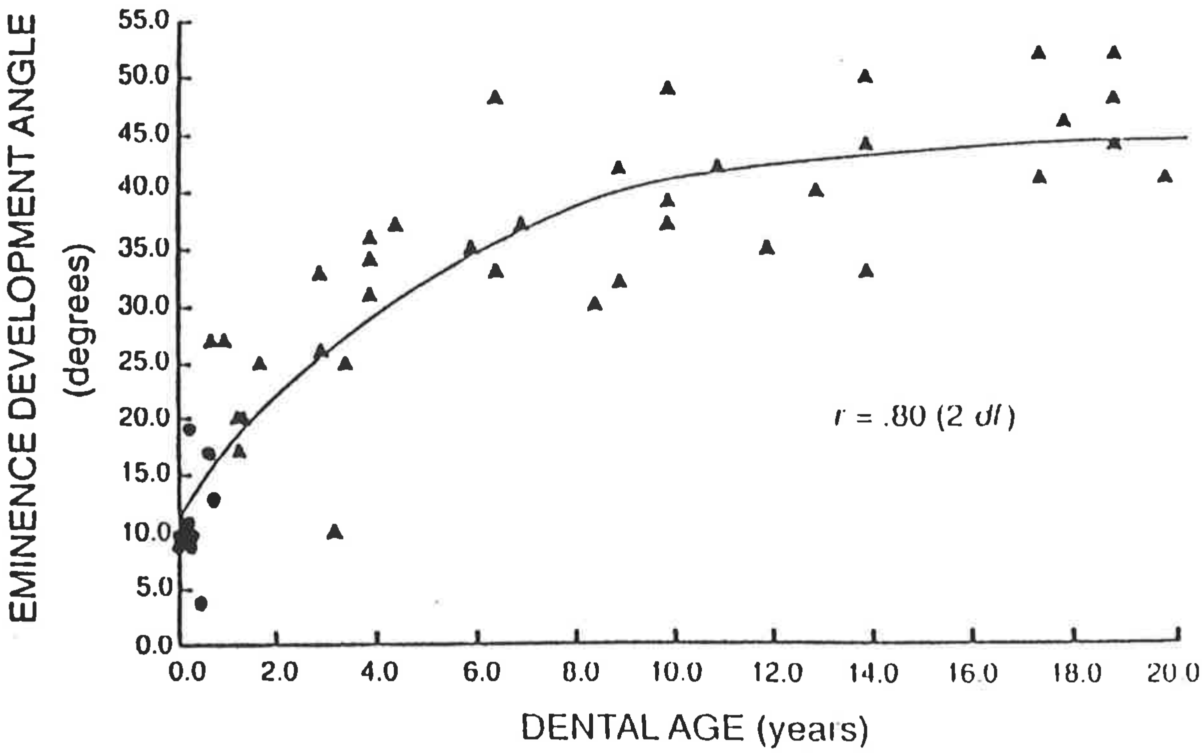


Figure 92 ▪ Eminence development angle vs. age (Nickel *et al*, 1997).

The angle of the eminence is believed to influence growth direction of the mandible. Steep eminences have been associated with more vertically oriented condylar growth and/or a retrognathic mandible while shallow fossae have been associated with more horizontal growth (Kantomaa, 1988; Kantomaa, 1989; Pirttiniemi *et al*, 1990; Pirttiniemi *et al*, 1991; Savastano & Craca, 1991; Tuominen *et al*, 1993). The results from the present study cannot be directly compared with previous studies due to the different techniques and reference lines used. Whether Class II children have steeper eminences than Class I or Class III children needs to be determined by further research.

To improve a Class II skeletal relationship from the use of a functional appliance, horizontal mandibular growth is anticipated. Consequently, a shallower eminence angle might be expected. Over the 6 months of observation in the present study, the eminence angle did not change significantly in either the control or the CTB groups. It was possible that the articular eminence was unaffected by CTB treatment or that the period of observation was too short for the remodelling of the eminence to be obvious. Previous studies have shown that remodelling in the fossa is less pronounced than in the condyle (Kuroe & Ito, 1990; Ruf & Pancherz, 1998).

Relocation of the glenoid fossa as a result of treatment with functional appliances has been demonstrated using cephalometric landmarks (Wieslander, 1984; Vargervik & Harvold, 1985; Woodside *et al*, 1987). However, these studies considered the glenoid fossa to be a single entity and did not reveal any intra-articular remodelling mechanisms that may lead to relocation of the fossa. A method of combining the data from MRI and 3D-cephalometric reconstructions using geometric co-ordinates of the calibration frame is being developed for a future investigation of remodelling patterns in the fossa.

Whether any relationship exists between the steepness of the eminence and disc displacement is unclear. A majority of previous studies have reported no significant correlation between the steepness of the eminence and disc displacement (Panmekiate *et al*, 1991a; Panmekiate *et al*, 1991b; Pullinger *et* *al*, 1993a; Galante *et al*, 1995; Sato *et al*, 1996), whereas some studies implicate a shallow eminence angle to be a predisposing condition for disc displacement (Carano & Keller, 1990; Keller & Carano, 1991). Conversely, other researchers have hypothesised that shallow eminences found in disc displacement cases may result from remodelling or degenerative changes of the bone following disc displacement (Ren *et al*, 1995b). No relationship between the steepness of the articular eminence and disc displacement could be demonstrated in the group of children examined in the present study.

5.3.6 Disc position

One of the advantages of MRI is its ability to depict soft tissue as well as hard tissue with high accuracy (Bell *et al*, 1992; De Laat *et al*, 1993; Santler *et al*, 1993; Tasaki *et al*, 1993; Tasaki & Westesson, 1993; Westesson, 1993; Yabuta *et al*, 1993; Liedberg *et al*, 1996). MRI is a reliable tool to visualise disc position, disc shape, disc deformity and disc behaviour during motion. It may be used for determining the 'disc recapture' position for splint therapy (Cohen & MacAfee, 1994). MRI has indicated a higher prevalence of internal derangement conditions than can be identified clinically (Brady *et al*, 1993; Marguelles Bonnet *et al*, 1995; Muller Leisse *et al*, 1996). On the other hand, MRI did not confirm disc displacement in 25% of the patients who were clinically diagnosed as having disc displacement (Davant *et al*, 1993). Therefore, diagnosis of disc displacement based on clinical signs and symptoms alone is questionable.

In the present study, measurement of disc position was modified from Drace and Enzmann's method (Drace & Enzmann, 1990). To construct the 12 o'clock point in the present study, the PC-line was used instead of the vertical axis of the condylar head because of better reproducibility. The 12 o'clock point in this study was approximately 20° posterior to that of Drace and Enzmann's. Although the reading of disc position relative to 12 o'clock was different between the two studies, the distribution of the position of posterior band of the disc was similar to Drace and Enzmann's study when their entire group of 30 asymptomatic subjects was analysed (Table 90). However, Drace and

Enzmann's study excluded subjects with histories of trauma and orthodontic treatment to derive a so-called "normal range" of the posterior band position using the range of mean ± 2SD (0° ± 10°).

Table 90 ▪ Comparison of disc position (posterior band) between the study of Drace and Enzmann (1990) and the present investigation.

	Subjects	Disc position Mean ± SD
Drace & Enzmann, 1990	• All subjects (n = 50)	5.1° ± 10.4°
	• Subjects with <u>no</u> history of trauma or orthodontics (n = 31)	0.2° ± 4.6°
	• Subjects with history of trauma or orthodontics (n = 19)	16.1° ± 23.2°
Present investigation (Initial MRI, control and CTB groups combined)	• Class II division 1 (n = 40) (42% had history of dental trauma)	24.8° ± 14.4°

Because disc displacement has been found to be associated with a history of facial trauma (Sullivan *et al*, 1995) and mandibular retrognathia (Schellhas *et al*, 1993; Bosio *et al*, 1998), it was assumed that the prevalence of disc displacement in the group of children in this present study would be high. Use of a range of the mean ± 2SD as recommended by Drace and Enzmann would be likely to include disc displacement cases within the so-called "normal range". Therefore, the mean value ± one SD was used to represent the "normal range" in the present study. Even though a range of one standard deviation either side of the mean was used, the calculated "normal range" in the present study was still approximately 10° greater than Drace and Enzmann's norm. Eight children (20%) were classified as having anterior disc displacement. However, when judged the appearance as described by Scapino and Mills (1997), only three children (7.5%) were classified as having anterior disc displacement. All of these three children displayed condyles that were posteriorly positioned relative to the fossa.

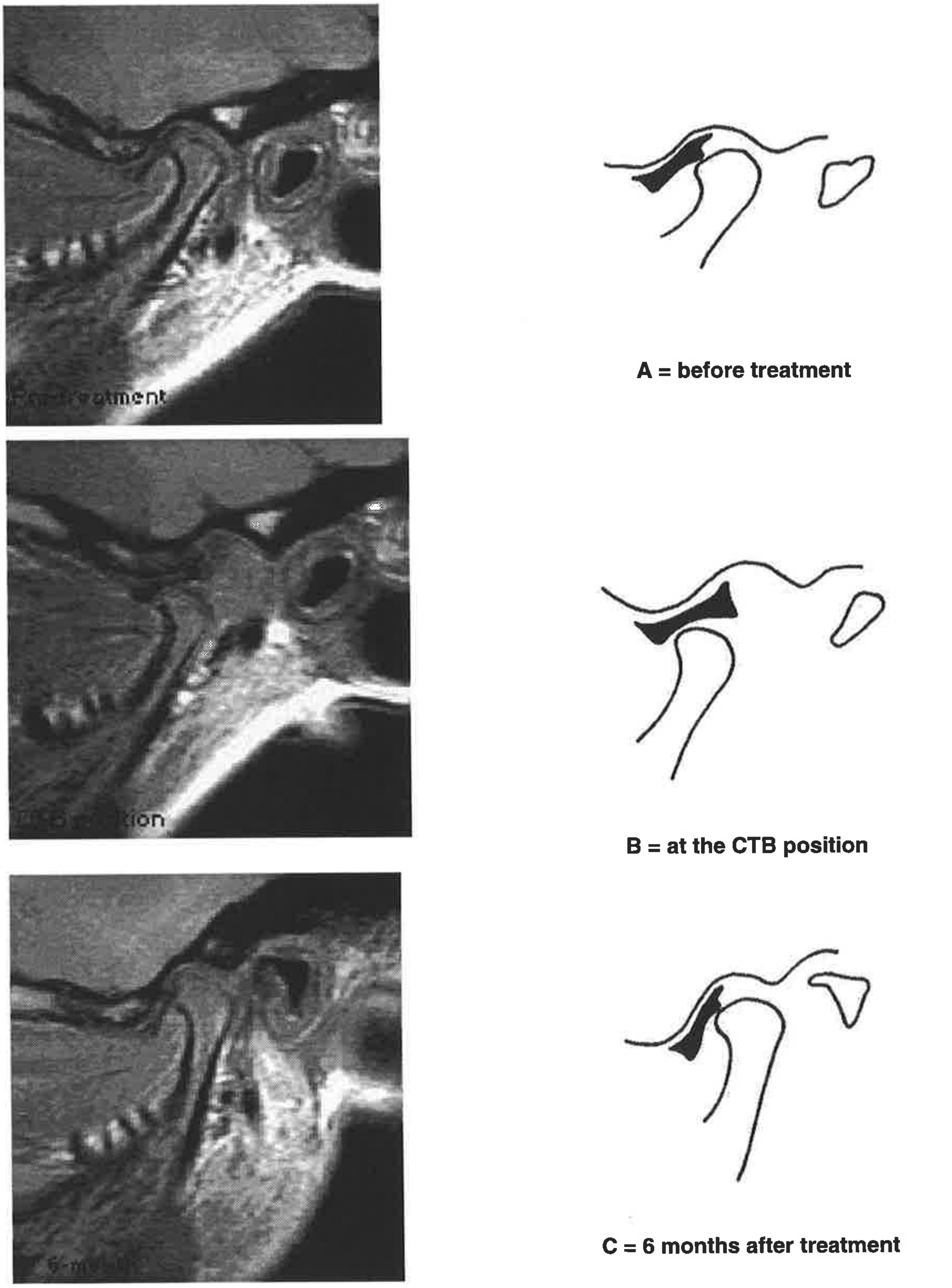


Figure 93 ▪ Appearance of sagittal MRIs from a girl (female/CTB/G.M.) who was considered as having anterior disc displacement. No evidence of "disc recapture" after treatment was found.

Coronal images are very helpful in detecting medial and lateral disc displacement that would have been missed if the diagnosis was based on sagittal images alone (Brooks & Westesson, 1993; Tasaki & Westesson, 1993; Wilkinson & Crowley, 1994). The reported prevalences of medial and lateral disc displacement were 13% (Tasaki & Westesson, 1993), 20.8% (Matsuda *et al*, 1994) and 26% (Brooks & Westesson, 1993). In this study, the prevalence of lateral disc displacement was 17.5% and the prevalence of medial disc displacement was 5%. Categorising medial or lateral disc displacement was less ambiguous in this present study than determining anterior disc displacement.

Prevalence of disc displacement in asymptomatic volunteers has been reported to range form 16% to 35% (Table 91), and in this study 30% of the asymptomatic children displayed disc displacement. Based on previous studies, this group of children would be considered to be a high-risk group because of their history of dental trauma and retrognathic mandibles. No consistent MRI characteristics associated with disc displacement were found (Table 92).

