THE HUMAN TRAPEZIO-METACARPAL JOINT

— an anatomical, osteometric and clinical study

A THESIS SUBMITTED FOR THE DEGREE OF MASTER OF SCIENCE

by

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SUMMARY

A study of the function of the human trapezio-metacarpal (T-M1) joint has been undertaken. This investigatory work comprised three separate components – anatomical, osteometric and clinical.

The *ANATOMICAL STUDY* of 28 unembalmed specimens within 24 hours of death demonstrated different attachments of the first inter-metacarpal ligament from those previously described.

The range of five passive movements, comprising circumduction, were measured radiologically, wide variation being found between individuals.

Ligamentous function was described in terms of the control of angular movement and axial rotation of the first metacarpal. While all four ligaments contributed to the control of each individual movement, the major limiting functions of each ligament were delineated.

Staining of the articular cartilage revealed fibrillation as early as the second decade of life. A consistent pattern of degeneration was noted, peripheral fibrillation being more marked on the antero-lateral, lateral and medial aspects of the trapezial surface and on the posterior aspect of the metacarpal.

The *OSTEOMETRIC STUDY* was carried out on the articular surfaces, cartilage in situ, of 23 T-M1 joints. A three-dimensional grid reference method of measurement of the articular surfaces was developed. Data thus obtained was used to measure, for the first time, the following geometrical features of the articular surfaces: the mean angle between the two axes on the trapezium and first metacarpal, the arc length of the two axes and the surface area of the cartilage.

The detailed *CLINICAL STUDY* of 492 T-M1 joints (using a questionnaire, radiological and clinical procedures), investigated the relationship of specific demographic variables, generalised peripheral joint hypermobility, occupational use and osteo-arthrosis to the mobility and stability of the T-M1 joint. Comparisons were made with a sample of 'medically normal' joints ($N=174$).

T-M1 joint mobility was found to decrease significantly with advancing age ($p < .005$) and with cumulative use of the thumb ($p < .005$). The incidence (%) of osteo-arthrosis was significantly related to a past history of pain at the thumb base ($p < .00001$), peri-articular thickening ($p < .00001$), ageing ($p < .0001$) and cumulative use of the thumb ($p < .005$).

The T-M1 joints of 33 individuals exhibiting generalised peripheral joint hypermobility showed a significantly higher incidence of dorso-lateral instability ($p < .0005$) when compared with the non-clinical group. Differences in mobility between the two groups were greatest for the accessory movements.

Consistently different usage of the thumb formed the basis of the three occupational groups studied — manipulative therapists (40 thumbs), tailors and dressmakers (72 thumbs) and players of the violin, viola and 'cello (70 thumbs). Occupational use resulted in loss of mobility in movements not regularly exercised and a higher incidence of osteo-arthrosis associated with long periods of isometric holding with the thumbs.

The incidence (%) of stiff and abnormal quality scores rose with advancing osteo-arthrosis, being a more consistent finding in the accessory movements (osteo-arthrosis group, $N=198$ thumbs). The earliest radiological sign of osteo-arthrosis was seen on the dorso-lateral aspect of the trapezial surface. As T-M1 joint osteo-arthrosis became more marked, so did the incidence of involvement of the other trapezial articulations. A regular menstrual cycle was found to be a significant factor in lowering the incidence of osteo-arthrosis of the T-M1 joint ($p < .01$).

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DECLARATION

I declare that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any University; and that to the best of my knowledge it does not contain any material previously published or written by another person except where due reference is made in the text.

PATRICIA H. TROTT
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LIST OF DEFINITIONS

Active Movements are those movements which can be performed voluntarily.

Passive Movements are those movements which are produced by an outside force.

Physiological Movements are movements which can be produced voluntarily. When these movements are carried out passively they are classed as PASSIVE PHYSIOLOGICAL MOVEMENTS.

Accessory Movements are movements which cannot be performed actively in the absence of resistance (Warwick and Williams, 1973). They can, however be produced passively.

Dorso-lateral instability)
Dorso-radial instability) In this study these terms are used synonomously.

Osteo-arthritis – an active inflammatory disease in joints with radiological evidence of osteo-arthrosis.

Osteo-arthrosis – radiological evidence of degenerative changes in a joint (classification of these changes is given in Table 4.2).

CHAPTER 1

INTRODUCTION

'The opposable thumb is man's greatest asset', wrote Curtis in 1974. While man is not unique in his ability to oppose digits he has undeniably superior versatility, skill and strength in movements of the digits largely arising from the range and strength of movements of the thumb.

Comparative studies involving this digit have been made through the centuries and continue today (Napier, 1956, 1960 and Lewis, 1977). With man's upright posture it seems rational to expect that a hand, freed of any locomotor function, would be more specialised in manipulatory skills. Two features of the human thumb are claimed to be of special significance: the length of the thumb is comparable with that of the other digits allowing 'pulp to pulp' contact and thereby extreme preciseness of digital movement (Napier, 1960): the angle between the trapezio-metacarpal (T-MI) joint and the rest of the carpus seems also to be of major importance in the achievement of both power and precision of digital movement (Lewis, 1977). The T-MI joint is of utmost importance to function of the thumb as the most important movements of abduction and opposition occur primarily at this joint.

The paramount functional importance of the thumb has been confirmed by many authors (Bunnell, 1938; Tubiana and Valentin, 1968; Eaton and Littler, 1969; Eiken and Carstam, 1970; Burton, 1973; Bosjen-Møller, 1976). Cooney and Chao (1977) give a neatly worded summary of the functional requirements of the thumb '. . . it must have the dexterity to handle firm objects and the intrinsic stability and strength to resist forces applied by one or all four fingers during pinch and grasp'. Recognition of the importance of the thumb by the lay community is evidenced by the fact that experts in accident insurance estimate the value of the thumb as half that of the whole hand (Hirsch et al., 1974).

A review of the literature pertaining to the T-MI joint shows that clinical reports related to osteo-arthritis and its surgical management far outnumber articles based on formal anatomical and clinical research.

Physiotherapists, and in particular Manipulative Therapists, have stressed the importance of maintaining and/or restoring 'normal' mobility at joints (Maitland, 1977a and b; Trott and Goss, 1978). Specifically they have emphasised the need to restore the accessory movements which occur concomitantly with active movements of a joint. Biochemical studies have supported the importance of movement to the nutrition of adult articular cartilage (Ekholm, 1955; Maroudas et al., 1968; Caterson and Lowther, 1978) and the capsule and ligaments (Akeson et al., 1973). There is a paucity of information related to normal function of the T-MI joint and how this may be altered by occupational and recreational stresses.

Due to lack of published reports related to the function of the T-MI joint, this study is planned to be of an investigatory nature rather than a testing of specific hypotheses. The treatise is divided into three separate studies of T-MI joint function whose broad aims are:

Anatomical study (based on unembalmed autopsy specimens)

a) to measure the range of passive movements* at the T-MI joint
b) to ascertain the function of the four ligaments of the T-MI joint
c) to establish whether a pattern of degenerative change typical for the T-MI joint exists in the articular cartilage

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* See List of Definitions

Osteometric Study (based on unembalmed autopsy specimens)

a) to visually examine the features of the articular surfaces of the T-MI joint

b) to develop a method of precise measurement of the shape of the articular surfaces and to use this to measure certain geometric features of the articular surfaces of the T-MI joint

Clinical Study (research based on live subjects)

a) to measure the range and quality of passive movements of the T-MI joint and to record the incidence of instability in a group of non-clinical, that is, 'medically normal' joints

b) to investigate the relationship of specific demographic variables, generalised peripheral joint hypermobility and occupational use to T-MI joint mobility, stability and osteo-arthrosis*

c) to study the pathogenesis of osteo-arthrosis of the T-MI joint and the relationship of osteo-arthrosis to the mobility and stability of the joint.

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* See List of Definitions

CHAPTER II

REVIEW OF THE LITERATURE

2.1 Introduction

The wide range of movements possible at the trapezio-metacarpal (T-MI) joint, and yet its stability during strong gripping and pinching of objects between the thumb and fingers, have interested both anatomists and clinicians.

The anatomical and functional aspects of the thumb as a whole have been well documented, but few authors have analysed in detail the function of the 'normal' T-MI joint and how this may be altered by the stresses of certain occupations or by pathological conditions such as osteo-arthrosis.

First, the anatomy of the T-MI joint will be reviewed with a description of the articular surfaces and ligaments and their role in the mobility and stability of the joint. Second, the T-MI joint will be reviewed from a kinematic point of view. As this is a study of passive mobility the literature review does not include the part played by muscles in producing active movements. Third, the review will include other factors considered to affect the stability and mobility of the T-MI joint. Fourth, the literature on individuals with generalised peripheral joint hypermobility will be reviewed in some detail as these constitute one group examined in this study.

2.2 Anatomy of the T-MI Joint

2.21 The alignment of the thumb in relation to the rest of the hand

According to Pieron (1973), Bichat in 1819 and again in 1830, was one of the earliest to record the 'oblique position of the trapezium in relation to the other carpal bones'. Warwick and Williams (1973) stated 'the thumb, however, lies in a plane set almost at right angles to that of the fingers' while Smith and Kuczynski (1978) found the angle to be 60^{o} - 80^{o}'. It appears that the alignment of the thumb is subject to considerable individual variation.

2.22 Description of the surfaces and their role in the stability and mobility of the T-MI joint.

According to Gedda (1954), Cruveilher in 1843 was the first to describe the T-MI joint as saddle-shaped. In 1854, Fick analysed the qualities of the joint on the basis of its saddle-shape. Thus it is of interest to find a relatively recent report by Kivilaakso (1949), classifying the joint as of the ball and socket variety, and Kapandji (1970) who likened the joint to a pivot.

Apart from these two, there was general agreement that the surfaces are saddle-shaped (or sellar), (Kaplan, 1965; Swanson, 1972; Burton, 1973; Eaton and Littler, 1973; Kuczynski, 1974; Landsmeer, 1976; and Smith and Kuczynski, 1978). However there is still contention over the degree of congruity between the two surfaces. Aune (1955), Napier (1956), Tubiana and Valentin (1968) and Swanson (1972) considered the surfaces to be non-congruent, whereas Eaton and Littler (1969, 1973) and Kuczynski (1974) described them as congruent, stating further that they play an important role in joint stability.

MacConaill (1953), in describing the principles of joint mechanics, stated that at all non-pivot joints the characteristic or habitual movements are composite ones involving some degree of rotation (conjunct rotation) and that this is most marked in joints with concavo-convex surfaces when it is effective in screwing the bones together into a locked position. In these 'close-packed positions' the articular surfaces are maximally congruent, and for the T-MI joint the characteristic position is opposition.

Pieron (1973) strongly disagreed with MacConaill as he found greater contact between the articular surfaces when the T-MI joint is abducted. Lewis (1977) considered there to be two close-packed positions for the T-MI joint. In describing these he applied MacConaill's (1953) principles to Napier's (1956) two functional positions of the thumb. During 'power grip' the first metacarpal is extended, adducted and laterally rotated and in the position of 'precision grip' it is abducted, flexed and medially rotated.

Kuczynski (1974) and Smith and Kuczynski (1978) were the only authors to conduct detailed research on the shape of the articular surfaces; however, the methodologies of both were relatively crude. In the 1974 paper, the surfaces of 15 dry skeletons were examined 'by visual inspection and palpation' and in the 1978 work only the depth of the trapezial groove was measured using a small tyre thread depth gauge (the results being quoted to the nearest 0.1mm). The metacarpal surface was not measured but described as 'of the usual configuration'. Their measurements were made on 32 specimens from the dissecting room aged between 60 and 80 years.

When examining for congruity between the articular surfaces of any joint, it would seem essential that specimens with articular cartilage (rather than dry ones) be selected as the uneven distribution of cartilage reduces congruity (Tubiana and Valentin, 1968). The finding of Simon et al. (1973) that the thickness of articular cartilage was inversely related to congruence supports this. These workers also found that congruent joints, with thin cartilage, have a low incidence of degenerative change. Additionally, subjects of varying age should be selected as Goodfellow and Bullough (1967) and Bullough et al. (1973) found that congruity increased with age. In 1977, Goodfellow and Mitsou found that reducing weight-bearing through the hip joints (of rabbits) increased the congruity of the joint surfaces. From this they postulated that 'there is a mechanism in joints to control the modelling of their shapes towards an ideal of incongruity and that that mechanism is pressure sensitive'. From their findings it would seem that incongruity renders a joint capable of transmitting physiological loads without inducing unphysiological stresses. Kurrat and Oberländer (1978) found that in the hip joint the thickness of cartilage is dependent on functional stressing. To date the thickness of different areas of articular cartilage has not been reported for the T-MI joint although the work of Cooney and Chao (1977) demonstrated that considerable forces are applied across the joint during normal function of the thumb. They demonstrated that for 1 kg of applied force, as in pinching, the compressive force across the T-MI joint was 12 kg, and that during strong grasping this may be as high as 120 kg.

2.23 Description of the capsule and ligaments and their role in the stability and mobility of the T-MI joint

Several authors described the capsule as loose (Napier, 1956; Eiken, 1971; Warwick and Williams, 1973; Bosjen-Møller, 1976; Kessler et al., 1976). Writers differed in their opinions as to whether it is thick or thin. Warwick and Williams described the capsule as thick, especially laterally and dorsally, whereas Bosjen/Møller considered it to be thin.

Pieron (1973) appears to be the only author to give a detailed description of the capsule. He described it as being thin on the 'radio-volar aspect' but thick on the ulno-volar side (in contradistinction to Warwick and Williams, 1973), and being inserted close to the articular margin on the volar, ulnar and radial aspects and re-inforced by ligaments volarly, dorsally and dorso-radially.

According to Kaplan (1965), Weitbrecht in 1742 was the first to describe four ligaments around the T-MI joint. He named them the dorsal, palmar, external lateral and internal lateral ligaments respectively. It was not until two centuries later that reference was again made to four ligaments (Haines, 1944). Pieron (1973) in reviewing the literature related to the T-MI joint mentioned several authors of the nineteenth century (Henle, 1856; Morris, 1879 and Virchow, 1898) who made mention of ligaments, but none of whom described them or their function in any detail.

The nomenclature used by Haines (1944) clearly described the position of the ligaments and has been adopted by most subsequent authors. From his dissections he was able to identify three strong ligaments to which he gave the names radial, anterior oblique and posterior oblique. He also described weak anterior, and strong posterior, inter-metacarpal ligaments situated between the first and second metacarpals. Pieron, while in general agreement, found the radial ligament to be dorsally placed and thus renamed it the 'dorso-radial ligament'.

MacConaill (1953) wrote 'Whatever the end intended by the arrangement of articular ligaments, that arrangement must allow the conjunct rotation imposed upon the moving part by the shape of the fixed surface'. Pieron (1973) found that the four ligaments of the T-MI joint 'are of a different length and also their insertion has an asymmetrical arrangement', and pointed out that a ligament only functions when it is tight, and that 'generally speaking it has an inhibiting function. Furthermore it has a specific role which depends on the course of its fibres and its points of attachment'. His findings are summarised in the following table, which also includes the area of joint contact.

Position of MI	Area of joint contact	Maximal span of ligaments
ulno-dorsal * (extension-adduction)	ulno-dorsal quadrant	1. ant. oblique 2. dorso-radial (radial ½)
radio-dorsal * (extension-abduction)	dorso-radial quadrant	1. ant. oblique 2. dorso-radial (ulnar ½) 3. post. oblique 4. inter-metacarpal
radio-volar * (radial-abduction)	dorso-radial quadrant radio-volar quadrant	1. ant. oblique 2. post. oblique 3. inter-metacarpal
ulno-volar * (opposition)	ulno-volar quadrant	1. dorso-radial 2. ant. oblique
ulnar * (adduction)	ulno-volar quadrant	1. dorso-radial 2. ant. oblique

Table 2.1 **T-MI joint ligamentous function.** Pieron (1973)
* = corresponding terms used in this study.

Although Pieron's is the most comprehensive report on the function of the various ligaments, others have contributed to our knowledge. To date the function of the ligaments is still debated.

Haines (1944) considered the anterior oblique ligament to limit the range of extension and to produce lateral rotation which he observed occurred at the limit of extension. Warwick and Williams (1973) supported this view, attributing the lateral rotation to the sellar articular surfaces and considered also that the ulnar side of the base of the metacarpal bone becomes anchored by tension in the anterior oblique ligament while the radial side remains free to move.

A number of authors (Gedda, 1954; Eiken, 1971; Burton, 1973; Eaton and Littler, 1973; Kessler et al., 1976) considered the anterior oblique ligament to be the most important ligament because, in their opinion, laxity in this ligament results in dorso-lateral subluxation of the T-MI joint.

Haines (1944) noted that medial rotation occurred at the limit of flexion; he claimed this was due to tension in the posterior oblique and the posterior inter-metacarpal ligaments. Warwick and Williams (1973) attributed medial rotation to the geometry of the articular surfaces and to the obliquity of the fibres of the posterior oblique ligament which, when taut, anchors the ulnar side of the base of the metacarpal leaving the radial side free to move. From his dissections, Lewis (1977) found that the posterior oblique ligament inserted also into the posterior aspect of the base of the first metacarpal but he did not mention what effect this might have on the function of the ligament.

Differing views have been expressed over which tissues limit abduction. Haines (1944) suggested the posterior oblique ligament, whereas Bosjen-Møller (1976) considered this the function of the inter-metacarpal ligament. He described the intermetacarpal ligament as being 'Y-shaped' with two attachments to the base of the second metacarpal. These unite and the common stem inserts into the medial aspect of the first metacarpal base. Bosjen—Møller further found that this ligament also prevented radial subluxation and that it was the axis for circumduction in abduction during which the metacarpal rotates on the radial part of the trapezium.

Eaton and Littler (1973) and Pieron (1973) *(see Table 2.1)* rated the function of the posterior oblique ligament as relatively insignificant. However, according to Gedda (1954), Strasser in 1917 considered that this ligament controlled the range of opposition. Haines (1944) was of the same opinion, but considered that the anterior oblique and inter-metacarpal ligaments contributed also.

While the exact position of maximal congruity of the T-MI joint is unresolved the following quotation, of Barnett et al. (1961, page 213) seems most appropriate — '. . . the occurrence of conjunct rotation in a joint as the close-packed position is being approached enables ligaments to become taut serially instead of in unison' and on page 214 '. . . not all ligaments are necessarily tense in all terminal positions'. Pieron's findings, as set out in Table 2.1 would appear to support these statements.

Barnett et al. (1961, page 208) also wrote 'It is generally accepted that the type of movement that can occur at any joint depends on the form of the articular surfaces, the restraining influence of ligaments and the control exerted by muscles acting upon the joint. It is obvious that the same factors are likely to play a part in bringing movement to a halt . . .'

Landsmeer (1976) considered that the 'role of the ligaments in producing axial rotation is fully recognised' but clearly, to date there is no agreement as to the contribution of the ligaments and articular surfaces to the mobility or the stability of the T-MI joint.

2.3 Kinematics of the T-MI Joint

As recently as 1976 Landsmeer wrote 'the designation and terminology of thumb movements have not been resolved satisfactorily'. Further to this statement there is still no standardisation of measurement.

Several authors have tried to analyse thumb movements and in particular the combined movement of circumduction, however they have used different points of reference. Söderberg (1953) and Ebskov (1970) used the tip of the thumb whereas Hamonet et al. (1972) related movements to the metacarpal head. The site of rotation has created much difference of opinion. Bunnell (1938), Kapandji (1963) and Tubiana and Valentin (1968) considered that it occurred at the metacarpo-phalangeal joint, whereas Napier (1955), Kaplan (1966) and Pieron (1973) described rotation as occurring at the T-MI joint.

Movements at the T-MI joint have been described in relation to the shape of the articular surfaces (Sömmering, 1839; Kivilaasko, 1949; and Kapandji, 1970). Most recent authors, Kaplan (1965), Swanson (1972), Burton (1973), Eaton and Littler (1973), Kuczynski (1974), Landsmeer (1976) and Smith and Kuczynski (1978), consider the joint to be saddle-shaped with three degrees of freedom. More recently, in an attempt to standardise the movements, de la Caffinière (1970) and Pieron (1973) have described the movements in relation to the plane of the second and third metacarpals.

The ranges of movements for 'normal' T-MI joints have been quoted by many authors, as set out in Table 2.2, but they omit to give the criteria for normalcy, whether they were active or passive movements performed *in vivo* or in autopsy material, whether related to age and gender and further to describe the exact direction of the movements or the fixed points from where the measurements were taken.

Author	**Date**	**Movement**	**Range**	
			Angular	**Rotary**
Söderberg	1953	Opposition	120°	90°
Bunnell	1938		120°	90°
Kaplan	1966		110°	25°
Tubiana & Valentin	1968		90-120°	
Curtis	1974			30°
Kapandji	1963	Flexion to Extension	50°- 90°	
Curtis	1974		55°	
Landsmeer	1976		55°	
Kapandji	1963	Adduction to Abduction	40°- 50°	
Curtis	1974		45°	
Landsmeer	1976		45°	
Leach & Bolton	1968	Palmar Abduction	60°	
Kessler & Axer	1971	All movements	15°- 30°	

Table 2.2 **Range of movements at the T-MI joint**

MacConaill (1946) described the surfaces of the T-M1 joint as 'sellar' (saddle-shaped). He also introduced a new terminology for movements at joints when he described two kinds of displacement of a moving surface upon a fixed one, 'spinning' and 'sliding'. A moving surface 'spins' when it rotates about an axis which is perpendicular, at the point of contact, to the fixed surface. All other movements are described as 'sliding'. When there is no concomitant 'spin' the movement of the bone is termed a 'swing' and occurs in the same plane. However 'slides' are often along curved pathways and thus 'spin' occurs simultaneously. This continuous spin is called 'conjunct rotation'.

Barnett et al. (1961, page 185) stated that in sellar joints 'the degree of congruity between the surfaces will determine to a certain extent the amount of conjunct rotation'. Haines (1944) described axial (conjunct) rotation as taking place at the extreme range of flexion and extension stating that this was a function of the ligaments. Pieron (1973) demonstrated that axial rotation occurs 'throughout the entire motion spectrum of extreme positions' which make up circumduction, rather than in flexion and extension only.

In reference to the T-M1 joint, MacConaill (1946) noted that 'a clockwise diadochal displacement upon a sellar surface is accompanied by an anti-clockwise conjunct rotation of the displaced body, and conversely'. This appears to be contradictory to further description of circumduction in which he stated that during the first half the metacarpal rotates about its own axis in one direction and then it rotates in the opposite direction as circumduction is completed. This is another example of the lack of definition of the direction and starting position of circumduction and in which thumb it is being described. Pieron (1973) described his findings in more detail, but he too, omitted to say (in his summary of findings) in which direction the right thumb was being circumducted. He failed to emphasise that in the same thumb the direction of axial (conjunct) rotation alters with the direction of the circumduction. Pieron (1973) found that 'during motion in the radial curve M1 rotates in a clockwise direction and in the ulnar curve axial rotation occurs in an anti-clockwise direction in the right hand, viewed from distal to proximal'. Landsmeer (1976) in quoting Pieron's work neglected to even mention which hand was being described, let alone the direction of circumduction.

Apart from axial (conjunct) rotation, the anatomical reports cited have tended to disregard the importance of accessory joint movements at the T-M1 joint. Warwick and Williams (1973) considered distraction and rotation to be the only accessory movements at this joint, disregarding the concomitant sliding movements that on x-ray can be seen to occur. Lassère et al. (1949) described the metacarpal sliding laterally during adduction, leaving the medial part of the trapezium uncovered (in direct contrast to Pieron's, 1973, findings). Some authors have built mechanical models in an attempt to show that movements occur about a moving axis. Bausenhardt (1949), built a model with symmetrically-shaped articular surfaces thus considering that the metacarpal follows a symmetrical path. Pieron (1973), realised the shortcomings of Bausenhardt's model and created a model based on a radiographic study of the location of the first metacarpal in five positions, which together comprise circumduction. He was then able to describe the pathway of the first metacarpal over the trapezium during circumduction. That the metacarpal moves over the trapezium implies that accessory movements must have occurred but he did not specifically describe these.

Clinicians have described the importance of the normal coupling of physiological movements with accessory movements (Mennell, 1964; Maitland, 1977 a and b; Trott and Goss, 1978) but only in the last decade or so has their clinical experience been supported by research. Pieron's work did much to lessen this gap between anatomists and clinicians, but further research is needed to establish the importance of accessory joint movements in the normal function of the T-M1 joint.

2.4 Congenital Abnormality of the T-M1 Joint

Apart from heritable disorders of connective tissue which may affect mobility of all joints (McKusick, 1972), congenital abnormality of the T-M1 joint appears to be uncommon.

Rushforth (1949) described a case of congenital abnormality involving both the trapezium and first metacarpal of both thumbs. He considered that the condition might be related to abnormal ossification of the trapezium, and quoted the work of Pfitzner (1895) who described four centres of ossification of the trapezium. Nissen (1933) recorded two cases of an accessory trapezium.

No report of congenital fusion of the T-M1 joint was found.

2.5 Mobility at Adjacent Joints and its Effect on T-M1 Joint Mobility

Studying joint mobility, Wood (1971) advanced the concept of considering the interrelationship of motion between joints. He noted that in the fingers the proximal inter-phalangeal joints with the lowest frequency of hyper-extension were associated with distal inter-phalangeal joints with the greatest frequency of hyper-extension, and vice versa.

Frequently loss of mobility at the T-M1 joint results in increased mobility at adjacent joints. Swanson (1972) and Burton (1973) reported that in patients with stiff osteo-arthrotic T-M1 joints there was increased mobility in the metacarpo-phalangeal and inter-phalangeal joints.

Following surgical fusion of the T-M1 joint, Müller (1949) and Kaplan (1966) found a compensatory increase in movement at the trapezio-scaphoid joint, whereas Eiken and Carstam (1970) noted an increase in the range of extension at the metacarpo-phalangeal joint. On the other hand, Carroll and Hill (1973) reported an increase in range in both these joints following surgical fusion of the T-M1 joint.

No reports were found in the literature that the converse is true, that is, that decreased mobility in adjacent joints may result in a compensatory increase in T-M1 joint mobility. Perhaps this is because of the negligible movement found in the other trapezial articulations with the scaphoid, trapezoid and second metacarpal (Kessler et al., 1976).

2.6 Other Factors Affecting Joint Mobility and their Effect on T-M1 Joint Mobility

Apart from local variation in shape of the articular surfaces and relative tension in the capsule and ligaments which affect the mobility of that particular joint, the following factors may affect an individual's overall state of joint mobility.

2.61 Race

Considerable confusion exists about racial variations. From his clinical experience, McKusick (1972) considered Negroes to be more mobile than Caucasians. This was substantiated by the earlier findings of Harris and Joseph (1949) who compared the mobility of Africans, Europeans and Indians in a study of the metacarpo-phalangeal and inter-phalangeal joints of the thumb. They found Indians to be the most mobile, followed by Africans and then the European group. The findings of Schweitzer (1970) were very similar.

Wood (1971) found no clear difference in mobility between Caucasians and Negroes. In some joints, such as the distal inter-phalangeal, Negroes were more mobile, but they were found to have stiffer elbows and proximal inter-phalangeal joints. Others (Beighton et al., 1973) looked at the mobility of ethnic African groups but no comparisons were drawn with recognised norms for Caucasians, the major problem being that of establishing suitable criteria by which to judge the existence and degree of mobility.

While finger joint mobility has been researched in some detail, no references to race and the mobility of the T-M1 joint were found.

2.62 Age

Most of the authors reviewed agreed that age had a bearing on peripheral joint mobility. Histologically there is adequate support for this concept on the basis of changes in collagen tissue. Versăr (1963) found an increase in the number of cross-linkages in collagen with ageing. Ridge and Wright (1966) and Sussman (1973) considered collagen to become stiffer in the elderly and as this is the main component of joint capsules and ligaments, which are largely responsible for limiting joint movements, joint mobility decreased.

Beighton et al., (1973) on examining an African population, found peripheral joint mobility to diminish with age, with range decreasing rapidly as childhood progressed, but more slowly through adult life. The earlier work of Wynne-Davies (1971) concurred with this.

Decreasing joint range with increasing age has been further illustrated by the work of Ellis and Bundick (1956) and Silverman et al. (1975) specifically in relation to extension of the metacarpo-phalangeal joint of the little finger, and by Wood (1971), who, while finding elbow mobility to be unaffected by age, noted a marked age gradient in the range of movement in the proximal inter-phalangeal joints of the hand.

No articles specifically discussing the mobility of the T-M1 joint in relation to ageing were found, except in relation to osteo-arthrosis and age. Gervis (1949), Aune (1955), Burton (1973), Eaton and Littler (1973), Kessler (1973) and Amor (1976) described osteo-arthrosis of the T-M1 joint as a complaint of middle age, finding it more prevalent in the fourth and fifth decade. However, Weinman and Lipscomb (1976) found it to be more common later in life, that is, in the fifty to seventy year group.

2.63 Gender

Harris and Joseph (1949) and Loebl (1972) noted the metacarpo-phalangeal and inter-phalangeal joints of the thumb and fingers to be more mobile in women. Clarke et al. (1975) in delineating the normal range of movements at the gleno-humeral joint found significant age and sex differences in range of motion (and stressed the importance of matching individuals on these two variables in studies on joint mobility).

In surveying a large number of peripheral joints, Beighton et al. (1973) and Grana and Moretz (1978) found women to be more mobile than men of the same age.

Sex differences in the mobility of the T-M1 joint have not been studied as far as an extensive literature review could ascertain.

2.64 Dominance

Greater finger joint mobility on the non-dominant side has been reported by a number of authors (Loebl, 1972; Wood, 1971; Beighton et al., 1973). While Beighton et al. (1973) gained the 'strong clinical impression . . . that all other paired joints conform to this pattern', Wood (1971) found the inter-phalangeal joint of the thumb and the proximal inter-phalangeal joint of the index finger, as well as the elbow, to be stiffer on that side. Accordingly, it is difficult to draw any conclusions re the effect of dominance.

Again, no references were found in which the effect of dominance on T-M1 joint mobility was reported.

2.65 Body build

Beighton et al. (1973) found no relationship between physique (as expressed by the ponderal index and metacarpal length) and joint mobility, commenting that the general assumption that tall, thin individuals tend to be more loose-jointed than those with a short stocky build is erroneous. This substantiated the earlier work of Nicholas (1970).

In contrast to the previously mentioned authors, Khasigian et al. (1978) reported an association between body type and rotational laxity of the knee.

No association between body build and the T-M1 joint has been found in the literature reviewed.

2.66 Obesity

Green et al. (1965) found the mobility of shoulders, elbows and wrists to be inversely related to body weight.

Apart from a possible relationship between obesity and the development of osteo-arthrosis (Silberberg et al., 1969; Kellgren, 1961; Goldin et al.,1976) no reference to obesity mechanically limiting joint movement and, in particular, movements of the T-M1 joint was found. This is somewhat surprising considering other joints in which soft tissue apposition is the limiting factor, for example, in hip and knee flexion.

2.7 Occupational influence on T-M1 Joint Mobility and Stability

No reports were found on the effect of particular occupations on the mobility and stability of the T-M1 joint. Occupational effects on the incidence of osteo-arthrosis of the T-M1 joint are discussed in section 2.82.

Although not related to any specific occupation, Cooney and Chao (1977) in a biomechanical analysis of static forces in the thumb during hand function demonstrated that on application of a pinching force of 1 Kg between the thumb tip and index finger a compressive force of 12 Kg is developed across the T-M1 joint, and during strong grasping this may be as high as 120 Kg. They considered the large rotational moments during 'pinch' and 'grasp', especially during pinching between the tips of the thumb and fingers, to be responsible for subluxation deformity and instability at the T-M1 joint.

Experimental evidence has demonstrated that articular cartilage is susceptible to compressive forces. Salter and Field (1960) and Bullough and Walker (1976) demonstrated compressive damage in areas of the knee joint where there are severe local stresses. Madrigal and Schwartz (1979) were able to induce degenerative changes in articular cartilage of rabbits by increasing and decreasing articular pressure. Further research is indicated to establish whether human articular cartilage responds in the same way.

The importance of movement to the nutrition of adult articular cartilage has been well established (Ekholm, 1955; Maroudas et al., 1968; Caterson and Lowther, 1978). Exercise of the joint appears to increase the penetration of cartilage by nutrients from the synovial fluid.

Direct evidence for the nutritional importance of joint movement and compression has been demonstrated by Caterson and Lowther (1978). They immobilised one foreleg of a sheep in a plaster cast, thus preventing movement and weight-bearing on that leg, and increasing the weight-bearing on the other foreleg. Since there was little change in the stress on the two hind legs these served as controls. After a month of immobilisation, the cartilage from the ankle joint in the plaster cast showed a significant reduction in proteoglycan content, apparently due to a reduced rate of synthesis by chondrocytes. Examination of the cartilage of the ankle of the other foreleg showed a slight increase in proteoglycan content and a marked increase in the rate of proteoglycan synthesis by the cells when compared with the control hind legs. Since there was no alteration in the histological appearance of either the synovium or cartilage from the foreleg joints the conclusion drawn was that alterations in proteoglycan synthesis and content were the result of nutritional changes directly related to joint movement and stress. The advantageous effect of increased compression, applied to varying areas of cartilage as the sheep moved its ankle, contrasts with the effects of severe stress reported above (Salter and Field, 1960; Bullough and Walker, 1976).

Clearly there is a need to study the effect of occupational use on the mobility, stability and incidence of osteo-arthrosis of joints. In relation to the T-M1 joint, occupations that involve intermittent compressive forces (for example, manipulative therapy) and occupations that require sustained gripping (for example, tailoring and dressmaking; playing the violin, viola and 'cello) suggest themselves for investigation.

2.8 Osteo-arthrosis of the T-M1 Joint

Burton (1973) described arthrosis of the T-M1 joint as occurring in three groups of patients. The largest comprised middle-aged individuals, mostly female, with no history of trauma. Those in the second group, often male, had a history of specific trauma, for example, fracture-dislocation of the T-M1 joint, with gradual onset of instability and osteo-arthrosis; the third group consisted of individuals with rheumatoid arthritis. As this study is related to the first group the literature review is accordingly confined.

2.81 Pathogenesis

There are two contradictory concepts regarding the pathogenesis of osteo-arthrosis of 'the base of the thumb'. Proponents of the first concept (Müller, 1949; Leach and Bolton, 1968; Eaton and Littler, 1969; Carroll and Hill, 1973) considered that in most cases, degenerative changes develop at the T-M1 joint without involving the other articular facets of the trapezium. The second concept postulates that osteo-arthrosis always develops in all, or most, of the articulating surfaces of the trapezium. This was advanced by Aune (1955), Sims and Bentley (1970), Swanson (1972), Kessler (1973) and Kessler et al. (1976) who also reported that degenerative changes are most marked in the T-M1 joint.

Burton (1973) took this subject one step further claiming that osteo-arthrosis at the base of the thumb develops progressively through three stages. The first two involve the T-M1 joint alone, whereas the third, the most advanced stage, represents a pantrapezial osteo-arthrosis.

2.82 Etiology

The etiology of osteo-arthrosis of the T-M1 joint remains a matter of conjecture.

Most authors (Gervis, 1949; Aune, 1955; Leach and Bolton, 1968; Eiken and Carstam, 1970; Sims and Bentley, 1970; Kessler and Axer, 1971; Kessler, 1973; Kessler et al., 1976) have described osteo-arthrosis of the T-M1 joint as being found predominantly in middle-aged women. Hormonal imbalance was postulated by several of these authors who found a high incidence in post-menopausal women. The hormonal effects of post-menopausal status are discussed in more detail in section 2.83. It is difficult to attribute systemic alterations in hormone levels as the sole cause of T-M1 joint involvement when other joints are spared. Local anatomical and functional conditions are undoubtedly of great importance as etiological and pathogenic factors.

It would seem reasonable to postulate that stresses upon a joint could predispose to osteo-arthrosis. Yet surprisingly there appears to be no formal research into the effect of occupation on the T-M1 joint. Although several authors refer to the deleterious effects of certain occupations, manipulative therapy and stringed instrument playing are not included.

Leach and Bolton (1968) reported osteo-arthrosis of the T-M1 joint to be more common in housewives over the age of 45 years. This statement was not based on scientific study but merely reflected the authors' clinical impressions. Possibly gender, age and hormonal status were etiological factors as important as the occupation of housewife.

Eiken and Carstam (1970) implicated tailoring and dressmaking and Müller (1949) reported advanced cases of osteo-arthrosis of the T-M1 joints of factory workers doing heavy sewing such as upholstery or mattress-making. In contrast to this, Aune (1955) reported no relationship between osteo-arthrosis of the T-M1 joint and occupation. He based his findings on 22 cases and drew attention to the fact that osteo-arthrosis was more common in women, from which he concluded that osteo-arthrosis was not related to heavy manual work undertaken by men.

As previously detailed, many authors described the capsule and ligaments of the T-M1 joint as being relatively loose which allows for 'mild subluxation' during normal functional activities of the thumb. Eaton and Littler (1973) advocated the use of stress X-rays to demonstrate any excessive laxity. They, with Leach and Bolton (1968), Cho (1970), Eiken (1970) and Burton (1973), considered instability a major cause of osteo-arthrosis in this joint, and in particular referred to dorso-radial subluxation. Kessler et al. (1976) considered that radial instability or subluxation, seen on an antero-posterior radiograph, is related not to osteo-arthritis but to hypermobility. Further evidence for this hypothesis had come from Kirk et al. (1967) who, from their study of people with generalised joint hypermobility, found the T-M1 joint to be one of the common sites of premature degeneration. The work of McDevitt and Muir (1976) lends experimental evidence to the concept that osteo-arthrosis is secondary to instability. Instability was produced in the knee joints of healthy dogs be severing the anterior cruciate ligament. This resulted in loss of proteoglycan and fibrillation of the cartilage surface. The experiment was suggested as a suitable animal model of the osteo-arthrotic process since the morphological and biochemical changes in the articular cartilage closely resemble those seen in the human disease process.

There are differences of opinion as to the first site of degenerative changes in the T-M1 joint. Burton (1973) and Eaton and Littler (1973) implicated the dorso-radial aspect of the trapezium. This would of course fit the concept of dorso-radial subluxation being a cause of osteo-arthrosis. Lassère et al. (1949) and Weinman and Lipscombe (1967) considered the medial aspect to be the primary site. The fact that joint contact is on the medial aspect during opposition and adduction (Pieron, 1973) may well support this latter viewpoint.

By staining the articular cartilage Meachim and Emery (1973) showed that in general the first signs of degeneration appear peripherally as early as the second decade of life and that the changes spread from the periphery to include the other areas of the cartilage. This occurs in a pattern that is typical for each joint. No pattern has been established for the T-M1 joint.

Aune (1955) noted, from X-rays of his series of 22 patients with osteo-arthrosis of the T-M1 joint, that the articular surface of the trapezium was directed in a more palmar and radial direction than usual, thus giving a more oblique and unstable supporting base to the proximal end of the first metacarpal. Smith and Kuczynski (1978), from their dissection of 32 hands, found degenerative changes in T-M1 joints in which the trapezii were directed, in the transverse plane, at an increased angle from the second and third metacarpals, that is, in a more palmar direction. Additionally these trapezii were more horizontal, that is, less inclined from the long axis of the shaft of the second metacarpal in the sagittal plane.

2.83 Post-menopausal hormonal effects

Discussion of the effects of hormonal changes associated with menopausal and post-menopausal status in women is pertinent to a study of osteo-arthrosis of the T-M1 joint as many authors associate the two.

Hormonal imbalance in post-menopausal women is considered by many to be an important factor not only in the development of osteo-arthrosis of the T-M1 joint, but also in the development of osteoporosis and osteopenia.

Osteopenia denotes a reduction in the cortical or trabecular bone volume, without indicating whether cortical porosity is present. When this occurs after the attainment of skeletal maturity it is referred to as 'involutional osteopenia'. According to Thomson and Frame (1976) 'involutional osteopenia is the most common metabolic bone disorder affecting the elderly'.

On the other hand, an osteoporotic bone has less bone than a comparable 'normal' one. According to Frost (1966) there is no characteristic quality in the histology. Further Khairi and Johnston (1978) described osteoporosis as 'the most common metabolic disease of the elderly'.

From these two examples it can be seen that the terms osteopenia and osteoporosis are frequently interchanged. Garn et al. (1971) wrote 'there are no established standards for separating these two entities since failure to form bone and loss of existing bone cannot be reliably differentiated from a single radiograph'.

Age-related bone loss commences at least a decade earlier in women than men (Thomson and Frame, 1976) and was termed 'post-menopausal osteopenia' by these authors. The rate of bone loss was found by Exton-Smith et al. (1969) to be 5% for men and 7% for women per decade. Lindsay et al. (1976) and Khairi and Johnston (1978) quoted 10% loss per decade but did not give separate rates for men and women.

Authors differ as to whether bone loss is due merely to age or to low oestrogen levels. Riggs et al. (1973) found no significant difference in circulating hormone levels between post-menopausal women and an age-matched control group. However, Nordin et al. (1975), Lindsay et al. (1976, 1977), Reeve et al. (1976), Marshall et al. (1977) supported the view that low oestrogen production, although not necessarily the sole cause, is definitely related to osteoporosis. Garn et al. (1964, 1967) and Newton-John and Morgan (1968) contended that osteoporosis can result solely from loss of bone due to age and that osteoporosis is more dependent on skeletal mass at maturity.

In women skeletal loss in the hands is due exclusively to endosteal bone loss (Thomson and Frame, 1976). Horsman et al. (1977) observed the sequential changes in bone mass in post-menopausal women in a controlled trial of oestrogen and calcium therapy. The results showed that pre-menopausal women neither gain nor lose bone from the endosteal surface. The onset of bone loss is temporarily associated with menopause due to low oestrogen levels, and that post-menopausal women with good oestrogen status lose bone less rapidly than women with poor oestrogen status.

Thomson and Frame (1976) consider radiogrammetry to be the only means of quantitating bone loss (or gain) at the periosteal or endosteal bone surfaces.

Clinically, when establishing criteria for normalcy, there is a need for a method of estimating the amount of bone which takes age into account. From postero-anterior X-rays of the hands, Exton-Smith et al. (1969) constructed percentile-ranking curves for the ratio of cortical bone to total area of bone. Using these curves an individual's skeletal status can be assessed in relation to others of the same age and gender. It was also found that this method minimised the effect of differences in skeletal size between men and women.

There have been no reports in the literature which establish a relationship between menstrual status, presence of osteopenia/osteoporosis and degree of osteo-arthrosis in the T-M1 joint.

2.9 Generalised Peripheral Joint Hypermobility

This subject is reviewed in considerable detail as it includes the characteristics of one group of individuals examined in this study. Further, the selected peripheral joint mobility tests carried out on all subjects in this study were based, with certain important modifications, upon those described in the literature.

While generalised hypermobility is a factor which may enter into the genesis, severity or progression of a joint or connective tissue disorder, it may occur without symptoms in normal individuals as a simple inherited entity or as an isolated finding.

According to McKusick (1972), Hippocrates in the fourth century B.C. made the first known reference to hypermobility when he portrayed the Scythians as being so loose-limbed that they 'can neither strain with their bows nor launch the javelin from their shoulder'.

2.91 Heritable disorders of connective tissue that manifest generalised peripheral joint hypermobility

Not until the close of the nineteenth century was hyper-mobility recognised as having any clinical significance; early descriptions were by Tschernogobow (1892) and Marfan (1896).

Later, further heritable disorders were described (Table 2.3).

Disorder	Predominant Manifestations	Author
Marfan's Syndrome	Ectopia lentis Excessive length of long bones	Marfan (1896)
Ehlers-Danlos Syndrome	Hyperelasticity anf fragility of the skin	Tschernogobow (1892)
Marfanoid Hypermobility Syndrome	Hyperelasticity of the skin and Marfan skeletal features	Walker et al. (1969)
Archard's Syndrome	Arachnodactyly with mandibular dysostosis	Parish (1960)
Osteogenesis Imperfecta	Brittle bones Blue sclera	Follis (1952)
Hyperlysinaemia	Gross physical and mental retardation	Ghadimi et al. (1969)

Table 2.3 Heritable disorders of connective tissue that manifest generalised joint hypermobility

All of these heritable disorders are rare; generalised joint hypermobility occurs more often as an isolated finding in an otherwise normal individual.

2.92 Generalised peripheral joint hypermobility in normal individuals

The literature supports a familial tendency for generalised hypermobility. Joint laxity in more than one member of a family was reported by MacLeod (1882) but Finkelstein (1916) was the first to examine hypermobile families.

Sturkie (1941) considered the inheritance of hypermobility to be dominant, with a variable degree of expression and with Beighton and Horan (1970) postulated two distinct and separate genetic entities. One in which excessive joint laxity existed without any musculo-skeletal signs or symptoms and a second, in which it was associated with numerous orthopaedic and rheumatic complaints. In 1967 Kirk et al. coined the phrase, 'hypermobility syndrome' to describe generalised joint laxity when it was the cause of musculo-skeletal complaints in an otherwise normal individual.

One of the few reports of isolated hypermobility where the family history was negative (Sutro 1947), showed in addition, that the young men concerned were unaware that they were hypermobile.

Wood (1971) considered that hypermobility was not a discrete entity, but one end of a normal continuum of joint mobility with limitation of movement at the other. Graham and Jenkins (1972) and Silverman et al. (1975) supported this concept.

2.93 Pathogenesis

Sutro (1947) described hypermobility due to 'overlengthened' capsular and ligamentous tissues. Both Beighton and Horan (1970) and Wynne-Davies (1970) suggested that hyper-extensible joints result from a defect in collagen formation, probably due to a minor inborn abnormality of connective tissue.

The nature of the structural or developmental change in collagen formation remains largely obscure, certainly for the normal individual with generalised hypermobility. Pinnell et al. (1972) recorded 'the first description of a chemical abnormality of collagen in man' — a deficiency of hydroxylysine in dermal collagen. Certain hydroxylysine residues in collagen are involved in cross-linkage and if defective, result in decreased structural integrity of the collagen allowing stretching beyond 'normal' limits.

2.94 Criteria for generalised joint hypermobility

The major difficulty in an investigation of this subject is that of establishing suitable criteria by which to judge the existence and the degree of hypermobility.

Various criteria have been propounded and are set out in Table 2.4. The number and type of tests and the criteria used show considerable variation.

Grant (1979), in selecting joint mobility tests for a matched pair study of hypermobility, first carefully excluded tests which involved movement at more than one joint (for example, thumb to anterior aspect of forearm); second, she modified tests which could be considered measures of muscle extensibility rather than joint laxity (for example, extension of the fifth metacarpo-phalangeal joint with the little finger extended); third, she included an equal sample of both upper and lower limb joints rather than a preponderance of upper limb movements (for example, Beighton et al., 1973); and fourth, all her tests were passive movement tests (Grahame and Jenkins, 1972, were the only workers reviewed who did not have a mixture of active and passive movement tests).

2.95 Incidence and sequelae

Sutro (1947) found 4% of 235 adults to have hypermobility of three or more pairs of joints, whereas Carter and Sweetnam (1960) noted only two individuals out of 200 in a review of adult outpatients; Carter and Wilkinson (1964) found 7% of 285 school children to be hypermobile.

Although generalised joint hypermobility is present in a relatively small segment of the population, it is sufficiently frequent to warrant diagnosis and treatment of the adverse sequelae that are reported by many authors to occur. These include injury to ligaments (Nicholas, 1970); recurrent dislocation of the shoulder and patella (Carter and Sweetnam, 1958, 1960); congenital dislocation of the hip (Carter and Wilkinson, 1964; Wynne-Davies, 1970); recurrent knee and ankle effusions (Sutro, 1947) and premature osteo-arthrosis (Kirk et al., 1967; Bird et al., 1978; Scott et al., 1979).

Scott et al. (1979) showed significantly greater joint laxity in a group of patients presenting with symptomatic osteo-arthrosis compared with a control population of similar age and gender with no clinical evidence of the disease. Bird et al. (1978) postulated an association between joint laxity and chondrocalcinosis, suggesting that this might be the end result of hypermobility in joints. They called this syndrome 'the arthritis of hypermobility'.

Kirk et al. (1967) specifically noted premature osteo-arthrosis in the T-M1 joint. It would appear that no detailed study has been conducted into the relationships between osteo-arthrosis, mobility of the T-M1 joint itself, and generalised joint hypermobility.

AUTHOR	CRITERIA FOR HYPERMOBILITY	MOVEMENT TESTS USED
Carter and Wilkinson (1964)	Three or more movement tests.	1. Passive finger extension so that the fingers lie parallel to the forearm. 2. Passive opposition of thumb to anterior forearm. 3. Hyperextension of elbow beyond 10° (active). 4. Knee extension beyond 10° (in weight bearing). 5. Passive ankle dorsiflexion and eversion to 'an excessive range'.
Kirk et al. (1967)	Three or more pairs of joints.	As for Carter and Wilkinson.
Kirk et al. (1967)	Eight or more joint movements	Selected movements, both active and passive, of all major peripheral joint groups. Each measurement 'in excess of normal' for that joint (age related) counted as one point. Maximum point score = 17.
Beighton and Horan (1969)	No specific criteria (most individuals, three or more joint pairs positive).	1. Passive fifth metacarpophalangeal extension beyond 90°. 2, 3 and 4. As for Carter and Wilkinson.
Beighton et al. (1973)	Numerical score (0-9).	5. Trunk flexion, palms flat on the floor.
Wynne-Davies (1970)	Three or more pairs of joints.	1 - 4. As for Carter and Wilkinson. 5. Passive ankle dorsiflexion beyond 45°.
Nicholas (1970)	A 'loose' individual = one or more movement tests accomplished	1. Spinal flexion, palms flat on floor. 2. Recurvatum of the knee of 20° or more, measured passively in prone. 3. Knee-ankle rotation – standing so that feet assume a straight angle of 180° heel to heel. 4. Hip rotation – 'lotus position' or its internal rotation equivalent. 5. Shoulder flexion, elbow extension and supination test for upper extremity laxity.
Howes and Isdale (1971)	One or two standard deviations above the mean of normal values given.	1. Extension of metacarpophalangeal joint of hand (? which one, or all). 2. Internal rotation of both hips. 3. Extension of right hip (? left as well). 4. Rotation of spine with pelvis fixed. 5. Back mobility index.
Grahame and Jenkins (1972)	Not specified	1 - 5. As for Beighton and Horan, with elbow extension performed passively. 6. Passive ankle dorsiflexion 15° beyond right angle.
Bird et al. (1978)	Four or more movement tests (numerical score 4/9 or greater).	1 - 5. As for Beighton and Horan.
McNerney and Johnston (1979)	More than 40 points out of a possible 72 points.	Tests graded according to degree of hypermobility and point score weighted accordingly. 1. Passive opposition of thumb to forearm. 2. Passive fifth metacarpophalangeal joint extension. 3. Passive hyperextension of elbow beyond 5°. 4. Passive hyperextension of knee beyond 5°. 5. Spinal flexion, fingertips to floor. 6. Ankle dorsiflexion and calcaneal stance position beyond 2° of eversion.
Jobbins et al. (1979)	Fifth metacarpophalangeal joint extension beyond 90° as an indication of generalized joint hypermobility.	Movement performed by the hyperextensometer (with pre-set torque of 2.6 kgcm).
Bird et al. (1979)	Not specified.	'Global index of joint laxity' All major joint groups represented in movement tests. Inclusion of cervical and lumbar spinal flexion and extension and straight leg raising.

Table 2.4 Criteria for generalised joint hypermobility (Grant, 1979)

CHAPTER III

GROSS ANATOMY OF THE TRAPEZIO-METACARPAL (T-M1) JOINT (INCLUDING RELATIONS)

3.1 Introduction

This section provides a general description of the T-M1 joint and its relations based on dissection under a dissecting microscope and forms the basis for more detailed studies of joint surfaces (Chapter V), ligamentous function (Chapter IV) and variations in joint function linked with osteo-arthrosis, occupation, ageing and hand dominance (Chapter VI).

To facilitate an understanding of the description of the capsule and ligaments, the bones are described first, although they were exposed last.

3.2 Material and Methods

Twenty-eight (28) un-embalmed specimens of Caucasians between the ages of 16 and 71 years were dissected within 24 hours of death.

An Olympus dissecting microscope with a zooming system was used, giving a magnification of up to x 40. Specimens were photographed at appropriate stages during dissection, except where otherwise stated, illustrations presented are based on these photographs.

The terminology introduced by Pieron (1973) has been used as this is considered to be the most widely known and most comprehensive.

3.3 Bony Components of the T-M1 Joint

The bony components and bony relationships of the T-M1 joint are illustrated in Figure 3.1. The main features of the two bones involved are described, limiting the description to those regions relevant to the T-M1 articulation.

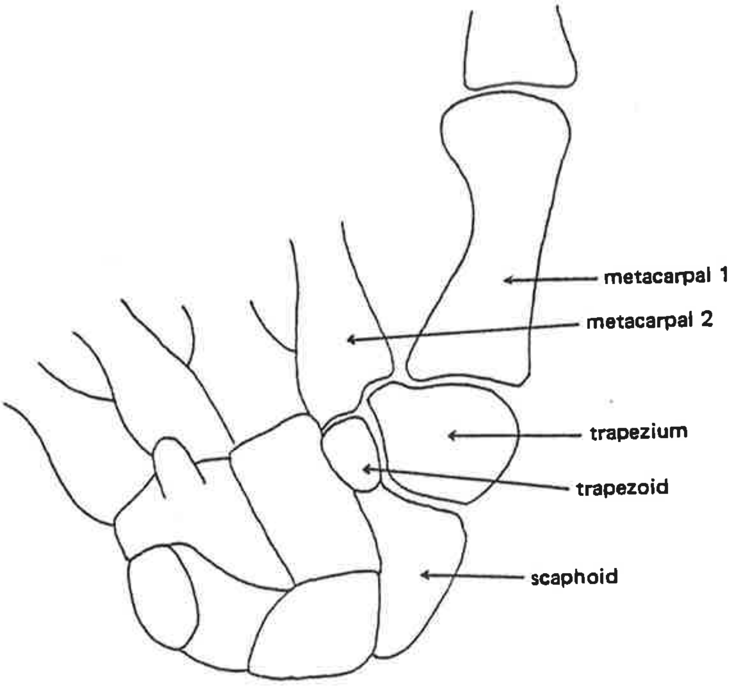


Figure 3.1 Bony relationships of the right T-M1 joint
The trapezium articulates distally with the base of the first metacarpal (M1), proximally with the scaphoid and medially with the trapezoid and the base of the second metacarpal (M2).

3.31 Trapezium

The trapezium is an irregularly shaped carpal bone which articulates distally with the base of M1, proximally with the scaphoid and medially with the trapezoid and the base of M2 (Figure 3.1).

Anteriorly is the large, almost centrally placed 'volar tubercle' with a 'volar ridge' extending laterally from it (Figure 3.2). Proximal and parallel to this ridge lies a well demarcated groove for the tendon of flexor carpi radialis.

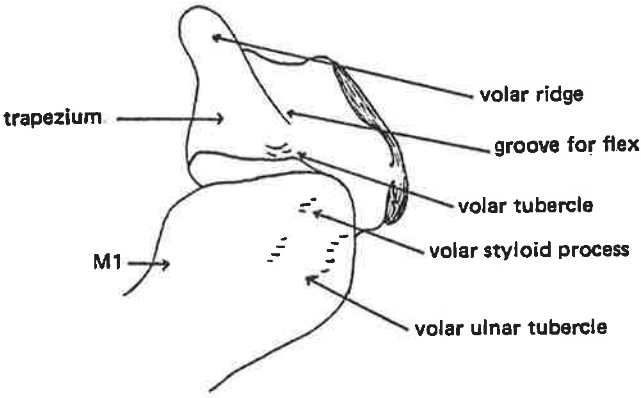


Figure 3.2 Anterior view of the right T-M1 joint illustrating the bony prominences of the trapezium and M1 (from Pieron, 1973)

Posteriorly (Figure 3.3) the rough surface has two well defined elevations; laterally is the 'dorso-radial tubercle', more medially is the 'dorso-ulnar tubercle'.

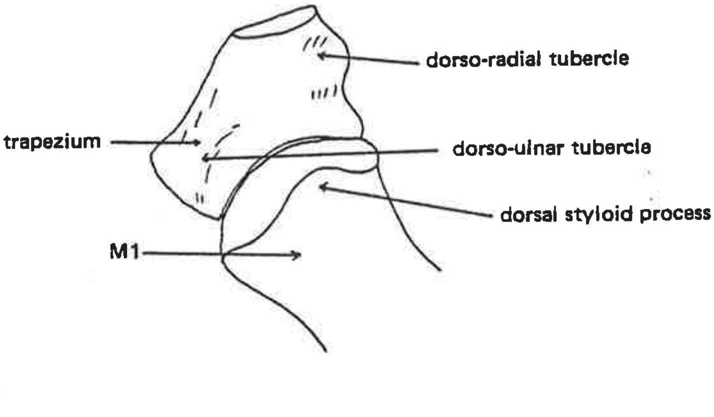
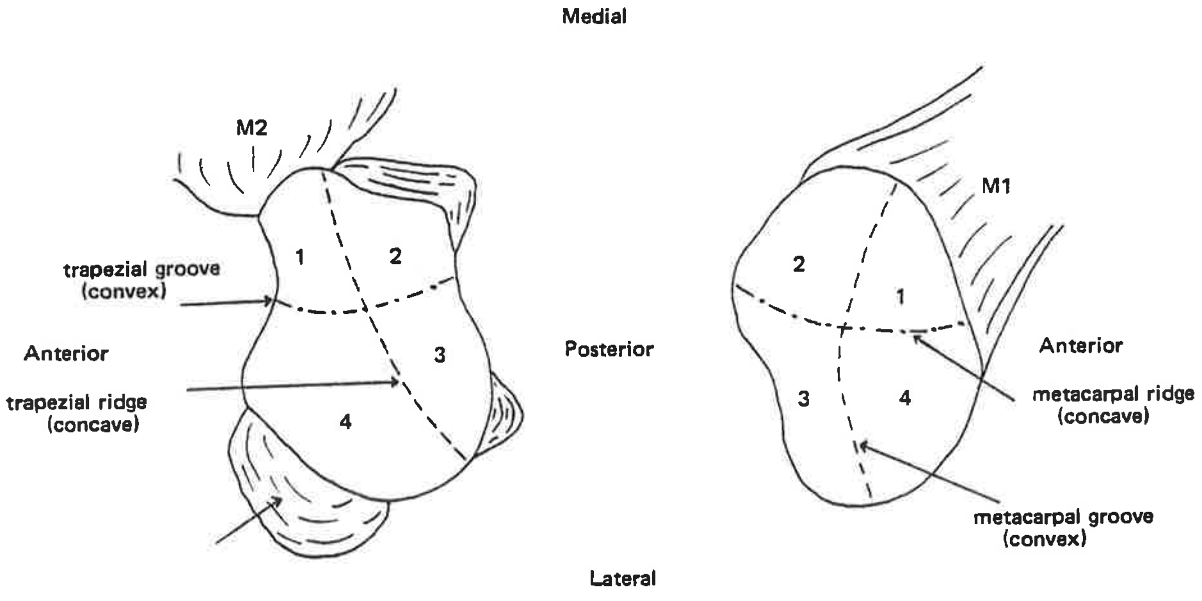


Figure 3.3 Posterior view of right T-M1 joint illustrating the bony prominences of the trapezium and M1 (from Pieron, 1973)

The lateral surface is narrow and roughened where the lateral ligament of the radio-carpal joint and the tendon of abductor pollicis longus attach.

The T-M1 articular surface, which occupies most of the distal surface of the bone, faces antero-laterally. It is asymmetrically saddle-shaped with a longer dimension directed medio-laterally and a shorter one antero-posteriorly. A ridge, concave in its long axis, runs antero-laterally from the region of the articular surface with M2. This is more pronounced at its medial end with a progressive flattening laterally. Running transversely to this ridge is a groove extending from the anterior to the posterior edge of the articular surface and with a convexity directed distally. The ridge and groove form the two main axes of the joint (adduction/abduction occurring along the ridge and flexion/extension in the direction of the groove). The four quadrants formed by the intersection of the ridge and groove each differ in size and contour (Figure 3.4). See Chapter V for a detailed account.



1= antero-medial quadrant
2= postero-medial quadrant
3= postero-lateral quadrant
4= antero-lateral quadrant
– – – – medio-lateral axis
–.–.–.–. antero-posterior axis

Figure 3.4 Articular surfaces of the right T-M1 joint showing the axes and quadrants

3.32 Base of first metacarpal (M1)

On its anterior surface the base of M1 projects sharply proximally. This 'volar styloid process' lies within the joint capsule. Distally and medial to the volar styloid process is a small 'volar-ulnar tubercle' which is extra-capsular (Figure 3.2). Posteriorly a 'dorsal styloid process' forms a proximal projection. This is smaller and more rounded than the corresponding volar one and lies within the capsule (Figure 3.3).

The **articular surface** is shaped to reciprocate that of the trapezium, but is less asymmetrical. The groove, corresponding to the trapezial ridge, runs antero-laterally but is longer than the ridge because the articular surface extends onto the antero-lateral and postero-medial aspects of the base of M1. The congruence of the T-M1 articular surfaces (in the neutral position) is not an exact one, there being close apposition along the medio-lateral axis but a definite discrepancy in the antero-posterior direction.

3.4 Superficial Dissection to Expose the T-M1 Joint

This dissection is made to expose the T-M1 joint and will be described briefly to indicate the principal close relations of the joint.

3.41 Anterior aspect

Removal of the superficial structures exposes the three muscles of the thenar eminence (abductor pollicis brevis, flexor pollicis brevis, opponens pollicis) as well as the lateral part of the adductor pollicis. Next the three thenar muscles are divided at their insertions and reflected proximally, exposing the tendon of flexor pollicis longus and the anterior aspect of the T-M1 joint. The thenar muscles are then carefully separated from their origin on the trapezium and flexor retinaculum and removed together with adductor pollicis and the tendon of flexor pollicis longus.

3.42 Posterior aspect

Removal of superficial structures exposes the tendon of abductor pollicis longus running along the lateral aspect of the carpus to insert into the base of M1. Lying medial to this are the tendons of extensor pollicis brevis, extensor pollicis longus and extensor carpi radialis longus.

The first dorsal interosseous muscle is exposed with its two heads of origin from contiguous sides of the bases and proximal shafts of M1 and M2.

The radial artery runs in an infero-medial direction, crossing the scaphoid and trapezium, to disappear into the interspace between M1 and M2. It passes beneath the arc formed by the two heads of the first dorsal interosseous muscle to enter the palm; prior to this it gives branches to that muscle and to both the thumb and index finger.

With removal of the first dorsal interosseous muscle, the radial artery is fully exposed on the medial aspect of the T-M1 joint. The artery, cushioned in fatty tissue, is superficial to the inter-metacarpal ligament of the T-M1 joint, and its main branch, the princeps pollicis artery, which passes anteriorly along the first metacarpal is now visible. The radial artery turns medially into the palm to form the deep palmar arterial arch. The artery, small veins and fatty tissue are then removed.

The T-M1 joint is now fully exposed from all aspects.

3.5 Deep Dissection of the T-M1 Joint

Fine fascia and adipose tissue were carefully dissected to reveal the joint capsule and ligaments. From the 28 dissections performed, individual variations were encountered in the width, length and attachments of the ligaments. However, a general ligamentous pattern could be readily recognised and is presented below.

3.51 Tendons of Abductor Pollicis Longus

On the lateral aspect of the T-M1 joint is the fibrous sheath of the tendon of abductor pollicis longus. The under-surface of this sheath is linked by many fine fibres to the antero-lateral aspect of the trapezium, the base of M1 and the intervening joint capsule, necessitating care not to tear the capsule during dissection.

The sheath, when opened, usually contains three separate tendons (in one specimen there were only two tendons, in another there were four and in a third, five tendons) which insert into the antero-lateral aspect of the base of M1, but fine fibres are also seen inserting into the joint capsule. The insertion of the tendons of abductor pollicis longus should therefore be included in a description of the capsule and ligaments of the T-M1 joint because their sheath re-inforces the capsule antero-laterally.

Lewis (1977) who dissected 14 hands described a bursa between the abductor pollicis longus tendon and the lateral ligament of the T-M1 joint: however, none was found in this series of specimens.

3.52 Ligaments

Four ligaments were identified — dorso-radial, posterior oblique, anterior oblique and first inter-metacarpal. The first three mentioned are all thickenings of the capsule whilst the first inter-metacarpal ligament is extra-capsular.

The shape, direction of fibres and attachments are described for each ligament:

i) Dorso-radial ligament

Immediately posterior to the insertion of the tendons of abductor pollicis longus is the dorso-radial ligament. This short, thick, easily recognisable ligament arises from the dorso-radial tubercle of the trapezium. Its fibres run infero-laterally to a fairly wide attachment to the edge of the base of M1 on its posterior, lateral and to a much lesser extent, anterior aspects.

ii) Posterior oblique ligament

This long ligament extends from its attachment to the dorso-ulnar tubercle of the trapezium, around the medial aspect of the T-M1 joint blending with the capsule, to end on the postero-medial aspect of the volar-ulnar tubercle of M1 (Figure 3.5).

In seven specimens (numbers 2,5,8,10,21,24 & 27) the posterior oblique ligament had a wide attachment into the posterior aspect of M1 just distal to the articular margin. In these specimens only a small number of fibres could be followed around the medial aspect of the joint to attach to the volar-ulnar tubercle.

iii) Anterior oblique ligament

The anterior oblique ligament is a short thickening in the anterior capsule. It extends obliquely between the volar tubercle of the trapezium and the anterior aspect of the volar-ulnar tubercle of the base of M1. This ligament has a consistent relationship with the posterior oblique and first inter-metacarpal ligaments. Its distal attachment is proximal and slightly lateral to the attachments of these two ligaments (Figure 3.6).

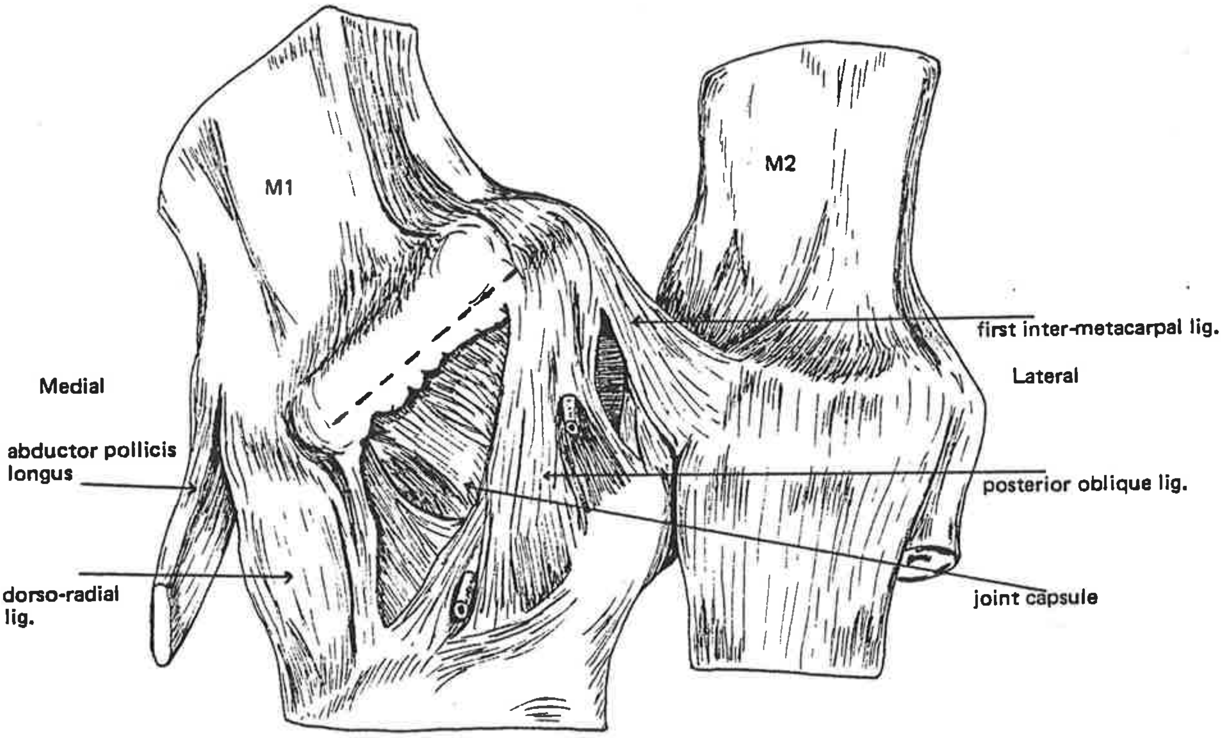


Figure 3.5 **Posterior view of right T-M1 joint**

Note the attachments and direction of fibres of the dorso-radial, posterior oblique and first inter-metacarpal ligaments. The broken line represents the attachment of the posterior oblique ligament found in seven specimens in this series. In these cases the posterior oblique ligament re-inforced the posterior aspect of the joint capsule.

iv) First inter-metacarpal ligament

The first inter-metacarpal ligament is extra-capsular and shows more variation in its size and attachment than do the other ligaments.

Most frequently this ligament was attached to the postero-lateral aspect of the base of M2, adjacent to the insertion of the tendon of flexor carpi radialis longus. The ligament passes obliquely in an antero-lateral direction to be attached to the medial aspect of the volar-ulnar tubercle of M1 (Figures 3.5 and 3.6). In some specimens the first inter-metacarpal ligament blended with the attachment of the posterior oblique ligament.

The most frequent variation from this pattern, found in six dissections, was a second attachment to the antero-lateral aspect of M2 and/or to the flexor retinaculum. In most cases this slip joined the posterior one.

