PERIODONTAL BONE LESIONS

L.W.J. VAN DER LINDEN

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An experimental study of interdental bone changes

VRIJE UNIVERSITEIT TE AMSTERDAM

PERIODONTAL BONE LESIONS

AN EXPERIMENTAL STUDY OF INTERDENTAL BONE CHANGES.

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van
doctor in de geneeskunde
aan de Vrije Universiteit te Amsterdam,
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hoogleraar in de faculteit der sociale wetenschappen,
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LEO WILLEM JACOB VAN DER LINDEN

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PROMOTOR	:	PROF. DR. C. O. EGGINK
COPROMOTOR	:	DR. P. F. VAN DER STELT
REFERENT	:	PROF. G. DEKKER

STELLINGEN

I

Aan de hand van één röntgenfoto is niet vast te stellen of bij een angulair botdefect de vestibulaire of orale wand verloren is gegaan.

dit proefschrift

II

Afbraak van spongieus bot van het coronaire deel van het interdentale septum beïnvloedt de zwarting en het trabekelpatroon op de röntgenfoto.

dit proefschrift

III

De uitbreiding van angulaire botdefecten op de röntgenfoto is met digitale beeldverwerkings- en patroonherkenningstechnieken te bepalen.

dit proefschrift

IV

De frequentie voor het vervaardigen van bitewing röntgenopnamen ten behoeve van cariesdiagnostiek dient aan de snelheid van het voortschrijden van caries gekoppeld te zijn en niet aan een tijdsnorm.

Gezondheidsraad 1982

V

Bij het vervaardigen van intra-orale röntgenopnamen dient met het ALARA-principe (the dosis as low as reasonably achievable, economic and social factors being taken into account) rekening te worden gehouden.

ICRP 26

VI

De tandarts-radioloog ziet het parodontium te veel zwart-wit.

VII

Vanuit parodontaal opzicht verdient een uitgebreide composietrestauratie in frontelementen de voorkeur boven een totale kroon.

VIII

De tandarts dient zich ervan bewust te zijn dat het tijdstip van het behandelen van een proximale caviteit afhankelijk is van de grootte van de caviteit en de cariesprogressie.

IX

Een histologisch preparaat is een weergave van een moment en belemmert longitudinaal onderzoek in tegenstelling tot klinisch en röntgenologisch onderzoek.

X

Eenvoudige orthodontische afwijkingen, waar vaste apparatuur is geïndiceerd, dienen door de tandarts algemeen practicus te worden behandeld.

XI

Een tandwortelimplantaat dient eenvoudig aangebracht te kunnen worden, opdat de tandarts algemeen practicus het toe kan passen.

XII

Een tandarts die deeltijds medewerker is aan een subfaculteit der tandheelkunde leidt (lijdt) een dubbel leven.

XIII

De stellingname van veel leden van de Nederlandse Maatschappij tot Bevordering der Tandheelkunde jegens het instituut van de mondhygienisten staat op gespannen voet met één der doelstellingen van deze beroepsorganisatie, n.l. "het bevorderen van de tandheelkundige gezondheidsvoorlichting en opvoeding van de bevolking, alsmede het bevorderen van de preventie".

XIV

De term "openbare belijdenis des geloofs" dient verandert te worden in "openbare christus belijdenis".

XV

Een schaatstourtocht is in vergelijking met een fietstourtocht een volkshappening.

For Judith,
Arie, Angelique
en Willem.

This thesis was prepared at the Department of Operative Dentistry, section of Dental Radiology, of the Free University, Amsterdam.

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CONTENTS

CHAPTER 1

INTRODUCTION, AIM AND DESIGN OF THIS STUDY.

1.1 The position of the radiograph in dentistry and more especially in periodontology

Since Walkhof made the first dental radiographs in 1895, 14 days after Roentgen had reported the discovery of the x-rays, this method of examining the maxillodental system has been indispensable in dentistry. The radiograph is one of the aids available to the dentist for detection of lesions in the hard tissue structures of the maxillofacial region. These changes can express themselves as radiopacity or radiolucency. For some changes, such as caries and periodontal bone loss, the radiograph provides valuable supplementary information. Other conditions, such as anodontia, impacted teeth or periapical bone resorptions, can often be diagnosed solely by radiography. As early as 1931 Ennis stated: "The scientific dentist must concede that it is absolutely impossible to practice properly and thoroughly without the assistance of roentgenology as an aid to diagnosis. There can be no discussion on that point. It is final". However, the radiograph should not be regarded as the sole means of making a diagnosis. Information can also be obtained by clinical, bacteriological, histopathological and immunological studies. The final diagnosis can be established by summation of the information obtained by the various methods of investigation. Before resorting to radiography one should establish, whether registration of the desired information is in fact possible by this method, to ensure that no radiograph is made of a condition which is not radiographically identifiable (e.g. marginal gingivitis). In order to minimize the application of roentgen rays one should also try to establish whether the information required cannot be obtained by other means, without using ionizing radiation. Radiography is permitted only if it can provide further significant information on the patient's health (ICRP, 1977; Van der Stelt, 1980; Gezondheidsraad, 1982). Caries and periodontal disease are lesions with which the general dental practitioner is most often confronted. With the advances made in prevention in the past few decades the incidence and extent of these lesions can be limited (Kwant et al., 1972; Houwink, 1979; Lindhe and Nyman, 1975; Axelsson and Lindhe, 1978). In the light of this fact early diagnosis remains important. In dental practice bite-wing and periapical radiographs are most widely used to study the approximal surfaces of teeth, the alveolar bone and the apical region; and they add information to data obtained by other means. Some parts of dentistry in which the use of radiographs is highly desirable will now be outlined in succession.

Caries diagnosis

Examination of caries with a probe reveals only whether there is an interruption in the approximal surface. The bite-wing radiograph however, reveals the size of the lesion in the enamel, its extension into the dentin, and the relation of the caries to the pulp cavity. Raper (1925), Sognaes (1940), Van den Berg (1944), Van Aken (1964), Dijkman (1969), Kalsbeek (1972), Purdell Lewis and Pot (1975) and Sanderink (1978) have demonstrated that caries can be detected much more accurately in this way.

Endodontic treatment

For **endodontic** purposes a periapical radiograph can be used to assess the anatomy of the root canals and the condition of the apical periodontium. In this context it is important to know whether the periodontal ligament space is periapically continuous or widened, or whether a radiolucency (or radiopacity) can be seen in the periapical bone. During endodontic treatment a radiograph is used to determine the relation of the length of the reamer to the length of the tooth and to determine the position of gutta-percha point or silver point in the root canal in relation to the apex.

Diagnosis of periodontal lesions

Several methods are available for the diagnosis of **periodontal** lesions. For certain tissues the following methods may be mentioned.

Gingiva	– gingival index (Loë and Silness, 1963).
	– sulcus bleeding index (Mühleman and Son, 1971).
	– bleeding index (Lindhe and Nyman, 1975, 1977; Axelsson and Lindhe, 1978).
Periodontal ligament	– pocket depth measurements (Loë and Silness, 1963; Lindhe and Nyman, 1975).
	– furcation analysis (Hamp, Nyman and Lindhe, 1975).
	– mobility registration (Lindhe and Nyman, 1975).
Alveolar bone	– pocket depth measurements.
	– radiography (Lindhe and Nyman, 1975).

This enumeration shows that diagnosis with the aid of radiographs is not a method in its own right but only one among many methods the dentist can use in order to make a responsible diagnosis and follow the course of any treatment which involves the bone. Radiography is indispensable, however, in the examination of parts beneath the surface of the periodontium (Goldman and Cohen, 1958; Orban and Orban, 1960; Regan and Mitchell, 1963; Rees et al., 1971).

Longitudinal evaluation

Radiographs can be used to determine at certain intervals after completion of endodontic treatment whether an existing radiolucency has become smaller or whether one is developing (Eggink, 1964; Klevant, 1981). After completing two-surface and three-surface restorations radiographs can be used to establish whether the cervical marginal adaptation meets the established criteria (Barr and Gresham, 1950; Pilot and Buurman, 1968; Van Amerongen, 1980). Or they can be used to evaluate the effects of methods of treatment on the jawbone (Lindhe and Nyman, 1975; Rösling et al., 1976; Markanen et al., 1981). In all these applications of radiography the aiming technique has to meet high requirements because conclusions based on interpretation of the radiographs largely depend on it.

1.2 The reason for this study

1.2.1 Introduction

The study described in this thesis focuses on the interdental bone of the periodontium. In the course of life the periodontium is subject to changes in the gingiva, the periodontal ligament and the alveolar cortical and cancellous bone which arise from either a physiological or a pathological process. Opinions differ about the question whether loss of tissue and displacement of the attachment level should be regarded as a normal physiological or as a pathological process (Van der Velden, 1982). According to Carranza, (1979) aging is a slow deterioration of natural functions, a disintegration of the balanced control mechanism and organization that characterize the periodontium of the young individual. This might be a more physiological explanation of the recession.

Pathological changes, on the other hand, can be caused by inflammations and may even lead to tooth loss. Micro-organisms are considered to be the principal aetiological factor in these processes (Theilade E. and J., 1976; Page and Schroeder, 1982). Gingivitis and periodontitis have been the subject of extensive experimental studies by Löe et al. (1965), Theilade et al. (1966) and Lindhe et al, (1973). Groen (1972), who had been in close touch with Gottlieb (1928), advocated that more attention be paid to endogenous factors as a cause of periodontal bone loss.

Periodontal changes, whether they be physiological or pathological, can be registered and followed by means of longitudinal studies. The same applies to the effect of treatments of the periodontium, which can be determined clinically as well as radiographically, bacteriologically and histologically. In the present study, however, the emphasis will be on the radiographic features.

1.2.2 Changes in bone height in the course of time, without treatment

Above all it is important to establish what happens when treatment is omitted. Becker et al. (1979) studied this question in a number of their patients who were summoned for a complete examination after 10 years without treatment (for whatever reason). They found an average annual loss of 0.36 tooth per patient, most losses involving molars (in mandible as well as maxilla). Pocket depth had increased by 0.24-2.46 mm per year. No quantitative determination of bone loss on the basis of radiographs occurred.

Björn and Hjort (1982) studied bone loss in 256 factory workers on the basis of orthopantomograms and bite-wing radiographs obtained over a period of 13 years. The degree of bone loss was determined in relation to the length of the tooth and expressed in percents (Björn, 1974). The bite-wings were used to detect incipient bone loss in the furcation during the period studied. The amount of bone loss increased from 18% to 32%; 9.5% of the teeth were lost, including about 2.5% presumably due to loss of supportive tissue.

