THE RADIOGRAPHIC ASSESSMENT OF DENTAL IMPLANT TREATMENTS

A PILOT STUDY ON TWO-IMPLANT SUPPORTED OVERDENTURE CASES

By

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DECLARATION

This report contains the results of original research. To the best of the author's knowledge, it contains no material from other sources unless due reference has been made.

The contents of this report have not been submitted, either in whole or in part, for consideration for any other degree or diploma at this, or any other, university.

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Candidate for the degree of Master of Dental Surgery

20 November 1998

Dedicated to my parents

PREFACE

This project is a pilot study to a project encompassing the radiographic aspects of all types of dental implant treatments. It has been established as a retrospective study of existing radiographs for only a small patient pool.

Due to the use of existing films, some methods of quantitative assessment of radiographs of implants could not be used because many of the essential components, such as step wedges, were not used. Also, direct digital imaging was not available to the Adelaide Dental Hospital, therefore suitable methods of converting existing films had to be determined.

Due to the shortage of available time (as a result of delays in obtaining necessary equipment) the project was designed as a pilot study, the results and methods to be adapted for future use. Consequently the results are only preliminary and many more aspects of the radiographic assessment of dental implants need to be addressed.

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SUMMARY

The introduction of the osseointegrated implant has revolutionised the way in which operators consider treating patients who are completely or partially edentulous, by providing an option which is more stable and less destructive to adjacent teeth than conventional modalities of treatment. In recent years the use of dental implants has become increasingly popular, with practitioners becoming aware of the results which may be achieved. Patients who have had marked resorption of their alveolar processes can be provided with comfortable, secure prostheses, subsequently improving their confidence.

Periodic radiographs have been found to be the best non-invasive means of assessing the marginal bone around an implant. In a retrospective pilot study, 24 patients provided with overdentures retained by two Calcitek Integral implants (Calcitek, Carlsbad, CA) had periodic radiographs taken, using a standardised projection technique, over a five year period (placement, six months, one year, two years, three years, four years, five years). These were then digitised through a scanner and imported into an implant analysis programme, the Radiographic Analysis of Dental Implants (RADI) (Biotek Pty Ltd, Adelaide, Australia).

The marginal bone immediately adjacent to the implant on the mesial and distal of the implant was then analysed using this programme. After calibration within the programme (using known dimensions), three components of the 'defect' adjacent to the implant were calculated - horizontal width, vertical height and average area. The patient population was then separated into subgroups according to the type of overdenture retention system provided - ball attachment, O-ring or Dolder bar.

The study found that the RADI programme was able to provide measurements and average areas within the same magnitude as other studies have - defect (horizontal) width 0.50 - 1.70 mm, (vertical) height 0.40 - 1.60 mm and average area 0.20 - 1.0 mm^2 for the

whole group. These are similar to the results of other studies and meet one of the criteria for the clinical success of an implant proposed by Smith and Zarb (1989).

Comparisons of the denture retention unit indicated that the ball attachment and O-ring attachment were statistically similar to each other, showing gradual increases in the dimensions of each component of the defect over the five years. These were found to be statistically significantly different to the Dolder Bar ($p<0.05$), which showed minimal changes to the bone over the five years. However, this differed to the findings of Bergendal and Engquist (1998), who found that ball attachment and bar retained overdentures followed similar patterns of changes in the bone.

This study showed that digitised radiographs of dental implants can be used to quantitatively assess the status of the marginal bone around an implant. These images may be obtained by converting plain film radiographs to digital images or by using direct digital imaging radiography. However, in order to gain a more accurate assessment of a patient pool, the population needs to be larger than a pool of 24. The radiographs ideally must be taken at regular intervals, using a standardised, reproducible projection technique.

1. INTRODUCTION

The introduction of the osseointegrated implant has revolutionised the way in which operators consider treating patients who are completely or partially edentulous, by providing an option which is more stable and less destructive to adjacent teeth than conventional modalities of treatment. In recent years the use of dental implants has become increasingly popular, with practitioners becoming aware of the results which may be achieved. Patients who have had marked resorption of their alveolar processes can be provided with comfortable, secure prostheses, subsequently improving their confidence.

Radiographic assessment of dental implant treatments has been accepted as one of the most appropriate non-surgical means to assess the condition of the functioning implant and the surrounding bone (Adell *et al*, 1986; van Steenberghe and Quirynen, 1993). Post-operatively, periapical and orthopantomograph radiographs have been the most convenient and accessible types of views available to practitioners at a reasonable cost, providing valuable qualitative information.

Radiographic techniques will vary with regard to the amount of information provided, magnification of the resulting image, availability and cost to the patient and, radiation dose. Accuracy is of primary importance in any technique. Intra-oral films provide information on a structure and its surroundings, but are limited in what they can provide, due to their size. Panoramic films provide a general overview of the teeth and surrounding structures in one view, but resulting images are prone to distortion (Frederiksen, 1995).

The need for more precise and varied information in diagnostic imaging has resulted in the great advancement in imaging techniques. With the increase in provision of implants as a treatment modality, an easy means to periodically assess functioning implants needs to be used for operators to review any changes. Implant images are currently assessed qualitatively, however, quantitative assessment will provide more valuable information over a projected period.

By the use of a computer and a means of capturing the image on a radiograph, radiographs can now be digitised for viewing on a computer monitor. This, by the use of computer software, has enabled images to be manipulated to improve the diagnostic quality of an image to provide more information without the need to expose a patient to excessive radiation. It has also provided the opportunity for operators to use the images to assess the bone surrounding implants quantitatively.

Non-invasive post-operative assessment of dental implants has been carried out by adapting assessment methods used in other disciplines in dentistry. Methods such as measurement of pocket depth, implant mobility and radiography have been used based on the assumption that the dental implant is similar to the tooth it replaces. Unfortunately, the implant does not behave as a tooth, so clinical techniques such as pocket depth measurement and mobility assessment can only be used qualitatively. Small changes in bone levels are difficult to detect clinically and are affected significantly by the inflammatory state of the adjacent tissues, while mobility testing results vary from no mobility to mild movement on percussion, which does not accurately indicate a problem.

Radiography, using accurately taken and correctly processed images, can provide a significant amount of accurate information quantitatively, and show a trend of change around an implant over a particular period. The type of projection technique used is dependent on the information required, but generally the most commonly and accessible techniques used by clinicians are the periapical views and orthopantomographs. Other projection techniques do not provide sufficient accurate information, or are expensive and impractical for the clinician to take or prescribe.

Currently, there is a paucity of information on the radiographic changes which occur around dental implants over a period of years. Additionally, there is no technique or means to quantitatively evaluate radiographic changes around implants which is easy for the clinician to implement, or not involve extravagant costs.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The use of dental implants for the treatment of an edentulous space has become increasingly popular in recent years. However, case selection and careful, thorough treatment planning must be carried out prior to placement of the implants. Patients must be screened on a number of factors: psychological, clinical and radiographic.

Evaluation of the bone quality and quantity are essential to the success of the implant and final prosthesis, to achieve an acceptable functional and aesthetic result. As bone cannot be evaluated directly without an invasive technique, images of the bone, provided primarily through radiography, must be used as the best available means of evaluation. Once the implant has been placed, continued periodic assessment of its condition is essential to ensure that any degenerative changes are detected and dealt with promptly. Again, radiography (in conjunction with other clinical assessments) provides the best available non-invasive means of assessment (Gröndahl and Lekholm, 1997). Additionally, implant types can be identified radiographically by a number of distinctive features (Sewerin 1991a, 1991b, 1992a, 1992b). This will be an advantage if patients move away from the operator who placed the implant, or for forensic purposes.

The use of radiography as a diagnostic tool has some inherent problems. Variations in film speed, emulsions, developer and fixer concentrations and exposure times, together with distortion, magnification and projection geometry in dental radiography are only a few of the factors which may affect the final image required for diagnostic value, both pre- and post treatment. Underestimation of bone loss from radiographic assessment has also been reported (Eickholz *et al*, 1998).

This literature review will discuss imaging related to dental implants, in particular radiography, and its use as a diagnostic tool when evaluating bone quality and quantity before and after placement of the implant. Although there are other forms of dental implants available which will be briefly introduced, the discussion will relate primarily to root form implants.

2.1.1 The Use Of Dental Implants

Dental implants have been used to support a prosthesis in either fully or partially edentulous cases. The prosthodontic options available include complete overdentures, removable implant-supported dentures (no tissue support), fixed implant-supported bridges, implant and tooth-supported fixed bridges and single implant-supported crowns (Rich and Augenbraun, 1991; Jemt and Pettersson, 1993; Schmitt and Zarb, 1993). In all cases the primary aim is to provide a functional and aesthetic prosthesis.

The most common reason for completely edentulous patients to elect to receive treatment with the use of implants is to improve eating ability (Grogono *et al*, 1989; Davis, 1990). Other reasons include dissatisfaction with appearance, speech problems and social embarrassment (Grogono *et al*, 1989; Davis, 1990; Rich and Augenbraun, 1991). In such cases, people need to develop their oral musculature skills considerably if they wish to make use of their dentures successfully, which is not possible in many cases. Davis (1990) reports that a study by Fiske in 1988 asked elderly people about their dentures in relation to function, comfort, self-image and social interaction (including avoidance of eating in company or embarrassment to smile fearing denture dislodgement). Of 765 people questioned, 92% felt that they had some form of 'oral handicap', although only 40% thought that they would benefit from new dentures. One hundred were provided with new dentures and, although there were fewer complaints about the dentures in general, one third were still dissatisfied with the functional aspect. The provision of dental implants to improve stability of the denture in such cases will help to overcome this problem and improve the psychological profile of the patients.

In partially edentulous patients, the reasons for the use of implants is dependent on the region in which there are teeth missing. In the posterior region of the mouth, a functional requirement for implant placement is generally the main reason, while in the anterior region appearance is the primary concern of the patient. In either situation the advantages of implants for partial edentulism over the traditional modes of treatment have been suggested as (Schnitman *et al*, 1988):

a. the elimination of the need to prepare teeth for retainers;
b. distal free-end saddles are eliminated with the provision of an implant-supported prosthesis;
c. interdental (pier) abutments can be provided for long-span fixed bridges; and
d. teeth with a questionable periodontal prognosis can be replaced with an implant with a better prognosis.

Patient attitudes to implants have been assessed by various investigators as generally positive, although there are cases in which problems have occurred. Harle and Anderson (1993) asked participants a number of questions relating to mechanical ability, eating, communication and psychosocial and general health. Implant patients reported fewer problems concerned with chewing and eating (reaching almost dentate levels), tongue movements and kissing, with general confidence improving. A similar result was obtained by Grogono *et al* (1989) where 95 implant patients were asked to complete a questionnaire. This survey found that 88% of participants reported improved confidence, 98% felt that their overall health had improved and general attitude to dental health became more positive. In studies on the efficacy of implants in partial edentulism, patients with single-tooth replacement and anterior or posterior partial edentulism reported subjective satisfaction with the appearance and function of their prostheses (Davis, 1990; Schmitt and Zarb, 1993; Zarb and Schmitt, 1993). However, there have been no studies carried out specifically dealing with patient attitudes in partial edentulism.

2.1.2 Clinical Criteria For Successful Implants

Osseointegration of the implant is vital to the success of the implant, which was defined by Brånemark as 'contact between the implant surface and the bone at light microscope level' (Albrektsson and Sennerby, 1990). However, an invasive technique which will compromise the success of the implant will be required to assess an implant at this level (Jeffcoat and Reddy, 1993). Therefore, non-invasive techniques such as pocket depth measurement, implant mobility and radiography need to be adapted from other disciplines of dentistry and applied to the assessment of implants.

The experimental placement of implants in dogs resulted in the evaluation of clinical methods available to assess implants (Wie *et al*, 1984). The authors determined that the use of periodontal assessment methods in combination with radiographs provided the most reliable method of assessing bone level. The use of periodontal parameters in a recent clinical study have indicated similar findings (Levy *et al*, 1996). In 1989, Smith and Zarb proposed a set of criteria for the assessment of dental implants, which is still used as the basis for guidelines developed more recently. They based their proposals on an assessment of other sets of criteria outlined by a variety of investigators, identifying five areas which may be evaluated clinically or radiographically:

1. *The individual unattached implant is immobile when tested clinically.*

With the introduction of the Periotest unit (Siemens AG, Bensheim, Germany) this criterion cannot be strictly adhered to. Initially, the use of methods developed for mobility testing in periodontal cases were found to be adequate, grading mobility on a non parametric, but subjective, scale. The implant may be tested by using instruments such as forceps, where force is applied laterally to assess mobility, but cannot detect the small amounts of mobility which can exist with implants. However, the introduction of the Periotest unit now provides an objective result. Chavez *et al* (1993) tested the unit *in vitro* and *in vivo*, reporting a high correlation between the Periotest value and implant mobility *in vitro*, and that clinically an implant can show a range of mobility of -6 to +2 Periotest units (which equates to an *in vitro* measurement of 0.038 mm to 0.113 mm) and not have a deleterious effect on its success.

2. *No evidence of peri-implant radiolucency is present as assessed on an undistorted radiograph.*

The most reliable radiographic view of an implant available in 1976 was found to be the periapical view (Cranin and Rabkin, 1976). This is still the case today, and, radiographs need to be taken regularly to assess the areas immediately surrounding the implant. A complete peri-implant radiolucency indicates the presence of soft tissue, probable implant mobility, and is considered a failure.

Smith and Zarb (1989) report that the presence of a connective tissue capsule around the implant, when viewed radiographically, demonstrates implant failure. They found that clinical research indicates that a mobile implant becomes tender to percussion or pressure, and that the mobility increases with time until removal is required.

3. *The mean vertical bone loss is less than 0.2 mm annually after the first year of service.*

Serial radiographs need to be taken using a standardised technique, and assessors need to remember that the images are only two dimensional, so that only the mesial and distal surfaces are projected whilst the buccal and lingual surfaces remain obscured by the implant. Also, standardised radiographs are essential to the accuracy of assessment of marginal bone levels (Smith and Zarb, 1989; Chaytor, 1993; Nasr and Meffert, 1993). Most guidelines proposed for the assessment of bone suggest the use of quantitative methods, using measurements obtained from the radiograph. The problems related to this are that the film is often distorted and image magnification is often not compensated for, therefore providing a false result (Chaytor, 1993; Nasr and Meffert, 1993). Another radiographic assessment based on percentages of implant image length has been proposed to compensate for these problems (Nasr and Meffert, 1993). A similar method using percentages has been applied clinically by Pham *et al* (1994).

4. *No persistent pain, discomfort or infection is attributable to the implant.*

This criterion is not related directly to the implant system used, but more to the placement of the implants at surgery. Damage to the adjacent teeth, entry to the maxillary sinus, mandibular canal and nasal cavity must be avoided by careful treatment planning and accurate radiographs. To minimise the risk of failure due to infection, an aseptic technique should be used for both the surgical placement of the implant and its subsequent exposure to place the abutment, and, the importance of excellent oral hygiene procedures needs to be stressed after implant placement.

5. *The implant design does not preclude placement of a crown or prosthesis with an appearance that is satisfactory to the patient and dentist.*

Using these criteria, and results from a 15 year observation period, a minimum success rate of 85% at the end of a five year observation period and 80% at the end of a ten year period has been established.

The success of the dental implant is highly dependent on regular revision of its condition both clinically and radiographically. However, neither of these tasks are simple to carry out. Of the five criteria outlined, two are directly reliant on accurate, high quality, standardised radiographs for their evaluation, whilst the remaining three are indirectly reliant on more subjective assessments, either pre- or post-operatively. The criteria for radiographic evaluation will be discussed later.

2.2 IMAGING TECHNIQUES

The need for more precise and varied information in diagnostic imaging has resulted in the great advancement in imaging techniques over recent years. Developments in techniques for general medicine have been adapted for use in dentistry with great success, particularly in the areas of digital imaging and computed tomography. Non-ionising radiation techniques such as ultrasonography and magnetic resonance imaging have been used in dentistry, specifically oral and maxillofacial surgery, however, the majority of techniques still require ionising radiation as the basis for imaging.

Computers now play an essential role in the acquisition of diagnostically valuable images, whether obtained through the use of xrays, magnetic resonance or ultrasonography. Xray-sensitive sensors are now available for image capture and immediate conversion to a digitised image. Even if the image has been captured on a conventional radiographic film, this can be converted to a digitised image on a computer which can be stored on a hard disc. However, the basic principles of radiography must still be carefully applied to the task, as the developments are mainly in the areas of image capturing, not image projection. The problems of radiation dosage and projection geometry remain significant concerns, although the development of more sensitive films, more accurate projection geometry and direct image sensors have helped reduce the overall exposure to irradiation a patient receives during treatment.

2.2.1 Image Recording Techniques

Conventional Film Radiography

The basis of film as the image receptor is the use of light and xray sensitive silver halide crystals (primarily silver bromide with some silver iodide) suspended in a gelatin matrix, supported by a polyethylene base (Goaz and White, 1982). In films used for extra-oral radiography, an intensifying screen is added to make the film more sensitive to exposure and to reduce the amount of radiation required to produce a readable image.

On exposure to light or xrays, the bromide ions (primarily) absorb the the xray photons and are converted to bromine atoms. The silver atoms remain within the gelatin matrix forming a latent image. In areas where there is more silver halide converted to silver, the film will have a black appearance after processing. Any xrays which have been attenuated by the object being imaged will either not reach the film, or reach it at a reduced amount of energy. The corresponding areas of the film will not have the silver halide converted, and the result is a white appearance of the film after processing. The final image which appears on the processed film is a black and white picture of the object which has been imaged.

The exposed film must be processed to remove the unexposed silver bromide crystals and convert the metallic silver grains into a form which can be visualised. The processing of the film involves:

1. immersing the film in a developing solution, which reduces the silver atoms forming the latent image to grains of metallic silver which can be visualised on the film. Care must be taken to avoid the contact of the developing solution with the unexposed silver halide crystals for excessive lengths of time, as this will lead to the eventual reduction of these crystals and over-development of the film.

2. rinsing the film with water to remove the activated developing solution prior to the fixing of the film.

3. immersing the film in a fixing solution to remove the undeveloped silver halide crystals from the emulsion. If these are not removed the resultant image will be diagnostically useless. The fixer also hardens the emulsion by strengthening the gelatin matrix and prevent damage to the film from handling.

4. washing the film again to remove all excess chemicals, then drying the film for eventual assessment and storage.

The use of conventional films involves the use of a number of chemical procedures and consumption of a significant amount of time to obtain a useful image. The greater the number of steps required in the procedure, the greater the risk of producing a radiograph which cannot be used diagnostically, and the need for another radiograph may occur. Concerns about the amount of radiation exposure received by dental patients have seen the investigation of dental radiation in comparison to medical radiography.

A study of the amount of radiation absorption by various tissues (Torabinejad *et al*, 1989) found that the doses received by patients during intra-oral radiography for endodontics are low when compared to those received in other radiographic procedures used in medicine. The doses received vary with the anatomical site, as there are varying degrees of tissue thickness and density, necessitating the variation in exposure times. These results could be applied to implant radiography as the techniques used are merely adaptations of those used for imaging dentate patients.