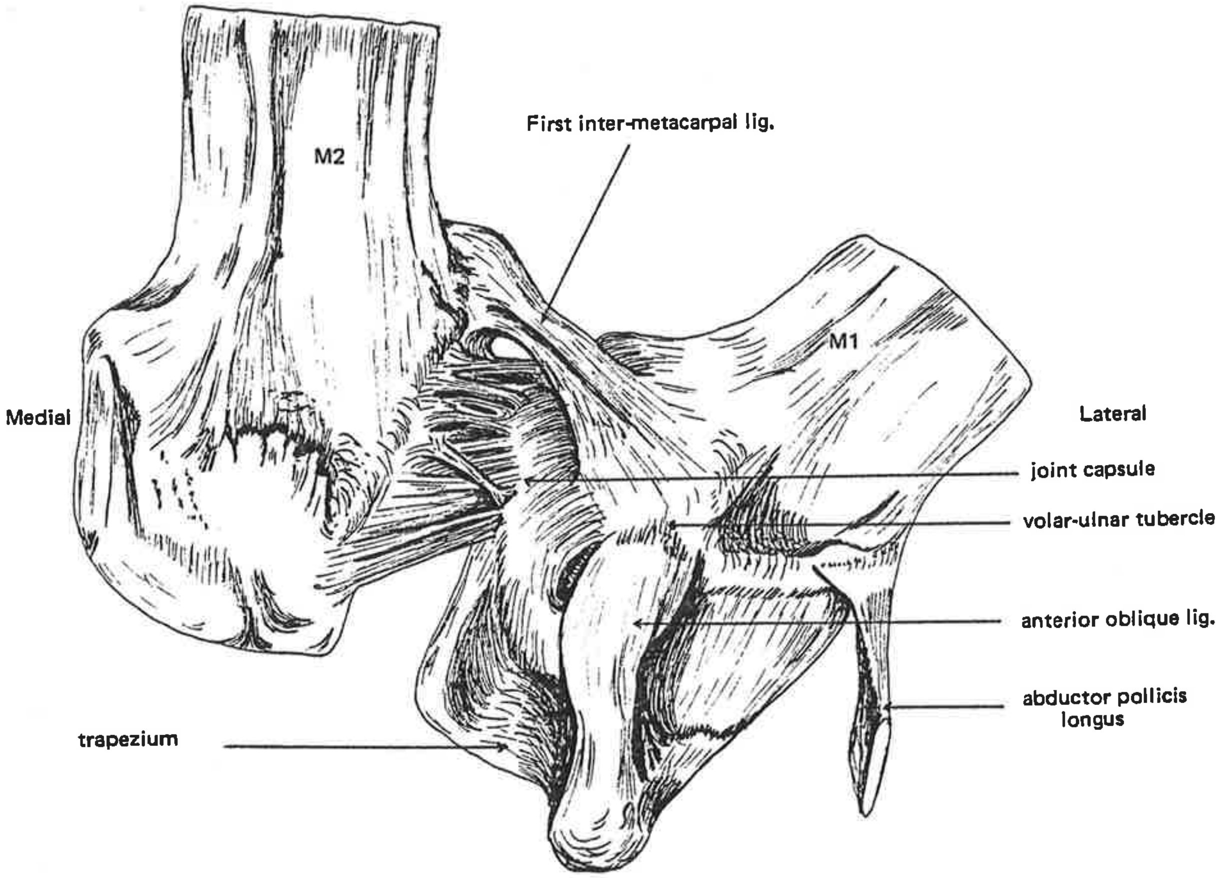


Figure 3.6 **Anterior view of right T-M1 joint** (from Pieron, 1973)
Note the direction of fibres and attachment of the first inter-metacarpal and anterior oblique ligaments into the volar-ulnar tubercle of M1.

The presence of separate anterior and posterior inter-metacarpal ligaments was not encountered, although four specimens (numbers 1,12,13 & 23) showed a second attachment to the postero-medial aspect of the base of M1. In these cases the posterior attachment was thicker than the anterior one. This is illustrated in Figure 3.7.

3.53 Joint capsule

Except where it is reinforced by the three ligaments already described, the joint capsule is thin. Dissection shows that it is generally lax even in the thickened regions. This laxity can be readily demonstrated by placing the joint in a neutral position between all its ranges of movement and noting the ease with which M1 can be passively distracted from the trapezium.

The attachment of the capsule in relation to the articular margin varies. This is of significance when considering its effect on the mobility/stability of the T-M1 joint. More movement

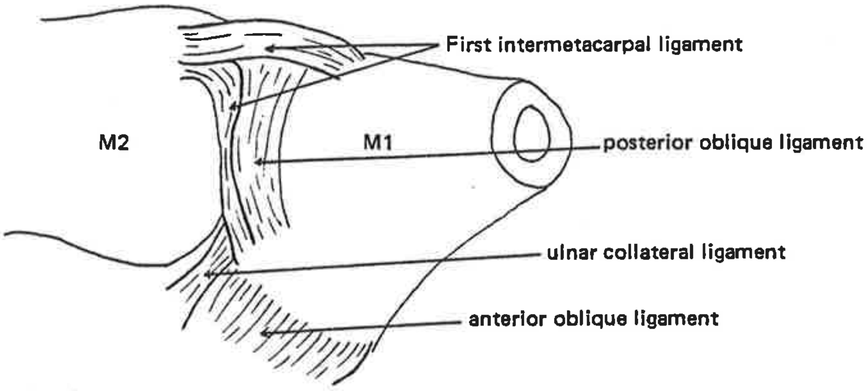


Figure 3.7 **View of first inter-metacarpal space**
Note the unusual second attachment of first inter-metacarpal ligament into the postero-medial aspect of M1 as found in specimens 1,12,13 & 23.

of M1 is permitted in areas where the capsule is attached at some distance from the articular margin, and conversely the joint is more stable where it is attached close to the joint margin. The capsular attachments are best viewed with the joint disarticulated.

The joint is disarticulated in the following manner. With the joint surfaces passively distracted, the capsule is divided by sharp dissection mid-way between its bony attachments; this enables an examination of the capsular attachments from within each half of the joint.

The capsule is attached to the trapezium at some distance from the articular margin posteriorly and antero-medially. This permits the posterior styloid process of M1 to slide posteriorly over the trapezium. Similarly, the anterior styloid process can slide forward and rotate medially. In all other areas the capsule is attached close to the articular margin.

The capsule attaches close to the joint margin of M1, except antero-laterally, this permits the anterior styloid process to rotate laterally.

3.54 Synovial membrane

The T-M1 joint cavity is quite separate from its adjacent joints. The capsule is lined with synovial membrane but, surprisingly, no synovial folds could be identified.

3.6 Discussion

This study would appear to contain the largest series (N=28) of T-M1 joints, the findings from which are compared with those of Haines (1944) – number of dissections unknown, Pieron (1973) – 8 dissections, Bosjen-Møller (1976) – 20 dissections, and Lewis (1977) – 14 dissections.

The bony features comprising the T-M1 joint found in this study did not differ from those described by the above authors.

Four ligaments were identified but the dissection revealed differences from other authors as to their attachments. These variations are discussed for each ligament.

Dorso-radial ligament

The findings agree with those of Pieron (1973) and Bosjen-Møller (1976) that this ligament is dorsally placed rather than being radially arranged as described by Haines (1944) and Lewis (1977).

Posterior oblique ligament

The metacarpal attachment of the posterior oblique ligament showed variation. In 21 (75%) specimens, it attached to the postero-medial aspect of the volar-ulnar tubercle of M1. Pieron (1973) and Bosjen-Møller (1976) concurred with this arrangement. In seven (25%) dissections the ligament had a wide attachment into the posterior aspect of M1. Lewis (1977) described the posterior oblique ligament as having this wide posterior attachment to M1, whereas Haines (1944) described the ligament as having a small attachment to M1 and a wide trapezial attachment.

Anterior oblique ligament

This thickening in the capsule was readily recognised and its attachments were consistent for all 28 specimens and with those reported in the literature.

First inter-metacarpal ligament

This extra-capsular ligament was present in all specimens, but its thickness and attachments showed wide individual variation. The most frequent finding of this study was that the ligament attached to the postero-lateral aspect of the base of M2 and to the medial aspect of the volar-ulnar tubercle of M1, agreeing with Pieron (1973). Bosjen-Møller (1976) found the ligament to be Y-shaped, having a second, antero-lateral attachment to M2. In this study a Y-shaped ligament, having two attachments to M2 was found in six dissections. It is possible that the second antero-lateral attachment is the ulnar-collateral ligament described by Bausenhardt (1949) and Pieron (1973).

The presence of separate anterior and posterior inter-metacarpal ligaments as described by Haines (1944) was not encountered, although four specimens showed a second attachment to the postero-medial aspect of the base of M1. This finding of a reversed Y-shaped ligament, that is, with one attachment to M2 and two attachments to M1 has not been described previously.

In his illustrations, although not in the text, Lewis (1977) showed separate anterior and posterior trapeziometacarpal ligaments spanning the trapezium and M2. Such ligaments were not encountered.

Capsule

In this study the capsule was found to be particularly lax, so much so that on removal of the surrounding musculature M1 flopped in any direction depending on the positioning of the specimen relative to gravity. Capsular looseness has been reported by Napier (1956), Warwick and Williams (1973), Eiken (1971), Pieron (1973), Kessler et al. (1976) and Bosjen-Møller (1976).

Except where reinforced by ligaments and the infra-tendinous layer of the tendon sheath of abductor pollicis longus, the capsule was found to be thin. Bosjen-Møller (1976) reported similarly, whereas Warwick and Williams (1973) described the capsule as thick. Although based on only one dissection, Pieron (1973) is the only author to have described in detail the thickness and attachments of the capsule; he found it to be thin antero-laterally but thick antero-medially. The findings of this study regarding capsular attachment to the trapezium and M1 agree with those of Pieron (1973).

Synovial membrane

The absence of synovial folds found in unembalmed specimens of the present study is consistent with the findings of Kuczynski (1974).

3.7 Summary

The 28 joints providing the basis of this study form the largest series yet reported. The main findings were:

1. the articular surfaces were asymmetrically saddle-shaped with the trapezium showing an antero-lateral ridge concave in its long axis and a transverse groove convex distally. The surface of M1 was shaped to reciprocate that of the trapezium, but was less asymmetrical. It extended further on to the antero-lateral and postero-medial aspects of M1. The 'fit' of the articular surfaces was not an exact one, with a greater discrepancy in the antero-posterior direction.
2. the joint capsule was thin except where three ligaments (anterior oblique, posterior oblique and dorso-radial) form thickenings. The tendon sheath of abductor pollicis longus reinforced the capsule antero-laterally. Generally the capsule and ligaments were lax. Capsular attachment was close to the joint margin of the trapezium except posteriorly and antero-medially thus facilitating posterior movement of the posterior styloid process and anterior movement and medial rotation of the anterior styloid process of M1. Similarly, the capsular attachment to M1 was close to the joint margin except antero-laterally thereby facilitating lateral rotation of its anterior styloid process.
3. the segment of the study related to detailed dissection of the ligaments confirmed the findings of previous investigations: however it revealed some important differences which were:
    a) the posterior oblique ligament had a wide attachment to the posterior aspect of M1 in seven specimens which differed from the general description of its attachment to the volar-ulnar tubercle of M1 (found in the other 21 dissections).
    b) in four specimens the first inter-metacarpal ligament attached to the postero-lateral aspect of M2 and then divided into two slips with separate attachments to the volar-ulnar tubercle and to the postero-lateral aspect of M1. This is the first description of a reverse Y-shaped first inter-metacarpal ligament.

CHAPTER IV

ANATOMICAL STUDY

4.1 Introduction

A review of the literature indicates that ligaments play an important role in the control of movements at the T-M1 joint. As previously discussed Pieron (1973) carried out the most extensive research on the ligaments and their function. However, he failed to state whether or not the specimens used were embalmed. In the present study fresh, unfixed specimens were chosen as they more closely resemble the *in vivo* flexibility of the capsule and ligaments of the living joint.

The aims of the present anatomical study of the T-M1 joint were:

i) to measure radiographically the ranges of the passive physiological movements (see List of Definitions)

ii) to ascertain the function of the four ligaments (anterior oblique, posterior oblique, first inter-metacarpal and dorso-lateral)

iii) by staining the articular surfaces, to investigate whether there is a pattern of degenerative change specific for the T-M1 joint.

Also recorded were other factors which may influence the ranges of motion at the T-M1 joint.

4.2 Material and Methods

The first and second metacarpals, trapezium and trapezoid were removed by gross dissection from 28 unembalmed cadavers within 24 hours of death. As described in the previous chapter, the T-M1 joint was then carefully dissected under a dissecting microscope with a zoom lens so that the capsule and ligaments were exposed, identified but left intact.

4.21 Selection of T-M1 joint specimens

Due to factors beyond the control of the author it was not possible to select specimens according to age and gender, nor to remove both thumbs from each cadaver. Twenty-three male and five female subjects, aged between 16 and 71 years, were used.

In order to exclude subjects with possible generalised hypermobility of joints resulting from Ehlers-Danlos Syndrome, the skin was examined for tearing and scarring from previous tears, particularly over bony prominences, and for the presence of thin skin (McKusick, 1972). Skin thickness to the nearest 0.5 mm was measured with Harpenden skin fold calipers (Figure 4.1) taking the mean of three readings. The skin over the dorsum of the fourth metacarpal was chosen as the test site as the skin in this area has little or no subcutaneous fat (McConkey et al., 1963). The results of *in vivo* reliability studies of this method are presented in Chapter VII.

4.22 Measurement of passive physiological movements of the T-M1 joint

i) General

It has been established that during movements of the thumb, the trapezium is relatively immobile, M1 being the more mobile part of the joint (Pieron, 1973).

Figure 4.1 Harpenden skin fold calipers used for measurement of skin thickness.

When planning the methodology of examination of the ranges of motion at the TM-1 joint this fact had to be considered.

In the somewhat 'artificial' isolation of bones in this study, a means of limiting movement other than in the T-M1 joint was necessary. To achieve this the ligaments and capsules between M1, M2, trapezium and trapezoid were left intact; to keep the joints immobile by keeping the ligaments and capsule under tension, small wooden wedges were inserted between the trapezium and trapezoid, and M2 and the trapezoid. (An initial attempt using wiring of these bones to ensure fixation was discarded because X-ray details of the T-M1 joint were obscured).

Each specimen was mounted on a perspex frame modified from that used by Pieron (1973) for a radiographic study of the ranges of motions of the T-M1 joint.

ii) Description of the reference frame

The reference frame, made of radiolucent perspex, consisted of a base and central pole 14 cm in height. From the base of the pole a datum line was drawn on the reference frame.

In this study all X-rays were taken with the X-ray tube in a horizontal position and with the reference frame made mobile in relation to the X-ray tube and film. This was achieved by mounting the perspex frame on a wooden base in the centre of which was a 360° protractor.

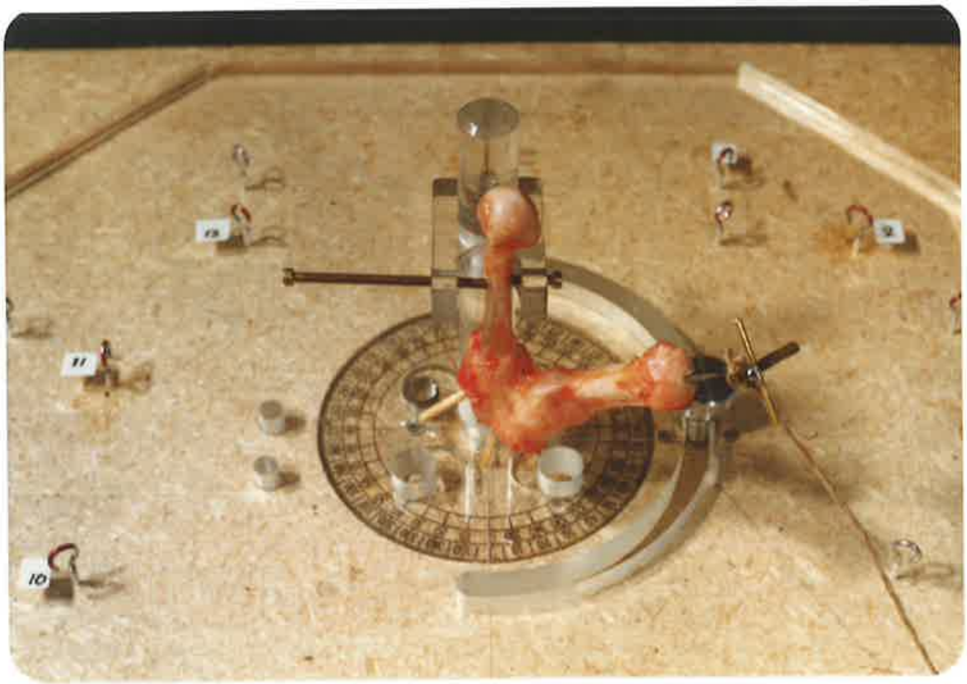


Figure 4.2 **Right hand specimen mounted on perspex frame**

In the neutral position the datum line, drawn on the reference frame, was at zero position on the protractor. The reference frame could then be placed in any desired position as read by the position of the datum line on the protractor. The frame was fixed by tightening a screw (Figure 4.2). This arrangement allows greater flexibility in the use of X-rays than was available to Pieron (1973) who was limited to two positions of 45^{o} to each other.

Based on Pieron's (1973) technique, and modified by preliminary studies on five specimens, the centre of the base of M1 was found to be 3 cm from the base of the perspex pole and at an angle of 45^{o} to the plane of the metacarpals (Figure 4.3). This pre-determined position of M1 was marked on the reference frame, and from it, at a distance of 14 cm, five hooks were placed. These hooks represented the position of five physiological movements, namely extension-abduction, radial-abduction, palmar-abduction, opposition and extension-adduction (Figure 4.3). Extension-adduction and palmar-abduction do not coincide with Pieron's method. His position I, 'ulnar' was not used in the present study because, from the preliminary trials, M1 was found to abut on the clamp holding M2 to the vertical pole. In addition, Kuczynski's (1974) finding that adduction occurs along the medio-lateral axis of the T-M1 joint was considered, thus indicating that adduction should be in the same plane as radial-abduction.

As illustrated in Figure 4.3, the positions of the hooks, relative to the plane of the metacarpals, but centred at M1, were:

- * extension-adduction — posterior to M1 at 70° (anti-clockwise)
- extension-abduction — posterior to M1 at 30° (anti-clockwise)
- radial-abduction — anterior to M1 at 45° (clockwise)
- * palmar-abduction — anterior to M1 at 90°
- opposition — anterior to M1 at 15° (anti-clockwise)

* do not correspond with Pieron's method (1973)

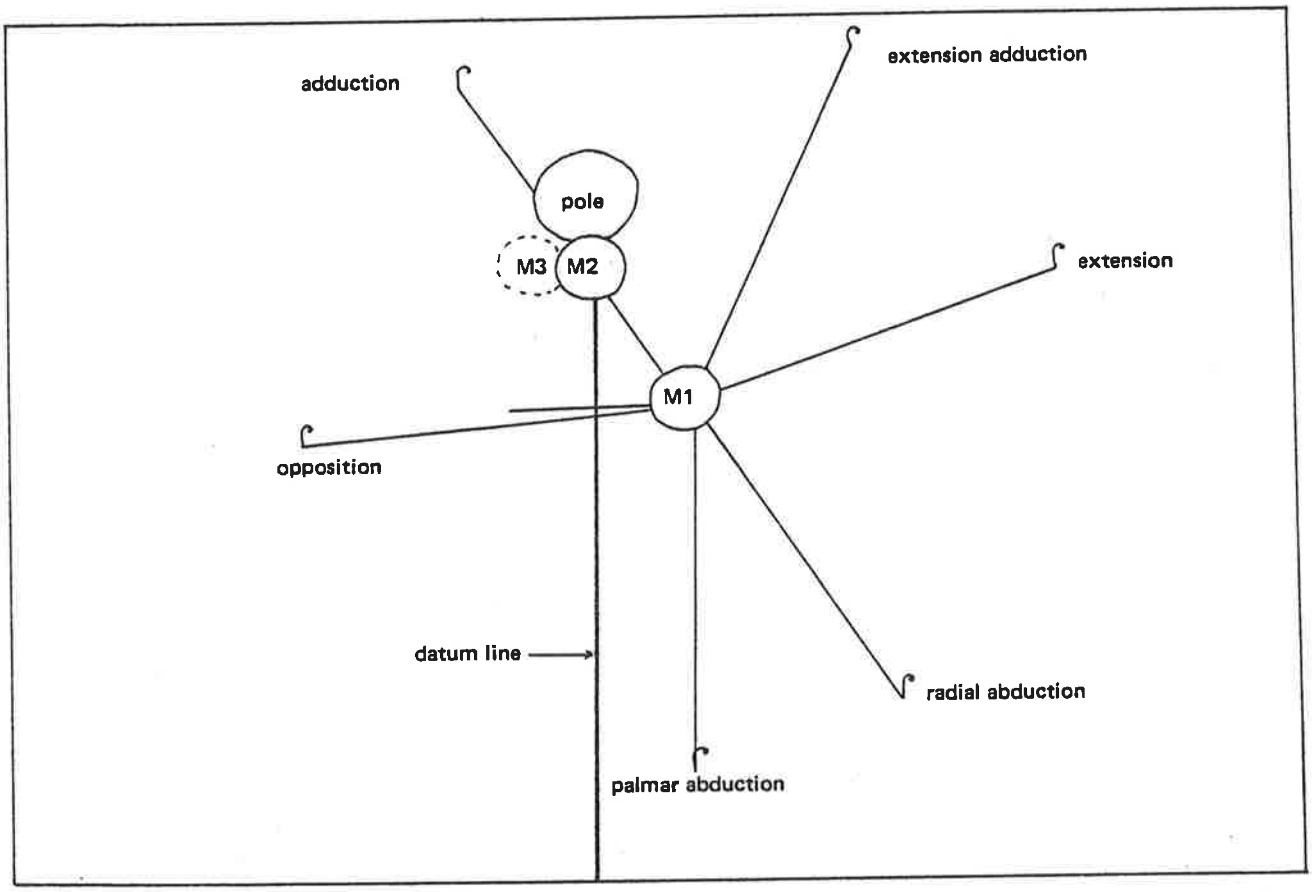


Figure 4.3 Diagram of reference frame showing position of M1 and hooks for a right hand specimen.
P = plane of metacarpals; D = datum line; • = hook; E—Ad = extension-adduction;
E—Ab = extension-abduction; R—Ab = radial-abduction; P—Ab = palmar-abduction;
Opp = opposition.

iii) Position of specimen on reference frame

As shown in Figures 4.2 and 4.4 the dorsal (relatively flat) aspect of M2 was firmly held in a clamp to the vertical perspex pole, keeping its long axis vertical and the trapezoid 4 cm above the reference frame. As previously described, wooden wedges were inserted into the articulations between the trapezium and trapezoid, and between M2 and the trapezoid to augment the rigidity between these bones. By this method the trapezium was fixed and movements of the T-M1 joint could be produced by passively moving M1.

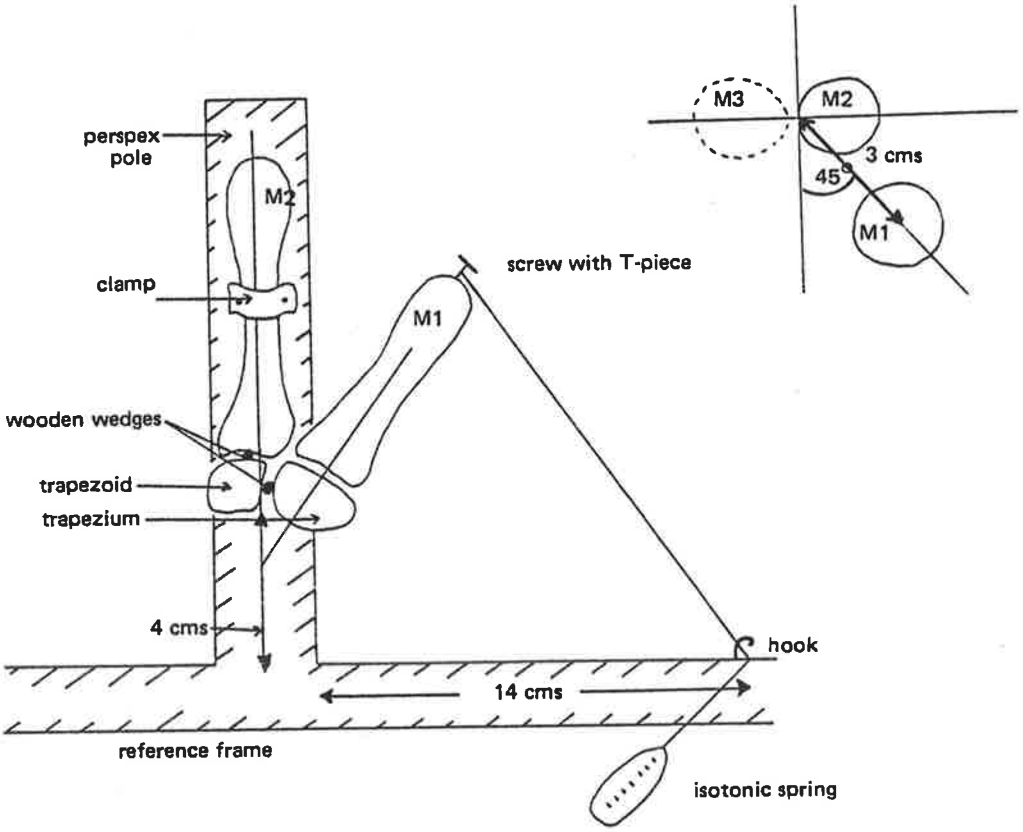


Figure 4.4 Diagram of right hand specimen mounted on reference frame.

Note the clamp firmly holding M2 to the perspex pole so that the trapezoid is 4 cm above the reference frame; the wooden wedges inserted between M2 and trapezoid and trapezoid and trapezium; the hook 14 cm from base of M1 and screw with T-piece in head of M1 attached by a length of string to an isotonic spring.

iv) Determination of force required, during passive movement tests, to put the ligaments on full span

A screw with a T-piece, with arms of unequal length, was inserted into the articular surface of the head of M1 and to the screw was attached an isotonic spring using a length of string (Figure 4.4). String was used instead of wire to avoid obscuring X-ray details. Deformation of the string due to stretch was not a source of error as the isotonic spring records tension independent of string length changes (that is, the desired force is not applied to the

T-M1 joint until the string has undergone possible elongation).

By placing the string around one of the hooks in the frame, M1 could be passively pulled in the direction of that hook. The force required to put the ligaments on full span (and yet not deform them by stretching) was calculated from preliminary trials on five specimens and found to be 0.5 kg. The thicker anterior oblique ligament required a slightly stronger force than 0.5 kg to put it on full span than did the other ligaments. Forces less than 0.5 kg resulted in movement of M1 comparable with the force, while forces of 0.5, 1.0 and 2.0 kg did not alter the position of M1, thereby indicating that the span of the ligaments had been taken up fully at 0.5, 1.0 and 2.0 kg. The minimal force (0.5 kg) was chosen in order to keep damage due to stretching to a minimum.

By placing the string around each hook, M1 was pulled with equal force (measured by the isotonic spring) in each of the five directions representing circumduction. For each measurement the distance between the base of M1 and the five hooks was kept at 14 cm, and the applied force was transmitted by the string to the metacarpal head only. Order effects, from possible stretching of the capsule and ligaments, was reduced by testing the five positions in random sequence.

v) Radiographic measurement of the passive physiological movements

Horizontal X-rays were taken with M1 passively pulled in each of the five directions. The range of a particular movement was obtained by measuring on the X-rays the angle between the long axes of M1 and M2 (Figures 4.5, 4.6 and 4.7 illustrate three measurements). No attempt was made to measure the components of these movements, for example, the contribution of extension and abduction to the position of extension-abduction.

Figure 4.5 **Radiographic measurement of extension-abduction.**
Note range = angle between long axes of M1 and M2.

Figure 4.6 **Radiographic measurement of radial-abduction.**
Note range = angle between long axes of M1 and M2.

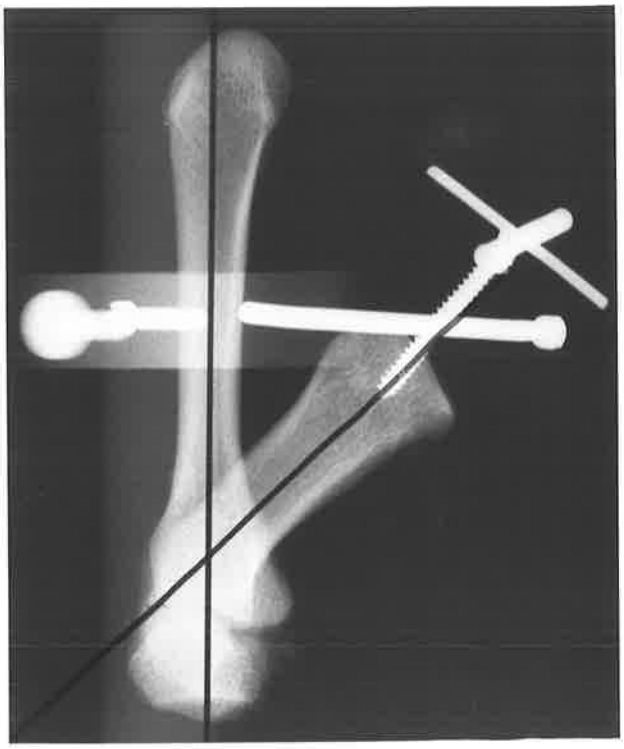


Figure 4.7 **Radiographic measurement of opposition.**
Note range = angle between long axes of M1 and M2.

To avoid distortion, the plane of the two metacarpals must be kept at right angles to the X-ray beam, that is, parallel to the X-ray tube and film (Edholm, 1967). This was achieved by rotating the reference frame (on the wooden base) in relation to the X-ray tube and film. Details of the positioning of the frame for each movement test are given in Table 4.1. The positions are based on the findings of a preliminary trial on five specimens.

Position of M1	Position of Datum Line on Reference Frame Relative to Zero Starting Position	
Extension-adduction	20°	clockwise
Extension-abduction	70°	clockwise
Radial-abduction	45°	anti-clockwise
Palmar-abduction	90°	clockwise
Opposition	30°	clockwise

Table 4.1 **Positioning of reference frame for radiographic measurement of movements of the right thumb.**

Note that positioning is identical for left thumb except that the rotation is in the opposite direction.

All X-rays were centred on the T-M1 joint and were taken with a focal film distance of 100 cm and an object film distance of 16 cm. In this way the X-ray beam was parallel and there was no enlargement of the image on the X-ray plate (Robertson, 1979).

The most recent studies of kinematics related to the spine (Selvik, 1974; Worth, 1980) and the elbow (Morrey and Chao, 1976) show the stereo-photogrammetric method of measuring joint motion to be superior to other methods. As this technique was unavailable the following method was devised, concentrating on two of the components of joint movement (angular movement and axial rotation).

As described, the ranges of movement for the five test positions were measured radiographically. *One* of the four ligaments was then severed, followed by re-measuring of the five positions to observe the effect on each range. Both the severing of ligaments and testing of movements was carried out in random order. For each specimen, only one ligament was severed and its function assessed by noting changes in movement in the five test positions. This principle is applied in other systems in the body, for example, conclusions as to the function of a nerve can be made by observing loss of function (sensation and muscle power) following denervation.

Alteration in the angle between the long axes of M1 and M2 and in axial rotation of M1 was recorded. Alteration in the length of the T-piece (on the screw inserted into the head of M1) indicated that axial rotation had occurred, as seen on the radiographs. Provided the arms of the T-piece were not parallel to the film, the image on the radiograph increased in length when the T-piece moved towards the film and decreased in length if the T-piece rotated away from the film. The unequal length of the arms on the T-piece allow ready identification of the direction of axial rotation (Figures 4.9 and 4.10).

Figure 4.8 **Specimen 12 – right thumb, position of extension-adduction prior to severing the anterior oblique ligament.**
Note angle between long axes of M1 and M2 and position of T-piece with its arms of unequal length.

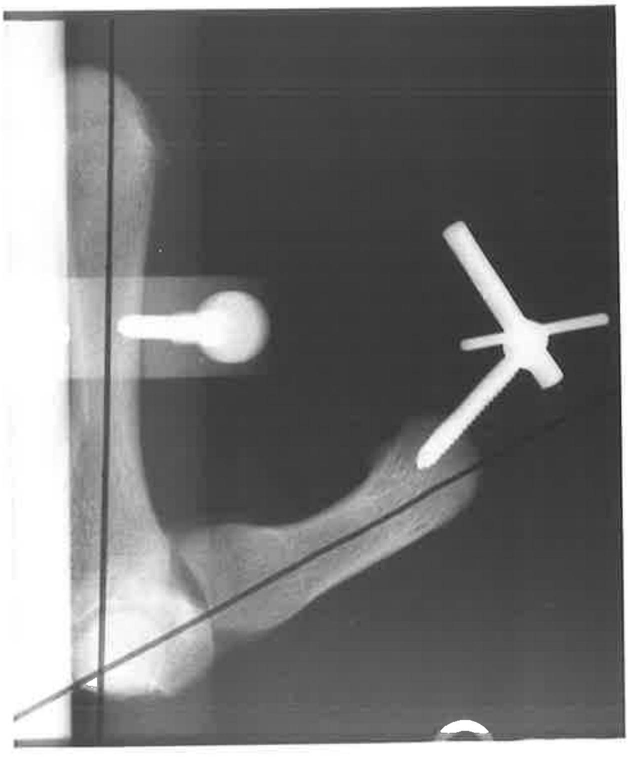


Figure 4.9 **Specimen 12 – right thumb, position of extension-adduction after severing the anterior oblique ligament.**
Note increased angle between long axes of M1 and M2. The T-piece is shorter indicating that axial rotation has occurred.

4.23 Measurement of degenerative change in the articular cartilage

i) Radiological method

For each specimen the radiographs were examined for the presence of degenerative changes in the T-M1 joint. The site and degree of any such changes were recorded, the latter being classified as mild, moderate or marked. This classification was based on text illustrations in an 'Atlas of Standard Radiographs of Arthritis', published by the Council for International Organisation in 1963. These details are set out in Table 4.2.

Degree of Osteo-arthrotic Change	Radiographic Changes
mild	early osteophytosis
moderate	osteophytosis ± narrowing of joint space
marked	loss of joint space with cystic and sclerotic subchondral bone changes, alteration in shape of articular surfaces with advanced osteophytosis ± subluxation of M1

Table 4.2 **Radiographic classification of osteo-arthrotic change.**

All assessments of osteo-arthrotic change were made independently by the author and by a senior radiologist (Dr. A. Robertson).

ii) Staining method

Following radiological examination, each T-M1 joint was disarticulated and the capsule, ligaments and synovium carefully removed: contact with or damage to the articular cartilage was strictly avoided.

The articular cartilage of the trapezium and base of M1 was stained by the method described by Meachim (1972) using a solution of Indian ink diluted to 50% by normal saline. Excess stain was removed by gently dripping normal saline onto the cartilage using a pipette. The articular surfaces were kept moist in a solution of formol saline (to minimise the development of artefacts) until photographed at a magnification of x 10.

The Indian ink enters any fine fissures in the cartilage and visualises the earliest signs of degeneration (fibrillation) as well as more advanced degenerative changes (Meachim, 1972). This method facilitates observation of changes in the cartilage before there is any radiological evidence of change. The articular surfaces were subdivided into five areas, the circumference and four quadrants (Figure 3.4). To ensure correct identification of the quadrants on the photographs, the specimens were photographed with their anterior aspects to the front of the picture. The ridge on the trapezium and corresponding groove on M1 were marked with a small black pin medially and a small white pin laterally. Later the photographs were labelled 'X' medially and 'Y' laterally. The degree of degenerative change was categorised as minimal, mild, moderate and marked (Table 4.3 and Figure 4.10). The degree of degenerative change was recorded for each area and this was related to the subject's age, gender, left or right hand and the degree of osteo-arthrosis noted in the radiographs. Finally, the results of the staining were examined for any pattern of degeneration specific for the T-M1 joint.

Classification of Degenerative Change	Effect of Staining Articular Cartilage
minimal	cartilage intact with only occasional fine irregular lines indicating early fibrillation
mild	over-all irregular pattern of fine lines = mild fibrillation
moderate	larger, darker lines, either straight or linked into a pattern on a background of mild fibrillation
marked	cartilage heavily stained. Occasional areas of full thickness loss with bone exposure.

Table 4.3 **Classification of degenerative change revealed by the staining method.** (Derived from Meachim and Emery, 1973).

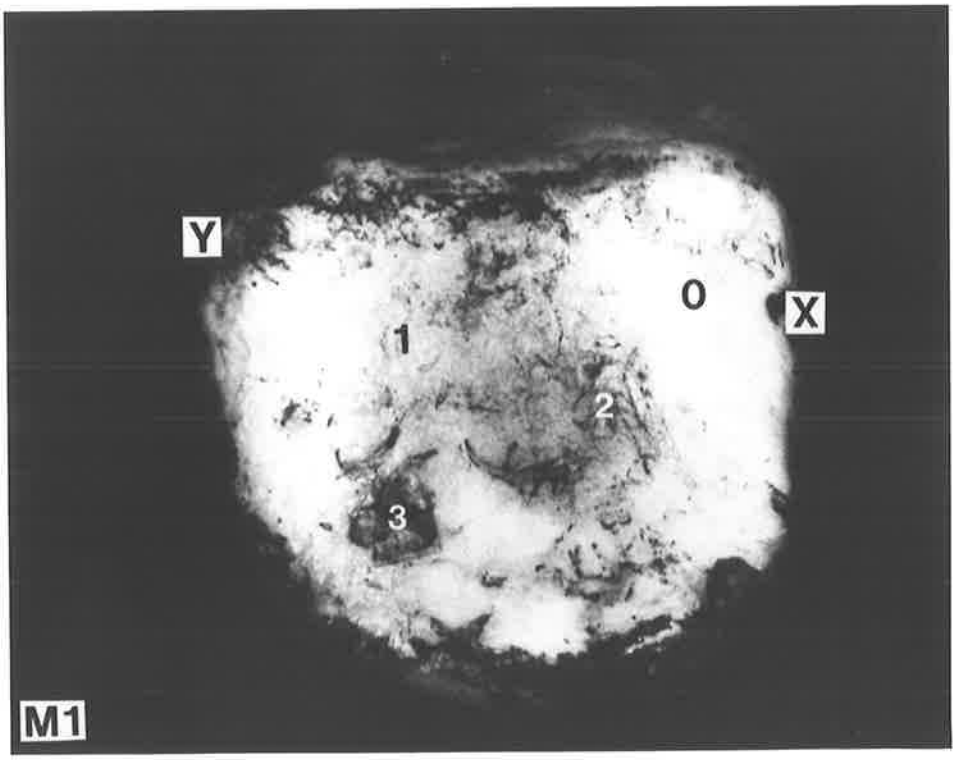


Figure 4.10 **Classification of degenerative change revealed by the staining method.**

The articular cartilage of metacarpal specimen 1 demonstrates each of the classes: 0 = minimal, 1 = mild, 2 = moderate, 3 = marked (see Table 4.3 for descriptions of each of these).

4.3 Results

4.31 General

Unembalmed specimens were examined from 28 cadavers within 24 hours of death.

The specimens were grouped according to gender, side and into six age categories (Table 4.4).

Age (years)	Male L. Hand	Male R. Hand	Female L. Hand	Female R. Hand	Total
15-24	1	7	1	1	10
25-34	1				1
35-44	2		1		3
45-54	4				4
55-64	3	3			6
65-74	1	1		2	4
Total	12	11	2	3	28

Table 4.4 Grouping of specimens according to age, gender and side.

Because of unalterable regulation it was not possible to obtain an equal number of males and females or to remove both thumbs of each cadaver. Similarly, details of hand dominance and occupation were seldom available.

Table 4.4 records that while there were an equal number of specimens from left and right hands, the ratio of males to females was 23:5

4.32 Range of physiological movements at T-M1 joint

Following micro-dissection and examination of the ligaments and their attachments, the specimens were mounted on the perspex frame for radiological measurement of the range of movements which occur at the T-M1 joint.

The results for the five physiological movement tests (extension-abduction, radial-abduction, palmar-abduction, opposition and extension-adduction) are shown in Table 4.5. The relatively large standard deviations for each movement indicate a wide variation between specimens.

Movement	Mean (degrees)	Standard Deviation
Extension-abduction	37°	11.23
Radial-abduction	62°	9.46
Palmar-abduction	56°	9.83
Opposition	38°	14.38
Extension-adduction	44°	10.53

Table 4.5 Range of physiological movements at the T-M1 joint.

Within the limits of the sample size, **age, gender** and **side** were found to have no significant relationship to these ranges of movement.

Skin thickness. None of the subjects exhibited abnormally thin skin (readings of 0.8 millimetres or less which Grahame and Beighton (1969) found in patients with Ehlers Danlos Syndrome). These findings together with no evidence of skin fragility (splitting of the skin and scars, especially over bony prominences), suggested that it was unlikely that any of the subjects had generalised joint hypermobility due to Ehlers Danlos Syndrome. This might bias the results by leading to greater range of movement. Skin thickness was found to be negatively correlated with age ($r = 0.50$, $p < .01$).

4.33 Ligamentous function

Angular movement was measured for each of the 28 specimens and axial rotation for 16. Table 4.6 lists the number of specimens used to test the function of the anterior oblique, posterior oblique, first inter-metacarpal and dorso-radial ligaments.

	Ligaments Tested				Total No. of Specimens
	Anterior oblique	**Posterior oblique**	**First Inter-metacarpal**	**Dorso-radial**	
Angular movement	7	7	7	7	28
Axial	4	4	4	4	16

Table 4.6 Test for ligamentous function — number of specimens used.

By referring to Table 4.7 the function of the ligaments can be summarised as:

i) **anterior oblique ligament**

This short, thick oblique ligament limits the range of extension-abduction and extension-adduction. It contributes to the control of medial rotation of these movements and of palmar-abduction and opposition.

Cutting this ligament resulted in excessive posterior translation of M1 when it was moved into extension.

ii) **posterior oblique ligament**

This ligament limits the range of opposition and contributes to the control of the three positions when M1 is in abduction. Its effect on axial rotation was not consistent for the four specimens tested. However, it restricted the medial rotary component of palmar-abduction and extension-abduction.

Movement	Increase in Angular Movement	Ligament Cut	Direction of Axial Rotation		
			Medial	Lateral	None
Extension-abduction	A 0 14°	A 0	2	1	1
	D-R 5°	P 0	3	1	
	P 0 4.6°	I-M	1	3	
	I-M 4.6°	D-R		4	
Radial-abduction	I-M 16.7°	A 0	2	1	1
	P 0 4.5°	P 0	2	1	1
	A 0 2°	I-M			4
	D-R 2°	D-R		2	2
Palmar-abduction	I-M 11°	A 0	3		1
	P 0 5°	P 0	4		
	D-R 3°	I-M		3	1
	A 0 1°	D-R	3	1	
Opposition	P 0 10°	A 0	3		1
	I-M 6°	P 0	2	1	1
	A 0 2°	I-M	4		
	D-R 0.3°	D-R	3	1	
Extension-adduction	A 0 10.9°	A 0	4		
	D-R 4.5°	P 0	1	2	1
	P 0 2°	I-M	1	3	
	I-M 1°	D-R	4		

Table 4.7 **Ligamentous control of T-M1 movements.**

A 0 = anterior oblique	I-M = first inter-metacarpal
P 0 = posterior oblique	D-R = dorso-radial

Table 4.7 summarises the contribution of each ligament to the control of angular movement for the five physiological movement tests. The mean is given for the seven specimens for which a capsular ligament was cut. Also included, on the right side of the table, is the effect of severing the ligaments on axial rotation. The degree of rotation could not be accurately quantified as movement occurred simultaneously in more than one plane.

iii) first inter-metacarpal ligament

This long extra-capsular ligament is primarily responsible for restricting the ranges of radial- and palmar-abduction; additionally, it contributes to the control of both the range and the medial rotation component of opposition. In the positions of extension-abduction, extension-adduction and palmar-abduction it limits lateral rotation.

Severing this ligament permitted excessive lateral translation of M1 along the trapezial ridge.

iv) dorso-radial ligament

This ligament was not found to be of prime importance in the control of angular movements although it assists the anterior oblique ligament in the control of extension-abduction and extension-adduction. Its main function is to control medial rotation during the movements of palmar-abduction, opposition and extension-adduction. In extension-abduction it contributes to the control of lateral rotation; however, this rotary effect is considered to be secondary to excessive postero-lateral translation of M1. In all four cases, severing the ligament resulted in M1 translating in a postero-lateral direction, which appeared to permit the articular surface of M1 to laterally rotate more readily.

4.34 Degenerative changes in the articular cartilage

a. Radiographic method

The radiographs of the 28 specimens were examined for evidence of osteo-arthrosis. Only three showed degenerative changes (Table 4.8). In specimen number 12 a small osteophyte projected from the medial aspect of the trapezium. In the other two specimens (numbers 16, 25) the osteo-arthrotic changes were more developed, with larger osteophytes both medially and laterally on the trapezium and early sub-chondral sclerosis of both bones.

Specimen Number	Age	Classification of Degenerative Changes
12	39	mild
16	68	moderate
25	71	moderate

Table 4.8 Degenerative change — radiographic method.

b. Staining method

For each specimen, Table 4.9 details the degree of degenerative change, age, gender and side from which the specimen was obtained.

It can be seen that:

i) the first signs of cartilage degeneration of class 'O' (Figure 4.10), were evident in the second decade of life (although this sample did not include any subjects below the age of 16).

ii) the degenerative change became more marked with advancing age. Statistical analysis using the Pearson correlation coefficient showed a positive correlation between the two ($r = 0.80$, $p < 0.01$).

iii) the side from which the specimen was taken was found to have no significant relationship to the degree of degenerative change.

Age	16	17	17	18	18	18	19	21	22
Specimen	28	2	8	4	21	26	14	30	27
M1 Degenerative Changes	00000	01010	00000	10000	00000	10000	00010	00000	00000
Trapezial Degenerative Changes	10101	00000	10001	10000	10000	11010	10000	10000	00101
Gender	M	F	M	F	M	M	M	M	M
Side	R	R	R	L	R	R	R	R	R

Age	24	29	39	41	44	47	48	48	50
Specimen	6	10	12	9	17	22	5	11	20
M1 Degenerative Changes	20001	10010	10000	10000	10002	10111	21212	10000	32222
Trapezial Degenerative Changes	21000	10000	20000	22121	21121	20112	31111	21200	31121
Gender	M	M	M	M	F	M	M	M	M
Side	L	L	L	L	L	L	L	L	L

Age	55	56	58	58	58	60	65	68	69	71
Specimen	19	18	1	3	7	23	24	16	13	25
M1 Degenerative Changes	10001	12111	22222	21211	20110	21212	22233	13000	11011	23233
Trapezial Degenerative Changes	12212	11121	32222	22111	21100	10110	21113	33211	10000	33222
Gender	M	M	M	M	M	M	F	F	M	M
Side	R	L	R	L	R	L	R	R	R	L

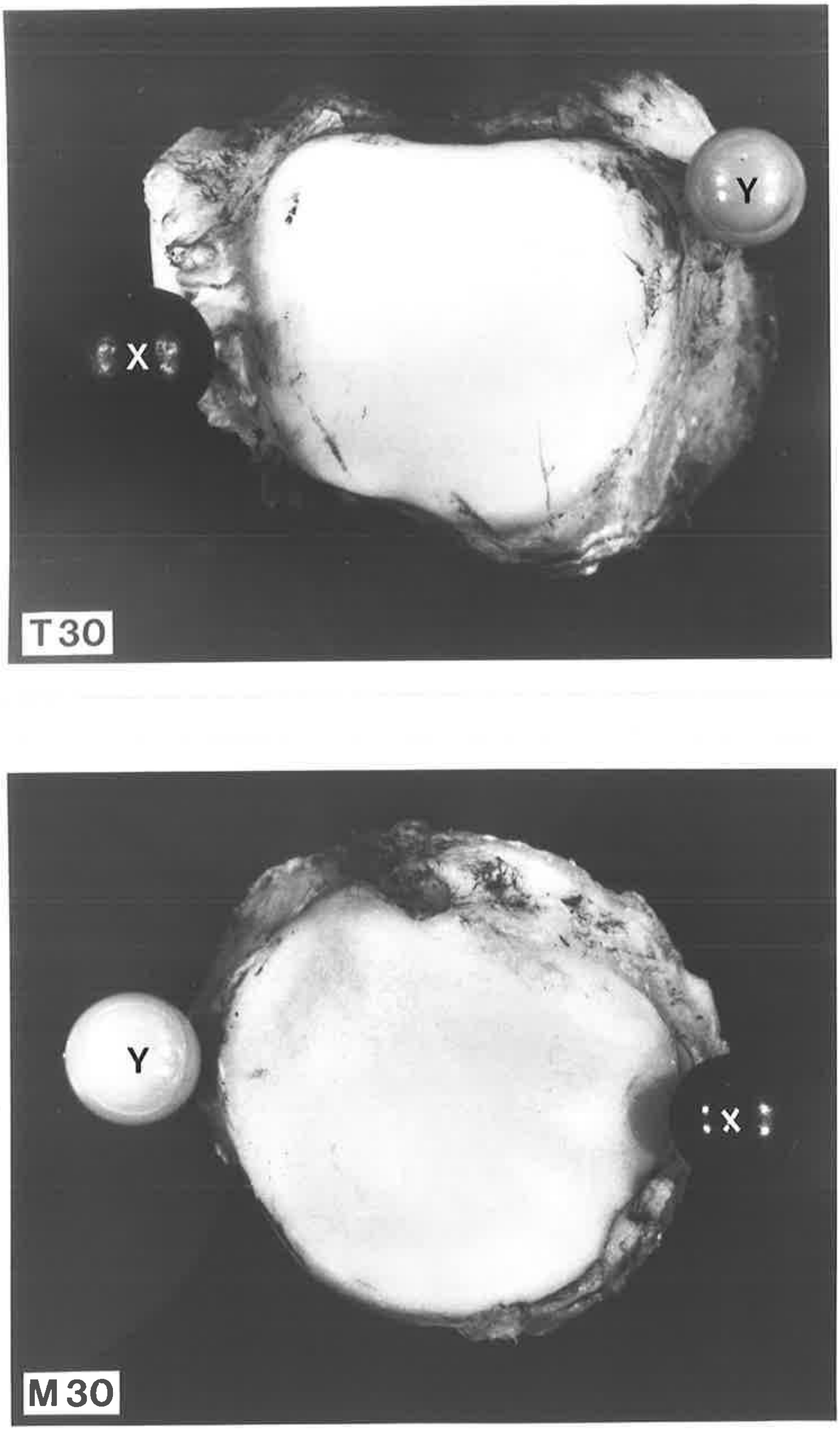
Table 4.9 **Age, gender, side and degenerative change (staining method) for each specimen.**

M = male, F = female, L = left, R = right
Degenerative changes are classified as 0 = minimal, 1 = mild, 2 = moderate, 3 = marked. They are listed for the trapezial and metacarpal surfaces in the following order (reading from left to right): circumference, antero-medial, antero-lateral, postero-medial and postero-lateral quadrants.

iv) In this sample there were only five specimens removed from female cadavers. This limited number makes it unfeasible to comment upon the relationship between gender and the degree of degenerative change in the articular cartilage.

For each T-M1 joint the enlarged photographs (x 10) of the articular surfaces were examined for a possible pattern of degenerative change. The findings are described separately for the metacarpal and trapezial surfaces.

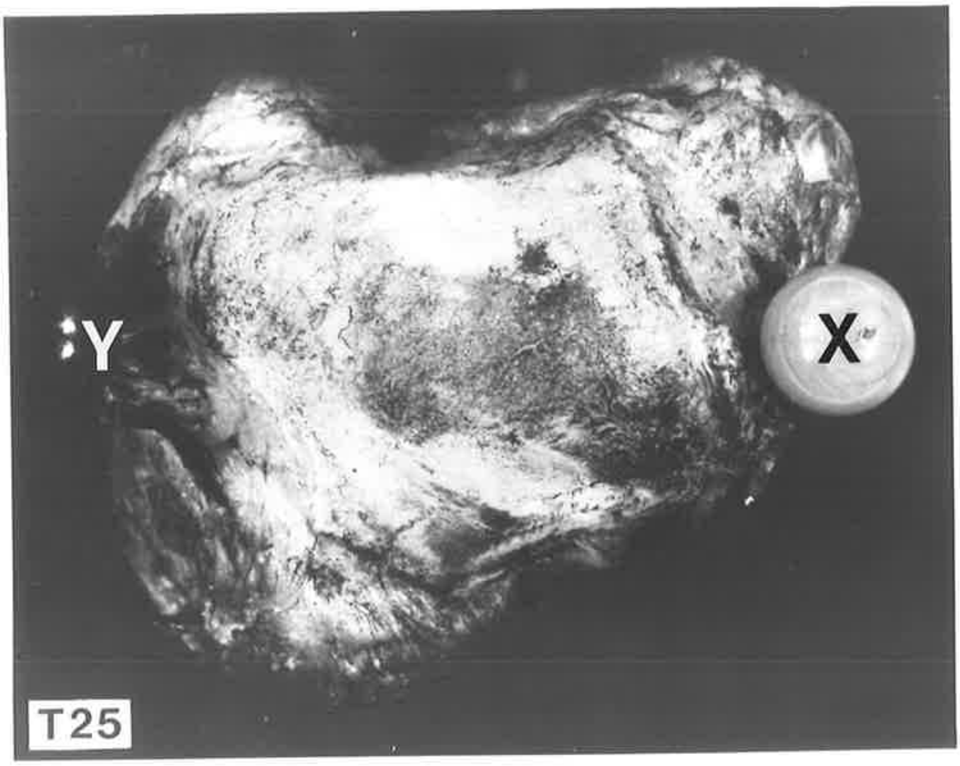
An example of minimal degeneration is shown in Figure 4.11 while Figure 4.12 demonstrates marked degenerative change.



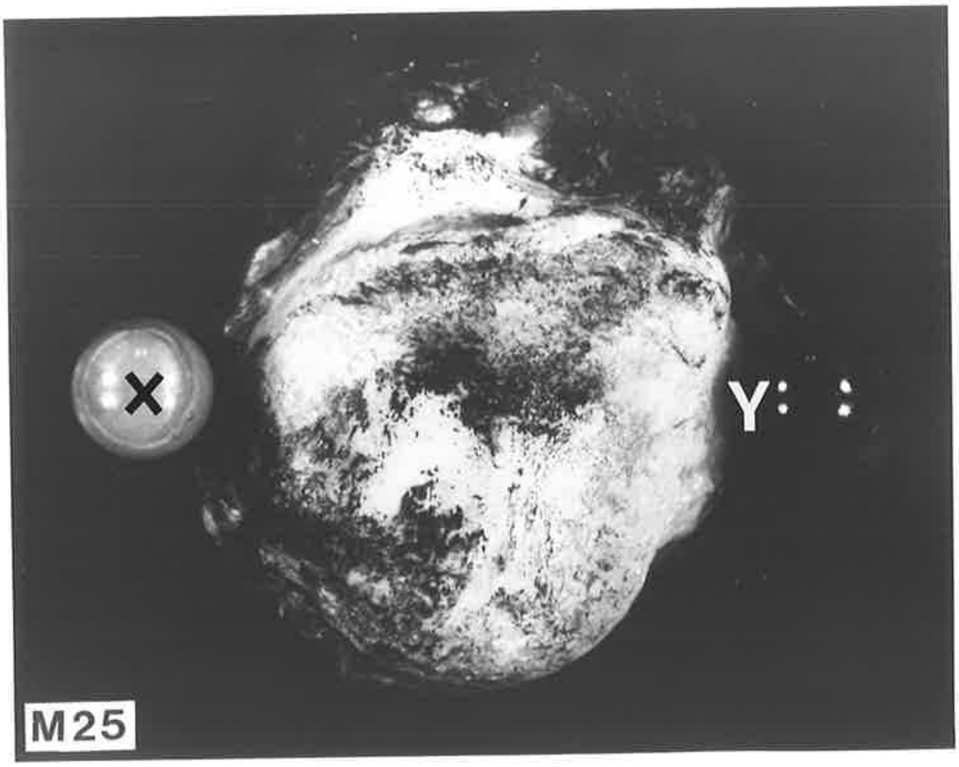
(a)

(b)

Figure 4.11 **Specimen 30 — minimal degeneration of (a) trapezial surface and (b) metacarpal surface.**
Note cartilage intact with fine irregular lines indicating early fibrillation around the periphery.



(a)



(b)

Figure 4.12 Specimen 25 — marked degeneration of (a) trapezial surface and (b) metacarpal surface.

Note cartilage is heavily stained.

Degenerative change — Staining method

a) Articular surface of M1

Fibrillation was seen around the circumference or periphery of the articular cartilage as early as the second decade of life. In contrast to this, involvement of the central region was seen in only three specimens from subjects aged 58, 58 and 65 years respectively.

The subjects were divided into two age groups; those under 40 years (12 specimens) and those over 40 years (16 specimens).

In the under 40 age group, four had minimal to no peripheral fibrillation while the remaining 10 had mild peripheral fibrillation which was more pronounced posteriorly in eight cases.

The pattern of a greater degree of fibrillation on the posterior aspect of the periphery of the cartilage continued in the over 40 year olds, being present in 12 of the 16 specimens. Peripheral fibrillation increased in its extent by centripetal spread; however, the degree of fibrillation varied between specimens. The three fibrillated centrally appeared to have isolated foci (rather than a spread from the periphery).

Only two specimens (numbers 20 and 24) did not conform to the above pattern in that they exhibited an even distribution of fibrillation over the entire articular surface. Specimen number 16 had a localised rounded defect in the antero-medial quadrant.

b) Articular surface of the trapezium

The specimens were divided into the same age groups as described for M1 above. On the whole, in the younger age group, the trapezial surface showed more fibrillation than that of M1 and this was evident in specimens as early as the second decade of life. There were no cases of central involvement but the peripheral area showed a fairly consistent pattern of involvement which differed from that evident in M1. In 12 of the 14 specimens there was more fibrillation along the circumference of the antero-lateral quadrant and nine of these also showed more fibrillation medially and laterally, that is, at either end of the trapezial ridge.

In the over 40 age group, the peripheral zone showed increased fibrillation and despite individual variation this continued to be most obvious antero-laterally (10 of 16 cases) and at both ends of the trapezial ridge (11 of 16 cases).

Six specimens had fibrillation centrally, three of these spreading from the periphery, while the other three appeared to be separate foci.

The same specimen (number 16) which had a defect anteriorly on M1, also had a localised rounded defect on the antero-medial quadrant of the trapezium.

4.4 Discussion

Results of the three aspects of the clinical study — range of passive physiological movements, ligamentous function and degenerative changes in the articular cartilage — lend themselves to separate discussion.

4.41 Range of passive physiological movements of the T-M1 joint

This is the first study to radiologically measure the passive mobility of the T-M1 joint. There was considerable variation between the 28 specimens in the range of the five passive physiological movements tested. This is shown by the size of the standard deviations (Table 4.5).

As reported in the literature review, several authors have measured the movement between flexion and extension and between adduction and abduction, while others have measured opposition. None of these studies isolated the movements to the T-M1 joint and there are no details as to whether the movements were active or passive, performed *in vivo* or on autopsy material, nor of the exact direction of the movements nor the fixed points from which the measurements were taken. For these reasons direct comparisons cannot be made with the results of the present study.

4.42 Ligamentous function

Considerable variation in the length and width of ligaments relative to each other and between specimens was observed. This, together with the varying attachments of the posterior oblique and first inter-metacarpal ligaments, may be the reason why, on severing a particular ligament, axial rotation was not seen to occur always in the same direction (Table 4.7). A larger sample might help to clarify this.

To date Pieron (1973) has presented the only detailed account of ligamentous function of the T-M1 joint. His results were based on examination of eight specimens but he did not state whether or not they were embalmed. The findings of the present study are based on the examination of 28 un-embalmed specimens within 24 hours of death as they more closely resemble the *in vivo* flexibility of the capsule and ligaments.

Pieron's (1973) method of assessment was based on visually noting which ligaments were on full span when M1 was placed in a particular position. In addition, he wired the ligaments so that he could confirm radiographically that the attachments were separated. Pieron ranked the ligaments according to their contribution to the control of the five movement tests; however, his methodology does not permit an accurate assessment of the contribution of each ligament.

In the present study a more detailed review of the function of the four ligaments has been carried out. This has been achieved in two ways; first, by recording the function in terms of the control of both angular movement and axial rotation of M1, and second, by severing individual ligaments. As a result a more accurate assessment has been obtained of the relative contribution of each ligament to the control of movements of M1.

Four of the five passive physiological movements tested in this study correspond with those of Pieron (1973). These are extension-adduction, extension-abduction, radial-abduction and opposition. The findings of both studies may be compared by reference to Tables 2.1 and 4.7 and are discussed below.

Extension-adduction – both studies found the anterior oblique ligament to exert the main control supplemented by the action of the dorso-radial ligament. The present study also found that the posterior oblique ligament exercises a lateral rotatory control while the first inter-metacarpal ligament assists the anterior oblique ligament in the control of medial rotation.

Extension-abduction – the present study corroborates the finding of Pieron (1973) that all four ligaments contribute to the control of this movement. It also confirms the relative contribution of each ligament, with the anterior oblique being the principal controlling force. In the present study medial rotation has been shown to be limited by the anterior oblique and posterior oblique ligaments while lateral rotation is controlled by the first inter-metacarpal and dorso-radial ligaments.

Radial-abduction – the results of the present study do not support those of Pieron (1973) who found the movement to be controlled by the anterior oblique, posterior oblique and first inter-metacarpal ligaments. The first inter-metacarpal ligament has been shown to exert the greatest control, with some assistance from the posterior oblique. Very little axial rotation resulted from severing any of the ligaments, suggesting good congruence between the articular surfaces.

Opposition – Pieron (1973) found the dorso-radial and anterior oblique ligaments to be taut in this position. Present findings are that the greatest control is effected by the posterior oblique ligament, aided by the first inter-metacarpal ligament. The anterior oblique and dorso-radial ligaments assist in the control of medial rotation of M1.

As described in Chapter III, the four ligaments are attached obliquely across the T-M1 joint and therefore could be expected to exert a rotary as well as an angular control of movements of M1. Each ligament's contribution to these two components of joint motion has been outlined although only the latter could be quantified.

The findings of the present study demonstrate that all ligaments play a part in the control of each movement (Table 4.7), some ligaments having a restraining effect on the angular component while others control axial rotation (the effect on the third component, translation or sliding, was visually assessed). This combined functioning of the ligaments produces a smooth control of T-M1 joint motion.

The determination of the function of the four ligaments of the T-M1 joint is discussed in relation to the reports of other authors:

The anterior oblique ligament – Haines (1944) and Pieron (1973) found that the anterior oblique ligament limits extension; the findings of this study support this. Haines further stated that at the limit of extension this ligament causes M1 to rotate laterally. Warwick and Williams (1973) were of the same opinion, although they considered that the shape of the articular surfaces plays a role in producing lateral rotation during extension. In the present study, severing the anterior oblique ligament resulted in medial rotation of M1 when in the position of extension-adduction; in extension-abduction the effect was less obvious (Table 4.7). Cutting the anterior oblique ligament resulted in excessive posterior translation of M1 when it was moved into extension. This is consistent with reports that laxity of this ligament causes dorso-lateral instability (Gedda, 1954; Eiken, 1971; Burton, 1973; Eaton and Littler, 1973; Kessler et al., 1976).

The posterior oblique ligament was described by Strasser (1917), Haines (1944) and Gedda (1954) as limiting opposition. The results of this study support this; and, in addition, indicate that it contributes to the control of M1 in the three positions of abduction. Haines (1944) attributed medial rotation of M1 at the limit of flexion to tension in the posterior oblique ligament. His description was supported by Warwick and Williams (1973); however, they also implicated the sellar articular surfaces. In the present study the rotary effect of the posterior oblique ligament was inconsistent. In contrast to the above authors, Eaton and Littler (1973) and Pieron (1973) rated this ligament's function as relatively insignificant.

The first inter-metacarpal ligament was studied in 20 cadavers by Bosjen-Møller (1976) who found it to limit abduction and to prevent radial subluxation. Results here support this in that the first inter-metacarpal ligament played the major role in limiting both radial-abduction and palmar-abduction, and that excessive lateral translation of M1 occurred during abduction after the ligament was cut. Further, the ligament was found to assist in the control of extension-abduction and opposition. Pieron (1973) found the first inter-metacarpal ligament to be taut in radial-abduction and extension-abduction but concluded that it played a minor role in the control of these movements.

The dorso-radial ligament – Pieron (1973) is the only author to mention the function of this ligament. He found the dorso-radial ligament to limit opposition and adduction and to assist the anterior oblique ligament in controlling extension-adduction and extension-abduction. Testing showed that it assists the anterior oblique ligament in the control of the two extension movements, but that its main function is limiting medial rotation of M1 in the positions of palmar-abduction, opposition and extension-adduction. Also it was found to prevent dorso-lateral subluxation when M1 was in the position of extension-abduction.

From the findings of the present study it would appear that the anterior oblique, first inter-metacarpal and dorso-radial ligaments all contribute to the prevention of dorso-lateral subluxation.

While the present study contains the largest series of T-M1 joints (N = 28) the results point to the need for a much larger sample to compensate for the effect of individual differences in the relative size of the four ligaments.

4.43 Degenerative changes in the articular cartilage

In this study only three specimens had radiological evidence of degenerative changes (Table 4.8) whereas all specimens showed some degree of fibrillation when the articular cartilage was stained (Table 4.9).

Fibrillation around the periphery of the articular cartilage was evident as early as the second decade of life. This is consistent with the findings of Meachim and Emery (1973) who reported on studies of the articular surfaces of 37 gleno-humeral and 32 hip joints. For the T-M1 joint the degree of fibrillation increased with advancing age but was subject to individual variation (Table 4.9). Generally, specimens in the under 40 age group showed more fibrillation on the trapezial surface than on M1. Meachim and Emery (1973) reported that fibrillation increased with advancing age but did not mention differences in the degree of degenerative change between the two articular surfaces of the shoulder or hip joints.

As with the shoulder and hip joints, there was a pattern of degenerative change typical for the T-M1 joint. On the trapezial surface peripheral fibrillation was more marked on the antero-lateral, medial and lateral aspects. The medial aspect is the area in which the joint surfaces are in contact during activities requiring 'power grip' (Napier, 1956; Pieron, 1973). Lateral and antero-lateral aspects are areas of joint contact during radial-abduction and palmar-abduction respectively. These are components of 'precision grip' (Napier, 1956).

On the metacarpal surface fibrillation was more marked on the posterior aspect, a position of joint contact during extension (Pieron, 1973) which is a component of strong gripping ('power grip', Napier, 1956).

It is interesting that both weight-bearing and non-weight-bearing joints show fibrillation as early as the second decade of life, and although this increases with advancing age, it is a slow progression and subject to wide individual variation.

4.5 Summary

The results of this study are based on the largest series of T-M1 joints examined to date (N=28) and this is the first study to report on the range of passive movements of the T-M1 joint and to describe a pattern of degenerative change in the articular cartilage specific for the T-M1 joint.

The main findings were:

1\. a) the range of the five passive physiological movements which comprise circumduction of the thumb were measured radiologically. The means were extension-abduction = 37°, radial-abduction = 62°, palmar-abduction = 56°, opposition = 38° and extension-adduction = 44°. Relatively large standard deviations for each movement indicate a wide variation between individuals.

b) within the limits of the sample size, age, gender and side were found to have no significant relationship to these ranges of movement.

2\. A more detailed study of the function of the four ligaments of the T-M1 joint than other reports in the literature has been carried out: first, by recording the function in terms of the control of both angular (swing) movement and axial rotation (spin) of M1; and second, by severing a ligament and obtaining a more accurate assessment of the relative contribution of each ligament to the control of movements of M1. The functions of the four ligaments were found to be:

a) the anterior oblique ligament limits the range of extension-adduction and extension-abduction and contributes to the control of medial rotation of these movements and of palmar-abduction and opposition.

b) the posterior oblique ligament limits the range of opposition and contributes to the control of the three positions in which M1 is in abduction. Its effect on axial rotation is inconsistent.

c) the first inter-metacarpal ligament restricts the ranges of radial-abduction and palmar-abduction. Additionally, it contributes to the control of the angular and medial rotary components of opposition. In the positions of extension-adduction, extension-abduction and palmar-abduction it limits lateral rotation.

d) the dorso-radial ligament assists in the control of extension-adduction and extension-abduction. Its main function is the control of medial rotation during the movements of palmar-abduction, opposition and extension-adduction.

The results show that all ligaments play a part in the control of each movement; some ligaments have a restraining influence on the angular component while others control rotation. This combined functioning of the ligaments produces the smooth control of T-M1 joint motion.

3. Staining the articular surfaces revealed peripheral fibrillation as early as the second decade of life. Although subject to individual variation, the degenerative changes increased significantly with advancing age ($p < .01$).

Staining revealed a pattern of degenerative change that was consistently present for the T-M1 joint. On the trapezial surface peripheral fibrillation was more marked on the antero-lateral, lateral and medial aspects while on the metacarpal surface it was more pronounced posteriorly.

CHAPTER V

OSTEOMETRIC STUDY

5.1 Introduction

On visual examination the articular surfaces of the T-M1 joint showed general congruence but it was evident that the two surfaces do not exactly fit. There seem to be differences in their total surface area, in particular the area of each quadrant (the two axes, the ridge and groove, divide the articular surface into four quadrants) and between corresponding quadrants of the two articular surfaces; in the length of the ridge on the trapezium and the corresponding depression in the metacarpal surface.

Only two detailed studies, known to the author, considered the shape of the articular surfaces (Kuczynski, 1974; Smith and Kuczynski, 1978). The methodology of both studies was relatively crude and the selection of specimens limited. In one study (Kuczynski, 1974) visual inspection and palpation was utilised on dry specimens devoid of articular cartilage which is essential to a consideration of congruence (Simon et al., 1973). In the other study (Smith and Kuczynski, 1978) measurement of the depth of the trapezial groove alone was carried out using a tyre thread depth gauge in embalmed specimens aged between 60 - 80 years.

The aims of this osteometric study were:

1. to visually examine the overall shape of the articular surfaces
2. to devise a method of measurement of the precise shape of the articular surfaces, and specifically to use the data so obtained to calculate the following geometric features of the surfaces:
   i) the angle between the two axes
   ii) the length of the two axes on each articular surface
   iii) the total surface area of each articular surface
   iv) the surface area of each quadrant on both articular surfaces
   v) a plot of the contour of the articular surfaces

5.2 Materials and Method

5.21 General

After staining with Indian ink diluted to 50% by normal saline, 23 of the 28 T-M1 joints were allowed to dry slowly over a period of three to five days at a temperature of 20°C and at a humidity of 47% in the metrology laboratory of the Department of Mechanical Engineering of the South Australian Institute of Technology.