Selikowitz et al. (1981) studied the loss of alveolar bone in 100 patients over a 10-year period on the basis of bite-wing radiographs. The annual amount of horizontal bone loss was between 0.04 mm and 0.06 mm, while that of vertical bone loss was between 0.03 mm and 0.05 mm (table 1.1).

Using the method of Schei et al. (1959), Rohner et al. (1983 determined the percentage of annual bone loss on the basis of periapical radiographs (table 1.1). The mean percentage of interdental bone loss was 0.51%. To permit comparison with other investigators they used a conversion factor to convert the percentual bone loss to mm, and found a mean annual bone loss of 0.07 mm. According to Socransky, Haffajee, Goodson and Lindhe (1984), destructive periodontal disease is not a continuous process. Longitudinal studies have shown that a periodontal lesion progresses in brief periods of accelerated degeneration of tissue. Each period is followed by a longer period of diminished activity or rest during which no bone loss occurs. Bone

loss can occur locally, without any loss elsewhere. Goodson, Haffajee and Socransky (1984) studied bone loss in relation to attachment loss and found that the latter preceded the former by 6-8 months.
It may be concluded that non-treatment of the affected periodontium leads to loss of alveolar bone, which can be general or local and takes an intermittent course.

1.2.3 The effect of various methods of treatment

Hirschfeld and Wasserman (1978) studied the results of periodontal treatment in 600 patients over a period of more than 22 years. They found marked interindividual differences in therapeutic effect, and consequently the patient material was divided into three groups on the basis of the loss of teeth: a large group of patients who responded well to treatment and showed but little periodontal change (the "well-maintained group"); a smaller group showing slow deterioration of the periodontium with loss of 4-9 teeth (the "down hill group"); and a group with periodontal deterioration and the loss of 10-23 teeth (the "extreme down hill group"). Loss of teeth averaged 0.68 per patient in the well-maintained group, 5.7 in the down hill group, and 13.3 in the extreme down hill group. Most losses involved upper and lower molars. Radiographs were available but it is not clear whether they were used to compare the amount of available bone during treatment with that after the follow-up period.
Comparison between the study of Becker et al. (1979) and that of Hirschfeld and Wasserman (1978) shows that Becker noted an annual loss of 0.36 tooth in the extreme down hill group, versus a loss of 0.6 tooth reported by Hirschfeld. It should be pointed out, however, that Becker had excluded teeth with a dubious prognosis, whereas Hirschfeld had not.
A population screening reported by Marshall Day and Shourie (1949) revealed a mean loss of 10 teeth per patient due to various causes over a period of 20 years without treatment. Hirschfeld and Wasserman found that patients with periodontal lesions showed a mean loss of 2.2 teeth over a period of 22 years after treatment.
These studies warrant the conclusion that treatment (regardless of the method used) plays a role in the preservation of periodontal tissue and teeth. It is rather striking that the available radiographs were evidently not used, and that the loss of supportive tissue was simply related to the loss of teeth. The objection to these studies is therefore that the effect of the various methods was assessed against the loss of teeth.

1.2.4 The effect of non-surgical methods of treatment

Helldén et al. (1979) studied the effect of instruction in oral hygiene, scaling and rootplaning and medication on probing depth. Using the method of Schei (1959) they determined the alveolar bone level prior to the study. Bone height was not radiographically determined after completion of the study. Reduction of probing depth was found in all cases and was most extensive in areas submitted to scaling and rootplaning. Cerceck et al. reported similar findings in 1983.
Axelsson and Lindhe (1978 and 1981) studied the effect of instruction in oral hygiene and professional tooth cleaning on caries and periodontal lesions in adults. Patients given accurate and very frequent care showed hardly any gingivitis or loss of epithelial attachment, and developed virtually no carious lesions. The control group (given traditional dental care) showed gingivitis, loss of periodontal tissue support and caries as well as carious lesions next to restorations. For each patient full-mouth radiographs were taken as described by Eggen (1969) prior to the clinical study.
Helldén et al. (1979) and Axelsson and Lindhe (1978 and 1981) made radiographs

prior to treatment, the former using them to determine the pre-treatment bone height.

1.2.5 The effect of surgical methods of treatment

Lindhe and Nyman (1975) studied 75 patients with advanced periodontal bone loss in an effort to establish whether the presence of micro-organisms in the plaque was the cause of periodontal lesions, and to determine the effect of optimal oral hygiene on maintenance of the situation after surgical treatment. Radiographs were made according to Eggen (1969) in order to obtain reproducible records. The interproximal bone level (bone score) was determined according to Björn et al. (1969). Initial treatment consisted of instruction in oral hygiene, scaling and root-planing as well as surgical treatment of the pathologically deepened pockets. After 5 years no further bone loss was found to have occured.

Nyman et al. (1975) studied 20 patients with a greatly reduced but non-inflamed periodontium in order to establish whether the periodontium and the teeth treated by the method described by Lindhe and Nyman might be used as abutments for extensive bridgework. After each year radiographs were made by the technique described by Eggen and the bone score was determined according to Björn. No bone loss occurred and no widening of the periodontal ligament space was evident. These results were obtained if the following criteria were met: no periodontitis, a high level of oral hygiene and professional tooth cleaning every 3-6 months.

Rosling et al. (1976) studied the effect of systematic plaque control on bone regeneration in infrabony pockets after surgical treatment (no bone resection) in 24 patients. The modified Widman flap operation was used. All plaque, calculus and granulation tissue were removed from the root, which was then carefully planed. In the test group, treatment was followed by professional cleaning at 14-day intervals; in the control group this was not done. In the test group the bone defects had filled up with bone after 2 years, but the control group showed degeneration of periodontal tissue.

Rosling et al. (1976) also studied the effect of various surgical methods on periodontal defects. After treatment it was ensured that the teeth were plaque-free. All groups showed slight marginal bone crest resorption, which was least in patients in whom no alveolar bone was removed. In all groups some bone regeneration in the infrabony pocket was noted, but this was most pronounced in patients treated by the modified Widman flap operation.

Axelsson and Lindhe (1981) studied the effect of maintenance care in a group of 90 patients. Patients with advanced periodontitis were treated by scaling and root-planing, the pockets being treated by the modified Widman flap operation. Given extensive maintenance care the patients were found to have a healthy gingiva and no markedly deepened pockets, whereas the control group showed signs of recurrence of periodontitis and loss of attachment. It may be concluded that surgical treatment is effective if the patient makes every effort to keep the teeth plaque-free and receives frequent instruction in oral hygiene as well as professional tooth cleaning.

1.2.6 Comparison of the effects of surgical and non-surgical methods of treatment

Pihlstrom et al. (1983) compared the effect on level of attachment and pocket depth of scaling and root-planing on the one hand and scaling and root-planing combined with a Widman flap operation on the other hand within the same patient (left versus right). For pockets deeper than 7 mm the reduction in pocket depth after 6.5 years

was 1.13 mm less after scaling and root-planing than after the other method. For pockets with a depth of 4-6 mm there was no statistically significant difference between the two methods. After treatment by the surgical method shallow pockets resulted in a loss of attachment. The gain in attachment level was 0.5 mm after scaling and root-planing combined with a Widman flap operation as compared with the level after scaling and root-planing alone for pockets of 4-6 mm. For deeper pockets (> 7 mm) the gain in level of attachment was the same with both methods.
Ramfjord et al. (1973), Knowles et al. (1979) and Hill et al. (1981) likewise compared different treatment techniques and found that deep pockets responded better to a surgical method of treatment. For shallow pockets the choice of method was of no importance with regard to the final result.

1.2.7 Longitudinal study of periodontal bone loss in which systemic diseases play a role

Local factors such as micro-organisms from the plaque are often held responsible for periodontal lesions (Löe et al., 1965; Theilade et al., 1966; Slots, 1979). As early as 1949, however, Marshall Day and Shourie already mentioned that other factors may also play a role. These are a manifestation of a disturbed or deficient metabolism due to diabetes mellitus, nephritis, endocrine disorders, pregnancy, etc.
Gottlieb (1928) and Groen (1972) likewise described periodontal lesions of non-infectious origin. Groen in addition described a number of patients who showed osteoporosis as well as periodontal bone loss.
A more recent study by Daniell (1983) revealed that patients with osteoporosis become edentulous more quickly and show more rapid loss of alveolar bone.

1.2.8 Conclusions and discussion

In the publications listed in table 1.1 the loss of supportive tissue was related to the bone height. As already pointed out, the periodontium is subject to regression in the course of life, as a result of a physiological or a pathological process. The changing bone level is literally of basic significance in this respect. Practically all investigators who have studied the bone level, have shown some bone loss in the course of time (table 1.1). Some, however, like Lindhe and Nyman, found no bone loss after treatment if the patient carefully tried to prevent plaque formation and frequently received instruction in oral hygiene and professional tooth cleaning. But recently Lindhe and Nyman (1984) reported that a few patients in their study population showed considerable loss of attachment with even loss of teeth after 14 years. They compared these patients with the down hill group and the extreme down hill group in the study population described by Hirschfeld and Wasserman (1978). These patients were not identifiable at the start of the study. It is not reported, however, whether a general medical examination was made, and systemic diseases may consequently have been involved (Daniell, 1983).
Alveolar bone loss varies between 0.06 mm and 0.07 mm annually if the patient receives no intensive treatment and care. Given more intensive and accurate care, bone loss is between 0.017 mm and 0.03 mm (table 1.1).
Every method used in the treatment of patients with loss of periodontal tissue proves to contribute to reduction of pocket depth and improvement of the level of attachment. Long-term effects, however, can be ensured only by paying close attention to plaque prevention and frequent professional tooth cleaning. Scaling and root-planing are to be preferred for shallow pockets, while surgical methods in combination with

root-planing give better results for deep pockets. The significance of micro-organisms in the aetiology of periodontal lesions has received much attention, but the influence of systemic factors has been largely disregarded. Yet further investigation of the latter factors would seem to be highly desirable as well.