In attempts to find ways of reducing the required amounts of irradiation for diagnostic imaging, films which are more sensitive to radiation have been developed and compared for diagnostic value. The films of the C speedgroup used in the 1970s have been succeeded by films of the D and E speedgroups. Sanderink (1993) reports that the E-speed films have twice the sensitivity of the D-speed films, but resolution on the E-speed films was equal to that of the slower D-speed. Comparisons of Ultraspeed (D-speed) (Eastman Kodak Co., Rochester, N.Y.) and Ektaspeed (E-speed) (Eastman Kodak Co., Rochester, N.Y.) films were made in a study on endodontists' perceptions of each film (Farman *et al*, 1988). The investigators found that for image quality and interpretation there was no significant difference between the films for diagnostic purposes. They recommended, however, that the E-speed film be used to reduce the amount of radiation required to obtain an image. If films faster than the E-speed film are required, there is a risk of reducing the resolution and quality of the radiographs (Sanderink, 1993).

Digital Radiographic Imaging

Although the need for conventional film radiography still exists, the adaptation of the computer to dentistry has provided practitioners with the ability to capture images for viewing on a computer screen or video monitor, either by conversion of a conventional film image or through direct digital imaging ('filmless radiography'). A digital image has been defined as 'an image formed by a spatially distributed set of discrete sensors and represented by a spatially distributed set of discrete picture elements ('pixels')' (Dunn and Kantor, 1993). Various software programmes have been developed to assist with the evaluation and analysis of different aspects of the image, from image enhancement to density analysis of calcified tissues.

Whether the image is digitised by conversion or directly obtained, the basis of digital imaging is a solid-state detector or image receptor connected to a computer (Brooks and Miles, 1993; Dunn and Kantor, 1993; Miles, 1993). The heart of the detector is a charge-coupled device (CCD), which has been in use since its introduction in the 1960s in videocameras, telescopes, microscopes and gastroscopes (Miles, 1993). The CCD is made of high grade crystalline silicon (Welander *et al*, 1993), and is an array of light or xray sensitive pixels, which are small 'boxes' or squares into which electrons are deposited after the detector has been activated by incoming light or xrays. These are also known as electron wells.

The electrons are a result of a direct interaction of the detector with the photons of xrays or light. The number of electrons in each pixel is dependent on the amount of light or xrays which have reached the CCD to charge it. The wells are contained in a silicon cell, which is connected through a silicon dioxide panel to a polysilicon gate or contact. The whole pixel is then connected to clocks which read the electronic signals from the pixels sequentially and transfer the information as analogue voltage through a readout amplifier to produce a signal for display. The brightness of each pixel on the monitor is a direct representation of the number of electrons gathered, which is a representation of the amount of light or xrays which have reached the detector. The pixels are viewed at the same time to produce the image. The whole process is carried out in a matter of seconds, which is a great advantage over conventional film radiography.

In cases where films have been used for imaging, these may be converted to a digital image by using a videocamera to record the film image. The principles of charge-coupling remain the same, but the light-sensitive CCD of the videocamera is used instead of the xray-sensitive CCD. The problem with this method is that it has not eliminated the need to use film imaging principles, or the requirement of processing with a number of chemicals and its associated problems. The majority of digitised imaging today is still by this method (Brooks and Miles, 1993), however, advances in technology have led to the development of CCDs which can be used for direct digital radiographic imaging.

Detectors which fit intra-orally are also used. The CCD in these detectors can be either light or xray sensitive. If a light-sensitive CCD is used, the detector must have a scintillation screen before the CCD, which can be activated by the xrays. When struck, the scintillator produces hundreds of light photons, which are sensed by the CCD, and the image is processed in the manner described. The scintillation information is usually transferred to the CCD by a fibreoptic minifier or a conventional optic lens. Direct sensors are xray sensitive and transfer the information directly to the CCD. A standard matrix of pixels in intra-oral imaging would be 512 x 512 pixels (Wenzel, 1993). Examples of direct imaging systems are the Trophy RadioVisioGraphy System (RVG) (Trophy Radiologic, Vincennes, France and Trophy USA Inc, Marietta, GA) (fibreoptic type) and the Sens-A-Ray system (Regam Medical Systems AB, Sweden) (xray sensitive). Other systems are also available commercially.

The imaging properties of CCDs have been outlined by Miles *et al* (1992) as:

1. High resolution. Resolution is the ability to distinguish between small objects that are close to one another, measured in line pairs per millimetre (lp/mm). The human eye can only resolve to 4-6 lp/mm, whilst dental films can resolve to 16 lp/mm. A typical CCD system can resolve to about 10 lp/mm. The smaller the pixel, the higher the resolution (Wenzel, 1993).

2. High xray and light sensitivity. CCDs are much more light and xray sensitive than dental films. A typical exposure time for a CCD is up to 80% less than that required to expose E-speed film. The patient 's absorbed dose is significantly reduced, but no detectable loss of image is seen. For light sensitive CCDs used for intraoral cameras, less light will be required for the image to be produced on the monitor.

3. Wide dynamic range. This property is the digital imaging equivalent to latitude (range of exposure levels) in film radiography. In film radiography, it is a measure of the range of object densities which may be visualised. A film with a wide latitude will be able to image a greater number of object densities, as it has a greater number of grey levels with which to show contrast of objects in. The dynamic range, or latitude, of CCDs is wider than that of film (usually 256 grey levels), allowing more sensitive imaging to be carried out.

4. Photometric accuracy. The recording of the light or xray intensity signal is digitised with great precision, as the read-out of the electron information is relatively slow. This allows each pixel to be recorded precisely, providing an accurate image.

5. High signal to noise ratio. Noise, or unrequired information, can be eliminated after exposure with CCDs. Because the image can be stored in a frame-grabber, it can be manipulated to improve image contrast and image clarity. This allows a more accurate assessment of the image. This is not possible with films.
Projection geometry remains the same in principle, the difference being that the digitised images are recorded electronically.

Comparisons of the two methods of imaging have been made for image quality and diagnostic value. Haus (1985) offered the definition of image quality as being controlled by sharpness and noise. Sharpness may then be defined by contrast and blur. Contrast is the magnitude of the optical density difference between structures of interest and their surroundings, whilst blur is the lateral spreading of the image of a structural boundary. Noise is all the unwanted information which can be detected during imaging (artefacts).

Image quality in conventional film radiography is determined by the sensitometric properties of the film (resolution and contrast) and the processing procedure. Once the film has been processed nothing can be done to improve its quality. Quality needs to be controlled by monitoring the performance of the xray unit, the processing unit and chemicals, the darkroom and the viewing boxes (Wenzel, 1993). Conversely, the image acquired through direct digital imaging requires no chemical processing and can be manipulated on the computer through the use of computer algorithms to improve the image quality prior to evaluation. The noise, or unrequired information, can be subtracted, contrast enhanced and structural boundaries can be enhanced for greater definition.

The diagnostic value of the image is improved significantly after image acquisition, a capability not available with conventional film imaging. Although the amount of diagnostic information available in the digitally acquired radiograph cannot be increased, image manipulation can alter the relative weight of information pertinent to a specific diagnostic task (Dunn and Kantor, 1993). Digital imaging allows the practitioner to optimise the factors affecting evaluation of a radiograph to enable the observer to recognise features more easily, by increasing sensitivity (ability to detect small changes) without the need to drastically decrease the specificity (resolution) of the radiograph (Brägger, 1994).

Contrast enhancement. A digital image allows the use of all grey levels available on the computer. To compare the diagnostic value of contrast enhancement, conventionally acquired radiographs were digitised and both images compared. Digitally processed images were found to have a significant increase in detectability of simulated low contrast radiographic patterns (Ishida *et al*, 1984). Underexposed conventional radiographs (70% dose reduction) with poor contrast were digitally processed and compared to optimally exposed films. The contrast enhancement allowed the creation of a density and contrast which could not be distinguished from the optimally exposed film (Wenzel, 1988). Use of contrast enhancement in caries studies found that the digitally acquired image provided a higher sensitivity and greater accuracy than conventional films for caries detection (Mouyen *et al*, 1989; Wenzel *et al*, 1990).

The conversion of grey levels to pseudo-colours has been tested and shown to enhance perceptibility of periapical bone lesions (Wenzel, 1993). The reason for this is that the human eye possesses a strong ability to discriminate colours, and the use of pseudo-colours for various shades of grey will improve perception of the presence, absence or changes within a pathological lesion. Brägger and Pasquali (1989) evaluated the use of colour-converted subtraction images for periodontal sites and found that there was a higher rate of agreement in assessment between different observers and for individual observers than there was for assessment with the use of grey level contrast only. Similar results were obtained by Reddy *et al* (1991).

The direct comparison of grey levels on a digital image and contrast on a film between a system viewed on a monitor and conventional radiographs was found to be difficult. Mouyen *et al* (1989) overcame this by using an oscilloscope to measure the signal output from the monitor. Certain parts of the signal provided information on the actual grey level, which could be compared to the density level measured from the conventional film. Welander *et al* (1993) plotted the grey level output of the digital image and the density of conventional film, but noted that a direct comparison of the two curves could not be made without normalising the curves. Shearer *et al* (1990) compared the two methods for use in endodontics, looking at the value of the digital imaging in reproduction of the root canal system. Using extracted teeth, they compared conventional films with contrast enhanced and unenhanced images from the RVG System for the accuracy and clarity of the root canal. All the investigations reported that the direct digital imaging provided contrast and density which is equivalent to that of film.

Wenzel (1993) suggests a number of advantages of contrast enhancement in digital imaging. As many radiographs which need to be retaken are often the result of improper density, the use of digital image contrast enhancement will minimise the need to retake a radiograph and reduce the amount of radiation dose for the patient. Additionally, as the contrast manipulation can be carried out for different grey levels, the same radiograph may be used to evaluate different areas which require different types of contrast for optimal diagnostic evaluation. For example, the assessment of marginal bone loss needs to be done with a light density, whilst the assessment of caries should be done with a darker density. Overall, the ability to manipulate contrast is a significant advantage for digital imaging.

Edge enhancement. The edges of a structure are the places of abrupt changes in optical density. The effect of edge enhancement is to sharpen the boundaries of the imaged object to facilitate the detection of boundaries between sound and pathological tissues. This is done by using techniques which will filter the image to smooth and enhance the edges. Edge enhancement has been used to improve the evaluation of periapical bone lesions and the radiographic analysis of endodontically treated teeth (Mol and van der Stelt, 1989).

Wenzel and Hintze (1993, 1994) asked observers to assess the quality of digitised images which were untouched, 'smoothed', 'enhanced' and 'enhanced and smoothed'. The treatments of the images to achieve the descriptions were done by using filtering programmes in the computer, and the observers were asked to assess the detectability of anatomic structures, bone lesions and caries. The investigators found that the observers who preferred the original untouched images thought that the enhanced images were 'grainy' in appearance whilst those who preferred the enhanced images thought the originals were 'blurry'. In general, the treated images were preferred over the untreated, but the type of treatment is dependent on the area and type of tissue that is to be evaluated. On current information, edge enhancement as a manipulative characteristic of digital images appears to be promising, however, further investigative studies are needed.

Magnification (zooming) A digital image can be magnified to allow an area to be 'zoomed in' to, to concentrate evaluation in that area. The magnification on the screen is different to that for conventional films (Sanderink,1993). The amount of magnification in digital imaging can vary from a factor of 3x to 8x. Magnification will not allow any improvement in resolution though, as this is controlled by the resolution (number of pixels) on the CCD array (Dunn and Kantor, 1993). The problem with magnification of the image is that there will be difficulty in assessing the actual lesion size. This can be overcome by the introduction of electronic grids and rules which can be overlayed on the image. These, however, cannot be applied if the detector and the sensor were not parallel at the time of imaging. There is also an inherent magnification of the object in digital imaging due to projection geometry. This prevents direct measurement of root canal length on the digital image, much the same as in conventional radiography (Shearer *et al*, 1990).

Resolution. The resolution of a CCD is about 10 lp/mm, compared to the resolution of 16 lp/mm of film. This is limited by the number of pixels in the CCD. Comparative studies on the diagnostic value of digital imaging have found that the procedure is equivalent in provision of information (Mouyen *et al* , 1989; Shearer, *et al*, 1990; Sanderink, 1993; Wenzel, 1993). However, films only offer their best resolution under a magnifying glass, while the digital imaging system already provides the necessary magnification (Mouyen *et al*, 1989).

Sensitivity. The sensitivity of the CCD sensor has been compared to that of the frequently used D-speed and E-speed films (Mouyen *et al*, 1989; Sanderink,1993; Welander *et al*, 1993). These measured radiation doses required for diagnostically valuable images with dosimeters and found that the CCD was far more sensitive to xrays than conventional films. Sanderink's comparison of the CCD to D-speed film found that the CCD required between 15% and 80% the dose required to expose the film, depending on the type of digital imaging system used and the mode that it is used in. From comparisons in film speed between D-speed and E-speed, it can be assumed that the dose reduction from the E-speed film will not be as significant. However, the CCD is still more sensitive than the fastest available film. Mol *et al* (1994) determined that the exposure settings for the RVG System is task dependent, according to the diagnostic information required.

The advantages and disadvantages of direct imaging CCDs include (Mouyen *et al*, 1989; Shearer *et al*, 1990; Brooks and Miles, 1993; Miles, 1993; Welander *et al*, 1993):

Advantages

1. instant images (elimination of the darkroom);
2. consistent quality;
3. high signal/noise ratio (better detection);
4. image manipulation (image processing);
5. greater exposure latitude;
6. teletransmission capability;
7. reduced radiation dose for patients; and
8. elimination of hazardous chemicals required for film processing.

Disadvantages

1. high initial cost of system;
2. currently unknown life expectancy of sensor; and
3. smaller size of detector than film (more exposures are required for full mouth surveys). Unfortunately, the size of the current intra-oral imaging system detectors is smaller than that of intra-oral films. For example, the RVG sensor is 23 x 40 mm, 10 mm thick whilst a film is

20 x 30 mm and much thinner (Miles, 1993). Larger detectors are being developed.

Although the currently available direct imaging systems have some disadvantages, the use of them appears to have some promising advantages over conventional film radiography. A comparison of the digital imaging to D-speed film for its accuracy in detecting osseous lesions found that the digital imaging was as accurate as conventional film (Vandre *et al*, 1994). While films are still used for imaging, these can be digitised by using a light sensitive CCD after the film has been processed in the usual manner, and can be manipulated on the computer similarly to the directly digitised image. This ability is advantageous for detailed assessment of films, but this does not eliminate the need for chemical processing and other associated disadvantages of films.

To digitise a film, however, is a costly process requiring a good computer system and costly software. In an attempt to offer a cheaper alternative, a prototype video enhancement unit was developed and tested for its ability to produce diagnostically valuable images (Van Dis *et al*, 1989). The films are not computer digitised, but imaged with a videocamera connected to a videomonitor. The investigators found that with medium optical density films there was no significant difference in the number of radiographic details detected, and that with dark films the conventional viewing method on the illuminated viewing box allowed better perception of detail. No recommendations for further application were offered.

Digital imaging, whether directly or indirectly acquired, has provided the practitioner with numerous techniques which can be used for evaluating bone quality and quantity with the assistance of specially designed computer software. Images can be manipulated to be made more uniform, or a structure can be reconstructed in three dimensions. Importantly, it has significantly increased the sensitivity of detection of bony changes radiographically (Brägger, 1988, 1994; Brägger *et al* , 1988). These techniques will be discussed later.

Xeroradiography

Xeroradiography is another method of 'filmless' radiography. It is based on the electrostatic charging of a metal plate after exposure to xrays, the image being recorded on paper or on acetate sheets. A selenium-coated plate is electrostatically charged prior to its use for imaging. The xrays hit the plate to selectively discharge it, the degree of discharge being dependent on the amount of attenuation of the xrays reaching it. The plate is then passed over a toner station in which there are charged toner particles suspended in a liquid vehicle, and the toner is deposited on the plate to develop the image. The plate is dried to remove the liquid vehicle, a clear adhesive tape is used to recover the image from the plate by pulling off the toner particles and placed on a translucent backing strip. Xeroradiographs have been reported as demonstrating a wide latitude, with the ability to edge enhance by being able to detect subtle changes in tissue density (Goaz and White, 1982; Gratt *et al*, 1989). A subjective study comparing xeroradiography to D-speed and E-speed films indicate that xeroradiography was preferred for diagnostic purposes in periodontics and endodontics, whereas film was preferred for routine restorative radiography. This is because xeroradiography causes artifacts around metal restorations which give the false appearance of caries (Gratt *et al*, 1989). Therefore, xeroradiography cannot be used for implant imaging.

2.2.2 Image Projection Techniques

Intra-oral Techniques

The use of the bitewing, periapical and occlusal views is a well known practise among dental practitioners. The bitewing and occlusal techniques have not been used for implant assessment due to the difficulty in standardising the production of the image, and the lack of accuracy that these techniques have. They may be used for pre-surgical assessment as an adjunct to other views, but are of no use after implant placement.

Periapical

The periapical view may be obtained with one of two projection techniques: the bisecting angle and paralleling techniques. The bisecting angle technique is based on a geometric theorem, Ciezynski's rule of isometry (Goaz and White, 1982). The rule states that if two triangles share one complete side, and each adjacent angle is equal, the two corresponding sides are equal. To apply this to dental radiography, the long axis of the tooth is one side of one triangle and the long axis of the film is the corresponding side of the other triangle. The common side to the two triangles is an imaginary line which bisects the angle formed by the film and tooth at the incisal edge. If a beam is projected perpendicular to the imaginary bisector, the image on the film is theoretically the same length as the tooth, although unequally magnified along the image. The difficulty with this technique is the ability to accurately position the film and project the central beam at the correct angle to get an undistorted and clearly-defined image. It is also impossible to standardise projection geometry to obtain consistent images. Consequently, this technique is not used for implant assessment.

The paralleling technique offers a better opportunity to produce standardised images. Also known as the right-angle and long-cone technique, the basis of the technique is the placement of the film in a support (film positioner) which will hold the long axis of the film parallel to the long axis of the tooth. The beam is then directed perpendicular to the tooth and film, and the geometric distortion will be minimised (Goaz and White, 1982). The long xray source-to-object distance is used to minimise magnification and increase definition. An L-shaped device is used to position the film at the correct angle and the patient closes down on the horizontal occlusal portion of the holder to keep it in position. An aiming rod perpendicular to the holder assists the operator with cone positioning.

The comparison of the bisecting angle technique with four different paralleling periapical view film holders for diagnostic quality in general practices showed that the use of a film holder of one brand or another resulted in a diagnostically better radiograph than the use of the bisecting angle technique (Rushton and Horner, 1994). The investigators looked at the use of the Stabe film holder (Cooke-Waite Laboratories Inc., NY, USA), which has a bite block and rigid film backing; the Eggen film holder (Firma Eggen, Lillehammer, Norway), which has a bite block, rigid backing and a metal bar extra-orally to guide tube position; the Rinn Extended Cone Paralleling (XCP)/Bisecting Angle Instruments (BAI) film holder (Rinn Corporation, Elgin, IL, USA) which has a bite block, rigid backing and metal bar with aiming ring; and the 'Superbite' film holder (Hawe-Neos Dental, Gentilino, Switzerland) which has a bite block, rigid backing and plastic arm and pointer as an aiming device. They compared radiographs obtained with each of these holders against each other and with the bisecting angle technique, looking at the image quality in relation to presence of tooth apex, clarity of the apex, vertical angulation, horizontal angulation, distortion due to bending, cone cut, superimposition of anatomy, absence of tooth crown, and film positioning. Generally the use of a film holder for the paralleling technique produced better diagnostic radiographs, however there were still some significant errors found.