Table 91 ▪ Prevalence of disc displacement from previous studies

Authors	Subjects	Prevalence
Solberg *et al*, 1985	Young adult (autopsy)	12%
Drace & Enzmann, 1990	Asymptomatic adult	16%
Liedberg *et al*, 1990	Adult (autopsy)	33%
Dijkgraaf *et al*, 1992	Adult (autopsy)	25%-35%
Jih *et al*, 1992	Adult (autopsy)	68%
Davant *et al*, 1993	Asymptomatic adult	35%
De Leeuw *et al*, 1995	Adult with TMD	90%
Tasaki *et al*, 1996	Adult with TMD	82%
	Asymptomatic adult	30%
Hans *et al*, 1992	Children (orthodontic patients)	12%

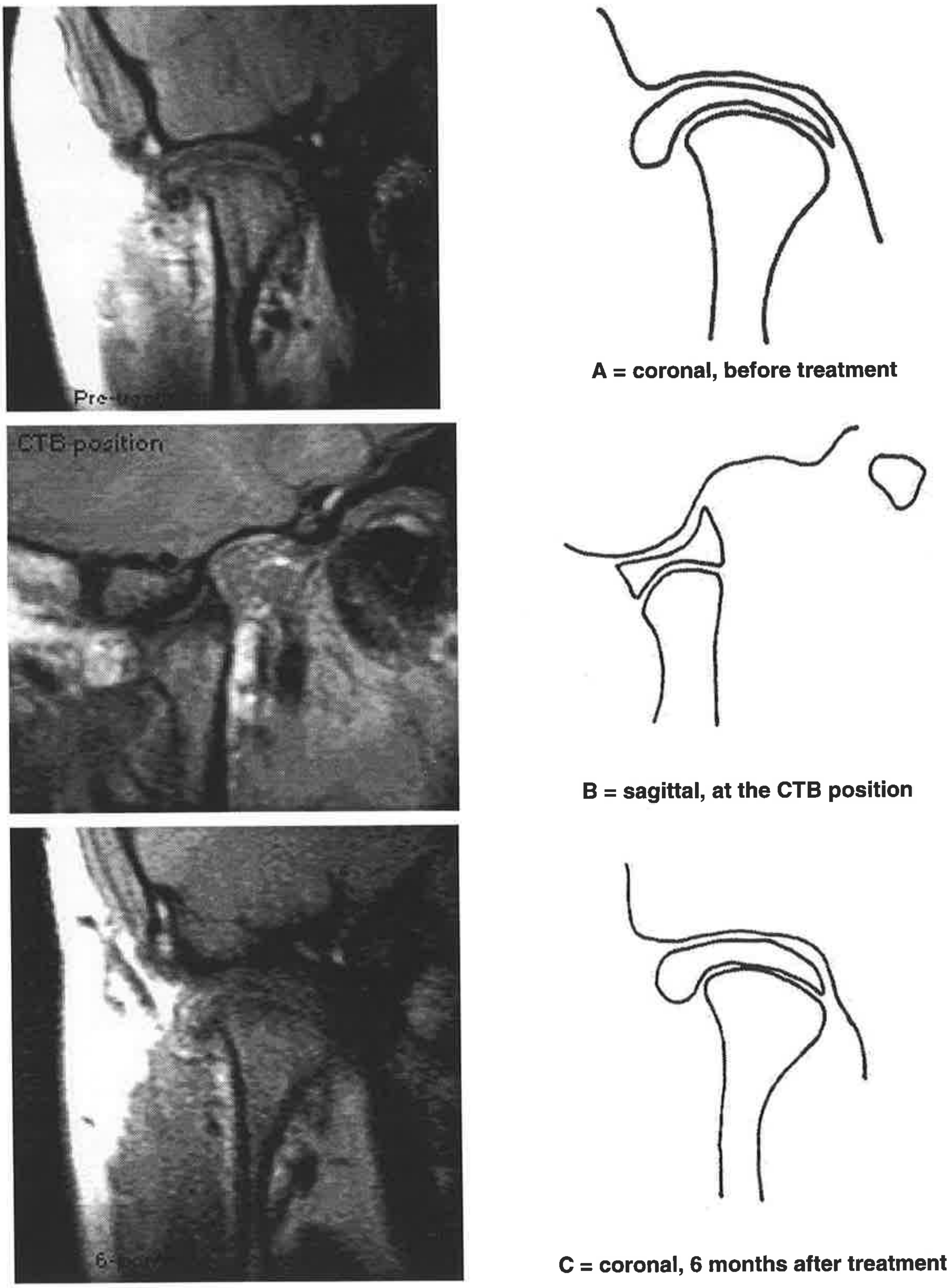


Figure 94 ▪ Appearance of coronal and sagittal MRIs from a boy (Male/CTB/L.J.) who was considered as having lateral disc displacement. No evidence of "disc recapture" after treatment was found.

(Note: Poor quality image was due to patient movement during MRI scanning)

Table 92 ▪ Summary of characteristics of children with disc displacement .

Children ID	Type of disc displacement	Age	Sex	Eminence steepness	History of trauma	Condylar position
CTB/GM	Anterior	11.6	F	Steep	Yes	Posterior
CTB/BR	Anterior	12.5	M	Normal	Yes	Posterior
CTB/SG	Anterior	12.2	M	Normal	Yes	Posterior
CTB/HD	Lateral	12.5	M	Normal	No	Anterior
CTB/JR	Lateral	14.7	M	Steep	No	Posterior
CTB/LJ	Lateral	9.7	M	Normal	Yes	Concentric
Control/AH	Lateral	11.6	F	Flat	No	Anterior
Control/TK	Lateral	10.8	F	Flat	No	Anterior
Control/JH	Lateral	11.5	M	Flat	Yes	Posterior
Control/TS	Lateral	11.3	M	Flat	No	Anterior
Control/BW	Medial	10.8	M	Normal	No	Anterior
Control/SM	Medial	10.4	M	Steep	No	Anterior

Lateral disc displacement was more common than medial disc displacement in the present study, in agreement with recent studies (Christiansen & Thompson, 1990b; Matsuda *et al*, 1994; Katzberg, 1996; Tasaki *et al*, 1996; Scapino & Mills, 1997). However, some earlier studies have led to contradictory findings (Khoury & Dolan, 1986; Katzberg *et al*, 1988; Liedberg *et al*, 1990).

Anterior positioning splints have been used commonly to treat disc displacement patients (Cohen & MacAfee, 1994; Joondeph, 1997). The splint aims to decrease adverse loading in the joint and to "recapture" the displaced disc by allowing the condyle to engage under the posterior band of the disc for a period of time. Correction of the subsequent posterior open bite is used to maintain the corrected disc/condyle relationship. Although the objective of functional appliance treatment is different from an anterior positioning splint, the effect on the disc/condyle relationship is similar. Therefore, functional appliances have been recommended for treatment of retrognathic children with disc displacement (Owen, 1988; Owen, 1989; Hall & Nickerson, 1994). However, recent imaging studies of the joint have shown that the rate of "disc recapture" is low even though clinical signs and symptoms of disc displacement may be absent (Kirk, 1991; Chen *et al*, 1995; Hosoki *et al*, 1995). Furthermore, Joondeph (1997) has reported that in the long-term there is a 100% relapse of patients treated in this manner. Histological studies suggest that "disc recapture" may be only a clinical impression. The articular disc remains displaced but the retrodiscal tissues, after the remodelling process, eventually become functional as an articular disc (Pereira Junior *et al*, 1996). In the present study, all of the children with disc displacement showed "disc recapture" in the initial MRI when wearing the CTB appliance. After 6 months of treatment, none of the children showed evidence of "recapture" of the disc.

In the present study, the position of the disc appeared to move posteriorly and closer to the 12 o'clock point when comparing 6-month with initial records for both the control and CTB groups. However, statistical analysis revealed different significance when using different reference lines. When using the **PC-line**, the posterior movement of the ***posterior margin*** of the disc after six months was found to be statistically significant for the CTB group (mean change = -7.6° ± 13.4°, $p<0.05$) but not for the control group (mean change = -3.6° ± 12.6°, $p = 0.22$). However, when using the **FH-line**, both the ***anterior and posterior margins*** of the disc moved posteriorly and closer to the 12 o'clock point for the control group (mean change for anterior margin = -7.1° ± 8.5°, $p<0.01$; mean change for posterior margin = -6.5° ± 9.3°, $p<0.01$). Although the changes were in the same direction, these changes did not reach significance in the CTB group (mean change for anterior margin = -3.5° ± 9.0°, $p=0.10$; mean change for posterior margin = -3.3° ± 8.7°, $p = 0.11$).

The contradictory results obtained when using different reference lines raises the question as to whether the apparent posterior movement of the disc was secondary to a change of the reference lines. If the disc actually moved posteriorly at the 6-month observation, the results should have been the same for both reference lines. But if the reference lines changed, the constructed 12 o'clock point would be affected and consequently would alter the relationship between the disc and the 12 o'clock point. An analysis of the relationship between the two reference lines was performed. It was found that at the 6 months observation, the angle between PC-line and FH-line was significantly decreased in the control group but remained unchanged in the CTB group (Table 93).

Table 93 ▪ Comparison of the angle between the FH-line and the PC-line from initial MRI and 6-month MRI.

	Initial MRI	6-month MRI
Control	**74.2 ± 9.3**	**69.3 * ± 5.3**
CTB	71.2 ± 5.6	70.8 ± 5.1

*Paired t-test: *Mean values for controls differ significantly at p<0.05*

In the **control** group, the disc was found to move posteriorly only when using the FH-line. At the same time, the angle between the FH-line and the PC-line was decreased. There are two possibilities to explain the reduction of the FH-line to the PC-line angle, i.e., either the FH-line tilted anteriorly downward or the PC-line rotated anteriorly upward.

1. If the FH-line tilted anteriorly and downward, the constructed 12 o'clock position relative to the FH-line would be moved forward. Consequently, the disc would appear as if it were situated more posteriorly relative to 12 o'clock/FH-line while disc position relative to the 12 o'clock/PC-line would be relatively unchanged (Figure 95). This postulate is in agreement with the actual result.

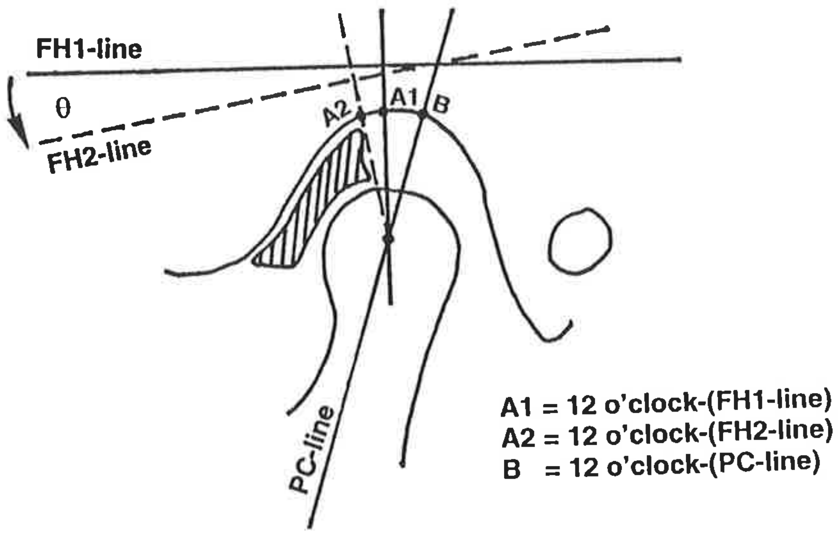


Figure 95 ▪ Change in the 12 o'clock point when the FH-line tilted anterior downward after 6 months of observation. FH-line to PC-line angle at 6 months observation was reduced.

2. If the PC-line rotated anteriorly and upward, the constructed 12 o'clock position relative to the PC-line would be moved posteriorly. Consequently, the disc would appear as if it was situated more anteriorly relative to the 12 o'clock/PC-line (Figure 96). This postulate is contrary to the actual result and can therefore be rejected.

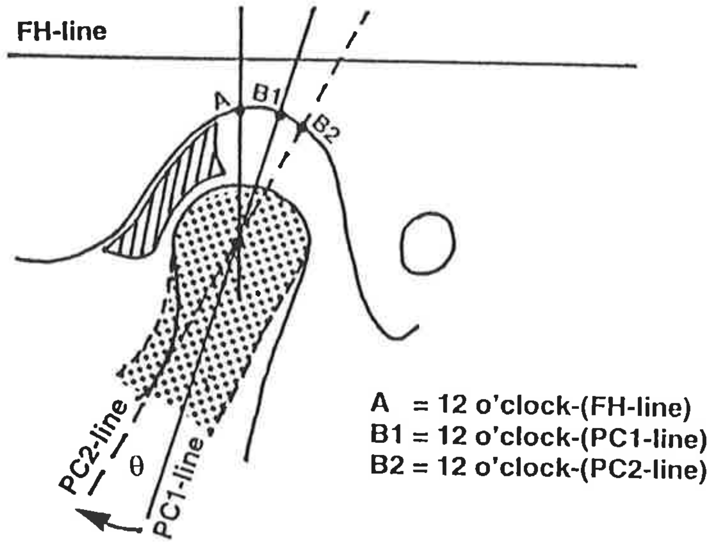


Figure 96 ▪ Change in 12 o'clock point when PC-line rotated anterior upward after 6 months of observation. FH-line to PC-line angle at 6 months observation was reduced.

There was also a possibility that both reference lines had moved. If this was the case, the FH-line would need to tilt downward relatively more than the PC-line tilted upward to be consistent with the actual result.

For the **CTB** group, significant posterior movement of the disc was found only when using the PC-line. The angle between the FH-line and the PC-line was relatively unchanged after 6 months of treatment. If it was assumed that the FH-line behaved the same way as in the control group, consequently the PC-line would rotate anteriorly and downward to the same degree as the FH-line. The constructed 12 o'clock/PC-line and 12 o'clock/FH-line would be moved anteriorly (Figure 97). The disc position would appear closer to both the 12 o'clock/PC-line and the 12 o'clock/FH-line. The average changes in disc position for both PC-line (mean change = -6.5° ± 9.3°) and FH-line (mean change = -3.3° ± 8.7°) were consistent with this explanation. However, the change when using the FH-line did not reach significance, perhaps due to the small sample size and consequent lack of statistical power.

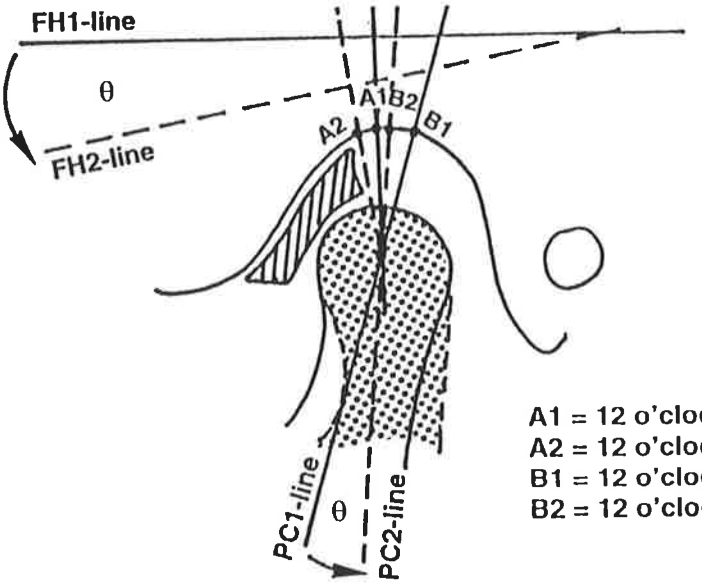


Figure 97 ▪ Change in 12 o'clock point when both FH-line and PC-line tilted anterior downward at the same degree after 6 months of treatment with CTB. The relationship between the two lines is unchanged.