Table 1.1 Some radiological studies of the rate of alveolar bone resorption

Authors	Population	Type of study	Type of radiography	Teeth	Annual resorption (mm)
Suomi et al. 1971	Employees	Longitudinal	Periapical, standardized		
	I oral hygiene, no special treatment			lower right posteriors	I 0.063
	II oral hygiene and recall				II 0.003
Boyle et al. 1973	Students, staff and patients of a dental school in a good periodontal health	Epidemiological	Periapical, not standardized	first molars, second premolars lateral and central incisors	0.017
Markanen et al. 1981	Employees	Epidemiological	Orthopantomogram, standardized	Entire dentition	0.06
Selikowitz et al. 1981	Patients of 2 general practitioners	Longitudinal	Bite-wings, not standardized	lower molars and premolars	0.03
Rohner et al. 1983	Patients of a dental school	Longitudinal	Periapical, not standardized	Entire dentition	0.07
Lindhe & Nyman 1975	Patients of a dental school	Longitudinal	Periapical, reproducible	Entire dentition	none
Nyman and Lindhe 1975	Patients of a dental school	Longitudinal	Periapical, reproducible	Entire dentition	none

Radiographs are frequently used in the diagnosis and treatment of periodontal conditions. In only a few cases is a follow-up performed in order to determine the amount of alveolar bone loss, and this is often done by periapical radiography. Due to the vertical angulation in periapical radiographs, the distance between the cemento-enamel junction and the alveolar crest differs significantly from the true distance. The value of radiography in periodontal treatment has so far been underrated. This is why research using a radiographic technique which optimally reflects reality, is desirable.

1.3 The aims of this study

Bite-wings and, in certain circumstances, periapical radiographs are advisable for periodontal diagnosis. They provide a two-dimensional projection of the teeth, the cortical layer, the junction area and the cancellous bone on the film plane. The image obtained is influenced by differences in beam angulation, film position and film den-

sity. The radiographs should be made using the long-cone parallelling technique (Van Aken, 1969), which ensures better image formation than the bisecting technique. It is also recommendable to use aiming devices for standardization of the radiographic technique. Without standardization the distance between the cemento-enamel junction and the top of the interdental bone can vary by more than one millimetre as a result of aiming variations; this is illustrated by the radiographs made for the study published by Stolk (1977). Standardized bite-wings alone are not suitable for longitudinal studies in separate individuals (Selikowitz et al., 1981). For longitudinal studies the radiographs should also be reproducible. Longitudinal studies of periodontal defects using a standardized and reproducible radiographic technique, are rare (the terms standardized and reproducible are defined in section 5.1).
Studies of especially the periapical region of the alveolar process have revealed a marked discrepancy between the radiological dimensions of a bone lesion and the true dimensions (Bender and Seltzer, 1961; Ramadan and Mitchell, 1961; Van der Stelt, 1979). The question is whether the same applies to the interproximal bone, more in particular the alveolar crest where the anatomical conditions of cancellous and cortical bone differ from those elsewhere in the maxilla and mandible.
The first aim of the study to be described here was therefore to gain insight into the relation between the true shape and size of periodontal bone lesions and their radiographic image. The second aim was to develop and test a method to obtain standardized and reproducible radiographs suitable for longitudinal studies of periodontal bone lesions. In order to define the efficacy of the radiographic and interpretative techniques developed, efforts were made to determine what information they provided on the condition of the periodontium, both in the presence and in the absence of bone lesions.
Once it was established how the radiographic image of periodontal lesions is produced and what information it contains, a search was started for methods to reduce imperfections in the interpretation of these images. Reasons for doing so were further reinforced by the fact that strong personal influences play a role in radiographic interpretation (Barr, 1961; Dijkstra et al., 1983).
This led to the third and final aim of this study: to establish how objective and reproducible interpretation of the radiographic image of periodontal bone lesions can best be achieved.

1.4 The design of this study

- Relation between the true dimensions of the lesion and its radiographic image.

In order to determine the relation between the true shape and size of a periodontal bone lesion and the resulting radiographic image, bone lesions were experimentally produced in the interdental bone of the mandible (Chapter 4).

- Development of standardized, reproducible radiographic and interpretative techniques and their application.

In order to obtain standardized, reproducible radiographs, an aiming device with individual bite-blocks was developed. A method of assessing periodontal bone less designed by Schei et al. (1959) was improved by Engelberger et al. (1963) and Björn et al. (1969) was applied to periapical radiographs. They expressed bone loss in percents of root length as measured in periapical radiographs. To obtain an optimally realiable impression of the amount of bone loss, it is better to measure the absolute distance between the cemento-enamel junction or the cervical margin of the restoration and the bone of the alveolar crest (Suomi et al., 1968; Stoner, 1972; Rohner et al., 1983).

This is why the design of our aiming device proceeded from the bite-wing aiming technique. The radiographs thus obtained were used for interpretation of the bone level after multiple magnification by means of projection. For each of the factors playing a role in obtaining and interpreting the radiograph, the influence on reliability was determined. These factors include magnification adjustment, determination of the measuring points and ensuring identical images at successive points of time (Chapter 5).
The radiographic technique described in chapter 5 was used in two groups of patients. One group, which could be assumed to have no periodontal bone lesions, was followed over a period of 4 years to study changes in alveolar bone level with increasing time. The second group consisted of patients with juvenile periodontitis, who were followed throughout the period of treatment and for about 6 months after (Chapter 6).

– Objectifying the interpretative technique.

Treatment of periodontal bone lesions diagnosed in an early stage gives more favourable results than treatment in cases already showing significant destruction (Keyes et al., 1978). According to Ainamo and Tammisalo (1973) and Hollender et al. (1966), small lesions cannot be radiographically visualized. Eggink (1964), Duinkerke (1976) and Van der Stelt (1979) demonstrated that observers asked to interpret bone lesions on radiographs frequently disagreed about the size of the lesion.
In order to establish whether interpretation of periodontal bone lesions on radiographs can be improved, radiographs showing such lesions were submitted to digitized image processing and pattern recognition. This procedure (Van der Stelt et al., 1985a, 1985b) was chosen because it provides objective and reproducible results.

CHAPTER 2

STRUCTURE, FUNCTION AND RADIOGRAPHIC FEATURES OF THE PERIODONTIUM

2.1 Introduction

Several methods of investigation are used in diagnosing periodontal affections. One of these is radiography. The interpretation of radiographs should always account for the fact that they provide a two-dimensional image of a three-dimensional object. This means that different anatomical structures are projected superposed, which results in a complex image. For a good understanding of the radiographic image, therefore, sound knowledge of the anatomy of the periodontium is required.

2.2 The anatomy of the periodontium

The teeth are fixed in the alveolar process by means of the periodontal tissues. The periodontium comprises the following tissues which either fix or directly surround the teeth (fig. 2.1):

- the gingiva and alveolar mucosa.
- the periodontal membrane.
- the cementum.
- the alveolar process:
  - cancellous bone.
  - alveolar bone or lamina cribrosa.
  - alveolar crest or interdental bone layer.
  - vestibular cortical bone and oral cortical bone.

The following descriptions focus mostly on the radiographically most important parts.

2.2.1 The gingiva

The gingiva is part of the oral mucosa. It covers the most coronary part of the alveolar process and the interdental area. The gingiva consists of (Schroeder, 1976):

1. The free gingiva.
2. The attached gingiva.
3. The interdental gingiva.

- the free gingiva (fig. 2.1) is localized on the vestibular and on the oral side of the tooth, festooning to follow the outline of the tooth cervix and the cemento-enamel junction. The free gingiva covers the cervical enamel, ending coronarily at the gingival margin and apically at the gingival groove. The gingival groove is not always present.
- the attached gingiva is bounded coronarily by the gingival groove, and at the

mucosal border is continuous with the mucosa of the alveolar process on the vestibular and with the mucosa of the floor of the mouth on the lingual side. In the maxilla the attached gingiva is absent on the palatal side, the palatal mucosa extending as far as the free gingiva. The attached gingiva is immovably attached to the cementum and the alveolar process (Schour, 1960).

- the interdental gingiva consists of free and attached gingival tissue (fig. 2.2). A cross-section of the interdental structures (fig. 2.3) reveals a papilla on the vestibular and on the lingual side from the premolars on, the vestibular papilla being localized more coronally than the one on the lingual side. Between the two papillae lies an interdental area which slopes down in apical direction: the so-called "col" (Cohen, 1959).

AE - alveolar epithelium
AW - alveolar wall
CT - connective tissue
OE - oral gingival epithelium
OP - oral papilla
VE - vestibular epithelium
VP - vestibular papilla

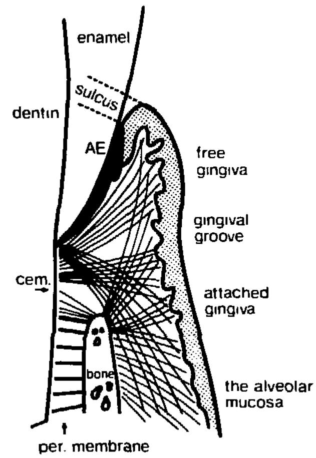


Fig. 2.1 Tooth with adjacent structures, vestibular aspect (after Schroeder, 1976).

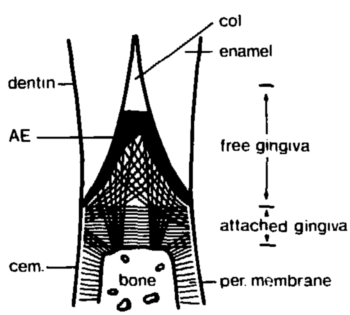


Fig. 2.2 Mesiodistal section through the centre of the interproximal space of teeth with the corresponding marginal periodontium (after Schroeder, 1976).

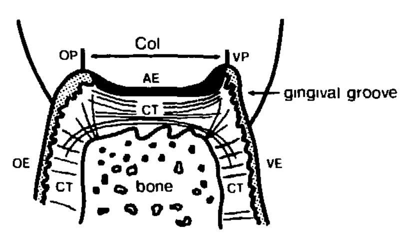


Fig. 2.3 Vestibulo-oral section through the centre of the interproximal space of teeth in the premolar and molar region, with the corresponding marginal periodontium (after Schroeder, 1976).

The healthy gingiva is often mottled and pale pink in colour or pigmented. The gingiva consists of epithelium and connective tissue. The latter largely consists of collagen fibres arranged in bundles. Oxytalan and reticular fibres are present as well. The collagen fibres (fig. 2.4) can be divided into:
- gingivodental fibres.
- alveologingival fibres.
- interpapillary fibres.
- transgingival and intergingival fibres.
- circular and semicircular fibres.
- dentoperiosteal fibres.
- transseptal fibres.
- periosteogingival fibres.
- intercircular fibres.