Vertical angulation errors were still apparent with the film holders, although reduced significantly when an extra-oral aiming device was used. Elongation and foreshortening still occurred, however the films were still diagnostically valuable. Horizontal angulation errors were frequent in all techniques used. Due to the curvature of the dental arch, horizontal overlapping is a problem, which cannot be avoided even with the use of an extra-oral aiming device. These are significant problems which are important in the assessment of marginal bone heights in dental implants, and must be considered when quantitative analyses are carried out (Sewerin, 1990). Distortion due to film bending, missed tooth apex and cone cut were minimised with the use of film holders with aiming devices.

With implants, there is the problem of a reduction of alveolar bone which results in the reduction in space available to fit the length of the film and holder. To place the film and holder to its full length, the plane must be adjusted and will not be parallel to the tooth, resulting in a distorted image. A device was designed in which the Eggen Holder was modified to hold a coping which fits over a specially designed radiography abutment (Cox and Pharoah, 1986). The superstructures were removed and the special abutment placed to take the radiography coping, ensuring parallelism. The technique was found to be clinically successful, providing accurate, highly reproducible serial radiographs. Meijer *et al* (1992) described an aiming device which they claim will fit over any abutment without the need for a special radiography coping. The device consists of a film holder, an indicating rod and a fastener which sits over the abutment. The fastener fits implant abutments with a diameter between 3.5 mm and 5 mm and is secured to the abutment by labial screws. The investigators suggest that the positioning can be reproduced by placing a screwhole in the superstructure if it is an overdenture. The test results and error analysis indicate that there are small deviations in reproducibility, but the technique appears suitable for routine evaluation of implants. However, the device has not been tested clinically, with no discussion of reproduction of position with fixed bridges or single implants being offered.

For single-implant crowns, Watson and Newman (1996) have described a method which they report as reproducible. A silicon putty key is adapted on a model of the case and the plastic film holder of a radiographic locator system is imprinted in the key, with the film holding portion carefully positioned parallel to the implant replica. This provides an easily reproducible film position parallel to the implant for accurate assessment of crestal bone height over a number of years. Although the report shows good quality radiographs using this technique, there has been no long term assessment of the accuracy of this method.

Jeffcoat *et al* (1987) described a method of taking standardised radiographs with minimal distortion, by using a cephalostat to stabilise the patient with a long source-to-object distance, designed specifically for use in digital subtraction radiography. The reason for the use of a cephalostat is that there are two sources of variance possible in the registration of an image. The first source is the position of the xray source to the object with the film in the correct position, where misalignment of the source will produce an image which cannot be corrected through manipulation of the digital image. The second is the malposition of the film in relation to the object, with the source and object in correct relation, which can be corrected on the digital image. Theoretically, the most important positioning is that of the source in relation to the object, which can be achieved through the use of a cephalostat to stabilise the patients head. The long source-to-object distance will minimise image magnification and increase sharpness, the beam area and shape being controlled with a collimator. The investigators found that the technique is reproducible and provided acceptable standardised images for digital subtraction radiography.

The periapical and bitewing views on conventional films have been standard in clinical application to assess for caries, endodontically associated problems and periodontal problems. Most commonly these are evaluated qualitatively, and can be digitised for more detailed assessment. The films have also been used for quantitative assessment of bone through the use of various techniques (Steen *et al*, 1985; Albandar and Abbas, 1986; Galgut *et al*, 1991; Fourmousis *et al*, 1994a, 1994b).

Extra-oral Techniques

Panoramic Radiography

Panoramic radiography (also known as pantomography or rotational radiography) produces a single image of both the maxillary and mandibular arches and their supporting structures. The image gives an overview of the jaws, allowing visualisation of anatomical structures such as the temporomandibular joints, maxillary sinuses, nasal cavity, mandibular canal and mental foramina. The principle of panoramic radiography lies in the movement of the xray source and the film around the patient's head, which is the axis of this rotation, while the film is rotated around its own individual axis at the same time. The film and source rotate in the same direction at the same rate, whilst the film is moved about the patient's head in a cassette which moves in the opposite direction to the source. With this principle of imaging, there is a narrow band within the tissues being imaged which will be in focus. This is known as the focal trough, and any object outside of this will be out of focus and blurred on the final image. The focal trough is controlled by the position of the centre of rotation of the cassette and source, which is set by the manufacturer. Most panoramic radiography machines have two centres of rotation to compensate for the shape of the jaws.

The theory of panoramic radiography has been applied to the use of CCDs to obtain a digital rotational panoramic image. The CCD pixels are arranged in a linear array instead of an area one, and rotated about the patient's head in the same manner as a film cassette is (McDavid *et al*, 1991). Preliminary experimental tests of the system on phantom heads have provided images that seem comparable in diagnostic quality to conventional panoramic radiography. The system described in the article was only a prototype at the time of reporting and further evaluation of its value in contrast, density, resolution, image quality and patient doses still needed to be carried out. There are no commercially available digital panoramic machines at present, but development is continuing in the US and Japan (Dove and McDavid, 1993).

The major advantages of panoramic radiography are that a broad anatomic region is imaged, a relatively low radiation dose is required and patients who cannot open their mouths can still have their jaws imaged. The major limitation of the technique is that the narrow focal trough means that objects beyond the trough will not be imaged clearly and vital information about the extent of a lesion may be missed if it is the only view taken (Lilienthal and Punia-Moorthy, 1991; Truhlar *et al*, 1993). Other disadvantages include poor resolution of fine anatomic detail, image magnification, geometric distortion and overlapping of structures (Goaz and White, 1982). Truhlar *et al* (1993) also suggest that the horizontal magnification is greater than the vertical magnification in panoramic radiography, therefore the horizontal measurements are unreliable.

A technique has been described in which the panoramic view can be standardised (Lambert *et al*, 1993). Class II helium-neon laser guides were used on an orthopantomograph machine to assist with the standardising of patient head position. Radiographic images of a phantom skull with radiographic markers were taken by a number of different operators following the same laser guided technique, with the skull being adjusted and needing to be repositioned for each radiograph. After computer imaging and analysis the results indicate that there was very little difference in the radiographic position of the markers, showing the technique to be accurately reproducible. Further investigations into the technique are required before it can be applied to bone level evaluation.

Edgerton and Clark (1991) used the panoramic radiograph to locate abnormalities in edentulous patients in an attempt to determine if there is a predictive basis for the occurrences of abnormalities by sex, age or location. Radiopacities, radiolucencies, retained roots and teeth were recorded by size and site, and other selective views were taken for more detailed analysis. Although the study was not designed to test the validity of the panoramic view, it shows that it can be used with confidence as a scanning technique to detect abnormalities in the first instance.

The panoramic technique is most commonly aimed at projecting images of the dental arch, but has been tested on a dry skull in imaging the posterior wall of the maxillary sinus (Ohba *et al*, 1991). By changing the point of rotation of the panoramic unit, the posterior wall of the maxillary sinus could be imaged more sharply than on the standard dental panoramic view. This could be significant when facial fractures are possibly present. Clinical testing is still required.

Another modification to the panoramic technique (the addition ofa linear component of movement) has been applied as specialised technique for viewing specific areas in more detail. This is known as panoramic zonography (Hartman *et al*, 1989, McDavid *et al*, 1990). The Zonarc system (Siemans Co., Palomex Instrumentarium, Helsinki, Finland) is a panoramic unit specifically designed to provide tomographic images of curved anatomic structures. The images are a result of a combination of circular and linear tube movements, providing detail of structures such as the alveolar process, zygoma and lateral walls of the orbit and maxillary sinus, which is superior to that provided by conventional panoramic radiography (Hartman *et al*, 1989).

Cephalometric Radiography

The lateral cephalometric view provides an image of the skull in profile, revealing the soft tissues of the nasopharynx, paranasal sinuses, hard palate, nose and lips. The film is placed vertically along the side of the face, with the central beam projected perpendicular to the film. A long xray source to object distance is used to minimise magnification and image unsharpness, the degree of which is dependent on the technique of imaging used, but it can provide valuable information about the maxillo-mandibular relationship (Kassebaum *et al*, 1992). This view is good for an overview, but lacks diagnostic information about the width of the bone buccolingually. Superimposition of hard tissue structures is also a major problem.

Linear and Multidirectional Tomography

Also previously termed stratigraphy, multisection radiography, laminography and planigraphy (Kassebaum and McDowell, 1993), tomography is a technique in which a slice of a region can be imaged to view an area normally obscured when using other conventional radiographic techniques. The image is obtained by movement of the source and the film in opposite directions around a fixed fulcrum, except that the film itself does not rotate as it does in panoramic radiography. As the film and source move, the objects within the layer being imaged remain in focus on the film, while the objects either side of the imaged plane become blurred. The thickness of this layer is dependent on the angle and length of rotation.

There are a number of types of movements which the components can undergo in rotation, which determines if the tomography is termed linear or multidirectional. In the simplest form of tomography, linear tomography, the source moves in one direction whilst the film moves in the other direction, and the fulcrum remains stationary. The level of the fulcrum in the patient is the plane of interest and these structures will be the ones in focus on the film. The film images frequently display streaking lines which represent the edges of radiopaque linear objects oriented along the path of motion. Multidirectional movements have been developed to minimise the streaking and provide a clearer image with better diagnostic value. The types of movements include elliptical, hypocycloidal, circular and transpiral. The more complex the movement, the clearer the image (Kassebaum and McDowell, 1993).

Conventional tomography has been used for imaging the temporomandibular joints (TMJs) when detailed assessment is required (Goaz and White, 1982; Kassebaum and McDowell, 1993; Pharoah, 1993) or to produce a cross-sectional image of the maxilla or mandible which is perpendicular to the commonly used views from the buccal side (Kassebaum *et al*, 1990; Miller *et al*, 1990; Stella and Tharanon, 1990a, 1990b; Poon *et al*, 1992).

Kassebaum and McDowell (1993) and Pharoah (1993) have reviewed some of the applications of tomography. Many tomographic studies of the TMJ include the lateral projection of the joint in open and closed positions, demonstrating the location of the condyle to the glenoid fossa. Attempts to use this information about the osseous tissue to make assumptions about the disc have not been reliable as the condylar position is so variable in its position that the disc position cannot be predicted . Arthrography of the TMJs has been described whereby a contrast medium is introduced to the joint spaces and tomographs are taken, the slice thickness of which vary according to the requirements (Kassebaum and McDowell, 1993).

Tomography has been described as a diagnostic technique to determine the buccolingual relationship of impacted third molars and the inferior alveolar neurovascular bundle (Miller *et al*, 1990). The technique enabled the operators to assess the radiographic size, shape, branching pattern location and degree of cortication of the mandibular canal (as well as bifid canals) and the inclination of the impacted third molars in the buccolingual plane. This provided diagnostic information which significantly aided the oral surgeon in the pre-surgical assessment of patients. Similarly, the cross-sectional technique has recently been more frequently applied to the pre-surgical assessment of patients for dental implants (Kassebaum *et al*, 1990; Stella and Tharanon, 1990a, 1990b; Poon *et al*, 1992).

However, there are some disadvantages associated with the technique. The method is time consuming, exposures of multiple sites in the jaw require additional calculations and changing the angle of the patient's head for each exposure (if the sites are not parallel to each other), and anatomic variations may occur which are difficult to interpret. Additionally, the location of the mandibular canal is occasionally difficult to determine and, if the floor of the maxillary sinus curves upwards, it may be difficult to visualise (Kassebaum *et al*, 1990). Pharoah (1993) also reports that tomographic blurring will decrease the sharpness of the image, which may obscure small changes in TMJ tomograms, whilst Schwarz *et al* (1989) state that there is a lack of cross referencing with standard lateral, frontal and panoramic radiographs, or intrinsic markers to indicate the precise location of each individual slice.

2.2.3 Computed Tomography

Commonly referred to as CT, and also known as computed axial tomography (CAT), this is a radiographic technique which combines the theory of slice radiography and computer assisted digital imaging. Introduced in the 1970s, its use as a diagnostic imaging technique has been steadily growing due to its accuracy and diagnostic value (Schwarz *et al*, 1989; Brooks, 1993; Brooks and Miles,1993).

Although the mathematics of the technique is complex, the basic principles can be readily understood. The image is captured by detectors of scintillation crystals or xenon gas, which produce electronic signals that are transmitted to a computer for the construction of the image, not unlike the CD used for direct digital imaging. The detectors are held in linear arrays in a gantry placed 360° around the patient. The patient is placed in the centre of the gantry, and the xray beam and detectors move around the patient, collecting information from different directions. After all the attenuation measurements are calculated, the computer calculates density at each pixel and assigns it with a grey level (from 1 to 256) which can be represented visually on a monitor. A series of tomographic scans at predetermined slice thicknesses are made, and the information stored in the computer. With this attenuation information about the different regions of the area of interest, the operator can manipulate the computer to reconstruct images of the same area in different planes (sagittal , coronal), or even in three dimensions, without the need to expose the patient to any more radiation (Lambert, 1989). Image contrast can be varied on the image to highlight soft tissues or concentrate on bone densities (Brooks, 1993)

CT in dentistry plays a significant role in the diagnosis and treatment of pathoses in the head and neck. The extent and presence of clinically suspected pathoses such as tumours, cysts and infections can be assessed more accurately and provide the clinician with a better guide towards the appropriate treatment (Brooks, 1993). If the clinician notes that there is a lesion on a standard radiograph which appears to extend further into the jaws or head, a CT scan will allow the clinician to examine the hard and soft tissues for the position and extent of the lesions. Fractures in the maxillofacial region can be carefully and thoroughly assessed with the use of CT, particularly when there may be multiple fractures which are often obscured in conventional radiographic views.

The use of thin contiguous slices (1.0 or 1.5 mm) in CT has provided the clinician with the ability to reconstruct the osseous structures in a three-dimensional form (Lambert, 1989; Yune, 1993). This allows the surgeon tovisualise spatial relationships which previously had to be conceptualised, frequently a difficult task. The three-dimensional image can be rotated in any plane for study, and individual bones and tumours can be disarticulated from the rest of the anatomy to increase the visualisation of specified structures. Pseudocolours can also be added to highlight particular structures or pathology (Yune, 1993), while model surgery can be carried out and an accurate splint constructed as a guide for the surgeon prior to the actual operation (Lambert, 1989).

Sagittal slices of the TMJ can be obtained through reformatting the information stored from the original scanning, or by imaging direct sagittal slices (Pharoah, 1993). The direct acquisition of sagittal slices will provide superior images but may be limited by the equipment and patient flexibility. Soft tissues and small bone detail can be better visualised, particularly the extent of any tumour involvement in the condylar head, articular disc or glenoid fossa.

Pre-operative implant surgery assessment is also facilitated by the use of CT (Andersson and Kurol, 1987; Andersson and Svartz, 1988; Engelman *et al*, 1988; Schwarz *et al*, 1989; Williams *et al*, 1992; Jeffcoat *et al*, 1991; Brooks, 1993; Klein *et al*, 1993; Miles and van Dis, 1993; Weinberg, 1993; Yosue and Takamori, 1994). The use of a stent with radiopaque markers incorporated at the planned implant sites allows the use of CT to assist in accurately assessing the bone for buccolingual width and vertical height, and for an assessment of the proximity of vital structures to the planned sites. If multiple sites are planned, CT may be the most cost-effective method of accurate bone assessment, as conventional cross-sectional tomography is time consuming, labour intensive and consequently will cost more, with more exposures (Miles and van Dis, 1993).

The software programme attempts to keep the images at actual life size, however, there are occasions where a reformatted image may be slightly distorted, so careful measurements using the scale provided with the scans need to be used (Weinberg, 1993). It is important that measurements of the anatomic structures are cross-referenced in all three planes to ensure that the prosthodontist and surgeon have accurate guides to implant placement. Various software programmes allow for various means of image manipulation, and the mock placement of an implant in bone (Jeffcoat *et al*, 1991). This programme placed an image over the CT images and constructed an 'implant' in the planned site, 'sliced' in the same plane as the CT image. Further software is under development to extend this for ideal pre-surgical implant assessment.

Although the CT has a great number of advantages over conventional imaging techniques, it does have its disadvantages. The most significant of these is the result of streak artifacts in the presence of metal (restorations and endodontic posts) (Schwartz *et al*, 1989; Williams *et al*, 1992). Therefore, CT imaging in partially edentulous cases which are planned to receive implants need to be ordered with caution, as the artifacts may eliminate the benefits which would normally be gained from a CT scan. Also, patients must remain motionless throughout the scan (approximately 10 to 15 minutes) to minimise distortion (Williams *et al*, 1992), although recent developments have reduced the required scanning time to less than one minute.

The advantages and disadvantages of CT in implantology have been suggested as (Williams *et al*, 1992):

Advantages

1. it is less time consuming
2. it allows for more accurate visualisation of anatomic structures without superimposition
3. it allows for continuous view of surface topography
4. soft tissue detail is preserved
5. it produces lower radiographic exposure than combination techniques and allows reconstruction from original data versus re-exposure of the patient
6. it permits pre-operative evaluation for maximal use of available bone
7. it allows visualisation and accurate location of developmental defects, foreign bodies and osseous pathology

8. patient comfort is excellent

9. it allows for verification of site and orientation of reconstruction

Disadvantages

1. streak artifacts are created in the presence of metal restorative/endodontic materials

2. patient movement must be avoided for the entire scan

3. patient orientation for sagittal technique is difficult

4. the technique and equipment are less accessible

5. cost is greater than for conventional techniques (may be less than multiple site conventional tomography)

2.2.4 General Comparisons

Radiographic techniques will vary with regard to the amount of information provided, magnification of the resulting image, availability and cost to the patient and radiation dose during the procedure (Kassebaum *et al*, 1992). Accuracy is of primary importance in any radiographic technique, along with the amount of information provided.

Intra-oral films provide information on a structure and its surroundings, but are limited in what they can provide in size. Panoramic views, however, provide a general overview of the teeth and surrounding structures in one continuous view and provide information on jaw relationships (Kassebaum *et al*, 1992). These films allow measurement of vertical bone height for implant and periodontal therapy assessment, provided the magnification is consistent and it is considered when measurements are made. Standardisation of the films is possible with the use of film holders, aiming devices and laser guiding lights, however, these are by no means perfect . Also, they are limited in that only one plane of a three-dimensional object can be visualised, which limits the accuracy of assessment. Lateral cephalometric views provide information on jaw relationship, bone quality and quantity, however there are many structures which are superimposed, and it is difficult to determine exactly where any detected abnormalities are. Conventional tomography and CT are capable of producing very accurate and diagnostically valuable images which provide the third dimension of the cross-section to see the buccolingual width of the bone.

Lindh *et al* (1992) compared five radiographic techniques in the visualisation of the mandibular canal. Using a dry mandible, the investigators imaged the structures with periapical radiography , panoramic radiography, hypercycloidal tomography, spiral tomography and computed tomography. They also sectioned the mandible in the area of tomographic slicing and placed the section in contact with the film at the time of exposure to get an image similar to a tomographic image to make a comparison. The results indicated that there was no difference between the periapical and panoramic techniques in visualising the mandibular canal, but there was a better image obtained with the use of cross-sectional tomography and computed tomography. These techniques provided images comparable to the image of the sectioned mandible in terms of accuracy. The investigators recommend the use of cross-sectional tomography for information on the buccolingual width of the bone. Mayfield-Donahoo *et al* (1994) found that digitising the tomograph from film and enhancing the image provided a better image which was preferred over the original tomograph.

Investigations comparing the most commonly used techniques with CT indicate that CT is probably the best of the available techniques. However, improvements in direct and indirect digital imaging, with continuing development of software for use with these techniques, may cause CT to become the least cost-effective for routine use, but remain a valuable tool in various cases.