This provided a firm surface for measurement by a metal stylus.

a) Visual examination of the articular surfaces

The overall shape of the articular surfaces of the T-M1 joint was described visually with particular attention to any deviation from the usual saddle shape.

b) Development of a method of precise measurement of the articular surfaces

The specimens were mounted in small blocks of plaster of Paris. The ridge on the trapezium was identified and its medial end marked 'X' and its lateral end, 'Y'. The trapezium and M1 were then articulated and the edges of the corresponding depression on M1 was marked 'X^1' and 'Y^1' so that 'X' on the trapezium articulated with 'X^1' on M1 and 'Y' with 'Y^1' (Figure 5.1).

Figure 5.1 **Specimens mounted in plaster of Paris blocks.**

a) trapezium; trapezial ridge marked X Y
b) M1; metacarpal depression marked X^1 Y^1

Using a Nikon Profile Projector with a magnification of ten, a plan view of the cartilage of each bone was obtained and a tracing made of the boundary of the cartilage. The projector is shown in Figure 5.2 with a close-up view of the specimen mounted on the table in Figure 5.3.

With the assistance of the Mechanical Engineering staff two methods were developed by which the articular surfaces could be measured.

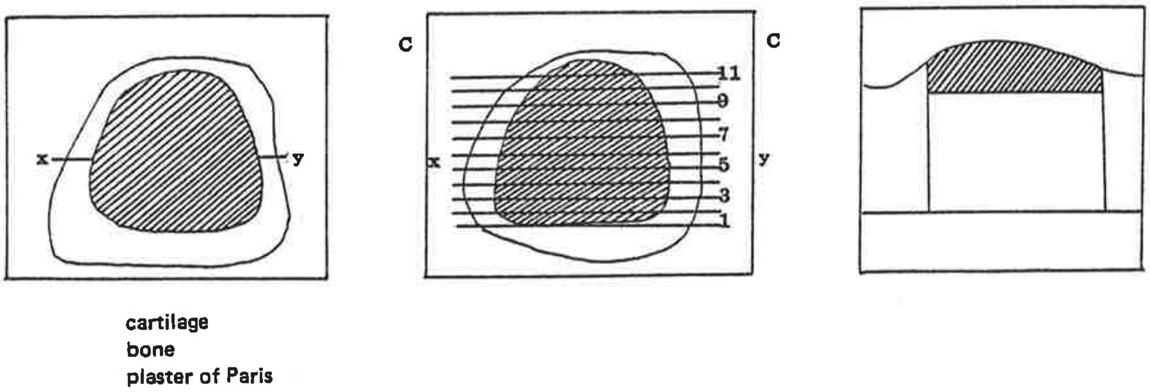
5.22 Method I — Sectioning

The tracing of the boundary of the cartilage was transferred onto a sheet of paper. Parallel lines were then drawn 1 mm apart across the tracing. These were drawn parallel to XY and X^1Y^1 (the ridge on the trapezium and corresponding groove on M1). As the tracing was magnified ten times, these lines represented sectional planes at increments of 1 mm being drawn 10 mm apart (Figure 5.4).

Figure 5.2 **Nikon Profile Projector with image magnified x 10 of the articular surface of metacarpal projected on the screen.**

Arrow indicates specimen on the table of the projector.

Figure 5.3 Close-up view of metacarpal specimen mounted on table of Nikon Profile Projector.

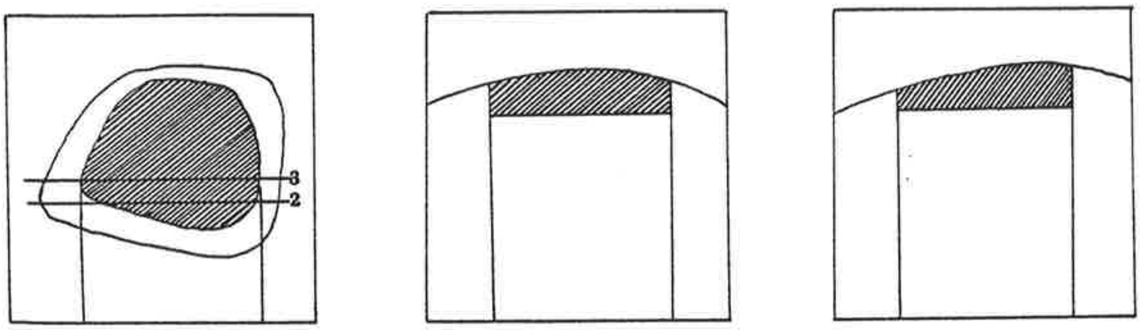


a) Specimen
(plan view)

b) Tracing
(plan view)

c) Tracing
Section Plane 1

Figure 5.4 **Plan views of specimen.**
(a) plan view of specimen (b) tracing (c) tracing of section plane 1.



b) Tracing of
Section Plane 2

c) Tracing of
Section Plane 3

Figure 5.5 **Tracings of sectional planes 2 and 3.**

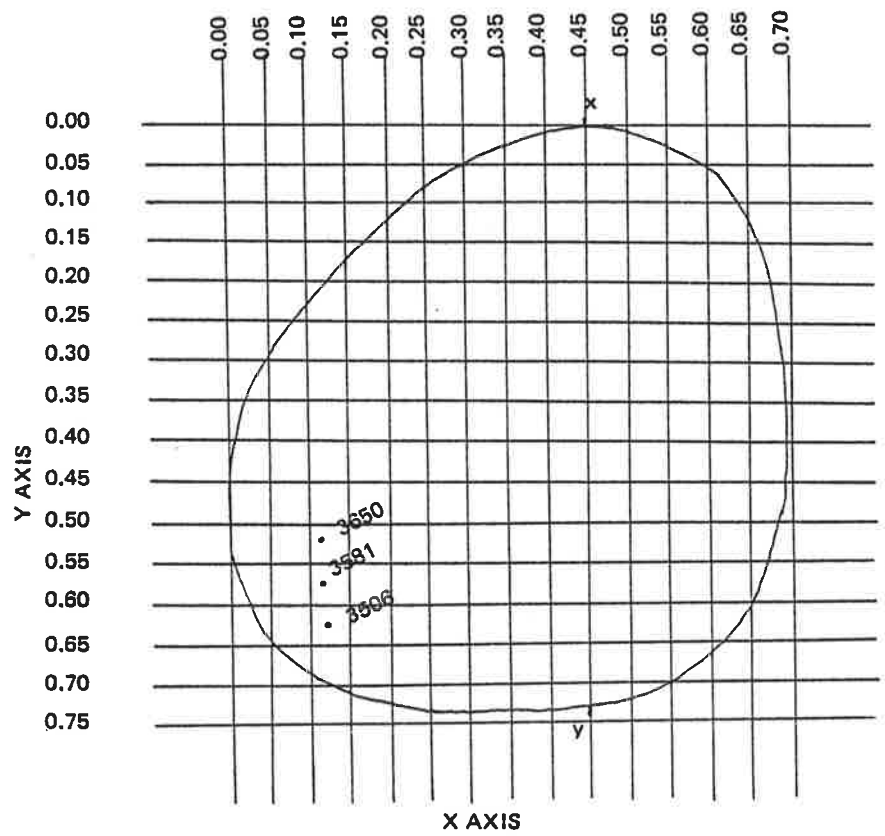


Figure 5.6 Grid method of measurement of articular surfaces.

The plaster of Paris was machined to the plane c – c to provide a datum face (Figure 5.4(b)). The front of the specimen was then machined off to correspond to the section line '1' and a section trace taken of this plane. A further 1 mm was machined away to reveal plane '2' and a section trace was then taken from this plane (Table 5.5). This procedure was continued until a set of section traces was obtained.

The approximate area of each thin slice could be calculated from the measurement of the length of the cartilage slice multiplied by the width (1 mm). Summation of each sectional area would give an approximate value for the total area of the articular surface.

A number of disadvantages rendered this method unsuitable. These included destruction of the specimen in machining, inaccuracies of the technique of obtaining each section of cartilage and in the method of calculation of the surface area, and difficulty in derivation of other measurements from the data thus obtained. As a consequence, another method of articular surface measurement was developed.

5.23 Method II – Grid method

The tracing of the boundary of the cartilage (obtained by the Nikon Profile Projector) was overlaid by a sheet of pre-printed paper having a grid with lines 0.50 inch apart marked on it. With the cartilage profile magnified ten times, the grid sections were equivalent to 0.050 inch. Thus the cartilage area could now be described as being comprised of a large number of ordinates (Figure 5.6).

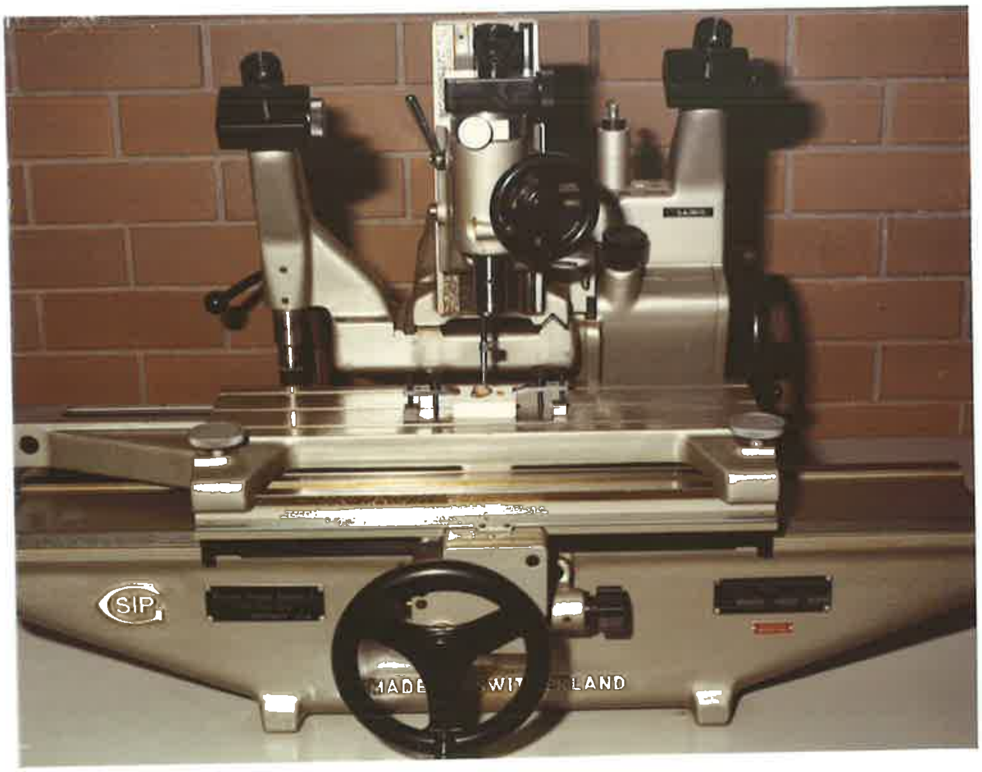


Figure 5.7 **Universal Measuring Apparatus**

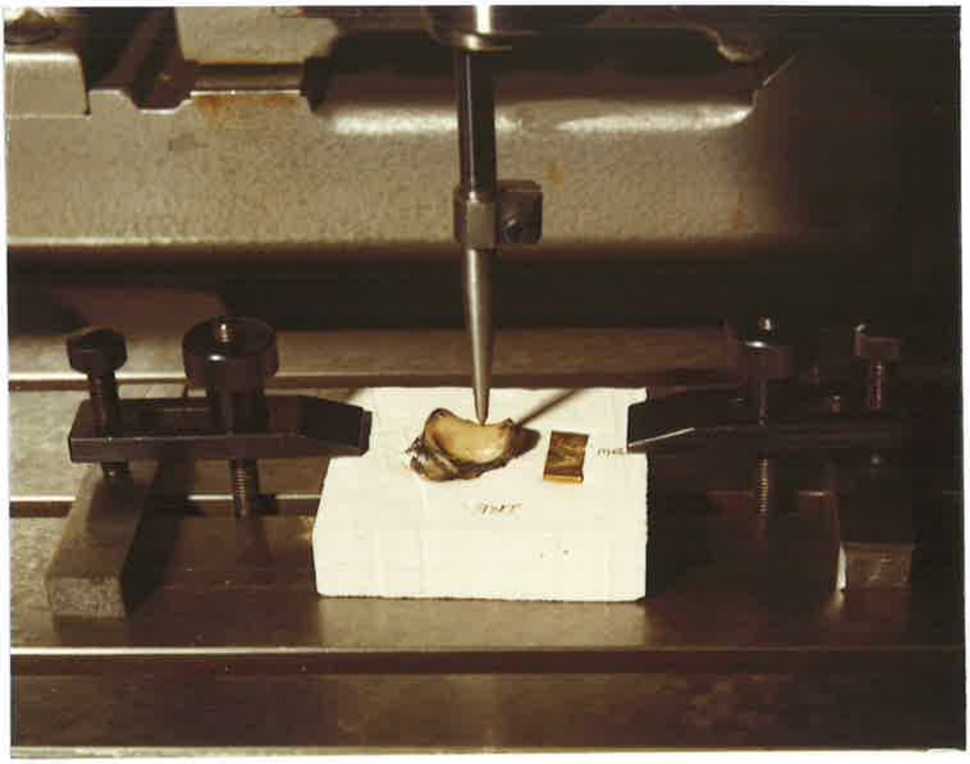


Figure 5.8 **Metacarpal specimen mounted on table of Universal Measuring Apparatus.**
The groove X^1 Y^1 is parallel to the Y axis of the machine. Metal stylus for measuring the contour (height or Z axis) of the articular surface.

The specimen was then fastened to the table of a Universal Measuring Apparatus (Model Type MU-2148, manufactured by Societé Genevoise D'Instruments de Physique) so that XY (trapezial ridge) and X^1 Y^1 (groove on M1) were parallel to its Y axis. A photograph of this machine and of the specimen fixed to its table are shown in Figures 5.7 and 5.8 respectively.

The Universal Measuring Apparatus described in Appendix I, allows for very fine adjustment of movement along the X and Y axes. By combining these two movements with the provision of a microscope to measure the change of vertical displacement of the metal stylus on the surface of the cartilage, as shown in Figure 5.8, it was possible to develop a three dimensional grid reference of the entire area of the cartilage. Figure 5.6 illustrates such a grid; for clarity, only three ordinate values are indicated. A complete set of ordinate values derived from one of the 46 surfaces measured is included in Appendix II.

Particular care was required when measuring at points of acute geometry (points at (A) in Figure 5.9) because here a slight change in the X or Y ordinate resulted in a bigger change in the Z axis, than would occur at point (B)). The tendency of the stylus to deviate laterally at

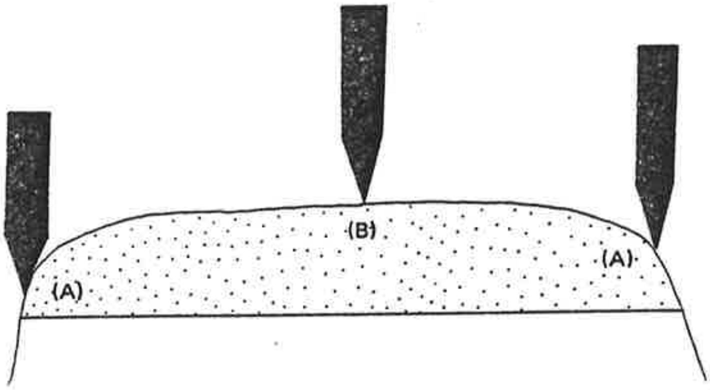


Figure 5.9 **Diagram of articular cartilage showing points of acute geometry at (A).**

these points required careful control as a slight lateral movement could markedly alter the Z ordinate reading. The visual aligning of the stylus on the periphery of the cartilage was the only feasible technique. However, the error of measurement (see results) indicated that this method was acceptable.

The grid method of measurement was further refined by the construction of a co-ordinate table with built-in digital readout equipment (Figures 5.10 and 5.11). A gauge was incorporated to measure the pressure of the metal stylus on the articular surface and to ensure that this was kept constant for each reading. The ease of operation of this special purpose equipment was superior to that of the Universal Measuring Apparatus, but the actual time expended in measuring each articular surface was still approximately one and a half hours.

5.24 Error of measurement

The Grid method of measurement was adopted for the measurement of the articular surfaces of 23 T-M1 joints. Because measurements were made by one operator it was necessary to test for intra-observer error in the repeatability of measurement.

To test for the repeatability of any one 'Z' value, that is, staying at the same co-ordinate, six measurements were made on each of three specimens. Three of these were performed at co-ordinates situated on the periphery of the articular surface; these are points of acute geometry requiring particular care by the operator. The other three measurements were made at co-ordinates situated anywhere within the boundary of the articular surface. The 'Z' values for these six co-ordinates were repeated after periods of five and ten minutes without reference to the previous results. The operator was unable to recall any of the 'Z' values (which were recorded to the fourth decimal place) so this was not considered to affect the results.

Figure 5.10 Co-ordinate table with digital readout equipment.

To allow for the possible effect of operator fatigue, the above tests were performed after a two-hour session of measurement. The results are presented on page 66.

The ordinant values were then used to calculate a number of geometrical features of the articular surfaces. These included:

5.25 Measurement of the angle between the two axes of the articular surfaces of the trapezium and M1

The two axes of the T-M1 joint correspond to the ridge and groove on the trapezial and metacarpal articular surfaces. The ridges were defined by a line joining the highest 'Z' values on the articular surfaces and the grooves were represented by a line joining the lowest 'Z' values. The angle subtended by these two lines was then measured to the nearest degree using a protractor.

5.26 Measurement of the length of the two axes on the trapezial and metacarpal articular surfaces

The arc length of these curves was approximated in the following way:

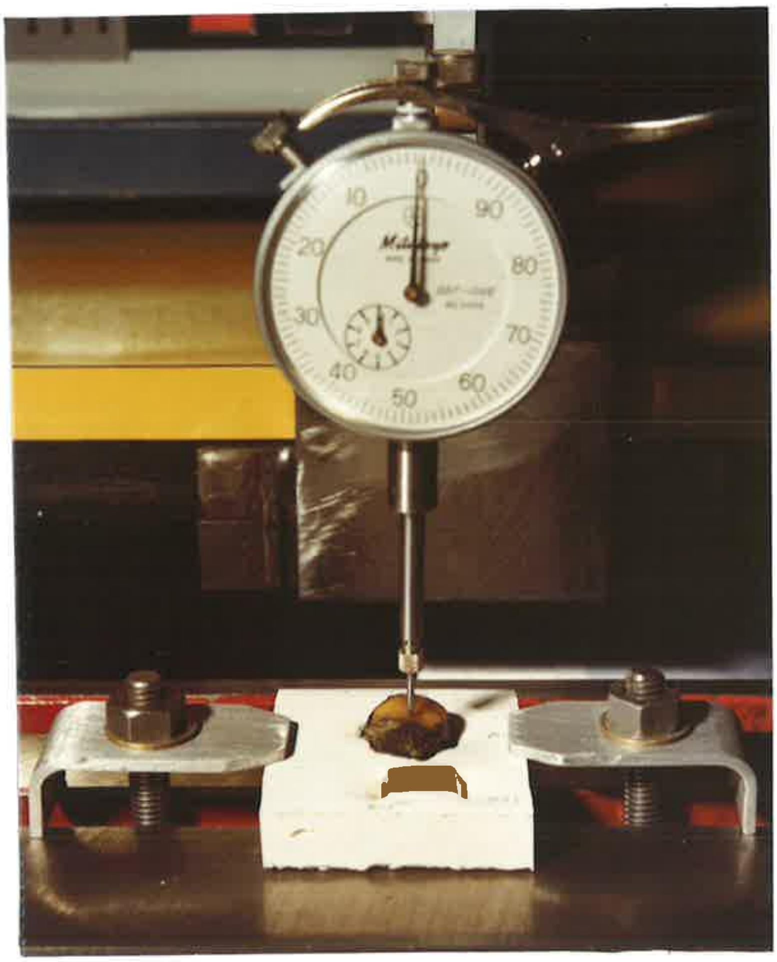


Figure 5.11 **Close-up view of metacarpal specimen on co-ordinate table.**

Note: gauge to record constant pressure of metal stylus on the articular cartilage.

a) the co-ordinates of a number (n) of points which lie on the curve (and the surface) were obtained from the articular surface data

b) points on the curve between data points have their co-ordinates (x, y, z) expressed as functions of the parameter, s, which is the chord length from point to point. Specifically x, y, z were each expressed as cubic splines on the accumulated chord length.

c) between each pair of data points, m points were obtained from the spline representation, and the accumulated chord length was recalculated using the intermediate points.

d) a), b) and c) were repeated until a consistent accumulated chord length was obtained.

e) total arc length = $\int_{S=0}^{t} \sqrt{\left(\frac{du}{ds}\right)^2 + \left(\frac{dy}{ds}\right)^2 + \left(\frac{dz}{ds}\right)^2}\, ds$ was calculated using Simpson's rule for numerical integration (Kreyszig, 1979, page 377 and Davis and Rabinowitz, 1967, page 20). The spline fitting uses the I.M.S.L. routines ICSICU, ICSEVU, DCSEVU (For details see I.M.S.L. library manual and appropriate reference therein).

The relative accuracy of the arc length calculation is ± 0.002 which is as accurate as the method of specifying the co-ordinates of the points on the curve. Three test runs are included in Appendix III. They illustrate the arc length calculation applied to:

i) the circle of radius which gave the result, arc length = 6.2767 (the exact answer being $2\pi \cong 6.28319$).

ii) the helix, $X = \cos\theta$, $y = \sin\theta$, $x = 2\theta$. The result was arc length = 14.04676 (the exact answer being $2\sqrt{5}\,\pi \cong 14.04963$).

iii) as for ii) except that the data were rounded to two decimal places before being used, to illustrate the effect of inaccurate data, the inaccuracy being of the same order as the possible inaccuracy in the calculation. This gave the result arc length = 14.04658 (the exact answer being $2\sqrt{5}\,\pi \cong 14.04963$).

5.27 Calculation of the total surface area of the articular surfaces of the trapezium and M1.

The calculation of the area A, of a surface specified mathematically by $z = g(x, y)$ was carried out by evaluating $A = \iint_S \sqrt{1 + \left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2}\, dx\, dy$ (Kreyszig, 1979, pages 429-439). The integral, expressed as a double integral was evaluated using Simpson's rule on sections which ran from posterior to anterior (i.e. sections at a right angle to XY in Figure 5.12) then the trapezium rule on sections which ran from medial to lateral (i.e. sections parallel to XY in Figure 5.12). The program SAREA listed in Appendix IV was used for this purpose.

The relative accuracy of this calculation for the given data was typically ± 0.001 for all specimens. The computation involved is considerable and it was thought that the accuracy obtained was adequate for the present investigation. More accurate calculations, with the present data, could be made if necessary.

5.28 Calculation of the surface area of the quadrants of the articular surfaces of the trapezium and M1.

The same method as described in 5.27 for estimating the total surface area of the articular surfaces was used to calculate the surface area of each quadrant.

5.29 Plotting the articular surfaces of the trapezium and M1

Plotting of sections of the surface used Subroutine Plot 3D by Watkins, S.L. (1974) (Algorithm 483) – for details see Appendix V.

This program plots sections from foreground to background with a 'hidden line feature' in that parts of sections lying behind more foreground sections are not drawn.

For each right hand specimen the trapezium was orientated so that the medial side was in the foreground and the anterior aspect to the right of the plot. The matching right hand metacarpal was placed with the lateral side in the foreground; again the anterior aspect was to the right of the plot.

For each left hand specimen the trapezium was orientated so that the lateral aspect was in the foreground, and the matching left hand metacarpal had the medial side in the foreground. For both these bones the anterior aspect was placed to the right of the plot. These details are illustrated in figure 5.12.

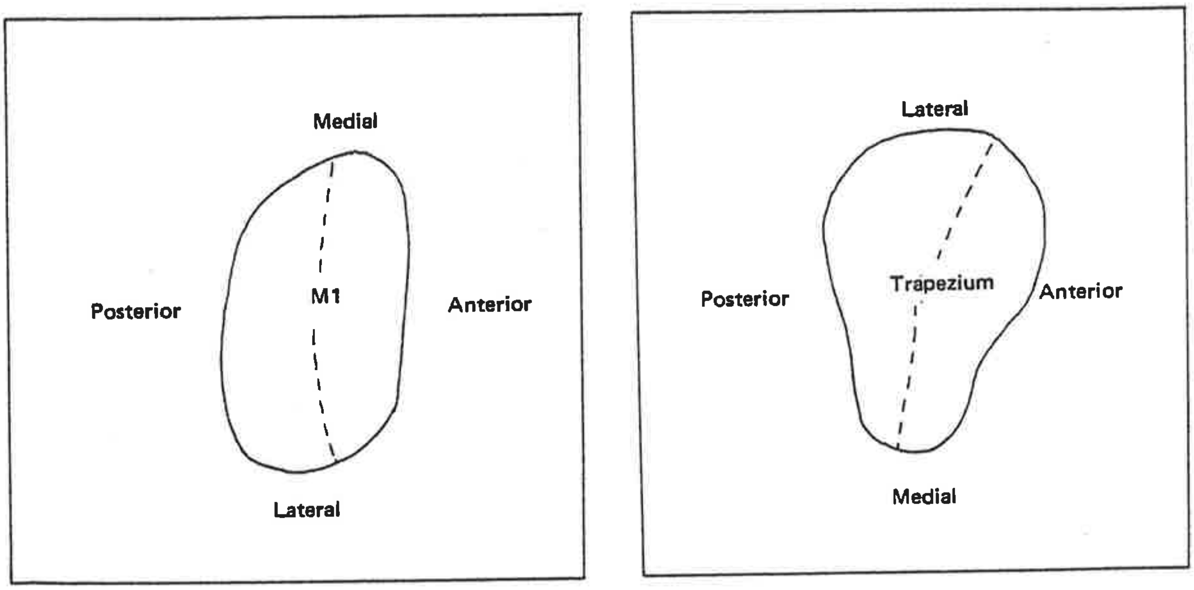


Figure 5.12 Orientation of specimens for plotting the articular surfaces (for the right hand)

For the surface plots to have some realism, it was necessary to construct several sections between each pair of sections given by the data measured from the articular surface. In the example shown in Figure 5.13, two sections were constructed between each pair of data sections. The construction of these sections was accomplished by using a two dimensional interpolating scheme based on the construction of quadric surfaces through six data points near the point where the interpolation was required. This was carried out with program GENCUR, a listing of which is included in Appendix VI. This interpolation involved a number of details relating to the specification of the boundary between data points and the method of choosing a set of six data points lying on a unique quadric. This is a rather specialised feature and not of sufficient interest to warrant a detailed description here.

5.3 Results and Discussion

5.31 Measurement error studies

Intra-observer error studies were performed and the repeatability of 'Z' values, that is, the ability to return to and measure the same co-ordinate was:

a) ± 0.0004 inch (± 0.01 mm) for co-ordinates situated within the periphery of the articular cartilage,

b) ± 0.002 inch (± 0.05 mm) for co-ordinates situated on the periphery of the cartilage where the geometry is acute and where there were small cracks.

These are acceptable errors of measurement when considered in relation to the degree of error in the mathematical calculations.

The data obtained by the grid method of measurement can be used for a number of geometrical calculations, making this method superior to that of Smith and Kuczynski (1978) who measured only the depth of the trapezial groove using a small tyre thread depth gauge. No error of measurement studies were included.

5.32 Visual examination of the articular surfaces

Visual examination of the overall shape of the trapezial and metacarpal surfaces of each T-M1 joint revealed that 22 of the 23 had the usual saddle shape. Specimen number 12 demonstrated not only a deviation from the 'normal' saddle shape, but, in addition, the two surfaces were quite dissimilar. The trapezial surface was saddle shaped: however its medio-lateral axis (ridge) was more posteriorly placed, while the metacarpal surface was almost convexo-convex. The metacarpal had no medio-lateral axis (the groove which corresponds with the trapezial ridge), but rather sloped posteriorly downwards from the high volar styloid process as illustrated in Figure 5.15.

	Total No.	Saddle	Triangular	Ovoid	Semi-cylindrical	Other
Smith & Kuczynski	32	24	1	1	6	0
This Study	23	22	0	0	0	1

Table 5.1 **Shape of trapezial articular surface — a comparison of the findings of this study with those of Smith and Kuczynski (1978).**

The findings of this study (Table 5.1) contrast strongly with those of Smith and Kuczynski (1978) who visually examined the shape of the articular surfaces of 32 T-M1 joints. Their specimens were aged between 60 and 80 years and demonstrated two almost distinct types. Twenty-four had the usual saddle-shaped surfaces and six were grossly arthrosed with semi-cylindrical surfaces (the trapezial groove being flat). The ages of specimens used in this study ranged from 16 to 71 years (see Table 4.4) with five specimens aged between 60 and 80 years.

Smith and Kuczynski also found that the semi-cylindrical joints were set at a different angle from the plane of the other metacarpals. As they found no specimens of an intermediate stage between these two extremes they suggested that the semi-cylindrical joints '. . . are a different anatomical variety . . . and are destined to become grossly arthrosed . . .' The position of the T-M1 joint relative to the plane of the other metacarpals was not examined in the present study. Although the sample is relatively small, the findings of the present study do not support the concept of there being a separate anatomical variety, nor that with increasing age (and increasing articular cartilage degeneration) the surfaces alter in their shape.

The following results are based on data obtained from 23 pairs of articular surfaces using the grid method.

5.33 Measurement of the angle between the two axes

The data show that 12 of the 23 T-M1 joints had articular surfaces with two distinct axes running approximately medio-laterally and antero-posteriorly. The other 11 specimens demonstrated one slightly abnormal axis on one or other of the articular surfaces. When this occurred the matching surface had clearly demarcated axes (Table 5.2).

	Specimen No.	Indistinct Axis Medio-lateral	
			Antero-posterior
	12	M absent	†
	18	M laterally	†
	19	†	T anteriorly
	20	†	T anteriorly
	21	M laterally	†
	22	†	T anteriorly
	23	†	T anteriorly
	24	M laterally	†
	25	†	T anteriorly
	27	M medially	†
	28	M laterally	†
Total	11	6	5

Table 5.2 **Details of indistinct axes on articular surfaces.**
M = metacarpal T = trapezial † = normal

Notably, deficiencies in the medio-lateral axis all occurred on the metacarpal surface while abnormalities in the antero-posterior axis were confined to the trapezial surface.

Details of the two axes, also giving the angle between them, are reported separately for the trapezial and metacarpal surfaces.

a) **Trapezial surface**

In all 23 specimens the medio-lateral axis (trapezial ridge) was well defined and therefore able to guide the movements of the metacarpal surface during adduction and abduction.

The antero-posterior axis (trapezial groove) which extends from the mid-posterior border in an antero-medial direction intersected the medio-lateral axis at a mean of 68.4° (range 57° - 88° but with only two within 10° of a right angle). At its anterior end the groove flattened and this, together with the direction of the axis relative to the medio-lateral axis, would help to guide the metacarpal into flexion with medial rotation.

Five specimens showed a deficiency in the antero-posterior axis. In all cases the groove was less distinct anteriorly where it sloped more medially than usual. In these five with excessive medial slope, the trapezial surface would probably guide M1 into even more medial rotation.

b) **Metacarpal surface**

No abnormality was seen in the antero-posterior axis (the ridge which corresponds with the trapezial groove); however, six specimens showed an abnormality in the medio-lateral axis (metacarpal groove).

In specimen 12 this axis was absent, the surface being convexo-convex (the opposing trapezial surface was saddle-shaped although its corresponding axis was more posteriorly placed than usual. It would seem unlikely that the articular surfaces played a major role in guiding the movement of M1).

In four of the other five specimens the groove was less well defined laterally; the surface gently sloped postero-laterally in two cases and antero-laterally in the other two. The flattening out of the lateral surface of M1 would allow the abducted metacarpal to rotate and translate (slide) more freely.

In contrast to the trapezial surface, the axes intersected closer to a right angle. The angle ranged from 69° to 89°, with a mean of 83°.

Other authors have not measured the angle between the two axes of the articular surfaces of the T-M1 joint, but Warwick and Williams (1973, page 400) in describing saddle-shaped or sellar surfaces, stated that the two axes are at right angles to each other. The discrepancy between the angles of the axes of the trapezial and metacarpal surfaces, found in this study, would favour conjunct rotation during movements of M1. As the two surfaces fit more closely along the medio-lateral axis, the conjunct rotation is more likely to occur with movements along the antero-posterior axis, that is, during flexion and extension. These findings support the concept that the articular surfaces help to guide M1 into flexion with medial rotation and extension with lateral rotation (Warwick and Williams, 1973; Kuczynski, 1974).

5.34 Measurement of the arc length of the two axes on the trapezial and metacarpal surfaces

From Table 5.3 it can be seen that the medio-lateral (X^1Y^1) axis of M1 was longer than the corresponding axis on the trapezial surface in 17 of 22 specimens (specimen number 12 was not included as the metacarpal surface was found to be convexo-convex with no distinct medio-lateral axis). These figures show a significant difference in arc length between the two axes (using the binomial, one-tailed test, $p < .01$). This supports the visual impression that generally the medio-lateral axis of M1 is longer than that of the trapezium.

No significant difference was found between the two surfaces in the arc length of the antero-posterior axis. In this small sample of 23 T-M1 joints, 13 showed the trapezium to have the longer antero-posterior axis.

Full details of the results of measurement of the arc length of the two axes are supplied in Appendix VII.

Axis	T>M1	T<M1	T=M1	Total
Medio-lateral	3 (14%)	17 (77%)	2 (9%)	22 *
Antero-lateral	13 (57%)	7 (30%)	3 (13%)	23

Table 5.3 **Arc length of the two axes of the T-M1 joint.**
T = trapezium, M1 = first metacarpal, * Metacarpal No.12 had no definite medio-lateral axis.

The mechanical significance of finding the medio-lateral axis to be longer on M1 is that it permits the articular surface of M1 to roll, on the underlying stationary trapezial surface, during adduction and abduction (radial-abduction).

5.35 Total surface area of the trapezial and metacarpal articular surfaces.

The total surface area of the trapezial and M1 surfaces was calculated and the results given in Appendix VIII. A summary of these data is given in Table 5.4. No significant difference between the two articular surfaces was found.

Total Surface Area	T > M1	T < M1	T = M1
	9 (39%)	8 (35%)	6 (26%)

Table 5.4 **Articular surfaces — total surface area. A comparison between the trapezial (T) and metacarpal (M1) surfaces.**

5.36 Surface area of the quadrants of the articular surfaces of the T-M1 joint.

The surface area of the four quadrants (antero-medial, antero-lateral, postero-medial and postero-lateral) was calculated for the articular surface of the trapezium and M1 (see Appendix IX).

A comparison was made between the trapezial and metacarpal surfaces for the area of each quadrant (with the exception of specimen No.12 which had no distinct medio-lateral axis) see Table 5.5. Also the mean surface area was calculated for each quadrant (Table 5.6).

These tables show little difference in the surface area between the articular surfaces for the antero-lateral and antero-medial quadrants. However, a larger postero-medial quadrant on the trapezium and a larger postero-lateral quadrant on M1 were the most frequent findings.

Total No. Specimens	Antero-medial			Antero-lateral			Postero-medial			Postero-lateral		
	T>M1	T<M1	T=M1	T>M1	T<M1	T=M1	T>M1	T<M1	T=M1	T>M1	T<M1	T=M1
22	7	13	2	11	7	4	16	3	3	2	14	6

Table 5.5 **Articular surfaces – surface area of each quadrant. A comparison between the trapezial (T) and metacarpal (M1) surfaces.**

Total No. Specimens		Mean Surface Area of Each Quadrant (sq. inches) Antero-medial	Antero-lateral	Postero-medial	Postero-lateral
22	T	0.0489	0.0627	0.0632	0.0489
	M1	0.0513	0.0597	0.0484	0.0667
Difference between T & M1		0.0024	0.0030	0.0148	0.0178

Table 5.6 **A comparison between the mean surface area for each quadrant of the trapezial (T) and metacarpal (M1) articular surfaces.**

A comparison of the relative size of each quadrant for each articular surface (Table 5.6) shows that for the trapezial surface the postero-medial and antero-lateral quadrants are the largest, whereas for M1 the largest quadrants are the postero-lateral and antero-lateral.

These findings do not support those of Kuczynski (1974) who found that '. . . the part of the trapezial surface antero-lateral to the groove [i.e. farthest from the base of the second metacarpal] is larger than the postero-medial part'.

The possible mechanical significance of the findings of this study are that:

a) the larger postero-medial quadrant on the trapezium may assist the accessory movement (antero-posterior gliding and lateral rotation) of M1 during 'flattening of the thenar eminence' to bring the head of M1 into the plane of the other metacarpals.

b) the relative flatness and size of the antero-lateral quadrant of the trapezium assists M1 to translate anteriorly and medially rotate to assume the position of palmar abduction. (For example, during clockwise circumduction of the right thumb).

c) the larger postero-lateral quadrant on M1 enhances the degree of rolling of M1 during extension-abduction of the thumb.

In all three cases accessory movements of M1 are enhanced by the relatively disproportionate sizes of the quadrants of the articular surfaces.

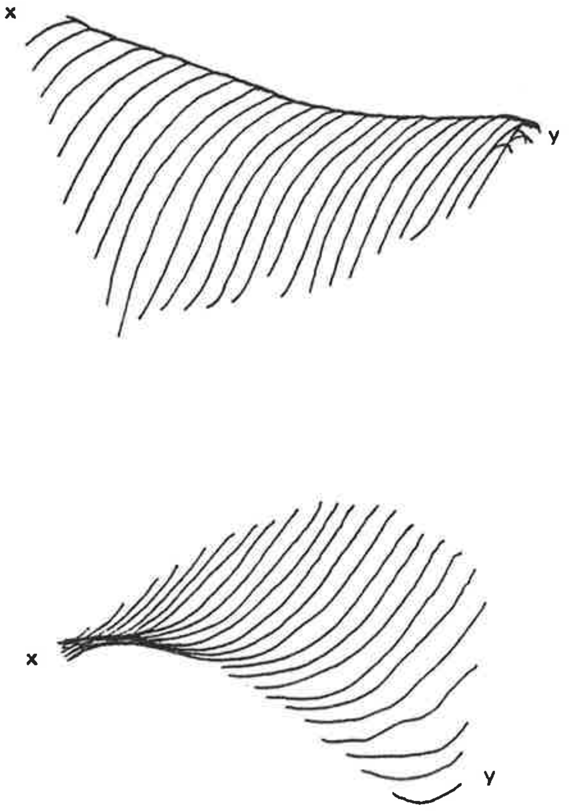


Figure 5.13 Plotting of the articular surfaces of specimen No.1 (magnification x 5). Two sections have been constructed between each pair of sections given by the data.

5.37 Plotting the articular surfaces of the T-M1 joint

The articular surfaces were plotted to show their contour. Two sections were constructed between each pair of sections given by the data. An example of this plotting is given for specimen No. 1 (Figure 5.13).

The articular surfaces of specimens 1 and 12 are plotted in Figures 5.14 and 5.15. Only the sections given by the data are included and to enhance interpretation they have been magnified x 10. Specimen No. 1 has the usual saddle-shaped surfaces, while specimen 12 showed

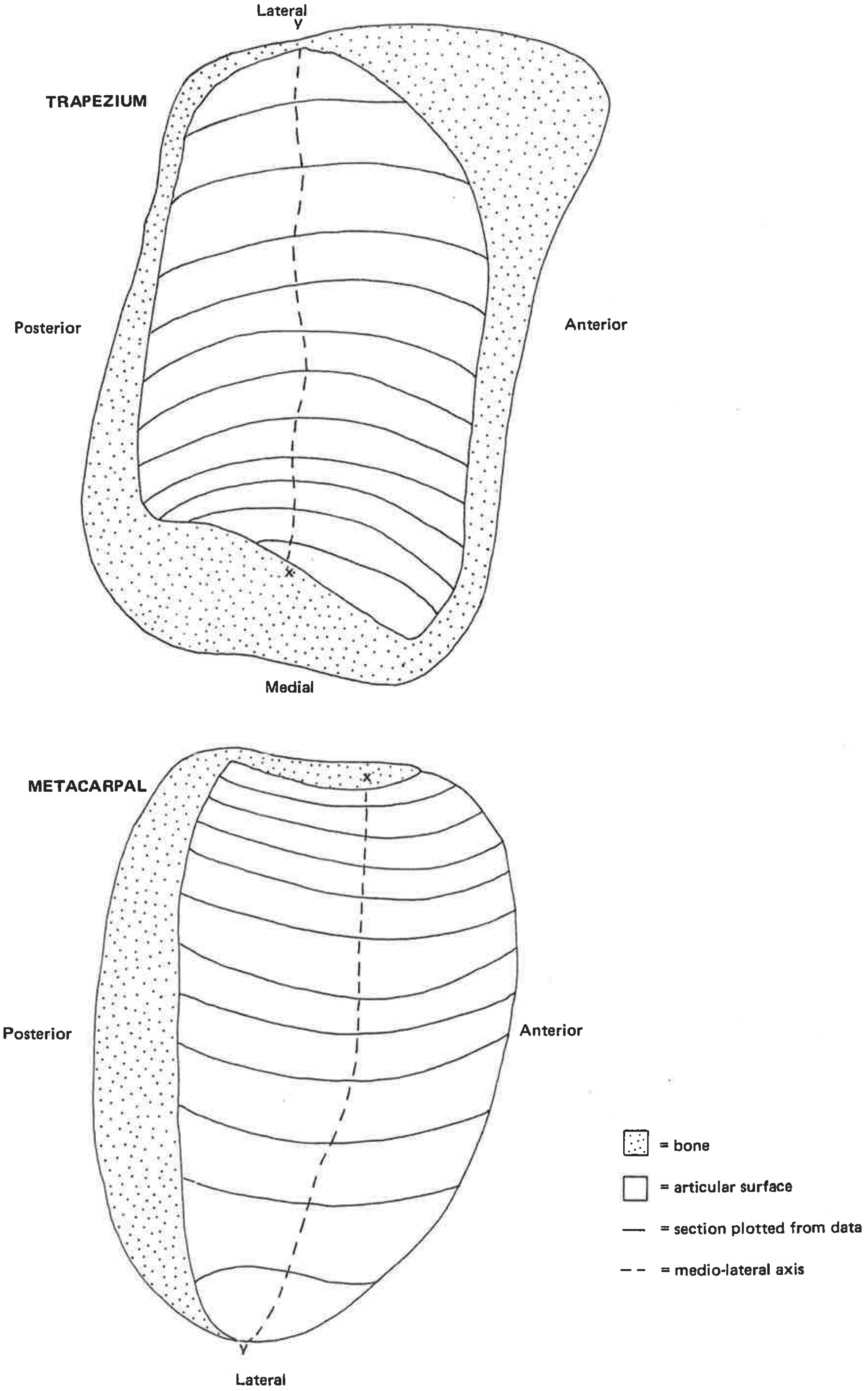


Figure 5.14 Plotting of the articular surfaces of specimen No. 1.
The sections are those obtained from the data but magnified x 10.

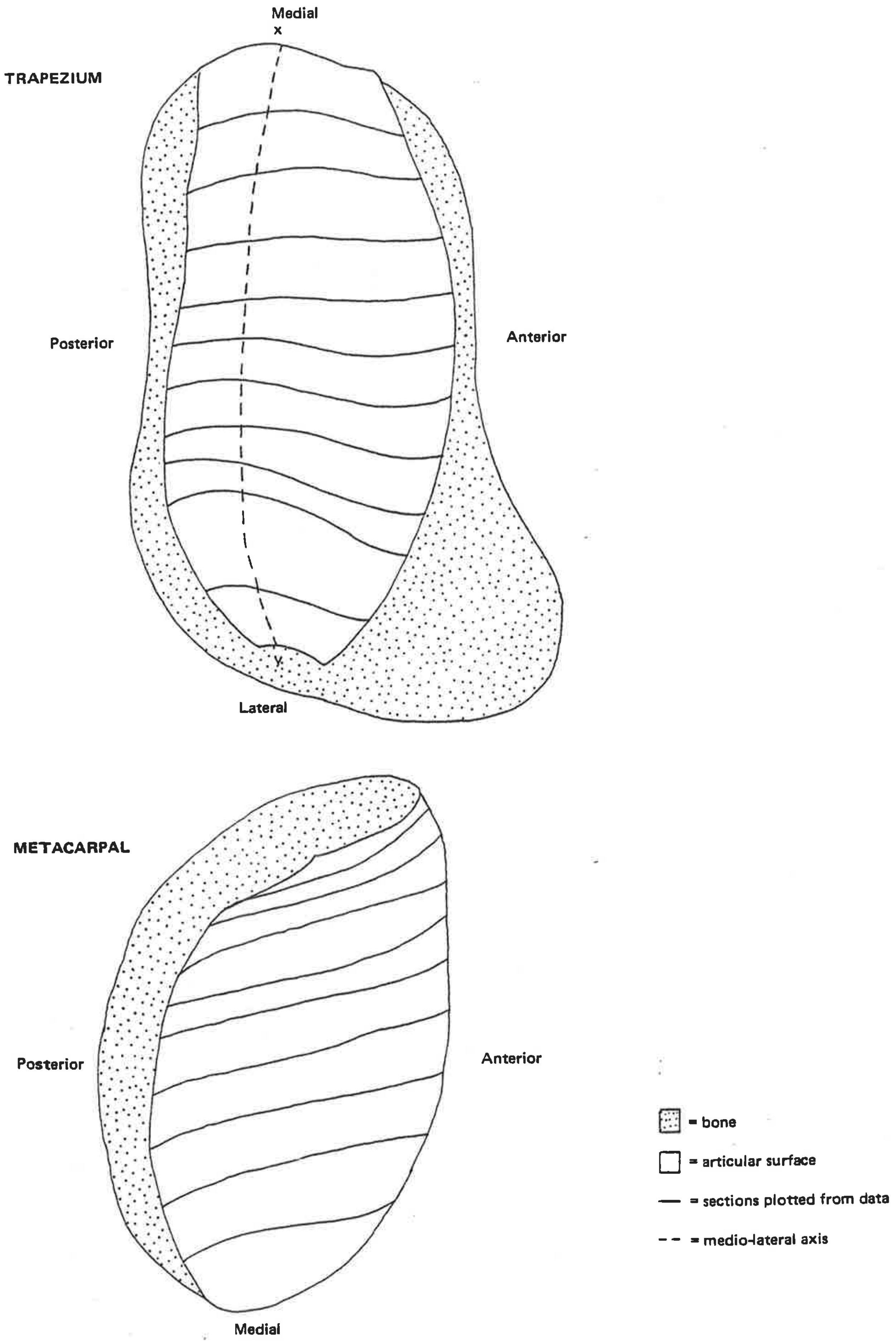


Figure 5.15 Plotting of the articular surfaces of specimen No. 12.

The sections are those obtained from the data, magnified x 10. The medio-lateral XY axis on the trapezium is placed posteriorly compared with specimen No. 1, and there was no distinct corresponding axis on the metacarpal surface.

deviation from this pattern in that its medio-lateral axis was more posteriorly placed on the trapezium and absent from the metacarpal surface. This latter surface gradually sloped posteriorly from a high peak on the anterior styloid process.

Plotting of the articular surfaces to give a visual display of their contours was disappointing as this method lacks realism where the surfaces are slowly 'undulating'. However, the plots for specimens 1 and 12 demonstrate use of the method in detecting differences in contour between the articular surfaces.

5.4 Summary

1. Two methods were devised for measuring the articular surfaces of the T-M1 joint. The first of these, the sectioning method, was discarded because of lack of accuracy in measurement of the total surface area and because it destroyed the specimen, making it impossible to calculate other features of the articular surfaces. The second, the grid method, was found to be reproducible with an acceptable degree of error. This method was then used to measure the articular surfaces of 23 T-M1 joints.

2. Computer programmes were written to use the data to determine the following geometrical features of the articular surfaces:

   a) measurement of the angle between the two axes. On the trapezial surface the axes intersected at a mean angle of 68^o (range 57^o to 88^o) while on M1 the axes intersected at a mean angle of 83^o (range 69^o to 89^o).

   b) measurement of the arc length of the two axes of the T-M1 joint. The medio-lateral axis was found to be significantly longer on the metacarpal surface ($p < .01$); however, the antero-posterior axis was not found to be significantly different in length between the two surfaces.

   c) measurement of the total surface area of the two articular surfaces of the T-M1 joint. Results showed no significant difference in surface area between the trapezial and metacarpal surfaces.

   d) measurement of the surface area of the quadrants of the articular surfaces. Results show that for the trapezial surface the postero-medial and antero-lateral quadrants were the largest, whereas for M1 the largest quadrants were the postero-lateral and antero-lateral. A comparison between the two articular surfaces showed a greater frequency for the postero-medial quadrant to be larger on the trapezium and for the postero-lateral quadrant to be larger on M1.

   e) plotting of the articular surfaces to display their contours.

CHAPTER VI

CLINICAL STUDY

6.1 Introduction

Although various studies of the T-M1 joint have been reported (Haines (1944), de la Caffinière (1970), Pieron (1973), Kuczynski (1974), Bosjen-Møller (1976), Lewis (1977)), the literature provides no detailed account either of joint mobility or of factors known to influence this. In aiming to remedy this situation, the present study provides a detailed account of the results of a wide-ranging investigation of passive movement of this joint.

The detailed aims of the clinical study were:

6.11 to note the relationship of demographic variables (gender, age, a past history of pain at the thumb base, use of the thumb, obesity, pain elicited during examination, peri-articular thickening) to the mobility and incidence of osteo-arthrosis of the T-M1 joint.

6.12 to record in a non-clinical group of T-M1 joints:

1) the range and quality of the physiological and accessory movements
2) the incidence of dorso-lateral instability

6.13 to compare in a group of individuals with generalised peripheral joint hypermobility

1) the range and quality of the physiological and accessory movements of the T-M1 joint with the non-clinical group
2) the incidence of dorso-lateral instability with the non-clinical group
3) the incidence of age-related osteo-arthrosis with reports in the literature

6.14 1) to compare in a group of osteo-arthrotic T-M1 joints, as against the non-clinical group:
   a) the range and quality of the physiological and accessory movements
   b) the incidence of dorso-lateral instability

2) to compare the pathogenesis of osteo-arthrosis of the thumb base with reports in the literature.

6.15 to investigate the relationship of specific occupations (manipulative therapy, tailoring, dressmaking, playing the violin, viola or 'cello) to T-M1 joint mobility and osteo-arthrosis.

6.16 to study the relationship of adjacent joint mobility to the range of movements of the T-M1 joint.

6.17 to investigate the relationship between osteo-arthrosis of the T-M1 joint and menstrual status and between osteopenia and menstrual status.

No subject was included in the clinical study who:

a) had a history of direct injury to the thumb base
b) had radiographic evidence of congenital abnormality of the T-M1 joint
c) had clinical or radiographic evidence of rheumatoid arthritis of any joint
d) was non-Caucasian

6.2 Selection of Subjects

Subjects were allocated to the following groups, the selection of which is detailed below.

6.21 Non-clinical

The subjects were drawn from the professional, clerical and domestic staffs of the Royal Adelaide Hospital, staff and students of the School of Physiotherapy, South Australian Institute of Technology, and staff and students of the School of Medicine, the University of Adelaide. There was a minimum of 10 males and 10 females in each age group — 20-29, 30-39, 40-49, 50-59 years.

Subjects were excluded if they had a history of trauma, pain and/or swelling of the thumb base or radiological evidence of any abnormality including osteo-arthrosis of the T-M1 joint. This group of 'medically normal' T-M1 joints was chosen to form a baseline for comparison with other groups.

6.22 Subjects with generalised hypermobility of peripheral joints

Subjects were required to score positively in three pairs of the following joint movements:

i) passive metacarpo-phalangeal (McP) joint extension of the little finger equal to or greater than 75°
ii) passive elbow hyper-extension greater than 10°
iii) passive knee hyper-extension greater than 10°
iv) passive ankle dorsi-flexion greater than 40°

While the visual assessment procedures of Beighton et al. (1973) now appear as the standard measurement system of peripheral joint hypermobility (Bird et al., 1979), the criteria used in the present study have been shown by Grant (1979) to be more stringent. She found that of 30 individuals scoring positively on the Beighton tests only 24 could be rated as exhibiting generalised peripheral joint hypermobility using the above criteria. Subjects were excluded if they were known cases of heritable disorders of connective tissue in which hypermobility was a feature, for example, the Ehlers-Danlos Syndrome or Marfan's Syndrome. Other than measuring the metacarpal index (Appendix X) no attempt was made to screen undiagnosed cases, either by skin elasticity or biochemical studies, these being well beyond the scope of this study.

6.23 Subjects with osteo-arthrosis of the T-M1 joint

Subjects were allocated to the osteo-arthrosis group if there was radiological evidence of degenerative changes at the T-M1 joint. Details of degenerative changes and their classification according to the degree of osteo-arthrosis are given in Table 4.2.

6.24 - 6.26 Occupational groups

The following three groups consist of people whose occupation are likely to stress the T-M1 joint leading to varying degrees of trauma. As well as presenting the criteria for selection into these groups, the possible cause of trauma is also described.

6.24 Manipulative therapists

For the purposes of this study manipulative therapists are defined as physiotherapists who use passive mobilising techniques, as described by Maitland (1977 a and b), in the treatment of vertebral and peripheral joint conditions.

The criteria for selection were:

i) the use of passive mobilising techniques for at least 80% of the time in the treatment of patients

ii) the use of these techniques for at least five years prior to this study.

The number of manipulative therapists in Australia who fulfil these requirements is limited, necessitating visits by the author to Sydney, Melbourne and Perth to examine 20 individuals. Had the requirement been use of these techniques for 10 years (in keeping with the requirement for selection into the other two occupational groups) the numbers would have been halved.

Passive mobilisation involves the imparting of small oscillatory movements to a joint using the thumbs.

Figure 6.1 Position of thumbs for passive mobilisation.

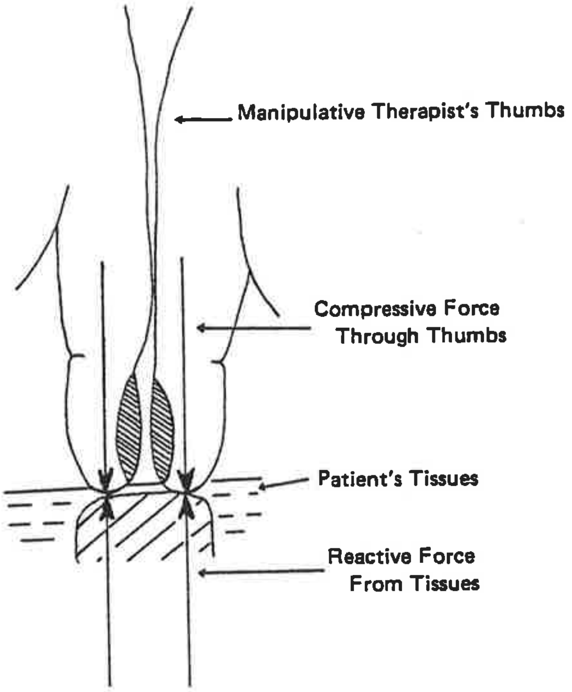


Figure 6.2 **Direction of forces during passive mobilisation.**

As can be seen in Figure 6.1 the thumbs are placed with the nails apposed, so that the thumb tips contact the bony surface, for example the spinous process of a vertebra. Pressure is exerted equally with both thumbs and may vary from very gentle pressure to firm pressures of up to 35 Kg. With each oscillation a reactive compressive force is imparted to the joints of the thumb (Figure 6.2).

6.25 Tailors and dressmakers

The criteria for selection into this group were:

i) tailors and dressmakers who do most of their sewing and cutting of material by hand (rather than by machine).

ii) tailors and dressmakers who had been engaged in their occupation full-time for at least 10 years prior to this study.

Those who had used their thumbs for a cumulative period of more than two years at a variety of other activities were excluded. Details of such activities are given on page 82.

Tailors and dressmakers may traumatise their thumbs in two ways. As illustrated in Figures 6.3 and 6.4, these are during repeated strong opposition occasioned by using large scissors to cut heavy material and during long periods of hand sewing with a needle and thread.

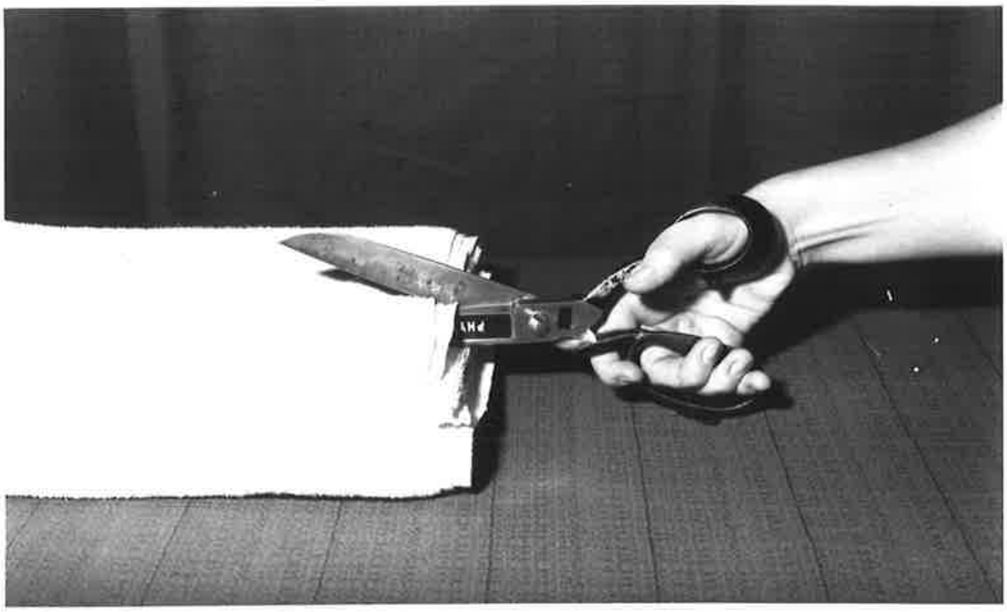


Figure 6.3 Thumb opposition during cutting with scissors.

6.26 Musicians — string instrument players

The criterion for selection into this group was that the musicians had played a violin, viola or 'cello for a cumulative period of 10 years prior to this study.

Those who had used their thumbs for an aggregate of more than two years at other activities were excluded. Details of such activities are given on page 82.

The T-M1 joints of violinists, 'cellists and viola players were examined because both thumbs are held statically for long periods. The right hand, in controlling very fine movements of the bow, holds the bow between the thumb and middle finger as the fulcrum with counter-pressure between the index on one side and the ring and little finger on the other (Figure 6.5).

The left thumb mostly acts as counter-pressure against the neck of the instrument while the fingers depress the strings (Figure 6.6). In playing the 'cello, the thumb is also used to depress the strings.

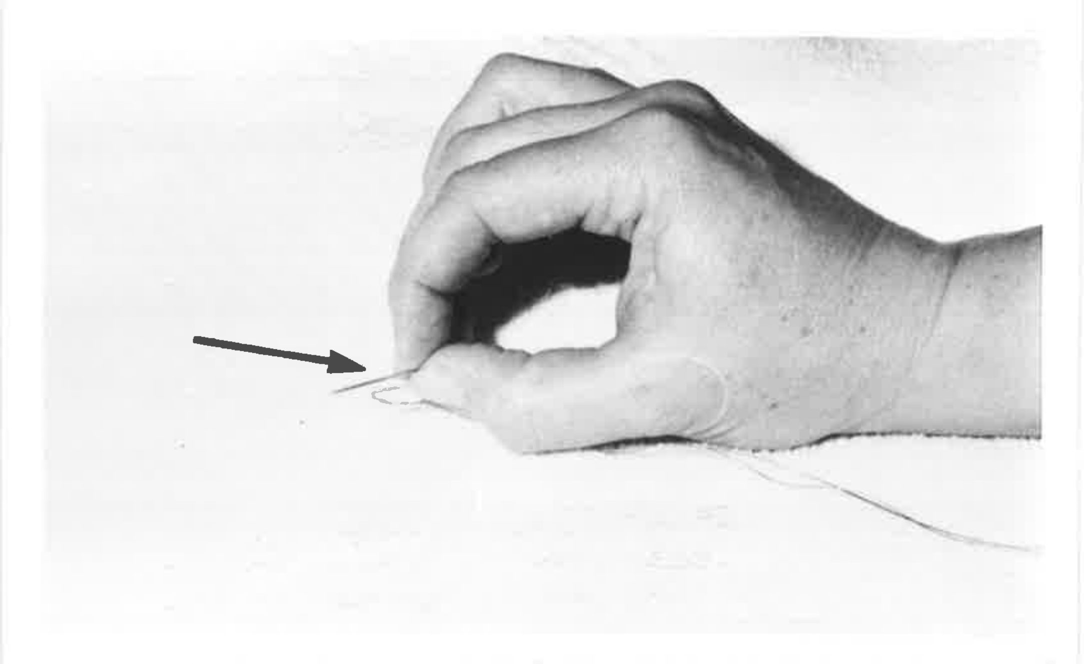


Figure 6.4 Sustained pressure between thumb and index finger during sewing with a needle and thread.

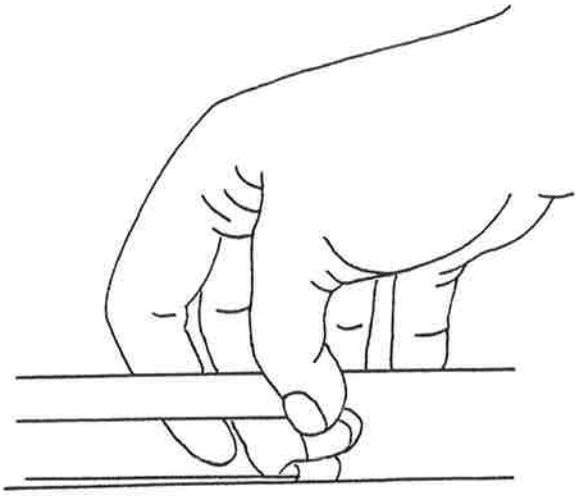


Figure 6.5 Position of right thumb in holding the bow.

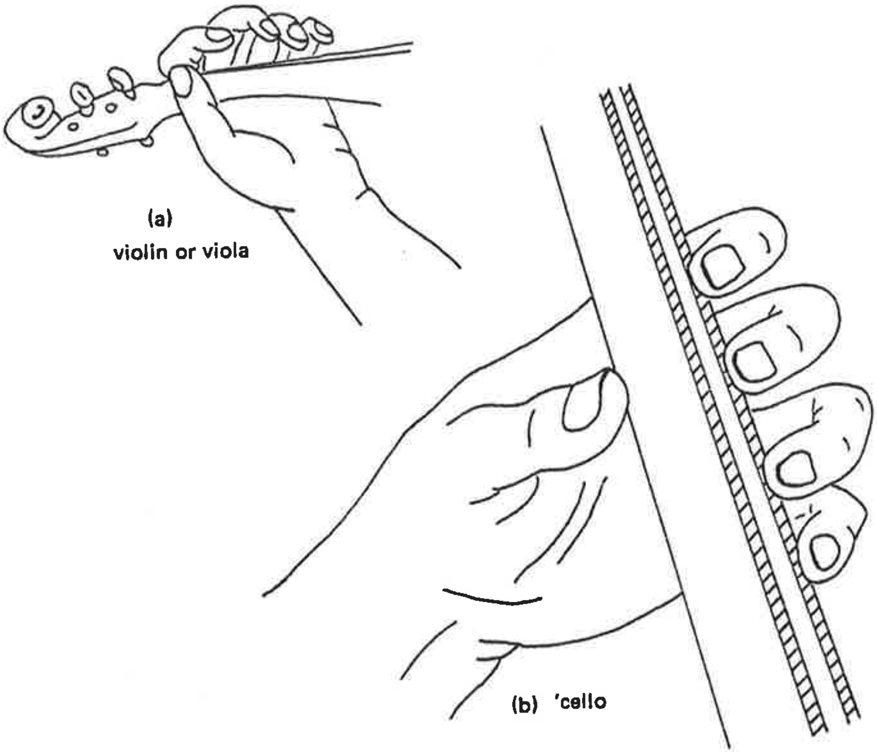


Figure 6.6 Position of left thumb in holding the neck of a violin, viola or 'cello.

6.3 Method

6.31 Introduction

Both thumbs of each subject were examined. The examination procedure consisted of:

- questionnaire (6.32)
- clinical examination
  - a) general (5 tests) (6.33)
  - b) T-M1 joint (6.34)
    - i) thickening or bony enlargement (1 test)
    - ii) passive physiological movements (3 tests)
    - iii) passive accessory movements (7 tests)
  - c) joints adjacent to the T-M1 joint (6.35)
    - i) trapezio-second metacarpal (T-M2) joint (2 tests)
    - ii) trapezio-trapezoid (T-T) joint (2 tests)
    - iii) trapezio-scaphoid (T-Sc) joint (2 tests)
    - iv) first metacarpo-phalangeal (McP) joint (2 tests)
  - d) generalised peripheral joint mobility (8 tests) (6.36)

- radiological examination (6.37)
  - a) normality of the T-M1 joint
  - b) range of physiological movements of the T-M1 joint
  - c) instability of the T-M1 joint
  - d) osteo-arthrosis of the T-M1 and adjacent joints
  - e) osteopenia

Except where information was required to either exclude an individual from the study or to fulfil the criteria for selection into groups, the questionnaire was completed following the clinical examination. This was done in order to avoid possible bias of the findings on the clinical examination from a knowledge of age, dominance and use of the thumbs.

Radiological examination was always the final procedure (again to avoid possible bias from a knowledge of the X-ray findings). Thus it was not until this stage that selection was made into the non-clinical and osteo-arthrotic groups.

6.32 Questionnaire

A copy of the questionnaire is included in Appendix XI. It included the following:

a) **Age**

Age to the nearest year was recorded following which the individual was allocated to one of the following groups — 20-29 years, 30-39, 40-49, 50-59 years.

b) **Gender**

The individual's gender was recorded.

c) **Side**

As both thumbs were examined for each subject, the side (left or right) was recorded.

d) **Dominance**

Dominance was categorised as left-handed, right-handed or ambidextrous.

e) **Use of the thumb**

Activities which involved the thumb in firm gripping were included as relevant use of the T-M1 joint. These included occupations in which a tool was grasped and recreational activities holding firmly the handle of a racquet, bat or stick.

As many of these activities involved only the dominant hand, use of the thumb was recorded for each side separately. Thumb use was expressed in number of years and categorised as 0-5 years, 6-10, 11-15, 16-20, more than 20 years.

f) **History of trauma to the thumb base**

Note was made of direct injury to the base of the thumb and thenar eminence, but injury distal to the metacarpo-phalangeal joint was not included.

g) **History of pain at the thumb base**

A history of pain in the T-M1 joint was recorded and the subject was asked whether the pain was related to use of the thumb. A history of pain around the metacarpo-phalangeal or inter-phalangeal joints of the thumb was not included.

h) **Menstrual status**

The menstrual status of all female subjects was classified as normal (regular), menopausal or post-menopausal/post-hysterectomy. For the last category, the number of years they had been post menopausal, or since their surgery, was recorded.

6.33 - 6.37 Clinical Examination

The findings of the clinical examination were recorded on a coded data sheet suitable for computer analysis. A copy of this is included in Appendix XI.

6.33 Clinical examination — general

i) **Height**

Height was measured to the nearest 0.5 cm with the individual standing in bare or stockinged feet.

ii) **Weight**

Weight was recorded to the nearest 0.5 kg after shoes and bulky clothing were removed.

iii) **Body build**

Body build was assessed as small, medium or large frame.

iv) **Obesity**

An individual was classed as normal or obese using the tables developed by the Metropolitan Life Insurance Company (1977) which take into account an individual's body build, age, height and weight.

v) **Skin thickness**

Using the same method as that described for the autopsy specimens (page 29) the thickness of skin over the dorsum of the fourth metacarpal was measured. The mean of three recordings was taken.

The tests used in the remainder of the clinical examination were carried out on 20 subjects to standardise testing procedures.

6.34 Clinical examination — T-M1 joint

i) **Thickening and/or bony enlargement of the T-M1 joint**

The T-M1 joint was palpated for any thickening of the peri-articular tissues (capsule and ligaments) and/or bony enlargement. These palpation findings were recorded as being present or absent.

ii) **Physiological movements of the T-M1 joint**

The **ranges** of physiological movements of the T-M1 joint were measured from radiographs as this has been shown to be one of the most accurate methods of measurement of joint range (Edholm, 1965).

To reduce the extent of exposure of the hands to radiation only three physiological movements were examined. These movements — extension, palmar abduction and opposition of the thumb to the base of the little finger — were chosen as they were considered to be the most important for hand (thumb) function. The relationship of these movements to the plane of the second and third metacarpals is illustrated in Figure 6.7.