If the FH-line was relatively unchanged, constructed 12 o'clock points relative to both the FH-line and the PC-line would be similar. The apparent position of the disc closer to the 12 o'clock point would be the result of an actual positional change of the disc. Significant changes in disc position would be expected regardless of the reference lines used. The finding that changes in disc position towards the 12 o'clock point occurred relative to both the reference lines could also be explained by this hypothesis. Reduction in power of the statistical test due to the small sample size may be the reason why a significant difference was not found when using FH-line.

Both the hypotheses that the reference lines had changed or that actual movement of the disc had occurred can be applied to explain the findings in the CTB group. However, there would appear to be no reason why the re-orientation of the FH-line that was found in the control group would be different in the CTB groups. It was possible that a combination of re-orientation of the reference line and actual reposition of the disc had occurred and the disc was more posteriorly positioned as a result of CTB treatment. However, three-dimensional cephalometric measurements failed to demonstrate significant changes of the FH-line relative to either the cranial base or palatal plane. Further study using other reference lines is needed to differentiate the mechanisms of positional change of the disc.

The findings from the present study are in contrast to the study by Foucart *et al* (1998) who have found that mean position of the posterior band of the disc is located anteriorly after treatment with the Herbst appliance. This was because of anterior disc displacement found in four cases after treatment in their study. Three lateral disc displacement cases were also found after treatment. None of the children displayed disc displacement on the MRI before treatment. Thus, it has been hypothesised that the Herbst appliance may induce asymptomatic derangements in 23.3% of the cases. In the present study, the number of children with disc displacement was similar before and after treatment with the CTB. It was considered that the CTB had neither positive nor negative effects on the disc displacement cases.

5.4 3D Cephalometric Analysis

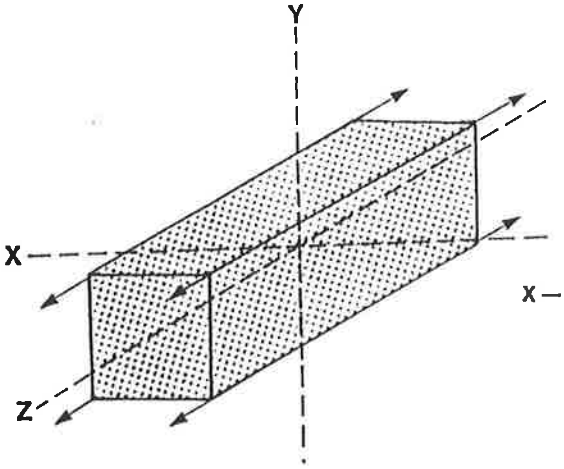
5.4.1 Advantages of Sculptor 3D-cephalometry

➢ ***Co-ordinate system***

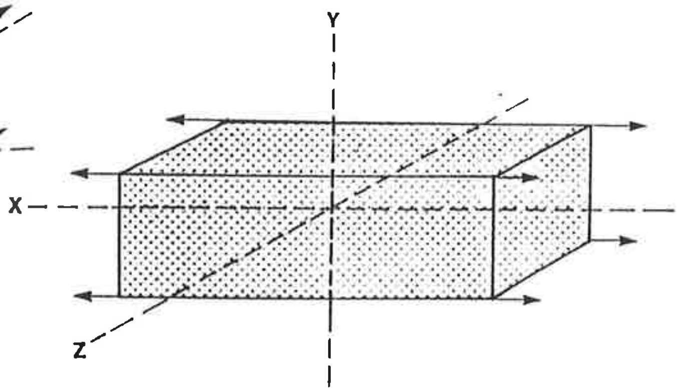
The use of the calibration frame in the Sculptor 3D-cephalometry offers greater flexibility and accuracy than previously reported 3D-cephalometric systems (Grayson *et al*, 1983; Grayson *et al*, 1988; Brown & Abbott, 1989). In previous methods, the position of the subject has been critical for co-ordinating cephalograms with improper positioning leading to greater measurement errors. To obtain multiple radiographs, special settings are required to either rotate the X-ray source or rotate the subject on a platform, minimising the movement of the head between each acquisition. With the Sculptor system, the co-ordination between each cephalogram was based on the calibration frame, therefore, eliminating the need for head fixation by a cephalostat while compensating for non-linear transformation due to perspective magnification and rotation effects. Provided that the calibration head frame is stable on the subject's head, two or more cephalograms can be obtained in any view within a relatively short time using standard radiographic settings. The degree of head rotation between each cephalogram can be calculated precisely using this self-calibration technology. In the present study, approximately 10° of head rotation was used for lateral cephalograms so that superimposition of the condylar head was avoided. It was not possible to position the subject precisely at the same angle for left and right sides but the calibration frame compensated for this variation in positioning.

➢ ***Envelope of errors***

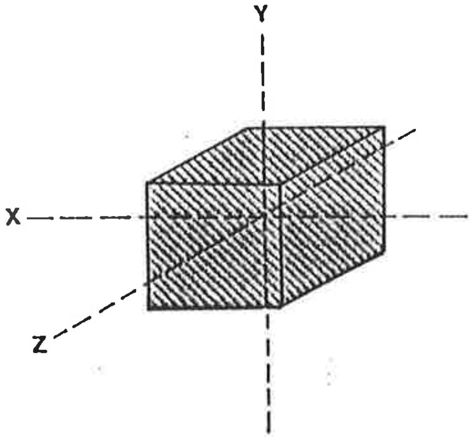
The standard frontal cephalogram provides information and limited errors on X- and Y-axes but no information and unlimited errors on the Z-axis. Lateral cephalograms provide information and limited errors on Y- and Z-axes but no information and unlimited errors on the X-axis. Previous 3D-cephalometric systems have combined these two cephalograms to obtain information and limit errors on X-, Y- and Z-axes (Figure 98). The Sculptor system readily provides information and limited errors on X-, Y- and Z-axes on each cephalogram using an internal co-ordinate system derived from the calibration frame. Each cephalogram provides an ellipsoid envelope of errors. The higher the number of cephalograms used, the narrower the envelope of errors.



A. Envelope of errors form a frontal cephalogram



B. Envelope of errors form a lateral cephalogram



C. Envelope of errors when frontal and lateral cephalograms are combined

Figure 98 ▪ Schematic diagram comparing the sizes of envelope of errors between 2D and 3D cephalometric systems.

In the present study, one frontal and two lateral cephalograms were used thus providing higher accuracy than 3D systems that use only two cephalograms. For example, the information of landmark location from image A is projected onto image B by an epipolar line corresponding to that pixel (picture element). This provided a constraint on the location of the image A point's counterpart on image B because it has to be on or near the projection line. When the same landmark is digitised on image C, the epipolar lines from image A and B intersect on image C, therefore, location of the landmark on image C is under multiple constraints from image A and B. This means that three confirmations were available for each landmark. This technique is very helpful for landmarks such as "Porion" that can be seen on two lateral cephalograms but not on the frontal cephalogram.

When multiple cephalograms are used, the radiation dose to the subject needs to be considered. The radiation can be reduced by using digital imaging where relatively low radiation is used and the image is enhanced for clarity. However, random errors associated with angular and linear measurements recorded on the digital images have been found to be greater than on the conventional radiographs (Macri & Wenzel, 1993; Forsyth *et al*, 1996b).

➢ ***System requirements***

The basic requirement to run the Sculptor system is a 75 MHz or faster Pentium PC with 16 MB RAM and Windows 95 as an operating system which is equivalent to a common office computer. As previously mentioned, standard radiographic cephalometric settings are used. The image source can be from any TWAIN-compatible standard flatbed scanner or digital camera. Because digitisation is performed on a monitor-displayed image, high screen resolution is preferred. A digitising tablet is not required, therefore possible errors at this step are also eliminated.

➢ ***Digitising process***

The Sculptor program is relatively user friendly. Image enhancement for selected areas is readily available during digitisation (Figure 99). However, if the image is stored at a high compression level, the enhancement function may not improve image clarity.

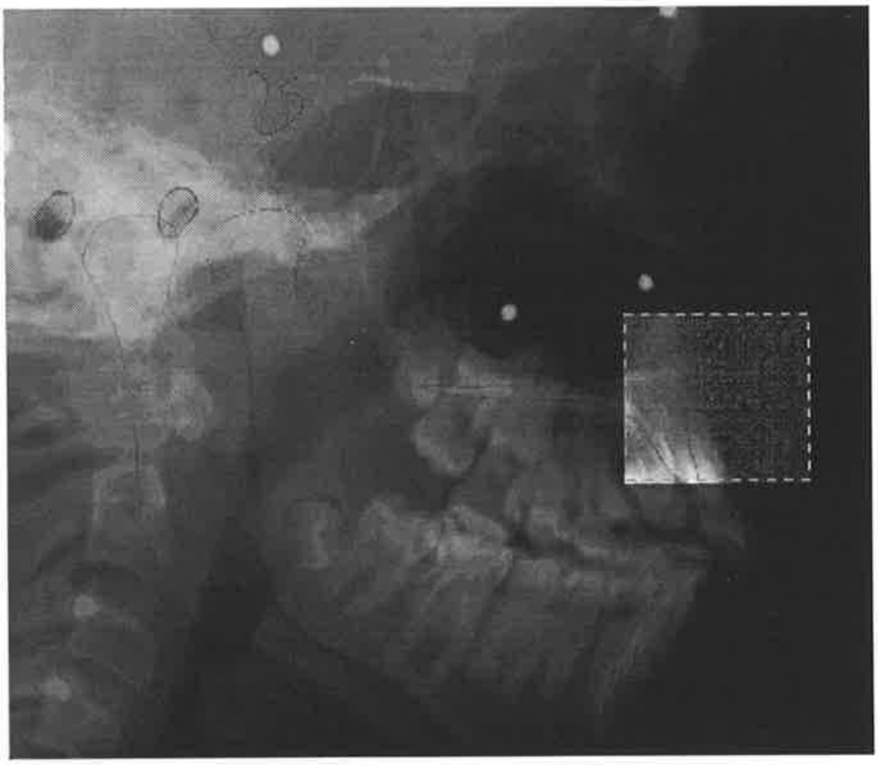
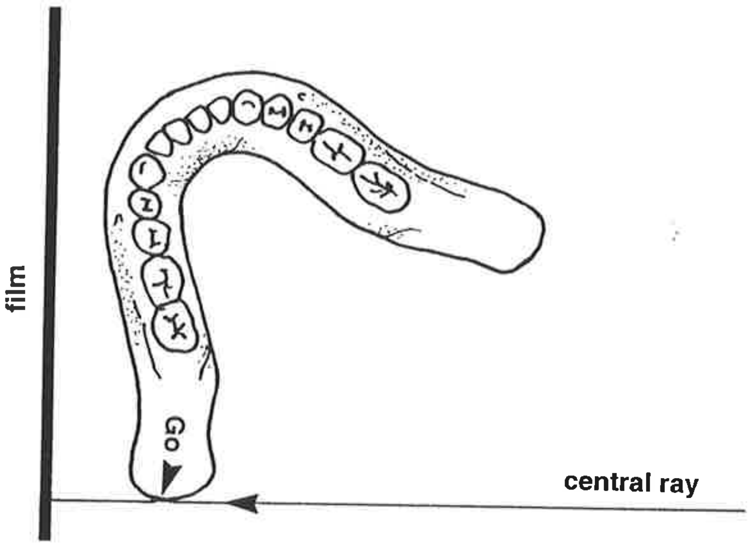


Figure 99 ▪ Enhancement function for selected area

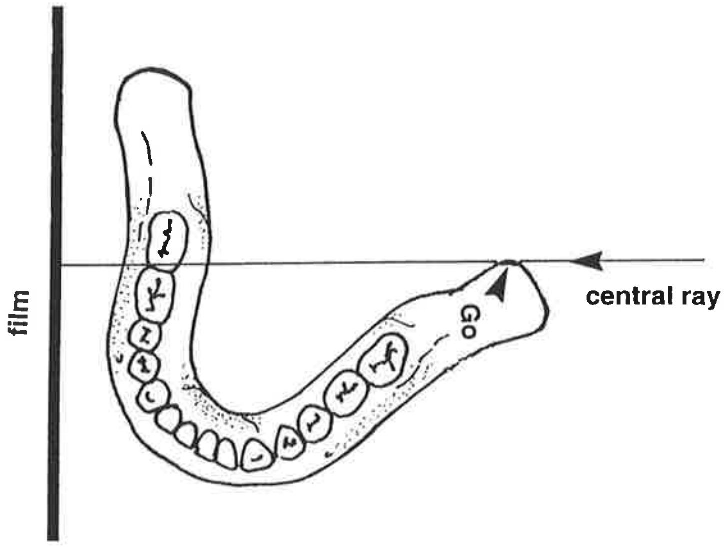
Several computerised cephalometric packages that are available on the market such as JOE™ (Jiffy Orthodontic Evaluation, Rocky Mountain Orthodontics, USA), OTP™ (Orthodontic Treatment Planning, Pacific Coast Software Inc., USA), QCIP™ (Quick Ceph Image Pro, Orthodontic Processing, USA), Dentofacial Planner Plus™ (Dentofacial Software Inc., USA), require input of set landmarks. All the landmarks need to be digitised in sequence. Correction of any digitisation needs to be done at the time or the whole sequence must be re-digitised. Sculptor is a flexible program in which only landmarks of interest need be digitised and other landmarks that are not used can be ignored. Correction of landmark digitisation can be done at any time and on separate sessions. "Landmark generator" is provided for the operator to nominate additional landmarks, if needed. On-screen measurement of distance between landmarks is also available. Multiple digitisation for outline tracing can be performed to represent the shape of the structure.

5.4.2 Problems in locating landmarks

Locating the same landmark on different cephalograms has been a major obstacle to 3D-cephalometry. Misidentification of landmarks also occurs in conventional 2D-cephalometric systems but it has been ignored as no additional data are available to verify accuracy. In conventional cephalometry, structures have been treated as though they have no thickness. However, in 3D-cephalometry, the thickness of the bony structure has become a concern because of projection errors. For example, Gonion is defined as a bisecting point of the angle formed by the line tangent to the posterior ramus and the inferior border of the mandible. When the right side of the head is rotated toward the film, the medial part of gonial angle forms the outline for Gonion, but when the left side of the head is rotated toward the film, the lateral part of the gonial angle forms the outline for Gonion (Figure 100). The final Gonion then relies on the average generated via a computer algorithm. From the error study in the present study, measurement associated with Gonion displayed greater random error both in inter- and intra-operator digitisation. Rules for digitisation are therefore important to minimise inter- and intra-operator variability. Location of a structure with sharp edging, such as orbital ridge, is considered more reliable.



A. Right side closer to the film.



B. Left side closer to the film.

Figure 100 ▪ The difference in the location of "Gonion" from two rotated lateral cephalograms.