2.3 PRE-TREATMENT RADIOGRAPHIC EVALUATION

Critical to the success of dental implant treatment is the diagnosis and treatment planning processes. A thorough assessment of the prosthodontic and surgical factors must be carried out before embarking on an extensive and expensive mode of treatment.

The first step is to gain a complete understanding of the patient's complaints (or perceived problems) about the existing conventional prostheses , along with their expectations from treatment with implants (Watson *et al*, 1988; Eckert and Laney, 1989; Rich and Augenbraun, 1991). This is the most critical component of treatment, as unrealistic expectations of outcomes, especially of appearance, may be a barrier to success. Clinical assessment of the patient follows, in which the attached and unattached mucosa are assessed for suitability, and the alveolar bone is examined clinically by palpation for its adequacy. After the clinical examination is carried out, the clinician must then decide on the type of prosthesis which will eventually be supported by the implants. As discussed earlier, the implant-supported prosthodontic options include overdentures, removable implant supported dentures (no tissue support), fixed implant dentures, fixed partial denture supported by implants, fixed implant and tooth supported bridges and single implant-supported crowns.

In addition to the clinical assessment, a thorough examination of the patient's physical and psychological profile is required. The patient must have a medical history updated, to ascertain his/her ability to withstand the anaesthetic and surgical trauma associated with the placement of the implants at stage one (Watson *et al*, 1988, Eckert and Laney, 1989).

After the clinical assessments are completed the condition of the bone needs to be examined more thoroughly. Multiple views of the proposed implant sites are obtained with different imaging techniques, intra- and extra-oral, to determine: (a) the quantity of bone present (height and width which is uncompromised by vital structures); (b) the quality of bone available (extent of the cortical plates and density of the cancellous and Harversian bone); (c) the location of critical anatomic structures; and (d) the presence or absence of any pathoses (Watson *et al*, 1988; Eckert and Laney, 1989; Miles and van Dis, 1993; Frederiksen, 1995; Potter *et al*, 1997). The radiographs will also allow visualisation of the adjacent teeth apices in single implant cases.

Importantly, the ideal imaging modality should have certain characteristics (Frederiksen, 1995). These include: 1) cross-sectional views of the arches to show the inclination of the alveolar processes and the spatial relationship of anatomical structures to the proposed site; 2) a flat imaging plane to allow accurate measurements; 3) the images should allow for evaluation of bone quality (density of trabecular and cortical bone; 4) the ability to provide information on the location of the image relative to the fixture site; and 5) it should be readily accessible and a reasonable cost.

Intra-oral radiographs provide good images of the anatomic structures and teeth adjacent to the proposed sites in localised areas, and must be taken with care to minimise distortion (Kassebaum *et al*, 1992; Miles and van Dis, 1993; Frederiksen, 1995). Accurate assessments of bone height and quality can be made with correctly-imaged radiographs, however the buccolingual width cannot be accurately determined. Although occlusal views may be used to provide some information on the buccolingual width of the bone, the image may be distorted, particularly in the posterior mandible or maxilla, preventing accurate evaluation (Modica *et al*, 1991; Miles and van Dis, 1993; Frederiksen, 1995).

To visualise both jaws simultaneously, a panoramic radiograph may be used. This is a useful overview of the proposed sites and surrounding structures, showing the location of the maxillary sinuses, nasal cavity, mandibular canal and mental foramina, allowing a comparison of contralateral structures. Bone pathoses and condylar changes which may compromise the placement of implants can also be detected. However, it cannot be relied on as the sole means of radiographic evaluation, being sensitive to patient positioning, providing information in one plane only. A study by Petersson *et* *al* (1992) found that when individuals were assessed for suitability for implants by one radiologist and one oral surgeon, approximately two-thirds of the patients required tomography for a more accurate assessment.

Lateral skull or cephalometric radiographs have also been used to show the pre-operative relationship of the maxilla and mandible, the height and width of the bone in the incisal region, the hard palate, the position of the mental foramina in relation to the anterior mandible, and the soft tissue profile of the patient (Watson *et al*, 1988; Watson *et al*, 1991; Kassebaum *et al* , 1992). Depicting the bone in the sagittal plane, the lateral skull radiograph can be used with or without any existing dentures to establish the maxillomandibular relationship. As an adjunct to other views it will provide helpful information to avoid any complications related to implant position, however, will not always provide an image of the exact region of the implant location (Engelman *et al*, 1988).

The problem of visualising the third dimension is dealt with by the use of conventional and computed tomography. Conventional tomographs may be taken to provide individual slices of the proposed sites (Petrikowski, *et al*, 1989; Kassebaum *et al*, 1990; Miller *et al*, 1990; Stella and Tharanon, 1990a, 1990b; Kassebaum *et al*, 1992; Poon *et al*, 1992; Weingart and Duker, 1993; Potter *et al*, 1997). CT information can be used and reformatted to provide a three-dimensional image of the proposed sites and allow the manipulation of the image for more accurate assessment (Jeffcoat *et al*, 1991; Modica *et al*, 1991; Klein, *et al*, 1993; Weinberg, 1993).

The majority of the literature advocate the construction of prosthodontic stents with radiopaque markers which depict the proposed position of the implants. Lechner *et al* (1992) describe a technique for constructing a radiographic/surgical stent using a newly-constructed diagnostic denture which has been duplicated. The lead foil markers have known dimensions, placed (a) vertically at the positions of the implants and the mental foramina, and (b) horizontally to act as distortion and magnification markers.

Panoramic and cephalometric radiographs are then taken and evaluated, and a surgical stent is constructed using this information. Adrian *et al* (1992) also employ lead foil as radiopaque markers for use in lateral cephalometric radiographs, which they describe as allowing them to place implants which are 'prosthodontically ideal'.

An alternative radiopaque marker used in conventional film tomography is a metal ball incorporated in the radiographic stent, at the position of each implant (Eckerdal and Kvint, 1986; Petrikowski *et al*, 1989; Arlin, 1990; Poon *et al*, 1992). Other metallic markers used for panoramic radiography and conventional tomography are pins (Kassebaum *et al*, 1990), while non-metallic materials such as gutta percha are used in CT, due to the artifacts created by metals (Schwartz *et al*, 1989; Klein *et al*, 1993; Lima Verde and Morgano, 1993; Weinberg, 1993). Plastic external guiding rods have also been used by some clinicians to assist them with positioning the tomographic slice they wish to take (Weingart and Duker, 1993).

The accuracy of the conventional tomogram to image the alveolar hard tissues has been tested by Petrikowski *et al* (1989). A dry specimen of the mandible had a radiographic stent constructed to fit onto it and hypocycloidal tomograms were taken at different positions to produce cross-sectional images of the mandible at 3 mm intervals. The specimen mandible was then sliced so that each slice corresponded to each tomographic image, the bone height and width measured from each, and the differences between the dry specimen and the tomograms when measured were calculated. The hypocycloidal tomogram was found to be accurate enough to be applied to the clinical treatment of patients. Stella and Tharanon (1990a, 1990b) also used the hypocycloidal tomograph to determine the location of the inferior alveolar canal in the posterior mandible.

A technique using linear tomography after stabilising the patient's head with a cephalostat has been described to provide an accurate cross-sectional view of the hard tissues (Kassebaum *et al*, 1990; Poon *et al*, 1992). The investigators found that the technique provided the clinician accurate detail of the imaged areas for evaluation for implant placement. They outline some of the disadvantages, such as the technique being time consuming, multiple exposures are required for multiple implant sites, requiring changes in patient position, and anatomic variations may result in images which are difficult to interpret. No quantification of measurements was carried out as the tomographs were clinical, however, the investigators report that the implants could be placed accurately and safely with the information obtained.

CT evaluation pre-operatively will allow for comprehensive evaluation of the bone in both jaws and the careful placement of the implants (Schwartz *et al* , 1989; Weinberg, 1993). The clinical objective of the CT scan is to provide information which will assist the determination of the optimum implant site, angulation and length through reformatted sectional images which can be used to create a three-dimensional image (Modica *et al*, 1991; Weinberg, 1993). It may be the most cost and time-effective technique when there are multiple sites in both the maxillae and mandible, allowing visualisation of a life-sized image (Miles and van Dis, 1993). Stents with non-metallic radiographic markers in the proposed implant sites are suggested by the majority of authors. Modica *et al* (1991) have described a technique using a parallelometer and aluminium tubes as surgical guides after evaluation of the sites is made from CT scans.

Two studies compared the cost and time effectiveness (in relation to information acquired) of CT to conventional panoramic radiography and tomography (Andersson and Kurol, 1987; Andersson and Svartz, 1988). The investigators reported their use of CT scans as providing: (a) visualisation of the concavities of the crestal bone and their extent; (b) a means of evaluating the quality of bone thickness of the cancellous bone; (c) an image of the location and width of the incisal canal; (d) the width of the maxillary sinus; and (e) the ability to obtain direct measurements of bone height and estimated fixture length. At the time, they suggested that CT could be used as a substitute for conventional panoramic and tomographic radiographs, however, the cost of CT for routine use has been estimated at three to five times more expensive than conventional tomography (Engelman *et al*, 1988). In a comparison with lateral cephalometric radiographs, CT was found to provide a more precise and more widespread estimation for bone quality, as the lateral cephalograph provided information on the midline of the jaws only (Yosue and Takamori, 1994).

Jeffcoat *et al* (1991) have described a technique using CT scans and superimposing images of implants over the imaged bone. With the use of specially designed software, a hospital CT scan can be converted from the recording medium to another computer image through a video camera and the implants imaged over this. The programme allows the operator to (a) 'try in' varying lengths and styles of implants to select the optimum implant; (b) place the implant anywhere in the jaw with full control over three-dimensional space; (c) display the implant from several different viewpoints; and (d) view any needs for alveoloplasty. One disadvantage of this system is that some of the grey scale information from the original CT scan is lost through the conversion to the new digital image. However, the system appears to be able to provide several advantages to treatment planning when used in conjunction with conventional techniques, but requires further evaluation for future use.

Implant placement should be carried out with as much precision as possible. A combination of the various radiographic techniques should be used, particularly the tomogram, to provide an image of the bone in the buccolingual dimension. CT is a valuable adjunct to conventional techniques, however, cost is a major factor to consider. When sufficient information can be acquired with conventional techniques, CT can be avoided to minimise costs, but must be used if a complete assessment is not able to be achieved otherwise. Table 1 provides a summary of pre-operative radiographic assessment techniques (Miles and van Dis, 1993).

Examination Type	Application	Usefulness	Limitations
Periapical	• Single implant site	• Good resolution/detail • Minimal geometric distortion	• Small size • Two dimensional only • Difficult to reproduce after placement
Occlusal	• Single Implant site	• Good detail • Buccolingual dimensions • Larger area of coverage	• Little anatomy visible • Distortion in maxilla due to technique
Panoramic	• Multiple sites • General view of bone, anatomy	• Can see anatomic structures such as foramina, sinuses, etc.	• Less resolution • Geometric magnification • Frequent positioning errors unless sufficient technique training
Tomography	• Exact imaging of implant site	• Very useful, detailed view of implant site(s) • Little superimposition of other anatomic structures	• Equipment cost • Availability of trained oral radiologist to perform the proceduresand calculate bone dimensions
CT	• Imaging of multiple implant sites	• Precise estimation of available bone levels • Automatic calculation of bone height, width • Reconstruction of image possible	• Cost • Availablility of service at hospital radiology unit • Access to CT unit
Lateral Cephalometric	• Single or multiple sites • General view of bone, jaw relationship, soft tissue imaging	• Height and with of bone in incisal seen • Hard palate image • Mental foramina position • Soft tissue profile	• Plane of image may not be in exact region of implant site(s) • Adjunctive only

Table 1. Pre-operative Implant Imaging Techniques

2.4 CLINICAL REVIEW OF FUNCTIONING IMPLANTS

Once the implants have been placed and a prosthesis provided, continued periodic maintenance and review of the system is vital to the success of the implants. Regular clinical and radiographic reviews are required to monitor any significant changes which may occur. Many techniques used in the assessment of periodontal disease, such as probing of pockets and mobility testing, were previously determined and accepted as the most suitable for the assessment of implants (Wie *et al*, 1984). Radiographic assessment of the bone has become one of the major non-surgical forms of monitoring implants, implementing some of the techniques previously discussed, with adaptations for specific forms of assessment and analysis. A study by Adell *et al* (1986) found that quantitative and qualitative radiographic examinations of the peri-implant bone appeared to provide a truer indication of the longitudinal events than conventional soft tissue observations. Similarly, Gröndahl and Lekholm (1997) found a high positive predictive value in radiographically identifying failing implants which have not been detected clinically. Ideally, a combination of clinical and radiographic assessment will provide a far better indication (van Steenberghe and Quirynen, 1993). A recommendation has been made of annual assessments in the first three years of function with individualising from there has been made (Gröndahl and Lekholm, 1997).

Radiographically, the only regions of bone around an implant which can be assessed are the mesial and distal aspects of the implant, as the image is produced in only one plane. The buccal and lingual aspects are obscured by the radiopaque implant. As a result, many of the discussions on radiographic assessment of implants predominantly deal with alveolar bone height proximal to the implant using intra-oral radiographs (Larheim and Eggen, 1982; Jeffcoat *et al*, 1984; Jeffcoat and Williams, 1984; Hausmann *et al*, 1985; Albandar and Abbas, 1986; Hausmann and Jeffcoat, 1988; Lindquist *et al*, 1988; Fredriksson *et al*, 1989; Benn, 1990; Sewerin, 1990; Benn, 1992; Meijer *et al*, 1992; Quirynen *et al*, 1992; Weber *et al*, 1992; Jemt and Pettersson, 1993; Nasr and Meffert, 1993; van Steenberghe and Quirynen, 1993; Gröndahl and Lekholm, 1997). Quantification of bone loss, as either a direct linear measurement or as a percentage of a reference marker, has been used extensively in implant studies, as opposed to qualitative assessment only. Consequently, there has been the development of many techniques of bone measurement, which include direct measurement from conventional radiographs, and the use of digital imaging for linear measurement, digital subtraction analysis, or densitometry.

Panoramic radiographs have been used for overviews of functional implants, however Friedland (1987) suggests that the poor resolution of the panoramic radiograph limits the detection of fine changes in horizontal bone height, and that standardised periapical radiographs are preferable. Truhlar *et al* (1993) suggest that although this is a problem, periapicals are limited by variations in anatomy, causing problems with geometry, possibly creating the need for multiple views of the one implant, increasing radiation exposure. Panoramic radiographs could be used for an initial screening of the implants, providing a guide for further intra-oral views, reducing the amount of radiation exposure to the patient.

The most widely accepted criterion in regards to radiographic assessment of implants has been proposed by Smith and Zarb (1989), suggesting that the mean vertical bone loss should be less than 0.2 mm annually after the first year of service, after an expected loss of 1-1.5 mm in the first year, based on the results of studies of various implant systems available. Albrektsson and Zarb (1993) proposed a change in this criterion to be less than 1mm bone loss after the first year. Bone loss in excess of these recommendations, in a longitudinal series of radiographs, could be indicators of problems such as occlusal overload or persisting gingival inflammation. This si significant if marked mobility is detected clinically (van Steenberghe and Quirynen, 1993; Brägger, 1994).

2.4.1 Quantitative Assessment

Bone levels can be assessed as a linear measurement between the crest and a fixed reference point, such as the junction of the implant and abutment (Watson and Newman, 1996) or a particular thread on the implant in those types of systems (Cox and Zarb, 1987; Smith and Zarb, 1989; Chaytor *et al*, 1991). This usually provides a crestal bone level in millimetres which is used for comparisons in sequential radiographs.

Various methods of quantifying bone level changes have been described and tested, initially for periodontal use and later adapted to implant assessment. Albandar and Abbas (1986) compared three methods for accuracy in depicting bone level changes around teeth. One method described was referred to as the 'absolute' technique reported by Albandar *et al* in 1985, in which the alveolar bone was measured from a reference point (e.g. the cementoenamel junction) in millimetres. The second method, known as the Schei technique (described by Schei *et al* in 1959), calculated the alveolar bone height as a fraction of the radiographic root length. The third method used was the Bjorn technique (described by Bjorn *et al* in 1969), which related the bone height to the total radiographic tooth length (as opposed to just the root length), giving the measurement as a proportion. Albandar and Abbas reported that the absolute method of assessment provided significantly better reproducibility and readability than the other two techniques, but none of the them allowed for variations in projection or magnification. Review of the literature indicates that the majority of investigators used some form of the absolute method described for assessing implants, particularly when digital imaging is used.

Another method of monitoring bone level, using a radiographic index and comparing serial radiographs, has been been described by McKinney *et al* in 1983, as reported by Nasr and Meffert (1993):

0 = no radiographic evidence of bone resorption around the implant

1 = slight (< 0.5 mm) resorption of alveolar bone around implant

2 = moderate resorption of alveolar bone around implant (0.5-2 mm)

3 = severe resorption of alveolar bone (> 2mm)

4 = radicular radiolucency >1.5 mm wide and along more than one third of
the root surface

Nasr and Meffert (1993) suggested that this index was inappropriate as it would lead operators to assume that a grade of 0 would rarely be encountered, whilst a grade of 2 (moderate resorption of 0.5-2 mm) covers a significantly broad range. As an alternative, they have proposed another radiographic index with seven grades (0-6), describing the bone level changes as percentages relative to implant body length (within bone) measured from its coronal-most margin in an apical direction:

0 = 0%-5% of implant length

1 = >5%-10% of implant length

2 = >10%-15% of implant length

3 = >15%-20% of implant length

4 = >20%-25% of implant length

5 = >25%-30% of implant length

6 = >30% of implant length

The principle underlying this index is based on the premise that the longevity of an implant is directly dependent on the relation between its size and the amount of interfacial bone loss it may experience (Nasr and Meffert, 1993). As the index considers the amount of bone in relation to the surface area of the implant, its use as a prognostic tool in periodic reviews could be valuable and easy to implement by the clinician. The concept is to provide a general indication of implant performance over time, and attempt to minimise errors which could be a result of elongation or foreshortening of the radiographic image (Jeffcoat and Williams,1984; Sewerin, 1990; Benn, 1992; Nasr and Meffert, 1993).

With the introduction of digital imaging, other methods of quantifying bone assessment have been developed. A technique using digitised bitewing radiographs for alveolar bone height measurement in periodontal treatment has been described and tested by Fredriksson *et al* (1989). Using unstandardised radiographs, the investigators carried out multiple direct linear measurements of alveolar bone height to test the reliability and reproducibility of the technique and the computer programme used. After testing 432 sites , they found a 96.5% level of agreement within a margin of error of 0.3 mm, concluding that the technique is reliable and consistently reproducible. However, bitewing radiographs of implant sites are difficult to produce accurately, and are likely to be more time consuming than periapical radiographs taken with modified film holder/aiming devices.

A study using a combination of digitally converted radiographs and analysis of bone height as a percentage of implant length has been applied clinically (Pham *et al*, 1994). The computer-assisted technique provided a measure of rate of bone change around non-submerged implants over a two year period, but did not provide analysis of bone density or an absolute measure of any changes. Radiographs were taken at time of surgery, 3-6 months after surgery (pre-loading), 12 months after surgery and 24 months after surgery (post-loading), with percentage of bone change measured in relation to the shoulder-apex length of the implant, at the mesial and distal sites adjacent to the implant.

The results indicate that in non-submerged implants the monthly rates of bone loss reduces with time of function and are greater in the maxilla than in the mandible. In the early post-loading phase, the maxilla gained a small amount of bone, while the mandible lost bone. The reasons for using percentage rate of bone change instead of absolute measures in millimetres was the variation in times in which patients returned for reviews. The results were obtained using a relatively small sample size, and the authors suggest further investigations clinically are required with larger sample sizes.