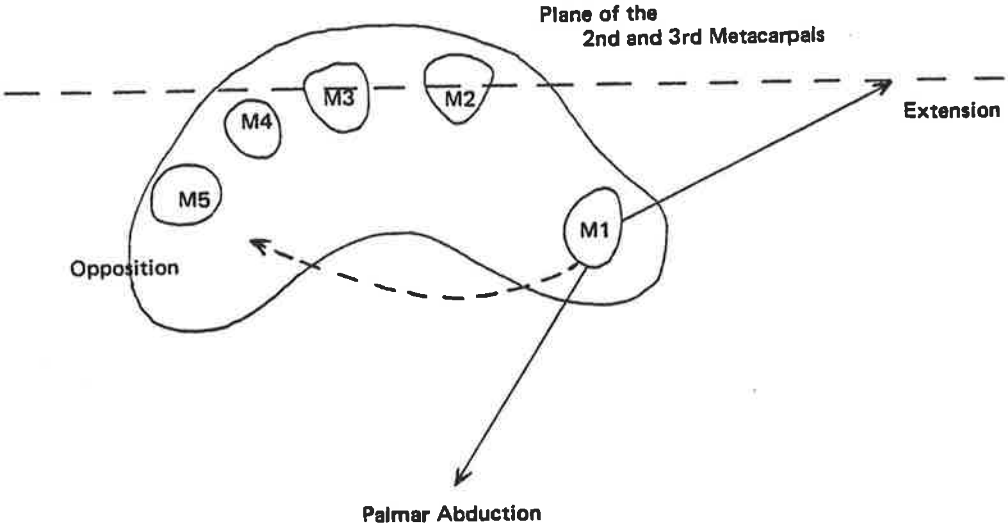
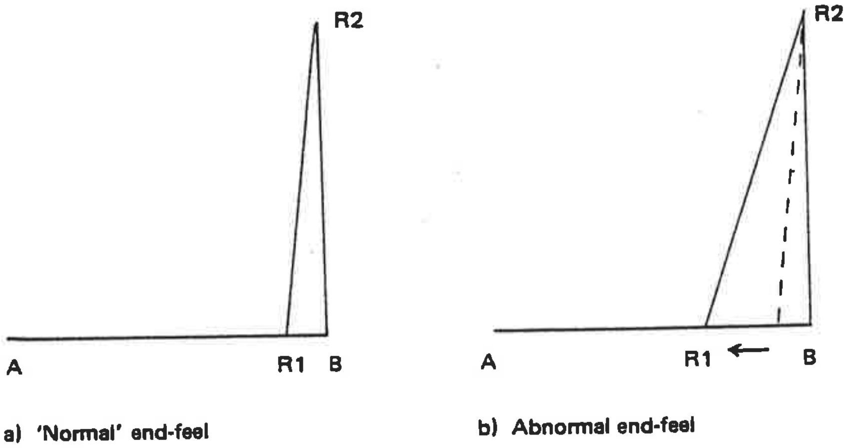


Figure 6.7 Right T-M1 joint – physiological movement tests.
Movements of M1 relative to the plane of the second and third metacarpals.



a) 'Normal' end-feel

b) Abnormal end-feel

Figure 6.8 Diagrammatic representation of 'end-feel' of passive movement.

Note: AB = any passive movement; A = starting point, and B = end of range in a 'normal' joint. R1 = position at which stiffness is first felt and R2 = point of maximal stiffness.

For each movement test the subject's position was standardised (see page 100 for a detailed description of these positions, under Radiological Assessment).

In addition to the radiological measurement of range, each of these physiological movements was clinically examined for:

a) **production of discomfort/pain localised to the T-M1 joint**
   This was recorded as:
   1) none (if the movement produced no discomfort when passively stretched to full range) or
   2) discomfort/pain.
   No attempt was made to quantify this pain or discomfort.

b) **the quality of the movement**
   1) the presence of **crepitus** in the T-M1 joint during the particular movement test, and
   2) **the 'end-feel' of the movement.** Normally these three passive physiological movements feel 'free' or 'loose' until the last few degrees of range, when slight stiffness is perceived as the ligaments and capsule are placed on stretch. This stiffness increases to a maximum when these structures prevent further motion.

As first described by Hickling and Maitland (1970), the 'end-feel' of a movement can be portrayed diagrammatically by a horizontal line AB representing any passive movement, where A is the starting point and B is the end of range in a 'normal' joint. Stiffness (resistance to movement) can be recorded by a line R1 – R2 where R1 represents the point in the range where resistance is first felt and R2 is the maximum intensity, that is, the point where resistance prevents further passive motion (Figure 6.8).

From clinical experience the author has often noted an abnormal 'end-feel' to certain movements in pathological joints. This abnormality can be expressed as the presence of stiffness (or resistance earlier in the range). This is depicted in Figure 6.8b where R1 is nearer to A.

Thus for each movement test the 'end-feel' was classified as:

(1) 'normal', or
(2) resistance early in the range

In T-M1 joints with a 'normal' range of extension and palmar-abduction, the limiting factor to these movements is the web between the thumb and index finger. Therefore, in order to appreciate the 'end-feel' of these movements at the T-M1 joint (and not simply stretch of the web) the trapezium was held between the thumb and index finger of one hand while the thumb and index of the other hand held M1. 'End-feel' is best perceived by oscillatory movements up to the end of the range, rather than one slow movement (Maitland, 1977a, page 344). With each oscillation of M1 the index finger was permitted to follow the movement, thus avoiding tension in the web.

iii) Accessory movements of the T-M1 joint

As defined earlier, accessory movements are not under voluntary control and can be produced only passively. These movements of one bone on another occur concomitantly with active and passive physiological movements and indeed they are essential for normal functioning of these movements.

During movements of the thumb, the trapezium is relatively fixed and the metacarpal is the moving component of the T-M1 joint. For this reason for each of the seven passive accessory movement tests used in this study, the trapezium was stabilised while M1 was moved in relation to it by holding M1 close to its proximal end, that is, adjacent to the T-M1 joint. In this way movements were localised to the T-M1 joint.

With each test, the T-M1 joint was held in a neutral position between all of its ranges of movement so that its capsule and ligaments were not put on tension. This permitted a maximal range of passive accessory movement in any desired direction. Care was taken not to compress the joint surfaces as this would restrict the range of movement. In addition, because several tendons span the T-M1 and its adjacent joints, the wrist and the first metacarpo-phalangeal joint were placed in a neutral position so that those tendons were not taut and therefore limiting the range of movement. Each movement test was performed as much as possible as a **pure** movement, not allowing other movements to occur simultaneously; for example, with antero-posterior gliding the metacarpal was not permitted to rotate.

The actual range of movement cannot be assessed in degrees. An ordinal scale of five grades was used. These were 'hyper-mobile', 'normal', 'slightly stiff', 'very stiff' and 'no movement'. To assist in quantifying such small ranges of movement, the test movement was performed as an oscillation using the arms rather than the fingers and thumbs. Reliability tests for this method of measurement were performed, the results of which appear on page 110.

As with the passive physiological movement tests, the quality of the movements and the production of any discomfort/pain were recorded.

The seven passive accessory movements tested for each T-M1 joint were distraction, postero-anterior and antero-posterior gliding, medial and lateral gliding and medial and lateral rotation. The direction of these movements in relation to the plane of the second and third metacarpals is shown in Figure 6.9.

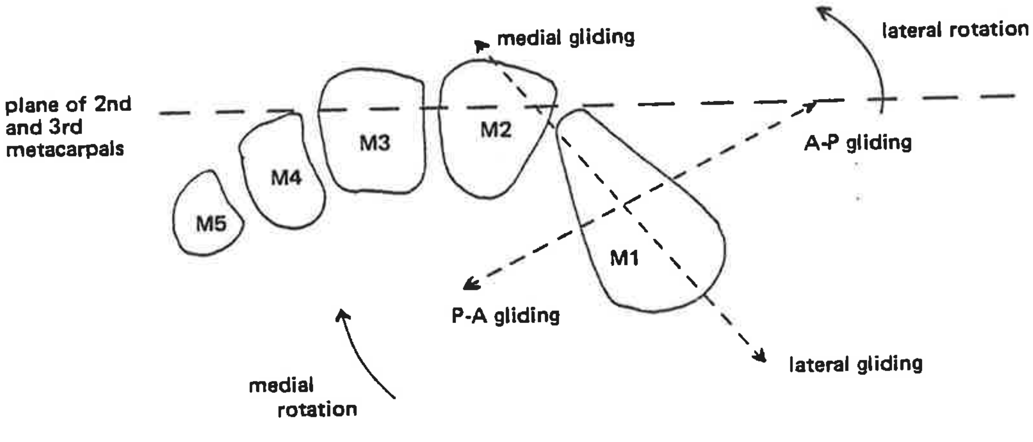


Figure 6.9 **Direction of passive accessory movements for the right hand.**
medial = medial gliding; med. rotn. = medial rotation; P-A = postero-anterior gliding; lateral = lateral gliding; lat. rotn. = lateral rotation; A-P = antero-posterior gliding.

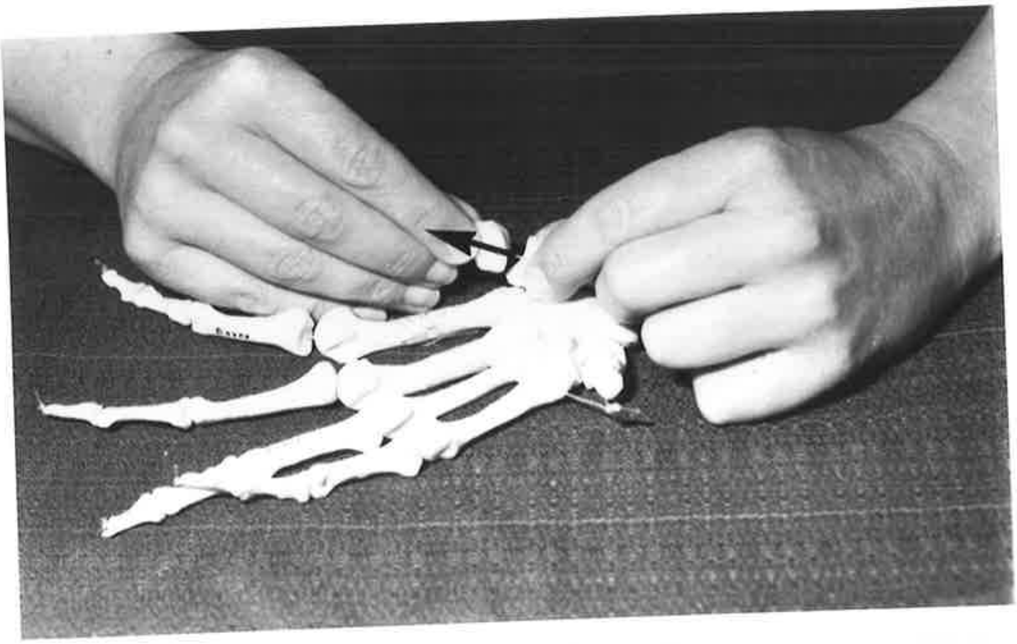
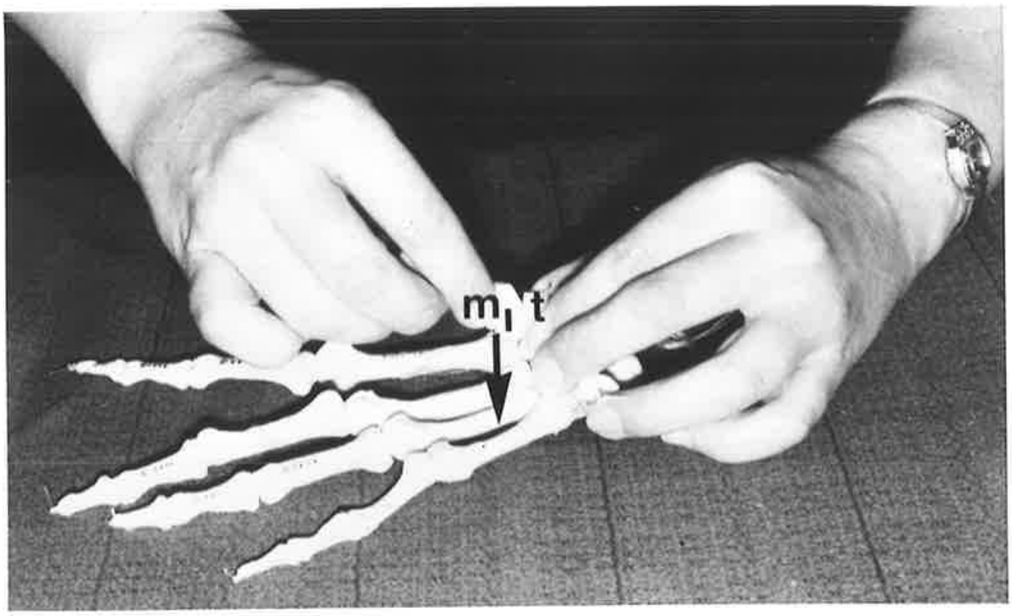


Figure 6.10 Right T-M1 joint – distraction.



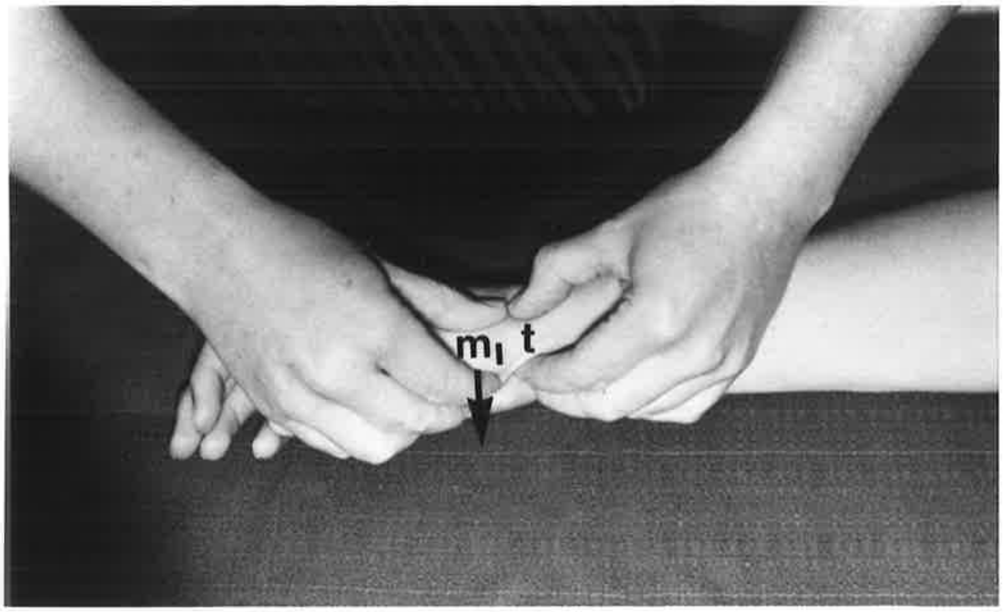


Figure 6.11 **Right T-M1 joint — postero-anterior gliding.**

A description of each passive accessory movement for the right T-M1 joint follows.

Distraction

Starting position: The examiner's left hand was placed around the lateral border of the subject's wrist so that the trapezium was securely grasped between the pads of the thumb and index finger. The subject's M1 was held at its proximal end, adjacent to the T-M1 joint, by the examiner's right thumb and index finger. The rest of the thumb was comfortably supported in the loosely flexed fingers of the examiner's right hand. Thus the examiner's two thumb pads were on the dorsal aspect and the two index fingers on the anterior aspect of the trapezium and M1 (Figure 6.10).

Method: The T-M1 joint was positioned in a neutral position. Distraction of M1 was produced by abducting the examiner's right shoulder. Small oscillatory distraction movements were produced along the long axis of M1.

Postero-anterior and antero-posterior gliding

Starting position: As for distraction (Figure 6.11).

Method: M1 was glided along the trapezial 'groove'.

a) **postero-anterior gliding**
From the neutral position, the M1 was passively glided in an anterior direction with pressure exerted through the examiner's right thumb, and then M1 was returned to the neutral position again, using pressure through the examiner's right index finger.

b) **antero-posterior gliding** was effected by gliding M1 posteriorly by pressure on the anterior aspect of M1 with the examiner's right index finger. The right thumb returned M1 to the neutral position.

Small oscillatory movements were performed firstly in one direction and then in the other. The movement was performed by extending and flexing the examiner's right elbow and not by pressure with the thumb and index finger. Care was taken to avoid angulating the movement by allowing the thumb to flex or extend.

Medial and lateral gliding

Starting position: As for distraction except that the trapezium and M1 were held on the *medial* aspect by the pads of the thumbs, and on the *lateral* aspect by the pads of the index fingers (Figure 6.12).

Method: M1 was glided along the 'ridge' of the trapezium. Medial gliding was effected by extending the examiner's right elbow so that pressure was exerted through the index finger. Similarly, with right elbow flexion pressure was produced with the thumb pad on the medial aspect of M1, the subject's M1 causing it to glide laterally. Small oscillatory movements were performed firstly in one direction and then in the other and again care was taken to avoid angulation of the gliding movement by permitting the thumb to adduct or abduct.

Medial and lateral rotation

Starting position: The trapezium was stabilised as described for medial and lateral gliding. The distal end of the subject's M1 was held on its medial and lateral aspects by the right thumb and index finger respectively. The metacarpo-phalangeal joint was held in approximately 20° of flexion by pressure on the dorsal aspect of the proximal phalanx with the examiner's right ring and little fingers (Figure 6.13).

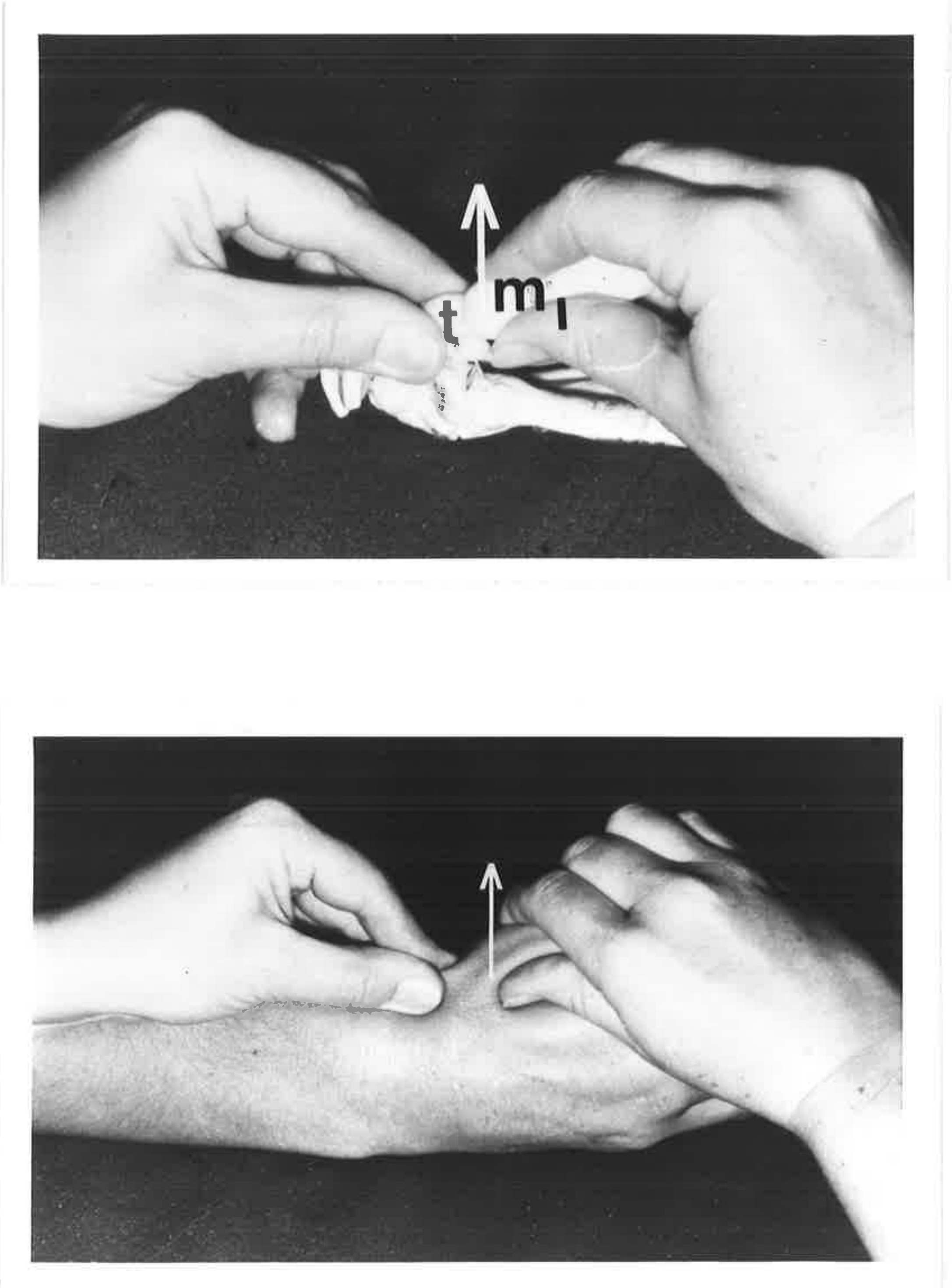


Figure 6.12 Right T.M1 joint – lateral gliding.

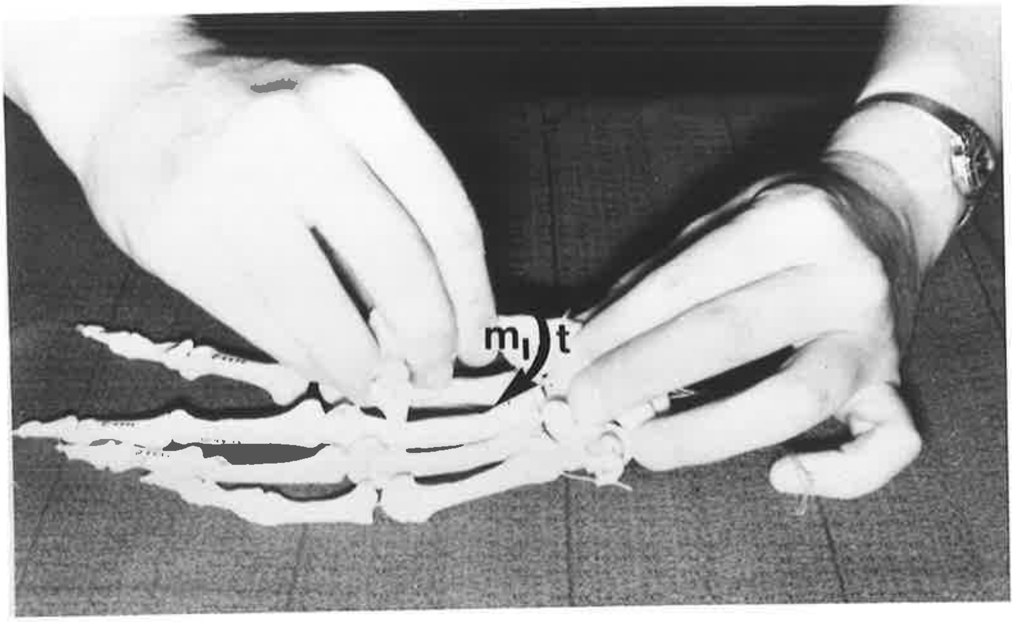


Figure 6.13 Right T-M1 joint – medial rotation.

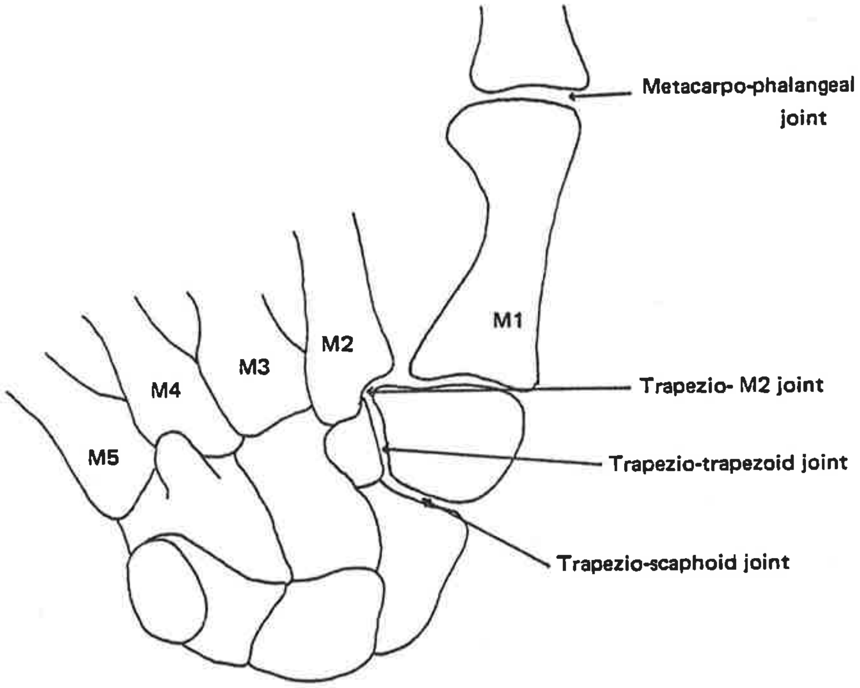


Figure 6.14 Anterior aspect of right hand showing joints adjacent to T-M1 joint.

Method: Supinating the examiner's forearm effects medial rotation of M1 (through holding the distal end of M1). Added effectiveness was gained by pressure of the examiner's middle finger against the medial aspect of the proximal phalanx. Similarly, pronating the forearm effects lateral rotation of M1, enhanced rotation resulting from pressure with the ring finger against the lateral aspect of the distal phalanx. The first metacarpal was oscillated from the neutral position to medial rotation and then from neutral to lateral rotation.

6.35 Clinical examination – joints adjacent to the T-M1 joint

Adjacent joint mobility was examined as this may affect the mobility of the T-M1 joint. For instance, stiffness in the metacarpo-phalangeal joint may result in the T-M1 joint becoming more mobile.

The joints adjacent to the T-M1 joint are the trapezio-scaphoid, trapezio-trapezoid, trapezio-second metacarpal and the metacarpo-phalangeal joint of the thumb (Figure 6.14).

The mobility of the articulations with the trapezium were tested by passive accessory movements of antero-posterior and postero-anterior gliding and recorded as 'normal' or 'stiff'. The passive physiological movements of flexion and extension were examined for the metacarpo-phalangeal joint and recorded in degrees. These are described for the right hand as follows:

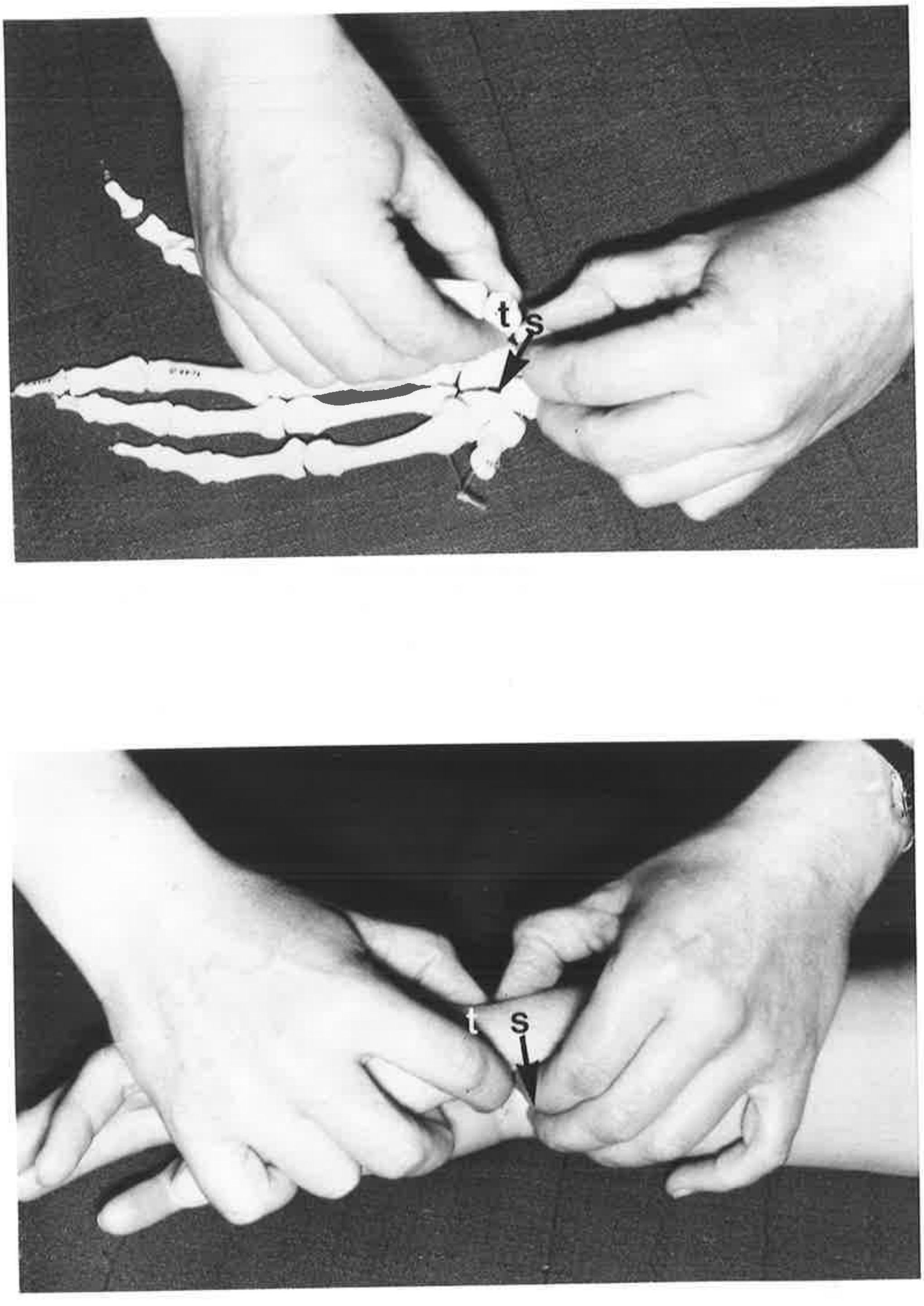


Figure 6.15 Postero-anterior gliding of right trapezio-scaphoid joint.

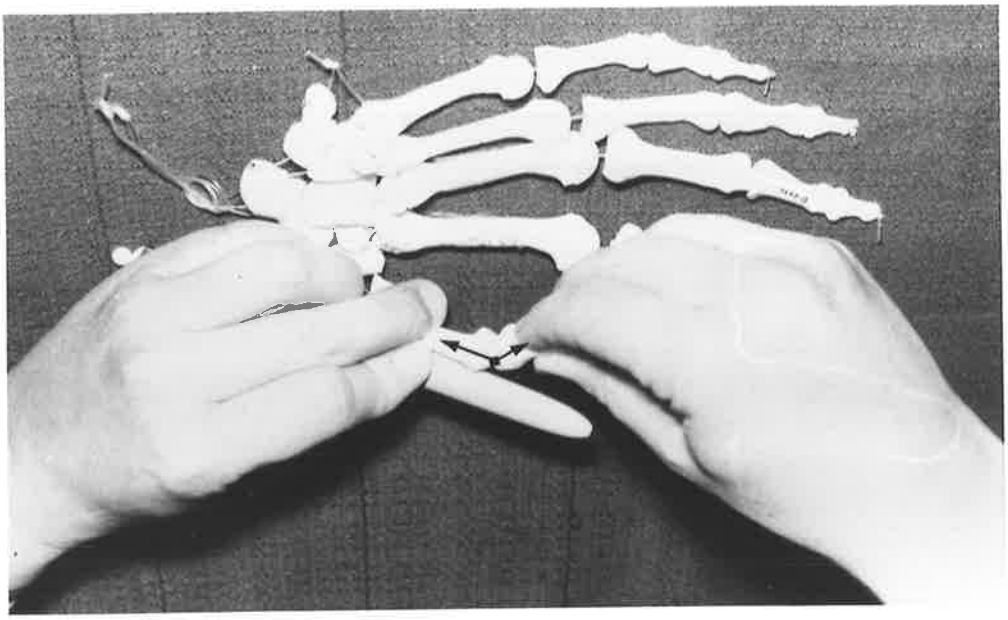


Figure 6.16 **Passive flexion of metacarpo-phalangeal joint of right thumb.**

Note: pen (parallel to metacarpal shaft) used to assist assessment of angle of flexion (between metacarpal and proximal phalanx).

i) Accessory movements of the trapezio-scaphoid, trapezio-trapezoid and trapezio-second metacarpal joints

Antero-posterior and postero-anterior gliding

Starting position: With the subject's hand facing palm downwards, the trapezium was firmly grasped between the pads of the examiner's right thumb and index finger. The subject's scaphoid was held in a pincer grip between the tips of the left thumb and index finger (placed on the dorsal and palmar aspects respectively). It was necessary to use the tips, rather than the pads, to enable the movement to be isolated to one small carpal bone (Figure 6.15). In turn, the scaphoid, trapezoid and then the base of the second metacarpal were 'pinched' in order to isolate movement between these bones and the trapezium.

Method: The right hand stabilised the subject's trapezium while the left thumb and index finger oscillated the subject's scaphoid (trapezoid or second metacarpal) in an anterior and then a posterior direction.

ii) Physiological movements of the first metacarpo-phalangeal joint

Passive flexion and extension

Starting position: With the subject's right hand facing palm upwards, the M1 was stabilised between the pads of the examiner's left thumb and index finger while the right thumb and index finger held around the subject's proximal phalanx.

Method: Using the right hand, the examiner passively flexed, and then extended, the metacarpo-phalangeal joint and noted the angle subtended between the shafts of M1 and the proximal phalanx (Figure 6.16).

6.36 Clinical examination — tests for generalised peripheral joint hypermobility

As enumerated on page 76, the four peripheral movement tests utilised in this study were all performed bilaterally as passive tests and were carried out on all individuals. Each subject's mobility was assessed as 'normal' mobility or hypermobile (according to the criteria set out on page 76). The four tests will now be described in detail.

i) Passive extension of the metacarpo-phalangeal joint of the little finger (5th McP extension)

As illustrated in Figure 6.17 the subject's forearm and hand were placed flat on the table with the palm downwards. The metacarpal of the little finger was held firmly against the table by the examiner's left hand whilst the McP joint was passively extended by the examiner's other hand applying pressure through the lateral and medial aspects of the intermediate phalanx. The inter-phalangeal joints were permitted to flex to avoid tension in the flexor tendon. The angle between the metacarpal and proximal phalanx was measured by visual assessment.

ii) Passive hyper-extension of the elbow

Hyper-extension is extension beyond a straight line (180°) between the arm and the forearm. Hyper-extension was measured in sitting, with the subject taking comfortable weight through the right arm. The arm was positioned with the shoulder laterally rotated,

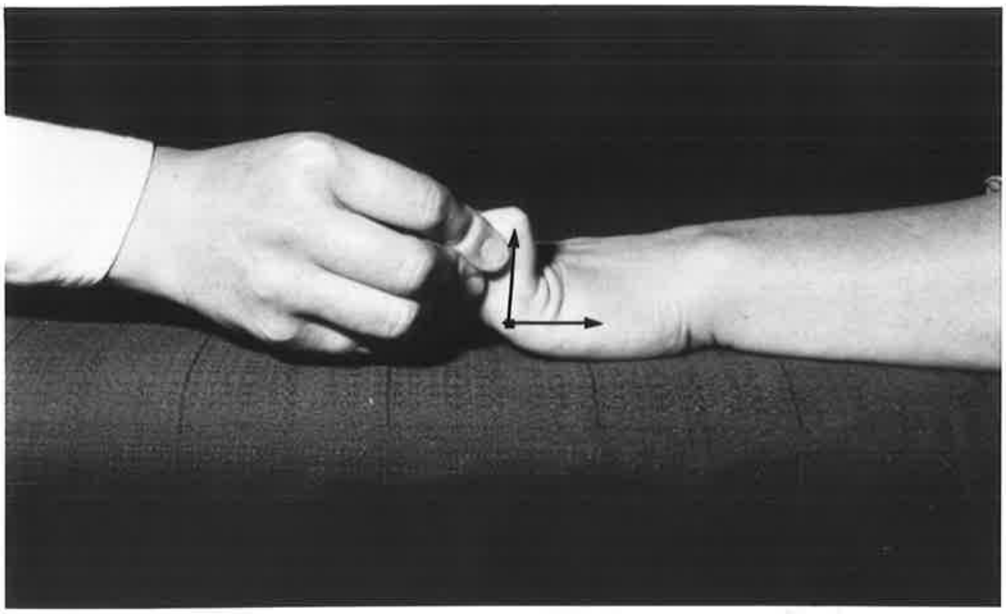


Figure 6.17 Measurement of passive extension of the left metacarpo-phalangeal joint of the little finger.
Note: i) hypermobility of the 5th McP joint
ii) for clarity the examiner's stabilizing hand is not included in the photograph

forearm supinated 90° (care being taken to prevent further supination which would allow the elbow to twist into 'the carrying angle') and the hand flat on the table (palm downwards and fingers facing posteriorly). If the subject lacked wrist extension, a small pad was placed under the heel of the hand.

The subject was asked to permit the elbow to sag into full hyper-extension while the angle was measured with a standard Zimmer goniometer centred over the lateral aspect of the head of the radius. The bony prominences used for alignment of the goniometer were the styloid process of the radius distally and midway along the lateral aspect of the acromion proximally (Figure 6.18).

iii) Passive hyper-extension of the knee

As with the elbow, extension beyond a straight line (between the thigh and the lower leg) is described as hyper-extension. This was measured with the subject standing bare-footed and weight-bearing through the leg. The subject was asked to allow the knee to sag into full hyper-extension. The landmarks used for goniometric measurement were the greater trochanter of the femur proximally, the lateral ligament of the knee joint, over which the goniometer was centred, and the lateral malleolus distally (Figure 6.19).

Figure 6.18 Measurement of passive hyper-extension of the left elbow.
Note hypermobility of the elbow.

iv) Passive dorsi-flexion of the ankle

Dorsi-flexion is measured by the angle between the shin and the sole of the foot.

Dorsi-flexion was measured with the subject standing bare-foot and weight-bearing through the foot. A 'Myrin' goniometer was strapped over the head of the fibula. Using a set-square, the head of the fibula was placed vertically above the lateral malleolus and the pendular needle of the goniometer set at zero. The subject was then asked to lunge forward, with the knee flexed, into full dorsi-flexion, keeping the heel flat on the floor (Figure 6.20 a & b).

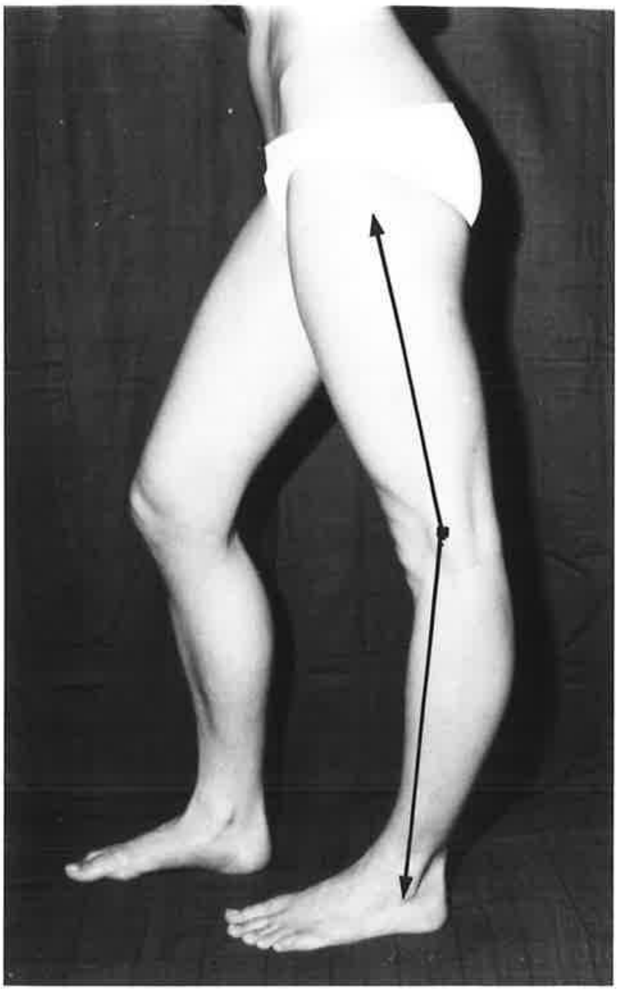


Figure 6.19 Measurement of passive hyper-extension of the left knee.

Note hypermobility of knee.

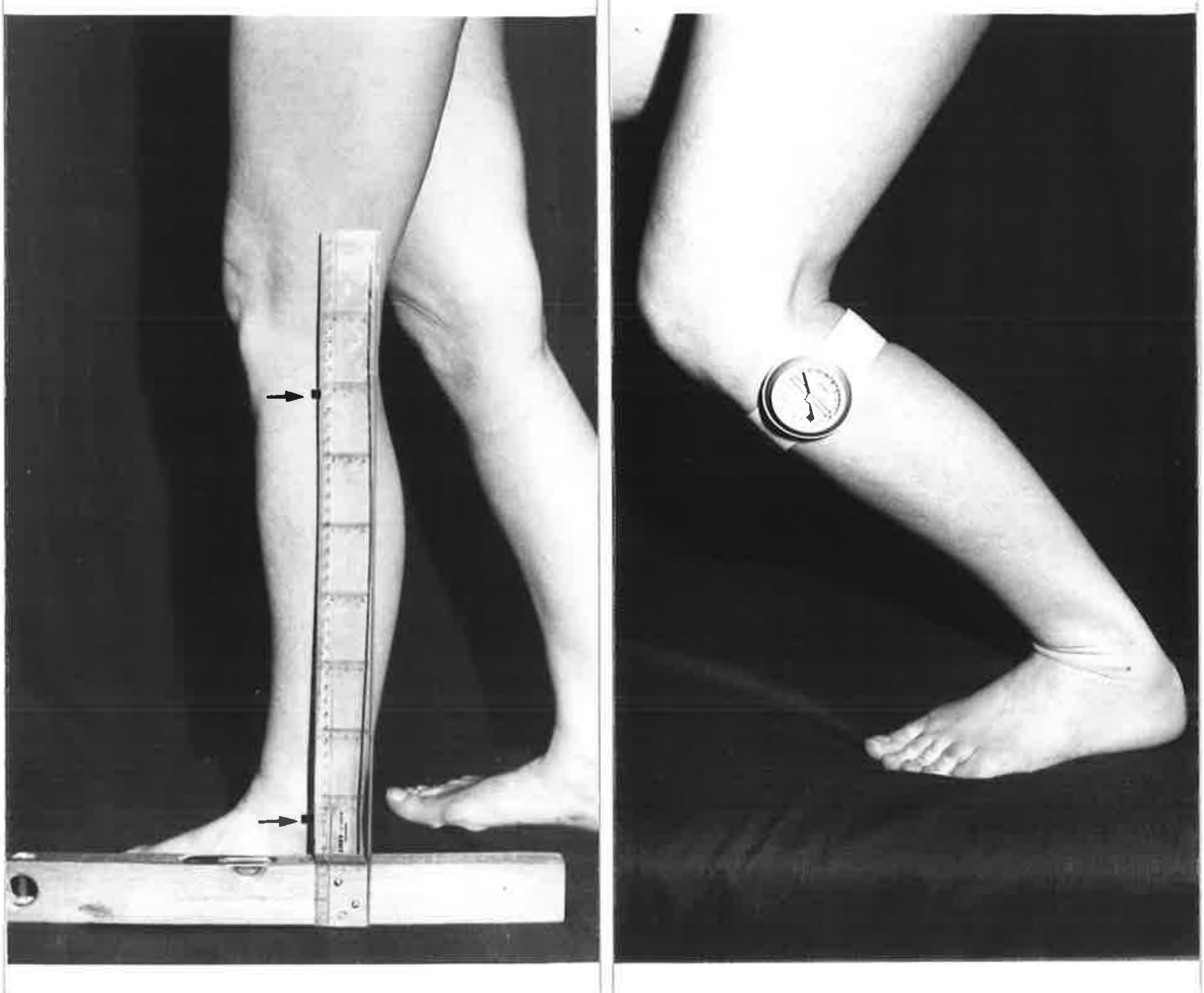


Figure 6.20 a & b Measurement of passive dorsi-flexion of the left ankle.

Note (a) set square alignment of lateral malleolus and head of fibula
(b) hypermobility of ankle. In this case, 40° on the 'Myrin' goniometer.

6.37 Radiological assessment

Radiological assessment included:

a) normality of the T-M1 joint
b) range of physiological movements
c) dorso-lateral instability
d) presence of osteo-arthrosis
e) presence of osteopenia

As discussed in the literature review many authors consider the incidence of osteo-arthrosis of the T-M1 joint to be highest in post-menopausal women, also that the post-menopause and post-hysterectomy states are linked with osteo-porosis and osteopenia. For all women in this study details were recorded of their menstrual status and the presence of osteo-arthrosis, and for those aged 40 years and over bone quantity calculation was made (by commencing at 40 years of age the author considered that it would include all cases of bone loss as Exton-Smith et al. (1969) showed that there is a normal loss in the quantity of bone after the age of 45 years).

To avoid possible bias, the radiological assessment always followed the clinical assessment.

(a) Normality of the T-M1 joint

The postero-anterior and lateral radiographs were examined for any abnormalities of the T-M1 joint such as congenital deformity, rheumatoid or osteo-arthrosis. The presence of congenital deformity or of rheumatoid arthritis excluded the individual from the study. The presence of osteo-arthrosis is discussed on page 38.

b) Measurement of physiological movement of the T-M1 joint

Radiographs were taken of the thumb in the physiological positions of extension, palmar-abduction and opposition.

As seen in Figure 6.21, special apparatus was designed to standardise the position of the subject's forearm and hand in relation to the X-ray tube and film.

The apparatus consisted of a wooden base, to support the forearm and wrist, and a mobile support for the fingers. The perspex support could be rotated on a central pivot through 90^{o} to the left and right to alter the position of the hand (T-M1 joint) relative to the film, (placed immediately under the hand, but on top of the wooden base) and to the vertically placed X-ray tube.

For radiological measurement of palmar-abduction and opposition it was necessary to stabilise the subject's wrist and palm in an isoprene splint with straps around the forearm, wrist and palm as illustrated in Figures 6.24 and 6.26. This stabilised the carpus and metacarpal of the index finger while the thumb was actively moved into the test position.

All X-rays were taken with a focal film distance of 100 cm and an exposure time of 100 mA/sec.

Details of the positioning of the thumb relative to the second and third metacarpals are described below. Originally it was planned to measure the **passive** range of extension, palmar-abduction and opposition but this was unwise due to excessive radiation of the author's hands. Instead, the **active** range was taken with encouragement to the subject to fully stretch the thumb in the desired direction.

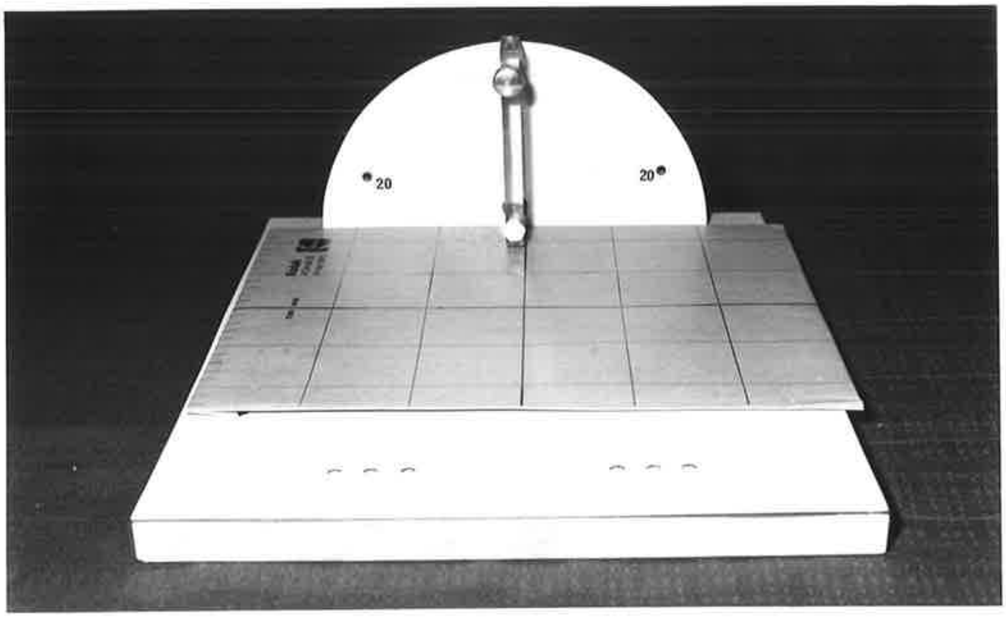


Figure 6.21 Apparatus used in radiographic measurement of movement at the T-M1 joint.

Figure 6.22 Position of right hand for radiographic measurement of extension.

Figure 6.23 **Postero-anterior view of right T-M1 joint showing radiographic measurement of extension.** Note range of extension = angle between long axes of M1 and M2.

i) **Extension**

The subject's forearm was pronated and hand placed palm downwards on the X-ray film. The subject was asked to actively extend the thumb away from the index finger, that is, in line with the metacarpals of the fingers (Figure 6.22). This permitted a postero-anterior view of the T-M1 joint (Figure 6.23).

ii) **Palmar abduction**

The subject's wrist and palm were stabilised in the isoprene splint. The fingers were supported against the vertically positioned perspex support and the forearm stabilised on the wooden base between 2 metal pegs so that the forearm was in mid-position between pronation and supination (Figure 6.24). The thumb (T-M1 joint) was actively abducted at right angles to the plane of the palm. This permitted a lateral view of the T-M1 joint (Figure 6.25).

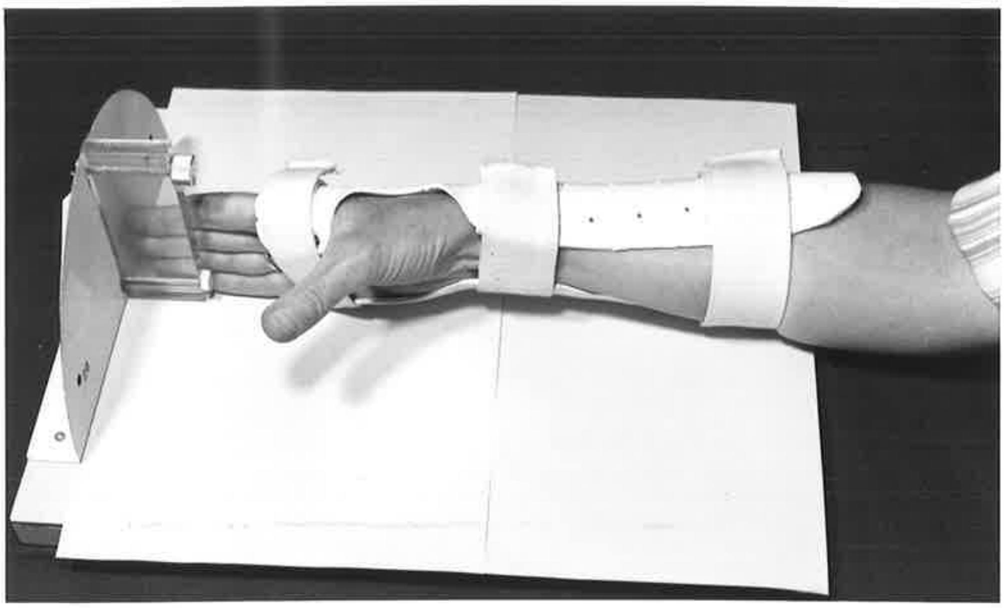


Figure 6.24 Position of right hand for radiographic measurement of palmar-abduction.

iii) **Opposition**

The subject's wrist and palm were stabilised in the isoprene splint. The fingers were supported against the perspex support which was adjusted to position the forearm and hand in 70° of medial rotation. The thumb tip was actively opposed towards the base of the little finger (Figures 6.26 and 6.27).

The range of physiological movement was obtained by measurement of the angle between the long axes of the metacarpals of the thumb and index finger on the radiographs.

(c) **Dorso-lateral instability**

A postero-anterior 'stress' X-ray was taken of both hands to note any dorso-lateral instability (subluxation) of the T-M1 joint. Following the method described by Eaton and Littler (1973) the subject's forearms were pronated and hands placed with palms facing downwards, flat on the X-ray film. With the thumbs extended approximately 45°, the subject was asked to firmly press the thumb nails together. An experienced radiologist examined the radiograph for the presence of dorso-lateral subluxation.

Figure 6.25 **Lateral view of right T-M1 joint showing radiographic measurement of palmar-abduction.**
Note range of palmar abduction = angle between long axes of M1 and M2.

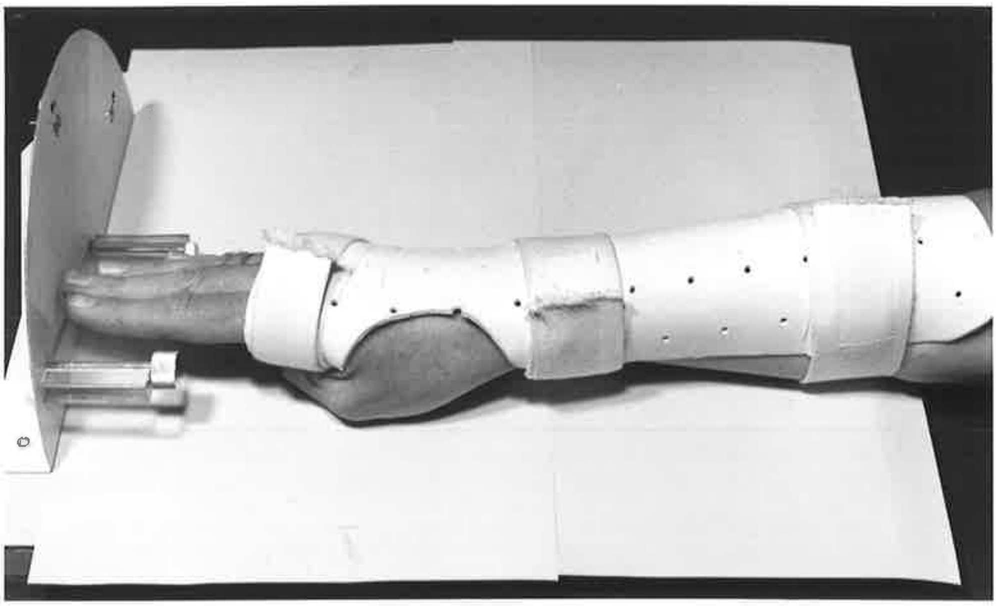


Figure 6.26 Position of right hand for radiographic measurement of opposition.

Figure 6.27 Right T-M1 joint — radiographic measurement of opposition.

Note range of opposition = angle between long axes of M1 and M2. No attempt was made to measure the components of opposition.

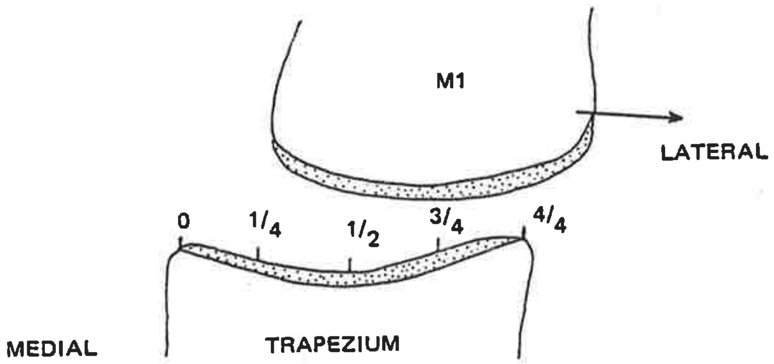


Figure 6.28 **Diagrammatic representation of dorso-lateral subluxation of right T-M1 joint. Note mild subluxation of M1.**

As depicted in Figure 6.28, the trapezial articular surface was divided into quarters in a medio/lateral direction and the degree of subluxation was graded as:

0 – ¼ = normal
¼ – ½ = mild subluxation
½ – ¾ = moderate subluxation
¾ – 4/4 = marked subluxation
\> 4/4 = dislocation

d) **Presence of osteo-arthrosis**

The postero-anterior and lateral X-ray views were examined for the presence of degenerative changes in the articulations of the trapezium with the first and second metacarpals, the trapezoid and the scaphoid and in the metacarpo-phalangeal joint of the thumb. The site and degree of degenerative changes were recorded, the latter being classified as mild, moderate or marked (Table 4.2).

All assessments of osteo-arthritic changes were made by the same experienced radiologist.

e) **Presence of osteopenia**

The quantity of bone was calculated using the method described by Exton-Smith et al. (1969) as it gave a better correlation ($r = 0.85$) with ash content than other indices of bone quantity described by Garn et al. (1964, 1967) and Newton-John and Morgan (1968).

Measurements were made from the postero-anterior radiographs of the metacarpal bones of the index, middle and ring fingers of both hands and then the mean of these was taken. The following measurements were made using a Vernier micrometer having an accuracy of 0.01 mm (Figure 6.29):

i) the length (L) of the metacarpal
ii) the *external* diameter (D) at the mid-point of the shaft of the metacarpal
iii) the *internal* diameter (d) at the mid-point of the shaft of the metacarpal

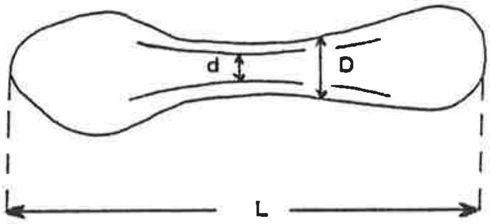


Figure 6.29 **Parameters used for bone quantity calculation** (Exton-Smith method)
L = length of metacarpal
D = the *external* diameter at the mid-point of the shaft of the metacarpal
d = the *internal* diameter at the mid-point of the shaft of the metacarpal

The cross-sectional area of the cortex was calculated by $D^2 - d^2$. Exton-Smith et al. (1969) used the product of the length (L) and the external shaft diameter (D) as a measure of bone size. Division of the cross-sectional area of the cortex ($D^2 - d^2$) by ($D \times L$) allows correction for variations between individual skeletal size.

Construction of percentile-ranking curves for the ratio of cortical area/total surface area of bone enables an individual's skeletal status to be assessed in relation to others of the same gender and age. Figure 6.30 shows the percentile curves for the ratio of $(D^2 - d^2)/DL$ for women up to 85 years.

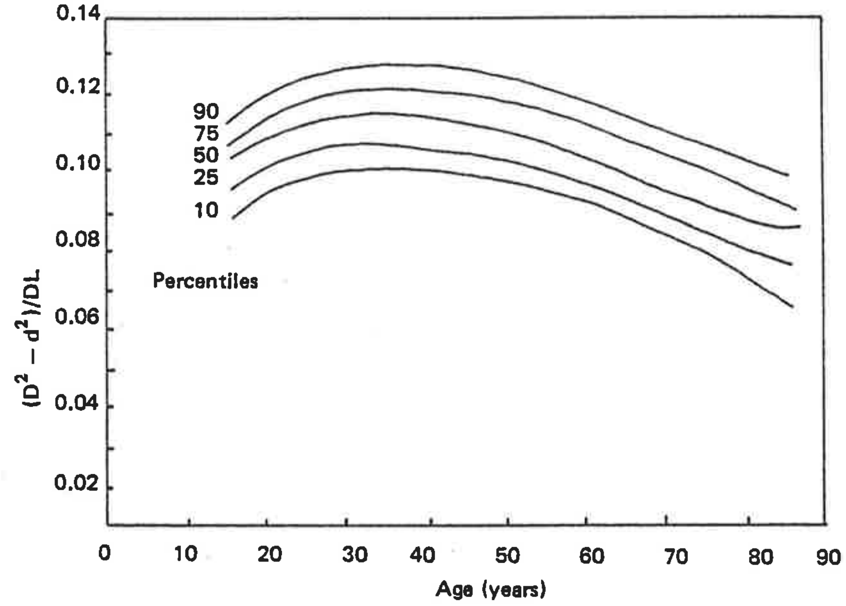


Figure 6.30 Percentile curves for the ratio $(D^2 - d^2)/DL$ for women up to 85 years. (Exton-Smith et al., 1969)

The values of $(D^2 - d^2)/DL$ were calculated and compared with the percentile chart. There is no definite level below which demineralisation results in osteopenia. Based on the findings of a series of bone biopsies at the Royal Adelaide Hospital (Robertson, 1979), values which were less than the 10th percentile indicated definite osteopenia. The transition from normal mineralisation to osteopenia occurred between the 10th and 25th percentiles. Values at the lower end of this segment were osteopenic: however, values at the upper end included 50% of cases with normal mineralisation. For the purpose of this study values which were less than the 13th percentile were taken as indicative of osteopenia.

6.4 Examiner Error Procedures

6.41 Measurement of range of accessory movements of the T-M1 joint

Inter-examiner error

The inter-examiner error procedures for the ordinal-scaled accessory movement tests of the T-M1 joint were carried out on seven subjects (14 thumbs). There being seven tests of range per T-M1 joint, a total of 98 decisions were therefore required. Here the author compared her reliability against another experienced manipulative therapist. Assessments by one examiner were made without a knowledge of the results obtained by the other.

Intra-examiner error was assessed by measurement of four subjects (eight thumbs) on three consecutive days. Seven accessory movement tests of range were carried out per T-M1 joint, that is a total of 168 tests were done over the three days, 56 each day. Assessments were made without knowledge of those made on the preceding days.

6.42 Peripheral joint mobility measurements

Inter-examiner error

Inter-examiner error was calculated by comparing the results obtained from eight subjects (that is, 16 joints of the same type). The author compared her reliability against another experienced manipulative therapist. Both had had considerable experience in measurement of peripheral joints. Care was taken to erase all markings between measurements, and measurements by one examiner were made without a knowledge of these results on the part of the other examiner.

The average of three readings was taken in calculation of inter-examiner error.

Intra-examiner error: The variation in the three readings taken on each joint in eight subjects formed the basis of the calculation of the intra-examiner error.

6.5 Results of Examiner Error Studies

Range of accessory movements of the T-M1 joint

Inter-examiner error: In the assessment of inter-examiner error in the measurement of the accessory range of movements of the T-M1 joint there was 90% agreement between the examiners. This is high agreement; however the author was particularly concerned to look at the nature of the disagreements. Did these disagreements follow a pattern? Did one examiner consistently find either greater or lesser mobility than did the other examiner? For this reason the McNemar test was employed. This test considers the type of disagreement and the significance of comparing these disagreements. The result of the application of the two-tailed binomial test was not significant. That is, there was no significant pattern to the disagreements between the examiners.

Intra-examiner error: On three consecutive days a total of 168 tests were carried out on a total of eight T-M1 joints. Eight disagreements were recorded overall. This represents a 4.8% error rate. Once again the author was concerned to investigate whether these disagreements tended towards a pattern. The two-tailed binomial test was not significant. That is, there was no significant pattern to the disagreements found on consecutive days.

Peripheral joint mobility tests

Inter-examiner error: The inter-examiner error was calculated from readings taken on eight subjects by two observers, that is, 16 joints of the same kind were measured. As can be seen from Table 6.1 there was high inter-examiner agreement.

Measurement	r	significance
Metacarpo-phalangeal extension of the little finger	0.89	$p < .01$
Elbow extension	0.9	$p < .001$
Knee extension	0.95	$p < .001$
Ankle dorsiflexion	0.96	$p < .001$

Table 6.1 **Inter-examiner error: correlation coefficients and significance levels of readings taken independently by two observers on eight subjects (16 joints).**

Intra-examiner error: Table 6.2 gives the values of the coefficients of variation (%) for three readings carried out on eight subjects (16 joints). The V% was greatest at 6% for elbow and knee extension and 2% or less for measures at the other two joints.

Measurement	V% (coefficient of variation %)
Metacarpo-phalangeal extension of the little finger	2%
Elbow extension	6%
Knee extension	6%
Ankle dorsiflexion	1%

Table 6.2 **Intra-examiner error: coefficients of variations for three readings on eight subjects (16 joints).**

6.6 Results and Discussion

The results of the clinical study were analysed using the Statistical Package for the Social Sciences (SPSS) on a Cyber computer, model number 173. Apart from the measurements of the three physiological movements, measurements of the other variables were classified into categories. Due to small numbers in some categories, it was necessary to collapse the categories to permit statistical analysis. The following categories were combined:

Range of accessory movements —
  (0) hypermobile, (1) normal, (2) slightly stiff, (3) very stiff, (4) no movement
  (2), (3) and (4) were combined = stiff
Quality of movement —
  (0) normal, (1) early resistance and (2) crepitus
  (1) and (2) were combined = abnormal
Radiological findings —
  (0) normal, (1) mild 0-A, (2) moderate 0-A, (3) marked 0-A
  (2) and (3) were combined = moderate/marked 0-A
Dorso-lateral instability (DLI) —
  (0) stable, (1) mild DLI, (2) moderate DLI, (3) marked DLI
  (2) and (3) were combined = moderate DLI

To allow for cumulative error in analyses involving several movements of the T-M1 joint, a conservative per test error rate of $p < .005$ has been adopted for the clinical study.

The results and discussion will be presented in the seven sections under the headings as outlined in the aims:

6.61 Relationship of demographic variables to the mobility and incidence of osteo-arthrosis of the T-M1 joint
6.62 Results and discussion of findings in the non-clinical group
6.63 Results and discussion of findings in the generalised peripheral joint hypermobility group

6.64 Results and discussion of findings in the osteo-arthrotic group
6.65 Results and discussion of findings in the occupational groups
6.66 The relationship of adjacent joint mobility to the range of passive movements of the T-M1 joint
6.67 The relationship between osteo-arthrosis of the T-M1 joint and menstrual status and between osteopenia and menstrual status.

6.61 Relationship of demographic variables to the mobility and incidence of osteo-arthrosis of the T-M1 joint

Except where otherwise stated, the relationship of the variables to the mobility of the T-M1 joint was assessed for the whole population (N=492). For the relationship to osteo-arthrosis of the T-M1 joint, the non-clinical group was excluded as criteria for inclusion in this group was radiological normality.

This section includes the following variables:

1. gender
2. age
3. a past history of pain and / or swelling of the thumb base
4. use of the thumb
5. obesity
6. pain experienced during examination
7. peri-articular thickening

The results, followed by discussion, are given separately for each of the seven variables.

1. Relationship of gender to the mobility and incidence of osteo-arthrosis of the T-M1 joint

The population contained 228 male joints and 264 female joints.

a) Relationship to the physiological movements

i) Range

Males were found to be more mobile than females for extension and palmar-abduction while females had a greater range of opposition (Table 6.3). The difference between the means for male and female joints was significant for each movement ($p < .0001$).

Gender	Extension		Palmar-abduction		Opposition	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Male	45°	7.3	49°	6.7	-6°	8.4
Female	41°	8.2	46°	7.0	3°	9.8
't' value	6.26		5.06		10.95	
significance	$p < .0001$		$p < .0001$		$p < .0001$	

Table 6.3 Relationship between gender and the range of physiological movements of the T-M1 joint (whole sample, N=492).

The same differences, between male and female joints, were obtained when the relationship of gender was analysed separately for each age group (Appendix XII).

ii) **Quality of movement**

Gender showed no significant relationship with the quality of the physiological movements.

b) **Relationship to the accessory movements**

There was no significant relationship between the range or quality of the accessory movements and gender, medial rotation being the exception. Women were significantly more mobile ($X^2 = 12.89, p < .005$) and had fewer abnormal scores for the quality of medial rotation ($X^2 = 7.10, p < .01$).

c) **Relationship to the incidence of osteo-arthrosis of the T-M1 joint**

There was a higher incidence of osteo-arthrosis in male joints (63%) compared with female joints (53%). Males had a higher percentage of mild osteo-arthrosis but there was little difference between the two in the moderate/marked category (Table 6.4). The difference in incidence of osteo-arthrosis between male and female joints was significant ($X^2 = 16.73, p < .0005$).

Radiological Findings	Male		Female	
Normal	42	(28%)	79	(47%)
Mild 0-A	77	(51%)	52	(31%)
Moderate/Marked 0-A	31	(21%)	37	(22%)
Total (N= 318)	150		168	

Table 6.4 **Relationship between gender and osteo-arthrosis of the T-M1 joint (whole sample minus non-clinical group, N=318).**

Discussion

The results of this study showed males to have significantly greater mobility in extension and palmar-abduction ($p < .0001$), whilst females had a significantly greater range of opposition ($p < .0001$) and medial rotation ($p < .005$) which is a component of opposition. It may be that opposition is more limited in males because the larger thenar muscle bulk effects earlier soft tissue apposition than in females. There are no reports in the literature with which to compare these results; however it is interesting to note that from a study of 294 individuals, Harris and Joseph (1949) found the inter-phalangeal joint was more mobile in women.

The finding of a significantly higher incidence of osteo-arthrosis in male T-M1 joints is contrary to the many reports in the literature (Gervis, 1949; Aune, 1955; Leach and Bolton, 1968; Sims and Bentley, 1970; Kessler and Axer, 1971; Kessler, 1973 and Kessler et al., 1976). These were reports of small series of patients with severe osteo-arthrosis with the exception of Kessler et al. (1976) who reviewed 148 hands. All were based on case histories of patients with disablement and pain of such a degree that surgery was considered. The present study contains the largest series of osteo-arthrotic T-M1 joints (198) and is the first study known to the author to investigate osteo-arthrosis in non-symptomatic, as well as symptomatic, joints. The relationship between gender and osteo-arthrosis of the T-M1 joint is discussed further in 6.67.

2. Relationship of age to the mobility and incidence of osteo-arthrosis of the T-M1 joint.

The population of 492 T-M1 joints was divided into four age categories. The number of joints in each category is set out in Table 6.5.

Age Group (years)				Total
20 - 29	30 - 39	40 - 49	50 - 59	
124	116	94	158	492

Table 6.5 Classification of T-M1 joints according to age (whole sample, N=492).

a) Relationship to the physiological movements

i) Range

There was no significant relationship between age and the range of palmar-abduction (Table 6.6). The range of opposition became significantly reduced with advancing age ($F = 6.50$, $p < .0005$) with a marked decrease in mean range in the fourth decade. While the mean range of extension was highest in the 30 - 39 years group, it became significantly lower with increasing age ($F = 5.73$, $p < .001$).

Movement	Age Group (years)								F value
	20 - 29		30 - 39		40 - 49		50 - 59		
	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	$\bar{x}$	S.D.	significance
Extension	44°	7.8	45°	7.4	43°	7.1	41°	9.0	5.73, $p < .001$
Palmar-abduction	48°	7.1	48°	6.5	47°	6.4	46°	7.7	Not significant
Opposition	2°	11.5	- 4°	10.3	- 1°	9.6	- 1°	8.8	6.50, $p < .0005$
Total (N=492)	124		116		94		158		

Table 6.6 Relationship between age and the range of the physiological movements of the T-M1 joint (whole sample, N=492).