In the present study, rotated lateral cephalograms were used to enable identification of left and right side condyles, providing an image that was slightly different from conventional lateral cephalograms. The appearance of some bony structures was harder to recognise and differences in the interpretation of these new image may lead to inter-operator variation. The most obvious change was seen in condylar head shape, with the condyle appearing broader on the side away from the film than the side closer to the film. This was one of the reasons why condylar centre (Cc) was used instead of Condylion (Co), because the condylar centre was considered to be less affected by the change of condylar head shape. Dental landmarks of posterior teeth were also more ambiguous on the rotated lateral cephalogram due to overlapping of interproximal outlines.

The extent of condylar growth is of major interest when analysing the effects of functional appliances. Unfortunately, superimposition of temporal structures and condylar head has made it difficult to identify anatomical landmarks in the temporomandibular joint area. Distances measured from Articulare (Ar) have been used to demonstrate increases in mandibular length because of ease of identification. However, Ar is not a true anatomical landmark but rather a constructed landmark based on the intersection of radiographic outlines of two separate bones. The assumption that the relationship between the glenoid fossa (represented by Ar) and condyle is stable throughout, and beyond, the treatment period is an oversimplification. With the use of MRI, it was demonstrated in the present study that condylar position relative to the fossa was not stable in either the control or CTB groups on an individual basis. In a recent longitudinal study by Buschang & Santos-Pinto (1998) it has been concluded that Ar systematically overestimates inferior fossa displacement, underestimates superior condylar growth, and overestimates posterior condylar growth. Using Ar seemed inappropriate as it did not represent an actual anatomical structure. Moreover, the outline of the glenoid fossa does not intersect with condylar neck in reality, therefore, Ar does not exist in three-dimensions.

Identification of the condylar head on lateral and frontal cephalograms has always been shown to have a large envelope of error due to the shadows of the clivus and the petrous part of the temporal bone obscuring the condylar outline on both lateral (Battagel, 1993; Buschang *et al*, 1987; Chate, 1987; Trpkova *et al*, 1997) and frontal cephalograms (el Mangoury *et al*, 1987; Major *et al*, 1994). To minimise this superimposition problem, it has been suggested that an additional lateral cephalogram be obtained with the mouth open. Although this method has been shown to reduce errors (Adenwalla *et al*, 1988), this increased accuracy on the average is not clinically significant (Forsberg & Odenrick, 1989; Moore *et al*, 1989). The justification for additional radiological risk for this single purpose is also questionable. Automatic computerised radiographic identification of cephalometric landmarks has been introduced recently (Rudolph *et al*, 1998; Stamm *et al*, 1998) but the error in identifying landmarks in the TMJ has not been improved by this method. The error was found to be as high as 5.1 mm for condyle and 5.7 mm for Porion (Rudolph *et al*, 1998). In the present study, identifying the shape of the condyle was very difficult. Function enhancement did not greatly improve the outline of the condyle. Condylar centre (Cc) was preferred to Condylion (Co) because it did not rely only on one side of the condylar outline, as with Condylion. Moreover, Condylion could not be identified on the frontal cephalograms. Therefore, using Condylion would have limited the information for three-dimensional reconstruction to only two lateral cephalograms. It was acknowledged that the centre of the condyle seen from lateral cephalograms was not the same as that seen from the frontal cephalogram. This was because the shape of the condylar head varied from the two views. Condylar centre derived from the frontal cephalogram was inferior to the centre of the condyle observed on the lateral cephalograms. However, by consistently digitising the condylar centre from the lateral cephalograms first, and then digitising the condylar centre on the frontal cephalogram, errors in the X-axis were minimised. This way, information from all three cephalograms was maximised.

5.4.3 Future developments

The accuracy of the calibration system could be improved by increasing the number of lead markers on the calibration frame, especially at the back of the head. The position of posterior and anterior markers would provide a visual image of the degree of head rotation on the frontal cephalogram. Setting a mid-sagittal reference line on the frontal cephalogram would then be more accurate.

In the present study, there was some evidence that the calibration frame was distorted by the cephalostat when the cephalogram was obtained in some children. The calibration frame needs to be more rigid, not interfering with the cephalostat and separated from the adjustable parts that stabilised the frame on the head. This would allow proper seating to minimise movement of the frame between each acquisition and it could be achieved without changing the co-ordination or geometry of the markers.

Output from 3D-cephalometric systems is still in the form of linear and angular variables which are two-dimensional in nature. Further development should provide information in the third dimension, such as volumetric changes. Although information about shape changes is available, this only enables comparison of the same individual at different times. Further work is needed so that the quantification of shape change for groups and statistical comparisons can be made.

In the present study, no facial soft tissue information was available because the soft tissue screen could not be used when the head was in the rotated position. An adjustable soft tissue screen incorporated on the cephalostat is needed in future research to acquire soft tissue information.

It is possible to combine information from photographs, cephalograms and MRIs to investigate the relationships between hard and soft tissue of the craniofacial structures, including the TMJ. The data from these three different sources could be linked together by the calibration head frame geometric co-ordinates. In the present study, all the photographs, cephalograms and MRIs were obtained while the calibration frame was in place. The software for combining these data is being developed and tested but no results are available as yet.

5.4.4 Comparisons with previous studies

To the best of the author's knowledge, this is the first 3D cephalometric study of the effects of functional appliances. Comparison of the magnitude of changes with conventional cephalometric data was inappropriate, except for the measurements of variables that are based on mid-sagittal landmarks. Available data for limited comparison were from two Twin Block studies (Lund & Sandler, 1998; Mills & McCulloch, 1998) where study designs and times of treatment were similar to the present study.

➢ *Untreated Class II*

The present study demonstrated significant spontaneous changes in the untreated children resulting from normal growth and development. These changes included a decrease in overjet, a reduction of upper incisal proclination, and an increase in mandibular growth on the left side. The increase in mandibular growth was demonstrated by the increases in effective mandibular length [Me-Cc(l)], ramal height [Cc(l)-Go(l)], mandibular dento-skeletal length [L1tip-Cc(l)] and anterior mandibular height [Me-L1tip]. None of these spontaneous improvements in Class II malocclusion have been addressed in previous Twin Block studies (Lund & Sandler, 1998; Mills & McCulloch, 1998).

The lack of evidence for any growth changes in the untreated groups included in previous studies (Lund & Sandler, 1998; Mills & McCulloch, 1998) could be because of two reasons. Firstly, the changes in mandibular dimensions may have been underestimated because of the use of 2D measurements. Secondly in previous studies, male and female data were combined. In the present study, only male data were analysed. Mandibular growth has been found to be more pronounced in males (Buschang *et al*, 1982; Lewis *et al*, 1982; Buschang *et al*, 1986). Carter (1987) has reported that the amount of mandibular growth in males is three times that of females during a six-year period of observation. It is not surprising then that the changes in the present study were more pronounced. Three-dimensional analysis of changes in females is needed to confirm this hypothesis.

Evidence of asymmetrical mandibular growth in the present study was unexpected. It is possible that asymmetrical mandibular growth had occurred in the untreated children or there may have been some systematic errors in the 3D cephalometric analysis. Several studies have reported mandibular asymmetry with the left side being longer than the right side in different populations (Pirttiniemi *et al*, 1991; Ponyi *et al*, 1991; Pirttiniemi & Kantomaa, 1992; Huggare & Houghton, 1995; Cohlmia *et al*, 1996). However, other studies have reported the opposite (Williamson & Simmons, 1979; Ferrario *et al*, 1994a; Piedra, 1995). Melnik (1992) has demonstrated in a longitudinal study that the dominant side of asymmetrical mandibular growth varies with time. Further studies are needed to clarify whether asymmetrical mandibular growth normally occurs over a longer period of time.

Systematic errors in the present study could have occurred in two ways. Firstly, the placement of the reference line on the mid-sagittal plane before digitisation could have introduced an error. Because there was no lead marker on the back of the head to align with the marker on the anterior side, the reference line was set according to the operator's judgement. Secondly, it was possible that the software may introduce a bias on one cephalogram more than the others. The 3D program in the present study required fixed assignment of each cephalogram to be right lateral, left lateral or frontal. Landmarks were digitised on the lateral cephalograms first and the information from these two cephalograms was used for assisting in locating landmarks on the frontal cephalogram which was digitised last. Once the landmarks were digitised on all three cephalograms, the triangulation function was then applied to compute the final position of the landmarks.

It was found that the digitisation on left lateral cephalograms was more stable than on the other two cephalograms. If the systematic errors were the reason for asymmetrical findings in the untreated children, then one would have expected the results from the CTB group to also be consistently larger on the left side than the right side. However, this was only true for the increase in ramal height [Cc(l)-Go(l)] but not for other variables. In fact, the increase in mandibular body length [Me-Go(r)] was found to be greater on the right side than on the left side for the CTB group. Future analyses to assess possible system bias could be done by varying the way the software manipulates the data from each cephalogram so that the type of cephalogram could be disregarded and free movement of the calibration allowed in any direction to fit the markers on the cephalogram. Random digitisation of the mirror images of the cephalograms for comparison would also provide a check of the system bias.

➢ *Treatment effects of the Twin Block appliance*

Treatment effects of the Twin Block appliance in the present study were similar to those reported recently (Lund & Sandler, 1998; Mills & McCulloch, 1998). Dento-alveolar changes such as reduction of overjet and overbite, reduction of upper incisal proclination and proclination of lower incisors were similar in direction but different in magnitude (Table 94). An increase in facial height and reduction of ANB angle were found in all three studies. Changes in the mandible were less conclusive. Significant increases in effective mandibular length, ramal height and gonial angle were found in all three studies, but in the present study the change in ramal height was not significant on the right side. A change in mandibular length was found in the study by Mills & McCulloch (1998), but in the present study on the right side only. The magnitude of increase in effective mandibular length in the present study was less than that noted in the previous two studies. It is possible that the differences were due to the shorter observation period in the present study which was approximately half that of the previous studies. However, to double the magnitude of the changes found in this study for comparison purposes may be inappropriate as the change in the mandibular growth may not be proportional to the time of treatment. A significant change in mandibular plane angle was found only in the present study with significance being only on the right side. Changes in the maxilla were minimal in all three studies but in the present study a significant change in the direction of maxillary growth with an anterior and downward rotation was found.

Both previous studies have demonstrated significant dento-facial changes in children treated with the Twin Block appliance by using paired t-tests to make comparisons within the treatment group. However, they did not present comparisons of the magnitude of changes with their control groups. In the present study, unpaired t-tests were used to compare the magnitude of changes between the control and treated groups. This aimed to detect the effects of the Twin Block alone by taking account of the effects of growth. It was found that the effects of the Twin Block appliance alone were mainly limited to dento-alveolar changes and an increase in anterior facial height. The effect on the mandible was found to be statistically significant only on the right side

[Me-Cc(r), Me-Go(r)-Cc(r), Me-Go(r) to SN]. This was because a significant increase in mandibular growth was also found on the left side for the control group. Anterior downward rotation of the maxilla was also considered to be an effect of the Twin Block appliance therapy.

Table 94 ▪ Comparison of treatment changes (mean ± SD) in three Twin Block studies.

	Lund & Sandler	Mills & McCulloch	Present study
SNA	-0.1° ± 1.6° NS	**-0.9° ± 1.0°**	-1.0° ± 2.5° NS
SNB	**1.9° ± 2.0°**	**1.9° ± 1.2°**	1.4° ± 2.4° NS
U1 to ANS-PNS	**-11.0° ± 7.6°**	NA	**-2.3° ± 2.8°**
U1 to SN	NA	**-2.5° ± 5.1°**	**-3.8° ± 2.8°**
L1 angle	L1 to Me-Go	L1 to GoGn	L1 to Me-Go(r)
	8.2° ± 7.1°	**5.2° ± 3.9°**	**3.5° ± 3.5°**
			L1 to Me-Go(l)
			3.2° ± 4.2°
ANB	**-2.0° ± 1.9°**	**-2.8° ± 1.4°**	**-2.5° ± 1.7°**
SN to mandibular	SN to Me-Go	SN to Go-Gn	SN to Me-Go(r)
plane	0.1° ± 2.7° NS	0.1° ± 1.6° NS	**1.3° ± 1.8°**
			SN to Me-Go(l)
			1.4° ± 2.3° NS
Gonial angle	Ar-Go-Me	Ar-Go-Gn	Cc(r)-Go(r)-Me
	1.4° ± 2.8°	**1.3° ± 2.1°**	**1.7° ± 1.4°**
			Cc(l)-Go(l)-Me
			1.7° ± 1.6°
Mandibular length	Ar-Pog	Co-Gn	Me-Cc(r) **3.3 ± 3.2**
(mm)	**5.1 ± 2.3**	**6.5 ± 2.1**	Me-Cc(l) **4.2 ± 2.4**
Ramal height	Ar-Go	Co-Go	Cc(l)-Go(l)
(mm)	**4.0 ± 2.9**	**4.1 ± 2.2**	**2.3 ± 1.3**
			Cc(r)-Go(r)
			0.2 ± 1.9 NS
Mandibular body	Go-Me	Go-Gn	Me-Go(r) **2.2 ± 3.0**
length (mm)	1.9 ± 2.2 NS	**3.0 ± 1.7**	Me-Go(l)1.3 ± 2.0 NS
Overbite (mm)	**-7.8 ± 3.8**	NA	**-2.3 ± 1.6**
Overjet (mm)	**-5.0 ± 2.8**	**-5.6 ± 2.6**	**-6.2 ± 2.4**
Face height (mm)	N-Me	N-Me	ANS-Me
	4.9 ± 2.6	**5.6 ± 2.8**	**2.2 ± 1.8**
Observation time	13 months	14 months	6 months

NS = not significant, NA = data not available, Bolded values significant p<0.05

Limitations of the present 3D-cephalometric study included the small sample size and the fact that data were obtained from males only. Sexual dimorphism in mandibular growth also could not be demonstrated in the present study. Power of statistical tests was reduced by the small sample size. Larger sample sizes are needed for the future research to increase the statistical power and to clarify whether the suggestion of asymmetrical mandibular growth can be confirmed in larger populations.

Chapter 6 MAIN FINDINGS AND CONCLUSIONS

This thesis presents the findings of a prospective study of the effects of treatment with the Clark Twin Block appliance (CTB) in children with Class II division 1 malocclusions. A matched group of untreated Class II division 1 children served as controls. The period of observation was 6 months. The study was subdivided into 4 parts:

1. Clinical aspects
2. Muscular adaptation investigated by muscle testing
3. Morphology of the temporomandibular joint investigated by MRI
4. Skeletal and dental changes investigated by three-dimensional cephalometric analysis

6.1 Clinical Aspects

1. The prevalence of children with a history of facial trauma was 42%. Most of the trauma cases (73%) involved the fracture of one or more upper anterior teeth.