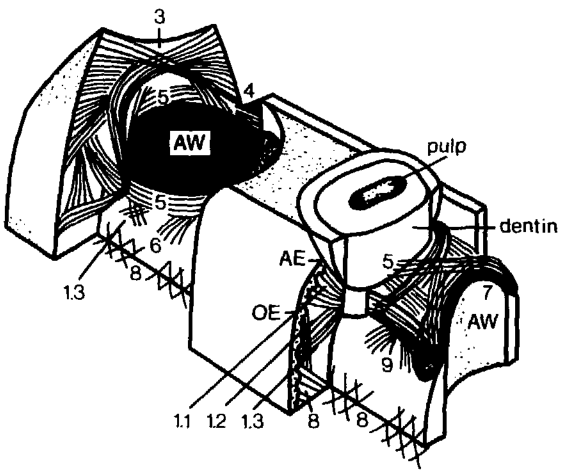


Fig. 2.4 Collagen fibres extending within the gingiva (after Schroeder 1976):
1. *gingivodental fibres (1.1 coronal; 1.2 horizontal and 1.3 apical)*
2. *alveologingival fibres*
3. *interpapillary fibres*
4. *transgingival fibres*
5. *circular and semicircular fibres*
6. *dentoperiosteal fibres*
7. *transseptal fibres*
8. *periosteogingival fibres*
9. *intercircular fibres*
10. *cementoalveolar fibres*

2.2.2 The periodontal ligament space

The periodontal ligament space is localized between the alveolar bone and the tooth. This space is filled by the periodontal membrane, which largely consists of connective tissue and ensures the fixation of the tooth in the alveolus. Coronally the membrane is continuous with gingival connective tissue, which has a sealing function. In the periodontal ligament space proper it ensures the connection between cementum and lamina cribrosa (Bhaskar, 1976).
The periodontal ligament space is hourglass-shaped, being narrowest in the area of the horizontal rotation axis of the tooth. Coolidge (1937) measured the width on 172 teeth at the alveolar crest, at midroot level and at the apex. His material consisted of postmortem specimens. His findings are presented in table 2.1.

The table shows that the width decreases with increasing age from 0.21 mm (11-16 years) to 0.15 mm at 51-67 years. The membrane has its minimum width at midroot level: 0.17 to 0.12 mm, dependent on age. Its maximum width is 0.23-0.17 mm at the alveolar crest; its width at the apex is slightly less: 0.24-0.16 mm.

Table 2.1 Thickness of the periodontal membrane of 172 teeth from fifteen human jaws (Coolidge, 1937)

	Average at alveolar crest (mm)	Average at midroot level (mm)	Average at apex (mm)	Average of tooth (mm)
Ages 11-16				
83 teeth from 4 jaws	0.23	0.17	0.24	0.21
Ages 32-50				
36 teeth from 5 jaws	0.20	0.14	0.19	0.18
Ages 51-67				
35 teeth from 5 jaws	0.17	0.12	0.16	0.15
Age 25 (1 case)				
18 teeth from 1 jaw	0.16	0.09	0.15	0.13

Kronfeld (1931) measured the width of the periodontal ligament space surrounding functioning and non-functioning teeth (table 2.2), and found differences from 0.35 mm to 0.06 mm, dependent on function and position of the tooth. Increased function was associated with increased width of the periodontal membrane. Decreased function showed the opposite. The tables show that, per individual, the periodontal ligament space varies per tooth and that the periodontal membrane of a tooth is not of constant width. Its width increases towards the alveolar crest. This means that a widening need not always be regarded as pathological.

Table 2.2 Comparison of the periodontal width of functioning and functionless teeth (Kronfeld, 1931)

	Heavy function; left upper second bicuspid (mm)	Light function; left lower first bicuspid (mm)	Functionless; left upper third molar (mm)
Average width of periodontal space at entrance of alveolus	0.35	0.14	0.10
Average width of periodontal space at middle of alveolus	0.28	0.10	0.06
Average width of periodontal space at fundus of alveolus	0.30	0.12	0.06

– *Fibres in the periodontal ligament space*

The periodontal ligament space contains the periodontal membrane consisting of the following fibres (fig. 2.1):

1. Cemento-alveolar fibres are attached to the supra-alveolar cementum and take their course from the apical aspect towards the alveolar crest.
2. Horizontal cemento-alveolar fibres run horizontally from bone to cementum in the coronary part of the periodontal membrane.
3. Oblique cemento-alveolar fibres extend from bone to cement at an angle of about 45°, attaching at about two-thirds of the root between apex and alveolar crest.
4. Apical cemento-alveolar fibres are arranged radially round the apex.

5. Interradicular cemento-alveolar fibres are arranged radially round the margin of the interradicular bony septum in multiradicular teeth. The fibres attach to the cementum of the tooth on the one hand and to the alveolar bone on the other.

It may finally be pointed out that the fibres of the periodontal membrane which attach to the alveolar bone and to the radicular cementum are known as Sharpey's fibres.

– *The cells, vessels and nerve tissue of the periodontal membrane*

Apart from the fibres, the periodontal membrane consists of cells for 40% (Beertsen and Everts 1977).

Small arteries enter the periodontal membrane via the canals and apertures of the alveolar bone. Venous return follows the course of the arteries. Lymph is drained off via small vessels extending parallel to the veins. The blood and lymph vessels form a capillary network in the periodontal membrane.

Nerve tissue extends through the apertures and canals of the alveolar bone. The nerve tissue in the periodontal membrane consists of sensory and autonomic nerve fibres which form a network.

Function and shape of the periodontal membrane

The functions of the membrane are:

1. Fixation of the teeth in the alveolar bone.
2. Transfer of forces to the bone.
3. Resistance to forces and protection of vessels and nerve tissue from damage inflicted by forces.

The possible movements of a tooth in the alveolus play an important role, as does the shape of the alveolus. When a force is applied to the tooth, the root is displaced in the alveolus; but this displacement is absorbed by the fibres, cells and fluid-filled vessels in the periodontal membrane within the cone-shaped alveolus (Davies and Picton, 1967; Picton and Davies, 1967).

2.2.3 The cementum

The cementum is a thin layer of calcified mesenchymal tissue which covers the dentin of the root.

According to Hopewell-Smith, the junction between cementum and enamel shows various types (Fig. 2.5) (Schour, 1960):

1. The cementum is partly superposed on the enamel (60-65%).
2. The cementum extends exactly as far as the enamel (30%).
3. The cementum fails to extend as far as the enamel (5-10%).

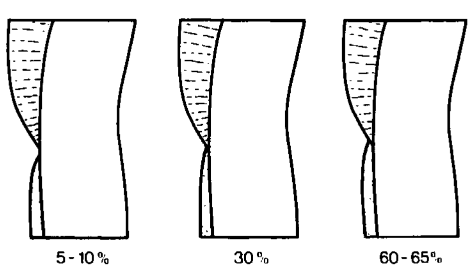


Fig. 2.5 Schematic drawing of the relation between enamel and cementum at the cemento-enamel junction (after Hopewell-Smith).

The thickness of the layer of cementum covering the root shows local variations. According to Bhaskar (1976) the thickness at the cemento-enamel junction is 20-25 μ, increasing to 150-200 μ at the apex. The thickness increases with increasing age from an average of 95 μ at age 20 tot 215 μ at age 60 (Zander and Hurzeler, 1958).

There are several types of cementum:

1. Afibrillar-acellular cementum is a layer of cementum which, in the form of islets or extensions, covers a small part of the enamel at the cemento-enamel junction. It differs from other types of cementum in that it contains neither fibres nor cementocytes (cells resembling osteocytes).
2. Fibrillar cementum is the cementum which covers the root and consists of an organic matrix of collagen fibres with, in between, an inorganic component which consists of hydroxyapatite. There are two types of fibrillar cementum:
   2.1 Acellular cementum
   This is found in particular on the coronally part of the root and is immediately adjacent to the dentin. Especially on incisors and cuspids the acellular fibrillar cementum covers the entire dentin from the cemento-enamel junction to the apex. The fact that it is laminated might indicate that the speed of apposition is varying. This cementum contains numerous collagen fibres but no cementocytes. Sharpey's fibres penetrate far into the cementum and have calcified in its oldest parts. These fibres are arranged in bundles, whereas other fibres are arranged haphazardly or run parallel to the surface of the cementum.
   2.2 Cellular cementum
   Cellular fibrillar cementum is found mainly at the apex of the tooth and can extend to midroot level. It is less calcified than acellular cementum (Ishikawa et al, 1964) and likewise laminated. It contains lacunae in which cementocytes are localized.

Cementum has no vascularization and no lymph drainage. It consists of inorganic substances (61% by weight) and organic substances and water (39%) (fig. 2.6; Schroeder, 1976). The formation of cementum is a continuous process which takes place at varying rates of speed, but much slower than the apposition of bone or dentin.

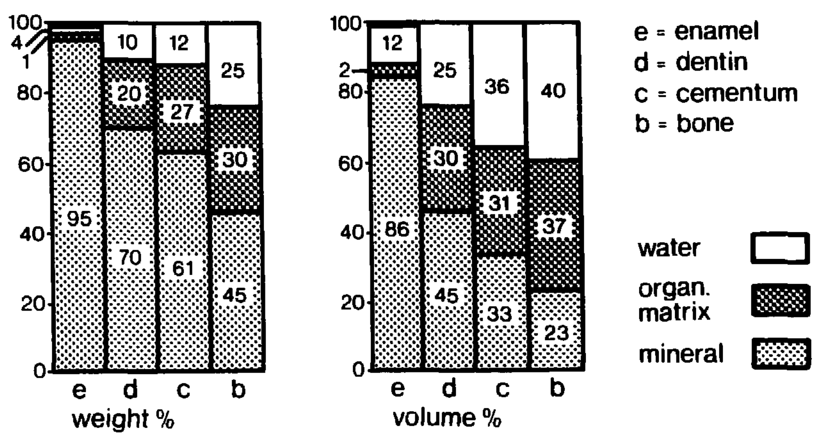


Fig. 2.6 Composition of enamel, dentine, cementum and bone in percents by weight (after Schroeder, 1976).