Currently there have been few clinical studies reported specifically dealing with radiographic aspects of implants.

Reddy *et al* (1992) introduced a technique using digital imaging of high quality unstandardised radiographs to measure bone changes around root form and blade implants. A computer programme was developed in which a grid of known dimensions is placed over the digitised image of the implant and bone, the grid being adapted in relation to the known dimensions of the implant. The investigator then identifies the boundaries of the osseous defect around the implant, and the grid is then used to measure the defect in linear millimetres for crestal bone height and area. The information is then stored for longitudinal monitoring. Tested on phantom skulls, the results indicate that the method is reproducible and reliable, but accuracy was not evaluated. Application of this programme will eliminate the need for standardised radiography, however clinical trials are required.

2.4.2 Digital Subtraction Radiography (DSR)

Radiographic images contain more information than the obvious picture which can be seen by the eye. The observer's attention may be distracted from the important diagnostic information by background structures such as the adjacent teeth and alveolar bone. Subtle changes, particularly in bone, are difficult to detect as a result of this anatomic and background noise, and disease progression may reach the point where it becomes irreversible to the detriment of the patient. Bender and Seltzer (1961) and van der Stelt (1985) (Tyndall *et al*, 1990) found that pathological lesions in bone could not be visualised on conventional radiographs unless the cortical plate was sufficiently damaged or perforated. They estimated that 30-50% of the mineralised component of bone must be lost before it can be detected radiographically and reported that a lesion which is confined to the cancellous bone is undetectable. DSR is a technique which will eliminate the anatomic and background noise and provide a clear indication of the changes which have occurred in the structures being examined. Important diagnostic information is more readily noted.

Subtraction radiology was originally applied to medical radiography in 1934 (Reddy and Jeffcoat, 1993) through the use of photographic subtraction. The basis of the technique is that when serial radiographs are taken at some time apart, any changes which may have occurred will be detected after all the common (unchanged) structures have been subtracted from the image. Originally developed for the assessment of vascular opacities, the technique was applied to dentistry to study the arterial vasculature of the mandible. A plain film of the area of study was taken on a beagle dog, prior to injection of a contrast medium. An identical second film was taken after the injection, providing the normal image with white teeth and white opacified vessels. Photographs of each film were taken, then positive and negative (with black teeth and opacities) prints of the radiograph were compared. The images (positive and negative) were aligned on the viewing box, with the structures common to both prints cancelling themselves to a neutral grey. Any changes were then displayed against a grey background, facilitating detection.

For either photographic or digital subtraction, it is vital that the images being compared are identical in projection geometry and radiographic density in order to be effective (Reddy and Jeffcoat, 1993). Photographic subtraction is limited in these two areas, as neither can be corrected after the film has been exposed and processed. Digital imaging, however, will allow the operator to manipulate the subsequent image to match the projection and contrast of the initial film, provided that the imaging is not excessively different from the original projection and contrast (Ruttiman *et al*, 1986). Also, less time is required than for the photographic technique, many of the problems associated with the photography are reduced and accurate results can be gained.

In order to achieve nearly identical image geometry and contrast, the serial radiographs must be taken with a standardised projection geometry and exposure settings which are reproducible (van der Stelt, 1993). Various methods of standardising projection geometry have been discussed earlier. The availability of computer programmes to correct any minor discrepancies inherent in these techniques has reduced the need to produce a perfectly identical serial radiographs, which was critical to the success of the photographic subtraction method. Programmes also allow film contrast correction of the computer image with a non-parametric method, by measuring the grey levels of the images to be matched and forming grey level histograms. The two histograms are compared and the images adjusted until identical grey levels are produced (Ruttimann *et al*, 1986). Methods of pseudocolour contrast enhancement have provided observers with images which are easier to evaluate by highlighting the areas of change, instead of looking at a grey image (Brägger and Pasquali, 1989; Reddy *et al*, 1991).

The validity of DSR has been evaluated by various investigators to ensure that the method is capable of providing the required information. Initial testing involved the use of dry skulls with artificially induced osseous lesions in bone, using round burs of varying sizes at varying depths into bone (Tyndall *et al*, 1990; Nicopoulou-Karyianni *et al*, 1991). These *in vitro* experiments compared the DSR technique with conventional film evaluation by digitally converting films, comparing the digital image with its original film image and asking experienced observers to view the radiographs for lesions without informing them which images had 'lesions' or where the lesions were. Comparisons of digitally-converted conventional radiographs to original radiographs have reported that the digitised and subtracted image is diagnostically superior to the original film image, regardless of whether the original film was taken with D-speed or E-speed film.

Its use for the evaluation of periodontal therapy and determining marginal bone changes in both periodontics and implantology has also been evaluated. Hausmann *et al* (1985) used radiographs from patients undergoing periodontal therapy. They digitised the radiographs and subtracted them to assess the use of DSR to detect changes in marginal bone height, comparing the measurements to the attachment level clinically obtained. They found that DSR provided a more sensitive measure of crestal bone changes which correlates well with clinical attachment measurements. Implant studies using the technique have indicated it as a valuable tool in the assessment of bone surrounding the implant, particularly regarding quantitative evaluation (Engelke *et al*, 1990; Jeffcoat *et al*, 1992; Jeffcoat and Reddy, 1993; Vlassis *et al*, 1994).

Engelke *et al* (1990) used the technique clinically to assess the qualitative aspects of bone around implants in patients, reporting that DSR successfully provided a reliable way to detect slight changes. Quantitative techniques using DSR have also been developed . Combining the principles of densitometry with DSR, Jeffcoat *et al* (1992) and Jeffcoat and Reddy (1993) placed small bone chips on the sides of dry mandibles after carefully weighing them, radiographed these areas with an aluminium reference wedge of known thickness included in the film, and digitised the images. The aluminium wedge was used as a reference for density measurements to be used for determining the mass of the bone chips from the radiographs. The calculated mass from DSR correlated extremely well with the actual mass, indicating the usefulness of the technique. The technique was used to successfully assess bone changes around root form and blade implants in terms of mass and marginal bone height (Jeffcoat *et al*, 1994).

DSR does have its limitations. One clinical limitation is that, when nearly identical radiographs are subtracted, the anatomical and prosthodontic structures cancel, making it difficult to visualise teeth or implants (Jeffcoat *et al*, 1992). Benn (1990) outlined some limitations of DSR after using digitised images and measuring grey levels. He noted that a primary concern is the technique's lack of ability to distinguish various anatomical structures. The cementoenamel junction (CEJ), alveolar crest margin and trabeculae are not represented by individual grey levels and measurements of the CEJ to crest will be difficult. Other limitations include the minimal thickness of bone which can be examined with DSR under optimal conditions (no geometric or contrast distortion), which has been found to be 0.12 mm. If the projection geometry was misaligned by 3°, the minimum thickness of cortical bone that could be detected was 0.35-0.42 mm (Reddy and Jeffcoat, 1993). Zappa *et al* (1994) in an *in vivo* study found that even 1° or less of misalignment could mimic biological effects.

Every effort must be made to minimise the errors and variations which can occur with imaging techniques, particularly regarding projection geometry. Additionally, there is unwanted information on images which are not easily subtracted, which operators need to be aware of. The sources of noise associated with DSR have been described as the physical noise from the videocamera while the film images are being converted and the noise resulting from geometric misalignments (Wenzel and Sewerin, 1991).

DSR can be applied to any procedure which requires radiographic assessment of bone. It has been applied to periodontal therapy cases to assess bone loss over a period of time (the images become darker in the area of loss) or gain through guided tissue regeneration (area of gain becomes whiter), to endodontics as a more sensitive technique to detect changes earlier than using conventional film, and in the assessment of implants (Reddy and Jeffcoat, 1993). Quantitative assessments are possible, giving a guide to the practitioner and a clearer idea of the extent of any lesions.

The technique of digital subtraction radiography (DSR) has been a valuable tool in both qualitative and quantitative assessment of periodontal tissues and implants. As a more sensitive and specific technique in comparison to assessment of conventional radiographs (Hausmann *et al*, 1985; Allen and Hausmann, 1990), DSR has provided a way to detect bone changes at an earlier stage than previously detected.

2.4.3 Densitometry

Densitometry was introduced as a method of quantification. The technique uses the density measurements on the radiograph to determine the radiographic density of an area in relation to a known density of a reference material (Trouerbach *et al*, 1984; Steen *et al*, 1985; Galgut *et al*, 1991; Dubrez *et al*, 1992; Jeffcoat *et al*, 1992; Jeffcoat and Reddy, 1993). The reference material is usually aluminium, as bone and aluminium cause almost the same radiation attenuation, due the similarity in atomic numbers (Zubery *et al*, 1993). The aluminium wedge has a known composition and thickness and is simultaneously exposed with the area of bone which is to be evaluated, using standardised radiographs. A densitometer is then used to measure the changes in brightness of the aluminium wedge and the region of interest, to form density curves. The curves then allow the observer to find spots along the area of interest which show the same absorption as a selected place on the aluminium wedge because they have the same grey level on the film. The density of the spot in question can then be expressed in terms of mm Al equiv, known as the Al eq value of bone. Density measurements can then be compared between appointments by using serial standardised radiographs.

Steen *et al* (1985) applied this technique, using a microdensitometer, to the evaluation of bone in periodontal disease. Using radiographs of a periodontal therapy patient, the method was tested in a pilot study to evaluate interdental bone changes. The investigators found that although there were no visual changes detected in the bone level on the radiograph after 21 months, a significant decrease in Al eq values could be detected at the top of the interdental alveolar bone, indicating that the technique could be of value in assessing periodontal therapy.

Digital imaging of the periapical and bitewing views has also been used for densitometry, and has been compared to photodensitometry (which measures optical density) for its accuracy (Dubrez *et al*, 1992). The problem outlined by Dubrez *et al* (1992) is that whilst digitising a conventional film using a video camera allowed powerful image manipulation, the spatial resolution of these images was insufficient for accurate assessment of the bone quantity. They developed a method of high-resolution digital analysis to measure bone density and compared it to the resolution achieved through the use of photodensitometry. The investigators found that using a CD camera system with up to 4096 grey levels and a spatial resolution of 4096 x 4096 pixels provided an image which is statistically as accurate as the photodensitometric method. Its use in implant assessment has yet to be investigated.

A method of assessing the alveolar bone density changes with the use of digital images was tested by Brägger *et al* (1988) and applied by Fourmousis *et al* (1994a, 1994b) experimentally. Known as computer-assisted densitometric image analysis (CADIA), it provides a highly sensitive means of detecting and quantifying bone changes of the smallest magnitude with a specific computer programme. The system of CADIA uses grey level analysis of the digital image without the need for a reference material, but compares the grey levels of serial radiographs for calculations.

It has been described for use in assessing osseointegrated implants due to its greater sensitivity, and tested for its accuracy in calculating experimental bone mass (Fourmousis *et al*, 1994a, 1994b). Using the mandible of a pig after placement of an implant, the investigators took radiographs of bone chips of known masses, varying from 1 mg to 15 mg in 1mg increments, added to the side of the implant. A serial radiograph after the bone chips were removed was then taken and the digital images subtracted to locate the areas of change. The computer calculated the average grey level values of all 2 x 2 pixels in the areas of interest, then calculated the number of pixels in the area. This is done for serial radiographs. The grey level values from the original radiograph are then subtracted from the grey level values of the subsequent radiograph to produce the grey level deviation value. Positive values calculated indicate a deposition of bone, whilst a negative value indicates bone resorption. A volume of grey level deviation is then calculated by multiplying the number of pixels by the deviation in grey level. This value is then multiplied by the pixel size in millimetres to produce the volume of bone change. This is then used as the CADIA value. Therefore:

CADIA value = (volume of grey level deviation) x (pixel size in mm)

where:

volume of grey level deviation = (number of pixels) x (deviation in grey level)

The results are then plotted against the known masses of the bone chips, a line of best fit is plotted and the correlation value calculated. The investigators found a near linear correlation between calculated and actual mass ($r^2 = 0.99$), and that CADIA is a system which needs to be developed further. They also attempted to use the method to assess soft tissue changes with less success in correlation, stating that in order to produce a useable soft tissue image the film needs to be slightly underexposed.

CADIA has also been used for monitoring the results of treatment of bone defects with ceramic HA implant material (Galgut *et al*, 1991). The investigators report that slight bone deposition was able to be detected by the use of this technique. Further development is required for its application clinically.

Comparisons of conventional radiographic assessment, DSR and CADIA, found that CADIA was more sensitive in detecting changes in bone than DSR, which in turn was more sensitive than the conventional method (Brägger *et al*, 1988, 1989; Allen and Hausmann, 1990; Nicopoulou-Karayianni *et al*, 1991; Fourmousis *et al*, 1994a, 1994b). Therefore, CADIA appears to show many advantages for implant radiographic assessment, however, a specific software programme is required, which may be impractical for the general dental practitioner. CADIA appears to have the required sensitivity to quantitatively detect early changes in bone, an important factor in the case of a possibly failing implant, as it enables corrective action to be carried out before there is total failure. Further clinical trials are required for its application.

The sensitivity of the CADIA system has been confirmed in an *in vitro* study carried out by Zubery *et al* (1993). Both DSR and CADIA were adapted to create a system of 'computer-aided radiographic evaluation' (CARE) which provides for both qualitative and quantitative comparisons of serial radiographs. Serial radiographs were taken on a dry mandible and converted to digital images through a videocamera for analysis. The investigators found that the calculated CADIA values correlated well with detected bone changes to provide a quantitative analysis, allowing quantification of changes equivalent to approximately 0.27 mm aluminium thickness (which could be converted to compact bone volume units). However, the correlation coefficient decreased significantly when there was little change in the grey levels within an image. This was explained as a limitation of the videocamera used. The investigators suggest a decrease in sensitivity of the system clinically, as there are variables which cannot be completely controlled, such as film processing, beam hardening and scatter and focus and light changes. Also suggested is the fact that the aluminium reference plates are flat with known density changes, unlike the unpredictable variables *in vivo*. However, the system may still be a valuable diagnostic tool, after further clinical trails are carried out.

2.4.4 Mass Image Ratios

Another method of quantification has been described using digital images and direct measurement of alveolar bone changes (Jean *et al*, 1994). After conversion form conventional radiographs to digital images, an undescribed computer programme produces a 'mass image', which represents the thickness of the absorbing mass, and are filtered by the computer. Mass image ratios are calculated, and bone mass changes are shown directly and displayed in pseudocolours. The changes are then quantified in relation to the calculated ratio values. However, the process is not described in detail. The method is reported to avoid difficulties encountered in other methods of quantification - such as film fog, numerical noise and emission characteristics of the xray tube - and estimate density without the need to calibrate, as there is a direct comparison of serial radiographs made. Further trials are required clinically.

2.5 LITERATURE REVIEW CONCLUSION

With the increasing popularity in the use of osseointegrated dental implants, clinicians require reliable, reproducible methods for careful, accurate treatment planning and periodic monitoring of functional implants and prostheses. Radiography is a non-surgical technique which allows the clinician to achieve these aims. Problems such as perforation of the maxillary sinus, inferior alveolar nerve damage or incorrect implant angulation can be avoided through careful imaging of the planned implant sites.

Radiography is an important aspect of implant treatment, providing a number of ways in which the hard tissues can be viewed indirectly. Projection techniques such as periapical radiographs and OPGs play important roles in both pre- and post-operative phases of treatment. However, provide an image in only one plane. Pre-operatively, conventional and computerised tomographic techniques provide images in the third dimension for thorough treatment planning. Post-operatively, the periapical view has been used to provide detailed assessment of the bone, and must be standardised in the projection geometry and exposure to allow accurate comparison of serial radiographs. Paralleling devices with modifications have been developed for attachment to implants to achieve this.

Another important aspect of radiography is the development of image production techniques. To assist clinicians in accurate analysis of radiographs, digital radiographic images can be produced by conversion of conventional films or through direct sensors. The resultant images can be manipulated in contrast or orientation, to provide a greater opportunity to detect changes. Use of the direct sensor also reduces the amount of radiation exposure required, providing a workable image in a matter of seconds, eliminating the need for films and processing solutions/equipment.

The majority of studies reported have been *in vitro,* discussing changes in marginal bone height around implants. Assessments have been reported as absolute measurements in millimetres, however these results do not compensate for errors resulting from image distortion and magnification. A number of authors have suggested describing the measurements as a proportion of the radiographic implant length to allow for distortion and magnification, however the accuracy of these techniques have not been tested *in vivo*.

Digital imaging has provided the opportunity to develop methods of quantifying changes in bone and teeth. Digital subtraction radiography (DSR) has been shown to be a more sensitive technique in detecting slight bone changes than assessment by conventional films, and has been applied to accurate calculation of the mass of the changes. Quantitative assessment of bone is also possible by a system known as computer-assisted densitometric image analysis (CADIA), which is more sensitive than DSR. With CADIA, the volume of change is calculated, but relies on DSR to detect the changes. Both techniques have been shown in *in vitro* studies to be very accurate, with correlation values very close to one, but still require *in vivo* testing. In addition to these techniques is the development of a method using mass image ratios, details of which have not been described fully in the literature at this stage. The initial results appear promising, but further work is required for its application to the clinical situation.

Periodic assessment of the implant is part of the overall provision of treatment. As a non-surgical technique, radiographic assessment of implants in function, in conjunction with other clinical techniques, is an excellent diagnostic tool which may provide early warning of failure of some implants. Although measurement of marginal bone height is the simplest method of quantifying bone changes currently available, the development and application of methods such as DSR and CADIA to assess mass and bone mineral content will provide more accurate assessments of functioning implants. With this development, a correlation with possible failures can be developed, to allow early detection and corrective action to be taken.

3. AIMS AND OBJECTIVES

From a review of the literature, the most suitable method of clinically assessing dental implants without surgical involvement is by the use of radiography, either by converting conventional films to digital images or constructing digital images through intra-oral sensors. The digital images can then be manipulated with the computer and analysed qualitatively or quantitatively.

Both periapical radiographs and orthopantomagraphs can be used for the assessment of implants. Conventional films can be digitised by a variety of methods, all of which will have a bearing on the final analysis of the dental implant images. The methods include:

1) capturing the image with a CCD, which is then digitised;
2) using a 35 mm slide scanner after taking photographic slides of the film;
3) converting the slides to photo-CD;
4) placing PA films directly in a slide scanner;
5) cutting the original OPG and placing it in the slide scanner;
6) cutting a copy of the OPG for the slide scanner; or
7) using a flatbed scanner with a transparency top to digitise films.

3.1 Implant Overdenture Study

The objective of this pilot study is to use a sequential series of periapical radiographs of dental implants, in two-implant overdenture cases, to quantify changes which may occur over a period of years. The study was also used to test the validity of the RADI programme for the periodic assessment of funcioning implants. Subgroups within the selected population will be compared to test the validity of the analysis programme used, which will then form the baseline for further studies of other types of implant cases. The effects over time, of each abutment type on the bone immediatley surrounding the implant, will also be compared. However, there will be no investigation of reasons for any detected differences.

3.2 Digitising Of Radiographs

The objective of the digitising project is to determine the most convenient and suitable method of digitising OPGs and PAs to carry out the quantitative analysis in the pilot study. This is to be carried out on randomly selected, existing clinical films which have not been taken specifically for the study.