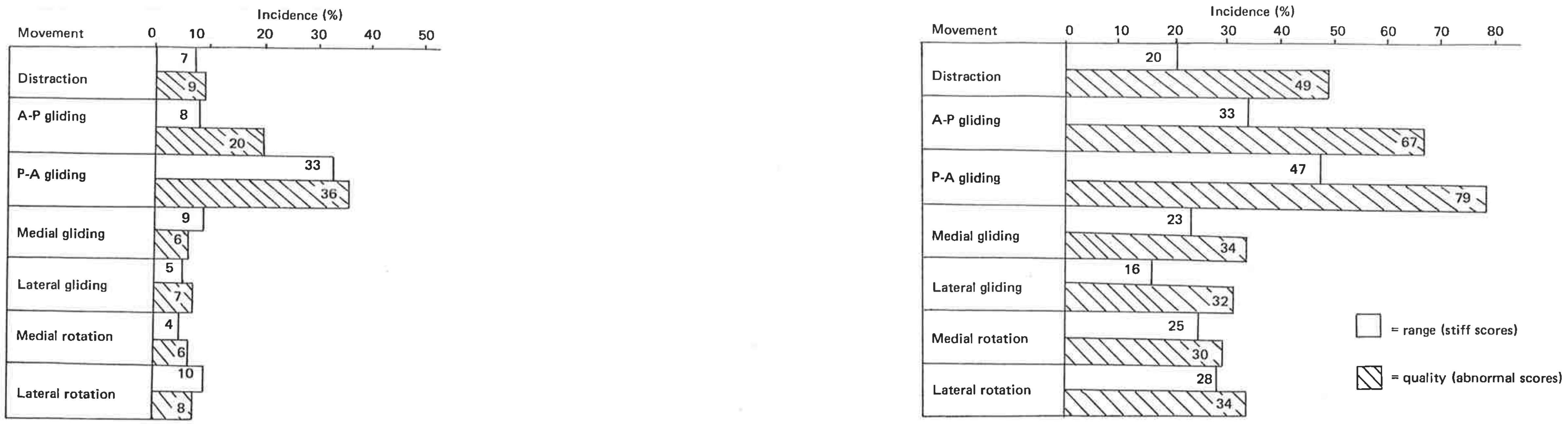
ii) Quality of movement

For the three movements the incidence of abnormal scores increased with advancing age. Chi Square tests showed this to be significant ($p < .00001$). The percentage of abnormal scores increased more rapidly after 40 years of age for extension and palmar-abduction but not until after 50 years for opposition (Appendix XIII).

b) Relationship to the accessory movements

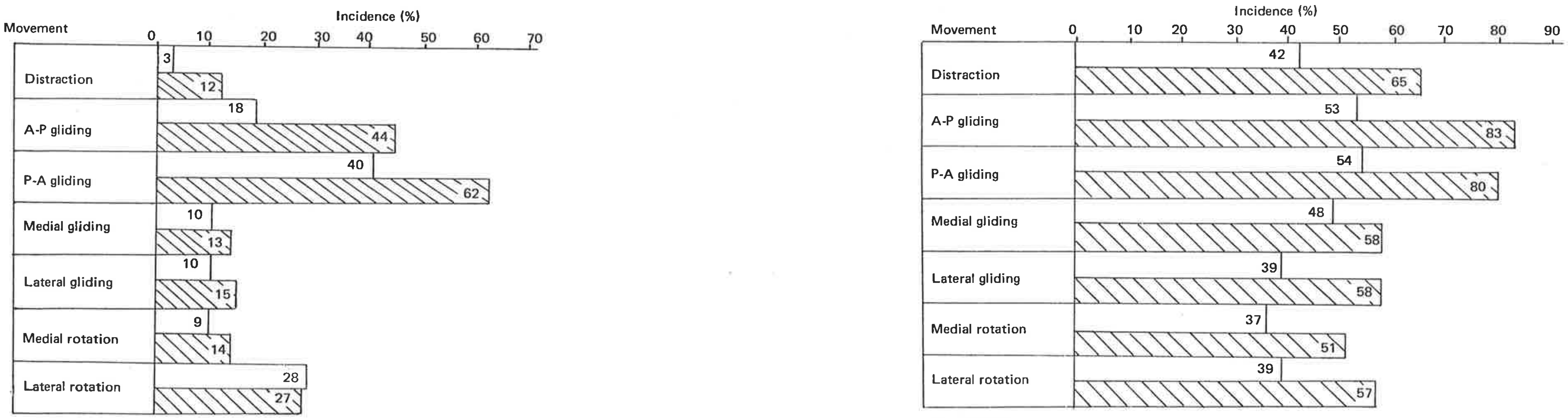
i) Range

Age was significantly related to the range of all accessory movements ($p < .00001$, postero-anterior gliding $p < .0001$). That is, with advancing age the incidence (%) of hypermobile scores decreased and the incidence (%) of stiff scores increased. For lateral rotation there was little further decrease (%) in hypermobile scores after the fifth decade. In all cases the incidence (%) of stiff scores increased markedly after the fifth decade, the percentage increase being least for postero-anterior gliding (Appendix XIV).



20 - 29 years

40 - 49 years



30 - 39 years

50 - 59 years

Figure 6.31 Incidence (%) of stiff scores and abnormal quality scores of the accessory movements of the T-M1 joint by age (whole sample, N=492)

ii) **Quality of movement**

There was a significant relationship between advancing age and abnormal quality scores for all movements ($p < .00001$). The Chi Square value was highest for distraction ($X^2 = 134.68$) and lowest for postero-anterior gliding ($X^2 = 69.21$), (Appendix XIII).

Figure 6.31 illustrates the relationship of age to the incidence of stiff scores and abnormal quality scores for the seven accessory movements.

c) **Relationship to the incidence of osteo-arthrosis of the T-M1 joint**

Both the incidence (%) and severity of osteo-arthrosis of the T-M1 joint increased with advancing age. The more advanced osteo-arthrotic changes were more evident after 40 years of age (Table 6.7). The relationship between age and osteo-arthrosis of the T-M1 joint was found to be significant ($X^2 = 149.78$, $p < .00001$).

Age (years)	Radiological Findings Normal		Mild 0-A		Mod/Marked 0-A		Total
20 - 29	65	(86%)	11	(14%)	0	(0%)	76
30 - 39	34	(48%)	32	(45%)	5	(7%)	71
40 - 49	17	(32%)	24	(45%)	12	(23%)	53
50 - 59	5	(4%)	62	(53%)	51	(43%)	118
Total	**121**		**129**		**68**		**318**

Table 6.7 **Relationship between age and the incidence of osteo-arthrosis (0-A) of the T-M1 joint (whole sample minus non-clinical group, N=318).**

Discussion

The criteria for selection into the various groups for this study influenced the age pattern of the group as a whole, for example, the hypermobile and manipulative therapist groups were predominantly young whilst the osteo-arthrotic and tailors and dressmakers were drawn from an older population.

There are no known reports in the literature related specifically to the effect of ageing and the mobility of the T-M1 joint. Wynne-Davies (1971) and Beighton et al. (1973) reported that generally range of mobility fell rapidly as childhood progressed but more slowly through adult life. The findings of this study (restricted to adults between the age of 20 - 59 years) support the findings of these authors.

Ageing had a more marked influence on the range and quality of the accessory movements than on the physiological movements. It was interesting to note that the two accessory movements (antero-posterior and postero-anterior gliding) that occur along the antero-posterior axis of the T-M1 joint showed an increase in the percentage of stiff scores in the 30 - 39 year age group whereas the other accessory movements were not markedly affected by age until the next decade.

As expected, the incidence of osteo-arthrosis rose significantly with increasing age ($p < .00001$). In this study, by the fourth decade 52% of T-M1 joints were osteo-arthrotic and this increased to 68% and 96% in the fifth and sixth decades respectively. It was in these two decades (that is, fifth and sixth) that the osteo-arthrotic changes became more marked. It is this group, of more advanced changes, which would best correspond with the reports in the literature which are based on the more severe cases of osteo-arthrosis presenting for surgery. Gervis (1949), Aune (1955), Burton (1973) and Kessler (1973) describe osteo-arthrosis of the T-M1 joint as being most common in the fifth and sixth decades whilst Weinman and Lipscomb (1967) found it to be more prevalent in patients aged 50 to 80 years.

From the results of this study it would appear that ageing significantly affects both the articular cartilage (there being a significant rise in the incidence of osteo-arthrosis, $p < .00001$) and the soft tissue components of the joint (significant reduction in the range of distraction ($p < .00001$) being indicative of capsular and ligamentous stiffness). The latter was an expected finding as a number of workers (Verzár, 1963; Ridge and Wright, 1966; Steer et al., 1971; Sussman, 1973) have established the fact that collagen stiffens with increasing age. A significant increase in the incidence of osteo-arthrosis with advancing age supports the results of staining of the articular cartilage presented in Chapter IV.

3. Relationship of a past history of pain and/or swelling of the thumb base to the mobility and incidence of osteo-arthrosis of the T-M1 joint

The non-clinical group was excluded from this analysis as by definition they had no history of pain and/or swelling of the thumb base. Of the remaining 318 T-M1 joints, 65 (20%) had a past history of pain at the thumb base. Fifty-nine (91%) of these reported the pain to be associated with use.

a) Relationship to the physiological movements

i) Range

While the mean ranges of extension and opposition were lower in joints with a past history of pain the difference was not significant, although extension showed a trend ($p < .01$) – Table 6.8.

Movement	History	No History	't' value	significance
	Mean	Mean		
Extension	41^{o}	43^{o}	2.45	$p < .01$
Palmar-abduction	47^{o}	47^{o}	.60	not significant
Opposition	-3^{o}	-1^{o}	1.71	not significant
Total (N=318)	65	253		

Table 6.8 Relationship between a past history of pain at the thumb base and the means of the physiological movements of the T-M1 joint (whole sample minus non-clinical group, N=318)

ii) Quality of movement

There was a significantly higher incidence (%) of abnormal scores for all three physiological movements (Table 6.9).

Movement	History Mean		No History Mean		X^2 value	significance
Extension	23	(35%)	30	(12%)	20.61	$p < .00001$
Palmar-abduction	25	(39%)	48	(19%)	11.11	$p < .001$
Opposition	30	(46%)	57	(23%)	14.52	$p < .0001$
Total (N=318)	65		253			

Table 6.9 **Relationship between a past history of pain at the thumb base and the incidence of abnormal quality scores for the physiological movements (whole sample minus non-clinical group, N=318).**

b) Relationship to the accessory movements

i) Range

A history of pain was associated with a higher incidence (%) of stiff scores for all seven accessory movements. This was significant for distraction ($p < .0005$), and showed a trend for medial and lateral rotation ($p < .05$) (Appendix XV).

ii) Quality

There was a higher incidence (%) of abnormal scores for all the accessory movements in joints with a past history of pain (Appendix XVI). This was significant for distraction ($p < .005$) and showed a trend for medial and lateral rotation ($p < .01$) and antero-posterior and lateral gliding ($p < .05$).

c) Relationship to the incidence of osteo-arthrosis of the T-M1 joint

From Table 6.10 a significantly higher incidence of osteo-arthrosis in those T-M1 joints having a past history of pain can be seen (X^2 = 14.19, $p < .001$). The incidence (%) is clearly higher in the moderate/marked osteo-arthrosis category.

Radiological Findings	History		No History		X^2 value significance
Normal	19	(29%)	102	(40%)	
Mild 0-A	21	(32%)	108	(43%)	14.19
Moderate/marked 0-A	25	(39%)	43	(17%)	$p < .001$
Total (N=318)	65		253		

Table 6.10 **Relationship between a past history of pain at the thumb base and the incidence of osteo-arthrosis (0-A) of the T-M1 joint (whole sample minus non-clinical group, N=318).**

Discussion

Despite excluding from this study all cases of known trauma to the thumb base, there were 65 (20%) T-M1 joints with a past history of pain in the region of the T-M1 joint.

Although there was a significantly higher incidence (%) of moderate/marked osteo-arthrosis in joints with a past history of pain ($p < .001$), the pattern of restriction of movements supports a greater involvement of the soft tissue elements of the T-M1 joint.

Capsular and ligamentous tightness (stiffness in distraction) results in apposition of the joint surfaces with consequent loss of range in medial and lateral rotation. These three accessory movements were stiffer and had a greater incidence of abnormal quality scores in joints with a past history of pain.

4. Relationship of use of the thumb to the mobility and incidence of osteo-arthrosis of the T-M1 joint

Classification of the whole sample according to years of use of the thumb is set out in Table 6.11.

Years of Use				
0 - 5	6 - 10	11 - 15	16 - 20	More than 20
121 (25%)	85 (17%)	86 (17%)	33 (7%)	167 (34%)

Table 6.11 **Classification of T-M1 joints according to years of use of the thumb (whole sample, N=492).**
Note: there were fewer thumbs in the 16-20 years of use category.

a) Relationship to the physiological movements

i) Range

Overall the mean ranges of the three movements decreased with cumulative use of the thumb (Appendix XVII). The interaction between years of use and the range of movement was not significant although there was a trend for extension ($F=2.75$, $p < .05$).

ii) Quality of movement

Results of the relationship between use and the quality of the physiological movements appear in Appendix XVII, where it can be seen that the incidence (%) of abnormal scores increased markedly after 20 years of use. Chi Square tests showed a significant relationship between thumb use and the quality of each movement ($p < .001$).

b) Relationship to the accessory movements

Range and quality of movement

Results of the relationship of use of the thumb to the range and quality of the accessory movements are listed in Appendices XVIII and XIX.

With the exception of postero-anterior gliding, a significant relationship was found between the range of each accessory movement and years of use ($p < .005$). After 20 years of use the incidence (%) of stiff scores rose markedly for all movements. Similarly the incidence (%) of abnormal scores for the quality of all the movements increased after 20 years of use. Chi Square tests showed these findings to be significant ($p < .005$).

c) Relationship to the incidence of T-M1 joint osteo-arthrosis

After 15 years of use of the thumb the incidence (%) of osteo-arthrosis of the T-M1 joint increased considerably (Table 6.12). The relationship between use and the incidence (%) of osteo-arthrosis was significant $X^2 = 60.82$, $p < .00001$).

Radiological Findings	Use of the Thumb (years)					Total
	0 - 5	6 - 10	11 - 15	16 - 20	Over 20	
Normal	31	30	34	8	18	121
Osteo-arthrotic	25 (45%)	19 (39%)	25 (42%)	15 (65%)	113 (86%)	197
Total	56	49	59	23	131	318

Table 6.12 **Relationship between use of the thumb and osteo-arthrosis of the T-M1 joint (whole sample minus non-clinical group, N=318)**

Discussion

While the mean ranges of the three physiological movements decreased with cumulative use (more clearly seen after 15 years) there was a definite trend for extension only ($p < .05$). As most functional activities of the thumb involve the gripping of objects, that is, with the T-M1 joint flexed and opposed to the other digits, it is not surprising that extension should show a reduction in range.

After 15 years of use the incidence (%) of radiological findings of osteo-arthrosis increased markedly. It is interesting to note that the only accessory movements which did not show a concomitant pattern of percentage increase in abnormal quality and stiffness scores were distraction, antero-posterior and postero-anterior gliding. With these movements the pattern clearly emerges only after more than 20 years of use. Distraction is a function of the whole capsule and surrounding soft tissues and therefore not influenced by the changes in the articular cartilage. Postero-anterior gliding exhibited the highest incidence (%) of stiff scores and abnormal quality findings in all categories of use and, as might be expected, was the movement to be least influenced by increasing use.

The pattern of limitation of movement associated with use of the thumb is very similar to that found in joints with moderate/marked osteo-arthrosis (that is, no significant change in the range of palmar-abduction, opposition and postero-anterior gliding). Years of use, age and osteo-arthrosis of the T-M1 joint are inter-dependent variables and because of the nature of the population sampled analyses of the separate relationship of these variables to the mobility of the T-M1 joint is not possible.

The findings of this study support the clinically based reports of Lassère et al., 1949; Müller, 1949; Weinman and Lipsombe, 1967; Leach and Bolton, 1968; Eiken and Carstam, 1970 and Burton, 1973, that osteo-arthrosis is related to use of the thumb. No reports in the literature relate use of the thumb to the mobility of the T-M1 joint.

5. Relationship of obesity to the range of opposition

The author wished to investigate the possible restriction of range of opposition due to early soft tissue apposition in obese individuals. However, in this population of 246 only six (2%) were obese and this represented too small a number for a reliable assessment of its relationship to the range of opposition.

6. Relationship of pain experienced during examination to

a) the mobility of the T-M1 joint

b) the radiological findings of osteo-arthrosis of the T-M1 joint

a) T-M1 joint mobility

i) Relationship of the range of physiological movements

The incidence of pain experienced during examination of the physiological movements was low, (Table 6.13), and in no instance did its intensity limit the examination.

Movement	Incidence of Pain
Extension	10 (2%)
Palmar-abduction	7 (1%)
Opposition	20 (4%)

Table 6.13 Incidence of pain experienced during examination of the physiological movements of the T-M1 joint (whole sample, N=492)

The mean range of extension and palmar-abduction was smaller in the painful joints (Table 6.14). Student's 't' test confirmed a significant difference between the means of the painful and non-painful joints for extension ($p < .005$) and palmar-abduction ($p < .001$).

Movement	Pain	No Pain	't' value	significance
Extension	35^o	43^o	3.08	$p < .005$
Palmar-abduction	39^o	47^o	3.20	$p < .001$
Opposition	$-.3^o$	$-.8^o$	.23	not significant
Total (N=492)	10	482		

Table 6.14 Relationship between the incidence of pain and the mean range of physiological movements of the T-M1 joint (whole sample, N=492)

ii) Relationship to the range of the accessory movements

Pain was an infrequent finding during examination of the accessory movements (Table 6.15), and in no joint did it limit the examination.

The relationship of the range of the accessory movements to pain experienced during their examination shows that, on the whole, pain was associated with stiff scores (Appendix XX). The incidence of pain was too low to permit statistical analysis.

Movement	Incidence of Pain
Distraction	3 (1%)
A-P gliding	14 (3%)
P-A gliding	14 (3%)
Medial gliding	7 (1%)
Lateral gliding	13 (3%)
Medial rotation	10 (2%)
Lateral rotation	16 (3%)

Table 6.15 **Incidence of pain experienced during examination of the accessory movements of the T-M1 joint (whole sample, N=492)**

b) **Radiological findings of osteo-arthrosis of the T-M1 joint**

There was a higher incidence (%) of pain associated with the examination of all movements in osteo-arthrotic T-M1 joints than in joints which were radiologically normal (Table 6.16). The incidence of pain was too small to permit statistical analysis.

Movement	Radiological Findings	
	Normal	Osteo-arthrotic
Extension	0	10 (5%)
Palmar-abduction	1 (1%)	6 (3%)
Opposition	2 (1%)	18 (9%)
Distraction	0	3 (2%)
A-P gliding	2 (1%)	12 (6%)
P-A gliding	1 (1%)	13 (7%)
Medial gliding	0	7 (4%)
Lateral gliding	4 (1%)	9 (5%)
Medial rotation	2 (1%)	8 (4%)
Lateral rotation	2 (1%)	14 (7%)
Total	294	198

Table 6.16 **Incidence of pain (experienced during examination of the physiological and accessory movements) in radiologically normal and osteo-arthrotic T-M1 joints (whole sample, N=492)**

Discussion

Pain was infrequently experienced during the examination of the physiological and accessory movements,being present in less than 4% of joints for each of the movement tests.

Pain was associated with stiffness in extension, palmar-abduction and each of the seven accessory movements. With such a small number of painful joints it was not feasible to investigate whether stiffness in these joints was associated with age, use of the thumb or more advanced stages of osteo-arthrosis.

The findings of this study confirm those of Aune (1955), Leach and Bolton (1968) and Burton (1973) that radiological findings do not necessarily indicate symptoms in the joint.

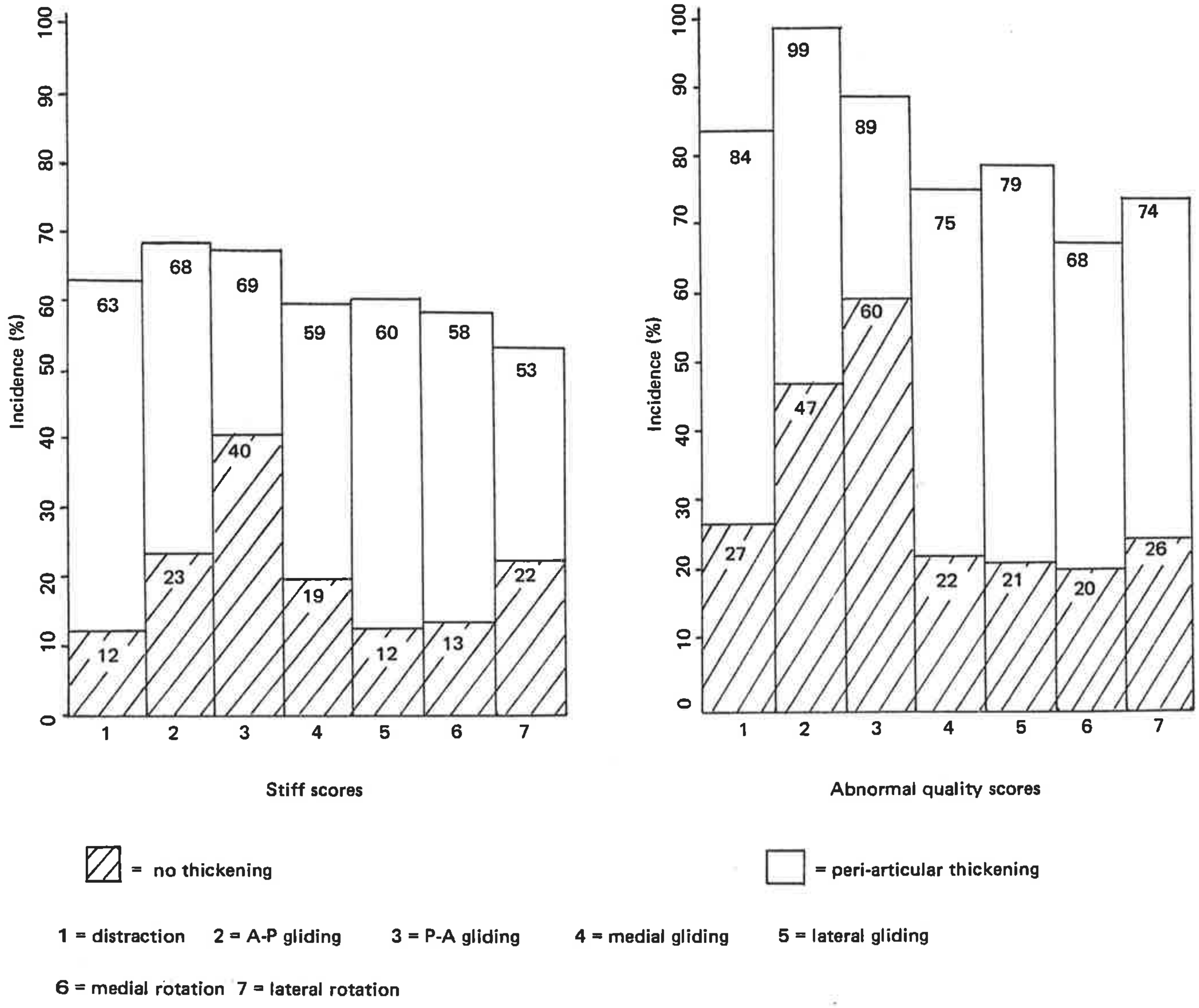


Figure 6.32 Incidence (%) of stiff scores and abnormal quality scores for the accessory movements of the T-M1 joint in joints with and without peri-articular thickening

7. Relationship of peri-articular thickening to the mobility and incidence of osteo-arthrosis of the T-M1 joint

Seventy-three (15%) of the 492 T-M1 joints were found to have peri-articular thickening.

a) Mobility of the T-M1 joint

i) Relationship to the physiological movements

The mean range of the three physiological movements was less in those joints with peri-articular thickening (Table 6.17). Student's 't' tests showed the difference between the mean values, of joints with and without thickening, to be significant for extension and palmar-abduction ($p < .0001$).

Movement	Thick	Not Thick	't' value	significance
Extension	39^o	43^o	4.00	$p < .0001$
Palmar-abduction	45^o	48^o	3.77	$p < .0001$
Opposition	-2^o	-1^o	.85	not significant
Total (N=492)	73	419		

Table 6.17 Relationship between peri-articular thickening/bony enlargement and the mean range of the physiological movements of the T-M1 joint (whole sample, N=492)

There was a significantly higher incidence of abnormal scores for the quality of the three physiological movements in joints with peri-articular thickening ($p < .00001$) (Appendix XXI).

ii) Relationship to the accessory movements

Results of the relationship of peri-articular thickening to the range and quality of the accessory movements are listed in Appendices XXI and XXII. For all movements, T-M1 joints with peri-articular thickening had a higher incidence (%) of stiff scores and abnormal quality scores. Chi Square tests confirmed these to be significant ($p < .00001$). The range of distraction had the highest Chi Square value indicating a closer relationship with peri-articular thickening than the other accessory movements. Figure 6.32 illustrates the relationship of peri-articular thickening with the incidence (%) of stiff scores and abnormal quality scores.

b) Relationship to the incidence of osteo-arthrosis of the T-M1 joint

Excluding the non-clinical group, 62 joints with peri-articular thickening remained, and of these all but one was associated with osteo-arthrosis (Table 6.18).

Radiological Findings	Thick	Not Thick	Total	X^2 value significance
Normal	1 (2%)	119 (46%)	120	43.38
Osteo-arthrosis	61 (98%)	137 (54%)	198	$p < .00001$
Total	62	256	318	

Table 6.18 Relationship between peri-articular thickening/bony enlargement and osteo-arthrosis of the T-M1 joint (whole sample minus non-clinical group, N=318)

Discussion

Based on clinical experience rather than formal studies Müller (1949) and Aune (1955) described synovial and capsular thickening and osteophytic lipping in osteo-arthrotic joints. Leach and Bolton (1968), Swanson (1972), Burton (1973) and Eaton and Littler (1973) spoke of swelling around these joints. None of these authors documented the incidence of swelling or thickening.

In this study of 492 T-M1 joints, peri-articular thickening was palpable in 15%. There was a significant relationship between peri-articular thickening and osteo-arthrosis of the T-M1 joint ($p < .00001$). No attempt was made to isolate the type of thickening, that is, thickening of the soft tissues of osteophytosis. However, the pattern of limitation of movements reflects soft tissue involvement in that distraction and lateral gliding had the highest Chi Square values.

6.62 Results and discussion of findings in the non-clinical group

1. Classification of the group according to age and gender
2. Mobility of the T-M1 joint, including range and quality of the physiological and accessory movements.
3. Incidence of dorso-lateral instability.
4. Discussion.

1. Classification of the non-clinical group according to age and gender

The T-M1 joints (N=174) in the non-clinical group included at least 20 male and 20 female joints in each of the four age groups (Table 6.19). The ratio of male:female joints was approximately 9:10.

Age Group (years)								
20 – 29		30 – 39		40 – 49		50 – 59		Total
M	F	M	F	M	F	M	F	
22	26	22	24	20	20	20	20	174

Table 6.19 Classification of T-M1 joints according to age and gender (non-clinical group, N=174)

2. T-M1 joint mobility

a) Physiological movements

i) Range

The mean range of extension, palmar-abduction and opposition is shown in Table 6.20. The mean range of palmar-abduction (47^{o}) was slightly greater than that for extension (43^{o}). During opposition of the thumb towards the little finger, the long axis of M1 was almost parallel with the long axis of M2 (that is, it lacked one degree). The large standard deviations reflect wide individual differences within the ranges of extension, palmar-abduction and opposition.

Movement	Mean	S.D.
Extension	43°	8.2
Palmar-abduction	47°	7.1
Opposition	-1°	10.0

Table 6.20 Range of physiological movements of the T-M1 joint (non-clinical group, N=174)

i) **Quality of movement**

The data from Table 6.21 indicates that the incidence of abnormality was similar for all three movements. Crepitus was found in only two joints and in each case it was associated with extension, whereas resistance early in the range was a much more frequent finding.

Movement	Normal Quality	Abnormal Quality		
		Early Resistance	Crepitus	Total
Extension	148 (85%)	24	2	26 (15%)
Palmar-abduction	146 (84%)	28	0	28 (16%)
Opposition	143 (82%)	31	0	31 (18%)

Table 6.21 Quality of the physiological movements of the T-M1 joint (non-clinical group, N=174)

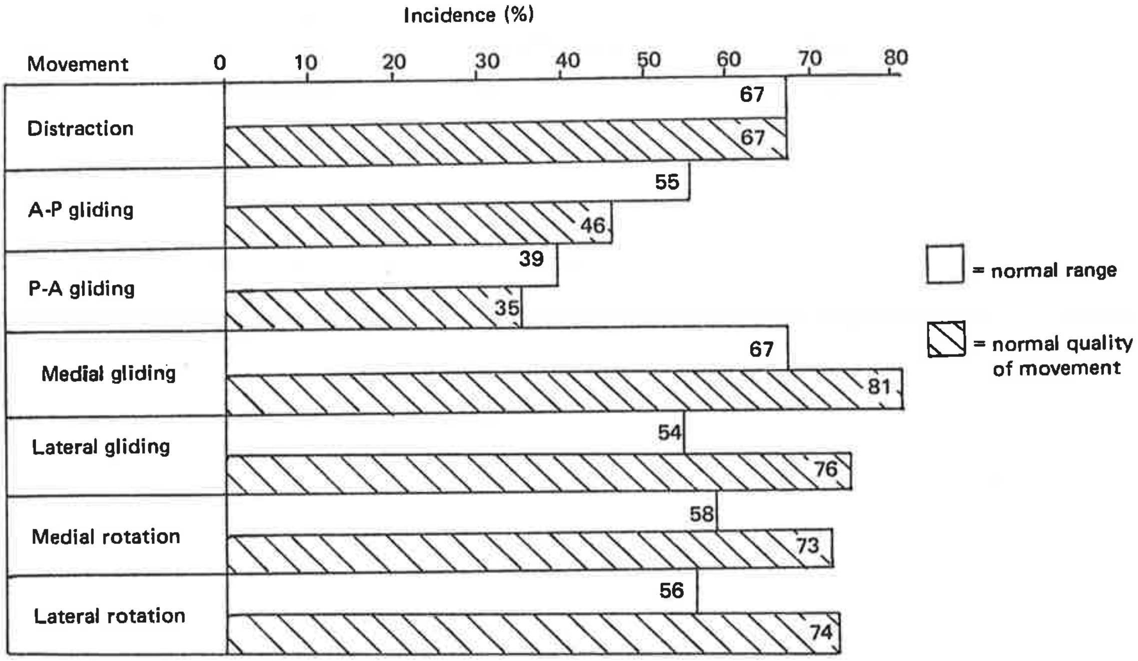
b) **Accessory movements**

i) **Range**

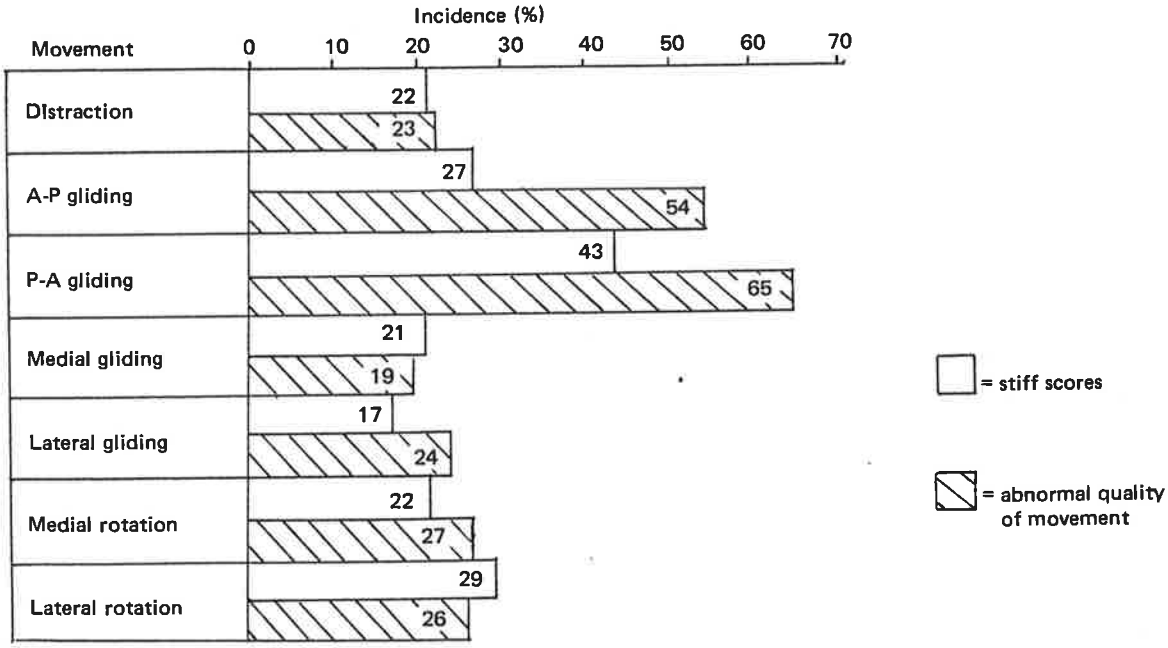
Few 'very stiff' scores and no 'no movement' scores were found but there was a higher incidence of stiff scores for postero-anterior (P-A) gliding and hypermobile scores for lateral gliding (Table 6.22).

Movement	Range of Movement				
	Hypermobile	Normal	Slightly Stiff	Very Stiff	No Movement
Distraction	19 (11%)	117 (67%)	37 (21%)	1 (1%)	0
A-P gliding	32 (18%)	95 (55%)	44 (25%)	3 (2%)	0
P-A gliding	31 (18%)	67 (39%)	58 (33%)	18 (10%)	0
Medial gliding	21 (12%)	116 (67%)	33 (19%)	4 (2%)	0
Lateral gliding	50 (29%)	94 (54%)	29 (16%)	1 (1%)	0
Medial rotation	34 (20%)	101 (58%)	39 (22%)	0	0
Lateral rotation	26 (15%)	98 (56%)	49 (28%)	1 (1%)	0

Table 6.22 Range of accessory movements of the T-M1 joint (non-clinical group, N=174)



(a) Normal scores



(b) Stiff and abnormal quality scores

Figure 6.33 Comparison of range and quality of movement of the accessory movements of the T-M1 joint (non-clinical group, N=174)

ii) **Quality of movement**

Antero-posterior and postero-anterior gliding had the highest incidence of abnormality in terms of both crepitus and resistance early in the range (Table 6.23).

Movement	Normal Quality	Abnormal Quality		
		Early Resistance	Crepitus	Total
Distraction	117 (67%)	50	7	57 (33%)
A-P gliding	80 (46%)	74	20	94 (54%)
P-A gliding	61 (35%)	87	26	113 (65%)
Medial gliding	140 (81%)	33	1	34 (19%)
Lateral gliding	132 (76%)	41	1	42 (24%)
Medial rotation	127 (73%)	47	0	47 (27%)
Lateral rotation	128 (74%)	44	2	46 (26%)

Table 6.23 Quality of the accessory movements of the T-M1 joint (non-clinical group, N=174)

Relationship between the mobility and quality of the accessory movements

Figure 6.33 suggests a close relationship between normal scores for both range and quality of movement, and similarly between stiff scores and an abnormal quality of movement. For each the incidence is expressed as a percentage.

Chi Square tests (Appendix XXIII) indicated that the relationship was statistically significant for all seven accessory movements ($p < .00001$).

3. Incidence of dorso-lateral instability

There were 38 cases (22%) of dorso-lateral instability; of these 37 were classified as mild and one as moderate (Table 6.24).

Stable	Instability		Total
	Mild	Moderate	
136 (88%)	37 (21%)	1 (1%)	174

Table 6.24 Incidence of dorso-lateral instability (non-clinical group, N=174)

4. Discussion

The criteria for selection into the non-clinical group were based on normality from a medical point of view, that is, asymptomatic joints, no history of symptoms or of direct trauma to the joint and radiological normality. Clearly then this could be no random sample.

The most important conclusion of this section of the study is that 'medically normal' joints exhibit abnormalities in the quality as well as the range of movement. This is well recognised by manipulative therapists and described by Maitland (1980) as 'normal abnormalities'. The present study is the first to document the incidence of range and quality of movement abnormalities in 'medically normal' or non-clinical T-M1 joints to form a baseline for comparison with other groups. Further the author knows of no similar study relating to other non-clinical joints.

The accessory movements exhibited a higher incidence of abnormal quality of movement than occurred with the physiological movements. This suggests that abnormality occurs firstly in the accessory movements and at a later stage becomes evident in the physiological movements. Clinically this gives strong support for the inclusion of tests of range and quality of both physiological and accessory movements in the physical examination.

Postero-anterior gliding had the highest incidence of stiff scores and together with antero-posterior gliding it had the highest incidence of abnormal quality of movement. These two movements occur along the antero-posterior axis of the T-M1 joint and as described in Chapter V, page 68, the articular surfaces along this axis were found to be less congruent than along the medio-lateral axis. It is tempting to hypothesise that a relationship may exist between the abnormalities in this plane and the lack of congruence of this axis.

6.63 Results and discussion of findings in the generalised peripheral joint hypermobility group

1. Classification of the group according to age and gender.
2. Mobility of the T-M1 joint, including the range and quality of the physiological and accessory movements, comparisons being made with the non-clinical group.
3. Incidence of osteo-arthrosis and dorso-lateral instability of the T-M1 joint.
4. Discussion.

1. Classification of T-M1 joints according to age and gender

The T-M1 joints of 33 individuals with generalised peripheral joint hypermobility were examined. In this sample there were 14 male and 52 female joints and 44 (67%) were in the 20-29 year age group (Table 6.25).

Age Group (years)								
20 - 29		30 - 39		40 - 49		50 - 59		Total
M	F	M	F	M	F	M	F	
8	36	2	8	2	4	2	4	66

Table 6.25 Classification of T-M1 joints according to age and gender (hypermobile group, N=66)

2 Mobility of the T-M1 joint

Two separate comparisons were made: first, taking each group as a whole the differences were compared; second, in order to minimise the influence of gender and age on T-M1 joint mobility (see 6.61) a restricted comparison between the two groups for female joints in the 20-29 years age group was undertaken.

2.1 Comparison between the hypermobile (N=66) and non-clinical (N=174) groups

a) Physiological movements

i) Range

Details of the range for the three physiological movements are set out in Table 6.26 where it can be seen that the hypermobile group was more mobile than the non-clinical group for all three movements. The Student's 't' test revealed a significant difference between the mean range of the two groups for palmar-abduction ($p < .005$) and opposition ($p < .0001$) and a trend for extension ($p < .01$).

Movement	Hypermobile		Non-clinical		't' value	significance
	$\bar{x}$	S.D.	$\bar{x}$	S.D.		
Extension	46°	7.5	43°	8.2	2.60	$p < .01$
Palmar-abduction	50°	6.1	47°	7.1	2.88	$p < .005$
Opposition	6°	13.1	-1°	10.0	4.28	$p < .0001$

Table 6.26 **Range of physiological movements of the T-M1 joint – comparison between hypermobile (N=66) and non-clinical (N=174) groups**

ii) **Quality of movement**

Apart from three joints in which crepitus was felt during the examination of palmar-abduction, there was a 'normal' quality to the physiological movements. This differs considerably from the results of the non-clinical group. Chi Square tests showed the difference between the groups to be significant for extension and opposition ($p < .005$) and a trend for palmar-abduction ($p < .05$) – Table 6.27.

Movement	'Normal' Endfeel		Abnormal Endfeel		X^2 value significance
	Hyper	N-C	Hyper	N-C	
Extension	66 (100%)	148 (85%)	0	26 (15%)	9.57, $p < .005$
Palmar-abduction	63 (96%)	146 (84%)	3 (4%)	28 (16%)	4.69, $p < .05$
Opposition	66 (100%)	143 (82%)	0	31 (18%)	11.97, $p < .0005$

Table 6.27 **Quality of physiological movements of the T-M1 joint – comparison between hypermobile (N=66) and non-clinical (N=174) groups**
Note: Hyper = hypermobile group N-C = non-clinical group

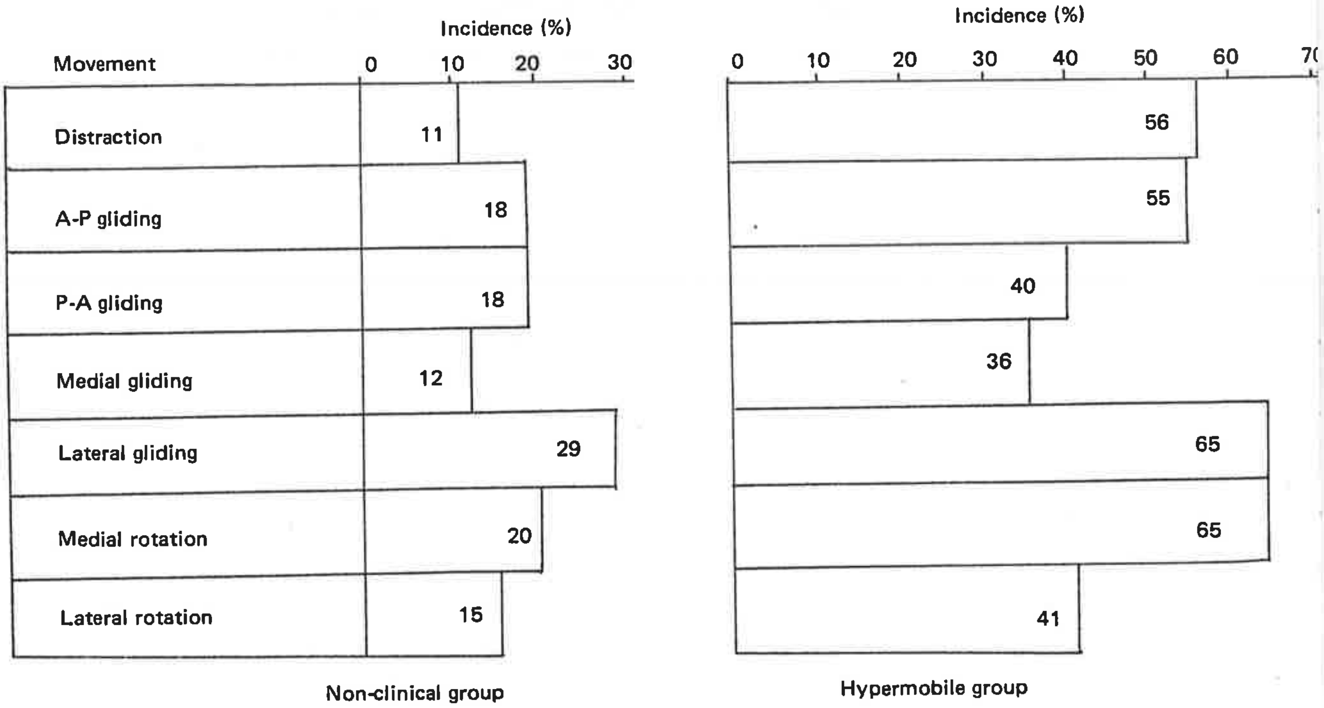
b) **Accessory movements**

i) **Range**

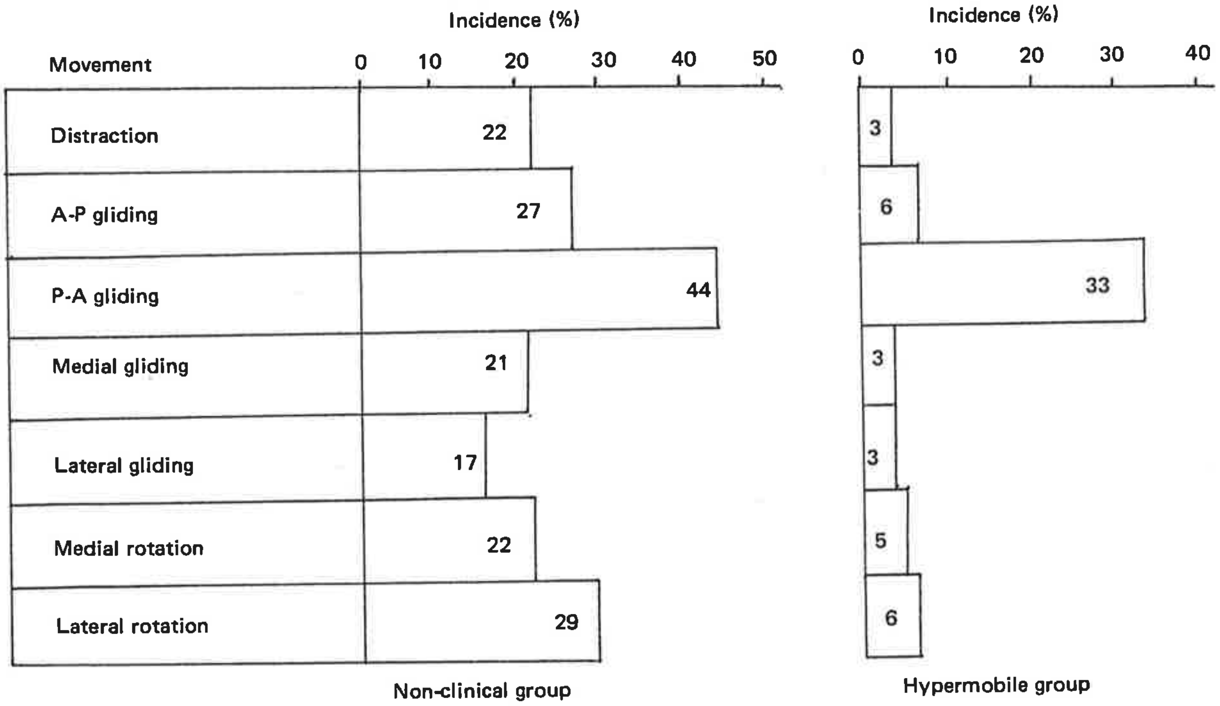
For all the accessory movements, the hypermobile group was found to have a higher percentage of hypermobile scores and a lower percentage of stiff scores than the non-clinical group. Chi Square tests showed the difference between the two groups to be significant ($p < .005$). These results appear in Appendix XXIV; however a histogram (Figure 6.34) of the hypermobile and stiff scores illustrates the difference between the two groups. For the stiff scores the relative mobility of each accessory movement remains almost the same for both groups.

ii) **Quality of movement**

When compared with the non-clinical group, the hypermobile group had a lower percentage of abnormal scores for the quality of movement for all the accessory movements (Appendix XXV). The difference between the two groups was not significant but there was a trend ($p < .05$) for each movement (Figure 6.35 illustrates the difference between the two groups).



(a) Hypermobile scores (expressed as a percentage)



(b) Stiff scores (expressed as a percentage)

Figure 6.34 (a) and (b) Hypermobile and stiff scores for accessory movements of the T-M1 joint — a comparison between the hypermobile (N=66) and non-clinical (N=174) groups

Figure 6.35 shows the difference between the two groups for the number of abnormal scores (expressed as a percentage). Again one notes that the 'pattern of abnormal scores' for each movement is similar for the two groups.

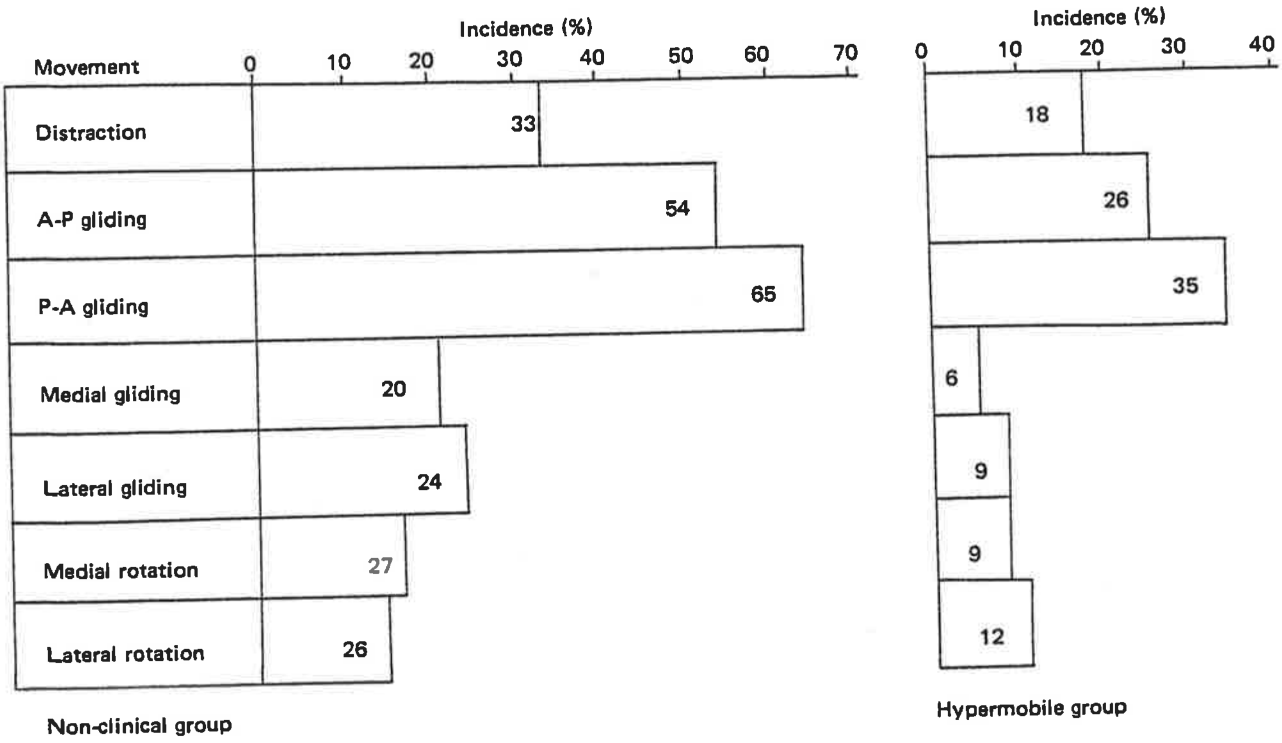


Figure 6.35 Incidence (%) of abnormal quality scores for the accessory movements of the T-M1 joint – a comparison between the hyper-mobile (N=66) and non-clinical (N=174) groups

2.2 Comparison between the hypermobile and non-clinical groups for female joints aged 20 - 29 years.

a) **Physiological movements**

i) **Range**

As set out in Table 6.28, the mean range of palmar-abduction was significantly higher in the hypermobile group and there was a trend for extension ($p < .01$) and opposition ($p < .05$).

Movement	Hypermobile Mean	Non-clinical Mean	't' value	significance
Extension	44^o	39^o	2.68	$p < .01$
Palmar-abduction	49^o	43^o	3.80	$p < .0001$
Opposition	10^o	4^o	2.08	$p < .05$
Total	36	26		

Table 6.28 Range of physiological movements of the T-M1 joint in females aged 20-29 years — comparison between hypermobile (N=36) and non-clinical (N=26) groups

ii) **Quality of movement**

There was no significant difference between the hypermobile and non-clinical groups for the quality of the physiological movements.

b) **Accessory movements**

i) **Range**

The results are given in Appendix XXVI, where it can be seen that the hypermobile group had a higher incidence (%) of hypermobile scores for all movements, and a lower incidence (%) of stiff scores for all except postero-anterior and medial gliding (where the two groups had a similar incidence). As there were very few stiff scores they were combined with the normal scores to permit statistical analysis. The results of the Chi Square tests (Appendix XXVI) showed a significant difference between the two groups for distraction, medial rotation and lateral gliding ($p < .005$) and a trend for antero-posterior gliding and lateral rotation ($p < .05$).

The difference between the hypermobile and non-clinical groups for the hypermobile and stiff scores is illustrated in Figure 6.36.

ii) **Quality of movement**

There was no significant difference between the hypermobile and non-clinical groups for the quality of the accessory movements.

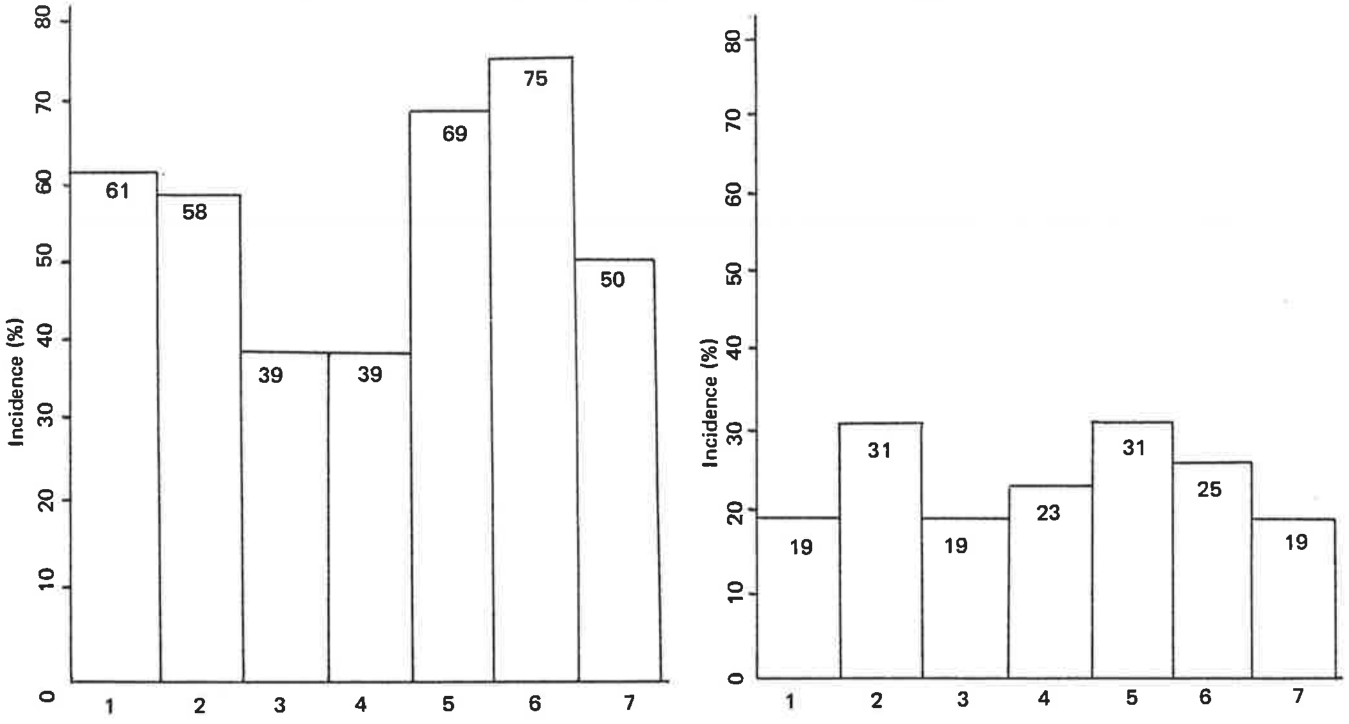
3. a) **Incidence of osteo-arthrosis**

Radiological examination showed that five (8%) of the T-M1 joints in the hypermobile group had osteo-arthrotic changes (Table 6.29). Three of these were classed as mild while the other two had moderate changes.

Radiological Findings Normal	 Mild O-A	 Moderate O-A	Total
51	3	2	66

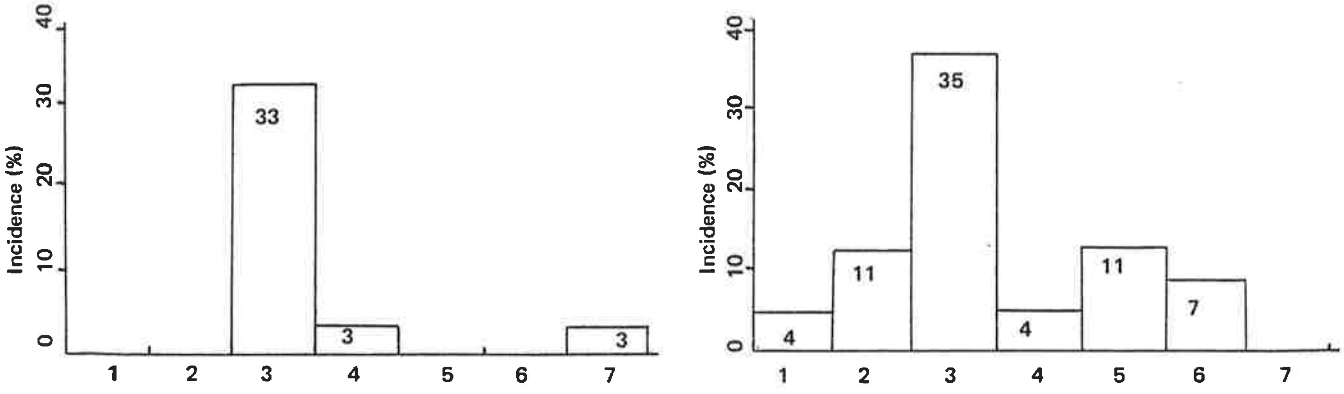
Table 6.29 Incidence of osteo-arthrosis (O-A) of the T-M1 joint (hypermobile group, N=66).

A comparison of radiological findings with age (Table 6.30) shows that, with the exception of one joint, osteo-arthrosis was not evident until the fifth decade.



Hypermobile group (N=36) Non-clinical group (N=26)

Incidence (%) of hypermobile scores



Hypermobile group (N=36) Non-clinical group (N=26)

Incidence (%) stiff scores

Code: 1 = distraction 2 = A-P gliding 3 = P-A gliding 4 = medial gliding 5 = lateral gliding
6 = medial rotation 7 = lateral rotation

Figure 6.36 **Incidence (%) of hypermobile and stiff scores for the accessory movements of the T-M1 joint in females aged 20-29 years — a comparison between the hypermobile (N=36) and non-clinical (N=26) groups**

Age	Radiological findings			Total
	Normal	Mild O-A	Moderate O-A	
20 - 29	43 (98%)	1 (2%)	0	44
30 - 39	10 (100%)	0	0	10
40 - 49	4 (66%)	1 (17%)	1 (17%)	6
50 - 59	4 (66%)	1 (17%)	1 (17%)	6
Total	61	3	2	66

Table 6.30 Relationship between age and osteo-arthrosis (O-A) of the T-M1 joint (hypermobile group, N=66)

b) **Incidence of dorso-lateral instability**

Thirty (45%) of the T-M1 joints had radiological evidence of dorso-lateral instability. Twenty-six were classed as mild while the remaining four had a moderate degree of instability.

Table 6.31 compares these results with those of the non-clinical group in which 22% of joints were unstable. The Chi Square test showed the difference between the two groups to be significant ($X^2 = 13.14$, $p < .0005$).

Figure 6.37 (Case number 9) is an example of moderate dorso-lateral instability of both left and right T-M1 joints.

Figure 6.37 Stress radiograph showing moderate dorso-lateral instability of both T-M1 joints.

Group	Stable	Instability		Total
		Mild	Moderate	
Hypermobile	36 (55%)	26 (30%)	4 (6%)	66
Non-clinical	136 (78%)	37 (21%)	1 (1%)	174

Table 6.31 **Incidence of dorso-lateral instability — comparison between the hypermobile (N=66) and non-clinical (N=174) groups**

4. Discussion

To the author's knowledge no normal values for T-M1 joint mobility have been delineated.

Forty-four (67%) of the T-M1 joints in this sample of subjects with generalised peripheral joint hypermobility were in the 20-29 years age group. This may reflect the finding of other authors, that is, that joints stiffen with advancing age (Wood, 1971; Wynne-Davies, 1971; Silverman et al., 1975) making it difficult for individuals to meet the criteria for selection into this group. Clearly there is a need for age-related norms to be established, upon which it may be necessary to modify the criteria for selection.

When compared with the non-clinical group, the hypermobile group as a whole was found to be significantly more mobile for opposition and palmar-abduction ($p < .005$). Maitland (1979) considered that joint hypermobility was associated with excessive movement (hypermobility) in the accessory movements. The findings of this study support this contention in that there was a significantly higher incidence of hypermobile scores for all accessory movements ($p < .005$) in the hypermobile group compared with the non-clinical group.

As expected, the differences between the hypermobile and non-clinical groups were less marked when the comparison was limited to female joints in the 20 to 29 years age group. The hypermobile group was significantly more mobile for palmar-abduction only (Table 6.28).

In keeping with the findings for the whole group, the difference between the two groups was more pronounced in the range of the accessory movements, and in particular — distraction, medial rotation and lateral gliding.

It is of interest to note that the quality of the physiological and accessory movements was not significantly different between the hypermobile and non-clinical groups. This is an expected finding if joint hypermobility is not an abnormal state but rather one end of a continuum of normal joint mobility (Wood, 1971).

From their study of 24 individuals with generalised joint hypermobility Kirk et al. (1967) concluded that 'the hypermobility syndrome appears to predispose to the premature development of degenerative joint disease'. They found .... 'the most common sites were the thumb bases and the cervical spine . . . .' From their statements one might expect to find osteo-arthrotic changes in the T-M1 joints of hypermobile individuals under 40 years of age, that is, premature osteo-arthrosis, as osteo-arthrosis of this joint is a disease of middle age (Gervis, 1949; Aune, 1955; Burton, 1973; Eaton and Littler, 1973 and Kessler, 1973). The findings of the present study do not support their observations as only one of 27 individuals in the 20-39 years age span had radiological evidence of T-M1 joint osteo-arthrosis.

Dorso-lateral instability was found in 45% of the T-M1 joints in the hypermobile group. Eaton and Littler (1973), Leach and Bolton (1968), Cho (1970), Eiken (1970) and Burton (1973) considered instability, in particular dorso-radial subluxation, to be a major cause of osteo-arthrosis in the T-M1 joint. As only 8% of T-M1 joints had osteo-arthrotic changes, the present study does not support the contention of the above authors, rather adding support to the work of Kessler et al. (1976) who considered that radial instability or subluxation was not related to osteo-arthrosis but rather to hypermobility.

6.64 Results and findings in the osteo-arthrotic group

1. Classification of the group according to age, gender, degree and pathogenesis of osteo-arthrosis.
2. Mobility of the T-M1 joint, including the range and quality of the physiological and accessory movements, comparisons being made with the non-clinical group.
3. Incidence of dorso-lateral instability.
4. Discussion.

The osteo-arthrotic group (N=198) consisted of 70 T-M1 joints which were directly assigned to the group on the basis of osteo-arthrosis on radiological examination, while the other 128 joints were taken from the other groups when found to have osteo-arthrotic changes.

1. Classification of T-M1 joints

a) Age and gender

The osteo-arthrotic group contained 198 T-M1 joints, 108 male and 90 female. As might be expected in a disease of middle-age, the sample contained few (6%) in the 20-29 years age group, the majority (57%) being in the 50-59 years category. The relatively low number (18%) aged between 40-49 years was due to sampling (Table 6.32).

Age Group (years)								
20 - 29		30 - 39		40 - 49		50 - 59		Total
M	F	M	F	M	F	M	F	
9	2	27	11	19	17	53	60	198

Table 6.32 Classification of T-M1 joints according to age and gender (osteo-arthrotic group, N=198)

b) Degree of osteo-arthrosis

As set out in Table 6.33, there were 130 T-M1 joints with mild osteo-arthrosis, 45 with moderate and 23 with marked osteo-arthrotic changes.

Degree of Osteo-arthrosis Mild	Moderate	Marked	Total
130 (66%)	45 (23%)	23 (11%)	198

Table 6.33 Classification of T-M1 joints according to degree of osteo-arthrosis (osteo-arthrotic group, N=198)

c) Pathogenesis of osteo-arthrosis of the thumb base

Of the 198 osteo-arthrotic T-M1 joints, 107 (54%) had degenerative changes isolated to that joint. Concomitant osteo-arthrosis was found in the trapezio-scaphoid joint in 86 (44%) cases; 29 (15%) in the trapezio-second metacarpal and 21 (11%) in the trapezio-trapezoid joint (Table 6.34).

Incidence of Osteo-arthrosis			
T - M1	Trapezio-scaphoid	Trapezio- M2	Trapezio-trapezoid
198 (100%)	86 (44%)	29 (15%)	21 (11%)

Table 6.34 Incidence of concomitant osteo-arthrosis in other trapezial articulations (osteo-arthrotic group, N=198)

Greater involvement of the other trapezial articulations was observed as the severity of osteo-arthrosis of the T-M1 joint increased. In the 130 joints with mild T-M1 osteo-arthrosis 3% had involvement of two or more of the other trapezial joints. The incidence rose to 7% and 91% in the moderate and marked categories respectively (Table 6.35).

Osteo-arthrotic Involvement	Mild O-A	Moderate O-A	Marked O-A
T-M1 joint alone	93 (71%)	14 (31%)	0
" + 1 other	34 (26%)	28 (62%)	2 (9%)
" + 2 other	2 (2%)	2 (5%)	6 (26%)
" + 3 other	1 (1%)	1 (2%)	15 (65%)
Total	130	45	23

Table 6.35 Pathogenesis of osteo-arthrosis at the thumb base (osteo-arthrotic group, N=198)

The radiographs of T-M1 joints with mild osteo-arthrosis of the T-M1 joint were examined for the site of the degenerative changes. The results (Table 6.36) show that the trapezial surface was much more frequently involved than that of M1. A small osteophyte was seen on the dorso-lateral margin of the articular surface of the trapezium in 73 (56%) joints and on the medial margin in 35 (27%) joints. The remainder had changes both medially and dorso-laterally. Of the 11 joints with mild changes on M1, nine were on the dorso-radial margin and only two medially.

Site of Osteo-arthrosis	Trapezium	M1
Medial and dorso-lateral	22 (17%)	0
Medial	35 (27%)	2 (18%)
Dorso-lateral	73 (56%)	9 (82%)
Total	130	11

Table 6.36 Site of the degenerative changes in T-M1 joints with mild osteo-arthrosis (N=130)

There was bilateral osteo-arthrosis of the T-M1 joints in 82 (83%) individuals (164 thumbs) and of the remaining 34 with unilateral involvement, 27 (82%) were on the dominant hand.

2. Mobility of the T-M1 joint

The mobility of the T-M1 joint was assessed by:

- comparing joints with mild osteo-arthrosis (N=130) with the non-clinical group
- comparing joints with more advanced osteo-arthrosis (moderate and marked categories) (N=68), with the non clinical group.

2.1 T-M1 joints with mild osteo-arthrosis

Figure 6.38, (Case number 91) is an example of early osteo-arthrosis of the T-M1 joint where there is a small radial osteophyte on the trapezium. There is no involvement of the other trapezial articulations.

Figure 6.38 **Radiograph of mild osteo-arthrosis of the T-M1 joint (postero-anterior view) (Case No. 91)**
Note small radial osteophyte on the trapezium

a) Physiological movements

Range and quality of movement

No significant difference was found in the range or quality of the physiological movements between the joints with mild osteo-arthrotic changes and those in the non-clinical group.

b) Accessory movements

Range and quality of movement

No significant difference in the range of the accessory movements between the non-clinical group and joints with mild osteo-arthrosis was found. The osteo-arthrotic joints had a significantly higher incidence (%) of abnormal scores for the quality of medial gliding ($p < .0001$), lateral rotation ($p < .005$) (Appendix XXVII).

2.2 T-M1 joints with moderate/marked osteo-arthrosis

Figure 6.39, (Case number 325) is presented as an example of marked osteo-arthrosis of the T-M1 joint with adduction deformity of the first metacarpal. There is also osteo-arthrotic involvement of the trapezial articulations with M2 and the trapezoid.

Figure 6.39 Radiographs of marked osteo-arthrosis of the T-M1 joint (Case No. 325)

Note: Adduction deformity of M1 and large radial osteophytosis (seen in postero-anterior view) and medial osteophytosis (seen in lateral view)

a) **Physiological movements**

i) **Range**

The mean range of extension and palmar-abduction was smaller in the joints with osteo-arthrosis; however, these differences were not significant, (Table 6.37).