2.2.4 The alveolar process

The alveolar process is that part of the maxilla and mandible that contains the teeth. The alveolar wall consists of a thin layer of cortical bone (Elfenbaum, 1958; Manson, 1963): the alveolar bone or lamina cribrosa. The alveolar bone is supported by cancellous bone which can be localized interdentally and on the vestibular and the oral side of the tooth. Cancellous bone is not always found on the vestibular and the oral side of a tooth; this depends on the position of the tooth in the dental arch. In the absence of cancellous bone the compact or cortical bone covering the alveolar process is localized immediately adjacent to and fuses with the alveolar bone of the tooth (Schour, 1960) (fig. 2.7).
The interdental septum consists of cancellous and alveolar bone which on the vestibular and the oral side is covered by compact bone. The coronal end of the interdental septum is marked by the alveolar crest.

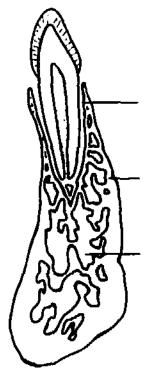


Fig. 2.7 Schematic drawing of the relation between tooth and alveolar process in the mandible (after Schour, 1960).

The interdental septum

– *The cancellous bone*

The interdental septum consists of cancellous and alveolar bone, surrounded by the vestibular and oral cortical bone. The cancellous bone consists of trabeculae. The spacing of these trabeculae and their thickness vary widely. The trabeculae in maxilla and mandible are arranged in a particular way (Wörth, 1963). They consist of lamellae which indicate varying bone activity, and haversian canals are found in the bone (Bhaskar, 1976).

– *The alveolar bone (lamina cribrosa)*

The alveolar bone or lamina cribrosa is the layer of compact bone which constitutes the alveolar wall. Radiologists call it lamina dura. It contains many canals and apertures through which arteries, veins, lymph vessels and nerves extend to and from the periodontal membrane. It consists of lamellated bone and bundle bone. The lamellated bone partly consists of lamellae parallel to the marrow spaces, while the other part forms haversian systems (Bhaskar, 1976). In the bundle bone the fibres for fixation of the tooth (Sharpey's fibres) are attached.

– *The alveolar crest*

The alveolar crest is the thin layer of compact bone which covers the interdental septum. The lamina cribrosa and the cortical bone of the interdental septum jointly change into the alveolar crest (Van de Poel, 1969). The crest has a number of apertures to accommodate blood vessels and nerves.

– The cortical bone of the alveolar process and the interdental septum

Vestibular to the radices of the teeth the alveolar process is slightly elevated, while interdentally it is slightly depressed. The thickness of the bone which covers the teeth shows local variations. The vestibular bony wall is thin at the sites of the teeth, where the lamina cribrosa is often fused with the compact bone of the alveolar process to form a single layer. In some cases, however, there may be partial or total absence of bone (dehiscence or fenestration). Orally, fusion takes place only in the marginal area, elsewhere cancellous bone is localized between the alveolar bone and the cortical bone. When radix and cortical bone are not adjacent, cancellous bone is found between alveolar bone and cortical bone. The cortical bone wall is often thicker in the mandible than in the maxilla.

In the frontal region, looking from occlusal to palatal aspect, cancellous bone is usually found between cortical and alveolar bone from halfway the lamina cribrosa or at the level of the apical half of the tooth (Becks and Grimm, 1945; Goldman et al., 1957; Schour, 1960). In the molar region, cancellous bone is usually found between cortical and alveolar bone from one-third of the root or midroot level to the apex. At the site of the alveolar crest the cortical bone and the lamina cribrosa are connected on the vestibular and the oral side.

The vestibular and the oral alveolar bone margin follow the course of the cemento-enamel junctions of the teeth. The optimal distance between bone margin and cemento-enamel junction is about 1 mm (Schei et al., 1959).

Remodelling by osteoclasts and osteoblasts is constantly taking place in the bone of the alveolar process (Schluger et al., 1977). The architecture of the bone is adapted to the forces applied to the bone via the teeth. Moreover, general systemic factors exert their influence. This means that the thickness, density and orientation of the bone trabeculae are subject to change (Becks and Grimm, 1945; Schour, 1960). Other investigators, however, maintain that the shape of the trabeculae changes but little with changing circumstances (Parfitt, 1962).

— The chemical composition of bone

Bone growth takes place by apposition in a matrix formed by osteoblasts. Some 90% of the organic matrix consists of collagen. Mineralization occurs in the matrix. Bone consists largely of mineral salts in the form of hydroxyapatite crystals (Carranza, 1979). According to table 2.3 (ICRU Handbook 85, 1964; ICRU Report 17, 1970) the dry weight of comptact bone has the following composition.

Table 2.3 The composition of bone (ICRU Handbook 85, 1964)

Element	Fractions by weight
H	0.064
C	0.278
N	0.027
O	0.410
Mg	0.002
P	0.070
S	0.002
Ca	0.147

– *The bone marrow*
The marrow spaces of the adult alveolar process are filled with yellow, inactive bone marrow. The marrow spaces of the mandibular angle and the maxillary tuberosity are filled with red, active bone marrow.

2.3 The periodontium on the radiograph

The gingiva and the alveolar mucosa hardly give a visible radiographic image. This is due to the low atomic number of the elements composing these tissues. Consequently the absorption of roentgen rays is very low. This means that the gingiva and its changes are not radiographically visible. For this reason these tissues will not be included in the discussion of the projection of periodontal tissue on the radiograph.
On the radiograph, the periodontal ligament space is visible as a dark line next to the radix of a tooth. A narrow radiopaque zone around it represents the lamina dura (lamina cribrosa), which is surrounded by cancellous bone. The walls of the alveolar process consist of a layer of cortical bone which influences only the density. The interproximal coronal demarcation of the alveolar process is known as alveolar crest.
When interpreting intraoral radiographs one should bear in mind that the "normal" image of the anatomical structures may show interindividual and even intra-individual variations.

2.3.1 The periodontal ligament space

The space between tooth and alveolar wall on the radiograph is the periodontal ligament space, which is filled by the periodontal membrane. This tissue as such gives no visible absorption of roentgen rays. The tooth and the lamina dura (fig. 2.7) consist of material which strongly absorbs roentgen rays: it is radiopaque (ICRU Handbook 85, 1964; ICRU Report 17, 1970; Schroeder, 1976). On the radiograph, therefore, the periodontal ligament space is a radiolucent line which, from the alveolar crest on, surrounds the entire radix of the tooth.
Van der Linden and Van Aken (1970) studied the factors which influence the width of the periodontal space on the radiograph. Apart from the normal anatomical variations, the function of the teeth and changes caused by forces, there are other factors which influence the interpretation of the width of the periodontal ligament space.
The degree of density influences the interpretation of width. Differences in density may result from:
1. The shape of the root.
2. The thickness of the alveolar process.
3. Exposure time.
4. The qualitative composition of the x-rays used.

This means that the observer may believe to see a change in the width of the periodontal space which does not exist in reality. The study of radiographs of plaster of paris, aluminium and wax phantoms revealed the following:
- darker lines are subjectively observed as broader; this means that the radiolucent line representing the periodontal space is interpreted as broader if it is darker.
- when two teeth with the same width of periodontal space but with a difference curvature of the radicular surface are compared, the one with the greater radius appears to have a wider space.
- a difference in the thickness of the alveolar process is of little influence if the other factors remain the same.

– an increased exposure time and an increase in kilo voltage cause changes in the interpretation of periodontal space width: the space is subjectively observed as wider; this implies that longitudinal radiographic studies should be performed with always the same exposure time and the same tube voltage.

Van der Linden and Van Aken (1970) maintained that with a decrease in the thickness of the alveolar process the periodontal space becomes subjectively wider due to the increased density as a result of decreasing attenuation.

The alveolar process at the level of the alveolar crest and the horizontal angulation also play a role in the radiographic width of the periodontal membrane. A study of series of radiographs shows that the periodontal space of a tooth can be wider, narrower or even absent - dependent on the beam direction. When the beam is aimed perpendicular to the tooth in the jaw, the marginal part of the periodontal ligament space is not covered by bone. Consequently the radiograph will show this part as darker and therefore as wider. A change in beam direction may cause part of the vestibular or oral bone to be projected superposed on the space, giving an image of a narrower or a closed space. Apically a crescent-shaped density is visible. An even more pronounced change in beam direction will cause the alveolar process to be projected superposed on the tooth, causing apparent absence of the periodontal ligament space (fig. 2.8).

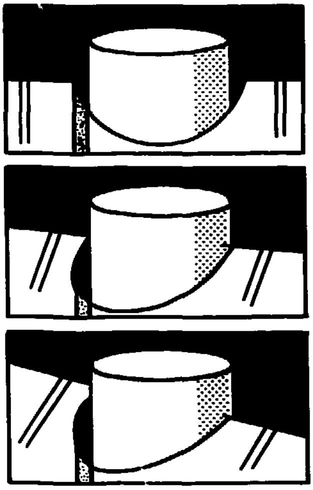


Fig. 2.8 Schematic representation of the relation between a tooth, the periodontal space and the marginal part of the interdental bone at different horizontal angulations. The right-hand part of the figure shows the visual frontal aspect and the left-hand part the radiographic features (Van der Linden and Van Aken, 1970).

On the radiograph the periodontal ligament space is not always visible as a single dark line. Van der Linden and Van Aken (1970) demonstrated that one, two or three lines may be visible. Radiographs were made of a tooth with a radicular concavity which had been provided with an artificial periodontium (wax) and artificial alveolar bone (plaster of paris); the beam direction was changed several times. The number of radiographically visible lines proved to depend on (fig. 2.9):

1. The horizontal angulation in relation to the tooth.
2. The width of the periodontal ligament space.
3. The degree of concavity of the root.
4. The length of the passage of x-rays through the space.
5. The angle between the line connecting the curvatures of the radicular surface and the tangents on the radicular surface where this changes from convex to concave.

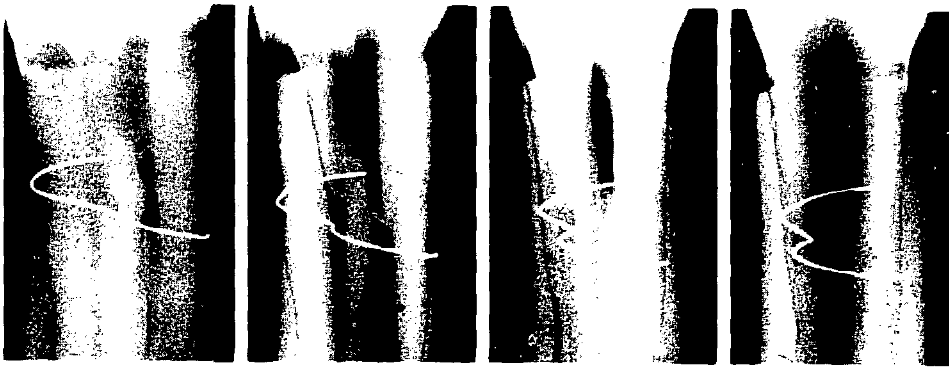


Fig. 2.9 Radiographs of an extracted tooth at different horizontal angulations, showing one, two or three periodontal ligament spaces (Van der Linden and Van Aken, 1970).