2. Based on incisal overjet, the severity of Class II malocclusion at the commencement of treatment was significantly greater in the CTB/male subgroup ($p<0.05$) than control/male, control/female and CTB/female subgroups. However, canine and molar relationships were similar among the four subgroups.

3. Chronological age and Skeletal Maturity Indicator (SMI) values were similar between the CTB and control groups at the commencement of treatment. However, dental emergence age in the CTB group was significantly greater

than in the control group (p<0.01), partly due to selection bias related to availability of teeth suitable for clasping.

4. The rate of physical growth (height and weight) during the 6-month observation period was similar in both the control and CTB groups.

5. Using combined control and CTB data from initial records, the strongest correlations among growth and development indicators were between SMI and dental emergence age for girls (r = 0.61, p<0.001) and between dental emergence age and chronological age for boys (r = 0.66, p<0.001).

6. Overbite was found to have increased significantly during the 6-month period in the control group (p<0.001). The mean increase was 1.5 ± 1.5 mm.

7. Spontaneous reduction of overjet was found in the majority of the children in the control group during the 6-month observation period (p<0.001). The mean reduction was 0.8 ± 1.2 mm. This was due to reduction of upper incisal proclination.

8. Based on the reduction of overjet and correction of canine and molar relationships, the success rate of treatment with the CTB in this study was 85%, with a mean reduction of overjet of 6.2 ± 2.4 mm and a mean reduction of overbite of 2.3 ± 1.6 mm. The most likely reason for failure of treatment was inability of children to wear the appliance full-time.

9. Significant improvement in maximum jaw movements such as opening, protrusion, retrusion and lateral excursions, was noted after treatment with the CTB (p<0.001). The most obvious improvements were increases in maximum opening (6.6 ± 2.4 mm) and maximum protrusion past edge-to-edge position (5.1 ± 2.8 mm). The only significant improvement of jaw movement in the control group was maximum protrusion (p<0.05).

6.2 Muscular Adaptation

1. Based on combined control and CTB data from initial records, maximum protrusive force ranged from 18.5 N to 160 N with a mean of 80.3 ± 30.7 N. Maximum protrusive force was significantly higher in males than in females ($p<0.001$).

2. Based on combined control and CTB data from initial records, fatigue time ranged from 17 to 206 seconds, with a mean of 69.1 ± 36.4 seconds. Although the mean fatigue time tended to be longer in males than in females, the difference was not statistically significant.

3. Based on combined control and CTB data from initial records, significant correlations ($p<0.05$) were found between
   - maximum protrusive force and chronological age for males ($r = 0.37$)
   - maximum protrusive force and SMI for females ($r = -0.43$)
   - maximum protrusive force and SMI for males and female combined ($r = -0.37$)

4. Based on combined control and CTB data from initial records, no significant correlation was found between maximum protrusive force and height or weight.

5. Maximum protrusive force at the 6-month observation was significantly higher than that of the initial record for the control group ($p<0.01$) as a result of growth, but did not reach the significant level for the CTB group. It is hypothesised that the CTB may have shortened the protrusive muscles and consequently slowed down the increase of muscle force observed in the untreated controls.

6. No significant difference in fatigue time was found between initial and 6-month records in both control and CTB groups. Fatiguing protrusive muscles did not alter mandibular position in the CTB group after six months of treatment with the CTB. The finding suggested a lack of forward mandibular posture or absence of a "Sunday bite".

7. Fatiguing protrusive muscles did not significantly change mandibular position in both the control and the CTB groups.

6.3 Temporomandibular Joint Morphology

1. The most common axial condylar shape in Class II division 1 children studied was concavo-convex.

2. Based on combined control and CTB data from initial records, axial condylar angle relative to cranial midline ranged from 40° to 72° with a mean of 55.5° ± 9.0°. No significant difference in the initial axial condylar angle was found between control and CTB groups.

3. Significant reduction of mean axial condylar angle between initial and 6-month records was found in the control group ($p<0.05$), with a mean change of 4.1° ± 8.6°. No significant difference in mean axial condylar angle between initial and 6-month records was found in CTB group. It is hypothesised that reduction of the axial angle represents a feature of the Class II growth pattern and that the CTB therapy may alter the direction of condylar growth.

4. Based on combined control and CTB data from initial records, condylar concentricity was found in 22.5% of the children. The majority of children (50%) displayed anteriorly positioned condyles and 27.5% had posteriorly positioned condyles.

5. Condyles that were positioned anteriorly at the crest of the articular eminence by the CTB at the beginning of treatment had repositioned back into the glenoid fossa after six months. However, more anteriorly positioned condyles were found as a result of 6-month treatment with CTB appliances. The percentage of anteriorly positioned condyles changed from 33.3% at the initial MRIs to 73.3% at the 6-month MRIs in the successful cases treated with CTB. The direction of change in the condylar position in the CTB group was more towards the anterior. Changes in the condylar position in the control group were also found but the direction of change was not uniform.

6. Based on combined control and CTB data from initial records, the mean eminence angle relative to PC-line was 18.5° ± 13.0°, and the mean eminence angle relative to FH-line was 52.7° ± 11.7°. No significant difference of eminence angle between boys and girls or between children with disc displacement and children without disc displacement was found.

7. Based on combined control and CTB data from initial records, correlations between eminence angle and chronological age, dental age or SMI were low and did not reach significance.

8. No significant difference in eminence angle between initial and 6-month MRIs was found in both the control and CTB groups. Therefore, there was no evidence of remodelling of the glenoid fossa at the eminence as a result of CTB treatment.

9. Based on combined control and CTB data from initial records, the mean position of the anterior margin of the disc relative to the PC-line was 116.6° ± 8.9° and mean posterior margin position was 24.8° ± 14.4°. The mean anterior margin position of the disc relative to FH-line was 99.5° ± 10.6° and mean posterior margin position was 4.9° ± 13.4°. The margin of the anterior band was strongly associated with the crest of the articular eminence while the position of the posterior band varied to a greater degree, as indicated by a greater standard deviation. No significant difference in disc positions between boys and girls or between control and CTB groups was found. The position of the posterior margin of the disc was more anterior in the group of condyles classified as being posteriorly positioned in the fossa than in the anterior or concentric condyle groups ($p<0.05$).

10. Disc position was found to be more posterior at the 6-month record for both the control and CTB groups. The statistical level of significance was dependent on the reference line used. Using the **PC-line**, the position of the posterior margin of the disc moved posteriorly and closer to the 12 o'clock point after 6-month of treatment with CTB ($p<0.05$) but no significant differences of disc positions were found in the control group. Using the **FH-line**, the position of the anterior and posterior margins of the disc moved

posteriorly and closer to the 12 o'clock point during the 6-month observation for the control group ($p<0.01$). Although the same trend was found, the changes did not reach significance in the CTB group. At the 6-month record stage, the angle between PC-line and FH-line was reduced in the control group but the angle was relatively unchanged in the CTB group.

11. CTB therapy had neither positive nor negative effects on disc position. There was no evidence of "re-capture" of the disc in children with disc displacement treated with the CTB.

12. Based on combined control and CTB data from initial records, mediolateral condylar width measured from coronal MRI ranged from 12.7 mm to 21.8 mm. No significant difference in coronal width was found between boys and girls. No relationship between coronal width and age was found.

13. Coronal disc position tended to be further to the lateral side than to the medial side. Coronal disc position did not change in either control or CTB groups during the 6-month observation period.

14. Based on combined control and CTB data from initial records, the prevalence of disc displacements from this study were:
    - anterior disc displacement = 7.5%
    - medial disc displacement = 5%
    - lateral disc displacement = 15%

6.4 Three-dimensional Cephalometric Analysis

1. At the six-month period of observation, some slight spontaneous improvement of Class II malocclusion was found in the control group, demonstrated by a reduction of ANB angle, a reduction of maxillary incisal proclination and an increase of mandibular growth. Mandibular growth was indicated by an increase in effective mandibular length (Me-Cc), ramal height (Cc-Go) and mandibular dento-skeletal arch length (L1-Cc). However, statistically significant increases in mandibular dimensions were found only on the left side.

2. Significant changes were found in the CTB group after six months of treatment including a reduction of ANB angle, an increase of facial height, redirection of maxillary growth, an increase in mandibular growth and dento-alveolar changes. Dentoalveolar changes were demonstrated by a reduction of upper incisal proclination and an increase of lower incisal proclination. Redirection of maxillary growth in the CTB group was demonstrated by an anterior downward rotation of the palatal plane. Mandibular growth was demonstrated by an increase in effective mandibular length (Me-Cc, both left and right sides), mandibular body length (Me-Go, right side), ramal height (Go-Cc, left side) and an increase in gonial angle (Me-Go-Cc, right side). The results were considered to represent a combination of normal growth and the effect of the Twin Block appliance.

3. A comparison of the magnitude of changes between the control and CTB groups, to evaluate the effects of Twin Block appliance alone, disclosed significant differences in reduction of upper incisal proclination, proclination of lower incisors, anterior downward rotation of the palatal plane, increase in facial height, increase in right effective mandibular length, increase in right gonial angle and increase in right mandibular plane angle.

❖ Conclusions

The Twin Block appliance proved to be a useful device for managing Class II division 1 malocclusions by reduction of overbite and overjet, correction of buccal dental relationship, and increase facial height in a relatively short period of time. The mechanism of correction was mainly from dento-alveolar changes, while skeletal changes were limited to some degree of mandibular growth and redirection of maxillary growth. The increase in effective mandibular length was thought to be achieved from an opening of gonial angle rather than an increase in the body length or ramal height. This research failed to demonstrate any remodelling of the glenoid fossa. Successful results were not found to be associated with specific growth and developmental indicators. Justification for using the Twin Block therapy would appear to be for the prevention of dental trauma with a simple appliance rather than a particular superiority in stimulating mandibular growth.

MRI demonstrated that the condyle-disc-fossa relationship was within the normal range after the use of Twin Block appliance. However, on average, the condyle was positioned more anteriorly in the fossa than before treatment. Modification of protrusive muscles by the Twin Block appliance was also found. Treatment with the Twin Block had neither positive nor negative effects on the condition of disc displacement.

Chapter 7 APPENDICES

Appendix 1 Consent form for children

The University of Adelaide

CONSENT FORM

See also Information Sheet attached.

1. I ____________________________(please print) hereby consent to take part in the research project entitled:
Magnetic resonance imaging (MRI) and cephalometric assessment of the temporomandibular joints: A prospective study of treatment with the Twin Block appliance.

2. I acknowledge that I have read the Information Sheet entitled:
Magnetic resonance imaging (MRI) and cephalometric assessment of the temporomandibular joints: A prospective study of treatment with the Twin Block appliance.

3. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

4. Although I understand that the purpose of this research project is to improve the quality of medical care, it has also been explained that my involvement may not be of any benefit to me.

5. I have been given the opportunity to have a member of my family or a friend present while the project was explained to me.

6. I have been informed that, while information gained during the study may be published, I will not be identified and my personal results will not be divulged.

7. I understand that I am free to withdraw from the project at any time and that this will not affect medical advice in the management of my health, now or in the future.

8. I am aware that I should retain a copy of this Consent Form, when completed, and the relevant Information Sheet.

Sign______________________________ **Date**________________________

Name of witness____ (please print)
Sign______________________________ **Date**________________________

I,_***Dr. Kanoknart Chintakanon***_ have described to ________________________
the nature of the procedures to be carried out. In my opinion she/he understand the explanation.
Sign______________________________ **Date**________________________
Status in project ___***Researcher***___

Appendix 2 Consent form for parent or guardian

The University of Adelaide

STANDARD CONSENT FORM FOR RESEARCH TO BE UNDERTAKEN ON A CHILD, THE MENTALLY ILL, AND THOSE IN DEPENDENT RELATIONSHIPS OR COMPARABLE SITUATION

FORM TO BE COMPLETED BY PARENT OR GUARDIAN
(See also Information Sheet attached)

1. I________________________________ (please print) hereby consent to allow ________________________________ (please print) to take part in the research entitled: ***Magnetic resonance imaging (MRI) and cephalometric assessment of the temporomandibular joints: A prospective study of treatment with the Twin Block appliance.***

2. I acknowledge that I have read the Information Sheet entitled: ***Magnetic resonance imaging (MRI) and cephalometric assessment of the temporomandibular joints: A prospective study of treatment with the Twin Block appliance*** and have had the project, as far as it affects ________________________________ fully explained to me by the research worker. My consent is given freely.

In addition, I acknowledge on behalf of ________________________ the following:

3. Although I understand that the purpose of this research project is to improve the quality of medical care, it has also been explained to me that there may not be any benefit to ____ by her/his involvement.

4. I have been given the opportunity to have a member of her/his family or friend present while the project was explained to me.

5. I have been informed that the information she/he provides will be kept confidential.

6. I understand that she/he is free to withdraw from the project at any time and that this will not affect medical advice in the management of her/his health, now or in the future.

7. I am aware that I should retain a copy of this Consent Form, when completed, and the relevant Information Sheet.

Sign________________________________ **Date**______________________
(Relationship to patient: Parent / Guardian)

Name of witness____ (please print)
Sign________________________________ **Date**______________________

I, ***_Dr. Kanoknart Chintakanon_*** have described to ________________________________
the nature of the procedures to be carried out. I my opinion she/he understood the explanation.
Sign________________________________ **Date**______________________
Status in Project *_Researcher_*

Appendix 3 Information sheet

Information Sheet

Magnetic resonance imaging (MRI) and cephalometric assessment of the temporomandibular joints: A prospective study of treatment with the Twin Block appliance

1. Scope and objective of the research

The “Twin Block appliance” has been used to correct poor alignment between upper and lower jaw bones in growing children by changing the posture of the lower jaw (mandible). The average treatment time is 6-9 months and is often followed by a short period of orthodontic braces. The treatment results with the Twin Block appliance rely upon the stimulation of the growth of the lower jaw and/or change in the position of the jaw joints (temporomandibular joints -TMJ). The objective of this research is to study the growth changes of the jaw joints in children treated with the Twin Block appliance in comparison to non-treated children. The participants of this research will include forty children (20 males and 20 females) for each control and experimental group. The age of the participants will be 9-13 years for females and 10-14 years for males.

2. Procedures

All of the patients selected for the experimental group in this research will be treated with the Twin Block functional appliance by the same operator in the Orthodontic Clinic, Adelaide Dental Hospital. The rest of the patients will be placed on a waiting list to be treated later and meanwhile serve as a control group.