Movement	Moderate/Marked Osteo-arthrosis	Non-clinical	't' value	significance
Extension	40°	43°	2.24	not
Palmar-abduction	45°	47°	1.88	significant
Opposition	.1°	- 1°	1.15	
Total	68	174		

Table 6.37 **Range of physiological movements of the T-M1 joint — comparison between moderate/ marked osteo-arthrotic (N=68) and non-clinical (N=174) groups**

ii) **Quality of movement**

A higher incidence of abnormal scores for the quality of the physiological movements in the osteo-arthrotic group was found. Chi square tests showed this to be significant ($p < .00001$), (Appendix XXVIII).

b) **Accessory movements**

i) **Range**

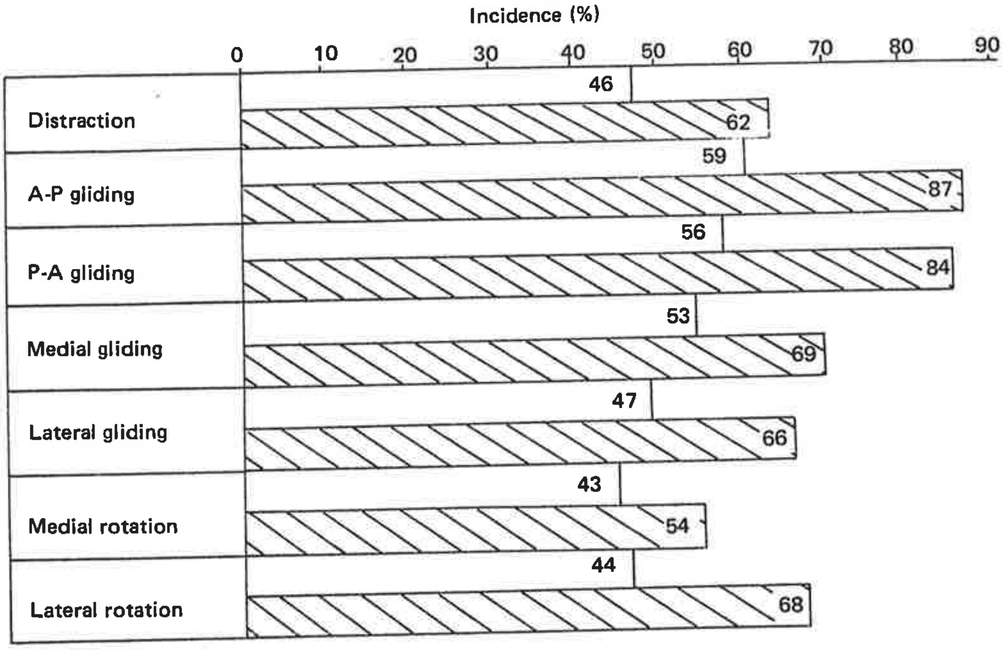
When compared with the non-clinical group there was a higher incidence of stiff scores for all seven accessory movements in the joints with moderate/marked osteo-arthrosis. This was significant for all movements ($p < .0001$) with the exception of postero-anterior gliding and medial and lateral rotation (see Appendix XXIX). Figure 6.40 illustrates the range and quality of the accessory movements for the two groups.

ii) **Quality of movement**

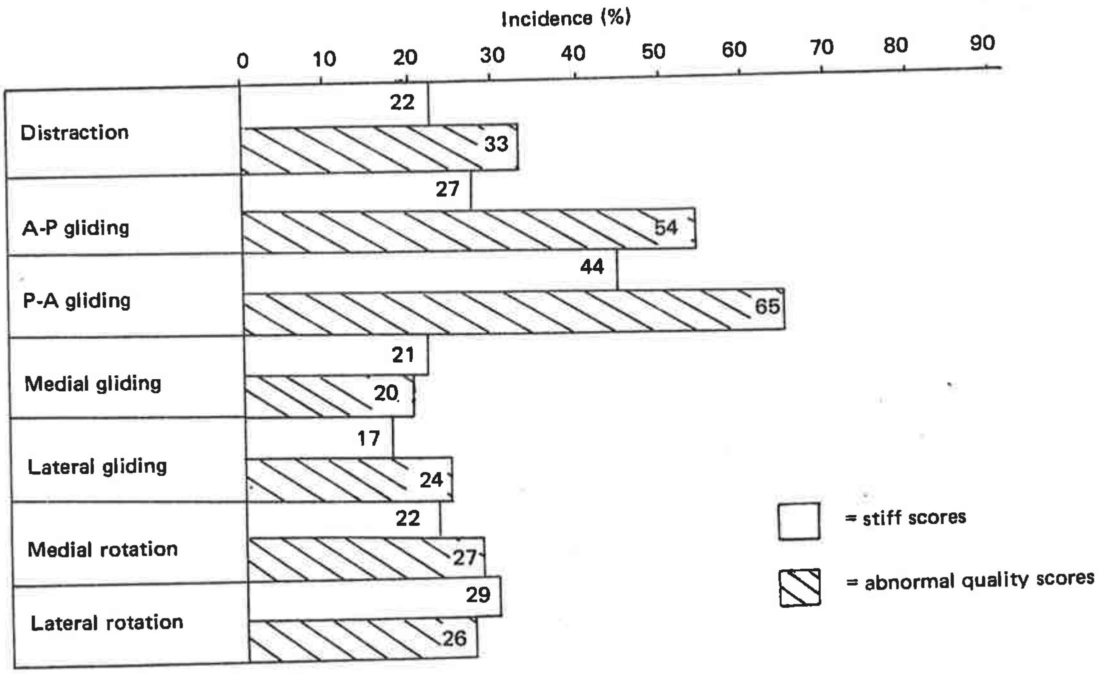
The results appear in Appendix XXVIII. The osteo-arthrotic joints had a significantly higher incidence of abnormal quality scores for each accessory movement ($p < .005$); however, this was least significant for postero-anterior gliding (Figure 6.40).

3. Incidence of dorso-lateral instability

Twenty-eight (14%) of the T-M1 joints in the osteo-arthrotic group showed a mild degree of dorso-lateral instability on the stress radiograph. There was only one joint with a moderate degree of instability (Table 6.38). The osteo-arthrotic group had a lower incidence of dorso-lateral instability than the non-clinical group; however this difference was not significant. With the exception of one joint, instability was found in T-M1 joints with mild osteo-arthrotic changes.



Moderate/marked osteo-arthrotic group (N=68)



Non-clinical group (N=174)

Figure 6.40 Incidence of stiff and abnormal quality scores for the accessory movements of the T-M1 joint – comparison between moderate/marked osteo-arthrotic and non-clinical groups

Group	Stable	Instability		Total
		Mild	Moderate	
Osteo-arthrotic	169 (85%)	28 (14%)	1 (1%)	198
Non-clinical	135 (78%)	37 (21%)	1 (1%)	174

Table 6.38 **Incidence of dorso-lateral instability – comparison between osteo-arthrotic (N=198) and non-clinical (N=174) groups**

4. Discussion

Stiffness in extension and palmar-abduction (there being only a trend for the latter) was found in the joints with more advanced stages of osteo-arthrosis. Müller (1949), Aune (1955), Swanson (1972) and Burton (1973) also described limitation of these two movements leading to an adduction deformity of M1 and compensatory hyper-extension at the metacarpo-phalangeal and inter-phalangeal joints of the thumb.

As expected, there was little difference between the non-clinical and mild osteo-arthrotic joints. The earliest changes in mobility were in the quality rather than in the range of the accessory movements. There was a significantly higher incidence (%) of abnormal scores for the two gliding movements along the medio-lateral axis of the joint (medial gliding, $p < .0001$, and lateral gliding, $p < .05$) and for lateral rotation ($p < .005$). Lateral gliding and lateral rotation are associated with extension, the movement most affected in the more advanced stages of osteo-arthrosis.

Medial and lateral osteophytes, common in the more advanced stages of osteo-arthrosis, (illustrated in the radiographs in Figure 6.39) clearly demonstrate the mechanical restriction to medial and lateral gliding. These two accessory movements, together with antero-posterior gliding (a component of extension and therefore likely to be restricted) showed the greatest difference from the non-clinical group, that is, these had the highest Chi Square values.

Postero-anterior gliding had a high incidence of stiff scores and abnormal quality scores even in 'medically normal' joints and, interestingly, the stiff scores were not significantly increased in the joints with advanced osteo-arthrosis.

Swanson (1972) found dorso-lateral instability in 16 (55%) of 29 osteo-arthrotic T-M1 joints. He considered that in the early stages of the disease effusion stretches the capsule resulting in instability. Burton (1973) also considered laxity and dorso-lateral instability to be the first stage in the pathogenesis of osteo-arthrosis. In contrast to this Leach and Bolton (1968) considered dorso-lateral instability to be secondary to osteo-arthrosis, as they found it in joints with advanced osteo-arthrotic changes. Eiken (1971) concurred with this when he described osteo-arthrosis affecting the medial and anterior aspects of the joint, the ensuing laxity in the capsule and anterior oblique ligament being the cause of the instability. Kessler et al. (1976) reported dorso-lateral instability in 22 (36%) of 61 T-M1 joints. They considered that instability was not a feature of osteo-arthrosis alone but also of joint laxity, in that it was associated with both mild and severe osteo-arthrosis. Sims and Bentley (1970) found a lower incidence of instability (6 (18%) of 33 joints with advanced osteo-arthrosis) but made no suggestion as to its cause.

In this study, 28 (14%) of 198 T-M1 joints exhibited dorso-lateral instability, all but one were associated with mild osteo-arthrotic changes. While this would appear to support the findings of Swanson (1972) and Burton (1973), a higher incidence of instability was found in the non-clinical group (22% of 174 joints) suggesting that instability is not secondary to osteo-arthrosis (see 6.62). Furthermore, the group with generalised joint hypermobility had an even higher incidence of instability (45% of 66 joints; see 6.63) which supports the concept of instability being secondary to joint laxity

Several authors (Müller, 1949; Leach and Bolton, 1968; Eaton and Littler, 1969; Carroll and Hill, 1973) considered that in most cases osteo-arthrosis is isolated to the T-M1 joint. Other authors (Aune, 1955; Sims and Bentley, 1970; Swanson, 1972; Kessler, 1973) reported the opposite, that is, they found that osteo-arthrotic changes involved most of the trapezial articulations.

The findings of this study do not support either concept in that 107 (54%) thumbs had osteo-arthrosis isolated to the T-M1 joint. The incidence (%) of osteo-arthrosis of the other joints is lower than that quoted by the above authors, this is to be expected as the populations sampled were dissimilar. This study included asymptomatic cases (mostly with mild osteo-arthrosis) whereas those of the other authors were drawn from individuals with marked radiological changes and disabling pain.

In this study the trapezio-scaphoid joint was more frequently involved (44%) than the trapezio-second metacarpal joint (15%) and the trapezio-trapezoid (11%). Osteo-arthrosis of all joints at the thumb base was found in 9% of cases.

In a review of 29 osteo-arthrotic T-M1 joints, Swanson (1972) found concomitant involvement of the trapezio-second metacarpal joint (86%), trapezio-scaphoid (48%) and trapezio-trapezoid (35%). Sims and Bentley (1970) found the trapezio-scaphoid joint to be involved in 54% of 33 cases of T-M1 osteo-arthrosis. Kessler et al. (1976) reported on the largest series (148 hands) in which 111 (75%) showed osteo-arthrosis of the T-M1 joint only. Thirty-one (21%) had involvement of all trapezial articulations; the trapezio-scaphoid showing the most degeneration.

Burton (1973) described three stages of osteo-arthrosis of the thumb base. The first two comprise osteo-arthrosis of the T-M1 joint alone with the third showing pantrapezial osteo-arthrosis, that is, involvement of one or more of the other trapezial articulations. The results of this study support his findings in that, with increasing severity of T-M1 joint osteo-arthrosis, there was a higher incidence (%) of involvement of the other trapezial articulations.

Burton (1973) and Eaton and Littler (1973) described the dorso-radial aspect of the trapezium as being the first site of osteo-arthrosis of the T-M1 joint; whereas Lassère et al. (1949) and Weinman and Lipscomb (1967) implicated the medial aspect. Results of this study lend support to the former, as 56% of joints with mild osteo-arthrosis showed a small osteophyte on the dorso-radial aspect of the trapezium, 27% had a small medial osteophyte and the remaining 17% had involvement of both the medial and lateral articular margins of the trapezium. The first metacarpal was less frequently involved, showing a small dorso-radial osteophyte in 6% of T-M1 joints.

In this study 83% had bilateral osteo-arthrosis of the T-M1 joint and, of those with unilateral involvement, 82% were on the dominant hand. Kessler et al. (1976), who reported on the only sample of any size, found a very similar distribution of osteo-arthrosis. They found bilateral involvement in 65% of thumbs; of the unilateral cases, 77% were on the dominant side. The higher incidence of osteo-arthrosis in the dominant hand may reflect the fact that this T-M1 joint is subjected to more forceful compressive forces during thumb function with resultant cartilage damage.

6.65 Results and discussion of findings in the occupational groups

The results of the three occupational groups, (a) manipulative therapists, (b) tailors and dressmakers and (c) musicians, will be discussed separately as few direct comparisons can legitimately be made between the groups as various constraints are imposed by the occupational populations sampled. First, there are few manipulative therapists in Australia who fulfil the criteria (25 in all, of whom 20 were examined); they tend to be in the younger age groups and to have fewer years of use than the other two professional groups sampled. Second, because of technological advances, individuals are no longer entering the tailoring and dressmaking professions, thus the sample is characterised by older individuals with many years of thumb use at their trade. Third, while a wide age range existed in the musicians sampled, only professional musicians were examined, thus years of use were generally high.

The results of each occupational group will follow the same format as previous sections:

1. Classification of the group according to age and gender.
2. Mobility of the T-M1 joint, including the range and quality of the physiological and accessory movements, comparisons being made with the non-clinical group.
3. Incidence of osteo-arthrosis of the T-M1 joint.
4. The relationship of years of occupational use, hand dominance and side to the mobility and osteo-arthrosis of the T-M1 joint.
5. Discussion.

Manipulative therapists group

1. Classification of the group according to age and gender

The T-M1 joints of 20 manipulative therapists were examined (Table 6.39). In this sample the majority were male (male:female = 3:1) and most (75%) were in the 30-39 years age group, which reflects the population of manipulative therapists in Australia. Manipulative therapy, as a specialty within Physiotherapy, has developed since 1965 and attracts more men than women.

Age Group (years)								
20 - 29		30 - 39		40 - 49		50 - 59		Total
M	F	M	F	M	F	M	F	
0	4	26	4	2	2	2	0	40

Table 6.39 Classification of T-M1 joints according to age and gender (manipulative therapists group, N=40)

2. T-M1 joint mobility

Sex and age have been shown to significantly influence T-M1 joint mobility (6.61), thus the comparison with the non-clinical group was restricted to males in the 30 to 39 years age category as this comprised 65% of the manipulative therapists group.

Physiological and accessory movements

There was no significant difference between the manipulative therapists and non-clinical groups in the range or quality of the physiological and accessory movements.

3. Incidence of osteo-arthrosis of the T-M1 joint

Twenty (50%) of the T-M1 joints were found to have mild osteo-arthrotic changes on X-ray while only one joint (2%) exhibited a moderate degree of osteo-arthrosis (Table 6.40).

Radiological findings				
Normal	Mild O-A	Moderate O-A	Marked O-A	Total
19 (48%)	20 (50%)	1 (2%)	0	40

Table 6.40 Incidence of osteo-arthrosis (O-A) of the T-M1 joint (manipulative therapists group, N=40)

4.1 Years of occupational use

In 6.61 it was shown that use of the thumb was not significantly related to the mobility of the T-M1 joint until after 15 years of use. Due to the nature of the manipulative therapist population (Table 6.41), that is, that only two had been subjected to over 14 years of occupational use, it was inappropriate to statistically analyse the influence of occupational use.

Occupational Use (years)	Frequency
5 - 9	26
10 - 14	10
15 - 19	2
20 & over	2
Total	40

Table 6.41 Classification of T-M1 joints according to occupational use (manipulative therapists group, N=40)

4.2 Side and dominance

Manipulative therapists use their thumbs equally during passive mobilisation thus the influence of side and dominance was not analysed.

Tailors and dressmakers group

1. Classification of the group according to age and gender

The T-M1 joints of 36 tailors and dressmakers were examined. As set out in Table 6.42, the sample contained no-one in the 20-29 years age group and only five (10 thumbs) in the 30-39 years group. This reflects the present state of this occupation, that is, machine-made clothing has overtaken the more time-consuming, and therefore more expensive, hand-sewn clothing. The ratio of males to females was 5:4.

Age Group (years)								
20 - 29		30 - 39		40 - 49		50 - 59		Total
M	F	M	F	M	F	M	F	
0	0	4	6	16	12	20	14	72

Table 6.42 Classification of T-M1 joints according to age and gender (tailors and dressmakers group, N=72)

2. T-M1 joint mobility

As there were only 10 (14%) T-M1 joints below the age of 40 years, comparison between the tailors and dressmakers and non-clinical groups was restricted to the 40 to 59 years age span.

Physiological and accessory movements

There was no significant difference in the range or quality of the physiological and accessory movements between the tailors and dressmakers and non-clinical groups.

3. Incidence of osteo-arthrosis of the T-M1 joint

Fifty-six (78%) of the T-M1 joints had radiological evidence of osteo-arthrosis. Thirty-three had mild changes, 21 moderate changes and two showed marked osteo-arthrosis (Table 6.43).

Radiological Findings				
Normal	Mild O-A	Moderate O-A	Marked O-A	Total
16 (22%)	33 (46%)	21 (29%)	2 (3%)	72

Table 6.43 Incidence of osteo-arthrosis (O-A) of the T-M1 joint (tailors and dressmakers group, N=72)

A significant relationship was found between the radiological findings and age ($X^2 = 14.22$, $p < .01$). The greatest increase in both the incidence and severity occurred in the sixth decade (Table 6.44).

Age	Radiological Findings			Total
	Normal	Mild O-A	Moderate/ Marked O-A	
30 - 39	4 (40%)	4 (40%)	2 (20%)	10
40 - 49	11 (39%)	9 (32%)	8 (29%)	28
50 - 59	1 (3%)	20 (59%)	13 (38%)	34
Total	16	22	23	72

Table 6.44 Relationship between age and radiological findings in the T-M1 joint (tailors and dressmakers group, N=72)

No significant association was found between the radiological findings and the range and quality of the physiological and accessory movements of the T-M1 joint.

4.1 Years of occupational use and dominance

In the tailors and dressmakers group 58 (81%) of the thumbs had been subjected to 20 or more years of use at the trade with only a small number in each of the other categories (Table 6.45).

Occupational Use (years)	Frequency
10 - 14	8
15 - 19	6
20 & over	58
Total	72

Table 6.45 **Classification of T-M1 joints according to occupational use (tailors and dressmakers group, N=72)**

As tailors and dressmakers use their dominant hand almost exclusively in their trade, the effect of occupational use can be assessed by comparing the dominant and non-dominant hands in a matched pairs analysis.

The T-M1 joint of the dominant hand was significantly stiffer in opposition (Sandler's 'A' statistic = 0.13, $p < .005$) and more mobile in postero-anterior gliding (Wilcoxon test, 'T' = 23.5, $p < .005$). There was a significantly higher incidence of osteo-arthrosis of the T-M1 joint on the dominant side (Wilcoxon test, 'T' = 44, $p < .005$).

Musicians group

1. Classification of the group according to age and gender

The T-M1 joints of 35 musicians (violin, viola and 'cello players) were examined. There were fewer T-M1 joints in the 40-49 years age group and the number of male and female joints was 44 and 26 respectively (Table 6.46).

Age Group (years)								
20 - 29		30 - 39		40 - 49		50 - 59		Total
M	F	M	F	M	F	M	F	
16	12	4	10	6	0	18	4	70

Table 6.46 **Classification of T-M1 joints according to age and gender (musicians group, N=70)**

2. Mobility of the T-M1 joint

a) Physiological movements

i) Range

The musician group was stiffer than the non-clinical group in opposition (having a mean range of -4° compared with a mean of -1° (Table 6.47). This difference was not statistically significant although the Student's 't' test supported a trend ($p < .05$). There was no difference between the means of the two groups for extension and palmar-abduction.

Movement	Musicians Mean	Musicians S.D.	Non-clinical Mean	Non-clinical S.D.	't' value	significance
Extension	43°	7.5	43°	8.2	0.01	not significant
Palmar-abduction	47°	7.2	47°	7.1	0.20	not significant
Opposition	- 4°	6.8	- 1°	10.0	1.95	$p < .05$

Table 6.47 Range of physiological movements of the T-M1 joint — comparison between musicians (N=70) and non-clinical (N=174) groups

ii) **Quality of movement**

No significant difference was found between the musician and non-clinical groups for the quality of the physiological movements.

b) **Accessory movements**

i) **Range**

Results of the range of the accessory movements are listed in Appendix XXX. With the exception of distraction, when compared with the non-clinical group little difference existed between the groups. The musician group had significantly fewer stiff scores for distraction ($X^2 = 14.11, p < .001$).

ii) **Quality of movement**

No significant difference existed between the musician and non-clinical groups for the quality of the accessory movements.

3. Incidence of osteo-arthrosis of the T-M1 joint

Forty-five (64%) of the T-M1 joints were found to have radiological evidence of osteo-arthrosis, and of these 32 were classed as mild, 11 as moderate and two as having a marked degree of osteo-arthrosis (Table 6.48).

	Radiological Findings			
Normal	Mild O-A	Moderate O-A	Marked O-A	Total
25 (36%)	32 (46%)	11 (15%)	2 (3%)	70

Table 6.48 Incidence of osteo-arthrosis (O-A) of the T-M1 joint (musicians group, N=70)

The radiological findings were found to be significantly related to age ($X^2 = 34.24, p < .00001$). From Table 6.49, it can be seen that both the incidence and degree of osteo-arthrosis increased with advancing age. Thirty-six percent of those in the 20-29 years age group had osteo-arthrosis and this had increased to 100% by the fifth decade.

Radiological Findings	Age Group (years) 20 - 29	30 - 39	40 - 49	50 - 59
Normal	18 (64%)	7 (50%)	0	0
Mild O-A	10 (36%)	6 (43%)	4 (67%)	12 (54%)
Moderate/ Marked O-A	0	1 (7%)	2 (33%)	10 (46%)
Total	28	14	6	22

Table 6.49 Relationship between age and osteo-arthrosis (O-A) of the T-M1 joint (musicians group N=70)

4.1 Years of occupational use

There were 24 T-M1 joints in the 10 to 14 years category, 10 in the 15 to 19 years and the remaining 36 had 20 or more years of use (Table 6.50).

Occupational Use (years)	Frequency
10 - 14	24
15 - 19	10
20 & over	36

Table 6.50 Classification of T-M1 joints according to occupational use (musicians group, N=70)

i) **Relationship to the physiological movements**

Years of occupational use were found to have no significant association with the range of the three physiological movements and no marked change in the quality of those movements was evident until after 20 or more years of use (Table 6.51). This relationship was not statistically significant.

	Occupational Use (years)		
Movement	**10 - 14**	**15 - 19**	**20 or more**
Extension	0	0	6
Palmar-abduction	0	1	8
Opposition	1	4	13

Table 6.51 Relationship between occupational use and the incidence of abnormal scores for the quality of the physiological movements of the T-M1 joint (musicians group, N=70)

ii) **Relationship to the accessory movements**

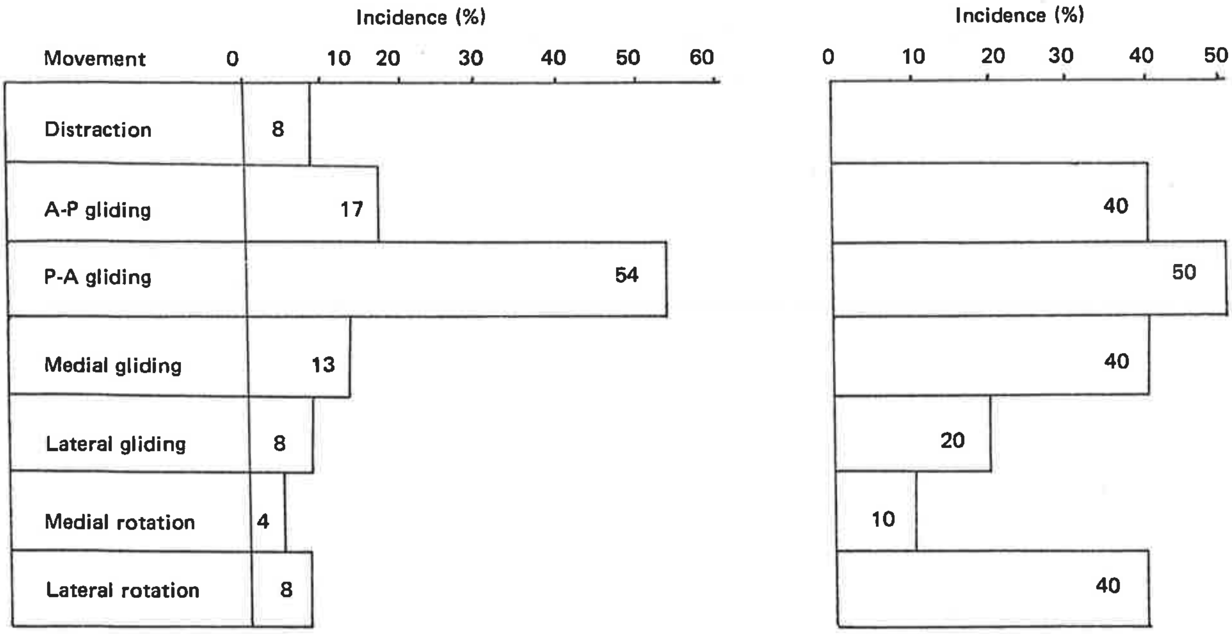
The relationship of occupational use to the range and quality of the accessory movements is tabled in Appendices XXXI and XXXII.

There was a trend towards the incidence (%) of stiff scores rising with cumulative use for distraction, antero-posterior and lateral gliding ($p < .05$). The ranges of the other accessory movements were not significantly associated with use.

Occupational use had a more noticeable influence on the quality of the accessory movements. For most movements the greatest increase in percentage of abnormal scores occurred after 20 years of use (Figure 6.41). Use had the greatest influence on the quality of antero-posterior gliding ($p < .0005$); however, a trend ($p < .05$) was found with the other movements.

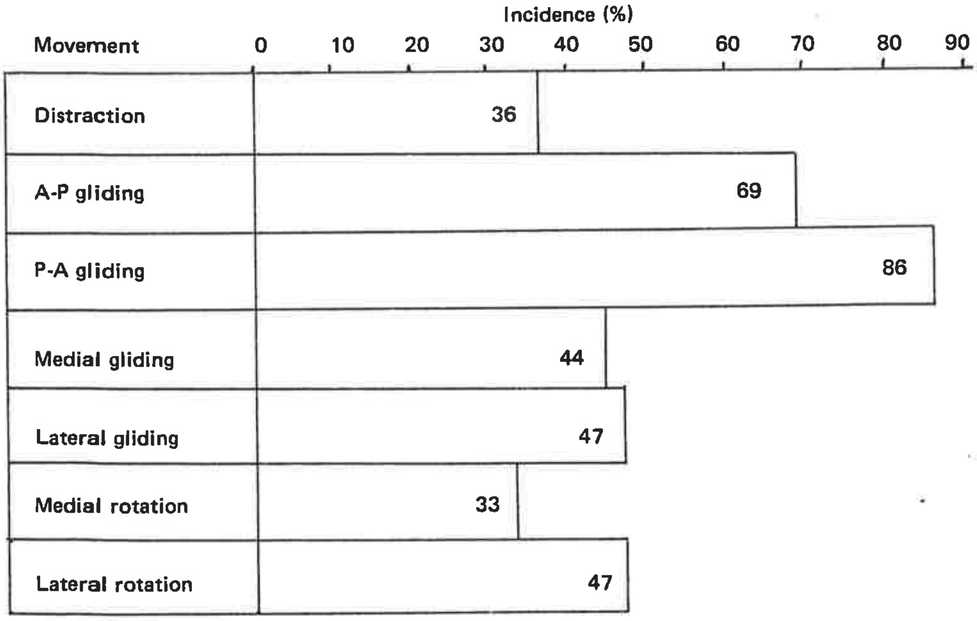
iii) **Relationship to the incidence of osteo-arthrosis of the T-M1 joint**

The incidence (expressed as a percentage) of the osteo-arthrosis rose with increased occupational use, there being a fairly even rise, of approximately 30%, between the three categories of use (Table 6.52). After 20 years there was an increase in the severity or degree of osteo-arthrosis, 36% having moderate to marked changes. The relationship between occupational use and osteo-arthrosis of the T-M1 joint was significant ($X^2 = 21.12$, $p < .0001$).



10 - 14 years of use (N=24)

15 - 19 years of use (N=10)



20 and over years of use (N=36)

Figure 6.41 Relationship between occupational use and the incidence (%) of abnormal scores for the quality of the accessory movements of the T-M1 joint (musicians group, N=70)

Radiological Findings	Occupational Use (years)		
	10 - 14	15 - 19	20 & over
Normal	17 (71%)	4 (40%)	4 (11%)
Mild O-A	7 (29%)	6 (60%)	19 (53%)
Moderate/Marked O-A	0	0	13 (36%)

Table 6.52 **Relationship between occupational use and the incidence of osteo-arthrosis of the T-M1 joint (musicians group, N=70)**

4.2 Thumb function: left and right side

Regardless of hand dominance the violin and viola are stabilised with the chin and left hand, and similarly the neck of the 'cello is stabilised by the left thumb against pressure of the fingers on the strings; with each instrument the bow is held in the right hand. The mobility of the left and right T-M1 joint was compared using a matched pairs analysis.

The right T-M1 joints were significantly more mobile for opposition and the two accessory movements associated with opposition, postero-anterior and medial gliding ($p < .005$) but there was no significant difference between the left and right sides for the range and quality of the other movements or for the incidence of T-M1 joint osteo-arthrosis.

5. Discussion

5.1 Manipulative therapists group

Due to the nature of this relatively young group, (85% being aged below 40 years and the thumbs of only two therapists having over 14 years of occupational use) no comparative information could be gained with regard to radiological changes or the influence of thumb use. These factors, young age and low usage, may account for there being no significant difference in the mobility of the T-M1 joint between the 30-39 year old male joints of this and the non-clinical groups. Clearly a follow-up study in 10 to 15 years' time is required.

5.2 Tailors and dressmakers group

This group was characterised by individuals in the older age groups (only 14% were younger than 40 years) with many years at their trade (81% had 20 or more years of experience). The effect of occupational use was assessed by comparing the dominant with the non-dominant side as tailors and dressmakers use their dominant hand (thumb) almost exclusively at their trade.

There was a significantly higher incidence of osteo-arthrosis of the T-M1 joint on the dominant side ($p < .005$). As it was a matched pairs study the variables of age and gender were controlled, permitting the observation that T-M1 joint osteo-arthrosis was affected by occupational use.

Opposition to the little finger, which incorporates adduction of the first metacarpal, was significantly stiffer on the dominant side ($p < .005$). This is consistent with the habitual position of abduction of the first metacarpal used in sewing with a needle held between the tips of the thumb and index finger.

5.3 Musicians group

Although occupational use as a musician showed no significant relationship to the range or quality of the physiological movements, the results showed a trend towards a higher incidence (%) of stiff scores (for distraction, antero-posterior and lateral gliding, $p < .05$) and abnormal quality scores for all the accessory movements ($p < .05$). This was significant for antero-posterior gliding ($p < .0001$) and lateral gliding ($p < .005$). This increase (%) was more noticeable after 20 years of thumb use. Loss of distraction range is indicative of capsular and ligamentous stiffness which may result from years of holding the thumbs relatively static. Antero-posterior and lateral gliding are associated with extension of the T-M1 joint, a movement not used in playing the violin, viola or 'cello.

A significant increase was found in the incidence (%) of osteo-arthrosis of the T-M1 joint with cumulative use ($p < .0001$), with a rise in its severity after 20 years. Professional musicians are one group of individuals who commence using their hands (and in particular their thumbs) from an early age. This is likely to account for the relatively high incidence (36%) of osteo-arthrosis in the 20 to 29 years age group.

Regrettably there are no norms for osteo-arthrosis of this joint and little value can be gained by making comparisons with the results of other authors, discussed in the literature review, which are based on sample populations with severe and disabling osteo-arthritis.

The importance of movement to the maintenance of nutrition of the articular cartilage has been demonstrated by the experimental work of Caterson and Lowther (1978). The musicians represent one occupation in which the thumb is not regularly exercised through different ranges of movements, but rather held statically for periods of several hours (professional musicians commonly practise continuously for three to four hours).

The force exerted by the right thumb during stabilisation of the bow is unknown. However, Cooney and Chao (1977) have shown that during a pinching force of 1 Kg between the thumb tip and the index finger a compressive force of 12 Kg is developed across the articular surfaces of the T-M1 joint. Other workers (Salter and Field, 1960; Bullough and Walker, 1976; Madrigal and Schwartz, 1979) have demonstrated that articular cartilage is susceptible to compressive forces. These findings lend support to this occupational group being one in which the articular cartilage of the T-M1 joint is 'at risk'.

Osteo-arthrosis of the T-M1 joint was also significantly related to age ($p < .00001$), but it was not possible to analyse the separate effects of occupational use and age.

Results showed a trend towards the T-M1 joints of musicians being stiffer in opposition than those of the non-clinical group ($p < .05$). At first this finding seemed contrary to expectation in that musicians hold their thumbs in a position of opposition while playing their musical instrument. A closer look at the position of their thumbs reveals the reason for this apparent discrepancy. The left thumb, in supporting the neck of the instrument, is held in palmar-abduction. Due to the thickness of the instrument's neck, the first metacarpal is held in abduction. On the right side, the thumb is opposed to the middle finger and in this case, with a smaller object, the first metacarpal is adducted. However, the test position used in this study was opposition to the little finger, which is not an habitual position for the thumbs of these musicians.

It is unclear why the difference between the musicians and non-clinical groups should manifest itself in opposition rather than extension.

As presented above, the two thumbs were held for long periods but in different positions. Analysis of the relationship of left and right side to the mobility of the T-M1 joint showed the right to be significantly more mobile for opposition and the two accessory movements associated with opposition, namely postero-anterior and medial gliding ($p < .005$). This is consistent with the positions in which the two thumbs are held during the playing of the violin, viola and 'cello. As both thumbs are held statically for long periods one would not expect the incidence of osteo-arthrosis to be different on the two sides and indeed no significant difference was found.

6.66 Relationship of adjacent joint mobility to the range of passive movements of the T-M1 joint

1. Mobility of the metacarpo-phalangeal (McP) joint of the thumb.
2. Mobility of the trapezial articulation with the second metacarpal (M2), trapezoid and scaphoid.
3. Results.
4. Discussion.

The joints adjacent to the T-M1 joint are the metacarpo-phalangeal (McP) joint of the thumb and the trapezial articulations with the second metacarpal (M2), trapezoid and scaphoid.

Results of the relationship of adjacent joint mobility to the range of the physiological and accessory movements of the T-M1 joint are presented for the total population sampled (N= 492). The mobility of the adjacent joints is presented first, followed by an analysis of their relationship to the mobility of the T-M1 joint.

1. Mobility of the metacarpo-phalangeal (McP) joint of the thumb

The mean range of flexion was 63.9^{o} while the mean for extension was 43^{o} (Table 6.53). The relatively large standard deviation for both movements indicates wide individual differences.

Movement	Mean	S.D.
Flexion	63.9^{o}	15
Extension	43.0^{o}	17

Table 6.53 Mobility of the metacarpo-phalangeal joint of the thumb (whole sample, N=492)

2. Mobility of the trapezial articulation with the second metacarpal (M2), trapezoid and scaphoid

The incidence of mobile and stiff scores for antero-posterior (A-P) and postero-anterior (P-A) gliding of the trapezial articulations with M2, trapezoid and scaphoid are given in Table 6.54.

The three joints showed a similar incidence of stiff scores for A-P gliding. P-A gliding was more frequently stiff when compared with A-P gliding especially for the trapezio-scaphoid and trapezio-trapezoid joints.

Joint	Movement	Range of Movement	
		Mobile	Stiff
Trapezio-M2	A-P gliding	457	35
	P-A gliding	447	45
Trapezio-trapezoid	A-P gliding	457	35
	P-A gliding	417	75
Trapezio-scaphoid	A-P gliding	454	38
	P-A gliding	407	85

Table 6.54 Mobility of the trapezial articulation with M2, trapezoid and scaphoid (whole sample, N=492)

The following movement comparisons were made on the basis that stiffness in one joint could be, in part, compensated for by increased mobility in the other joint:

i) metacarpo-phalangeal flexion with T-M1 opposition
ii) metacarpo-phalangeal extension with T-M1 extension and palmar-abduction
iii) antero-posterior gliding of the three trapezial articulations with antero-posterior gliding of the T-M1 joint
iv) postero-anterior gliding of the three trapezial articulations with postero-anterior gliding of the T-M1 joint.

3. Results

(i) Using the Pearson correlation coefficient no significant correlation was found between metacarpo-phalangeal flexion and T-M1 joint opposition, or between metacarpo-phalangeal extension and T-M1 joint extension and palmar-abduction.

(ii) - (iv) Rather than the expected finding of a negative relationship between the mobility of the accessory movements of the T-M1 joint and its adjacent joints, the opposite was found. Stiffness in the T-M1 joint was associated with stiffness in the other three joints (Table 6.55). This relationship was significant for trapezio-M2 antero-posterior gliding, trapezio-trapezoid antero-posterior and postero-anterior gliding ($p < .0001$); also a trend was supported for trapezio-M2 postero-anterior gliding ($p < .01$) and trapezio-scaphoid antero-posterior gliding ($p < .05$).

Joint (stiff scores)	T-M1 Joint Mobility			Total	X^2 value	significance
	Hypermobile	Normal	Stiff			
Trapezio-M2 stiff	2	9	24	35	28.05	$p < .00001$
Trapezio-trapezoid stiff	2	11	22	35	20.93	$p < .00001$
Trapezio-scaphoid stiff	2	22	14	38	6.16	$p < .05$

(a) Antero-posterior gliding

Joint (stiff scores)	T-M1 Joint Mobility			Total	X^2 value	significance
	Hypermobile	Normal	Stiff			
Trapezio-M2 stiff	5	10	30	45	10.42	$p < .01$
Trapezio-trapezoid stiff	8	16	51	75	20.87	$p < .00001$
Trapezio-scaphoid stiff	10	32	43	85	3.96	not significant

(b) Postero-anterior gliding

Table 6.55 Comparison of T-M1 mobility scores with stiff scores of the trapezial articulations with M2, trapezoid and scaphoid for a) antero-posterior gliding; b) postero-anterior gliding (whole sample, N=492)

4. Discussion

In this sample of 492 thumbs, stiffness in the T-M1 joint was not associated with compensatory increased mobility in its adjacent joints, or vice versa. In contrast, stiffness in the accessory movements of the T-M1 joint was associated with stiffness in the three adjacent joints.

Compensatory increased mobility at one or more adjacent joints following surgical fusion of the T-M1 joint has been reported by a number of authors (Müller, 1949; Kaplan, 1966; Eiken and Carstam, 1970; Swanson, 1972 and Carroll and Hill, 1973). Absence of movement in the physiological and accessory tests, comparable with surgical fusion, was an extremely rare finding in the T-M1 joints in the present study (0.06% of movements tested). Clearly the present sample is not comparable with those of the above authors and this is a likely explanation for the difference in findings.

6.67 Relationship between osteo-arthrosis of the T-M1 joint and menstrual status and between osteopenia and menstrual status

1. Classification according to menstrual status
2. Incidence of osteopenia
3. Incidence of osteo-arthrosis in female T-M1 joints
4. Relationship between osteo-arthrosis of the T-M1 joint and menstrual status
5. Discussion.

1. Classification according to menstrual status

Of the 132 females (264 T-M1 joints) in this study 80 (61%) were pre-menopausal, 11 (8%) were menopausal and 41 (31%) were either post-menopausal or post-hysterectomy (Table 6.56).

Menstrual Status			
Pre-menopausal	Menopausal	Post-menopausal	Total
80 (61%)	11 (8%)	41 (31%)	132

Table 6.56 **Classification of female subjects according to menstrual status**

Note: post-menopausal includes post-hysterectomy

Menstrual status was significantly related to age (X^2 = 244.13, $p < .00001$) (Table 6.57).

Age (years)	Menstrual Status			Total	X^2 value
	Pre-menopausal	Menopausal	Post-menopausal		significance
20 - 39	128	0	2	130	244.13
40 - 59	32	22	82	136	$p < .00001$
Total	160	22	84	264	

Table 6.57 **Classification of female T-M1 joints according to age and menstrual status**

Note: post-menopausal includes post-hysterectomy

2. Incidence of osteopenia

In 68 females, aged 40 years and over, radiogrammetry showed that six (9%) were osteopenic, that is, they had percentile values of less than 13 (Appendix XXXIII). These six females were from the post-menopausal/post-hysterectomy group. With so few cases of osteopenia it was inappropriate to analyse the relationship between osteopenia and menstrual status.

3. Incidence of osteo-arthrosis in female T-M1 joints

Of the 264 female T-M1 joints 92 (35%) showed osteo-arthrotic changes on X-ray. Fifty-five (21%) had mild osteo-arthrosis and 37 (14%) moderate or marked changes (Table 6.58).

Radiological Findings			
Normal	Mild O-A	Moderate & Marked O-A	Total
172 (65%)	55 (21%)	37 (14%)	264

Table 6.58 **Incidence of osteo-arthrosis in female T-M1 joints**

4. Relationship between menstrual status and osteo-arthrosis of the T-M1 joint

A higher incidence (72%) of osteo-arthrosis of the T-M1 joint was found in post-menopausal/post-hysterectomy women compared with 16% and 32% in the pre-menopausal and menopausal categories respectively (Table 6.59). Osteo-arthrosis was also more advanced in the post-menopausal/post-hysterectomy group. The relationship between menstrual status and osteo-arthrosis of the T-M1 joint was significant (X^2 = 80.91, $p < .00001$).

Menstrual Status	Radiological Findings			Total
	Normal	Mild O-A	Mod./Marked O-A	
Pre-menopausal	134 (84%)	19 (12%)	7 (4%)	160
Menopausal	15 (68%)	6 (27%)	1 (5%)	22
Post-menopausal	23 (28%)	30 (37%)	29 (35%)	82
Total	172	55	37	264

Table 6.59 Relationship between menstrual status and osteo-arthrosis of the T-M1 joint

Note: post-menopausal includes post-hysterectomy

Two separate analyses were performed, on dominant thumbs only, to assess the relationship between menstrual status and osteo-arthrosis independent of age.

In the first analysis the Chi Square value was computed for age by menstrual status by osteo-arthrosis and partitioned into orthogonal components (Winer, 1971). The total Chi Square was partitioned into independent additive components of age by osteo-arthrosis, age by menstrual status, menstrual status by osteo-arthrosis and age by menstrual status by osteo-arthrosis.

The Chi Square partitioning (Table 6.60) indicated a significant association between age and menstrual status (partial $X^2 = 53.0$, $p < .001$), this accounted for 50.4% of the total variability in the data. The independent association between age and osteo-arthrosis was significant (partial $X^2 = 21.2$, $p < .001$), accounting for 19.7% of the total variability. Menstrual status and osteo-arthrosis were significantly related (partial $X^2 = 28.3$, $p < .001$) and accounted for 26.4% of the total variability. The age by osteo-arthrosis by menstrual status interaction was not statistically significant.

A similar analysis was undertaken for age by gender by osteo-arthrosis data (Table 6.61). This analysis confirmed a significant association between age and osteo-arthrosis (partial $X^2 = 26.8$, $p < .001$) which accounted for 74.9% of the total variability. It also showed a significant partial association between gender and osteo-arthrosis (partial $X^2 = 7.6$, $p < .01$), which accounted for 21.4% of the total variability. The age by gender by osteo-arthrosis effect was not significant nor was the age by gender effect.

Examination of the frequency of osteo-arthrosis of the T-M1 joint in the older age group (40 - 59 years) showed that the male rate was 66% while that for females was 33% in the pre-menopausal group and 68% for the menopausal/post-menopausal/post-hysterectomy group. In the younger age group (20 - 39 years) the incidence of osteo-arthrosis was 38% in men, 12% in pre-menopausal females and 25% in the menopausal/post-menopausal/post-hysterectomy group.

5. Discussion

On the basis of case studies alone, hormonal imbalance was postulated the likely reason why osteo-arthrosis of the T-M1 joint is found predominantly in middle aged women (Aune, 1955; Eiken and Carstam, 1970 and Sims and Bentley, 1970). To the author's knowledge this is the first study to put this postulation to test.

Taken together, the two analyses performed to assess the relationship between menstrual status and osteo-arthrosis of the T-M1 joint independent of age, suggest that menstruation is a significant factor in lowering the incidence of osteo-arthrosis. In the older age group (40 - 59 years) the male osteo-arthrosis rate was 66% compared with 33% in pre-menopausal females and 68% in the menopausal/post-menopausal/post-hysterectomy group (as for males). In the younger age group (20 - 39 years) the male osteo-arthrosis rate was 38%. In females still menstruating the incidence of osteo-arthrosis was 12% while the rate for the young menopausal/post-menopausal/post-hysterectomy group was 25%, more like that of young males, but this estimate is based on only four cases. Over-all the data suggest a protective value in the menstrual cycle or something underlying its physiology.

Hormonal imbalance in post-menopausal women is considered to be an important factor in the development of osteoporosis and osteopenia (Gitman and Kamholtz, 1965; Nordin et al., 1975; Lindsay et al., 1976, 1977; Reeve et al., 1976 and Marshall et al., 1977). In the present study six (15%) of 41 post-menopausal/post-hysterectomy women were found to be osteopenic. While so few cases make it inappropriate to analyse the relationship between osteopenia and menstrual status, it would appear that the results do not support the findings of the above authors. It may well be that the level of hormonal imbalance needed to produce osteopenia was not present in these 41 women. Measurement of circulating hormones was clearly outside the scope of this study.

ABC = age by menstrual status by osteo-arthrosis of T-M1 joint

Age	Menstrual Status				Total
	Pre-menopausal		Menopausal		
	Normal	O-A	Normal	O-A	
20 - 39	54	7 (12%)	1	2 (25%)	65
40 - 59	10	5 (33%)	12	26 (68%)	53
Total	64	12	15	27	118

X^2 TOT (adj) = 107.11

AB = age by menstrual status

Age	Menstrual Status		Total
	Pre-menopausal	Menopausal	
20 - 39	61	4	65
40 - 59	15	38	53
Total	76	42	118

X^2 AB = 53.93 ($p < .001$)

AC = age by osteo-arthrosis of the T-M1 joint

Age	Radiological Findings		Total
	Normal	O-A	
20 - 39	57	8	65
40 - 59	22	31	53
Total	79	39	118

X^2 AC (adj) = 21.13 ($p < .001$)

BC = menstrual status by osteo-arthrosis of the T-M1 joint

Menstrual Status	Radiological Findings		Total
	Normal	O-A	
Pre-menopausal	64	12	76
Menopausal	15	27	42
Total	79	39	118

X^2 BC (adj) = 28.31 ($p < .001$)

X^2 ABC = X^2 TOT − X^2 AB − X^2 AC − X^2 BC = 3.73 (not significant)

Table 6.60 Chi Square partitioning for the relationship between age, menstrual status and osteo-arthrosis of the T-M1 joint

Menopausal includes post-menopausal and post-hysterectomy cases
O-A = osteo-arthrosis
Analysis performed on dominant thumbs only

ABC = age by gender by osteo-arthrosis of the T-M1 joint

Age	Male		Female		Total
	Normal	O-A	Normal	O-A	
20 - 39	35	21 (38%)	54	8 (13%)	118
40 - 59	19	37 (66%)	25	31 (55%)	112
Total	54	58	79	39	230

X^2 TOT (adj) = 35.77

AB = age by gender

Age	Male	Female	Total
20 - 39	56	62	118
40 - 59	56	56	112
Total	112	118	230

X^2 AB (adj) = 0.11 (not significant)

AC = age by osteo-arthrosis of the T-M1 joint

Age	Radiological Findings		Total
	Normal	O-A	
20 - 39	89	29	118
40 - 59	44	68	112
Total	133	97	230

X^2 AC = 26.79 ($p < .001$)

BC = gender by osteo-arthrosis of the T-M1 joint

Gender	Radiological Findings		Total
	Normal	O-A	
Male	54	58	112
Female	79	39	118
Total	113	97	230

X^2 BC (adj) = 7.64 ($p < .01$)

X^2 ABC = X^2 TOT – X^2 AB – X^2 BC – X^2 AC = 1.22 (not significant)

Table 6.61 Chi Square partitioning for the relationship between age, gender and osteo-arthrosis of the T-M1 joint

O-A = osteo-arthrosis
Analysis performed on dominant thumbs only

6.7 Summary

To the author's knowledge this clinical study of 492 T-M1 joints involving a questionnaire and physical and radiological examination is the most detailed clinical study reported to date. The published literature deals almost exclusively with the management of osteo-arthritis of the T-M1 joint.

To allow for cumulative error in analyses involving several movements of the T-M1 joint a conservative per test error rate of $p < .005$ *was adopted.*

The results of this study cannot be generalised to the normal population as selection methods were based on specific criteria pertaining to osteo-arthrosis, hypermobility or occupation.

6.71 Results of the relationship of specific demographic variables are summarised below.

1. Gender

The sample contained 228 male and 264 female T-M1 joints. Females were significantly more mobile for opposition ($p < .005$) while males had a significantly greater mean range for extension and palmar-abduction ($p < .0001$).

In contrast to the many reports in the literature, men were found to have a significantly higher incidence (%) of osteo-arthrosis of the T-M1 joint ($p < .0005$). In the main the reports cited in the literature were based on T-M1 joints with marked osteo-arthritis with disabling pain. The results of the present study are not comparable because there were no cases of severe pain or disability, and it contained both asymptomatic and symptomatic joints.

2. Age

With the exception of palmar-abduction, the physiological and accessory movements of the T-M1 joint became significantly stiffer with advancing age ($p < .005$). Ageing had a more marked influence on the range and quality of the accessory movements than on the physiological movements. The incidence (%) of stiff scores and abnormal quality scores rose after the fifth decade.

The incidence (%) of osteo-arthrosis rose significantly with increasing age ($p < .00001$), the osteo-arthrotic changes being more marked in the fifth and sixth decades.

3. Past history of pain at the thumb base

Excluding the non-clinical group, 65 (20%) of the remaining 318 T-M1 joints had a past history of pain at the thumb base, in 59 (91%) the pain was associated with use.

There was a significantly higher incidence of moderate/marked osteo-arthrosis of the T-M1 joint in those thumbs with a past history of pain ($p < .001$) and the pattern of restriction of mobility supported greater involvement of the soft tissue elements, rather than of the articular surfaces, of these joints.

4. **Use of the thumb**

Cumulative use of the thumb showed no significant relationship with the mean range of the physiological movements. With the exception of postero-anterior gliding, the range of the accessory movements of the T-M1 joint decreased significantly ($p < .005$), especially after 20 years of use. Similarly there was a significant increase ($p < .005$) in the incidence (%) of abnormal quality scores for all the physiological and accessory movements, this also being most obvious after 20 years of use.

There was a significant relationship between use of the thumb and the incidence (%) of osteo-arthrosis of the T-M1 joint ($p < .00001$). After 15 years of use the incidence of osteo-arthrosis rose.

Age, use of the thumb and osteo-arthrosis are three interdependent variables. Due to the population sampled, it was not possible to analyse the separate effect of these on the T-M1 joint.

5. **Obesity**

There were too few cases of obesity (six out of 246 individuals) to reliably assess its relationship to the range of opposition at the T-M1 joint.

6. **Pain elicited during examination**

The frequency of pain elicited during examination of the movements of the T-M1 joint was too low to permit statistical analysis. Pain was associated with stiffness in extension, palmar-abduction and all seven accessory movements; there was a higher incidence (%) of pain in those joints with osteo-arthrosis.

7. **Peri-articular thickening**

Seventy-three (15%) of the 492 T-M1 joints exhibited peri-articular thickening.

A significant relationship ($p < .00001$) was found between peri-articular thickening and osteo-arthrosis of the T-M1 joint, 98% of thickened joints have osteo-arthrosis.

6.72 For the 174 T-M1 joints in the non-clinical group

1. a) the mean range of movement for the three physiological movements was established; extension = 43^{o}, palmar-abduction = 47^{o} and opposition = -1^{o}.
   b) the incidence (%) of abnormal quality scores was similar for each of the physiological movements.
   c) the range of the seven accessory movements was recorded. There were few very stiff scores and none in the 'no movement' category. Postero-anterior gliding had a higher incidence of stiff scores (43% compared with 23% which was the mean for the other movements), and lateral gliding had a higher incidence of hypermobile scores (29% compared with the mean of 16%).
   d) antero-posterior and postero-anterior gliding had the highest incidence of abnormal scores for the quality of movement (54% and 65% respectively) compared with a mean value of 22% for the other accessory movements.
   e) a significant relationship ($p < .00001$) was found between the range and quality of movement of each of the accessory movements.

2. Thirty-eight joints (22%) exhibited dorso-lateral instability.

6.73 There were 66 T-M1 joints in the group with generalised peripheral joint hypermobility. The majority (55%) were females in the 20 to 29 years age group.

1. a) Comparison of the whole group with the non-clinical group revealed the hypermobile group to be significantly more mobile for opposition ($p < .0001$) and palmar-abduction ($p < .005$). A more marked difference was found between the two groups for the range of all accessory movements. In the hypermobile group there was a significantly higher incidence (%) of hypermobile scores and lower incidence (%) of stiff scores ($p < .00001$). No significant difference was found between the groups for the quality of the physiological and accessory movements.

   b) The more specific comparison between the two groups, that is, between female joints in the 20-29 years age category, showed a tendency for the hypermobile group to be more mobile for the three physiological movements ($p < .05$) and to be significantly more mobile for the accessory movements of distraction, lateral gliding and medial rotation ($p < .005$). No significant difference was found between the groups for the quality of the physiological and accessory movements.

2. Thirty joints (45%) had radiological evidence of dorso-lateral instability which was found to be significantly more frequent than in the non-clinical group ($p < .0005$).

3. Of the 54 joints in the 20-39 years age span only one was found to have osteo-arthrosis, thus the result of this study does not support the work of Kirk et al. (1967), who noted 'premature arthrosis' in individuals with generalised peripheral joint hypermobility, the T-M1 joint being a common site.

6.74 The osteo-arthrotic group contained 198 T-M1 joints of which 130 exhibited mild changes, 48 moderate and 20 marked osteo-arthrosis.

1. a) Two comparisons were made with the non-clinical group. These were between joints with mild osteo-arthrotic changes and between those with moderate/marked changes.

   i) There was little difference between the non-clinical group and joints with mild osteo-arthrosis. The earliest changes were in the quality of the accessory movements, the results supporting a trend towards a higher incidence (%) of abnormal scores in the arthrotic joints for medial and lateral gliding (movements along the medio-lateral axis of the joint) and lateral rotation ($p < .05$). Lateral gliding and lateral rotation are components of extension, the movement showing the greatest difference from the non-clinical group in joints with more advanced osteo-arthrotic changes. The earliest radiological changes were seen on the dorso-lateral and medial aspects of the joint which is consistent with lateral and medial gliding having a greater incidence of abnormal quality scores.

ii) The range of physiological movements was not significantly stiffer in T-M1 joints with more advanced osteo-arthrosis although extension showed a trend ($p < .05$). The accessory movements showed a greater difference between the two groups, there being a higher incidence (%) of stiff scores. This was significant for distraction, antero-posterior, medial and lateral gliding ($p < .001$). The movements most affected were medial and lateral gliding ($p < .00001$) which are consistent with radiographic evidence of marked osteo-arthrotic changes on the medial and dorso-lateral aspects of the joint. The incidence (%) of abnormal quality scores was significantly higher in joints with advanced osteo-arthrosis for all the physiological and accessory movements ($p < .005$).

b) Twenty-eight (14%) exhibited dorso-lateral instability on the stress radiograph; all but one were associated with mild osteo-arthrotic changes. No significant difference was found between the osteo-arthrotic and non-clinical groups in the incidence of dorso-lateral instability. This finding does not support the concept of dorso-lateral instability being secondary to osteo-arthrosis.

2. There were 107 thumbs (54%) with osteo-arthrosis of the T-M1 joint. Of the other trapezial articulations, the trapezio-scaphoid was the most commonly affected (44%) compared with 15% and 11% in the trapezio-M2 and trapezio-trapezoid joints respectively.

   The findings of the present study do not support the concepts of osteo-arthrosis being isolated to the T-M1 joint (propounded by Müller, 1949; Leach and Bolton, 1968; Eaton and Littler, 1969; Carroll and Hill, 1973) or of osteo-arthrosis involving most of the trapezial articulations (reported by Aune, 1955; Sims and Bentley, 1970; Swanson, 1972; Kessler, 1973).

   With increasing severity of T-M1 osteo-arthrosis a higher incidence (%) of involvement of the other trapezial articulations was found. This supports the findings of Burton (1973).

   The earliest radiological sign of osteo-arthrosis was found most frequently on the dorso-lateral side of the trapezium (56%) compared with 17% on the medial side, the remaining 27% showing osteophytosis on both the medial and dorso-lateral aspects of the joint.

   In this study 83% had bilateral osteo-arthrosis of the T-M1 joint and of those with unilateral involvement 82% were on the dominant side.

6.75 The occupational group (182 thumbs) comprised manipulative therapists, tailors and dressmakers and musicians.

1. Due to the nature of the population of manipulative therapists, 85% being aged below 40 years and the thumbs of only two therapists having over 14 years of occupational use, it was not appropriate to analyse the relationship between occupational use and T-M1 joint mobility.
2. In the tailors and dressmakers group (72 T-M1 joints) the influence of occupation was assessed by comparing the dominant with the non-dominant thumb. The T-M1 joint of the dominant hand was significantly stiffer in opposition ($p < .005$).

This is consistent with use of the dominant thumb in sewing, in which the first metacarpal is abducted to allow a needle to be held between the tips of the thumb and index finger. The incidence of osteo-arthrosis of the T-M1 joint was significantly higher on the dominant side ($p < .005$).

3. There were 70 T-M1 joints in the musicians group. No significant relationship was found between occupational use and the range or quality of the physiological movements, but there was a trend ($p < .05$) with increased use towards stiffness in the accessory movements not regularly exercised during their occupation as musicians. These movements were distraction, antero-posterior and lateral gliding. Occupational use was significantly related to a change in the quality of antero-posterior gliding ($p < .0001$) and lateral gliding ($p < .005$) while all other accessory movements showed a trend towards a higher incidence of abnormal scores ($p < .05$).

   Forty per cent of the musicians were in the 20-29 years age group: of these 36% had radiological evidence of osteo-arthrosis of the T-M1 joint, rising to 100% by the fifth decade. There was a significant relationship between occupational use and osteo-arthrosis of the T-M1 joint ($p < .0001$).

   Differences in mobility of the T-M1 joints between the left and right thumbs were consistent with the position in which the thumbs are held during playing of the violin, viola and 'cello. In fine stabilisation of the bow, the right thumb is opposed to the middle finger, and results showed the right T-M1 joints to be significantly more mobile in opposition, postero-anterior and medial gliding ($p < .005$). No significant difference was found between the two sides in the incidence of osteo-arthrosis of the T-M1 joint.

6.76 In the whole sample of 492 thumbs, stiffness in the T-M1 joint was not associated with compensatory increased mobility in its adjacent joints, or vice versa.

Stiffness in the T-M1 joint was associated with stiffness in the other trapezial articulations. This was significant for trapezio-M2 antero-posterior gliding, trapezio-trapezoid antero-posterior and postero-anterior gliding ($p < .0001$), and with the exception of postero-anterior gliding of the trapezio-scaphoid joint, a trend was shown for the other accessory movement tests ($p < .05$).

6.77 The association between osteopenia and menstrual status could not be assessed as there were only six cases of osteopenia.

Analyses performed to assess the relationship between menstrual status and osteo-arthrosis of the T-M1 joint, independent of age, suggest that the presence of active menstruation is a significant factor in *lowering* the incidence of osteo-arthrosis ($p < .001$). Reports in the literature, based on case histories, (Aune, 1955; Eiken and Carstam, 1970; Sims and Bentley, 1970) state that due to hormonal imbalance osteo-arthrosis of the T-M1 joint is more common in post-menopausal women. The findings of the present study do not support this assertion as the incidence of osteo-arthrosis of the T-M1 joint in older (40-59 years of age) menopausal/post-menopausal/post-hysterectomy women (68%) was similar to that of men of the same age (66%).

CHAPTER VII

SUMMARY OF AUTHOR'S MAIN CONTRIBUTIONS

The author's contributions to T-M1 joint studies are in three main fields reported in detail in Chapters IV, V and VI. This summary is provided to specify more clearly the author's new findings derived from the present study.

The anatomical study (Chapter IV), as far as is known, the most extensive yet carried out, provided the following results:

- confirmation of the structural features of the joint as described in briefer reports while providing more detailed information on ligamentous attachments (Chapter III)
- a new dimension of information on passive movements based on a radiological study of five movements
- information on the function of ligaments in limiting movements based on severing one ligament and carefully measuring any resultant effect on the range of movements.

While all four ligaments exert a co-ordinated control over individual movements this study reports the major limiting functions of each ligament:

- anterior oblique ligament limits extension and medial rotation of M1
- posterior oblique ligament limits opposition and contributes to the control of abduction
- first inter-metacarpal ligament restricts abduction of M1 and controls lateral rotation when M1 is in extension-adduction, extension-abduction or palmar-abduction
- dorso-radial ligament controls medial rotation when M1 is in palmar-abduction or opposition

- degenerative changes found in the joint cartilage at a surprisingly early age were stained and photographed. This provides the first detailed report of such findings and confirms that the antero-lateral, lateral and medial aspects of the trapezial and the posterior aspect of the metacarpal cartilage are the most common sites of fibrillation.

The osteometric study (Chapter V), based on measuring the articular surfaces, cartilage in situ, of 23 T-M1 joints used a new accurate grid method providing a three dimensional depiction of articular surface contour. Data obtained by the grid method were used to measure for the first time geometrical features of the articular surfaces. The main findings were:

- the mean angle between the two axes (ridge and groove) on the trapezial surface was 68^{o} compared with 83^{o} on the metacarpal surface. The discrepancy between the angle of the axes on the two surfaces helps to explain conjunct rotation during movements of M1
- the medio-lateral axis was found to be significantly longer on M1 ($p < .01$) which would permit M1 to roll on the underlying trapezial surface during abduction and adduction
- the surface area of the quadrants showed asymmetry in that on the trapezium the postero-medial and antero-lateral quadrants were the largest while on the metacarpal the two lateral quadrants were the larger. Disproportionate sizes of the quadrants were considered to facilitate accessory movements of M1.

Accurate measurement of the shape of the articular surfaces forms the basis for calculation of their congruity. The grid method of measurement showed sufficient accuracy to confidently recommend its use in future studies of joint congruence.

The clinical study (Chapter VI) is the first detailed general clinical study reported and provides new information on the T-M1 joint and the relationship of its mobility to a number of factors including occupation and osteo-arthrosis. The T-M1 joints (N=492) were examined using a questionnaire, radiological and clinical procedures. *To allow for cumulative error in analyses involving several movements of the T-M1 joint a conservative per test error rate of* $p < .005$ *was adopted.*

The author's principal findings were:

- in the 174 joints comprising the non-clinical ('medically normal') group the mean for each of the three ranges of physiological movements was established. Each movement showed a similar incidence (15-18%) of abnormal quality scores. Of the seven passive accessory movements measured, postero-anterior gliding recorded the highest incidence of stiff scores (43%) and lateral gliding the highest incidence of hypermobile scores (29%). The quality of movement was more frequently abnormal in postero-anterior and antero-posterior gliding. Thirty-eight (22%) joints exhibited dorso-lateral instability.
- in a study of the relationship of specific demographic variables to T-M1 joint mobility and osteo-arthrosis:
  - females were significantly more mobile for opposition ($p < .005$) while males had a significantly greater mean range of extension and palmar-abduction ($p < .0001$)
  - movements of the T-M1 joint became significantly stiffer with advancing age ($p < .005$) and ageing had a more marked effect on the accessory movements than the physiological movements. The incidence of osteo-arthrosis was also significantly associated with advancing age ($p < .00001$)
  - a significantly higher incidence of moderate/marked osteo-arthrosis was found in T-M1 joints with a past history of pain ($p < .001$)
  - cumulative use of the thumb was significantly related to a decrease in the range of accessory movements ($p < .005$) (the exception was postero-anterior gliding) and an increase in the incidence of abnormal quality scores in both the accessory and physiological movements ($p < .005$). This was seen most clearly after 20 years of use. Thumb use was significantly related to the incidence of osteo-arthrosis ($p < .00001$) which was seen to rise after 15 years of use.
  - a significant relationship was noted between peri-articular thickening and osteo-arthrosis of the T-M1 joint ($p < .00001$).

- sixty-six T-M1 joints formed the sample from individuals exhibiting generalised peripheral joint hypermobility. Dorso-lateral instability was a significantly more frequent finding than in the non-clinical group ($p < .0005$). A specific comparison between the two groups, of female joints aged between 20-29 years, showed a tendency for the hypermobile group to be more mobile in the three physiological movements ($p < .05$), but to be significantly more mobile in the accessory movements of lateral gliding, medial rotation and distraction ($p < .005$).

- consistently different usage of the thumbs formed the basis of the choice of the three occupational groups studied (manipulative therapists, tailors and dressmakers, players of violin, viola or 'cello):
  - occupational effects in the 72 T-M1 joints comprising the tailors and dressmakers group were assessed by comparing the dominant with the non-dominant thumb. The T-M1 joint of the dominant thumb was significantly stiffer in opposition ($p < .005$). This is consistent with constant abduction of M1 in holding a needle for sewing. Osteo-arthrosis was a significantly more frequent finding in the dominant T-M1 joint ($p < .005$)
  - differences in the mobility of the left and right thumbs in the 35 musicians examined were consistent with the position in which the thumbs are held during the playing of the violin, viola and 'cello. Right T-M1 joints (involved in fine stabilisation of the bow) were found to be significantly more mobile in opposition and its accessory components, postero-anterior and medial gliding ($p < .005$). The incidence of abnormal quality scores for antero-posterior and lateral gliding rose significantly with occupational use ($p < .00001$, $p < .00005$). Further there was a trend for these two movements to become stiffer with use ($p < .05$). These accessory movements are associated with extension, a movement not regularly exercised by these musicians. The incidence and degree of osteo-arthrosis rose significantly with increasing use ($p < .0001$). Forty per cent of the musicians were in the 20-29 years age category and of these 36% had radiological evidence of osteo-arthrosis. This high incidence of osteo-arthrosis may well be related to long hours of occupational use from an early age, subjecting the cartilage of the T-M1 joint to compressive forces for long periods.
- in the osteo-arthrotic group comprising 198 T-M1 joints:
  - the concept that dorso-lateral instability is secondary to osteo-arthrosis was not supported, no significant difference being found between the osteo-arthrotic group and the non-clinical group in the incidence of instability
  - a significant increase in the number of stiff scores for distraction, antero-posterior, medial and lateral gliding ($p < .001$) and in the incidence of abnormal quality scores for both the physiological and accessory movements ($p < .005$) was found in those joints exhibiting moderate/marked osteo-arthrosis when compared with the non-clinical group
  - the earliest radiological evidence of osteo-arthrosis was most frequently seen on the dorso-lateral aspect of the trapezial surface. As T-M1 joint osteo-arthrosis became more marked, so did the incidence of involvement of the other trapezial articulations
  - a regular menstrual cycle was found to be a significant factor in lowering the incidence of osteo-arthrosis of the T-M1 joint ($p < .001$). In the older age group (40-59 years) a similar incidence of osteo-arthrosis was found in menopausal/post-menopausal/post-hysterectomy women (68%) and men (66%).

APPENDIX I

The Universal Measuring Apparatus

The Universal Measuring Apparatus (Model Type MU-214B) is manufactured by Société Genevoise D'Instruments de Physique.

The main body of the apparatus is illustrated in Figure A together with details of the main components. The prime function of this assembly is to provide movement in three mutually perpendicular axes. The locating of points on these planes is achieved by a system of auxiliary scales and micrometer microscopes, providing for precise measurement.

Component Parts of Figure A.

1. Main bed
2. Longitudinal carriage
3. Transversal slide
4. Tool holder
5. Handwheel of 2
6. Gear housing of 5 and 7
7. Fine setting of 2
8. Auxiliary scale of 2
9. Protection strip
10. Microscope of 2
12. Rubber fitting
13. Focussing of 10
15. Microscope of 3
16. Handwheel of 3
17. Fine setting of 3
18. Protection glass
19. Auxiliary scale of 3
21. Handle of 20
27. Cover of 9
28. Housing of longitudinal scale

36.) This item replaced with vertical
38.) measuring microscope.

63.) This item replaced with cast iron
64.) table.
65.)

The apparatus is capable of a wide variety of measuring applications and for this study two accessories were used in conjunction with the basic apparatus, namely the vertical measuring microscope and the cast iron table.

A more detailed drawing of the component known as the Vertical Measuring Microscope is illustrated in Figure B.