4. MATERIALS AND METHODS

A. Determination Of The Most Suitable Digitising Method

An OPG and PA radiographs of one patient with five mandibular implants placed were used, to allow comparison of different images of the same objects. Ten individuals of differing backgrounds blindly compared the digital images for quality, clarity, contrast resolution and available information. The individuals included a professional photographer, endodontists, prosthodontists, an oral surgeon and general practitioners.

Digitising Of Radiographs

The OPG was copied on a Curix Printer radiograph copier (Agfa-Gevaert, Belgium) on Agfa Curix Duplicating Film (Agfa-Gevaert, Belgium) as a 'normal' copy of same density (0.8 s exposure), a 100% greater density copy (0.3 s exposure) and 50% lesser density copy (8 s exposure).

Charged Couple Device (CCD)

A Photophone digitising system, model CP 256 (Image Data Corp., San Antonio, Texas) was used to capture the implant images. The system used a CCD in a video camera (Cohu Solid state model 4012-5000) with the film illuminated by a Watson Victor model 767 radiographic illuminator (Watson Victor Limited, New Zealand/Australia), with the radiographic film surrounded by a black light-safe box to minimise extraneous light on the radiograph. This CCD was connected to the Photophone capture board and dedicated computer which completed the digitising.

Digital images of each individual implant site on the OPG and PAs were captured, then transferred to the Sun SparcStation 5 (Sun Microsystems, Mountain View, CA) computer for the comparisons, using the XV (Pasadena, USA) imaging programme to produce and manipulate the images. This was done for implant images on the original, normal, light and dark copies.

Flatbed Scanner

A Umax Vista flatbed scanner (Umax Data Systems, Inc., Taiwan, ROC) was modified with a light source in the lid to scan transparencies and radiographs. The software used for the flatbed scanner was Adobe Photoshop 3.0 (Adobe Systems Inc., USA). The original and three copy types were scanned capturing the whole OPG, which was then transferred to the Sun computer, where the image was manipulated to isolate the individual implant sites.

35 mm Slide Scanner

A ScanMaker 35T 35 mm photographic slide scanner (Microtek Corp., Redondo Beach, CA, USA) was used to digitise implant sites from both the radiographs and the photographs of the implant images.

The radiographs were digitised by cutting the radiographs of the individual implants to fit into a glass slide mount, scanned as a 35mm slide would be, and the images transferred to the Sun computer. This procedure was carried out for the original, normal, dark and light copies of the OPG. Periapical radiographs were mounted in glass slide mounts, scanned in the slide scanner, then transferred to the Sun computer.

<u>Image Comparisons</u>

All digitised images of the implants were transferred to the Sun Sparc Station and displayed as a composite image. Each of the individual observers were asked to compare the various images of the implants on the same computer. No observer was informed of the method in which each image was produced. They were asked to provide comments on the quality, resolution, contrast, clarity and accuracy of information for each image, then indicate which image they felt was the best image.

Appendix 1 contains the definitions of the image characteristics observers were asked to assess.

The images which were regarded as the best by the group of observers were recorded. The method which was found to be the most convenient as well as producing the best images was then used for this project.

From table 2, the image most frequently selected by observers as the 'best' was that produced from making a dark copy of an OPG, cutting the film, placing it in a slide mount then scanning it with a slide scanner. The next most frequently selected image was that produced by mounting a periapical film and scanning it with a slide scanner. Observers stated that these images provided the most amount of diagnostic information, with the least amount of image noise or blurring of image outlines.

The two most frequently selected images were formed by the use of a slide scanner, one by placing a PA film in a glass slide mount for scanning, the other by copying an OPG, cutting the image of the implant, mounting in a slide mount, then scanning it. As the best images were formed by the use of a slide scanner, this technique was the method selected for the digitising of films for the project.

Table 2 - COMPARISON OF IMPLANT IMAGES

Image Digitising Method	No. Times Selected	Percentage Frequency
OPG Dark Copy, CCD	0	0
OPG Light Copy, CCD	1	2.2
OPG Normal Copy, CCD	1	2.2
OPG Original Film, CCD	1	2.2
Periapical Film, CCD	0	0
OPG Dark Copy, Flatbed Scanner	0	0
OPG Light Copy, Flatbed Scanner	0	0
OPG Normal Copy, Flatbed Scanner	8	17.8
OPG Original Film, Flatbed Scanner	6	13.4
OPG Dark Copy, Slide Scanner	11	24.4
OPG Light Copy, Slide Scanner	0	0
OPG Normal Copy, Slide Scanner	0	0
Original OPG Film, Slide Scanner	7	15.6
Periapical Film, Slide Scanner	10	22.2

B. Assessment Of Two-Implant Overdenture Cases

A patient pool of 24 two-implant overdenture cases treated at the Adelaide Dental Hospital was selected to carry out the quantitative analysis of radiographs of the implants, which have been collected over a period of five years. The treatment provided involved Calcitek Integral implants (Calcitek, Carlsbad, CA), with periapical radiographs of individual implants taken annually.

Periapical Radiographs

The periapical radiographs were obtained using the paralleling technique, to include at least the bony crest around the implant, preferably the entire length of the implant. However, sulcus depth often precluded the inclusion of the entire length. Kodak Ektaspeed size 0 double-film (Eastman Kodak, Rochester, NY, USA) was exposed with an Acuray 071A unit (Acuray, Belmont, USA) and long cone, at 70 kvP and 10mA. These were then processed through a Procomat D129 automatic processing machine (Siemans, Germany).

Digitising Of Radiographs

The radiographs were mounted into glass slide mounts 2mm thick and 24 x 36 mm in dimension. All PAs were converted to digital images by using a Polaroid Sprintscan 35 (Polaroid, CA, USA) slide scanner operated through Adobe Photoshop 3.0 (Adobe Systems Inc., USA). The following settings were used:

Type:	Grayscale
Output Resolution:	250 dpi
Scale:	400%
View:	Portrait or Landscape

Each image was saved as a PICT file and compressed with maximum quality for importing into the analysis database. Individual images were identified using a twelve character code which specified the patient group, implant site, patient, timeframe of radiograph and abutment type.

Radiographic Analysis Of Dental Implants

A computer programme was designed for the quantitative analysis of the digitised images. Radiographic Analysis Of Dental Implants (RADI) (Biotek Pty Ltd, Adelaide, Australia) measured the horizontal and vertical components (in millimetres) as well as the average area (in square millimetres) of the radiolucent areas adjacent to the implant image. The known dimensions and tolerances of the implant and abutments (as provided by the manufacturer) were used for calibrating the measuring component of the programme to compensate for any image distortion created in the taking of the radiographs. This provided measurements in millimetres. A sample screen of the programme is in appendix 2 at figure 14.

A database of patient details, implant and abutment characteristics, implant site and time of radiograph has been written into the programme, into which each implant image has been imported for analysis. The mesial and distal aspects of each implant were measured and the data recorded. Definitions and descriptions of reference points and techniques used are in appendix 2 at figure 13.

Statistical Analysis

SPSS Release 4.0 (USA) for Unix was used for the statistical analysis of results. Subjects were divided into groups according to their implant abutment type - ball attachment, O-ring or Dolder bar. The effects from each abutment type, over a period of time, on the bone immediately surrounding the implants, were compared using a Multiple Analysis Of Variance (MANOVA).

Intra-Observer Comparisons

Seventy-six sites were randomly selected for second measurements by the same operator at different times to assess the significance of intra-observer differences in the analyses. This provided an indication of any inconsistencies in landmark identification or measurement technique arising from variations in radiograph or image production. The 'Student's t-test' for paired samples was used to compare the measurements of two different occasions. The standard deviation of a single measure (s_s) was calculated using the method of Dahlberg (1940):

$$s_s = \frac{\sqrt{\Sigma (x_1 - x_2)^2}}{2n}$$

where x_1 and x_2 are the two repeated measurements and n is the number of double determinations carried out. This was then expressed as a percentage of the observed variance s_t to provide an error variance and an indication of the significance of any differences in measurements. The results are presented in table 3.

	n	Mean Difference	S.E. Difference	S_s	S_t	Error Percent
Width	76	-.07	.04	.07	.27	25.9
Height	76	-.03	.04	.07	.32	21.9
Area	76	-.07	.05	.08	.44	18.2

Table 3 - Results of Double Determination Analysis

The negative values for the mean difference in defect width, height and area measurements indicate that on average the second measurements were slightly (but not significantly) larger than the first. Sources of errors and image variation include difficulties in landmark determination, anatomical variation affecting film angulation, image distortion, image resolution, image quality (Truhlar *et al*, 1993) and minor inherent inaccuracies in the placement of the computer mouse when carrying out measurements.

Although the contributors of errors to total observed variation (error percent) appeared relatively large (width 25.9%, height 21.9%, area 18.2%), this is not unexpected. This was due to the sources of errors, the small values of measurements, the small population size and the difficulties associated with measuringfrom radiographs. However, when considering the mean differences, it can be seen that absolute differences are small and the mean differences are not significantly different from zero. When the sources of errors and difficulties are accounted for, the percentages were considered to not be significant and have not affected the results of the remaining analyses.

5. RESULTS

5.1 THE RADIOGRAPHIC ANALYSIS OF DENTAL IMPLANTS

Twenty-two of the original twenty-four patients from the two-implant overdenture group were included in the study. There were inconsistencies in patient attendances however, all except one patient presented for five years, the time selected as the limit of the study.

From a possible 308 single implant images, 232 images were used for measurement and analysis. The remaining were either not available due to patient failure to attend or the resultant image was assessed as unsuitable for analysis. This provided a total of 464 sites which could be analysed using RADI.

5.1.1 Implant Side And Defect Site

From the second, third and fourth order comparisons using MANOVA, there were no significant differences in results for implant side (right or left) or defect site (mesial or distal) (table 4). Therefore, the results from one side and site (right implant, mesial) have been presented as indicative of findings.

Table 5 and figure 1 show the mean defect width for each attachment type over the first five years of function. Although there is a general trend for defects to increase in width for all three attachment types, the O-ring and Dolder bar data showed more consistent trends than was the case for the ball attachment. Ranges of means and standard deviations for each attachment type are all quite small (ball: 0.85-1.70 mm, s.d. 0.40-0.94; O-ring: 0.80-1.50 mm, s.d. 0.33-1.05; bar: 0.50-0.92 mm, s.d. 0.31-0.59).

** $p < 0.001$ * $p < 0.05$	F-RATIO		
	Width	Height	Area
Attachment (A)	14.10**	16.24**	16.44**
Side (B)	1.21	0.01	0.31
Time (C)	1.87	2.62*	5.32**
Defect (D)	0.01	0.28	1.76
A x B	0.62	0.05	0.54
A x C	0.71	0.51	1.33
A x D	0.27	0.16	0.27
B x C	0.18	0.26	0.19
B x D	2.59	0.77	0.52
C x D	0.41	0.38	0.89
A x B x C	1.07	0.95	0.81
A x B x D	0.04	0.28	0.19
A x C x D	0.29	0.19	0.56
B x C x D	0.12	0.21	0.54
A x B x C x D	0.83	0.29	0.44

Table 4 - MANOVA For Attachment, Side, Time and Defect and For Interactions For Variables

WIDTH	Ball			O-Ring			Dolder Bar		
Months	n	mean (mm)	s.d.	n	mean (mm)	s.d.	n	mean (mm)	s.d.
0	5	0.94	0.40	9	1.18	0.89	8	0.89	0.59
6	5	1.32	0.88	9	0.86	0.58	7	0.67	0.48
12	5	1.40	0.49	9	1.46	1.05	6	0.50	0.40
24	4	1.13	0.56	7	0.80	0.81	5	0.88	0.45
36	5	1.22	0.94	8	1.23	0.65	6	0.92	0.31
48	2	0.85	-	7	1.31	0.33	3	0.60	-
60	1	1.70	-	1	1.50	-	1	0.80	-

Table 5 - Defect Width For Right Implant, Mesial

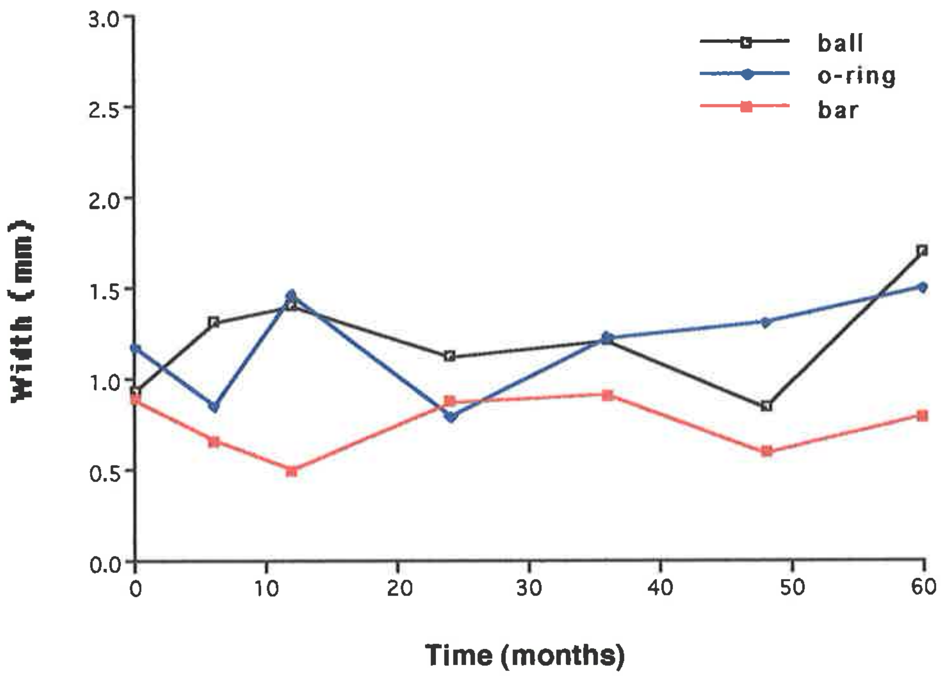

Figure 1 - Defect Widths For Ball, O-Ring and Dolder Bar

For the defect height, there are fewer inconsistencies in the trends for each of the attachment types (table 6 and figure 2). For the ball attachment the initial trend is inconsistent, however this becomes more consistent with time. The bar attachment results remain the most consistent, with a very small range of means (0.40-0.72 mm, s.d. 0.11-0.50), demonstrating that the ball attachment has a less negative effect on the crestal bone adjacent to the implant. The defect areas for each attachment type demonstrate similar trends to the defect heights, showing the same initial inconsistencies moving to more consistent results with time. Ranges for areas are also generally small (table 7 and figure 3).

5.1.2 Overdenture Attachment Type

A comparison of effects of attachment type on the bone defect was also carried out using MANOVA. Results of this test show that defect width, height and area differed significantly ($p < 0.001$) between attachment types and that defect height and area differed significantly ($p < 0.05$) with time. This can be seen in each of the graphs in figures 1, 2 and 3. Review of the results demonstrate that the Dolder bar attachment had less bone changes than the ball attachment and O-ring attachment. The latter two showed similar effects on the crestal bone, with the ball attachment causing less linear bone loss in horizontal width, more linear bone loss in vertical height, resulting in approximately the same average area of bone loss.

HEIGHT	Ball			O-Ring			Dolder Bar		
Months	n	mean (mm)	s.d.	n	mean (mm)	s.d.	n	mean (mm)	s.d.
0	5	1.12	0.74	9	0.87	0.62	8	0.45	0.31
6	5	0.60	0.49	9	0.76	0.71	7	0.50	0.37
12	5	1.10	0.85	9	0.92	0.57	6	0.52	0.50
24	4	1.27	0.59	7	1.07	1.46	5	0.66	0.11
36	5	0.88	0.75	8	0.66	0.42	6	0.72	0.20
48	2	0.95	-	7	1.00	0.33	3	0.40	0.46
60	1	1.60	-	1	1.30	-	1	0.40	-

Table 6 - Defect Height For Right Implant, Mesial

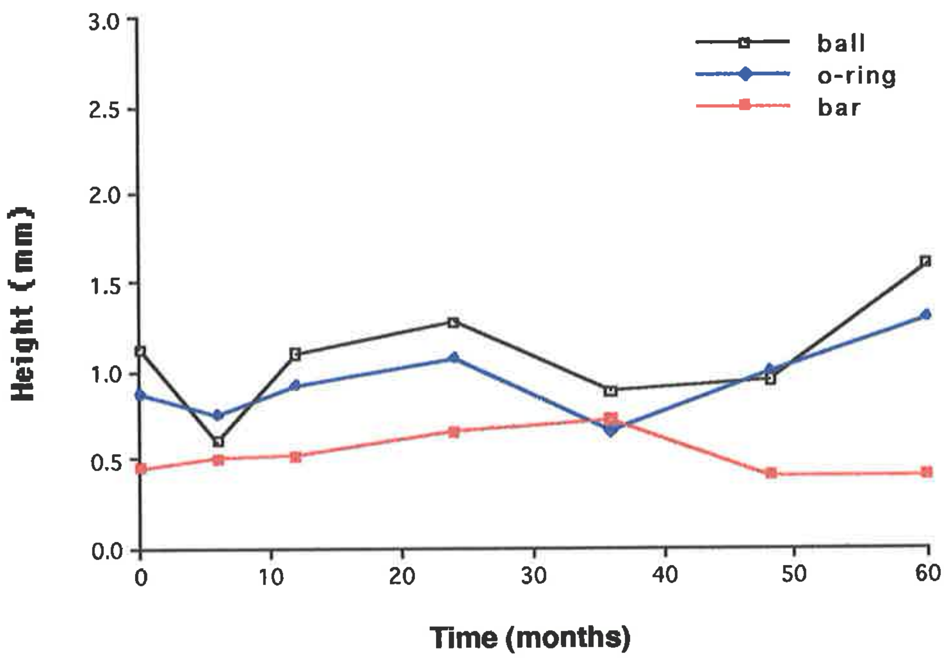

Figure 2 - Defect Heights For Ball, O-Ring and Dolder Bar

AREA	Ball			O- Ring			Dolder Bar		
Months	n	mean (mm^2)	s.d.	n	mean (mm^2)	s.d.	n	mean (mm^2)	s.d.
0	5	0.48	0.33	9	0.58	0.58	8	0.21	0.15
6	5	0.46	0.38	9	0.39	0.40	7	0.21	0.20
12	5	0.80	0.96	9	0.94	1.11	6	0.20	0.22
24	4	0.95	0.58	7	0.84	1.41	5	0.30	0.19
36	5	0.82	0.86	8	0.45	0.52	6	0.30	0.13
48	2	0.50	0.14	7	0.49	0.24	3	0.20	0.20
60	1	1.00	-	1	0.90	-	1	0.30	-

Table 7 - Defect Area For Right Implant, Mesial

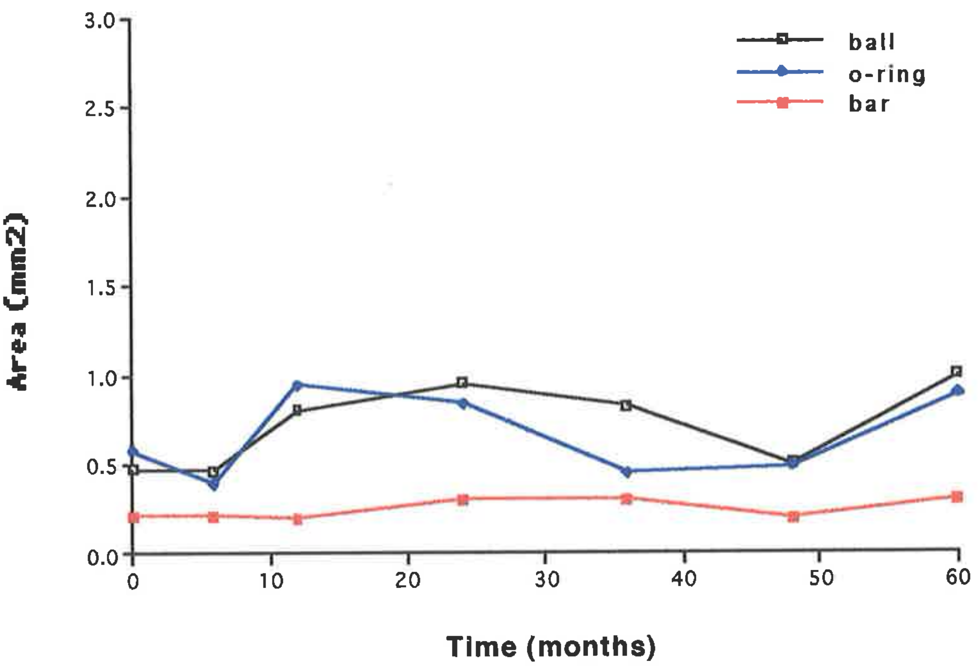

Figure 3 - Defect Areas For Ball, O-Ring and Ball

5.1.3 Subject Comparisons

Ball Attachment (Figures 4 to 6)

Of the three, this sub-group had the least number of patients who returned for annual reviews, with only five presenting regularly, none of whom presented for every review appointment. The measured widths of this sub-group were consistently in the range 0.5 - 2.5 mm except for two cases which had single measurements beyond the mean. However, many individual cases had measurements varied suggesting positive and negative changes in defect width. The means of these have resulted in the sub-group summary in figure 1.