General information will be collected which will include clinical examination, models of teeth and photographs. There will be some radiographs of head and hand taken. A simple muscle test will be conducted after some clinical sessions. The procedure is not painful and will take about 15 minutes. A series of magnetic resonance images (MRIs) of the jaw joints will also be taken (within Adelaide) to allow us to see the soft tissue changes in the joints which are not normally visible on radiographs. The MRI technique is non-invasive in nature and has no association with radiological risk. All clinical procedures used in this research are the same as those normally used for orthodontic patients except for the use of MRIs and muscle test.

3. The possible benefits from the study

This research project will provide better understanding of the mechanism of orthodontic treatment with the Twin Block appliance. This may lead to a better prediction of treatment outcome and a better selection of patients for successful results.

Your co-operation in this project is greatly appreciated and will contribute significantly to the store of knowledge in the area of dentistry.

Researcher: Dr. Kanoknart Chintakanon
Ph.D. candidate, Department of Dentistry, The University of Adelaide
Supervisors: Professor Wayne J. Sampson, Professor Grant C. Townsend, Dr. Tom Wilkinson, Dr. Kemal Türker

If any problems arise, please contact Dr. Kanoknart Chintakanon (Nim)
Phone: 82228287 (Orthodontic clinic), 83033102 (office),
82782710 (after hours)

Appendix 4 Examination form

Magnetic resonance imaging (MRI) and cephalometric assessment of the temporomandibular joints: A prospective study of treatment with the Twin Block appliance.

Researcher: Dr. Kanoknart Chintakanon

EXAMINATION FORM

Research serial number ______________________ (experiment / control)
Hospital number ______________________________
❑ Information sheet given and consent form signed

Visit 1: Date ____________________
Name ______________________________
Sex ______________ Ethnic group ______________
Height ______________ cm. Weight ______________ kg
Birth date ______________ Age ______________
School ______________________ Grade __________
School dentist ______________________________
Address ______________________ Telephone __________

Chief complaint ______________________________
Attitude ______________________________

History with related problems:
- birth injuries ☺ No ☹Yes ______________
- allergies ☺ No ☹Yes ______________
- nasorespiratory problems ☺ No ☹Yes ______________
- facial trauma ☺ No ☹Yes ______________
- past illness ☺ No ☹Yes ______________
- present illness ☺ No ☹Yes ______________
- present medications taking ☺ No ☹Yes ______________
- abnormal oral habits ☺ No ☹Yes ______________
- family members with similar malocclusion ☺ No ☹Yes ______________

____
- others ______________________________

____

Extra-oral examination:
- facial type ❑ dolichofacial ❑ mesofacial ❑ brachyfacial
- facial profile ❑ convex ❑ straight ❑ concave
- nose ❑ symmetry ❑ deviate
- chin ❑ symmetry ❑ deviate ❑ receded ❑normal ❑ prominent
- lips in rest position ❑ sealed ❑ unsealed
- lip morphology ❑ short ❑ normal ❑ long ❑ tight ❑ flaccid
- swallowing pattern ❑ normal ❑ abnormal ______________
- others ______________________________

____

Intra-oral examination
Soft tissue
- gingiva ❑ normal ❑ gingivitis ❑ recession
- tonsils ❑ normal ❑ tonsillitis ❑ removed
- tongue ❑ normal ❑ abnormal ______________
- fraenum ❑ normal ❑ abnormal ______________
- palate ❑ normal ❑ abnormal ______________

Teeth
- teeth present ______________|______________
- missing ❑ no ❑ yes ______________
- supernumerary ❑ no ❑ yes ______________
- abnormal morphology ❑ no ❑ yes ______________
- discoloration ❑ no ❑ yes ______________
- caries ❑ no ❑ yes ______________
- upper dental midline to facial midline ❑ correspond ❑ deviate ________
- lower dental midline to facial midline ❑ correspond ❑ deviate ________
- molar relationship right ____________ left ____________
- canine relationship right ____________ left ____________
- incisal relationship overbite ________ mm overjet ________ mm
- anterior crossbite ❑ no ❑ yes ______________
- posterior crossbite ❑ no ❑ yes ______________

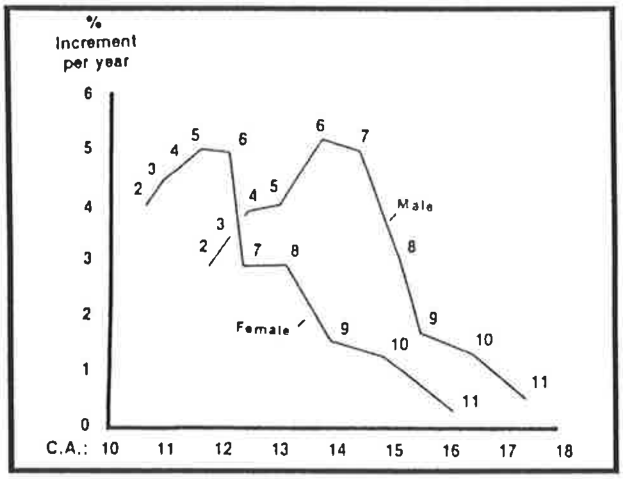
Functional analysis of TMJ
History
- headaches ❑ no ❑ yes ______________
- pain ❑ no ❑ yes ______________
- clicking ❑ no ❑ yes ______________
- locking ❑ no ❑ yes ______________
- parafunction ❑ no ❑ yes ______________

Examination
- maximum opening ______________ mm.
- maximum protrusion ______________ mm.
- maximum retrusion ______________ mm.
- maximum excursion right ____________mm. left ____________mm.
- path of closure of the mandible ❑ straight ❑ deviated ____________
- passive clicking ❑ no ❑ yes ______________
- bruxofacets ❑ no ❑ yes ______________
- CO/CR difference ❑ no ❑ yes ______________
- non working side interference ❑ no ❑ yes ______________
- ❑ canine guidance or ❑ group function
- pain on palpation (masseter, temporalis, digastric, lateral pole, lateral pterygoid, medial pterygoid, coronoid, sternomastoid)
  ❑ no ❑ yes ______________
- pain on function ❑ no ❑ yes ______________

Helkimo index
- Clinical dysfunction index (Di) ❑ 0 ❑ 1 ❑ 2 ❑ 3
- Anamnestic dysfunction index (Ai) ❑ 0 ❑ 1 ❑ 2

Impressions
❑ upper ❑ lower ❑ bite registration
Slides
Extra-oral: ❑ frontal ❑ smile ❑ profile ❑ protruded
Intra-oral: ❑ upper ❑ lower ❑ right ❑ front ❑ left
Radiographs
❑ OPG ❑ hand wrist

Growth analysis (date __________)



- chronological age __________
- statural growth __________
- dental age __________
- skeletal maturation age ______

OPG analysis (date __________)

- teeth present
- number of permanent teeth ☐ normal ☐ missing ________ ☐ supernumerary ________
- caries ______________________________
- periodontal ligament______________________________
- abnormalities ______________________________
- others ______________________________

____
____
____

Model analysis (date __________)

- teeth present
- upper arch form ☐ parabolic ☐ U-shape ☐ V-shape
- lower arch form ☐ parabolic ☐ U-shape ☐ V-shape
- curve of Spee ☐ flat ☐ moderate ☐ pronounced > 2mm.
- space condition ☐ upper ______________________________ ☐ lower ______________________________
- molar relationship right __________ left __________
- canine relationship right __________ left __________
- incisal relationship overbite __________ mm. overjet __________mm.
- anterior crossbite ☐ no ☐ yes __________
- posterior crossbite ☐ no ☐ yes __________
- others ______________________________

____
____
____
____

Visit 2 Date ____________________

- ❑ Formasil® bite (centric occlusion) and nosepiece
- ❑ working models for Clark Twin Block appliance (CTB)
- ❑ Formasil® bite construction ➢ protrusive distance ________________ mm.
  ➢ posterior interocclusal distance __________ mm.
- ❑ muscle test maximum protrusive force ______________
  fatigue time ____________________
- ❑ frontal, 10° right and 10° left lateral cephalograms
- ❑ referral for MRIs at Flinders Medical Centre Date _______________

Visit 3 Date ____________________

- ❑ CTB insertion
- ❑ wearing and maintenance instruction given
- ❑ wearing time recording form given

Extraoral slides with jaw tracking device

With CTB ❑ frontal ❑ profile
Without CTB ❑ frontal ❑ profile

Visit 4 Date ____________________

- ❑ wearing time recording form checked
- ❑ Height _______________ cm. Weight ___________________ kg
- ❑ treatment progress:
  overbite_____________ mm overjet _____________ mm
  molar relationship right class ______ left class __________
  canine relationship right class ______ left class __________
- ❑ CTB adjustment ____
  ____
  ____

Mandibular movement examination

- ➢ maximum opening ________________ mm.
- ➢ maximum protrusion _______________ mm.
- ➢ maximum retrusion ________________ mm.
- ➢ maximum excursion right __________mm. left __________mm.
- ➢ passive clicking ❑ no ❑ yes __________________________
- ➢ CO/CR difference ❑ no ❑ yes __________________________
- ➢ pain on palpation (masseter, temporalis, digastric, lateral pole, lateral pterygoid, medial pterygoid, coronoid, sternomastoid)
  ❑ no ❑ yes __________________________
- ➢ pain on function ❑ no ❑ yes __________________________

Visit 5 Date ____________________

- ❑ wearing time recording form checked
- ❑ Height _______________ cm. Weight ___________________ kg
- ❑ treatment progress:
  overbite_____________ mm overjet _____________ mm
  molar relationship right class ______ left class __________
  canine relationship right class ______ left class __________
- ❑ CTB adjustment ____
  ____
  ____

Mandibular movement examination
- maximum opening ____________________ mm.
- maximum protrusion ____________________ mm.
- maximum retrusion ____________________ mm.
- maximum excursion right ____________mm. left ____________mm.
- passive clicking ❑ no ❑ yes ______________________________
- CO/CR difference ❑ no ❑ yes ______________________________
- pain on palpation (masseter, temporalis, digastric, lateral pole, lateral pterygoid, medial pterygoid, coronoid, sternomastoid)
  ❑ no ❑ yes ______________________________
- pain on function ❑ no ❑ yes ______________________________

Visit 6 Date ________________________

❑ wearing time recording form checked
❑ Height __________________ cm. Weight ______________________ kg
❑ treatment progress:
overbite_______________ mm overjet ________________ mm
molar relationship right class _______ left class ___________
canine relationship right class _______ left class ___________

❑ CTB adjustment ____
____
____

Mandibular movement examination
- maximum opening ____________________ mm.
- maximum protrusion ____________________ mm.
- maximum retrusion ____________________ mm.
- maximum excursion right ____________mm. left ____________mm.
- passive clicking ❑ no ❑ yes ______________________________
- CO/CR difference ❑ no ❑ yes ______________________________
- pain on palpation (masseter, temporalis, digastric, lateral pole, lateral pterygoid, medial pterygoid, coronoid, sternomastoid)
  ❑ no ❑ yes ______________________________
- pain on function ❑ no ❑ yes ______________________________

Visit 7 **6 MONTHS RECORDS** Date ________________________

❑ wearing time recording form checked
❑ Height __________________ cm. Weight ______________________ kg
❑ treatment progress:
overbite_______________ mm overjet ________________ mm
molar relationship right class _______ left class ___________
canine relationship right class _______ left class ___________

❑ CTB adjustment ____
____
____

Mandibular movement examination
- maximum opening ____________________ mm.
- maximum protrusion ____________________ mm.
- maximum retrusion ____________________ mm.
- maximum excursion right ____________mm. left ____________mm.
- passive clicking ❑ no ❑ yes ______________________________
- CO/CR difference ❑ no ❑ yes ______________________________

- pain on palpation (masseter, temporalis, digastric, lateral pole, lateral pterygoid, medial pterygoid, coronoid, sternomastoid)
  ❑ no ❑ yes ______________________
- pain on function ❑ no ❑ yes ______________________

Helkimo index

- Clinical dysfunction index (Di) ❑ 0 ❑ 1 ❑ 2 ❑ 3
- Anamnestic dysfunction index (Ai) ❑ 0 ❑ 1 ❑ 2

Impressions

❑ upper ❑ lower

❑ Formasil® bite (most retruded position) and nosepiece

Slides

Extra-oral:	❑ frontal	❑ smile	❑ profile	❑ protruded	
Intra-oral:	❑ upper	❑ lower	❑ right	❑ front	❑ left