Component Parts of Figure B

4. Tool holder
32. Interchangeable diaphragms
35. Illumination device of locating microscope
37. Stop for vertical microscope
47. Hinged arm of 35
62. Cast iron table
100. Clamp
107. Feeler (metal stylus)
125. Clamp of microscope to 37
127. Knob for raising 107
128. Clamp for micrometer
129. Cover plate
130. Objective of vertical microscope

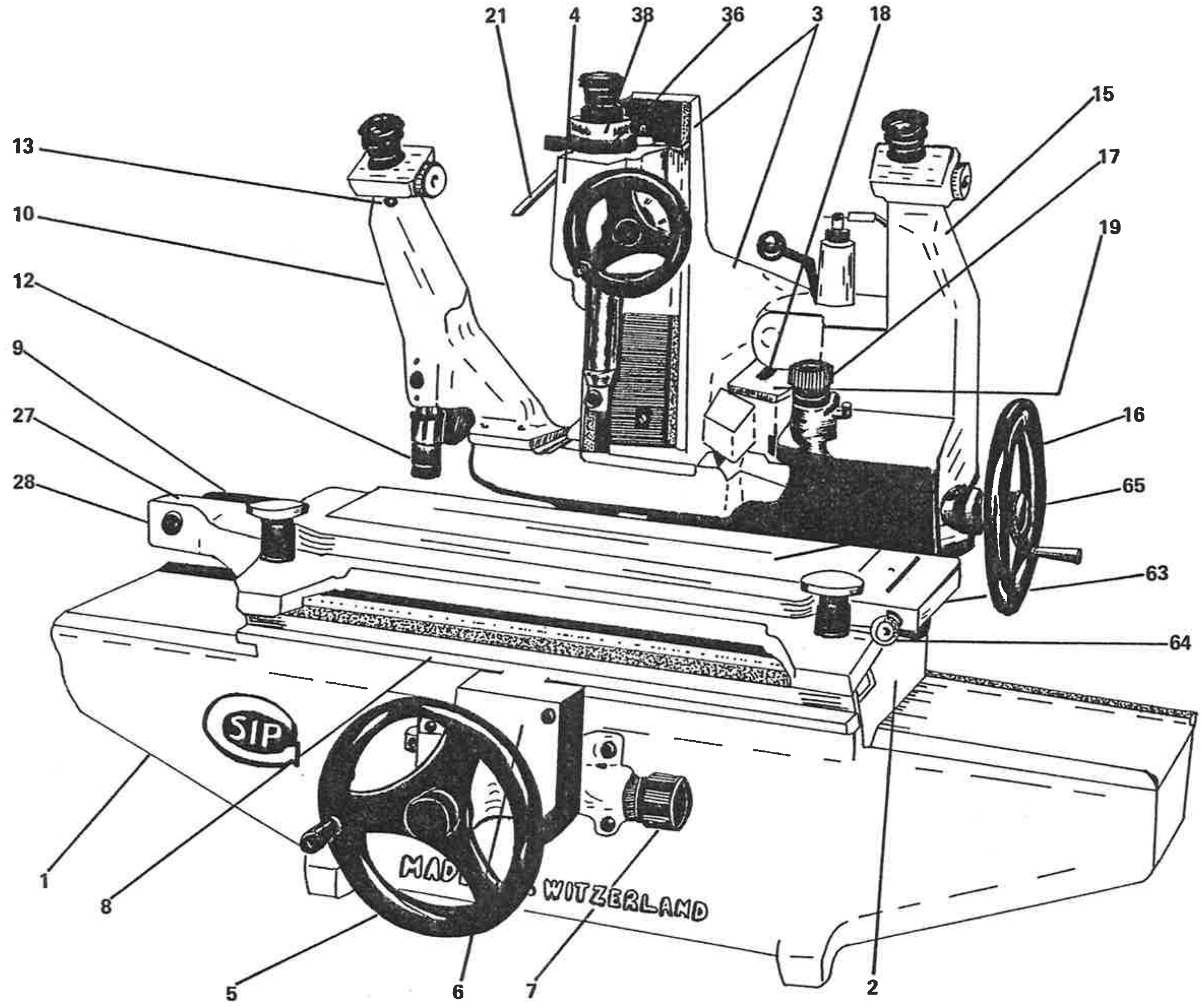


Figure A. The Universal Measuring Apparatus (see text for details)

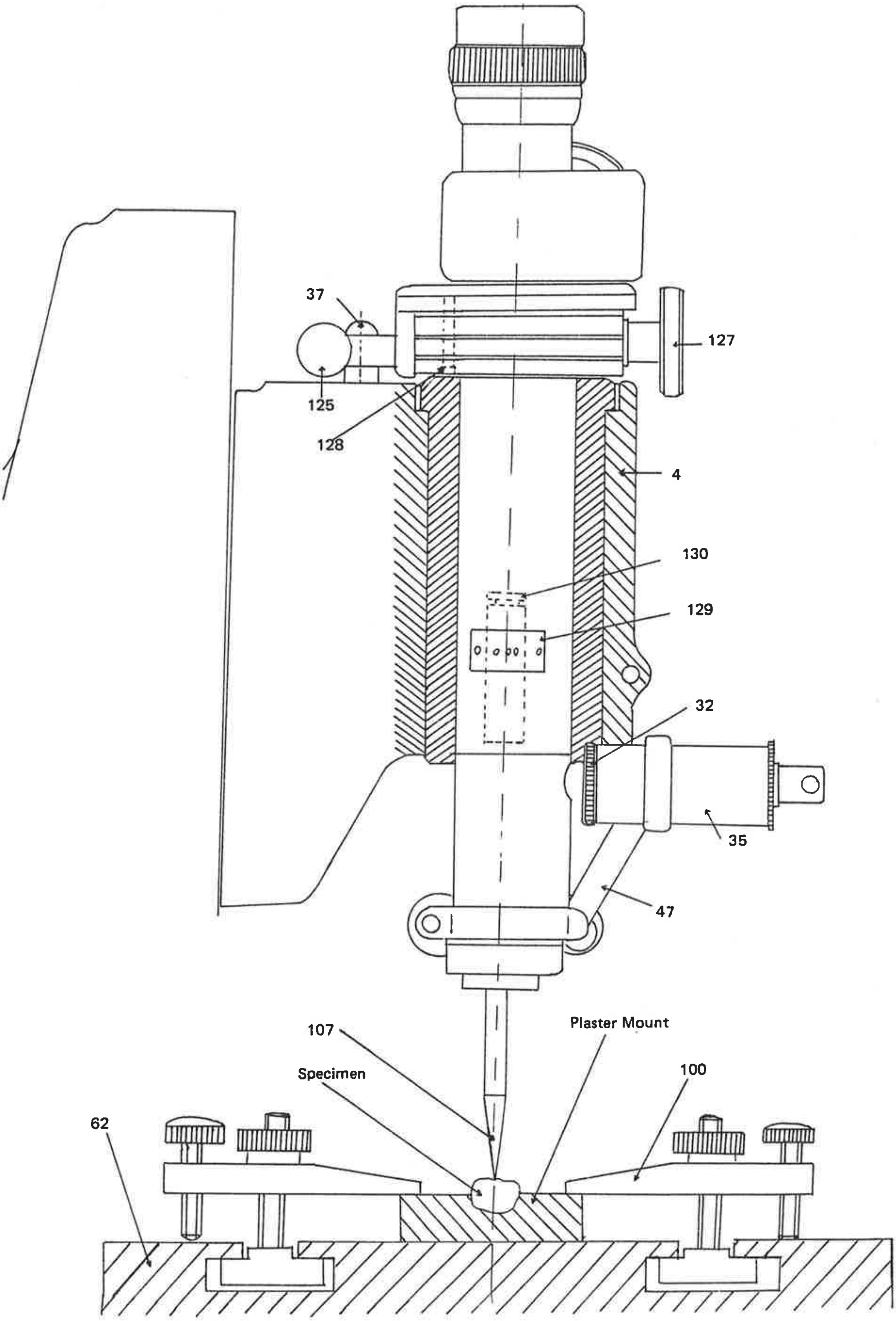


Figure B. Details of the Vertical Measuring Microscope

Operation of the Apparatus and Method of Taking Readings

Each specimen was set in a block of plaster of Paris which was clamped firmly to the table as shown in Figure B-62. By turning the handwheel (Figure A-5) the table was then located in the correct position of the X-axis, find adjustments being achieved by use of the control knob (Figure A-7).

A similar procedure was then adopted to locate the ordinate on the Y-axis (this time approximating the position by using the handwheel (Figure A-16) and fine control knob (Figure A-17).

The increments of the X-Y axes were made at intervals of 0.050 inch.

During the re-locating of the X and Y axes, the metal stylus (Figure B-107) was raised and lowered again when the new ordinates had been located. The pressure of the metal stylus is low (approximately 2.5 oz = 70g) making this device suitable for measuring small alterations in the Z-axis with minimal deformation of the surface. Repetition of the readings gave an error rate ± 0.0004 inch.

The procedure for reading of the microscopes is given below.

Method of reading X and Y axes

Two microscopes are shown in Figure A, one for the X-axis (number 10) and one for the Y-axis (number 15).

The procedure for accurately determining the position on these two axes was by reference to the auxiliary scale (X-axis (8) and Y-axis (19)).

A typical reading is as shown in Figure C where the position of the scale reads 2.3 inch.

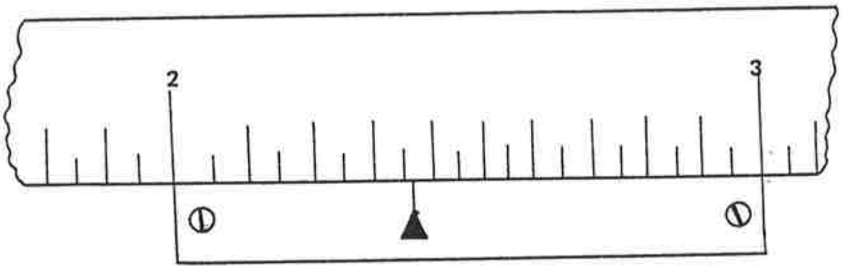
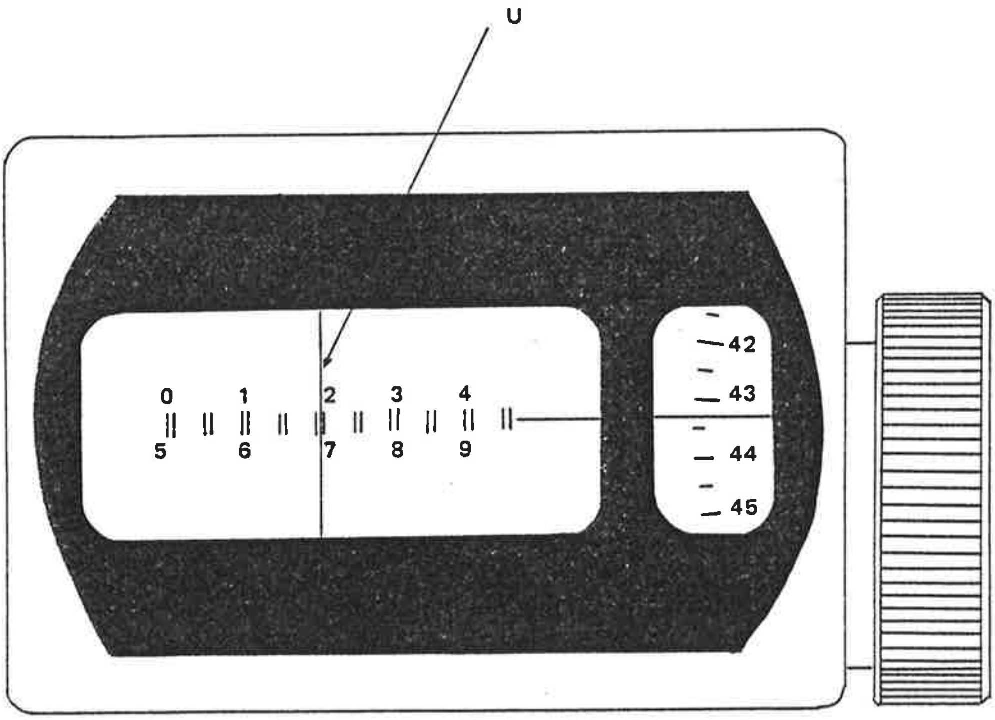


Figure C. Reading on auxiliary scale

To establish the value of the reading beyond the tenth unit, reference was made to the appropriate microscope. By viewing the eyepiece a typical value would be as shown in Figure D.



Reading:

Auxiliary scale :	**x, y**	**or**	**x, y**
Reticle :	**20**		**70**
Limb :	**433**		**433**
	x, y2433 in.		**x, y7433 in.**

Figure D. Reading on reticle and limb

As can be seen, the line 'U' is sitting on the graduations 2/7, therefore reference is again made to the auxiliary scale. The index is seen to be lying between the values 2.35 inch and 2.40 inch, therefore the selected value from the microscope must be 2.370 inch and not 2.320 inch. By further inspection, the small window on the right displays a reading 433. Therefore the reading is taken as follows:

Auxiliary Scale	2.3 - - -
Reticle	.07
Limb	.00433
	2.37433 inch

Method of reading the Z-axis

The readings taken in the Z-axis differ slightly in method as there is no auxiliary scale to which to refer initially. However, the procedure is similar and is described below in reference to Figure E

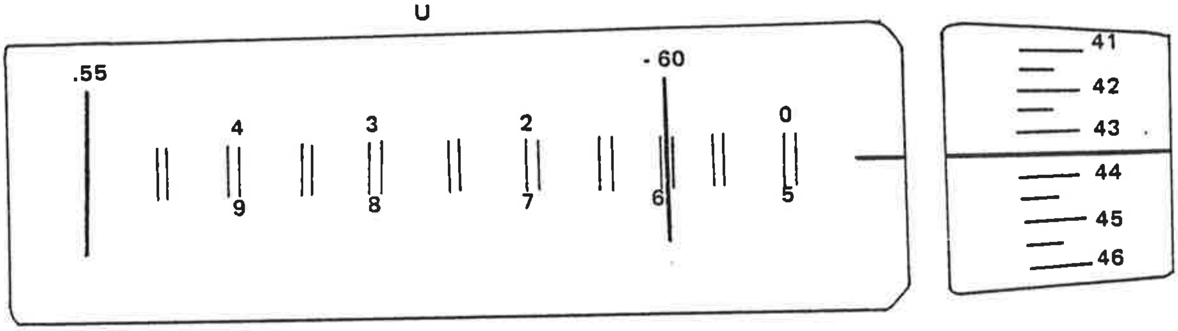


Figure E

By viewing vertically down through the eyepiece (Figure B) the scales illustrated in Figure E can be seen. The method of reading is as follows: the value of the tenths is noted first (0.60 inch). As this is lying on the graduation 1, the correct value is 0.610 inch. By referring to the limb, in the right hand window, the value is seen to be 435. Therefore the complete reading is:

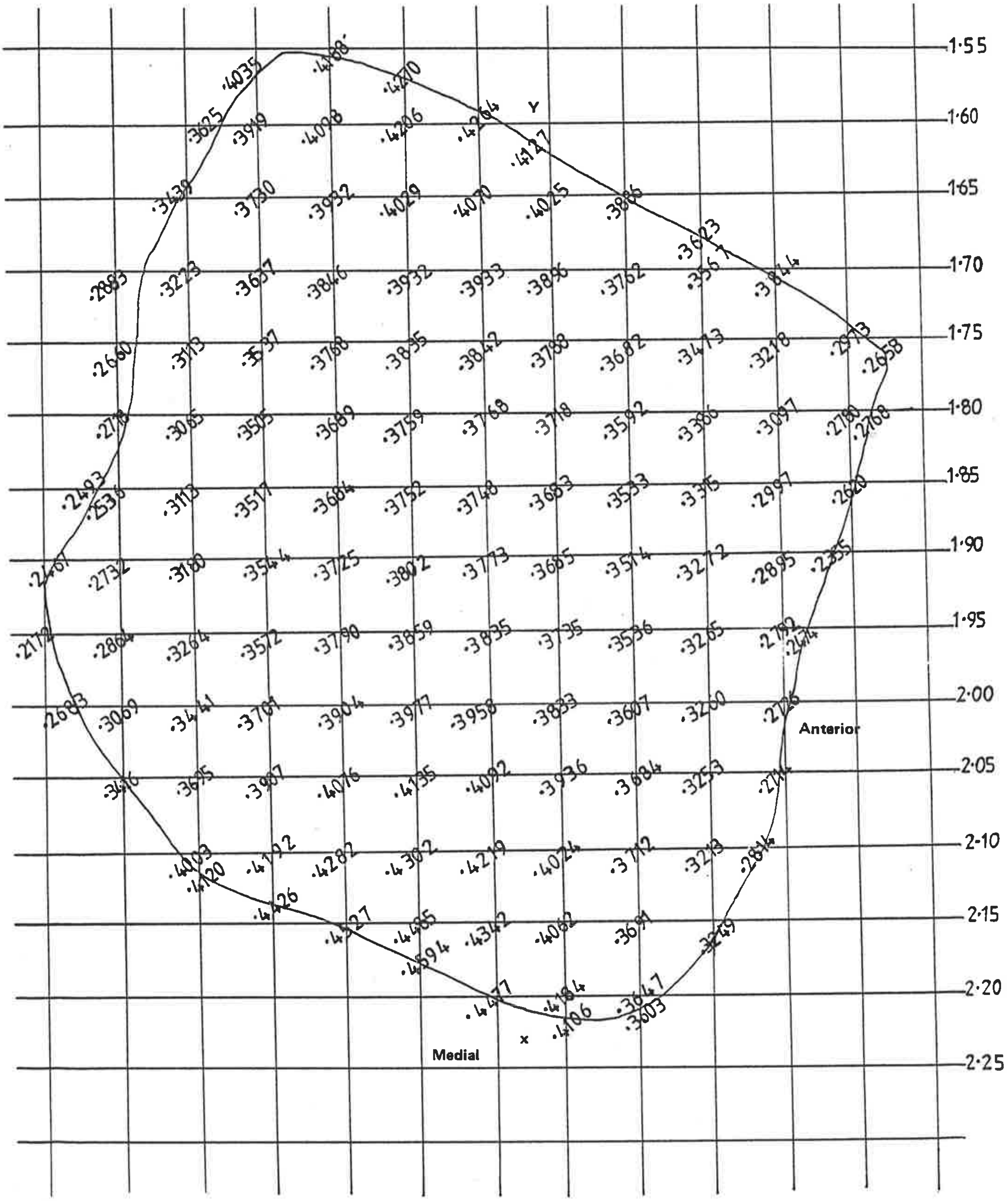
0.610
.00435
0.61435 inch

These readings provide very accurate dimensions (0.00001 inch), however it must be pointed out that this is the instrument reading and does not necessarily suggest that every component measured is correct to the same order of accuracy. Error of measurement studies were performed on the repeatability of Z scores at given co-ordinates, (error rate ± 0.0004 inch).

APPENDIX II

Ordinate Values for the Trapezial Articular Surface (Specimen No. 1)

Indicating grid sections at 0.050" spacing Mag. x 10



APPENDIX III

- Computer Programme CURV3D (for calculating the arc length of curves on the articular surface)
- calculation of the arc length of the circle of radius
- calculation of the arc length of the helix

```
list
      PROGRAM CURVE3D(CDATA,OUTPUT,RESULT,TAPE1=CDATA,TAPE2=OUTPUT)
      DIMENSION X(20),Y(20),Z(20),T(20),U(400),SX(400),SY(400),SZ(400)
      DIMENSION C(20,3), ST(20),BP(4),DX(400),DY(400),DZ(400)
CCCCC READ(1,*)N,M
CCCCC READ(1,*)(X(I),Y(I),Z(I),I=1,N)
      CALL READER(X,Y,Z,N,M)
      T(1)=0.
      WRITE(2,201)  (X(I),I=1,N)
      WRITE(2,202)  (Y(I),I=1,N)
      WRITE(2,203)  (Z(I),I=1,N)
C****    FIND LENGTH OF CHORDS BETWEEN NODES
      CALL  CLENGTH(X,Y,Z,T,N,N)
      WRITE(2,204)  (T(I),I=1,N)
C****    FIT SPLINES TO X=X(T),Y=Y(T),Z=Z(T)
   11 K=1
      U(K)=0.
      DO 19 I=2,N
      H=(T(I)-T(I-1))/M
      DO 19 J=1,M
      K=K+1
      U(K)=T(I-1)+J*H
   19 CONTINUE
C****
      BP(1)=0.
      BP(2)=0.
      BP(3)=0.
      BP(4)=0.
      CALL ICSICU(T,X,N,BP,C,20,IER)
      CALL ICSEVU(T,X,N,C,20,U,SX,K,IER)
      CALL DCSEVU(T,X,N,C,20,U,DX,K,DX2,1,IER)
      CALL ICSICU(T,Y,N,BP,C,20,IER)
      CALL ICSEVU(T,Y,N,C,20,U,SY,K,IER)
      CALL DCSEVU(T,Y,N,C,20,U,DY,K,DY2,1,IER)
      CALL ICSICU(T,Z,N,BP,C,20,IER)
      CALL ICSEVU(T,Z,N,C,20,U,SZ,K,IER)
      CALL DCSEVU(T,Z,N,C,20,U,DZ,K,DZ2,1,IER)
C****
      TN=T(N)
      CALL CLENGTH(SX,SY,SZ,T,N,K)
      WRITE(2,204)(T(I),I=1,N)
      IF(ABS(TN-T(N)).GT.1E-6) GO TO 11
C****
      ST(1)=0.
      CALL CLQUAD(DX,DY,DZ,T,ST,N,M,K)
      WRITE(2,205)(ST(I),I=1,N)
      WRITE(2,206) ST(N)
      STOP
  201 FORMAT(1H1,13H            X   ,20(F5.2,1X) )
  202 FORMAT(1H ,13H            Y   ,20(F5.2,1X) )
  203 FORMAT(1H ,13H            Z   ,20(F5.2,1X) )
  204 FORMAT(/13HCHORD LENGTH ,   20(F5.2,1X) )
  205 FORMAT(/13H  ARC LENGTH ,   20(F5.2.1X) )
  206 FORMAT(/20H TOTAL ARC LENGTH = , F9.6)
      END
      SUBROUTINE CLENGTH(X,Y,Z,T,N,K)
      DIMENSION X(K),Y(K),Z(K),T(N)
      M=K/N
      SUM=0.0
      DO 19 J=2,K
      SUM=SUM+SQRT((X(J)-X(J-1))**2+(Y(J)-Y(J-1))**2+(Z(J)-Z(J-1))**2)
      L=(J-1)/M
      IF(L*M.EQ.J-1) T(L+1)=SUM
   19 CONTINUE
      RETURN
      END
      SUBROUTINE READER(X,Y,Z,N,M)
      DIMENSION X(20),Y(20),Z(20),T(20)
      TH=ASIN(1.0)/4.0
      A=0.
      R=1
      N=17
      DO 19 I=1,N
      T(I)=(I-1)*TH
      X(I)=R*COS(T(I))
      Y(I)=R*SIN(T(I))
      Z(I)=A*T(I)
   19 CONTINUE
      M=10
      RETURN
      END
      SUBROUTINE CLQUAD(DX,DY,DZ,T,ST,N,M,KMAX)
      DIMENSION DX(KMAX),DY(KMAX),DZ(KMAX),T(N),ST(N),V(400)
      DO 19 K=1,KMAX
      V(K)=SQRT(DX(K)**2+DY(K)**2+DZ(K)**2)
   19 CONTINUE
      DO 49 I=2,N
      K=0
      S2=0.
      S4=0.
      LAST=1
      DO 29 J=2,M,2
      K=K+2
      S4=S4+V(K)
      S2=S2+V(K+1)
   29 CONTINUE
      IST=LAST
      LAST=K+1
      ST(I)=(V(IST)+4*S4+2*S2-V(LAST))*(T(I)-T(I-1))/(3*M)+ST(I-1)
   49 CONTINUE
      RETURN
      END
/
```

A.

```
ftn(i=curv3d.l=0)
      .686 CP SECONDS COMPILATION TIME
/lgo
1            X    1.00    .92    .71    .38   -.00   -.38   -.71   -.92  -1.00   -.92   -.71   -.38   -.00    .38    .71    .92   1.00
             Y    0.00    .38    .71    .92   1.00    .92    .71    .38   -.00   -.38   -.71   -.92  -1.00   -.92   -.71   -.38    .00
             Z    0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00

CHORD LENGTH   0.00    .39    .78   1.17   1.56   1.95   2.34   2.73   3.12   3.51   3.90   4.29   4.68   5.07   5.46   5.85   6.24

CHORD LENGTH   0.00    .35    .71   1.06   1.41   1.77   2.12   2.47   2.83   3.18   3.53   3.89   4.24   4.59   4.95   5.30   5.65

CHORD LENGTH   0.00    .35    .71   1.06   1.41   1.77   2.12   2.47   2.83   3.18   3.53   3.89   4.24   4.59   4.95   5.30   5.65

CHORD LENGTH   0.00    .35    .71   1.06   1.41   1.77   2.12   2.47   2.83   3.18   3.53   3.89   4.24   4.59   4.95   5.30   5.65

  ARC LENGTH   0.00    .39    .78   1.18   1.57   1.96   2.35   2.74   3.14   3.53   3.92   4.31   4.71   5.10   5.49   5.88   6.28

 TOTAL ARC LENGTH =   6.276575
      .399 CP SECONDS EXECUTION TIME
```

B.

```
x,lgo
1            X    1.00    .92    .71    .38   0.00   -.38   -.71   -.92  -1.00   -.92   -.71   -.38   0.00    .38    .71    .92   1.00
             Y    0.00    .38    .71    .92   1.00    .92    .71    .38   0.00   -.38   -.71   -.92  -1.00   -.92   -.71   -.38   0.00
             Z    0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00

CHORD LENGTH   0.00    .39    .78   1.17   1.56   1.95   2.34   2.73   3.12   3.51   3.90   4.29   4.68   5.07   5.46   5.85   6.24

CHORD LENGTH   0.00    .35    .70   1.06   1.41   1.76   2.12   2.47   2.82   3.18   3.53   3.88   4.24   4.59   4.94   5.29   5.65

CHORD LENGTH   0.00    .35    .70   1.06   1.41   1.76   2.12   2.47   2.83   3.18   3.53   3.88   4.24   4.59   4.94   5.29   5.65

CHORD LENGTH   0.00    .35    .70   1.06   1.41   1.76   2.12   2.47   2.83   3.18   3.53   3.88   4.24   4.59   4.94   5.29   5.65

CHORD LENGTH   0.00    .35    .70   1.06   1.41   1.76   2.12   2.47   2.83   3.18   3.53   3.88   4.24   4.59   4.94   5.29   5.65

CHORD LENGTH   0.00    .35    .70   1.06   1.41   1.76   2.12   2.47   2.83   3.18   3.53   3.88   4.24   4.59   4.94   5.29   5.65

CHORD LENGTH   0.00    .35    .70   1.06   1.41   1.76   2.12   2.47   2.83   3.18   3.53   3.88   4.24   4.59   4.94   5.29   5.65

  ARC LENGTH   0.00    .39    .78   1.18   1.57   1.96   2.35   2.74   3.14   3.53   3.92   4.31   4.70   5.10   5.49   5.88   6.27

 TOTAL ARC LENGTH =   6.273588
READY.
```

Calculation of Arc Length

A. applied to the circle of radius

B. applied to the circle of radius (data rounded to two decimal places)

A.

```
ftn(i=curv3d,l=0)
       .681 CP SECONDS COMPILATION TIME
/lqo
1            X    1.00    .92    .71    .38  -.00  -.38  -.71  -.92 -1.00  -.92  -.71  -.38  -.00   .38   .71   .92  1.00
             Y    0.00    .38    .71    .92  1.00   .92   .71   .38  -.00  -.38  -.71  -.92 -1.00  -.92  -.71  -.38   .00
             Z    0.00    .79   1.57   2.36  3.14  3.93  4.71  5.50  6.28  7.07  7.85  8.64  9.42 10.21 11.00 11.78 12.57

CHORD LENGTH   0.00    .88   1.75   2.63  3.51  4.38  5.26  6.14  7.02  7.89  8.77  9.65 10.52 11.40 12.28 13.15 14.03

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.85 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.85 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.85 12.64

  ARC LENGTH   0.00    .88   1.76   2.63  3.51  4.39  5.27  6.14  7.02  7.90  8.78  9.66 10.53 11.41 12.29 13.17 14.05

 TOTAL ARC LENGTH = 14.046761
       .408 CP SECONDS EXECUTION TIME
/
```

B.

```
x,lqo

1            X    1.00    .92    .71    .38  0.00  -.38  -.71  -.92 -1.00  -.92  -.71  -.38  0.00   .38   .71   .92  1.00
             Y    0.00    .38    .71    .92  1.00   .92   .71   .38  0.00  -.38  -.71  -.92 -1.00  -.92  -.71  -.38  0.00
             Z    0.00    .79   1.57   2.36  3.14  3.93  4.71  5.50  6.28  7.07  7.85  8.64  9.42 10.21 11.00 11.78 12.57

CHORD LENGTH   0.00    .88   1.75   2.63  3.51  4.39  5.26  6.14  7.01  7.89  8.76  9.65 10.52 11.40 12.28 13.15 14.03

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.85 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.85 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.86 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.86 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.86 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.86 12.64

CHORD LENGTH   0.00    .79   1.58   2.37  3.16  3.95  4.74  5.53  6.32  7.11  7.90  8.69  9.48 10.27 11.06 11.86 12.64

  ARC LENGTH   0.00    .88   1.75   2.64  3.51  4.39  5.27  6.14  7.02  7.90  8.78  9.65 10.53 11.41 12.28 13.17 14.05

 TOTAL ARC LENGTH = 14.046579
READY.
```

Calculation of Arc Length

A. applied to the helix

B. applied to the helix (data rounded to two decimal places)

APPENDIX IV

- **Computer Programme SAREA**
- **data for Articular Surfaces of Specimen No. 1**

```
et,sarea

:EADY.
ist,f=sarea

79/11/27. 09.50.27.
'ROGRAM   SAREA

      PROGRAM SAREA(BONE,RESULT,OUTPUT,TAPE1=BONE,TAPE2=RESULT)
:****     CALCULATES SURFACE AREA BY TRANSFORMING  SS 1 DS  TO THE
:****     REPEATED INTEGRAL   SS F(X,Y) DYDX . F(X,Y)=SQRT(1+DZ/DX**2+DZ/DY**2)
      COMMON     X(20,20),Y(20,20),Z(20,20),K(20,2),XMESH,YMESH
      DIMENSION  R(20),U(20),V(20),F(20),C(6)
:****     FOR INTEGRATION USE N NODES IN X-DIRN.,M NODES IN Y-DIRN.
:****     READ DATA  --(NOTE:N,M MAY BE ODD OR EVEN )--
      READ(1,*) N,M,XMESH,YMESH,NUMBER
      DO 09 I=1,N
      READ(1,*) K(I,1),K(I,2)
      KI1=K(I,1)
      KI2=K(I,2)
      READ(1,*) (X(I,J), Y(I,J), Z(I,J), J=KI1,KI2)
   12 IF(EOF(1).NE.0) WRITE(2,200)
   09 CONTINUE
      NM1=N-1
      MM1=M-1
      WRITE(2,201) NUMBER
      DO 19 I=1,N
      WRITE(2,202) (X(I,J),J=1,M)
      WRITE(2,203) (Y(I,J),J=1,M)
      WRITE(2,204) (Z(I,J),J=1,M)
   19 CONTINUE
      WRITE(2,206)
C****     CARRY-OUT INTEGRATIONS IN Y-DIRECTION THEN INTEGRATE IN X-DIRECT2ON
      T1=X(1,K(1,1))
      T2=X(N,K(N,1))
      CALL RNODES(T1,T2,U,N,HX)
      R(1)=0.
      R(N)=0.
      DO 39 I=1,N
      XI=U(I)
      Y1=Y(I,K(I,1))
      Y2=Y(I,K(I,2))
      IF(Y1.EO.Y2) GO TO 39
      CALL RNODES(Y1,Y2,V,M,HY)
      DO 29 J=1,M
      YJ=V(J)
      CALL QUADRIC(XI,YJ,C,I,J,N)
      DZDX=2*C(1)*XI+C(2)*YJ+C(4)
      DZDY=2*C(3)*YJ+C(2)*XI+C(5)
      F(J)=SQRT(1.0+(DZDX)**2+(DZDY)**2)
```

```
   29 CONTINUE
      CALL SIMPSON(HY,F,M,S)
      R(I)=S
   39 CONTINUE
      CALL TRAPEZE(HX,R,N,S)
      WRITE(2,205) NUMBER,S
      WRITE(2,206)
      STOP
  200 FORMAT(55H CHECK DATA INPUT  "END OF FILE"DETECTED AT STATEMENT12)
  201 FORMAT(1H1,32H HUMAN TRAPEZIO-METACARPAL JOINT  /
     + 52H STUDY OF ARTICULAR SURFACES OF UNEMBALMED SPECIMENS  /
     + 21H DATA FOR BONE NUMBER  , A10   )
  202 FORMAT(2H0X,12(F9.3,1X))
  203 FORMAT(2H Y,12(F9.3,1X))
  204 FORMAT(2H Z,12(F9.3,1X))
  205 FORMAT(1H0/12H0BONE NUMBER,A10,9X,12HSURFACE AREA,F8.4,8H SQ.INCH)
  206 FORMAT(1H1)
      END
      SUBROUTINE RNODES(A,B,X,N,H)
      DIMENSION X(N)
      H=(B-A)/(N-1)
      C=(B+A)/2
      X(1)=A
      DO 9 I=2,N
      X(I)=A+(I-1)*H
    9 CONTINUE
      RETURN
      END
      SUBROUTINE SIMPSON(H,F,N,S)
      DIMENSION F(N)
      SUM4=0.
      SUM2=0.
      DO 19 I=3,N,2
      SUM4=SUM4+F(I-1)
      SUM2=SUM2+F(I)
   19 CONTINUE
      S=F(1)+4*SUM4+2*SUM2-F(N)
      S=H/3*S
      WRITE(2,222) S,(F(I),I=1,N)
  222 FORMAT(22H0SIMPSON'S RULE GIVES ,F10.4/6H  FROM ,12(1X,F9.3))
      RETURN
      END
      SUBROUTINE TRAPEZE(H,F,N,S)
      DIMENSION F(N)
      S=0.5*(F(1)+F(N))
      DO 19 I=3,N
      S=S+F(I-1)
   19 CONTINUE
      S=H*S
      WRITE(2,222) S,(F(I),I=1,N)
```

```
  222 FORMAT(22H0TRAPEZIUM RULE GIVES ,F10.4/6H  FROM ,12(1X,F9.3))
      RETURN
      END
      SUBROUTINE QUADRIC(U,V,C,I,J,NX)
      COMMON  X(20,20),Y(20,20),Z(20,20),K(20,2),XMESH,YMESH
C****     SELECTS 6 POINTS NEAREST TO P(U,V) FROM DATA AND CALCULATES
C****     COEFFICIENTS OF QUADRIC  Z=AX2+BXY+CX2+DX+EY+F  THROUGH THEM.
      DIMENSION D(60),XX(60),YY(60),ZZ(60),AM(6,6),C(6),WKAREA(100)
      N=0
      IM=AMAX0(I-2,1)
      IP=AMIN0(IM+4,NX)
      DO 19 L=IM,IP
      JM1=K(L,1)
      JP1=K(L,2)
      DO 19 M=JM1,JP1
      DX=U-X(L,M)
      DY=V-Y(L,M)
      IF(ABS(DX).GT.2.1*XMESH.OR.ABS(DY).GT.2.1*YMESH) GO TO 19
      N=N+1
      D(N)=SQRT(DX*DX+DY*DY)
      XX(N)=X(L,M)
      YY(N)=Y(L,M)
      ZZ(N)=Z(L,M)
CCCCC WRITE(2,234)XX(N),YY(N),ZZ(N),D(N)
  234 FORMAT(5H XYZD ,4(2X,F9.3))
   19 CONTINUE
      IF(N.GT.6) CALL SORTER(D,XX,YY,ZZ,N)
CCCCC WRITE(2,234)(XX(M),YY(M),ZZ(M),D(M),M=1,N)
      IF(N.LT.6) WRITE(2,201) N
      NCALLS=1
   21 DO 29 M=1,6
      AM(M,1)=XX(M)**2
      AM(M,2)=XX(M)*YY(M)
      AM(M,3)=YY(M)**2
      AM(M,4)=XX(M)
      AM(M,5)=YY(M)
      AM(M,6)=1.0
      C(M)=ZZ(M)
CCCCC WRITE(2,245)(AM(M,JJ),JJ=1,6),C(M)
  245 FORMAT(6H AM,C ,7(3X,F9.3))
   29 CONTINUE
      IDGT=0
      CALL LEQT2F(AM,1,6,6,C,IDGT,WKAREA,IER)
CCCCC WRITE(2,202) IER,IDGT,(C(M),M=1,6)
      IF(NCALLS.GE.9) STOP99
      IF(IER.NE.0) CALL RESORT(D,XX,YY,ZZ,5,N)
      NCALLS=NCALLS+1
      IF(IER.NE.0) GO TO 21
      RETURN
```

```
  201 FORMAT(1H0/47H 6 NEAR POINTS NEEDED FOR QUADRIC,BUT HAVE ONLY,I2)
  202 FORMAT(7H0 IER =,I3,8H IDGT = ,I2,26H   COEFFICIENTS OF QUADRIC,
     +   6(1X,F10.5))
      END
      SUBROUTINE SORTER(D,X,Y,Z,N)
C****     SORTS N POINTS (X,Y,Z) INTO ORDER OF INCREASING D
      DIMENSION D(N),X(N),Y(N),Z(N)
      DO 29 L=2,N
      LM1=L-1
      DO 19 K=1,LM1
      IF(D(L).GE.D(K)) GO TO 19
      LMK=L-K
      T0=D(L)
      T1=X(L)
      T2=Y(L)
      T3=Z(L)
      DO 9 M=1,LMK
      D(L+1-M)=D(L-M)
      X(L+1-M)=X(L-M)
      Y(L+1-M)=Y(L-M)
      Z(L+1-M)=Z(L-M)
    9 CONTINUE
      D(K)=T0
      X(K)=T1
      Y(K)=T2
      Z(K)=T3
   19 CONTINUE
   29 CONTINUE
      RETURN
      END
      SUBROUTINE RESORT(D,X,Y,Z,K,N)
C****     MOVES POINT K TO THE END OF THE ARRAY
      DIMENSION D(N),X(N),Y(N),Z(N)
      NM1=N-1
      T0=D(K)
      T1=X(K)
      T2=Y(K)
      T3=Z(K)
      DO 9 M=K,NM1
      D(M)=D(M+1)
      X(M)=X(M+1)
      Y(M)=Y(M+1)
      Z(M)=Z(M+1)
    9 CONTINUE
      D(N)=T0
      X(N)=T1
      Y(N)=T2
      Z(N)=T3
      RETURN
      END
```

```
1 HUMAN TRAPEZIO-METACARPAL JOINT
 STUDY OF ARTICULAR SURFACES OF UNEMBALMED SPECIMENS
 DATA FOR BONE NUMBERBONE M1
0X        -I     1.550     1.550     1.550        -I        -I        -I        -I        -I        -I        -I
 Y        -I     7.600     7.650     7.700        -I        -I        -I        -I        -I        -I        -I
 Z        -I      .381      .354      .367        -I        -I        -I        -I        -I        -I        -I
0X     1.600     1.600     1.600     1.600     1.600     1.600     1.600        -I        -I        -I        -I
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850        -I        -I        -I        -I
 Z      .431      .413      .399      .393      .390      .357      .390        -I        -I        -I        -I
0X     1.650     1.650     1.650     1.650     1.650     1.650     1.650     1.650     1.650     1.650        -I
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     7.980        -I
 Z      .466      .444      .429      .422      .416      .419      .428      .443      .454      .468        -I
0X     1.700     1.700     1.700     1.700     1.700     1.700     1.700     1.700     1.700     1.700     1.700
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000     8.020
 Z      .487      .466      .454      .443      .435      .437      .446      .464      .483      .510      .508
0X     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000     8.030
 Z      .503      .486      .472      .458      .448      .448      .457      .475      .498      .519      .526
0X     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000     8.050
 Z      .518      .500      .482      .467      .458      .456      .464      .479      .501      .525      .536
0X     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000     8.050
 Z      .518      .498      .485      .469      .460      .459      .463      .477      .498      .522      .535
0X     1.900     1.900     1.900     1.900     1.900     1.900     1.900     1.900     1.900     1.900     1.900
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000     8.050
 Z      .515      .497      .483      .470      .459      .455      .460      .473      .491      .511      .527
0X     1.950     1.950     1.950     1.950     1.950     1.950     1.950     1.950     1.950     1.950     1.950
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000     8.050
 Z      .506      .490      .478      .465      .453      .448      .451      .461      .478      .496      .503
0X     2.000     2.000     2.000     2.000     2.000     2.000     2.000     2.000     2.000     2.000     2.000
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000     8.030
 Z      .491      .479      .467      .453      .439      .435      .435      .445      .460      .474      .480
0X     2.050     2.050     2.050     2.050     2.050     2.050     2.050     2.050     2.050     2.050        -I
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950     8.000        -I
 Z      .469      .469      .446      .433      .418      .410      .414      .422      .433      .457        -I
0X     2.100     2.100     2.100     2.100     2.100     2.100     2.100     2.100     2.100        -I        -I
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850     7.900     7.950        -I        -I
 Z      .435      .428      .416      .401      .386      .379      .380      .386      .410        -I        -I
0X     2.150     2.150     2.150     2.150     2.150     2.150     2.150        -I        -I        -I        -I
 Y     7.550     7.600     7.650     7.700     7.750     7.800     7.850        -I        -I        -I        -I
 Z      .380      .391      .376      .350      .341      .334      .352        -I        -I        -I        -I
```

```
1
0SIMPSON'S RULE GIVES      .1413
  FROM     1.520     1.452     1.373     1.491     1.558     1.477     1.511     1.384     1.225     1.257     1.297
0SIMPSON'S RULE GIVES      .4282
  FROM     1.290     1.251     1.251     1.242     1.260     1.149     1.132     1.518     2.010     1.914     1.926
0SIMPSON'S RULE GIVES      .5091
  FROM     1.247     1.202     1.163     1.144     1.119     1.095     1.244     1.171     1.205     1.244     1.389
0SIMPSON'S RULE GIVES      .5296
  FROM     1.186     1.134     1.111     1.088     1.058     1.049     1.063     1.112     1.142     1.271     1.253
0SIMPSON'S RULE GIVES      .5193
  FROM     1.111     1.098     1.077     1.062     1.035     1.020     1.040     1.079     1.111     1.090     1.428
0SIMPSON'S RULE GIVES      .5237
  FROM     1.057     1.069     1.059     1.037     1.014     1.007     1.029     1.069     1.100     1.058     1.004
0SIMPSON'S RULE GIVES      .5223
  FROM     1.108     1.055     1.041     1.031     1.005     1.001     1.018     1.059     1.101     1.076     1.011
0SIMPSON'S RULE GIVES      .5243
  FROM     1.084     1.051     1.038     1.030     1.013     1.006     1.023     1.062     1.088     1.093     1.082
0SIMPSON'S RULE GIVES      .5314
  FROM     1.088     1.055     1.045     1.044     1.034     1.021     1.038     1.076     1.106     1.095     1.184
0SIMPSON'S RULE GIVES      .5193
  FROM     1.082     1.049     1.079     1.087     1.078     1.074     1.064     1.091     1.127     1.099     1.079
0SIMPSON'S RULE GIVES      .5204
  FROM     1.150     1.149     1.174     1.157     1.161     1.134     1.156     1.156     1.182     1.171     1.124
0SIMPSON'S RULE GIVES      .5071
  FROM     1.340     1.258     1.227     1.307     1.332     1.280     1.261     1.252     1.187     1.255     1.268
0SIMPSON'S RULE GIVES      .4209
  FROM     1.730     1.312     1.245     1.385     1.491     1.396     1.476     1.448     1.431     1.406     1.284
0TRAPEZIUM RULE GIVES      .2958
  FROM      .141      .428      .509      .530      .519      .524      .522      .524      .531      .519      .520      .507
      .421
0
0BONE NUMBERBONE M1            SURFACE AREA    .2958 SQ.INCH
1
 -END OF FILE-
?
```

```
1 HUMAN TRAPEZIO-METACARPAL JOINT
 STUDY OF ARTICULAR SURFACES OF UNEMBALMED SPECIMENS
 DATA FOR BONE NUMBERBONE T1
0X       -I        -I        -I     1.550        -I        -I        -I        -I        -I        -I        -I        -I
       -I
 Y       -I        -I        -I     7.930        -I        -I        -I        -I        -I        -I        -I        -I
       -I
 Z       -I        -I        -I      .418        -I        -I        -I        -I        -I        -I        -I        -I
       -I
0X       -I        -I     1.600     1.600     1.600     1.600     1.600        -I        -I        -I        -I        -I
       -I
 Y       -I        -I     7.870     7.900     7.950     8.000     8.050        -I        -I        -I        -I        -I
       -I
 Z       -I        -I      .363      .392      .410      .421      .425        -I        -I        -I        -I        -I
       -I
0X       -I        -I     1.650     1.650     1.650     1.650     1.650     1.650     1.650        -I        -I        -I
       -I
 Y       -I        -I     7.850     7.900     7.950     8.000     8.050     8.100     8.150        -I        -I        -I
       -I
 Z       -I        -I      .344      .373      .393      .403      .407      .403      .389        -I        -I        -I
       -I
0X       -I     1.700     1.700     1.700     1.700     1.700     1.700     1.700     1.700     1.700     1.700        -I
       -I
 Y       -I     7.820     7.850     7.900     7.950     8.000     8.050     8.100     8.150     8.200     8.250        -I
       -I
 Z       -I      .288      .322      .364      .385      .393      .393      .390      .376      .357      .334        -I
       -I
0X       -I     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750     1.750
    1.750
 Y       -I     7.820     7.850     7.900     7.950     8.000     8.050     8.100     8.150     8.200     8.250     8.300
    8.330
 Z       -I      .266      .311      .354      .377      .384      .384      .379      .368      .347      .322      .297
     .266
0X       -I     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800     1.800
    1.800
 Y       -I     7.800     7.850     7.900     7.950     8.000     8.050     8.100     8.150     8.200     8.250     8.300
    8.320
 Z       -I      .272      .307      .351      .369      .376      .377      .372      .359      .339      .310      .278
     .277
0X    1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850     1.850
       -I
 Y    7.780     7.800     7.850     7.900     7.950     8.000     8.050     8.100     8.150     8.200     8.250     8.300
       -I
 Z     .249      .254      .311      .352      .368      .375      .375      .368      .353      .332      .300      .262
       -I
```

```
OX    1.900    1.900    1.900    1.900    1.900    1.900    1.900    1.900    1.900    1.900    1.900    1.900
       -I
 Y    7.750    7.800    7.850    7.900    7.950    8.000    8.050    8.100    8.150    8.200    8.250    8.280
       -I
 Z     .247     .273     .318     .354     .373     .380     .377     .369     .351     .327     .290     .236
       -I
OX    1.950    1.950    1.950    1.950    1.950    1.950    1.950    1.950    1.950    1.950    1.950    1.950
       -I
 Y    7.750    7.800    7.850    7.900    7.950    8.000    8.050    8.100    8.150    8.200    8.250    8.270
       -I
 Z     .217     .286     .326     .357     .379     .386     .384     .374     .354     .327     .279     .247
       -I
OX    2.000    2.000    2.000    2.000    2.000    2.000    2.000    2.000    2.000    2.000    2.000       -I
       -I
 Y    7.770    7.800    7.850    7.900    7.950    8.000    8.050    8.100    8.150    8.200    8.250       -I
       -I
 Z     .268     .307     .344     .370     .390     .398     .396     .383     .361     .326     .273       -I
       -I
OX       -I    2.050    2.050    2.050    2.050    2.050    2.050    2.050    2.050    2.050    2.050       -I
       -I
 Y       -I    7.800    7.850    7.900    7.950    8.000    8.050    8.100    8.150    8.200    8.250       -I
       -I
 Z       -I     .342     .370     .391     .408     .414     .409     .394     .368     .325     .271       -I
       -I
OX       -I       -I    2.100    2.100    2.100    2.100    2.100    2.100    2.100    2.100    2.100       -I
       -I
 Y       -I       -I    7.850    7.900    7.950    8.000    8.050    8.100    8.150    8.200    8.250       -I
       -I
 Z       -I       -I     .400     .419     .428     .430     .422     .402     .371     .321     .281       -I
       -I
OX       -I       -I       -I    2.150    2.150    2.150    2.150    2.150    2.150    2.150       -I       -I
       -I
 Y       -I       -I       -I    7.900    7.950    8.000    8.050    8.100    8.150    8.200       -I       -I
       -I
 Z       -I       -I       -I     .443     .453     .449     .434     .406     .369     .325       -I       -I
       -I
OX       -I       -I       -I       -I       -I       -I    2.200    2.200    2.200    2.200       -I       -I
       -I
 Y       -I       -I       -I       -I       -I       -I    8.050    8.100    8.150    8.170       -I       -I
       -I
 Z       -I       -I       -I       -I       -I       -I     .448     .418     .365     .343       -I       -I
       -I
1
```

```
0SIMPSON'S RULE GIVES      .2066
  FROM    1.585     1.401      1.285     1.162     1.076     1.088     1.081     1.073     1.068     1.064     1.094     1.075
     1.074
0SIMPSON'S RULE GIVES      .3320
  FROM    1.699     1.226      1.150     1.113     1.074     1.052     1.046     1.051     1.048     1.049     1.059     1.079
     1.106
0SIMPSON'S RULE GIVES      .4870
  FROM    1.692     1.424      1.238     1.095     1.041     1.023     1.027     1.031     1.046     1.067     1.097     1.123
     1.136
0SIMPSON'S RULE GIVES      .5854
  FROM    1.107     1.462      1.182     1.060     1.018     1.014     1.019     1.037     1.076     1.120     1.145     1.204
     1.752
0SIMPSON'S RULE GIVES      .5801
  FROM    1.457     1.262      1.256     1.060     1.014     1.005     1.006     1.023     1.061     1.113     1.177     1.204
     1.008
0SIMPSON'S RULE GIVES      .5975
  FROM    1.038     1.511      1.326     1.108     1.025     1.004     1.001     1.013     1.047     1.090     1.170     1.274
     1.192
0SIMPSON'S RULE GIVES      .6292
  FROM    1.188     1.236      1.330     1.209     1.064     1.019     1.006     1.013     1.037     1.079     1.154     1.459
     2.308
0SIMPSON'S RULE GIVES      .6712
  FROM    3.927     1.575      1.284     1.181     1.103     1.033     1.016     1.025     1.051     1.098     1.172     1.400
     2.040
0SIMPSON'S RULE GIVES      .5873
  FROM    1.871     1.480      1.259     1.167     1.115     1.051     1.038     1.042     1.068     1.120     1.206     1.384
     1.828
0SIMPSON'S RULE GIVES      .5409
  FROM    1.538     1.283      1.213     1.155     1.093     1.060     1.043     1.061     1.097     1.171     1.321     1.432
     1.554
0SIMPSON'S RULE GIVES      .4702
  FROM    1.232     1.185      1.150     1.102     1.074     1.055     1.068     1.103     1.162     1.288     1.390     1.303
     1.250
0SIMPSON'S RULE GIVES      .3502
  FROM    1.137     1.106      1.133     1.097     1.085     1.088     1.116     1.172     1.204     1.245     1.290     1.335
     1.055
0SIMPSON'S RULE GIVES      .1627
  FROM    1.094     1.127      1.171     1.221     1.278     1.340     1.402     1.481     1.471     1.476     1.485     1.497
     1.523
0TRAPEZIUM RULE GIVES      .3059
  FROM    0.000      .207       .332      .487      .585      .580      .597      .629      .671      .587      .541      .470
      .350      .163
0
0BONE NUMBERBONE T1            SURFACE AREA    .3059 SQ.INCH
1
 -END OF FILE-
```

APPENDIX V

Computer Programme GENDAT
(for the plotting of sections of the Articular Surface)

PROGRAM   GENDAT

```
      PROGRAM GENDATA(PDATA.INPUT,BONE,OUTPUT,TAPE1=BONE,
     +                TAPE2=OUTPUT,TAPE77=PDATA,TAPE3=INPUT)
C
C     CREATE DATA FOR A PLOT OF Y VERSES Z
C
      REAL X(40,20),Y(40,20),Z(40,20),K(40,2),YP(1000),ZP(1000)
      REAL YPLOT(1000),ZPLOT(1000)
      INTEGER XUSERV,YUSERV,PTREQ,BONEID,ANS
      M3=2
      NC=0
      READ (1,*) N,M.XMESH,YMESH,BONEID
      IF(EOF(1).NE.0) STOP "INSUFFICIENT DATA ON FILE BONE"
      DO 20 I=1,N
         READ(1,*) K(I,1),K(I,2)
      IF(EOF(1).NE.0) STOP "INSUFFICIENT DATA ON FILE BONE"
         K1=K(I,1)
         K2=K(I,2)
         READ(1,*) (X(I,J),Y(I,J),Z(I,J),J=K1,K2)
      IF(EOF(1).NE.0) STOP "INSUFFICIENT DATA ON FILE BONE"
   20 CONTINUE
C
C     CALCULATE INITIAL PLOT DATA FOR 3-D PLOT
C
      DO 21 I=1,N
         NPTS=K(I,2)-K(I,1)
         IF(NPTS.LE.1) GOTO 21
         NC=NC+1
   21 CONTINUE
      WRITE(77,22) NC,M3,BONEID
   22 FORMAT(I3,1H,,I2,1H,,1H",A10,1H")
C
C     INPUT THE PLOTTING INTERVAL H
C
      PRINT *,"ENTER PLOTTING INTERVAL "
      READ *,H
C
C     USE NEVILLES ALGORITHM TO INTERPOLATE BETWEEN POINTS
C
      DO 50 I=1,N
         NPTS=K(I,2)-K(I,1)+1
         IF(NPTS.GT.1) GOTO 25
         PRINT *,"ONLY 1 DATA POINT - IGNORED"
         GOTO 50
   25    KPT=K(I,1)
         DO 30 J=1,NPTS
            YP(J)=Y(I,KPT)
            ZP(J)=Z(I,KPT)
            KPT=KPT+1
   30    CONTINUE
         CALL RNODES (YP(1),YP(NPTS),YPLOT,PTREQ,H)
         CALL BRBFIT (NPTS,YP,ZP,YPLOT,ZPLOT,PTREQ)
C
C     WRITE PLOT DATA TO FILE PDATA FOR 3-D PLOT
C
         WRITE(77,36) PTREQ
         WRITE(77,35)(ZPLOT(J),YPLOT(J),X(I,K(I,1)),J=1,PTREQ)
   35    FORMAT(2(F10.5,1H,),F10.5)
   36    FORMAT(I3)
C
C        IMPLEMENT PLOTTING OF DATA POINTS IN ARRAYS YPLOT,ZPLOT
C
         CALL PLOTS (5HCAL25)
C
C        CALCULATE ORIGIN AND SCALING FACTORS
C
         YPLOT(1)=YPLOT(1)*10.0
         ZPLOT(1)=ZPLOT(1)*10.0
         CALL PLOT (YPLOT(1),ZPLOT(1),3)
      DO 37 J=2,PTREQ
         YPLOT(J)=YPLOT(J)*10.0
         ZPLOT(J)=ZPLOT(J)*10.0
         CALL PLOT(YPLOT(J),ZPLOT(J),2)
   37 CONTINUE
      CALL PLOTE
      PRINT *,"SECTION ",I," OF ",BONEID
   50 CONTINUE
      PRINT *,"  END OF PLOTTING"
      STOP
      END
      SUBROUTINE RNODES (A.B.X,N,H)
      REAL X(N)
      N=(B-A)/H +1
      X(1)=A
      X(N+1)=B
      DO 10 I=2,N
         X(I)=X(I-1)+H
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BRBFIT (N,YPT,ZPT,Y,Z,M)
      REAL YPT(N),ZPT(N),Y(N),Z(N)
      REAL YDAT(3),ZDAT(3)
      DO 10 I=1,M
         NN = N
         CALL PICK (NN,YPT,ZPT,Y(I),YDAT,ZDAT)
         IF(NN.NE.2) NN=3
         CALL NEVILLE(NN,YDAT,ZDAT,Y(I),Z(I))
   10 CONTINUE
      RETURN
      END
      SUBROUTINE NEVILLE (N,X,Y,Z,W)
      DIMENSION X(40),F(40,40),Y(40)
      NM1=N-1
      NP1=N+1
      DO 19 J=1,N
      F(1,J)=Y(J)
   19 CONTINUE
      DO 39 K=2,N
      KM1=K-1
      DO 29 J=K,N
   29 F(K,J)=(F(KM1,J-1)*(X(J)-Z)-F(KM1,J)*(X(J-K+1)-Z))/(X(J)-X(J-K+1))
   39 CONTINUE
      W=F(N,N)
      RETURN
   51 W=F(K,K)
      RETURN
      END
```

```
      SUBROUTINE PICK (N,YPT,ZPT,YVAL,YDAT,ZDAT)
      INTEGER PT
      REAL YPT(N),ZPT(N),YDAT(3),ZDAT(3)
      IF(N.LT.3) GOTO 25
      IF(YVAL.GT.YPT(N-1)) GOTO 40
      N1 = N -1
      DO 10 I=2,N1
         IF(YVAL.LT.YPT(I)) GOTO 15
   10 CONTINUE
   15 L1 = I - 1
      L2 = I + 1
      PT = 1
      DO 20 I=L1,L2
         YDAT(PT)=YPT(I)
         ZDAT(PT)=ZPT(I)
         PT = PT + 1
   20 CONTINUE
      RETURN
   25 N = 2
      DO 30 I=1,N
         YDAT(I)=YPT(I)
         ZDAT(I)=ZPT(I)
   30 CONTINUE
      RETURN
   40 PT = 1
      L1 = N - 2
      DO 50 I=L1,N
         YDAT(PT)=YPT(I)
         ZDAT(PT)=ZPT(I)
         PT=PT+1
   50 CONTINUE
      RETURN
      END
```

APPENDIX VI

Computer Programme GENCUR

(for the plotting of extra curves on surfaces)

 79/11/30. 14.27.35.
PROGRAM   GENCUR

```
      PROGRAM GENC(INPUT,NEW,OUTPUT,BONE,TAPE5=NEW
     +                ,TAPE2=OUTPUT,TAPE1=BONE)
      COMMON  X(20,20),Y(20,20),Z(20,20),K(20,2),XMESH,YMESH
      REAL XBEG(20),YBEG(20),XFIN(20),YFIN(20)
      REAL YSTART,YSTOP,C(6),YPT(20),XDAT(3),YDAT(3)
      INTEGER BONEID
C
C     PROGRAM TO GENERATE EXTRA CURVES FOR 3-D PLOTTING
C
      READ (1,*) N,M,XMESH,YMESH,BONEID
      IF(EOF(1).NE.0) STOP "INSUFFICIENT DATA ON FILE BONE"
      DO 20 I=1,N
         READ(1,*) K(I,1),K(I,2)
      IF(EOF(1).NE.0) STOP "INSUFFICIENT DATA ON FILE BONE "
         K1=K(I,1)
         K2=K(I,2)
         READ(1,*) (X(I,J),Y(I,J),Z(I,J),J=K1,K2)
      IF(EOF(1).NE.0) STOP "INSUFFICIENT DATA ON FILE BONE"
   20 CONTINUE
      DO 30 I=1,N
         XBEG(I)=X(I,K(I,1))
         XFIN(I)=X(I,K(I,2))
         YBEG(I)=Y(I,K(I,1))
         YFIN(I)=Y(I,K(I,2))
   30 CONTINUE
      PRINT *,"HOW MANY EXTRA CURVES "
      READ *,NCUR
      XGAP=XMESH/(NCUR+1)
      NCURVES=N+(N-1)*NCUR
      WRITE(5,34) NCURVES,M,XMESH,YMESH,BONEID
   34 FORMAT(2(I2,1H,),F5.2,1H,,F5.2,1H,,1H",A10,1H")
     .DO 50 I=1,N
         K1=K(I,1)
         K2=K(I,2)
         WRITE(5,35) K1,K2
         WRITE(5,36)(X(I,J),Y(I,J),Z(I,J),J=K1,K2)
C
C        TEST IF LAST KNOWN DATA CURVE
C        IF LAST SKIP TO END AS NO MORE SURFACE FITTING REQUIRED
C
         IF(I.EQ.N) GOTO 55
   35    FORMAT(I2,1H,,I2)
   36    FORMAT(3(F10.5))
         DO 40 J=1,NCUR
               XPT=XBEG(I)+J*XGAP
               CALL PICK (N,XBEG,YBEG,XDAT,YDAT,I)
               CALL BRBFIT(3,XDAT,YDAT,XPT,YSTART,1)
               CALL PICK (N,XFIN,YFIN,XDAT,YDAT,I)
               CALL BRBFIT(3,XDAT,YDAT,XPT,YSTOP,1)
C
```

```
C     ADD POINTS BETWEEN THE CALCULATED ENDPOINTS
C
            CALL FILLPTS(YPT,YSTART,YSTOP,I,NFITPTS,J,M,JJ,MM)
             JJ=JJ+1
             MM=MM+1
               WRITE(5,35) JJ,MM
            DO 39 L=1,NFITPTS
               II=I
               CALL QUADRIC (XPT,YPT(L),C,II,L,N,ZPT)
               WRITE(5,36) XPT,YPT(L),ZPT
   39       CONTINUE
   40    CONTINUE
   50 CONTINUE
   55 STOP
      END
      SUBROUTINE BRBFIT (N,YPT,ZPT,Y,Z,M)
      REAL YPT(N),ZPT(N)
      DO 5 I=1,N
    5 CONTINUE
      DO 10 I=1,M
         CALL NEVILLE(N,YPT,ZPT,Y,Z)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE NEVILLE (N,X,Y,Z,W)
      DIMENSION X(40),F(40,40),Y(40)
      NM1=N-1
      NP1=N+1
      DO 19 J=1,N
      F(1,J)=Y(J)
   19 CONTINUE
      DO 39 K=2,N
      KM1=K-1
      DO 29 J=K,N
   29 F(K,J)=(F(KM1,J-1)*(X(J)-Z)-F(KM1,J)*(X(J-K+1)-Z))/(X(J)-X(J-K+1))
   39 CONTINUE
      W=F(N,N)
      RETURN
   51 W=F(K,K)
      RETURN
      END
      SUBROUTINE FILLPTS(YPT,YSTART,YSTOP,I,NPTS,J,M,JJ,MM)
      COMMON  X(20,20),Y(20,20),Z(20,20),K(20,20),XMESH,YMESH
      LOGICAL BEGPT,ENDPT
      INTEGER P
      REAL XPT,YPT(20)
C
C     SUBROUTINE TO FILL IN DATA POINTS ON GRID FOR NEW CURVE
C
```

```
      NPTS=0
      BEGPT=.FALSE.
      ENDPT=.FALSE.
      K1=K(I,1)
      K2=K(I,2)
      DO 10 JJ=K1,K2
         IF(Y(I,JJ).GE.YSTART) GOTO 20
   10 CONTINUE
      JJ=K1
   20 L=0
      DO 30 P=K1,K2
         MM=K2-L
         IF(Y(I,MM).LE.YSTOP) GOTO 40
         L=L+1
   30 CONTINUE
      MM=K2
   40 NPTS=MM-JJ+1
      IF(ABS(Y(I,JJ)-YSTART).LE.1E-4) BEGPT = .TRUE.
      IF(ABS(Y(I,MM)-YSTOP).LE.1E-4) ENDPT = .TRUE.
C
C     TEST TO SEE WHETHER ENDPOINTS INCLUDED
C
      IF((BEGPT).AND.(ENDPT))GOTO 100
      IF(BEGPT) GOTO 60
      IF(ENDPT) GOTO 80
      NPTS=NPTS+2
      YPT(1)=YSTART
      PT=2
      DO 50 L=JJ,MM
         YPT(PT)=Y(I,L)
         PT=PT+1
   50 CONTINUE
      YPT(PT)=YSTOP
      JJ=JJ-1
      MM=MM+1
      RETURN
   60 NPTS=NPTS+1
      PT=1
      DO 70 L=JJ,MM
         YPT(PT)=Y(I,L)
         PT=PT+1
   70 CONTINUE
      YPT(PT)=YSTOP
      MM=MM+1
      RETURN
   80 NPTS=NPTS+1
      YPT(1)=YSTART
      PT=2
      DO 90 L=JJ,MM
         YPT(PT)=Y(I,L)
         PT=PT+1
   90 CONTINUE
```

```
      JJ=JJ-1
      RETURN
  100 PT=1
      DO 110 L=JJ,MM
         YPT(PT)=Y(I,L)
         PT=PT+1
  110 CONTINUE
      RETURN
      END
      SUBROUTINE QUADRIC(U,V,C,I,J,NX,ZPT)
      COMMON   X(20,20),Y(20,20),Z(20,20),K(20,2),XMESH,YMESH
C****    SELECTS 6 POINTS NEAREST TO P(U,V) FROM DATA AND CALCULATES
C****    COEFFICIENTS OF QUADRIC  Z=AX2+BXY+CX2+DX+EY+F  THROUGH THEM.
      DIMENSION D(60),XX(60),YY(60),ZZ(60),AM(6,6),C(6),WKAREA(100)
      N=0
      IM=AMAX0(I-2,1)
      IP=AMIN0(IM+4,NX)
      DO 19 L=IM,IP
      JM1=K(L,1)
      JP1=K(L,2)
      DO 19 M=JM1,JP1
      DX=U-X(L,M)
      DY=V-Y(L,M)
      IF(ABS(DX).GT.3.0*XMESH.OR.ABS(DY).GT.3.0*YMESH) GO TO 19
      N=N+1
      D(N)=SQRT(DX*DX+DY*DY)
      XX(N)=X(L,M)
      YY(N)=Y(L,M)
      ZZ(N)=Z(L,M)
CCCCC WRITE(2,234)XX(N),YY(N),ZZ(N),D(N)
  234 FORMAT(5H XYZD ,4(2X,F9.3))
   19 CONTINUE
      IF(N.GT.6) CALL SORTER(D,XX,YY,ZZ,N)
CCCCC WRITE(2,234)(XX(M),YY(M),ZZ(M),D(M),M=1,N)
      IF(N.LT.6) WRITE(2,201) N
      NCALLS=1
   21 DO 29 M=1,6
      AM(M,1)=XX(M)**2
      AM(M,2)=XX(M)*YY(M)
      AM(M,3)=YY(M)**2
      AM(M,4)=XX(M)
      AM(M,5)=YY(M)
      AM(M,6)=1.0
      C(M)=ZZ(M)
CCCCC WRITE(2,245)(AM(M,JJ),JJ=1,6),C(M)
  245 FORMAT(6H AM,C ,7(3X,F9.3))
   29 CONTINUE
      IDGT=0
      CALL LEQT2F(AM,1,6,6,C,IDGT,WKAREA,IER)
CCCCC WRITE(2,202) IER,IDGT,(C(M),M=1,6)
      IF(NCALLS.GE.9) STOP "TOO MANY CALLS"
```

```
      IF(IER.NE.0) CALL RESORT(D,XX,YY,ZZ,5,N)
      NCALLS=NCALLS+1
      IF(IER.NE.0) GO TO 21
      ZPT = C(1)*U**2 + C(2)*U*V + C(3)*V**2
     +            + C(4)*U    + C(5)*V     + C(6)
      RETURN
  201 FORMAT(1H0/47H 6 NEAR POINTS NEEDED FOR QUADRIC,BUT HAVE ONLY,I2)
  202 FORMAT(7H0 IER =,I3,8H IDGT = ,I2,26H   COEFFICIENTS OF QUADRIC,
     +   6(1X,F10.5))
      END
      SUBROUTINE SORTER(D,X,Y,Z,N)
C****     SORTS N POINTS (X,Y,Z) INTO ORDER OF INCREASING D
      DIMENSION D(N),X(N),Y(N),Z(N)
      DO 29 L=2,N
      LM1=L-1
      DO 19 K=1,LM1
      IF(D(L).GE.D(K)) GO TO 19
      LMK=L-K
      T0=D(L)
      T1=X(L)
      T2=Y(L)
      T3=Z(L)
      DO 9 M=1,LMK
      D(L+1-M)=D(L-M)
      X(L+1-M)=X(L-M)
      Y(L+1-M)=Y(L-M)
      Z(L+1-M)=Z(L-M)
    9 CONTINUE
      D(K)=T0
      X(K)=T1
      Y(K)=T2
      Z(K)=T3
   19 CONTINUE
   29 CONTINUE
      RETURN
      END
      SUBROUTINE RESORT(D,X,Y,Z,K,N)
C****     MOVES POINT K TO THE END OF THE ARRAY
      DIMENSION D(N),X(N),Y(N),Z(N)
      NM1=N-1
      T0=D(K)
      T1=X(K)
      T2=Y(K)
      T3=Z(K)
      DO 9 M=K,NM1
      D(M)=D(M+1)
      X(M)=X(M+1)
      Y(M)=Y(M+1)
      Z(M)=Z(M+1)
    9 CONTINUE
      D(N)=T0
      X(N)=T1
      Y(N)=T2
      Z(N)=T3
      RETURN
      END
      SUBROUTINE PICK(N,X,Y,XDAT,YDAT,I)
      REAL X(N),Y(N),XDAT(3),YDAT(3)
C
C     SUBROUTINE TO FIND 3 NEAREST POINTS
C
      IF(I.EQ.1) GOTO 20
      IF(I.EQ.N) GOTO 40
      L1=I-1
      L2=I+1
      PT=1
      DO 10 J=L1,L2
         XDAT(PT)=X(J)
         YDAT(PT)=Y(J)
         PT=PT+1
   10 CONTINUE
      RETURN
   20 DO 30 J=1,3
         XDAT(J)=X(J)
         YDAT(J)=Y(J)
   30 CONTINUE
      RETURN
   40 PT=1
      L1=I-2
      DO 50 J=L1,N
         XDAT(PT)=X(J)
         YDAT(PT)=Y(J)
         PT=PT+1
   50 CONTINUE
      RETURN
      END
```

APPENDIX VII

Results of arc length of the two axes of the T-M1 joint
Medio - lateral axis

Specimen No.	T (inches)	M1 (inches)	T >M	T <M	T = M
1	0.5914	0.6207		†	
3	0.4336	0.5504		†	
5	0.6691	0.8713		†	
7	0.6390	0.7192		†	
10	0.6617	0.6763		†	
11	0.5604	0.7001		†	
12	0.6654	- *	-	-	-
13	0.6293	0.7345		†	
16	0.6384	0.6032	†		
17	0.5435	0.5911		†	
18	0.7448	0.9267		†	
19	0.8328	0.9125		†	
20	0.7624	0.7267	†		
21	0.6002	0.6830		†	
22	0.6275	0.7317		†	
23	0.6155	0.6089			†
24	0.5443	0.5529			†
25	0.5662	0.6037		†	
26	0.7333	0.6981	†		
27	0.7584	0.9038		†	
28	0.6007	0.6924		†	
29	0.5999	0.6296		†	
30	0.4763	0.6207		†	
Total 22			3	17	2

Note T = trapezium M1 = First metacarpal

* M12 had no definite medio-lateral axis

APPENDIX VII

Antero-posterior axis

	Specimen No.	T (inches)	M1 (inches)	T >M	T < M	T = M
	1	0.8075	0.6258	†		
	3	0.5340	0.4204	†		
	5	0.6502	0.5423	†		
	7	0.5584	0.5017	†		
	10	0.5790	0.4865	†		
	11	0.5808	0.8045		†	
	12	0.4787	0.4902		†	
	13	0.6744	0.5967	†		
	16	0.6413	0.4872	†		
	17	0.5132	0.4505	†		
	18	0.5342	0.9347		†	
	19	0.6268	0.6253			†
	20	0.5377	0.6341		†	
	21	0.5880	0.5852			†
	22	0.5241	0.5620		†	
	23	0.5125	0.5619		†	
	24	0.4638	0.4326	†		
	25	0.5139	0.5067			†
	26	0.6409	0.5394	†		
	27	0.5371	0.6008		†	
	28	0.5191	0.5078	†		
	29	0.5144	0.4832	†		
	30	0.6383	0.5603	†		
Total	23			13	7	3

APPENDIX VIII

Surface area of the articular surfaces of the T-M1 joint

Specimen No.	T (sq. inches)	M1 (sq. inches)	T >M 1	T < M1	T = M1
1	0.3059	0.2958	†		
3	0.1532	0.1640		†	
5	0.2533	0.2179	†		
7	0.2018	0.2097			†
10	0.2412	0.2424			†
11	0.2702	0.2707			†
12	0.2268	0.1816	†		
13	0.2485	0.2723		†	
16	0.2336	0.1924	†		
17	0.1647	0.1759		†	
18	0.2710	0.2848		†	
19	0.2921	0.3257		†	
20	0.2575	0.2541			†
21	0.2789	0.2462	†		
22	0.1873	0.2702		†	
23	0.2035	0.1652	†		
24	0.1773	0.1751			†
25	0.2014	0.1746	†		
26	0.2712	0.2264	†		
27	0.2688	0.3148		†	
28	0.2457	0.2147	†		
29	0.1868	0.1972		†	
30	0.1951	0.1911			†
Total 23			9	8	6

APPENDIX IX

Surface area of the four quadrants of the trapezial and metacarpal articular surfaces

Specimen	Antero-medial		Antero-lateral		Postero-medial		Postero-lateral	
No.	T (sq. ins.)	M (sq. ins.)	T (sq. ins.)	M (sq. ins.)	T (sq. ins.)	M (sq. ins.)	T (sq. ins.)	M (sq. ins.)
1	0.0743	0.0602	0.0689	0.0802	0.0828	0.0732	0.0703	0.0934
3	0.0344	0.0363	0.0587	0.0345	0.0460	0.0413	0.0265	0.0498
5	0.0527	0.0594	0.0961	0.0624	0.0623	0.0430	0.0471	0.0636
7	0.0392	0.0424	0.0538	0.0432	0.0482	0.0672	0.0664	0.0655
10	0.0952	0.0181	0.0233	0.0360	0.0885	0.0863	0.0645	0.0744
11	0.0594	0.0474	0.0445	0.0717	0.0818	0.0857	0.0467	0.0890
12 *	–	–	–	–	–	–	–	–
13	0.0410	0.0744	0.0779	0.0916	0.0615	0.0484	0.0493	0.0416
16	0.0455	0.0540	0.0736	0.0510	0.0597	0.0353	0.0602	0.0562
17	0.0251	0.0520	0.0330	0.0634	0.0426	0.0241	0.0495	0.0387
18	0.0681	0.0780	0.0685	0.0381	0.0732	0.0512	0.0422	0.1112
19	0.0575	0.0683	0.1071	0.0835	0.0772	0.0580	0.0656	0.1106
20	0.0351	0.0426	0.0763	0.0563	0.0941	0.0816	0.0774	0.0729
21	0.0473	0.0787	0.0977	0.0990	0.0724	0.0463	0.0301	0.0295
22	0.0307	0.0642	0.0838	0.0822	0.0258	0.0341	0.0328	0.0673
23	0.0354	0.0563	0.0535	0.0360	0.0473	0.0353	0.0356	0.0424
24	0.0379	0.0170	0.0385	0.0324	0.0307	0.0385	0.0478	0.0710
25	0.0150	0.0468	0.0528	0.0487	0.0458	0.0312	0.0420	0.0415
26	0.0704	0.0501	0.0443	0.0790	0.0716	0.0414	0.0518	0.0631
27	0.0431	0.0561	0.0695	0.0599	0.0980	0.0493	0.0663	0.1028
28	0.0531	0.0357	0.0700	0.0447	0.0620	0.0441	0.0479	0.0518
29	0.0299	0.0367	0.0466	0.0824	0.0582	0.0146	0.0452	0.0543
30	0.0860	0.0544	0.0409	0.0377	0.0612	0.0346	0.0078	0.0775
Mean	**0.0489**	**0.0513**	**0.0627**	**0.0597**	**0.0632**	**0.0484**	**0.0489**	**0.0667**

* Specimen 12 had no distinct medio-lateral axis

APPENDIX X

Tests used to exclude rheumatoid arthritis, Marfan's syndrome and Ehlers Danlos syndrome as causes of generalised peripheral joint hypermobility

a. Rheumatoid Arthritis

Subjects were excluded from this research project if they were:

1) a **known history of rheumatoid arthritis,**
2) a **history of multi-arthrodial inflammation** characterised by pain, swelling and stiffness (particularly in the mornings which differentiates them from those caused by mild traumata characteristic of primary hypermobility).
3) **the presence of pain, swelling and/or deformity of the joints of the fingers and toes.**

b. Marfan's Syndrome

Subjects were excluded from this research project if they exhibited the classical features of Marfan's Syndrome as described by Sinclair, R.J.G. et al. (1960) and Eldridge, R. (1964). These are:

1) **arachnodactyly**
2) **metacarpal index greater than 8.8 for men and 9.4 for women**

Eldridge found these to be the upper limits for his 'normal group'.