The measured heights were much more consistent for the sub-group, with only one patient's results sitting well above the values of the remainder of the group. Mostly in the range 0 - 1.5 mm, one patient's measurements remained consistently higher than the remainder, but inconsistent on an individual basis, ranging from 1.3 - 2.5 mm.

The average areas were mostly in the range 0 - 1.0 mm^2 over the five year period. However, there is one patient whose defect area was consistently higher than the remainder of the group (0.8 - 2.5 mm^2), regardless of the time point.

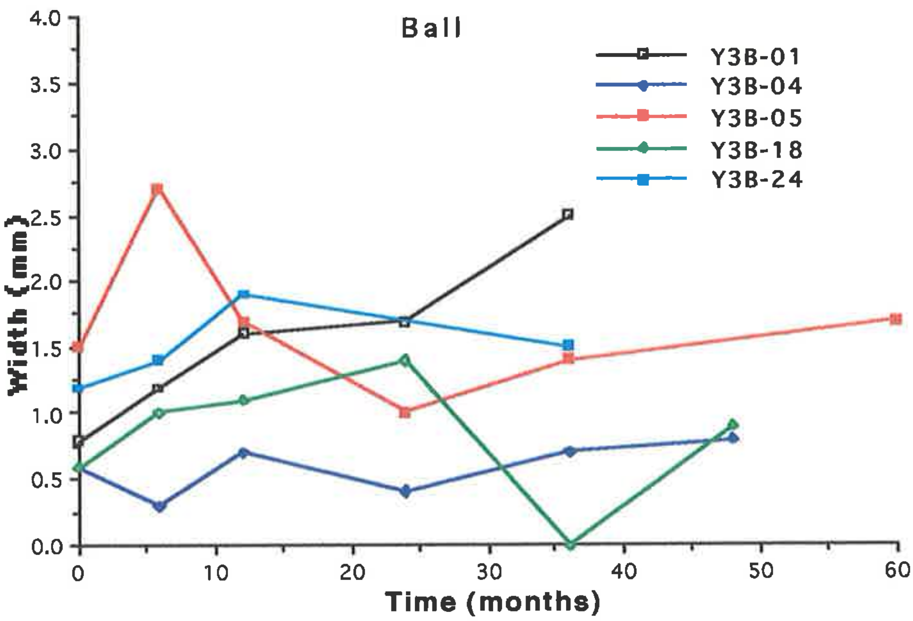

Figure 4 - Defect Width For Ball Attachments By Subject

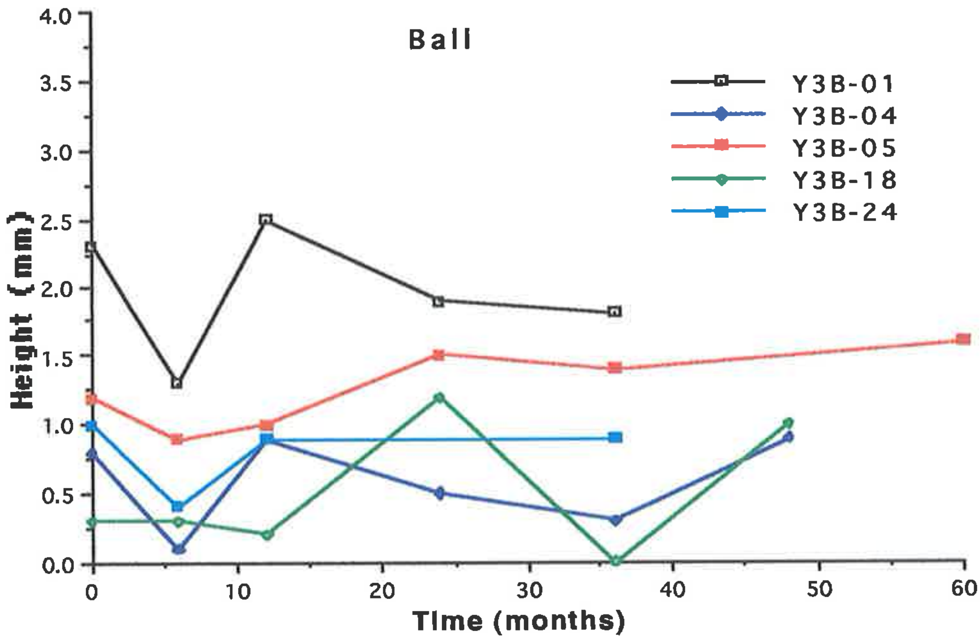

Figure 5 - Defect Height For Ball Attachments By Subject

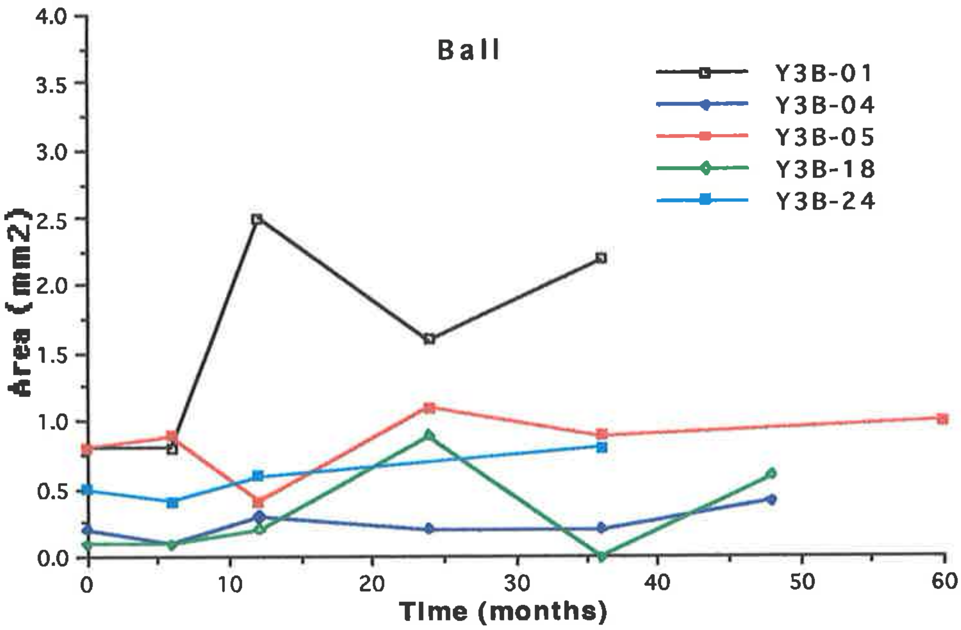

Figure 6 - Defect Area For Ball Attachments By Subject

<u>O-Ring Attachment (Figures 7 to 9)</u>

This sub-group had the largest number of patients who returned for regular reviews, with the most consistency in being seen each year. The defect widths of this sub-group had quite a comparatively large range of 0 - 3.3 mm, most of which sat in the area 0.5 - 2.0 mm.

Similarly, measured heights and calculated areas showed a complex pattern of change.

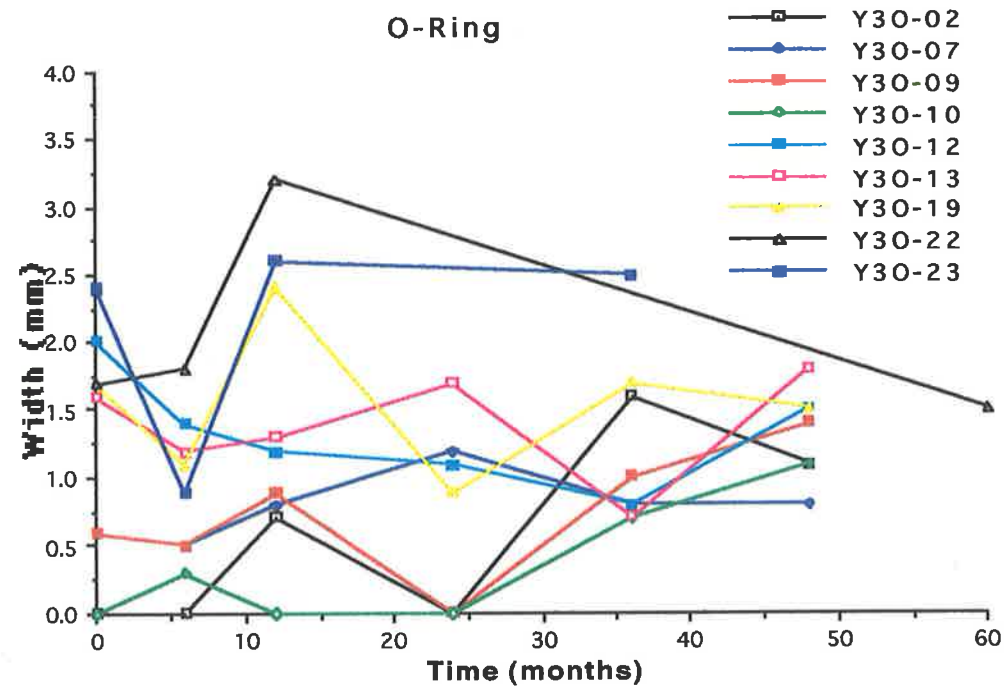

Figure 7 - Defect Width For O-Ring Attachments By Subject

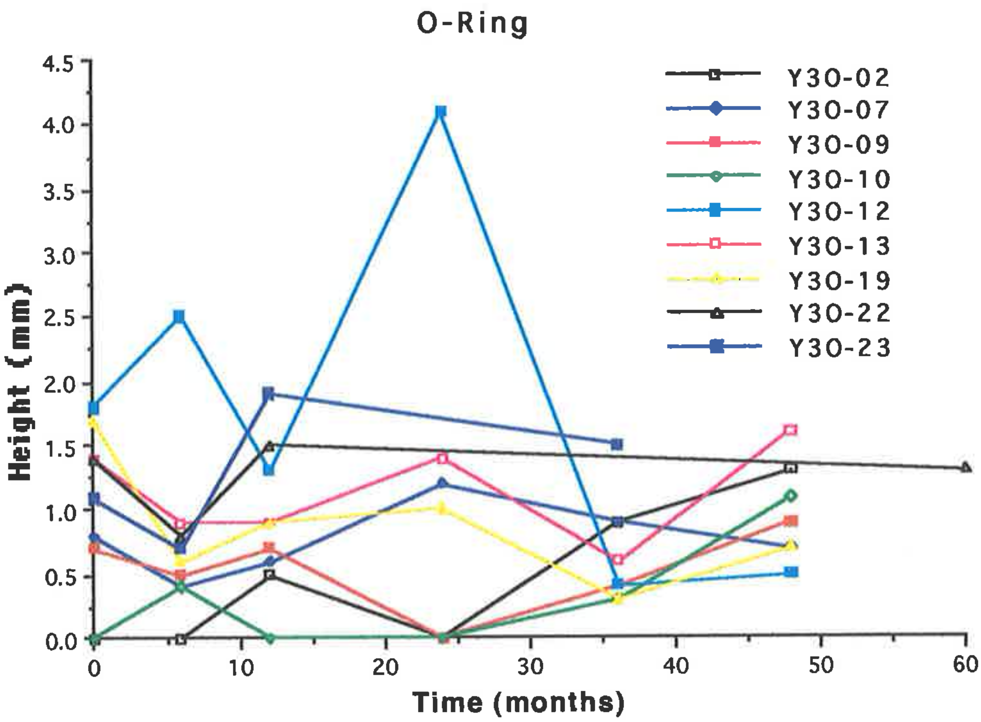

Figure 8 - Defect Height For O-Ring Attachments By Subject

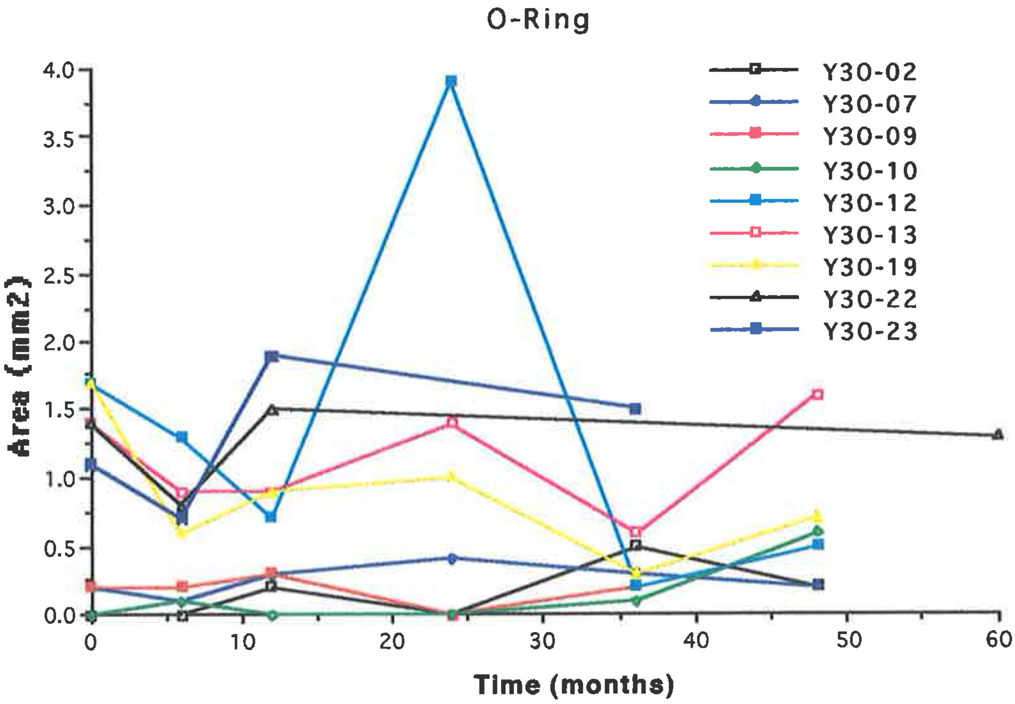

Figure 9 - Defect Area For O-Ring Attachments By Subject

Dolder Bar Attachment (Figures 10 to 12)

As with the sub-groups for ball attachments and O-ring attachments the patients of the Dolder bar sub-group were inconsistent with their attendance for reviews. Of the three components of the defect which were considered, the widths for this sub-group were found to be the least consistent, with a wide spread of results in the early part of the assessment period. As time progressed the results became more consistent, reducing the amount of change in the average for the sub-group. The measured widths ranged from 0 - 1.5 mm, mostly remaining in the region of 0.5 - 1.3 mm.

The measured heights and areas appear to be more consistent as a group, ranging from 0 - 1.4 mm and 0 - 0.7 mm^2 respectively. The height measurements were mostly around 0.5 - 0.7 mm with minimal deviation from this over the five years. The resultant summary graph shows the general trend for the defect height to be gradually decreasing over time, with a low gradient.

With a much smaller range of results, the calculated areas for each patient result in a summary graph which showed very little change over the five years.