2.3.2 The alveolar process

The interdental septum

– *The cancellous bone of the alveolar process*

The radiographic image of the alveolar process seems to be determined by the trabeculae of the cancellous bone, which appear to be irregularly arranged. This image is known as trabecular pattern. The bone trabeculae can be arranged in various ways.

- a linear and parallel arrangement is found especially in the mandible.
- a random arrangement without evident orientation, with the trabeculae so closely packed as to produce a mottled or granular aspect, is found especially in the maxilla.

According to Parfitt (1962) the bone trabeculae vary in shape, size and thickness. On the radiograph the radiopaque trabeculae seem to form a criss-cross pattern enclosing radiolucent spaces. Histological examination, however, reveals that these spaces are interconnected. On the basis of standardized radiographs Parfitt classified trabeculae as: coarse (0.25 - 0.3 mm, with predominance of the larger thickness), medium (0.2 - 0.3 mm, with a predominant thickness of 0.25 mm), and fine (0.2 - 0.25 mm). Parfitt's findings are listed in table 2.4, which shows that the number of intertrabecular spaces per centimetre depends on the thickness of the trabeculae and their position in relation to the alveolar crest.

It is to be noted that the trabecular pattern on the radiograph is not a direct result of the cancellous bone structures. This will be further discussed in the paragraph on the junction area and in subsection 2.3.3.

Table 2.4 Trabecular bone in the molar-premolar region of the mandible (Parfitt, 1962)

Pattern	Number of spaces made by interlacing trabeculae				Size of spaces (mm)	Thickness of trabeculae (mm)
	Across labio-lingually	Per cm across	Per cm down			
			0.0 to 1.0 cm	0.5 to 1.5 cm		
Coarse	3	6	9	7	2-3	0.25 - 0.30
Medium	5	7	11	8	1-2	0.20 - 0.30
Fine	7-8	8	12	10	1-2	0.20 - 0.25

– Maxilla

The marrow spaces in the maxilla are smaller than those in the mandible, ranging in size from 1 mm to 3-4 mm (Wörth, 1963). The size per individual is fairly uniform. The trabeculae of the maxilla are arranged haphazardly.

– Mandible

In the mandible the intertrabecular space can vary from one area to the next. Characteristic radiographic configurations of the trabeculae are:
- a reticular pattern.
- a linear, horizontally oriented arrangement of the trabeculae.

Not infrequently the trabecular pattern in the mandible becomes less dense in the direction of the apices and towards the caudal cortical demarcation, or is even absent. In that case the bone shows a uniform radiographic density, largely caused by the cortical bone. Yet some trabeculae are often still visible at the apex and between the roots. The intertrabecular space in the mandible and between the roots. The intertrabecular space in the mandible is usually larger than that in the maxilla.
When the patterns are very deviant it may be useful to compare the radiographs of the left and of the right side in order to establish whether an abnormality is present. In the case of doubt it is also important to repeat radiography after a certain interval.

– The alveolar bone (lamina dura)

The alveolar bone or lamina dura is radiographically visible as a radiopaque band indicating the periodontal ligament space. According to Elfenbaum (1958) and Manson (1963) it is a thin layer of compact bone. The many foramina in the lamina dura are not visible radiographically (Updegrave, 1958). As in the periodontal ligament space, the shape of the radix plays an important role in the radiographic features of the lamina dura.
Given a large radius of the radicular circumference the length of the passage of rays through the lamina dura is considerable, and the strong absorption will produce a radiopaque line. This is even more pronounced for teeth with a flat radicular surface in the direction of the x-ray beam (longer passage of rays). The horizontal angulation is very important in such cases. If the beam passes longitudinally through the lamina dura, it produces a narrower, more evident and more radiopaque line than if the beam is not parallel to the lamina dura (Wörth, 1963). If the beam is perpendicular to the lamina dura, the length of ray passage is too short to permit sufficient absorption to produce a visible radiopacity. This is the case on the vestibular and on the oral side. In the periapical region the length of x-ray passage is very short (short radicular radius), and this leads to absence of a lamina dura projection on the radiograph. This absence does not warrant the conclusion that a pathological change has occurred. Moreover, the image of the lamina dura can be further influenced unfavourably by cortical and cancellous bone projected superposed on the roots and the lamina dura (Updegrave, 1958).
Goldman et al. (1957) concluded that resection of the vestibular and oral bone has no effect on the image of the lamina dura; this conclusion is at odds with the findings reported by Van der Linden and Van Aken (1970).

– The junction area

The junction area is the ill-defined area of transition from cancellous to cortical bone. Van der Stelt (1979) defined it as the area in which a cross-section through the bone reveals spaces visible to the naked eye but not of the dimensions found elsewhere in the bone (the larger part of the cancellous bone). In the interpretation of intraoral radiographs it should be borne in mind that the visible trabecular pattern is not caused by the trabeculae of the cancellous bone but by those of the junction area. The influence of the cortical bone, cancellous bone and junction area on the radiographic image is discussed in subsection 2.3.3. On the radiograph a trabecular pattern is often projected superposed on the roots. This means that lamina dura and cortical bone are present. Because the trabecular structure is produced by the junction area, there may be radiographic evidence of bone trabeculae even though no cancellous bone is localized between cortical bone and lamina dura.

– *The alveolar crest*

The cervical demarcation of the alveolar process is the alveolar crest. Schei et al. (1959) reported the distance between cemento-enamel junction and alveolar crest on the radiograph to be 1 mm. Björn and Holmberg (1966) regarded 65% of the total length of the tooth (measured from the apex) as optimal bone height. The normal radiographic image of the alveolar crest has the following characteristics:

1. In a number of cases there is a smooth radiopaque line, indicating that a layer of cortical bone constitutes the boundary. Often, however, this layer is not visible on the radiograph. Factors of great influence are the width of the alveolar crest in bucco-lingual direction and the vertical angulation of the beam. The longer the ray passage through the alveolar crest, the more radiopaque is the image of the crest.
2. At lower incisors, where the mesiodistal interdental distance is less, the alveolar crest is sharp, indicating fusion of the lamina dura and the alveolar crest.
3. Between molars and premolars there is often no radiopaque image of the alveolar crest. This may be a result of anatomical conditions or of the beam direction.

According to Ritchey and Orban (1953) the alveolar crest may have several different shapes, which are influenced by the shapes of adjacent teeth. In bucco-lingual direction the bone can be flat or roof-shaped. In mesiodistal direction the amount of space between two adjacent teeth determines the shape of the alveolar crest as flat, showing rounded corners, round or (if there is very little space, as in the lower frontal region) pointed. The relative positions of the teeth play a role as well. Given an intact periodontium, the radiograph shows the alveolar crest as parallel to an imaginary line connecting the cemento-enamel junctions of two adjacent teeth.

– *The cortical lining of mandible and maxilla*

The cortical lining constitutes the vestibular and oral demarcation of the maxilla and mandible. Due to its more uniform structure, the cortical bone does not contribute to the formation of the trabecular pattern. In actual fact the difference between cancellous and compact bone lies in the density of the bone trabeculae: in the former the density is low, and in the latter the bone tissue is denser.
However, the cortical bone does contribute to an overall increase in radiopacity on the radiograph (Goldman et al., 1957; Bender and Seltzer, 1961; Van der Stelt, 1979).

2.3.3 The influence of the various bone structures on image formation

The question may raise whether the trabeculae are responsible for the trabecular pattern on the radiograph.
Goldman et al. (1957) found that resection of cortical bone exerted no influence on the trabecular pattern. However, the overall density of the alveolar bone increased.

Bender and Seltzer (1961) reported that large amounts of cancellous bone could be removed without visible consequences. Experimentally produced periapical lesions did not become visible unless they involved the cortical bone. The trabecular pattern on the radiograph was caused by the bone in the junction area. Ramadan and Mitchell (1962), Pauls and Trott (1966) and Van der Stelt (1979) likewise found that large amounts of cancellous bone could be removed without visible consequences. Only resection of cortical bone influences radiographic density. The cortical bone proves to determine the overall density of the radiographic image, but not to cause any specific structure or pattern. The cancellous bone seems neither to contribute to the density nor to influence the trabecular pattern. The junction area, however, is responsible for the characteristic so-called trabecular pattern.
Research into the formation of the image of the trabecular pattern has been largely confined to the apical level of the teeth and the area beneath it. Data on the level of the alveolar crest are virtually lacking. Consequently the relative contributions of cortical bone, junction area and cancellous bone to image formation may be different in this area. In chapter 3 these data will be related to the image formation of periodontal bone lesions.

CHAPTER 3

PERIODONTAL DISEASES

3.1 Introduction

One of the causes of periodontal diseases is plaque accumulation leading to gingivitis. Since gingivitis produces no radiographic changes, it will only briefly be mentioned in the discussion of periodontal diseases; yet it should be borne in mind that every periodontitis starts as a gingivitis. Periodontitis is a condition predominated by irreversible loss of the epithelial attachment of the gingiva to the tooth. The presence of pockets is a clinical symptom of periodontitis. A pocket is defined as a pathologically deepened gingival sulcus (Carranza, 1979). In addition, osseous changes occur: bone is destroyed as a result of inflammation.

Lindhe (1985) distinguished the following stages:
- intact, healthy periodontium: there are no pockets, and no tissue degeneration has occurred.
- gingivitis: part of the periodontium is inflamed.
- periodontitis: the entire periodontium is inflamed and there is loss of periodontal tissue support.
- healthy but reduced periodontium: the pockets have healed following loss of periodontal tissue.

3.2 Gingivitis

Gingivitis is an inflammation of the gingiva which is clinically characterized by redness, swelling, a tendency to bleed when touched or spontaneously, and effusion of crevicular fluid. The colour of the gingiva can change from pink to vivid red.