Radiographs

❑ frontal, 10° right and 10° left lateral cephalograms

Muscle test maximum protrusive force ____________

fatigue time ______________

❑ referral for MRIs at Flinders Medical Centre Date ______________

❑ re-evaluation for further treatment ______________________

____

____

❑ transfer for further treatment ______________________

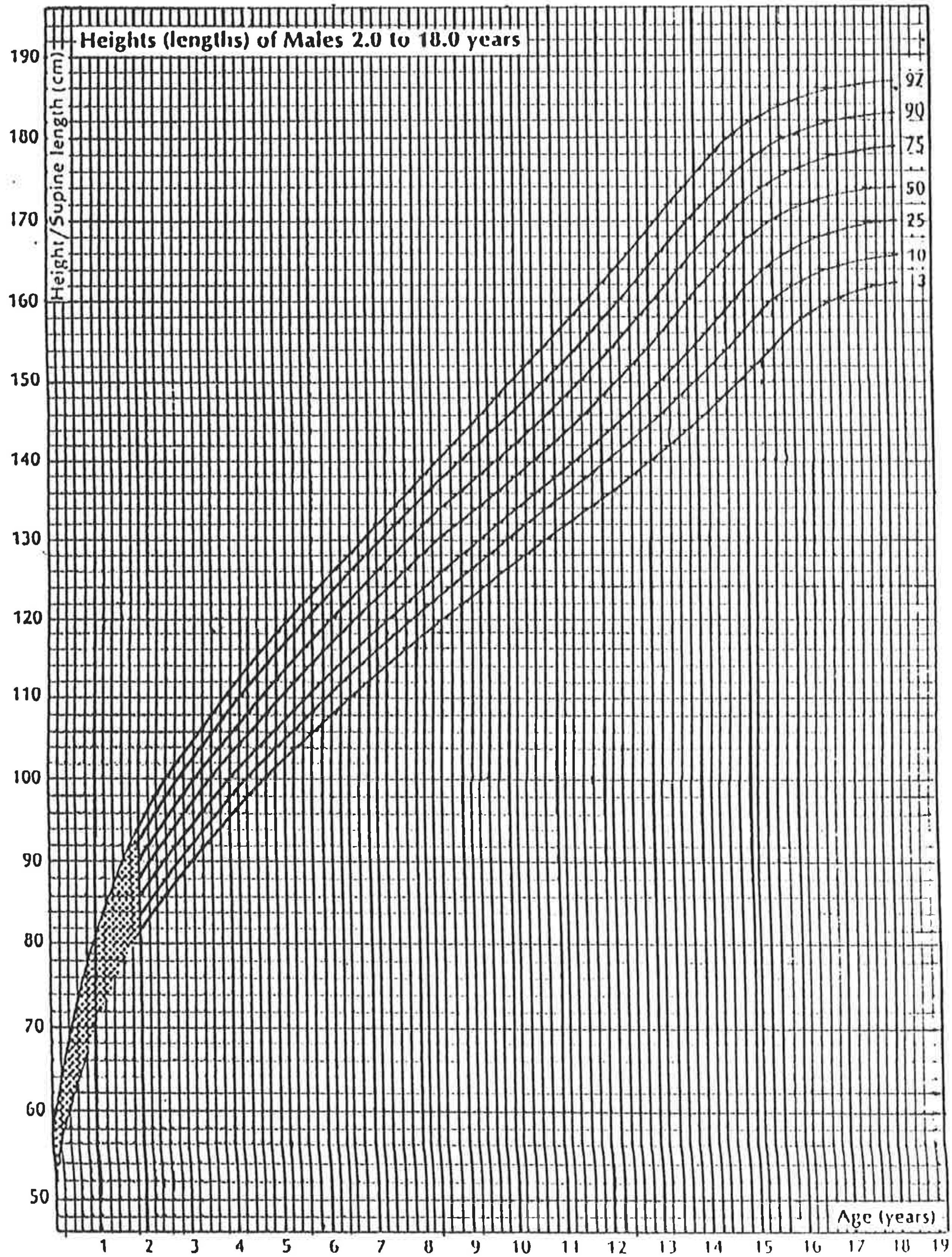
____

____

*****✿✿✿✿✿*****

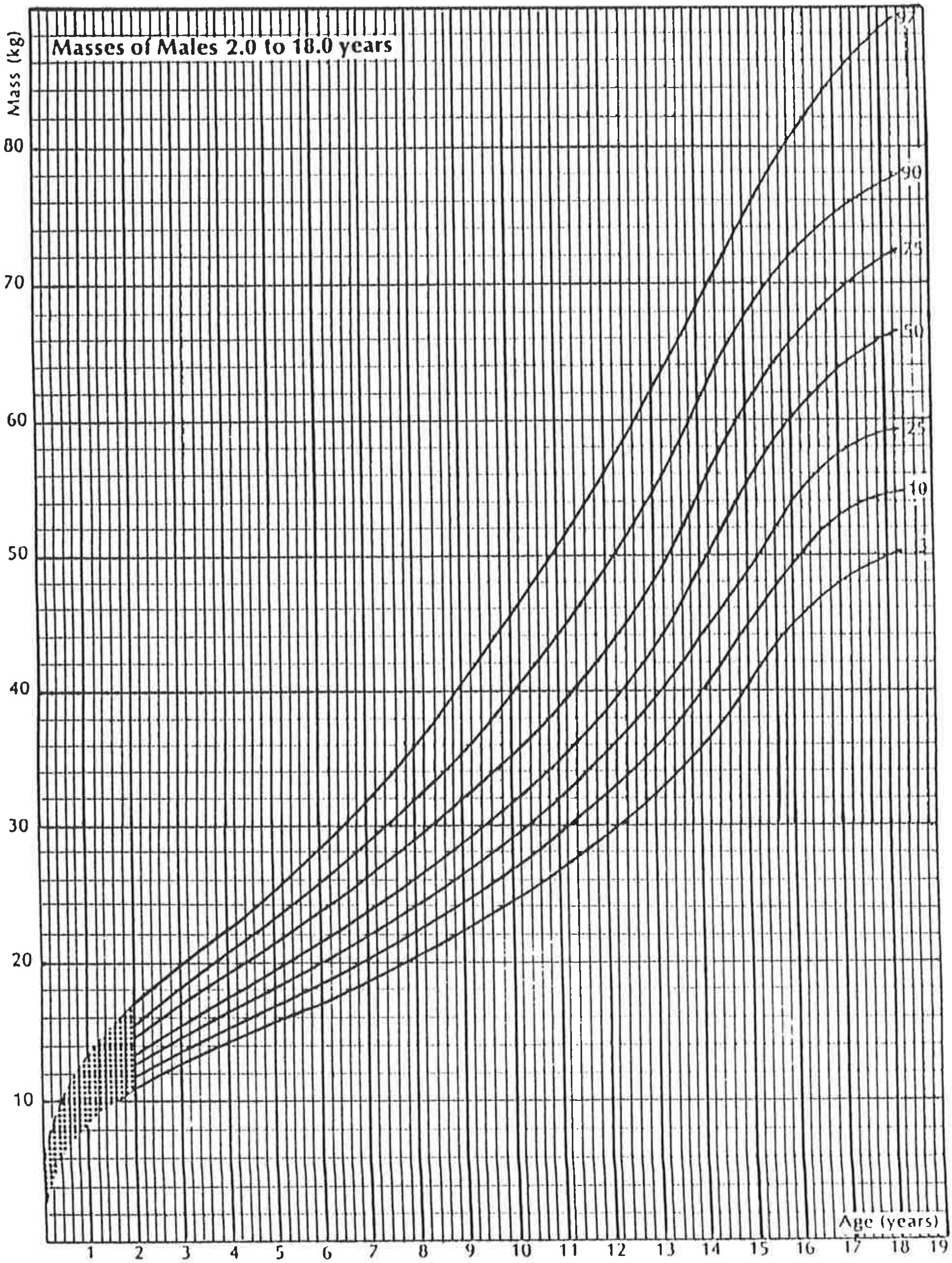
Appendix 5 Height chart for males

Heights (lengths) of males 2.0 to 18.0 years (Australian Department of Health, 1975)



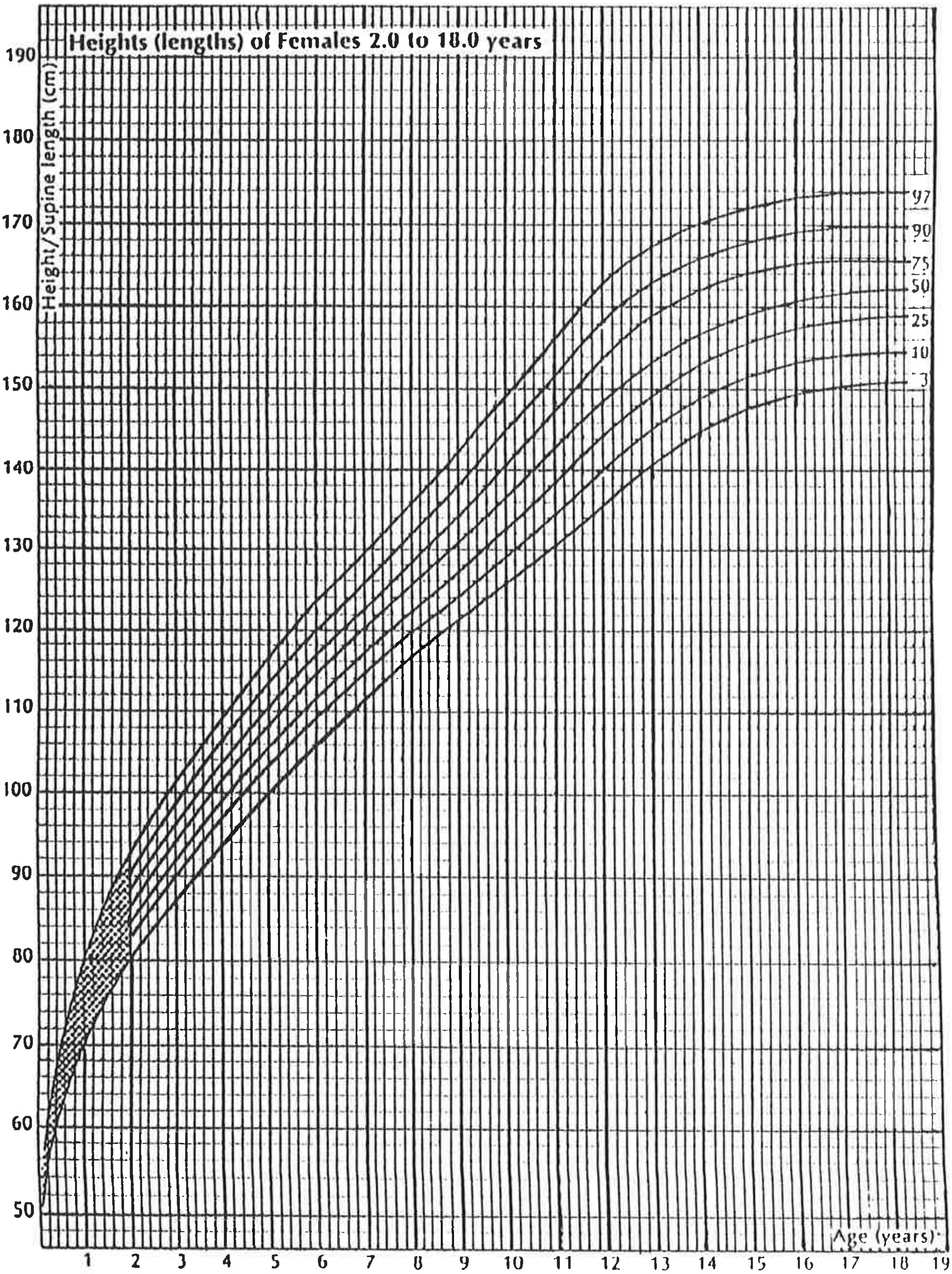
Appendix 6 Weight chart for males

Masses of males 2.0 to 18.0 years (Australian Department of Health, 1975)



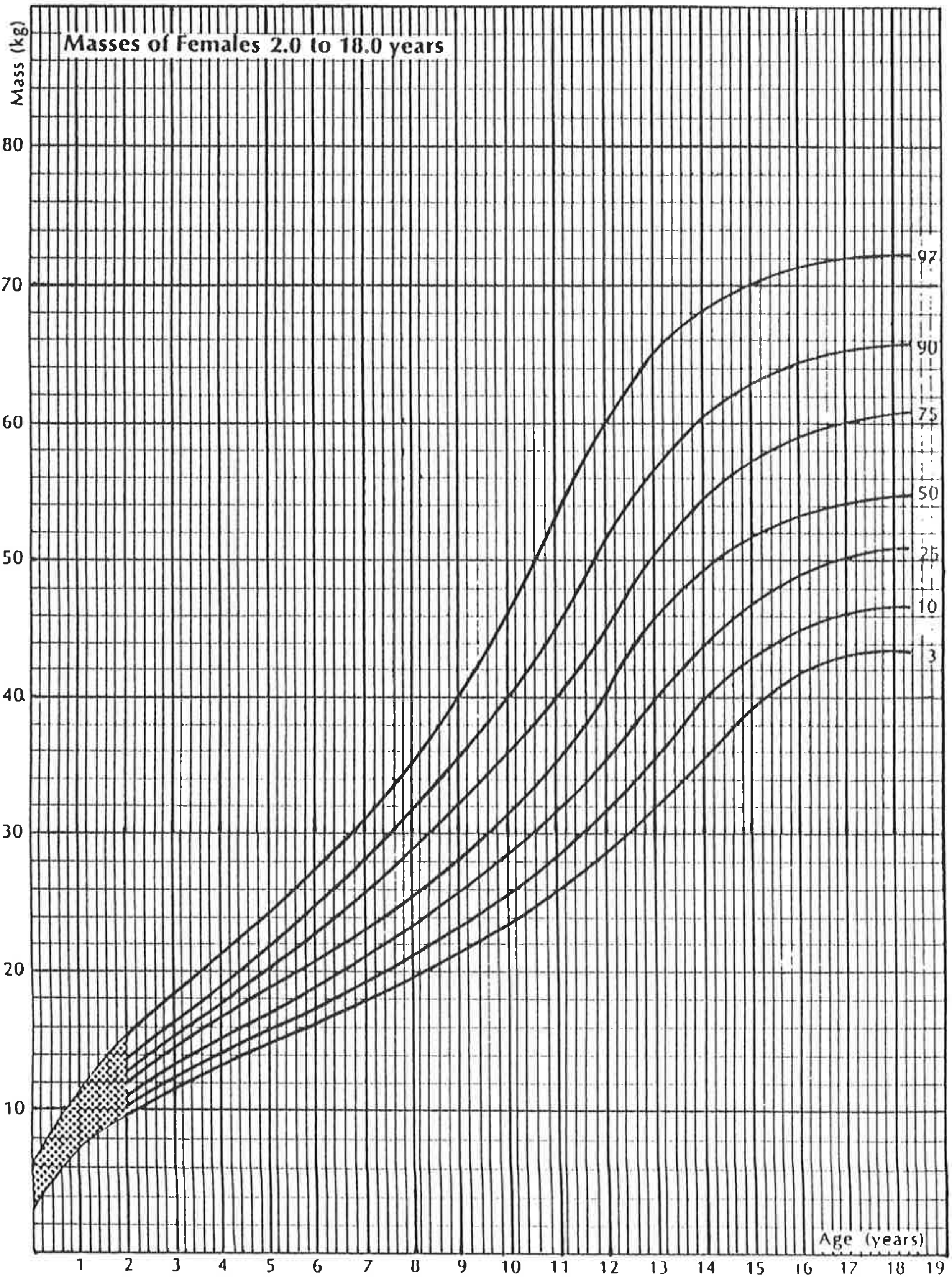
Appendix 7 Height chart for females

Heights (lengths) of females 2.0 to 18.0 years (Australian Department of Health, 1975)



Appendix 8 Weight chart for females

Masses of females 2.0 to 18.0 years (Australian Department of Health, 1975)



Appendix 9 Time of emergence of the permanent teeth

The Time of Emergence (decimal years) of the Permanent teeth for South Australian Boys and Girls (Diamanti, 1991)

Tooth		Male	Female
Maxilla	1	7.4	7.2
	2	8.6	8.2
	3	11.8	11.2
	4	11.3	10.8
	5	12.1	11.7
	6	6.7	6.6
	7	12.7	12.3
Mandible	1	6.6	6.4
	2	7.8	7.5
	3	11.0	10.1
	4	11.2	10.6
	5	12.1	11.7
	6	6.6	6.4
	7	12.2	11.8

Appendix 10 Skeletal maturity indicators

Radiographic Evaluation of Skeletal Maturation

A Clinically Oriented Method Based on Hand Wrist Films (Fishman, 1982)