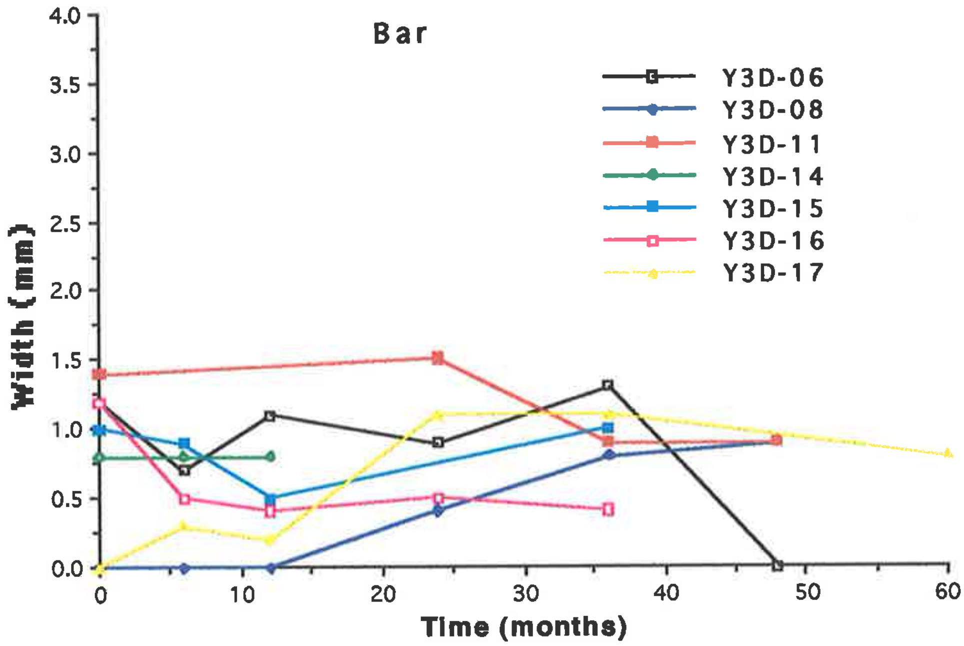

Figure 10 - Defect Width For Dolder Bar Attachments By Subject

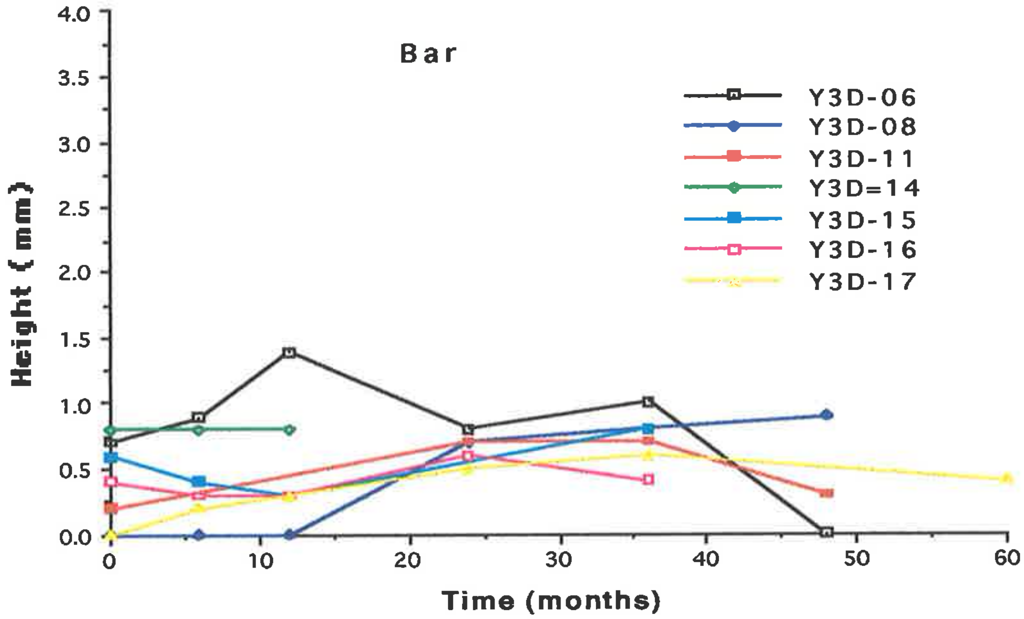

Figure 11 - Defect Height For Dolder Bar Attachments By Subject

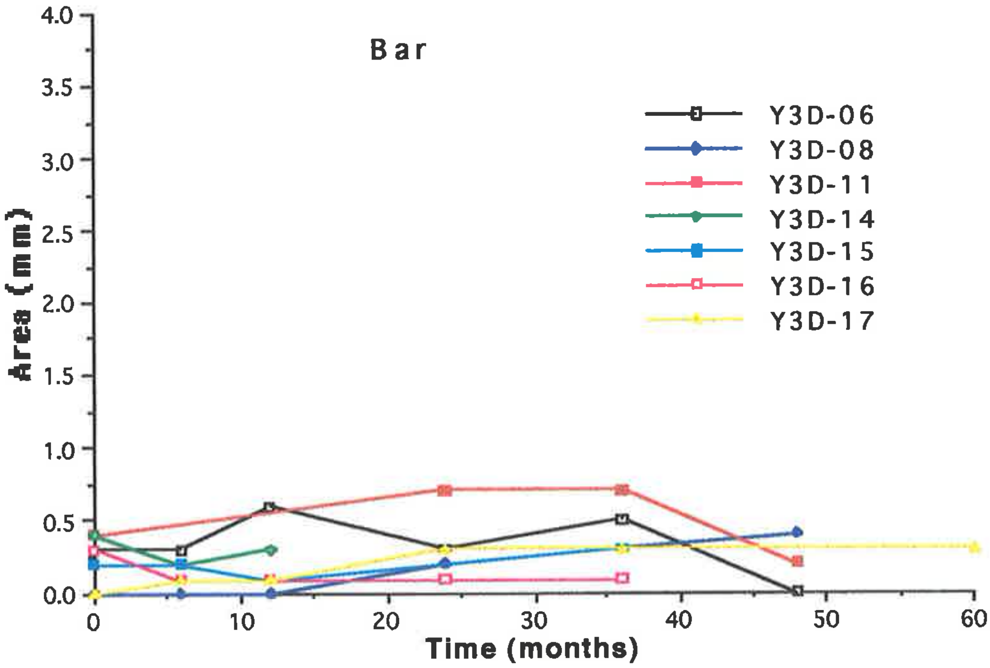

Figure 12 - Defect Area For Dolder Bar Attachments By Subject

6. DISCUSSION

Standardised periapical radiographs have been suggested as the preferred view to non-invasively assess the functioning implant (Friedland, 1987) and, have been shown to have a high positive predictive value on identifying failing implants radiographically (Gröndahl and Lekholm, 1997). Various authors have suggested the assessment of marginal bone levels by linear measurement from a fixed reference point (Cox and Zarb, 1987; Smith and Zarb, 1989; Chaytor *et al*, 1991) whilst others have suggested the bone changes be described as a percentage of the total implant surface area (Nasr and Meffert, 1993).

This study assessed the value of using periapical radiographs to assess the marginal bone surrounding functional implants supporting mandibular overdentures. These overdentures were retained by one of three abutment types - ball attachment, O-ring attachment or Dolder bar. The effectiveness of the database Radiographic Assessment of Dental Implants (RADI) was also tested, as it encompassed much of what other authors have suggested - the use of sequential, standardised periapical radiographs and the linear measurement of bone changes (vertically). It also assessed linear changes horizontally and changes in the average area of the 'defect' adjacent to the implant.

Only a small patient pool was used as this study is a pilot study used to test the validity of the RADI programme. Although the majority of patients returned for their annual reviews, not all returned annually, creating a higher risk of inconsistencies in radiograph production. This is because there were different operators of varying levels of experience taking the radiographs, making standardisation difficult to control. Also, in a hospital situation, there is a high volume of radiographs processed through the day, reducing the effectiveness of the processing solutions late in the day. This will also contribute to inconsistencies in the quality of the radiographs. The changes between samples at each time point explain at least part of the fluctuation in the trends in the change with time.

Difficulties were also experienced with obtaining some radiographs due the anatomy of some patients. Many of the patients had very resorbed mandibles with a very shallow mandibular sulcus, which made the placement of the film and film holder at an effective depth in the mouth difficult. Many of the radiographs have only the coronal portion of the implant and abutment in view, with very few showing the full implant length. This also affected the angle at which the film was held, often leading to foreshortening or elongation of the implant image, decreasing the accuracy of the measurements. Changes in horizontal angulation did not appear to be a significant factor. Attempts to correct for differences in vertical angulation were built into the programme.

The majority of radiographs were of reasonable quality and assessable, however there were many which were of poor quality and rejected from the analysis. A number of operators were involved in the taking of the radiographs, ranging from experienced dentists to undergraduate dental students, resulting in varied quality of radiographs available. Unfortunately, the project was developed after the majority of radiographs had been taken, and the quality could not be standardised.

6.1 RADI

The use of this programme was found to be quite effective in the quantitative analysis of sequential radiographs. The use of digitised images to quantitatively assess the bone has been shown to be more accurate than using the original film (Brägger *et al*, 1988; Allen and Hausmann, 1990; Nicopoulou-Karayianni *et al*, 1991; Fourmousis *et al*, 1994a, 1994b). Although the films could be digitised for importation into the programme, the original image could not be manipulated sufficiently to overcome any errors created in the original film. Image contrast and brightness could be adjusted to improve detection of defect borders however, there were still difficulties with accurately determining the borders of the defects, even when magnified.

The resultant digital image is dependent upon the original radiograph being of high quality and standardised, and this must be borne in mind when radiographic assessment is to be a key factor in the monitoring process. The use of direct digital radiography may help to overcome this problem by allowing instant viewing of the image and the opportunity to take another radiograph to obtain the required quality. It will also save time by avoiding the need to process films and avoiding the need to digitise any plain film radiographs, thus reducing the introduction of errors in the whole process. Further investigation is required.

As radiographs are two-dimensional images of three-dimensional objects, changes in projection geometry between consecutively obtained radiographs may result in different images of the same object. Resultant artefacts are difficult to distinguish from true biological changes, therefore highly standardised radiographs are required for an accurate assessment of the marginal bone (Eickholz *et al*, 1998). Calibration of the programme by using a known dimension (the implant diameter and length or abutment diameter and length) compensated for distortions in implant image due to oral anatomy (e.g. shallow sulci). The calculated errors are minimal for the size of the defect.

6.1.1 Marginal Alveolar Bone

A 'saucerised defect' in the marginal bone adjacent to the implant surface was frequently seen on both the mesial and distal sides of the implants. All studies have only assessed the changes in the vertical dimension of the marginal bone, but have not considered the horizontal component or the average area of the defect.

Defect height was regarded as a measure of the vertical change in marginal bone. The annual vertical bone loss (after the first year of function) ranged from -0.49 - 0.65 mm for ball attachments, -0.41 - 0.34 mm for O-ring attachments and -0.32 - 0.14 mm for Dolder bars. After the first year of function, the radiographic marginal bone loss was found to be less than 1.0 mm, as proposed by Albrektsson and Zarb (1993). The mean vertical bone loss annually (after the first year of function) for each of the abutment types was found to be less than 0.2 mm, which meets one criterion for implant success proposed by Smith and Zarb (1989).

The average annual changes in defect width and average areas were also calculated. The mean change in width for the ball attachment was 0.73 mm, 0.01mm for the O-ring and 0.08 mm for the Dolder bar. Although not mentioned as a criterion for the success of an implant, average annual changes in defect width and average areas could be used as an adjunctive indicator of any significant horizontal bone loss in the marginal bone. The mean annual change in defect area were all less than 0.1 mm^2, and may possibly be used an *indicator* of possible significant changes in the volume of the defect around the implant, although it will not be accurate at all as the image is a two dimensional picture of a three dimensional object. However, valuable information may still be obtained.

The graphs in figures 2 and 3 demonstrate that the differences between each attachment type for defect height and area both become significant as time progresses, providing a possible trend which needs to be closely monitored beyond the five year point of review in function. Initially the dimensions for each of these defect components lie relatively close to each other, but diverge as time progresses. Such results may be due to variations in film angulation, reduced floor of mouth space or true bone loss. This will need to be assessed carefully at future review appointments and, in future studies of a similar nature.

Comparisons of the graphs for each component of the defect which was considered (width, height or area) show that where there is a gradual increase in the average area for an attachment type, the widths and height show a corresponding gradual increase (ball and O-ring), and where the area remains relatively consistent there has been opposing trends in the changes of the width and height. These results suggest that any increases in the defect around the ball and O-ring attachments will see changes in both the width and height of the defect, whilst with Dolder bars when there is a change in one linear component there appears to an opposing change in the other linear component resulting in the average calculated area remaining relatively unchanged. Film placement and image capturing may have an effect on this as well.

6.1.2 Abutment Types

The graphs for height, width and area showing the mean marginal bone changes in this patient group show that the Dolder Bar retained overdenture has undergone the least amount of changes throughout the five years, and has defects which have not increased in size, unlike those of the ball attachment and O-ring attachment patients. The defects have remained constant or decreased slightly.

Using the defect height as the measure of vertical bone change, the results of this study differ slightly to that of Bergendal and Engquist (1998). Their study assessed maxillary and mandibular overdentures supported by a minimum of two implants, the mandibular overdentures all being supported by two implants and retained by a Dolder bar or ball attachment. They showed that the mean marginal bone loss in mandibular ball attachment and bar retained overdentures had no significant differences over the five year period. Using a larger patient pool prospectively, they were able to standardise the production of radiographs and had a more consistent attendance of patients for annual review.

Although this study was retrospective, with less control of the production of radiographs, the differences are not significant. The smaller patient pool with irregularities in patient attendances has meant that any changes in the measurements are quickly reflected in population means and will differ slightly to other studies. This can be seen in the graphs of individual patients in the study.

Additionally, techniques of obtaining radiographs differed, and no digitising of the radiographs was carried out in the other study. Differences may be due to measuring techniques or the use of non-standardised radiographs. This study used the horizontal alveolar bone level as a reference point, instead of the abutment/implant junction, as suggested by other authors. Being more difficult to locate, and subject to change, variations in measurements are more likely to occur. Larger populations and standardised radiographs are required to provide a better indication of any bone changes which may occur.

This study looked specifically at the use of radiographs for the assessment of functioning implants on a regular basis. In addition, it assessed the validity of RADI, a programme developed to carry out quantitative analysis of radiographs retrospectively. As a pilot study, it used only a small patient pool and did not consider other factors which may affect the success of a functioning implant, such as patient age, smoking factors, medication or prosthesis design and loading. Correlation with clinical findings has not been considered at this stage, although there is the capability to do this in the future. These will be subjects of future studies using RADI.

6.1.3 Future Investigations

RADI has been found to be useful in the analysis of functioning dental implants. It is to be redesigned to include a horizontal reference line which will provide a measure of the bone crest to implant interface. This will then indicate if the crestal bone level has changed in relation to the implant face, improve the accuracy of the defect measurement and provided a truer indication of and detected changes in defect dimensions.

Confidence levels of image analysis will also be incorporated into overall investigations to provide accurate results and indications of significant changes in marginal bone around the implants.

Prospective studies using standardised, periodic radiographs need to be developed using larger populations to gain a more accurate assessment. The principles used throughout this study may be applied to the investigation of other forms of implant treatments, such as maxillary implant-supported overdentures or single implants and multiple implant-supported bridges in either the maxillary or mandibular arches. Significantly, factors such as patient age, smoking, oral hygiene, implant distribution and angulation and prosthesis type may be analysed long term for their contribution to the success or failure of an implant in function.

7. CONCLUSION

From this retrospective pilot study, a number of factors were obtained. Only a small patient pool was used for the study, which reduced the possible correlation with other studies assessing the marginal bone around implants. To improve the accuracy and correlation with other studies, a larger patient pool is required, to minimise the effects of large changes from one subject having a significant effect on results of the whole group.

The programme was found to be useful in quantitatively assessing the marginal alveolar bone surrounding the implant. It was designed to compensate for any distortion or image magnification which will occur in the production of a radiograph, and provided linear measurements in the vertical and horizontal direction, as well as calculating an average area for a given 'defect'. The figures provided were in the approximately the same magnitude as in other studies (< 2mm). These need to be correlated with clinical investigations to assess the accuracy of the calculations.

RADI needs to be correlated with clinical findings to confirm its validity. It may be used for future studies of other implant treatments and assist in providing an indication of the status of an implant, without the need to surgically invade the implant sites. Direct digital radiographic imaging will be the most convenient and time-saving method to use, however, existing radiographic films may be digitised for analysis. The most critical factor in this process will be to ensure that the images (plain film or digital) are taken with a standardised, reproducible projection technique, and are of a very high quality.

Most significantly, we must remember that although radiographs will provide us with vital information about the status of an implant, it is only one of a number of periodic investigations which should be used. It is a useful non-invasive method, but must be carried out with care, and its limitations as a tool should be borne in mind at any time it is used.

IMAGE CHARACTERISTICS

RESOLUTION/CLARITY

Resolution is the ability to distinguish between small objects that are close to one another. Observers were asked to assess the resolution oclarity of the images.

DETECTABILITY OF STRUCTURES

Observers were asked to assess the ease with which images of structures could be detected.

IMAGEQUALITY

STRUCTURE BOUNDARIES (SHARPNESS)

Structural boundaries vary in sharpness and definition. Observers were asked to grade how sharp or blurry the boundaries of the images were produced.

CONTRAST

Contrast is the image's production of black or white, or a level of grey in between Observers were asked to grade the contrast of the image, particularly in its ability to assist assessment of various parts of the image.

NOISE

Noise is defined as any unwanted information included in the image which may reduce the diagnostic value of the image. A grade for the amount of noise produced was requested.

DEFINITIONS OF MEASUREMENTS

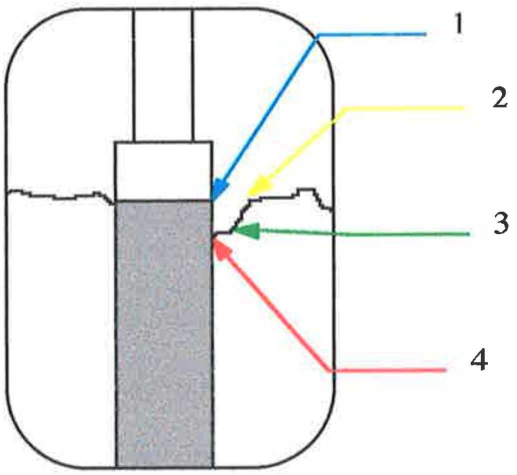

Figure 13 - Points used during image analysis

A 'bony defect' was identified at the bony crest adjacent to the implant on the mesial and distal aspects of the implant (fig 13). The known implant or abutment diameter was used for calibration of the horizontal component of measurements whilst the known implant or abutment length was used for the calibration of the vertical component of measurement.

Four reference points were used to outline the 'defect':

1. at the edge of the implant horizontally in line with the crest of the alveolar ridge in the image;
2. the border of the 'defect' at the crest of the alveolar ridge;
3. the point of maximum curvature of the 'defect'; and
4. the most apical point of the 'defect' adjacent to the implant surface.

Using these defined points on each image, the 'defect' width, height and area were calculated for each implant at each time period on both mesial and distal aspects. Radiographic image distortion and magnification were considered in the calculations. Using known dimensions the number of pixels measured was converted to millimetres by the programme to provide a real measurement. A sample screen of the RADI programme is at figure 14.

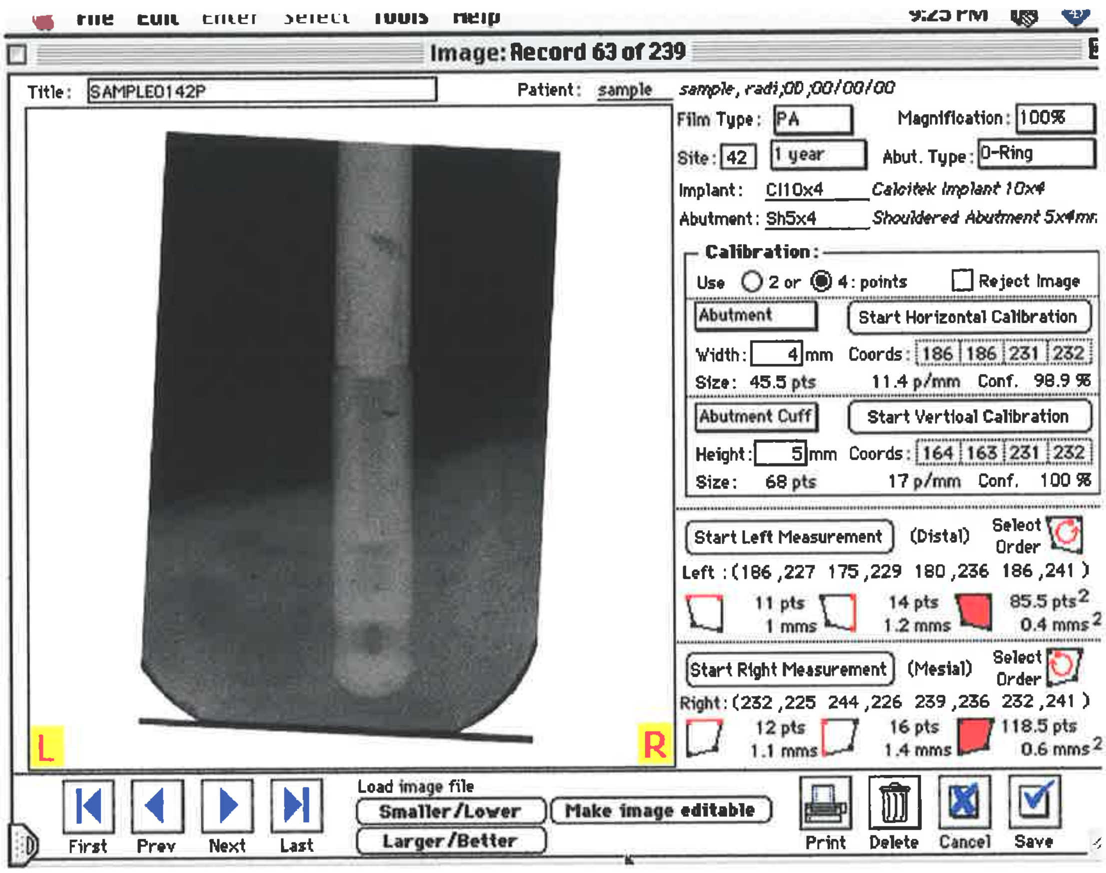

Figure 14 - Sample screen of RADI programme

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