Vascular changes occur beneath the gingival epithelium. Oedema develops and neutrophilic granulocytes migrate through the sulcular epithelium. The collagen fibres change; in severe forms of gingivitis they are replaced by inflammatory infiltrate (Page and Schroeder, 1976).

Plaque accumulation on the tooth and in the sulcus is held responsible for the development of gingivitis (Loë et al., 1965; Theilade E. et al., 1966).

3.3 Periodontitis

As pointed out, all forms of periodontitis result from the fact that the inflammation started in the gingiva spreads and leads to irreversible destruction of hard and soft tissues. Since this study is confined to some particular forms of periodontitis, the discussion distinguishes between:
- experimentally induced periodontitis.
- adult periodontitis with horizontal or vertical bone loss.
- juvenile periodontitis.

The development of periodontal diseases is not dependent on the presence of specific bacteria (Van Palenstein Helderman, 1981). De Graaff (1981) however maintained that the Non-Specific Plaque Hypothesis is no longer tenable.

3.3.1 Experimental periodontitis

Lindhe et al. (1973) studied the disease features on the basis of periodontitis experimentally induced in beagles. Experimental periodontitis is in fact a continuation of gingivitis research. In the experimental periodontitis model they distinguished the following stages:

- subclinical gingivitis: increased effusion of crevicular fluid containing neutrophilic granulocytes, monocytes and lymphocytes.
- clinical gingivitis: the gingiva is red and swollen due to the increased blood supply resulting from vasodilatation; there is an increased bleeding tendency and secretion of crevicular fluid.
- destruction of the periodontium: loss of dento-alveolar fibres and radiographically visible bone loss; in Lindhe's experimental periodontitis model a loss of epithelial attachment of 0.1 mm occurred after 6 months, and unmistakable bone loss was observed after 18 months.

3.3.2 Periodontitis in adults

Periodontitis is an inflammatory process in the connective tissue which may lead to attachment loss and bone loss. Page and Schroeder (1982) described a number of characteristic features of adult periodontitis:

1. **Age of onset is usually 30-35 years or more.**
2. **The disease is not confined to first molars and incisors but molars and incisors are more commonly and more severely affected than are the canines and premolars.**
3. **The disease usually affects many teeth and there is no evidence of rapid progression.**
4. **Conditions enhancing plaque accumulation are present, and amounts of microbial deposits are consistent with the severity of the lesions.**
5. **No serum, neutrophil or monocyte abnormalities have so far been identified.**
6. **The extent and distribution of bone loss is highly variable; both vertical and horizontal patterns may be seen.**
7. **Highly acute inflammation with marginal poliferation of the gingiva is usually not seen.**
8. **Gingival tissues may be thickened and fibrotic.**
9. **Lesions are not as amenable to antibiotic treatment as with other forms of periodontitis.**
10. **At one or more sites the disease may convert to rapidly progressive periodontitis.**

Mechanism of periodontal destruction

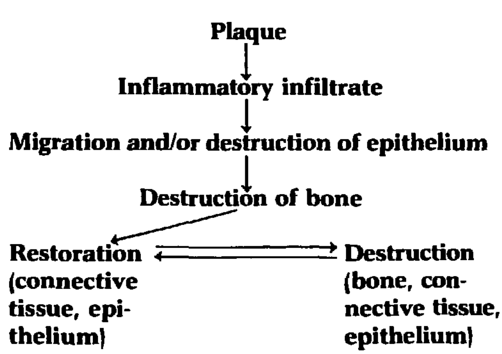
The mechanism of periodontal destruction has been described in detail by Page and Schroeder (1982). To summarize: clinically healthy periodontium is characterized by constant transport of neutrophilic granulocytes from the blood vessels in the gingiva through the connective tissue and epithelium to the gingival sulcus. The bacteria in the plaque produce substances which attract neutrophilic granulocytes through chemotaxis. Under normal circumstances a few neutrophilic granulocytes penetrating the tissues cause no damage. These cells constitute one of the defence mechanisms. They should prevent bacterial proliferation by killing and phagocytizing bacteria.

However, they are short-lived cells which sometimes are themselves killed by the bacterium, in which case enzymes may be released which are capable of destroying body tissues (e.g. connective tissue).

Pockets develop as follows. From a layer of bacteria on the surface of the tooth, bacteria or bacterial products enter the intercellular spaces of the sulcular epithelium. The presence of plaque causes an increased effusion of neutrophilic granulocytes through the vascular wall and increased migration via the connective tissue to the epithelium. The neutrophilic granulocytes massively migrating through the epithelium disturb its continuity. In principle, more plaque equates to more disruption of epithelium and an increased risk of dead cells. Upon failure of the defence mechanism, more and more neutrophilic granulocytes migrate through the epithelium, which can no longer protect the connective tissue. Ulceration results. Because the epithelial protection has disappeared, bacterial products can more easily enter the connective tissue. The neutrophilic granulocytes are activated and attempt to phagocytize bacteria and their products. The lysosomal enzymes released upon the disintegration of a neutrophil in their turn damage other cells and destroy extracellular tissue components. In the subsequent chain of reactions other cells such as lymphocytes, plasma cells, macrophages and osteoclasts are activated. In this process proteins are released (e.g. prostaglandins) which activate the destruction of connective tissue or bone.

Restoration of the epithelial layer is possible. This is associated as a rule with migration of epithelium along the tooth surface. As a result of the loss of connective tissue fibres and the epithelial migration, the gingiva is detached from the tooth. A periodontal pocket forms, which may have an inner lining of epithelium (so-called pocket epithelium). Bone loss occurs within the area involved in the inflammation and as a result of activation of osteoclasts by the inflammation. Within the pocket, periods of inactivity may alternate with acute flare-ups of the inflammatory process (Socransky et al., 1984). During periods of inactivity there may be some restoration of connective tissue and epithelium. Bone restoration as a rule does not occur. This implies that, in principle, bone destruction continues and reduces the fixation of the tooth in the alveolar bone, resulting in increased mobility.

A schematic representation of this process looks as follows:



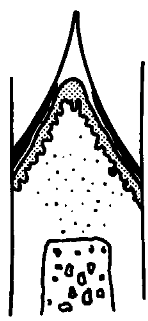
Types of bone lesion

The degree of bone destruction can vary widely, the pattern of bone loss being dependent on the anatomical conditions. Factors of importance in this respect are:
- thickness and width of the alveolar crests.
- thickness of the vestibular and oral cortical bone.
- the structure of the bone trabeculae and the size and shape of the marrow spaces.

Apart from the anatomical conditions within the bone, general factors (health, bone metabolism, etc.) and local factors (plaque, calculus, quality of the gingiva, etc.) can influence the pattern of bone loss. The following types can be distinguished:

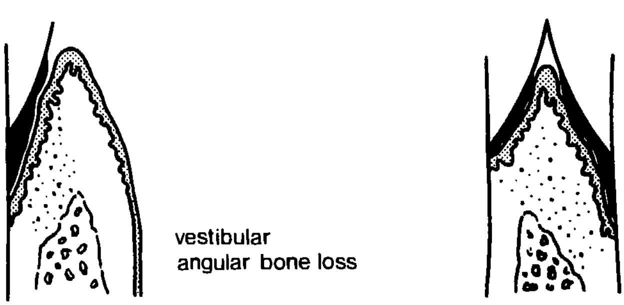
a. suprabony pocket,
b. infrabony pocket,
c. intrabony pocket.

The floor of the suprabony pocket is localized coronally to the alveolar bone level (Carranza and Glickman, 1957). Only horizontal bone loss takes place (fig. 3.1).
The floor of the infrabony pocket is localized apically to the level of the adjacent alveolar crest. The pocket wall lies between the root surface and the alveolar bone. Most infrabony pockets are interproximal pockets, but vestibular and oral pockets are also seen (Carranza and Glickman, 1957) (figs. 3.2). If an infrabony pocket has interproximal walls of bone, it is also known as intrabony pocket. Infrabony pockets can be classified according to the number of bony walls surrounding them (Goldman and Cohen, 1958; Carranza, 1979).



interproximal horizontal
bone loss

Fig. 3.1 Horizontal bone loss, the base of the pocket being localized coronally to the level of the underlying bone (suprabony pocket).



vestibular
angular bone loss

interproximal angular
bone loss

Fig. 3.2 Vestibular and interdental angular bone loss; the base of the pocket is localized apically to the level of the adjacent bone.

1. In the simplest case the lesion involves only one bone surface. This is a three wall infrabony pocket (fig. 3.3A).
2. More complex pockets involve two or more bone surfaces. These are four wall, two wall, one wall bone lesions (fig. 3.3B, C and D).
3. Combined forms are also encountered.

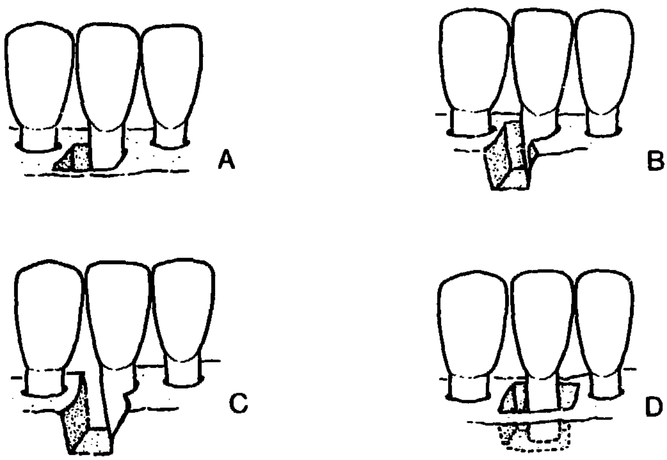


Fig. 3.3 A. Three wall bone lesion; B. Two wall bone lesion; C. One wall bone lesion; D. Four wall bone lesion.

Infrabony pockets can also be classified by their depth and width. The pocket may be: shallow and narrow, shallow and wide, deep and narrow, or deep and wide (Goldman and Cohen, 1958).

In a study of 337 skulls (Larato, 1970), intrabony pockets (three wall bone lesions) were found most frequently mesially to the second and third molars of the maxilla and mandible.

In cases showing severe recession of the gingiva and vestibular or oral bone loss, the furcation of multirooted teeth is involved in the bone lesion. Bone destruction may have progressed so far that no bone at all is found in the furcation. Larato (1970) studied the presence of furcation lesions in 305 skulls, and found that the mean number of teeth with furcation lesions per skull increased with increasing age. Most lesions involved the upper and lower first molars. A remarkable finding was that the number of lesions decreased with a more distal position of the tooth in the jaw. Both in the maxilla and in the mandible most lesions were found on the vestibular side. The functional life-span of a tooth seems to correlate with the occurrence of furcation lesions.