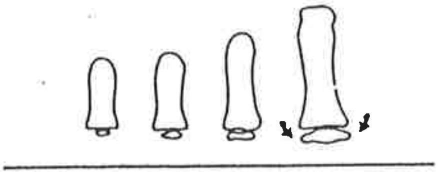
Skeletal Maturity Indicators (SMI)

Width of epiphysis as wide as diaphysis

SMI 1 Third finger – proximal phalanx

SMI 2 Third finger – middle phalanx

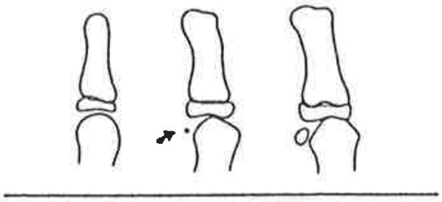
SMI 3 Fifth finger – middle phalanx



WIDTH OF EPIPHYSIS

Ossification

SMI 4 Adductor sesamoid of thumb



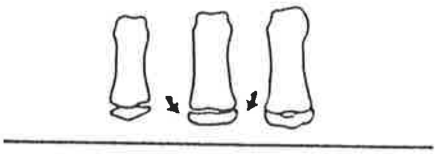
OSSIFICATION

Capping of epiphysis

SMI 5 Third finger – distal phalanx

SMI 6 Third finger – middle phalanx

SMI 7 Fifth finger – middle phalanx



CAPPING OF EPIPHYSIS

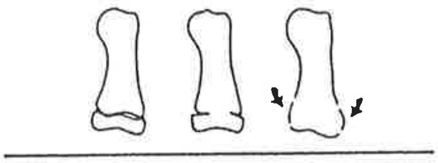
Fusion of epiphysis and diaphysis

SMI 8 Third finger – distal phalanx

SMI 9 Third finger – proximal phalanx

SMI 10 Third finger – middle phalanx

SMI 11 Radius



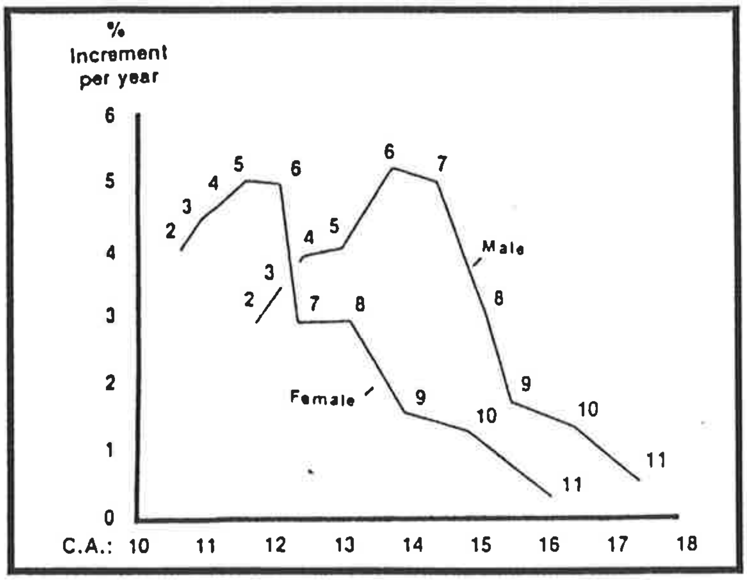
FUSION

Chronological Age Values (decimal years) for Adolescent

Skeletal Maturity Indicators

SMI	Female		Male		Differences
No.	Mean	S.D.	Mean	S.D.	
1	9.94	0.96	11.01	1.22	1.07
2	10.58	0.88	11.68	1.06	1.09
3	10.88	0.99	12.12	1.00	1.23
4	11.22	1.11	12.33	1.09	1.11
5	11.64	0.90	12.98	1.12	1.35
6	12.06	0.96	13.75	1.06	1.69
7	12.34	0.90	14.38	1.08	2.04
8	13.10	0.87	15.11	1.03	2.01
9	13.90	0.99	15.50	1.07	1.61
10	14.77	0.96	16.40	1.00	1.62
11	16.07	1.25	17.37	1.26	1.30

Relative Growth Rate Statural Height



Average statural growth rate for females and males from SMI 2 to 11

Appendix 11 Information for MRI scan

ABOUT YOUR MRI SCAN

HOW DOES MRI WORK?

An MRI machine uses a strong magnetic field and radiowaves which has no association with radiological risk. The images help us to accurately analyse both soft and hard tissues.

WHAT HAPPENS DURING THE SCAN?

You will be lying on your back in a large tunnel which is open both ends. There is a video camera to monitor your position during the scan. The machine makes loud knocking sounds when it takes the pictures. We provide earplugs for your comfort. You can ask for some music or bring your own CD or cassette tapes to listen during the scan. You may bring someone with you into the room if you wish.

IS THERE ANY PREPARATION?

Metallic objects such as watches, keys, coins, wallets, credit cards cannot be taken into the room but will be locked away for safe-keeping. It is important to tell us if you have metal in your body such as pacemaker, artificial heart valve or metallic implant. Wet hair sometimes causes interference with the images.

HOW LONG WILL THE SCAN TAKE?

There are 2 scans if you are a control subjects. Each scan takes about 5-8 minutes. You have to lie still (with a bite block in your mouth) during the scan to get good images. If you move around which causes blurred images, we have to do the scan again. If you are an experimental subjects there is an extra scan with the bite block that we made for making the appliance.

LOCATION

The MRI will be taken at the Flinders Medical Centre, Flinders drive, Bedford Park. The MRI unit is located with the Radiology Department on level 3. To enter go via the FMC main entrance and follow the directional signs to Radiology and take the lift to level 3. Car parking is available at a cost in the FMC multi-storey car park. You can also enter from the level 4 car park via the Accident and Emergency Department.

See you Saturday Morning!

Appendix 12 MRI questionnaire

FLINDERS MEDICAL CENTRE

MAGNETIC RESONANCE IMAGING (MRI) QUESTIONNAIRE

PATIIENT NAME ______________________________ F.M.C. U.R. ____________

This examination requires you to enter a strong magnetic field.

For safety reasons, please answer all of the following questions before your MRI scan.

Should you wish to have a friend or relative accompany you in the MRI room, this questionnaire is relevant to them as well.

If you do not fully understand any question, the MRI staff will be happy to help.

1. Do you have any foreign metal in your body? --------------------------- NO YES

2. Do you have any of the following?
   - Cardiac pace maker -- NO YES
   - Artificial heart valve -- NO YES
   - Aneurysm clip from an operation on an artery ---------------------- NO YES
   - Joint replacement or a metal plate related to a broken bone ----- NO YES
   - Any kind of implanted device eg. Insulin pump, patient activated pain control -- NO YES
   - Denture or removable dental plate ----------------------------------- NO YES
   - Permanent tattooed eye liner -- NO YES

3. Have you ever been a metal worker (e.g. lathing, welding metal)? -- NO YES

4. Have you ever had metal in your eyes following an injury? ------------ NO YES

5. Do you have a hearing aid or any ear implants? ------------------------ NO YES

6. Is there any possibility that you might be pregnant? ------------------- NO YES

If you have answered **YES** to any of the above questions please give details below:

IS COMPENSATION AN ISSUE WITH REGARD TO THIS INVESTIGATION --- NO YES

PLEASE REMOVE THE FOLLOWING ITEMS BEFORE ENTERING THE SCAN ROOM:

WATCHES JEWELLERY WALLET COINS CREDIT CARDS KEYS HAIRCLIPS PENS

I have answered the above questions to the best of my knowledge.

I hereby give my consent to have an MRI scan and procedures necessary to complete the examination.

SIGNED ______________________________ (patient) date ________________

______________________________________ (accompaniment)

Checked by ______________________________

Appendix 13 Ethics approval (University of Adelaide)

PROJECT NO: H/18/96

Date Received: [illegible] 1996

THE UNIVERSITY OF ADELAIDE
COMMITTEE ON THE ETHICS OF HUMAN EXPERIMENTATION

Applications will be considered in terms of the University's guidelines on the ethics of human experimentation, based on the NH&MRC Statement of Human Experimentation, refer application Information Kit. Submit the application plus 9 duplicate copies to the Secretary, Committee on the Ethics of Human Experimentation, Registry Secretariat.

COVER SHEET FOR APPLICATION FOR ETHICAL APPROVAL OF A PROJECT INVOLVING HUMAN EXPERIMENTATION

APPLICANT: Surname: CHINTAKANON Initials: K. Title: Dr.

DEPARTMENT: Dentistry **Tel:** 3035153

OTHERS INVOLVED: Professor W.J. Sampson
Professor G.C. Townsend
Dr. T.M. Wilkinson

PROJECT TITLE: Magnetic resonance imaging and cephalometric assessment of the temporomandibular joints

SOURCE OF FUNDING:

DATE PROJECT TO BEGIN: July 1996

ESTIMATED DURATION OF PROJECT: 3 years

LOCATION OF RESEARCH: Adelaide Dental Hospital

BRIEF DESCRIPTION OF THE PLAN/DESIGN OF PROJECT (In lay terms):

The "Twin Block appliance" will be used to correct poor alignment between upper and lower jaw bones in growing children by changing the posture of the lower jaw (mandible). General information will be collected which will include clinical examination, models of teeth and photographs. There will be some radiographs of head and hand taken. A simple muscle test will be conducted after some clinical sessions. The procedure is not painful and will take about 15 minutes. A series of magnetic resonance images (MRIs) of the jaw joints will also be taken (within Adelaide) to allow to see the soft tissue changes in the joints which is not normally visible on radiographs.

BRIEF DESCRIPTION OF THE AIMS OF PROJECT (In lay terms):

The objective of this research is to study the growth changes of the jaw joints in children treated with the Twin Block appliance in comparison to non-treated children. Better understanding of the mechanism of orthodontic treatment with the Twin Block appliance may lead to a better prediction of treatment outcome and a better selection of patients for successful results. Relapse potential therefore may be more accurately assessed and relevant counter measures taken.

ETHICAL IMPLICATIONS OF PROJECT:

All clinical procedures used in this research are the same as those normally used for orthodontic patients except for the use of MRIs and muscle test. However,both MRI technique and muscle test are non-invasive in nature and have no association with radiological risk. All phases of the experimental program will be conducted in accordance with the NHMRC statement on Human Experimentation and Supplementary Notes. All subjects together with their parents or guardians will be provided with an information sheet and clear verbal explanations in lay terms concerning the purpose and the procedures of the experiment. Free consent of the subjects will be obtained in writing. The subjects will be free to withdraw consent to further participation at any time.

DRUGS: Will drugs be administered to subjects? YES / (NO)
If YES - give name of drug(s):

Will this project be conducted under the Clinical Trials Notification (CTN) Scheme? YES / NO

Is Commonwealth Department of Health permission required? YES / NO

Has Commonwealth Department of Health permission been obtained? YES / NO

Is the administration for therapeutic purposes? YES / NO

Dosage:
Method of administration:

SUBJECTS: Forty children (20 males and 20 females)

Source: School Dental Service and private referral

Age range: 9-13 years for females and 10-14 years for males.

Selection criteria: Class II division 1 malocclusion requiring functional appliance treatment

Exclusion criteria: Those who do not wish to participate

SIGNATURE OF ALL INVESTIGATORS NAMED IN THE PROTOCOL:

THE UNIVERSITY OF ADELAIDE COMMITTEE ON THE ETHICS OF HUMAN EXPERIMENTATION

PROJECT NO: H/18/96

APPROVED BY THE COMMITTEE ~~AT THE MEETING HELD ON:~~ ....

SUBJECT TO:

FOR THE PERIOD UNTIL: 31 AUGUST 1997

Signed:

Date: 26-7-96.

Appendix 14 Ethics approval (SADS Board of Directors' Ethics Committee)

SADS
SOUTH AUSTRALIAN DENTAL SERVICE
Frome Road ADELAIDE 5000 Telephone (08) 8222 8222
Facsimile (08) 8222 8234 Email sads@dental.health.sa.gov.au

25th October, 1996
RJH:ds

SADS 09/75/37

Professor W J Sampson
Orthodontic Unit
Department of Dentistry
THE UNIVERSITY OF ADELAIDE

Dear Professor Sampson

After consideration by the SADS Board of Directors' Ethics Committee it has been agreed that project protocol and permission to liaise with school dentists be granted to Dr. Kanoknart (Nim) Chintakanon, Specialist Orthodontist. Arrangements can be made with Dr Peter Telfer for Hospital clinic access rights.

We are happy to be able to assist in this matter.

Regards

Yours sincerely

RJ Hassam
CHIEF EXECUTIVE OFFICER
SOUTH AUSTRALIAN DENTAL SERVICE

Appendix 15 Effective radiation dosage

Royal Adelaide Hospital
Nuclear Medicine Department
North Terrace, Adelaide, SA, 5000

PHYSICS AND RADIATION SAFETY SECTION
Phone: (08) 8222 5408
Fax: (08) 8222 5949

Title: Magnetic resonance imaging (MRI) and cephalometric assessment of the temporomandibular joints (TMJ): A prospective study of treatment with the Twin Block appliance.

Investigators:
Dr K Chintakanon, Prof W Sampson, Prof G Townsend and Dr T Wilkinson.

Studies performed:
As part of this research investigation, three 10 degree lateral oblique and two PA skull x-rays will be taken. These views will be in addition to the normal x-rays taken as part of the clinical investigation (ie. 1 lateral oblique skull, 1 OPG and 1 x-ray of the left wrist). Only the dosimetry for the research component is outlined below.

Effective Dose (E.D):
The ED estimates are taken from Table III of the paper by McDonald et al (1996)(see below). The values for AP and lateral skull for children in the 10 - 15 yr age group were used.
It should be noted that the published estimates were for examinations using a grid. In the proposed protocol, an air-gap technique will be used without a grid - this will result in a considerable reduction in mAs and therefore, radiation dose (typical values used in current study: PA =13 mAs, Lat = 8 mAs). Consequently, the doses have been adjusted by a correction factor - equal to the ratio of the mAs in the proposed and published (Table I) studies.

<u>Correction factor</u>	(PA)	= 13/38	= 0.34
	(Lat)	= 8/31	= 0.26

<u>ED</u>	(PA)	= 0.34 x 0.023 mSv
		= 8 μSv
	(Lat)	= 0.26 x 0.018 mSv
		= 5 μSv
<u>Total ED</u>		= 2 x 8 + 3 x 5
		= 31 μSv

Comment:
The total radiation burden for the research component of the project is 31 μSv.

Reference: Mc Donald S, Martin CJ, Darragh CL and Graham DT. Dose-area product measurements in paediatric radiography. Br. J. Radiol., 69, 318-325 (1996).

P.J. Collins
Radiation Safety Officer
Royal Adelaide Hospital
23rd July 1997

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