The metacarpal index was obtained by taking measurements of the second, third and fourth metacarpals of both hands. From the postero-anterior X-ray the length and external diameter (at midpoint of its length) of each metacarpal were measured. The metacarpal index is the average ratio of the metacarpal length divided by the external diameter for both hands.

As can be seen from the results following, none of the people exhibiting generalised joint hypermobility had an abnormally high metacarpal index.

Case No.		Left hand metacarpals			Right hand metacarpals			Average Metacarpal Index (L/D)	Sex	Metacarpal Index	
		2	3	4	2	3	4			Normal	Abnormal
007	L	6.23	6.07	5.36	6.25	6.05	5.42				
	D	0.67	0.65	0.61	0.65	0.65	0.62	9.16	F	†	
008	L/D	9.36	9.17	8.83	9.56	9.28	8.77				
009	L	6.37	6.31	5.59	6.24	6.08	5.52				
	D	0.74	0.74	0.59	0.74	0.77	0.57	8.77	F	†	
010	L/D	8.61	8.53	9.47	8.43	7.90	9.68				
043	L	5.98	5.73	5.10	6.02	5.73	5.18				
	D	0.74	0.69	0.51	0.78	0.75	0.56	8.48	F	†	
044	L/D	7.96	8.30	10.00	7.72	7.64	9.25				
053	L	6.43	6.06	5.34	6.73	6.30	5.48				
	D	0.83	0.77	0.58	0.92	0.79	0.62	8.16	F	†	
054	L/D	7.75	7.87	9.21	7.32	7.97	8.84				
055	L	6.16	6.00	5.21	6.18	5.92	5.11				
	D	0.78	0.82	0.65	0.83	0.82	0.65	7.63	F	†	
056	L/D	7.90	7.32	8.02	7.45	7.22	7.86				
063	L	6.31	6.10	5.34	6.47	6.10	5.23				
	D	0.83	0.78	0.66	0.83	0.81	0.68	7.76	F	†	
064	L/D	7.60	7.82	8.09	7.80	7.53	7.69				
065	L	6.61	6.49	5.76	6.53	6.30					
	D	0.90	0.77	0.66	0.90	0.73	-	8.08	M	†	
066	L/D	7.34	8.43	8.73	7.26	8.63					
075	L	6.45	6.18	5.42	6.35	6.06	5.43				
	D	0.89	0.89	0.70	0.91	0.89	0.65	7.35	F	†	
076	L/D	7.25	6.94	7.74	6.98	6.81	8.35				
077	L	6.49	6.05	5.49	6.66	6.09	5.48				
	D	0.74	0.69	0.51	0.73	0.73	0.55	9.29	F	†	
078	L/D	8.77	8.77	10.76	9.12	8.34	9.96				
079	L	6.33	6.05	5.30	6.37	6.16	5.51				
	D	0.80	0.78	0.56	0.79	0.75	0.57	8.51	F	†	
080	L/D	7.91	7.76	9.46	8.06	8.21	9.67				
081	L	6.16	5.69	5.20	6.16	5.67	5.19				
	D	0.65	0.71	0.55	0.71	0.66	0.55	8.94	F	†	
082	L/D	9.48	8.01	9.45	8.68	8.59	9.44				
083	L	6.73	6.25	5.54	6.71	6.17	5.61				
	D	0.81	0.80	0.65	0.85	0.85	0.63	8.12	F	†	
084	L/D	8.31	7.81	8.52	7.89	7.26	8.90				

Case No.		Left hand metacarpals			Right hand metacarpals			Average Metacarpal Index (L/D)	Sex	Metacarpal Index	
		2	3	4	2	3	4			Normal	Abnormal
089	L	6.72	6.64	5.87	6.75	6.67	5.82				
	D	0.76	0.80	0.67	0.78	0.83	0.70	8.48	F	†	
090	L/D	8.84	8.30	8.76	8.65	8.04	8.31				
103	L	6.15	5.83	5.20	5.95	5.81	5.22				
	D	0.72	0.74	0.54	0.72	0.72	0.58	8.56	F	†	
104	L/D	8.54	7.88	9.63	8.26	8.07	9.00				
121	L	6.37	6.10	5.51	6.38	6.16	5.40				
	D	0.81	0.75	0.52	0.89	0.83	0.56	8.47	F	†	
122	L/D	7.86	8.13	10.60	7.17	7.42	9.64				
161	L	6.36	6.42	5.67	6.37	6.32	5.67				
	D	0.72	0.70	0.55	0.80	0.73	0.56	9.18	F	†	
162	L/D	8.83	9.17	10.31	7.96	8.66	10.13				
175	L	6.30	6.08	5.14	6.24	6.00	5.46				
	D	0.82	0.79	0.67	0.82	0.82	0.65	7.73	F	†	
176	L/D	7.68	7.70	7.67	7.61	7.32	8.40				
205	L	6.06	6.00	5.18	6.15	6.12	5.18				
	D	0.78	0.76	0.63	0.73	0.85	0.62	7.98	F	†	
206	L/D	7.77	7.89	8.22	8.42	7.20	8.35				
209	L	6.32	6.14	5.48	6.36	6.20	5.65				
	D	0.74	0.67	0.60	0.84	0.72	0.62	8.69	F	†	
210	L/D	8.54	9.16	9.13	7.57	8.61	9.11				
219	L	7.12	6.88	7.30	7.00	6.26					
	D	0.92	0.92	0.96	0.94	0.74		7.75	M	†	
220	L/D	7.74	7.48	7.60	7.15	8.46					
227	L	6.82	6.27	5.63	6.90	6.29	5.67				
	D	0.90	0.90	0.73	0.98	0.93	0.73	7.31	M	†	
228	L/D	7.58	6.97	7.71	7.04	6.76	7.77				
239	L	6.19	5.87	5.31	6.28	5.98	5.28				
	D	0.78	0.75	0.61	0.82	0.80	0.79	7.72	M	†	
240	L/D	7.94	7.83	8.70	7.66	7.48	6.68				

c. Ehlers Danlos Syndrome (E.D.S.)

Subjects were excluded from this research project if they exhibited the classical features of Ehlers Danlos syndrome as outlined by Grahame & Beighton (1969). In addition to generalised joint hypermobility, these features are:

1) **fragility of the skin** – splitting of the skin and scars, especially over bony prominences.

2) **thin skin.** Measurements for skin thickness were made over the dorsum of the fourth metacarpal with Harpenden calipers. Grahame & Beighton found people with E.D.S. to have significantly thinner skin than a matched normal group. Women with E.D.S. had a mean skin thickness of 0.8 mm (normals = 1.1 mm) and men with E.D.S. 0.8 mm (normals = 1.2 mm). The measurements of skin thickness for the hypermobile group are detailed below.

Case No.	Sex	Skin thickness	Case No.	Sex	Skin thickness	Case No.	Sex	Skin thickness
007	F	0.9	076	F	0.9	161	F	0.9
008	F	0.9	077	F	1.1	162	F	1.1
009	F	1.0	078	F	1.1	175	F	1.0
010	F	0.9	079	F	0.9	176	F	1.0
043	F	0.9	080	F	1.0	205	F	1.1
044	F	1.0	081	F	0.9	206	F	1.1
053	F	1.3	082	F	0.8	209	F	1.0
054	F	1.1	083	F	0.9	210	F	0.9
055	F	1.0	084	F	0.9	219	M	1.3
056	F	1.1	089	F	0.9	220	M	1.4
063	F	0.9	090	F	1.0	227	M	1.2
064	F	0.9	103	F	0.9	228	M	1.1
065	M	1.0	104	F	1.0	239	M	1.1
066	M	1.0	121	F	0.8	240	M	1.0
075	F	0.9	122	F	0.9			

Hypermobile Group — skin thickness

Reference to the above table shows that there were only two cases (082 and 121) with a reading of 0.8 mm. These people were not excluded from the research project as the skin of their other hand (081 and 122 respectively) was within normal limits and they did not exhibit fragility of their skin.

Although **hyper-elasticity of skin** is a classical feature of Ehlers Danlos syndrome this was not measured as it requires sophisticated equipment.

APPENDIX XI

Clinical Study — Questionnaire and Data Form

Case Number

Group: Normal (0) Hypermobile (1) Osteo-Arthrotic (2)
Manipulative Therapists (3) Tailors and Dressmakers (4) Musicians (5)

Age Group (Years): 0-29 (0) 30 - 39 (1) 40-49 (2) 50-59 (3)

Gender: Male (0) Female (1)

Dominance: Left (0) Right (1) Ambidextrous (2)

Side: Left (0) Right (1)

Years of thumb use: 0-5 (0) 6-10 (1) 11-15 (2) 16-20 (3) > 20 (4)

History of pain/swelling: Yes (0) No (1)

History of pain assoc. with use: Yes (0) No (1)

History of trauma to T-M1 joint: Yes (0) No (1)

Menstrual Status: Regular (0) Menopausal (1)
Post-Menopausal/Hysterectomy (2) Not Applicable (9)

Skin Thickness (mm):

Height (cm):

Weight (kg):

Obesity: Obese (0) Not Obese (1)

Peri-Articular Thickening: Thick (0) Not Thick (1)

Physiological Movements of T-M1 Joint

Range < Degrees >

Range 1 Extension

Range 2 Palmar-Abduction

Range 3 Opposition

Pain Experienced During Examination No Pain (0) Pain (1)

Pain 1 Extension

Pain 2 Palmar-Abduction

Pain 3 Opposition

Quality of Movement

Normal (0) Early Resistance (1) Crepitus (2)

Quality 1	(Extension)
Quality 2	(Palmar Abduction)
Quality 3	(Opposition)

Accessory Movements of T-M1 Joint

Range	No Movement (0) Very Stiff (1) Slightly Stiff (2) Normal (3) Hypermobile (4)
Range 4	Distraction
Range 5	Antero-Posterior Gliding
Range 6	Postero-Anterior Gliding
Range 7	Medial Gliding
Range 8	Lateral Gliding
Range 9	Medial Rotation
Range 10	Lateral Rotation

Pain Experienced During Examination Yes (0) No (1)

Pain 4	Distraction
Pain 5	Antero-Posterior Gliding
Pain 6	Postero-Anterior Gliding
Pain 7	Medial Gliding
Pain 8	Lateral Gliding
Pain 9	Medial Rotation
Pain 10	Lateral Rotation

Quality of Movement Normal (0) Early Resistance (1) Crepitus (2)

Quality 4	Distraction
Quality 5	Antero-Posterior Gliding
Quality 6	Postero-Anterior Gliding
Quality 7	Medial Gliding
Quality 8	Lateral Gliding
Quality 9	Medial Rotation
Quality 10	Lateral Rotation

Adjacent Joint Mobility

Metacarpo-Phalangeal Joint

Range 11 Flexion < Degrees >

Range 12 Extension < Degrees >

Trapezio-M2 Joint

MVT 1 Antero-Posterior Gliding Stiff (0) Mobile (1)

MVT 2 Postero-Anterior Gliding Stiff (0) Mobile (1)

Trapezio-Trapezoid Joint

MVT 3 Antero-Posterior Gliding Stiff (0) Mobile (1)

MVT 4 Postero-Anterior Gliding Stiff (0) Mobile (1)

Trapezio-Scaphoid Joint

MVT 5 Antero-Posterior Gliding Stiff (0) Mobile (1)

MVT 6 Postero-Anterior Gliding Stiff (0) Mobile (1)

Peripheral Joint Mobility < Degrees >

Range 13 Little Finger McP Extension

Range 14 Elbow Extension

Range 15 Ankle Dorsiflexion

Range 16 Knee Extension

Generalised Peripheral Joint Mobility

Normal (0) Hypermobile (1)

Radiological Examination Normal (0) Mild Osteo-Arthrosis (1)
Moderate Osteo-Arthrosis (2) Marked Osteo-Arthrosis (3)

X-ray 1 T-M1 Joint

X-ray 2 Metacarpo-Phalangeal Joint

X-ray 3 Trapezio-Trapezoid Joint

X-ray 4 Trapezio-Scaphoid Joint

X-ray 5 Trapezio-M2 Joint

Dorso-Lateral Instability None (0) Mild (1) Moderate (2) Marked (3)

Bone Quantity Normal (0) Osteopenia (1)

Congenital Deformity Yes (0) No (1)

Rheumatoid Arthritis Yes (0) No (1)

APPENDIX XII

Whole Sample (N=492) – influence of gender on the range of the physiological movements of the T-M1 joint, analysed for each age group

Range of Extension

			Gender				
Age Group		Male			Female		't' value
(years)	Total	$\bar{x}$	S.D.	Total	$\bar{x}$	S.D.	significance
20 - 29	46	47°	6.7	78	42°	7.9	3.77, $p < .0001$
30 - 39	65	46°	7.8	51	42°	6.3	3.06, $p < .005$
40 - 49	48	45°	6.8	46	41°	6.8	3.03, $p < .005$
50 - 59	70	43°	7.3	88	39°	9.9	2.96, $p < .005$

Range of Palmar-abduction

			Gender				
Age Group		Male			Female		't' value
(years)	Total	$\bar{x}$	S.D.	Total	$\bar{x}$	S.D.	significance
20 - 29	46	51°	6.4	78	46°	7.0	3.34, $p < .001$
30 - 39	65	50°	6.5	51	46°	5.6	3.51, $p < .001$
40 - 49	48	48°	5.9	46	47°	7.0	not significant
50 - 59	70	48°	7.4	88	45°	7.7	2.51, $p < .01$

Range of Opposition

			Gender				
Age Group		Male			Female		't' value
(years)	Total	$\bar{x}$	S.D.	Total	$\bar{x}$	S.D.	significance
20 - 29	46	-6°	9.0	78	6°	10.6	6.47, $p < .0001$
30 - 39	65	-7°	9.0	51	0°	10.8	3.62, $p < .0001$
40 - 49	48	-5°	7.2	46	2°	10.6	3.72, $p < .0001$
50 - 59	70	-5°	8.3	88	3°	7.2	6.93, $p < .0001$

APPENDIX XIII

Whole Sample (N=492) — influence of age on the quality of the physiological and accessory movements of the T-M1 joint

Movement	Age Group (years)				X^2 value
	20 - 29	30 - 39	40 - 49	50 - 59	significance
Extension					
Normal	122	111	77	103	72.58
Abnormal	2 (2%)	5 (4%)	17 (18%)	55 (35%)	$p < .00001$
Palmar-abduction					
Normal	122	106	74	89	89.18
Abnormal	2 (2%)	10 (9%)	20 (21%)	69 (44%)	$p < .00001$
Opposition					
Normal	119	99	77	79	93.06
Abnormal	5 (4%)	17 (15%)	17 (18%)	79 (50%)	$p < .00001$
Distraction					
Normal	113	102	48	55	134.68
Abnormal	11 (9%)	14 (12%)	46 (49%)	103 (65%)	$p < .00001$
A - P gliding					
Normal	99	65	31	27	121.68
Abnormal	25 (20%)	51 (44%)	63 (67%)	131 (83%)	$p < .00001$
P - A gliding					
Normal	79	44	20	31	69.21
Abnormal	45 (36%)	72 (62%)	74 (79%)	127 (80%)	$p < .00001$
Medial gliding					
Normal	117	101	62	66	112.48
Abnormal	7 (6%)	15 (13%)	32 (34%)	92 (58%)	$p < .00001$
Lateral gliding					
Normal	116	99	64	66	106.11
Abnormal	8 (7%)	17 (15%)	30 (32%)	92 (58%)	$p < .00001$
Medial rotation					
Normal	117	100	66	77	86.87
Abnormal	7 (6%)	16 (14%)	28 (30%)	81 (51%)	$p < .00001$
Lateral rotation					
Normal	114	85	62	68	77.86
Abnormal	10 (8%)	31 (27%)	32 (34%)	90 (57%)	$p < .00001$
Total (N=492)	**124**	**116**	**94**	**158**	

APPENDIX XIV

Whole Sample (N=492) – influence of age on the range of the accessory movements of the T-M1 Joint

Movement	Age Group (years)				X^2 value
	20 - 29	30 - 39	40 - 49	50 - 59	significance
Distraction					
Hypermobile	46 (37%)	23 (20%)	8 (9%)	6 (4%)	126.11
Normal	70 (56%)	90 (77%)	67 (71%)	86 (54%)	$p < .00001$
Stiff	8 (7%)	3 (3%)	19 (20%)	66 (42%)	
A - P gliding					
Hypermobile	49 (40%)	26 (22%)	15 (16%)	13 (8%)	93.08
Normal	65 (52%)	69 (60%)	48 (51%)	62 (39%)	$p < .00001$
Stiff	10 (8%)	21 (18%)	31 (33%)	83 (53%)	
P - A gliding					
Hypermobile	40 (32%)	23 (20%)	16 (17%)	15 (9%)	27.20
Normal	43 (35%)	47 (40%)	34 (36%)	58 (37%)	$p < .0001$
Stiff	41 (33%)	46 (40%)	44 (47%)	85 (54%)	
Medial gliding					
Hypermobile	32 (26%)	20 (17%)	8 (9%)	10 (6%)	88.88
Normal	81 (65%)	84 (73%)	64 (68%)	72 (46%)	$p < .00001$
Stiff	11 (9%)	12 (10%)	22 (23%)	76 (48%)	
Lateral gliding					
Hypermobile	59 (48%)	50 (43%)	22 (23%)	28 (18%)	80.79
Normal	59 (47%)	55 (47%)	57 (61%)	69 (43%)	$p < .00001$
Stiff	6 (5%)	11 (10%)	15 (16%)	61 (39%)	
Medial rotation					
Hypermobile	58 (47%)	31 (27%)	18 (19%)	23 (15%)	81.03
Normal	61 (49%)	75 (64%)	53 (56%)	77 (48%)	$p < .00001$
Stiff	5 (4%)	10 (9%)	23 (25%)	58 (37%)	
Lateral rotation					
Hypermobile	36 (29%)	21 (18%)	8 (8%)	16 (10%)	43.76
Normal	76 (61%)	63 (54%)	60 (64%)	81 (51%)	$p < .00001$
Stiff	12 (10%)	32 (28%)	26 (28%)	61 (39%)	
Total (N=492)	**124**	**116**	**94**	**158**	

APPENDIX XV

Whole Sample (minus non-clinical group, N=318) — **relationship of a past history of pain at the thumb base to the range of the accessory movements of the T-M1 joint**

Movement	History		No History		X^2 value significance
Distraction					
Hypermobile	10	(15%)	54	(21%)	16.12
Normal	32	(49%)	164	(65%)	$p < .0005$
Stiff	23	(36%)	35	(14%)	
A - P gliding					
Hypermobile	14	(22%)	57	(22%)	2.39
Normal	26	(40%)	123	(49%)	not significant
Stiff	25	(38%)	73	(29%)	
P - A gliding					
Hypermobile	9	(14%)	54	(21%)	2.33
Normal	23	(35%)	92	(37%)	not significant
Stiff	33	(51%)	107	(42%)	
Medial gliding					
Hypermobile	10	(15%)	39	(15%)	2.48
Normal	33	(51%)	152	(60%)	not significant
Stiff	22	(34%)	62	(25%)	
Lateral gliding					
Hypermobile	21	(32%)	88	(35%)	4.74
Normal	25	(39%)	121	(48%)	not significant
Stiff	19	(29%)	44	(17%)	
Medial rotation					
Hypermobile	15	(23%)	81	(32%)	7.47
Normal	31	(48%)	134	(53%)	$p < .05$
Stiff	19	(29%)	38	(15%)	
Lateral rotation					
Hypermobile	10	(15%)	45	(18%)	7.34
Normal	30	(46%)	152	(60%)	$p < .05$
Stiff	25	(39%)	56	(22%)	
Total (N=318)	**65**		**253**		

APPENDIX XVI

Whole Sample (minus non-clinical group, N=318) – **relationship of a past history of pain at the thumb base to the quality of the accessory movements of the T-M1 joint**

Movement	History		No History		X^2 value significance
Distraction					
Normal	31		170		8.46
Abnormal	34	(52%)	83	(33%)	$p < .005$
A - P gliding					
Normal	22		120		3.81
Abnormal	43	(66%)	133	(53%)	$p < .05$
P - A gliding					
Normal	20		93		.81
Abnormal	45	(69%)	160	(63%)	not significant
Medial gliding					
Normal	38		168		1.43
Abnormal	27	(42%)	85	(34%)	not significant
Lateral gliding					
Normal	37		176		3.74
Abnormal	28	(43%)	77	(30%)	$p < .05$
Medial rotation					
Normal	39		194		7.35
Abnormal	26	(40%)	59	(23%)	$p < .01$
Lateral rotation					
Normal	32		169		6.86
Abnormal	33	(51%)	84	(33%)	$p < .01$
Total (N=318)	**65**		**253**		

APPENDIX XVII

Whole Sample (N=492) – influence of years of use of the thumb on the range and quality of the physiological movements of the T-M1 joint

Years of use	Mean Range			Total
	Extension	Palmar-abduction	Opposition	
0 - 5	44°	48°	.5°	121
6 - 10	43°	48°	-1°	85
11 - 15	44°	48°	-.5°	86
16 - 20	42°	47°	-2°	33
Over 20	41°	46°	-2°	167
F value	F = 2.73	F = 1.88	F = .62	492
Significance	$p < .05$	Not significant	Not significant	

Quality of Movement	Years of use					X^2 value significance
	0 - 5	6 - 10	11 - 15	16 - 20	Over 20	
Extension						
Normal	107	77	78	27	124	19.25
Abnormal	14 (12%)	8 (9%)	8 (9%)	6 (18%)	43 (26%)	$p < .001$
Palmar-abduction						
Normal	105	76	77	26	107	38.73
Abnormal	16 (13%)	9 (11%)	9 (10%)	7 (21%)	60 (36%)	$p < .00001$
Opposition						
Normal	105	79	78	24	88	81.22
Abnormal	16 (13%)	6 (7%)	8 (9%)	9 (27%)	79 (47%)	$p < .00001$
Total (N=492)	**121**	**85**	**86**	**33**	**167**	

APPENDIX XVIII

Whole Sample (N=492) — relationship of years of use of the thumb to the range of the accessory movements of the T-M1 joint

Range of Movement	Years of Use					X^2 value significance
	0 - 5	6 - 10	11 - 15	16 - 20	Over 20	
Distraction						
Hypermobile	27 (22%)	21 (25%)	21 (24%)	10 (30%)	4 (2%)	69.28
Normal	71 (59%)	59 (69%)	60 (70%)	17 (52%)	106 (64%)	$p < .00001$
Stiff	23 (19%)	5 (6%)	5 (6%)	6 (18%)	57 (34%)	
A - P gliding						
Hypermobile	29 (24%)	27 (32%)	23 (27%)	9 (27%)	15 (9%)	40.71
Normal	57 (47%)	44 (52%)	48 (56%)	16 (49%)	79 (47%)	$p < .00001$
Stiff	35 (29%)	14 (16%)	15 (17%)	8 (24%)	73 (44%)	
P - A gliding						
Hypermobile	25 (21%)	24 (28%)	20 (23%)	4 (12%)	21 (12%)	13.18
Normal	43 (35%)	30 (35%)	28 (33%)	16 (49%)	65 (39%)	not significant
Stiff	53 (44%)	31 (37%)	38 (44%)	13 (39%)	81 (49%)	
Medial gliding						
Hypermobile	20 (17%)	19 (22%)	15 (18%)	5 (15%)	11 (7%)	33.77
Normal	75 (62%)	56 (66%)	58 (67%)	17 (52%)	95 (57%)	$p < .00001$
Stiff	26 (21%)	10 (12%)	13 (15%)	11 (33%)	61 (36%)	
Lateral gliding						
Hypermobile	42 (35%)	34 (40%)	36 (42%)	16 (49%)	31 (18%)	48.10
Normal	64 (53%)	44 (52%)	41 (48%)	10 (30%)	81 (49%)	$p < .00001$
Stiff	15 (12%)	7 (8%)	9 (10%)	7 (21%)	55 (33%)	
Medial rotation						
Hypermobile	36 (30%)	25 (29%)	32 (37%)	8 (24%)	29 (17%)	39.90
Normal	68 (56%)	49 (58%)	49 (57%)	18 (55%)	82 (49%)	$p < .00001$
Stiff	17 (14%)	11 (13%)	5 (6%)	7 (21%)	56 (34%)	
Lateral rotation						
Hypermobile	26 (21%)	17 (20%)	23 (27%)	2 (6%)	13 (8%)	23.33
Normal	65 (54%)	50 (59%)	44 (51%)	19 (58%)	102 (61%)	$p < .005$
Stiff	30 (25%)	18 (21%)	19 (22%)	12 (36%)	52 (31%)	
Total (N=492)	**121**	**85**	**86**	**33**	**167**	

APPENDIX XIX

Whole Sample (N=492) – relationship of years of use of the thumb to the quality of the accessory movements of the T-M1 joint

Quality of Movement	Years of use					X^2 value significance
	0 - 5	6 - 10	11 - 15	16 - 20	Over 20	
Distraction						
Normal	78	75	69	26	70	70.47
Abnormal	43 (36%)	10 (12%)	17 (20%)	7 (21%)	97 (58%)	$p < .00001$
A - P gliding						
Normal	70	46	53	15	38	53.90
Abnormal	51 (42%)	39 (46%)	33 (38%)	18 (55%)	129 (77%)	$p < .00001$
P - A gliding						
Normal	54	39	31	13	37	21.65
Abnormal	67 (55%)	46 (54%)	55 (64%)	20 (61%)	130 (78%)	$p < .0005$
Medial gliding						
Normal	93	75	73	21	84	57.07
Abnormal	28 (23%)	10 (12%)	13 (15%)	12 (36%)	83 (50%)	$p < .00001$
Lateral gliding						
Normal	96	77	70	26	76	76.59
Abnormal	25 (21%)	8 (9%)	16 (19%)	7 (21%)	91 (54%)	$p < .00001$
Medial rotation						
Normal	97	70	77	22	94	43.36
Abnormal	24 (20%)	15 (18%)	9 (10%)	11 (33%)	73 (44%)	$p < .00001$
Lateral rotation						
Normal	89	73	66	21	80	47.36
Abnormal	32 (26%)	12 (14%)	20 (23%)	12 (36%)	87 (52%)	$p < .00001$
Total (N=492)	**121**	**85**	**86**	**33**	**167**	

APPENDIX XX

Whole Sample (N=492) – accessory movements of the T-M1 joint, relationship between range of movement and incidence of pain elicited during examination

Incidence of Pain	Range of Movement			Total
	Hypermobile	Normal	Stiff	
Distraction				
Pain	0	0	3 (3%)	3
No pain	83	313	93	489
Total	83	313	96	492
A - P gliding				
Pain	1 (1%)	3 (1%)	10 (7%)	14
No pain	102	241	135	478
Total	103	244	145	492
P - A gliding				
Pain	1 (1%)	2 (1%)	11 (5%)	14
No pain	93	180	205	478
Total	94	182	216	492
Medial gliding				
Pain	0	0	7 (6%)	7
No pain	70	301	114	485
Total	70	301	121	492
Lateral gliding				
Pain	1 (1%)	1 (1%)	11 (12%)	13
No pain	158	239	82	479
Total	159	240	93	492
Medial rotation				
Pain	1 (1%)	2 (1%)	7 (7%)	10
No pain	129	264	89	482
Total	130	266	96	492
Lateral rotation				
Pain	1 (1%)	3 (1%)	12 (9%)	16
No pain	80	277	119	476
Total	81	280	131	492

APPENDIX XXI

Whole Sample (N=492) — relationship between peri-articular thickening and the quality of the physiological and accessory movements of the T-M1 joint

Quality of Movement	Thick	Not Thick	X^2 value significance
Extension			
Normal	27	386	136.16
Abnormal	46 (63%)	33 (8%)	$p < .00001$
Palmar-abduction			
Normal	26	365	97.92
Abnormal	47 (64%)	54 (13%)	$p < .00001$
Opposition			
Normal	22	352	96.03
Abnormal	51 (70%)	67 (16%)	$p < .00001$
Distraction			
Normal	12	306	84.65
Abnormal	61 (84%)	113 (27%)	$p < .00001$
A - P gliding			
Normal	1	221	64.21
Abnormal	72 (99%)	198 (47%)	$p < .00001$
P - A gliding			
Normal	8	166	21.10
Abnormal	65 (89%)	253 (60%)	$p < .00001$
Medial gliding			
Normal	18	328	83.11
Abnormal	55 (75%)	91 (22%)	$p < .00001$
Lateral gliding			
Normal	15	330	97.79
Abnormal	58 (79%)	89 (21%)	$p < .00001$
Medial rotation			
Normal	23	337	73.32
Abnormal	50 (68%)	82 (20%)	$p < .00001$
Lateral rotation			
Normal	19	310	63.40
Abnormal	54 (74%)	109 (26%)	$p < .00001$
Total	**73**	**419**	

Thick = peri-articular thickening
Not Thick = no peri-articular thickening

APPENDIX XXII

Whole Sample (N=492) – relationship between peri-articular thickening and the range of the accessory movements of the T-M1 joint

Movement	Range of Movement			X^2 value significance
	Hypermobile	Normal	Stiff	
Distraction				
Thick	2	25	46 (63%)	104.90
Not Thick	81	288	50 (12%)	$p < .00001$
A - P gliding				
Thick	1	22	50 (68%)	66.50
Not Thick	102	222	95 (23%)	$p < .00001$
P - A gliding				
Thick	3	21	49 (67%)	22.18
Not Thick	91	161	167 (40%)	$p < .00001$
Medial gliding				
Thick	1	29	43 (59%)	57.44
Not Thick	69	272	78 (19%)	$p < .00001$
Lateral gliding				
Thick	6	23	44 (60%)	98.26
Not Thick	153	217	49 (12%)	$p < .00001$
Medial rotation				
Thick	6	25	42 (58%)	80.49
Not Thick	124	241	54 (13%)	$p < .00001$
Lateral rotation				
Thick	2	32	39 (53%)	35.50
Not Thick	79	248	92 (22%)	$p < .00001$

Thick = peri-articular thickening (N=73)
Not Thick = no peri-articular thickening (N=419)

APPENDIX XXIII

Non-clinical Group (N=174) – relationship between range and quality for each accessory movement of the T-M1 joint

Quality of Movement	Range of Movement			X^2 value significance
	Hypermobile	Normal	Stiff	
Distraction				
Normal	17	90	10	38.14
Abnormal	2	27	28	$p < .00001$
A - P gliding				
Normal	18	57	5	32.51
Abnormal	14	38	42	$p < .00001$
P - A gliding				
Normal	16	38	7	39.84
Abnormal	15	29	69	$p < .00001$
Medial gliding				
Normal	21	110	9	94.49
Abnormal	0	6	28	$p < .00001$
Lateral gliding				
Normal	50	75	7	61.91
Abnormal	0	19	23	$p < .00001$
Medial rotation				
Normal	34	85	8	73.45
Abnormal	0	16	31	$p < .00001$
Lateral rotation				
Normal	24	84	20	41.10
Abnormal	2	14	30	$p < .00001$

APPENDIX XXIV

Hypermobile Group (N=66) — a comparison with the non-clinical group (N=174) for the range of the accessory movements of the T-M1 joint

Movement	Hypermobile group	Non-clinical group	X^2 value significance
Distraction			
Hypermobile	37 (56%)	19 (11%)	54.47
Normal	27 (41%)	117 (67%)	$p < .00001$
Stiff	2 (3%)	38 (22%)	
A - P gliding			
Hypermobile	36 (55%)	32 (18%)	34.15
Normal	26 (39%)	95 (55%)	$p < .00001$
Stiff	4 (6%)	47 (27%)	
P - A gliding			
Hypermobile	26 (40%)	31 (18%)	12.33
Normal	18 (27%)	67 (39%)	$p < .005$
Stiff	22 (33%)	76 (43%)	
Medial gliding			
Hypermobile	24 (36%)	21 (12%)	25.12
Normal	40 (61%)	116 (67%)	$p < .00001$
Stiff	2 (3%)	37 (21%)	
Lateral gliding			
Hypermobile	43 (65%)	50 (29%)	28.55
Normal	21 (32%)	94 (54%)	$p < .00001$
Stiff	2 (3%)	30 (17%)	
Medial rotation			
Hypermobile	43 (65%)	34 (20%)	47.06
Normal	20 (30%)	101 (58%)	$p < .00001$
Stiff	3 (5%)	39 (22%)	
Lateral rotation			
Hypermobile	27 (41%)	26 (15%)	25.64
Normal	35 (53%)	98 (56%)	$p < .00001$
Stiff	4 (6%)	50 (29%)	
Total	**66**	**174**	

APPENDIX XXV

Hypermobile Group (N=66) — a comparison with non-clinical group (N=174) for the quality of the accessory movements of the T-M1 joint

Movement	Hypermobile group	Non-clinical group	X^2 value significance
Distraction			
Normal	54	117	4.28
Abnormal	12 (18%)	54 (31%)	$p < .05$
A - P gliding			
Normal	49	80	14.26
Abnormal	17 (26%)	94 (54%)	$p < .01$
P - A gliding			
Normal	43	61	16.44
Abnormal	23 (35%)	113 (65%)	$p < .01$
Medial gliding			
Normal	62	140	5.55
Abnormal	4 (6%)	34 (20%)	$p < .05$
Lateral gliding			
Normal	60	132	5.86
Abnormal	6 (9%)	42 (24%)	$p < .05$
Medial rotation			
Normal	60	127	7.92
Abnormal	6 (9%)	47 (27%)	$p < .01$
Lateral rotation			
Normal	58	128	4.83
Abnormal	8 (12%)	46 (26%)	$p < .05$
Total	**66**	**174**	

APPENDIX XXVI

Female joints aged 20-29 years — a comparison between hypermobile (N-36) and non-clinical (N=26) groups for the range of the accessory movements of the T-M1 joint

Movement	Hypermobile group	Non-clinical group	X^2 value significance
Distraction			
Hypermobile	22 (61%)	5 (19%)	11.45
Normal	14 (39%)	20 (77%)	$p < .005$
Stiff	0	1 (4%)	
A - P gliding			
Hypermobile	21 (58%)	8 (31%)	7.41
Normal	15 (42%)	15 (58%)	$p < .05$
Stiff	0	3 (11%)	
P - A gliding			
Hypermobile	14 (39%)	5 (19%)	3.35
Normal	10 (28%)	12 (46%)	Not significant
Stiff	12 (33%)	9 (35%)	
Medial gliding			
Hypermobile	14 (39%)	6 (23%)	1.73
Normal	21 (58%)	19 (73%)	Not significant
Stiff	1 (3%)	1 (4%)	
Lateral gliding			
Hypermobile	25 (69%)	8 (31%)	11.05
Normal	11 (31%)	15 (58%)	$p < .005$
Stiff	0	3 (11%)	
Medial rotation			
Hypermobile	27 (75%)	9 (35%)	11.18
Normal	9 (25%)	15 (58%)	$p < .005$
Stiff	0	2 (7%)	
Lateral rotation			
Hypermobile	18 (50%)	5 (19%)	7.35
Normal	17 (47%)	21 (81%)	$p < .05$
Stiff	1 (3%)	0	
Total	**36**	**26**	

APPENDIX XXVII

Quality of the Accessory Movements – a comparison between T-M1 joints with mild osteo-arthrosis (N=130) and the non-clinical group (N=174)

Movement	Mild O-A group	Non-clinical group	X^2 value significance
Distraction			
Normal	75	117	2.79
Abnormal	55 (42%)	57 (33%)	Not significant
A - P gliding			
Normal	51	80	1.25
Abnormal	79 (61%)	94 (54%)	Not significant
P - A gliding			
Normal	40	61	.51
Abnormal	90 (69%)	113 (65%)	Not significant
Medial gliding			
Normal	77	140	16.17
Abnormal	53 (41%)	34 (20%)	$p < .0001$
Lateral gliding			
Normal	84	132	4.44
Abnormal	46 (35%)	42 (24%)	$p < .05$
Medial rotation			
Normal	90	127	.47
Abnormal	40 (31%)	47 (27%)	Not significant
Lateral rotation			
Normal	75	128	8.25
Abnormal	55 (42%)	46 (26%)	$p < .005$
Total	**130**	**174**	

O-A = osteo-arthrosis

APPENDIX XXVIII

Quality of the Physiological and the Accessory Movements of the T-M1 Joint — a comparison between moderate/marked osteo-arthrotic (N=68) and non-clinical (N=174) groups

Movement	**Moderate/marked O-A group**	**Non-clinical group**	**X^2 value significance**
Extension			
Normal	38	148	23.40
Abnormal	30 (44%)	26 (15%)	$p < .00001$
Palmar-abduction			
Normal	32	146	34.13
Abnormal	36 (53%)	28 (16%)	$p < .00001$
Opposition			
Normal	25	143	47.51
Abnormal	43 (63%)	31 (18%)	$p < .00001$
Distraction			
Normal	26	117	17.02
Abnormal	42 (62%)	57 (33%)	$p < .00001$
A - P gliding			
Normal	9	80	22.54
Abnormal	59 (87%)	94 (54%)	$p < .00001$
P - A gliding			
Normal	11	61	8.34
Abnormal	57 (84%)	113 (65%)	$p < .005$
Medial gliding			
Normal	21	140	53.97
Abnormal	47 (69%)	34 (20%)	$p < .00001$
Lateral gliding			
Normal	23	132	37.52
Abnormal	45 (66%)	42 (24%)	$p < .00001$
Medial rotation			
Normal	31	127	16.20
Abnormal	37 (54%)	47 (27%)	$p < .0001$
Lateral rotation			
Normal	22	128	35.24
Abnormal	46 (68%)	46 (26%)	$p < .00001$
Total	**68**	**174**	

O-A = osteo-arthrosis

APPENDIX XXIX

Range of the Accessory Movements of the T-M1 Joint — a comparison between moderate/marked osteo-arthrotic (N=68) and non-clinical (N=174) groups

Movement	Moderate/marked O-A group	Non-clinical group	X^2 value significance
Distraction			
Hypermobile	3 (4%)	19 (11%)	14.28
Normal	34 (50%)	117 (67%)	$p < .001$
Stiff	31 (46%)	55 (22%)	
A - P gliding			
Hypermobile	3 (4%)	32 (18%)	23.51
Normal	25 (37%)	95 (55%)	$p < .00001$
Stiff	40 (59%)	47 (27%)	
P - A gliding			
Hypermobile	7 (10%)	31 (18%)	3.60
Normal	23 (34%)	67 (38%)	Not significant
Stiff	38 (56%)	76 (44%)	
Medial gliding			
Hypermobile	4(6%)	21 (12%)	23.41
Normal	28 (41%)	116 (67%)	$p < .00001$
Stiff	36 (53%)	37 (21%)	
Lateral gliding			
Hypermobile	12 (18%)	50 (29%)	22.83
Normal	24 (35%)	94 (54%)	$p < .00001$
Stiff	32 (47%)	30 (17%)	
Medial rotation			
Hypermobile	11 (16%)	34 (20%)	10.03
Normal	28 (41%)	101 (58%)	$p < .01$
Stiff	29 (43%)	39 (22%)	
Lateral rotation			
Hypermobile	5 (7%)	26 (15%)	4.15
Normal	36 (53%)	98 (56%)	Not significant
Stiff	27 (40%)	50 (29%)	
Total	**68**	**174**	

O-A = osteo-arthrosis

APPENDIX XXX

Range of Accessory Movements of the T-M1 Joint — a comparison between the musicians (N=70) and non-clinical (N=174) groups

Movement	Group		X^2 value significance
	Musicians	Non-clinical	
Distraction			
Hypermobile	13 (19%)	19 (11%)	14.11
Normal	55 (79%)	117 (67%)	$p < .001$
Stiff	2 (2%)	38 (22%)	
A - P gliding			
Hypermobile	8 (11%)	32 (18%)	2.11
Normal	44 (63%)	95 (55%)	Not significant
Stiff	18 (26%)	47 (27%)	
P - A gliding			
Hypermobile	15 (22%)	31 (18%)	.59
Normal	24 (34%)	67 (39%)	Not significant
Stiff	31 (44%)	76 (43%)	
Medial gliding			
Hypermobile	6 (9%)	21 (12%)	.76
Normal	47 (67%)	116 (67%)	Not significant
Stiff	17 (24%)	37 (21%)	
Lateral gliding			
Hypermobile	18 (26%)	50 (29%)	.75
Normal	42 (60%)	94 (54%)	Not significant
Stiff	10 (14%)	30 (17%)	
Medial rotation			
Hypermobile	19 (27%)	34 (20%)	4.55
Normal	43 (62%)	101 (58%)	Not significant
Stiff	8 (11%)	39 (22%)	
Lateral rotation			
Hypermobile	8 (11%)	26 (15%)	6.06
Normal	51 (73%)	98 (56%)	$p < .05$
Stiff	11 (16%)	50 (29%)	
Total	**70**	**174**	

APPENDIX XXXI

Musicians Group (N=70) – relationship of occupational use to the range of the accessory movements of the T-M1 joint

Movement	Occupational Use (years)			Total	X^2 value significance
	10 - 14	15 - 19	20 & over		
Distraction					
Hypermobile	7	5	1	13	15.99
Normal	17	5	33	55	$p < .05$
Stiff	0	0	2 (6%)	2	
A - P gliding					
Hypermobile	4	2	2	8	14.09
Normal	19	6	19	44	$p < .05$
Stiff	I (4%)	2 (20%)	15 (42%)	18	
P - A gliding					
Hypermobile	8	2	5	15	4.86
Normal	6	5	13	24	Not significant
Stiff	10 (42%)	3 (30%)	18 (50%)	31	
Medial gliding					
Hypermobile	2	2	2	6	4.26
Normal	17	5	25	47	Not significant
Stiff	5 (21%)	3 (30%)	9 (25%)	17	
Lateral gliding					
Hypermobile	10	4	4	18	13.27
Normal	13	4	25	42	$p < .05$
Stiff	1 (4%)	2 (20%)	7 (19%)	10	
Medial rotation					
Hypermobile	10	1	8	19	8.72
Normal	14	8	21	43	Not significant
Stiff	0	1 (10%)	7 (19%)	8	
Lateral rotation					
Hypermobile	4	1	3	8	8.51
Normal	18	5	28	51	Not significant
Stiff	2 (8%)	4 (40%)	5 (14%)	11	
Total	**24**	**10**	**36**	**70**	

APPENDIX XXXII

Musicians Group (N=70) — relationship of occupational use to the quality of the accessory movements of the T-M1 joint

Movement	Occupational Use (years)			Total	X^2 value significance
	10 - 14	15 - 19	20 & over		
Distraction					
Normal	22	10	23	55	10.29
Abnormal	2 (8%)	0	13 (36%)	15	$p < .05$
A - P gliding					
Normal	20	6	11	37	21.10
Abnormal	4 (17%)	4 (40%)	25 (69%)	33	$p < .00001$
P - A gliding					
Normal	11	5	5	21	9.32
Abnormal	13 (54%)	5 (50%)	31 (86%)	49	$p < .05$
Medial gliding					
Normal	21	6	28	47	9.10
Abnormal	3 (13%)	4 (40%)	16 (44%)	23	$p < .05$
Lateral gliding					
Normal	22	8	19	49	13.94
Abnormal	2 (8%)	2 (20%)	17 (47%)	21	$p < .0005$
Medial rotation					
Normal	23	9	24	56	9.38
Abnormal	1 (4%)	1 (10%)	12 (33%)	14	$p < .05$
Lateral rotation					
Normal	22	6	19	47	10.53
Abnormal	2 (8%)	4 (40%)	17 (47%)	23	$p < .05$
Total	**24**	**10**	**36**	**70**	

APPENDIX XXXIII

Measurement of Quantity of Bone. Performed on all females over 40 years of age

Case No.		Left hand metacarpals			Right hand metacarpals			Average $\frac{D^2 - d^2}{DL}$	Age	% ile	Bone Density	
		2	3	4	2	3	4				N	P
011	L	6.57	6.29	5.57	6.62	6.25	5.58	0.10	43	10		†
012	D	0.72	0.71	0.53	0.75	0.70	0.56					
$\frac{D^2 - d^2}{DL}$	d	0.11	0.11	0.08	0.13	0.09	0.15					
		0.11	0.11	0.09	0.11	0.11	0.09					
013	L	6.58	6.23	5.43	6.52	6.39	5.63	0.11	52	55	†	
014	D	0.86	0.80	0.63	0.83	0.83	0.65					
$\frac{D^2 - d^2}{DL}$	d	0.33	0.29	0.21	0.34	0.34	0.24					
		0.11	0.11	0.11	0.11	0.11	0.10					
015	L	6.42	6.35	5.60	6.55	6.40	5.50	0.10	47	10		†
016	D	0.72	0.68	0.55	0.76	0.70	0.58					
$\frac{D^2 - d^2}{DL}$	d	0.10	0.12	0.09	0.12	0.12	0.14					
		0.11	0.10	0.09	0.11	0.11	0.10					
061	L	6.95	6.83	5.98	6.82	6.74	5.95	0.10	55	25	†	
062	D	0.77	0.85	0.64	0.73	0.85	0.63					
$\frac{D^2 - d^2}{DL}$	d	0.30	0.29	0.25	0.28	0.27	0.24					
		0.09	0.11	0.09	0.09	0.11	0.09					
069	L	6.43	6.40	5.64	6.61	6.38	5.76	0.11	54	55	†	
070	D	0.77	0.79	0.63	0.83	0.92	0.63					
$\frac{D^2 - d^2}{DL}$	d	0.25	0.36	0.25	0.29	0.26	0.18					
		0.12	0.10	0.10	0.11	0.13	0.10					
071	L	6.60	6.29	5.07	6.58	6.36	5.47	0.11	65	75	†	
072	D	0.85	0.81	0.61	0.89	0.87	0.62					
$\frac{D^2 - d^2}{DL}$	d	0.28	0.33	0.15	0.34	0.36	0.15					
		0.11	0.11	0.11	0.11	0.11	0.11					
073	L	6.43	5.90	5.43	6.39	5.98	5.19	0.10	61	35	†	
074	D	0.85	0.73	0.60	0.88	0.80	0.62					
$\frac{D^2 - d^2}{DL}$	d	0.36	0.40	0.22	0.45	0.34	0.27					
		0.11	0.09	0.10	0.10	0.11	0.10					
087	L	6.34	6.05	5.35	6.34	6.13	5.47	0.11	50	50	†	
088	D	0.72	0.74	0.60	0.75	0.74	0.57					
$\frac{D^2 - d^2}{DL}$	d	0.18	0.22	0.12	0.17	0.18	0.03					
		0.11	0.11	0.11	0.11	0.11	0.10					
097	L	6.63	6.32	5.74	6.66	6.33	5.69	0.11	50	50	†	
098	D	0.83	0.88	0.62	0.84	0.84	0.63					
$\frac{D^2 - d^2}{DL}$	d	0.31	0.37	0.18	0.40	0.34	0.20					
		0.11	0.11	0.10	0.10	0.11	0.10					
101	L	6.41	6.05	5.48	6.35	6.08	5.46	0.12	51	90	†	
102	D	0.83	0.78	0.61	0.85	0.78	0.61					
$\frac{D^2 - d^2}{DL}$	d	0.25	0.14	0.05	0.28	0.16	0.12					
		0.12	0.13	0.11	0.12	0.12	0.11					
103	L	6.02	5.73	5.12	5.70	5.85	5.25	0.11	47	50	†	
104	D	0.72	0.75	0.58	0.71	0.74	0.60					
$\frac{D^2 - d^2}{DL}$	d	0.21	0.29	0.28	0.21	0.22	0.11					
		0.11	0.11	0.08	0.11	0.12	0.11					

Case No.		Left hand metacarpals			Right hand metacarpals			Average $\frac{D^2 - d^2}{DL}$	Age	% ile	Bone Density	
		2	3	4	2	3	4				N	P
111	L	6.48	6.22	5.45	6.69	6.27	5.59	0.11	45	45	†	
112	D	0.88	0.88	0.67	0.85	0.87	0.79					
$\frac{D^2 - d^2}{DL}$	d	0.42	0.35	0.31	0.36	0.32	0.35					
		0.10	0.12	0.10	0.10	0.12	0.11					
113	L	6.46	6.21	5.43	6.44	6.23	5.54	0.09	57	10		†
114	D	0.75	0.80	0.65	0.74	0.79	0.59					
$\frac{D^2 - d^2}{DL}$	d	0.34	0.41	0.29	0.38	0.39	0.20					
		0.09	0.09	0.10	0.09	0.10	0.09					
127	L	6.34	6.23	5.75	6.57	6.24	5.59	0.12	60	95	†	
128	D	0.75	0.72	0.54	0.72	0.77	0.60					
$\frac{D^2 - d^2}{DL}$	d	0.32	0.34	0.21	0.35	0.39	0.19					
		0.10	0.09	0.08	0.08	0.09	0.10					
129	L	6.04	5.76	5.33	6.01	5.86	5.27	0.12	47	75	†	
130	D	0.90	0.83	0.60	0.83	0.85	0.65					
$\frac{D^2 - d^2}{DL}$	d	0.34	0.30	0.17	0.21	0.26	0.27					
		0.13	0.13	0.10	0.13	0.13	0.10					
139	L	6.09	5.74	4.93	6.12	5.85	5.11	0.11	42	40	†	
140	D	0.78	0.81	0.61	0.79	0.80	0.64					
$\frac{D^2 - d^2}{DL}$	d	0.23	0.30	0.25	0.26	0.30	0.20					
		0.12	0.12	0.10	0.11	0.12	0.11					
141	L	5.84	5.55	5.09	5.91	5.70	5.08	0.12	47	75	†	
142	D	0.74	0.74	0.56	0.76	0.70	0.64					
$\frac{D^2 - d^2}{DL}$	d	0.22	0.20	0.08	0.22	0.19	0.18					
		0.12	0.12	0.11	0.12	0.11	0.12					
143	L	6.15	5.91	5.26	6.26	6.03	5.30	0.11	58	70	†	
144	D	0.75	0.74	0.57	0.77	0.77	0.57					
$\frac{D^2 - d^2}{DL}$	d	0.20	0.17	0.12	0.20	0.17	0.14					
		0.11	0.12	0.10	0.11	0.12	0.10					
153	L	6.72	6.56	5.66	6.68	6.41	5.55	0.10	51	20	†	
154	D	0.78	0.82	0.52	0.79	0.56	0.55					
$\frac{D^2 - d^2}{DL}$	d	0.34	0.28	0.13	0.23	0.18	0.19					
		0.10	0.10	0.09	0.11	0.08	0.09					
165	L	5.81	5.58	5.30	5.95	5.69	5.38	0.11	55	60	†	
166	D	0.78	0.75	0.60	0.84	0.77	0.65					
$\frac{D^2 - d^2}{DL}$	d	0.34	0.29	0.25	0.31	0.23	0.23					
		0.11	0.11	0.09	0.12	0.12	0.11					
167	L	7.04	6.76	6.00	7.04	7.03	6.25	0.11	41	35	†	
168	D	0.78	0.78	0.61	0.80	0.79	0.64					
$\frac{D^2 - d^2}{DL}$	d	0.73	0.06	0.13	0.17	0.13	0.10					
		0.11	0.12	0.10	0.11	0.11	0.10					
169	L	6.33	6.19	5.69	6.53	6.38	5.81	0.10	57	25	†	
170	D	0.75	0.80	0.70	0.84	0.82	0.57					
$\frac{D^2 - d^2}{DL}$	d	0.24	0.36	0.34	0.34	0.29	0.16					
		0.11	0.10	0.09	0.11	0.11	0.09					
173	L	6.16	6.13	5.30	6.27	6.12	5.46	0.12	40	75	†	
174	D	0.76	0.83	0.62	0.89	0.86	0.64					
$\frac{D^2 - d^2}{DL}$	d	0.22	0.14	0.10	0.25	0.22	0.13					
		0.11	0.13	0.11	0.13	0.13	0.12					

Case No.		Left Hand metacarpals			Right hand metacarpals			Average $\frac{D^2 - d^2}{DL}$	Age	% ile	Bone Density	
		2	3	4	2	3	4				N	P
175	L	6.29	6.14	5.45	6.26	5.93	5.44	0.12	50	85	†	
176	D	0.84	0.81	0.68	0.80	0.85	0.65					
$D^2 - d^2$	d	0.34	0.26	0.18	0.22	0.26	0.22					
DL		0.11	0.12	0.12	0.12	0.13	0.12					
177	L	6.19	6.18	5.70	6.31	6.22	5.69	0.10	47	10		†
178	D	0.74	0.76	0.55	0.79	0.73	0.56					
$D^2 - d^2$	d	0.15	0.27	0.15	0.28	0.29	0.19					
DL		0.12	0.11	0.09	0.11	0.10	0.08					
179	L	6.00	5.78	5.15	6.09	5.86	5.26	0.12	52	90	†	
180	D	0.77	0.75	0.60	0.82	0.83	0.70					
$D^2 - d^2$	d	0.15	0.21	0.10	0.16	0.28	0.22					
DL		0.12	0.12	0.11	0.13	0.13	0.12					
181	L	6.11	5.77	5.14	6.06	5.70	5.06	0.11	59	70	†	
182	D	0.79	0.78	0.64	0.75	0.78	0.60					
$D^2 - d^2$	d	0.18	0.25	0.27	0.22	0.32	0.18					
DL		0.12	0.12	0.10	0.11	0.11	0.11					
183	L	5.44	5.50	4.85	5.63	5.53	4.89	0.13	54	100	†	
184	D	0.76	0.81	0.65	0.82	0.86	0.68					
$D^2 - d^2$	d	0.20	0.32	0.22	0.35	0.38	0.24					
DL		0.13	0.13	0.12	0.12	0.13	0.12					
185	L	6.33	6.05	5.38	6.50	6.40	5.75	0.11	43	45	†	
186	D	0.74	0.96	0.69	0.77	0.92	0.70					
$D^2 - d^2$	d	0.35	0.37	0.27	0.33	0.39	0.24					
DL		0.09	0.13	0.11	0.10	0.12	0.11					
187	L	5.80	5.62	5.00	6.17	5.94	5.36	0.12	59	90	†	
188	D	0.83	0.80	0.75	0.84	0.84	0.80					
$D^2 - d^2$	d	0.29	0.30	0.25	0.41	0.41	0.33					
DL		0.13	0.12	0.13	0.10	0.11	0.12					
189	L	5.96	5.95	5.11	6.34	6.09	5.24	0.12	71	100	†	
190	D	0.77	0.77	0.59	0.90	0.85	0.67					
$D^2 - d^2$	d	0.26	0.33	0.19	0.46	0.49	0.34					
DL		0.11	0.10	0.10	0.11	0.09	0.09					
191	L	6.59	6.27	5.54	6.60	6.46	5.73	0.10	57	25	†	
192	D	0.76	0.73	0.58	0.77	0.75	0.65					
$D^2 - d^2$	d	0.27	0.30	0.23	0.32	0.34	0.25					
DL		0.10	0.10	0.09	0.10	0.09	0.10					
193	L	6.37	6.28	5.45	6.43	6.26	5.53	0.11	50	50	†	
194	D	0.85	0.91	0.66	0.83	0.89	0.70					
$D^2 - d^2$	d	0.37	0.37	0.20	0.30	0.35	0.30					
DL		0.11	0.12	0.11	0.11	0.12	0.10					
195	L	6.31	6.20	5.61	6.41	6.10	5.74	0.11	45	45	†	
196	D	0.78	0.80	0.67	0.83	0.85	0.69					
$D^2 - d^2$	d	0.28	0.33	0.35	0.30	0.38	0.32					
DL		0.11	0.13	0.09	0.11	0.11	0.10					
197	L	6.22	5.90	5.35	6.56	6.31	5.56	0.11	46	45	†	
198	D	0.78	0.76	0.60	0.80	0.84	0.63					
$D^2 - d^2$	d	0.24	0.28	0.25	0.26	0.22	0.17					
DL		0.11	0.11	0.09	0.11	0.12	0.11					

Case No.		Left hand metacarpals			Right hand metacarpals			Average $\frac{D^2 - d^2}{DL}$	Age	% ile	Bone Density	
		2	3	4	2	3	4				N	P
199	L	6.24	6.17	5.28	6.45	6.03	5.36	0.13	49	100	†	
200	D	0.95	0.93	0.78	0.95	1.02	0.84					
$\frac{D^2 - d^2}{DL}$	d	0.36	0.38	0.36	0.34	0.41	0.29					
		0.13	0.13	0.12	0.13	0.14	0.14					
201	L	5.75	5.81	5.23	5.79	5.76	5.20	0.11	53	50	†	
202	D	0.63	0.71	0.58	0.69	0.71	0.59					
$\frac{D^2 - d^2}{DL}$	d	0.18	0.18	0.17	0.14	0.20	0.13					
		0.11	0.10	0.10	0.12	0.11	0.10					
209	L	6.31	6.19	5.49	6.38	6.22	5.56	0.11	47	50	†	
210	D	0.75	0.67	0.62	0.83	0.75	0.61					
$\frac{D^2 - d^2}{DL}$	d	0.20	0.15	0.17	0.26	0.21	0.21					
		0.11	0.10	0.10	0.12	0.11	0.10					
225	L	6.07	5.87	5.22	6.01	5.79	5.27	0.11	52	55	†	
226	D	0.82	0.67	0.54	0.77	0.75	0.58					
$\frac{D^2 - d^2}{DL}$	d	0.21	0.19	0.16	0.25	0.23	0.16					
		0.13	0.10	0.09	0.11	0.12	0.10					
229	L	6.65	6.39	5.57	6.76	6.48	5.64	0.10	55	25	†	
230	D	0.92	0.85	0.66	1.02	0.87	0.69					
$\frac{D^2 - d^2}{DL}$	d	0.37	0.43	0.37	0.53	0.48	0.32					
		0.12	0.10	0.08	0.11	0.09	0.10					
267	L	6.80	6.48	6.03	6.82	6.65	6.01	0.11	57	60	†	
268	D	0.90	0.83	0.55	0.93	0.85	0.64					
$\frac{D^2 - d^2}{DL}$	d	0.28	0.23	0.18	0.33	0.27	0.15					
		0.12	0.12	0.08	0.12	0.12	0.10					
269	L	6.10	5.64	5.07	6.07	5.68	4.92	0.10	68	50	†	
270	D	0.79	0.73	0.57	0.76	0.76	0.66					
$\frac{D^2 - d^2}{DL}$	d	0.28	0.23	0.18	0.33	0.27	0.15					
		0.12	0.12	0.08	0.12	0.12	0.10					
271	L	6.09	5.65	5.38	6.21	6.01	5.54	0.11	64	75	†	
272	D	0.85	0.87	0.58	0.94	0.89	0.69					
$\frac{D^2 - d^2}{DL}$	d	0.37	0.37	0.25	0.45	0.45	0.30					
		0.11	0.13	0.09	0.12	0.11	0.11					
273	L	6.12	5.87	4.96	6.51	6.04	5.24	0.11	52	50	†	
274	D	0.78	0.75	0.58	0.75	0.73	0.64					
$\frac{D^2 - d^2}{DL}$	d	0.22	0.26	0.20	0.23	0.28	0.23					
		0.12	0.11	0.10	0.10	0.10	0.11					
275	L	7.03	6.97	6.12	7.04	6.94	6.09	0.10	58	25	†	
276	D	0.76	0.80	0.57	0.79	0.86	0.59					
$\frac{D^2 - d^2}{DL}$	d	0.27	0.28	0.15	0.28	0.25	0.22					
		0.10	0.10	0.09	0.10	0.11	0.08					
277	L	6.79	6.66	5.74	6.90	6.75	5.77	0.10	57	25	†	
278	D	0.80	0.77	0.60	0.80	0.80	0.64					
$\frac{D^2 - d^2}{DL}$	d	0.25	0.25	0.16	0.29	0.30	0.18					
		0.11	0.10	0.10	0.10	0.10	0.10					
279	L	6.25	6.02	5.07	6.26	5.85	4.97	0.12	66	100	†	
280	D	0.84	0.85	0.63	0.85	0.85	0.66					
$\frac{D^2 - d^2}{DL}$	d	0.27	0.36	0.24	0.32	0.32	0.18					
		0.12	0.12	0.11	0.12	0.12	0.13					

Case No.		Left hand metacarpals			Right hand metacarpals			Average $\frac{D^2 - d^2}{DL}$	Age	% ile	Bone Density	
		2	3	4	2	3	4				N	P
281	L	6.37	6.05	5.39	6.57	6.33	5.65	0.10	47	12		†
282	D	0.79	0.69	0.46	0.77	0.77	0.44					
$\frac{D^2 - d^2}{DL}$	d	0.16	0.11	0.04	0.11	0.08	0.03					
		0.12	0.11	0.08	0.11	0.12	0.08					
295	L	6.36	6.14	5.55	6.50	6.30	5.56	0.12	57	95	†	
296	D	0.89	0.86	0.68	0.92	0.87	0.65					
$\frac{D^2 -d^2}{DL}$	d	0.12	0.32	0.20	0.37	0.41	0.19					
		0.12	0.12	0.12	0.12	0.11	0.11					
297	L	5.61	5.67	4.82	5.93	5.76	5.04	0.10	58	50	†	
298	D	0.68	0.63	0.53	0.69	0.73	0.60					
$\frac{D^2 - d^2}{DL}$	d	0.19	0.30	0.17	0.26	0.28	0.22					
		0.11	0.09	0.10	0.10	0.11	0.11					
317	L	6.22	5.79	5.04	6.32	5.82	5.00	0.11	44	50	†	
318	D	0.69	0.81	0.59	0.74	0.79	0.58					
$\frac{D^2 - d^2}{DL}$	d	0.19	0.38	0.17	0.17	0.27	0.16					
		0.10	0.11	0.11	0.11	0.12	0.11					
319	L	6.56	6.45	5.60	6.58	6.39	5.60	0.10	71	60	†	
320	D	0.85	0.77	0.64	0.90	0.80	0.63					
$\frac{D^2 - d^2}{DL}$	d	0.28	0.34	0.24	0.29	0.39	0.24					
		0.11	0.09	0.10	0.12	0.10	0.10					
321	L	6.44	6.05	5.32	6.45	6.13	5.29	0.11	45	50	†	
322	D	0.80	0.75	0.62	0.76	0.78	0.59					
$\frac{D^2 - d^2}{DL}$	d	0.23	0.21	0.18	0.22	0.23	0.16					
		0.11	0.11	0.11	0.11	0.12	0.10					
323	L	6.28	6.27	5.44	6.42	6.30	5.44	0.11	58	70	†	
324	D	0.85	0.78	0.57	0.84	0.81	0.61					
$\frac{D^2 - d^2}{DL}$	d	0.25	0.25	0.18	0.27	0.22	0.23					
		0.12	0.11	0.09	0.12	0.12	0.10					
325	L	6.91	6.61	5.75	7.10	6.65	5.72	0.11	64	75	†	
326	D	0.85	0.82	0.60	0.88	0.93	0.66					
$\frac{D^2 - d^2}{DL}$	d	0.28	0.36	0.17	0.33	0.32	0.18					
		0.11	0.10	0.10	0.11	0.12	0.12					
397	L	6.16	5.94	5.08	6.14	5.85	5.01	0.10	44	20	†	
398	D	0.66	0.71	0.61	0.68	0.75	0.58					
$\frac{D^2 - d^2}{DL}$	d	0.27	0.30	0.20	0.31	0.35	0.24					
		0.11	0.10	0.11	0.09	0.10	0.10					
405	L	6.45	6.30	5.70	6.45	6.35	5.63	0.12	53	100	†	
406	D	0.78	0.82	0.70	0.83	0.88	0.68					
$\frac{D^2 - d^2}{DL}$	d	0.23	0.31	0.27	0.21	0.35	0.20					
		0.11	0.11	0.11	0.13	0.12	0.11					
429	L	6.68	6.58	5.89	6.80	6.54	5.83	0.10	47	25	†	
430	D	0.80	0.81	0.70	0.88	0.79	0.67					
$\frac{D^2 - d^2}{DL}$	d	0.30	0.30	0.29	0.37	0.27	0.28					
		0.10	0.08	0.10	0.11	0.11	0.09					
431	L	6.63	6.18	5.65	6.63	6.21	5.68	0.10	40	25	†	
432	D	0.87	0.87	0.62	0.90	0.88	0.68					
$\frac{D^2 - d^2}{DL}$	d	0.39	0.41	0.23	0.45	0.39	0.25					
		0.11	0.11	0.09	0.10	0.11	0.10					

Case No.		Left hand metacarpals			Right hand metacarpals			Average $\frac{D^2 - d^2}{DL}$	Age	% ile	Bone Density	
		2	3	4	2	3	4				N	P
445	L	6.01	5.83	5.20	5.95	5.82	5.14	0.11	62	75	†	
446	D	0.74	0.74	0.52	0.78	0.72	0.52					
$\frac{D^2 - d^2}{DL}$	d	0.25	0.26	0.17	0.26	0.27	0.15					
		0.11	0.11	0.09	0.12	0.11	0.09					
447	L	6.32	5.81	4.79	6.30	5.79	5.01	0.10	51	28	†	
448	D	0.77	0.75	0.55	0.80	0.77	0.50					
$\frac{D^2 - d^2}{DL}$	d	0.31	0.30	0.17	0.35	0.24	0.13					
		0.10	0.11	0.10	0.10	0.12	0.09					
463	L	6.51	6.09	5.39	6.46	6.12	5.42	0.10	50	25	†	
464	D	0.75	0.70	0.54	0.82	0.72	0.55					
$\frac{D^2 - d^2}{DL}$	d	0.23	0.20	0.14	0.31	0.25	0.13					
		0.10	0.11	0.09	0.11	0.10	0.09					
465	L	6.78	6.37	5.80	6.93	6.61	5.90	0.10	61	50	†	
466	D	0.74	0.75	0.59	0.82	0.78	0.58					
$\frac{D^2 - d^2}{DL}$	d	0.22	0.12	0.11	0.27	0.20	0.26					
		0.10	0.12	0.10	0.11	0.11	0.08					
469	L	6.50	6.28	5.62	6.48	6.32	5.56	0.12	40	75	†	
470	D	0.89	0.81	0.66	0.89	0.82	0.71					
$\frac{D^2 - d^2}{DL}$	d	0.22	0.20	0.13	0.27	0.13	0.16					
		0.13	0.12	0.11	0.12	0.13	0.12					
491	L	6.81	6.69	5.91	7.00	6.64	5.85	0.09	60	10		†
492	D	0.78	0.77	0.54	0.74	0.80	0.59					
$\frac{D^2 - d^2}{DL}$	d	0.33	0.34	0.20	0.25	0.29	0.14					
		0.09	0.09	0.08	0.09	0.11	0.10					

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