Hamp et al. (1975) proposed the following classification of clinical loss of attachment in the furcation area:
- horizontal loss of periodontal tissue support which equals or is less than 3 mm; access to the furcation entrance is limited.
- horizontal loss of periodontal tissue support which exceeds 3 mm, but not throughout the furcation area; the furcation entrance is readily accessible.
- horizontal loss of periodontal tissue support throughout the furcation area; the furcation is patent.

The pocket

Dorland's Medical Dictionary (24th edition, 1965) defines a pocket as: a sac-like space or cavity, such as an abnormal extension of a gingival sulcus (periodontal pocket). It defines an absolute pocket as a dental condition in which the deepening of the gingival sulcus entails migration of the epithelial attachment along the root and destruction of the periodontal membrane. It may be either gingival or infrabony.

A deepened, inflamed pocket is one of the principal clinical signs of periodontal disease. To be distinguished are:

- pseudopockets: these result from swelling and coronal displacement of the gingival margin; their depth exceeds 3 mm and the sulcular epithelium shows ulceration; they are not radiographically detectable.
- deepened, inflamed pockets: these result from apical displacement of the epithelial attachment, giving rise to a suprabony or an infrabony pocket.

According to Carranza (1979), the following clinical features of a pocket should be distinguished:

- the marginal gingiva is swollen and bluish-red, and is detached from the tooth surface.
- the gingivitis has extended to the attached gingiva and the alveolar mucosa.
- the interdental gingival epithelium may be interrupted.
- the gingiva is glossy, discoloured and swollen.
- pressure exerted on the gingiva produces a purulent exudate.
- the gingiva bleeds readily.
- teeth show increased mobility, extrusion and migration.
- diastemata may develop.
- in the presence of a pocket there is little or no pain.
- halitosis.

The depth of a pocket can be measured with the aid of a probe. A pocket is radiographically detectable only in so far as loss of alveolar bone has occurred.

3.3.3 Juvenile periodontitis

1. **Onset is at puberty only, but the diagnosis can be made at any age beyond puberty.**
2. **Lesions are predominantly confined to the permanent first molars and/or incisors, and their distribution is usually symmetrical.**
3. **Clinically, gingival tissues may appear to be entirely normal and the amount of microbial deposits is much less than might be expected.**
4. **Affected individuals appear to be more caries-resistant than others no affected.**
5. **The disease is about four times as prevalent in females than in males, and may be more prevalent in blacks than in other ethnic groups or races.**
6. **Prevalence among teenagers is estimated to be in the range of 0.06-0.2%.**
7. **Familial distribution is consistent with an X-linked dominant genetic trait.**
8. **Probably all affected individuals have functional defects in either neutrophils or monocytes; patients with defects in both cell types have so far not been found.**
9. **Lesions are highly active immediately after puberty but subsequently destruction may slow down or cease spontaneously.**
10. **Lesions are more responsive to treatment than was previously thought.**

Juvenile periodontitis is an uncommon form of periodontitis which usually occurs in individuals aged between 12 and 22 years (Waerhaug, 1977). Lehner et al. (1974) described periodontitis in patients aged 14-21 years as juvenile periodontitis, and that in patients aged 22-29 years as postjuvenile periodontitis.
The disease occurs locally. A striking feature is that deep pockets are often to be found near the incisors and first molars. This applies in lesser degree to the distal surface of the premolars. At cuspids, the other premolars and the second molars there are usually no pockets (Liljenberg and Lindhe, 1980). Waerhaug (1977) found subgingival plaque in areas showing loss of attachment and bone loss.
Page and Schroeder (1982) described the following characteristic features of juvenile periodontitis.

3.4 Periodontal lesions and the radiographic features

Periodontal lesions are diagnosed primarily on the basis of clinical findings. Next, radiography is used to determine the presence, extent and localization of bone destruction (Prichard, 1961). Requirements for proper interpretation of the radiographic features of bone lesions are:
- knowledge of normal anatomical relationships.
- knowledge of the normal radiographic features.
- knowledge of the pathology of the disease and of the radiographic changes it produces.

Prichard (1961) also outlined the limitations of radiographs:
- they do not show the periodontal pocket.
- they do not specifically distinguish between the successfully treated and the untreated case.
- they do not record the morphology of bone deformities.
- they do not show the structures on the buccal or lingual aspects of the tooth.
- they show no soft-to-hard tissue relationship.
- they do not record tooth mobility.

Several signs and symptoms of periodontitis can be detected clinically, radiographically, or by both methods.

Signs and symptoms	Clinical	Radiographic
colour of the gingiva	+	–
gingival recession	+	–
pocket depth	+	–
exudate from pocket	+	–
widened periodontal space	–	+
structure and surface of the alveolar crest	–	+
horizontal bone loss	–	+
vertical bone loss (approximal)	–	±
vestibular or oral bone loss	–	±
shape of alveolar crest	–	±
difference between vestibular and oral bone level	–	±

In order to gain a proper impression of the extent of the bone lesion in relation to tooth length, the entire tooth should be depicted on a periapical radiograph. The vertical angulation of the beam in relation to the tooth is of great importance in this context. The direction of the beam should be aimed as perpendicular as possible to the tooth in order to limit the degree of distortion. In the mandible the film can be positioned roughly parallel to the tooth axis. In the maxilla the shape of the palate precludes this, so that the film is mostly positioned at an angle with the tooth. Aiming devices can be used to position the film more parallel to the tooth. This is important because an attempt must be made to depict the level of the alveolar crest in the correct position in relation to the cemento-enamel junction, and to avoid a difference in height between its vestibular and its oral part as a result of the radiographic projection.

The bite-wing is the type of radiograph that depicts the area of the cemento-enamel junction as the most reliably (Van Aken, 1969). This is why the bite-wing is to be preferred to periapical radiographs for determination of the degree of bone resorption. The conventional bite-wing does not completely depict the alveolar bone when significant bone resorption has already taken place. This applies in particular when aiming devices are used. This difficulty can be overcome by using vertical bite-wings for patients with periodontal bone loss. Determination of bone height in order to measure the absolute amount of alveolar bone loss should therefore be done from this type of radiograph.

3.4.1 Widening of the periodontal ligament space

Van der Linden and Van Aken (1970) reported that a widened periodontal ligament space need not necessarily imply periodontal bone loss. Given a widening of the coronal part of the periodontal ligament space, it should be borne in mind that the coronal part of the space is slightly wider in an intact, healthy periodontium (Coolidge, 1937).

Marshall-Day and Shourie (1949) accepted widening of the marginal part of the periodontal space as indicating an incipient periodontal lesion.

Ainamo and Tammisalo (1973), who studied the width of the periodontal space, the continuity of the alveolar crest and the trabecular pattern on 100 bite-wing radiographs, were unable to demonstrate a correlation between the Gingival Index according to Löe and Silness (1963) (clinical situation) and the radiographic features. In a similar study of children, Hollander et al. (1966) reached the same conclusion.

3.4.2 Changes of the alveolar crest

In the presence of periodontitis the alveolar crest may show several changes (Wörth, 1963; Page and Schroeder, 1982):

- any cortical bone visible on the radiograph may become less radiopaque; the radiopaque outline may be interrupted or disappear completely; the superficial marrow spaces lose their superficial bony demarcation and seem open rather than closed.
- the radiopacity of the crest may diminish; the trabeculae at the surface of the alveolar crest or immediately beneath is become more radiolucent.
- decalcification may progress further; the trabeculae of the alveolar crest and those adjacent to them are lost, and bone loss can manifest itself in various ways.

According to Ritchey and Orban (1953) the alveolar crest may assume a concave, cup-like appearance. On the other hand, resorption may affect only one side of the crest, the crest level not being lowered.

There is no demonstrable correlation between the presence of a radiopaque alveolar crest and the presence or absence of clinical evidence of inflammation such as bleeding after pocket depth measurements, periodontal pockets or loss of epithelial attachment (Greenstein et al., 1981).

3.4.3 Periodontal bone loss

According to Herulf (1950), bone height is optimal if the distance to the cemento-enamel junction is about 1 mm. According to Belting et al. (1953), bone destruction has occurred if the distance between alveolar crest and cemento-enamel junction exceeds 2 mm.

A sign of incipient bone loss is a rounding of the 90° angle between the surface of the alveolar crest and the lamina dura. Other characteristic features of periodontal bone loss are:

- loss of height of the alveolar crest, indicating horizontal bone loss.
- local, partial bone destruction, indicating vertical or angular bone loss; as pointed out, these lesions can be classified as one wall, two wall, three wall and four wall bone lesions, or by depth and width (Goldman and Cohen, 1958; subsection 3.3.2).

Degrees of vestibular, oral or interdental and proximal bone loss may vary. This is expressed in the presence of two bone levels on the radiograph. Theilade (1960) observed that bone loss in the mandible was maximal at the cuspids, premolars and first and second molars. Bone loss mesially and orally to the tooth was observed at third molars. In a number of mandibles Theilade encircled the teeth with a metal wire at the level of the alveolar crest and then made radiographs which showed that the degree of bone loss is seriously underestimated from radiographs.

In the case of bone resorption vestibularly or orally to a tooth, a smaller part of the tooth is covered with bone. There is less absorption of roentgen rays and that part of the root in question is depicted as more radiolucent. If the interproximal bone level on one side is more coronally localized than that on the other side of the alveolar process, then the transition from the radiolucent to the radiopaque area corresponds with the level on the side of the process where resorption has been more pronounced. This means that two levels of bone demarcation are visible. In other situations, only one level may be visible, or none at all; this depends on the localization and shape of the vestibular and the oral bone level. The exact shape of the bone can only be determined during surgery which involves exposure of the bone (Orban T.R. and B.J., 1960).

More exact information on anatomical relations can be obtained by making radiographs at different vertical angles. In the mandible, radiographs at a vertical angle of 0° (beam perpendicular to the longitudinal axis of the tooth) give a projection showing the correct position of the vestibular and the lingual part of the bone. At an angle of +25° the vestibular level moves apically while the oral level more or less retains its position; and at an angle of −25° the vestibular level moves coronally while the oral level more or less retains its position. It can thus be established whether a lesion is localized on the vestibular or on the oral side of a tooth. The same method can also be used to determine whether vestibular or oral bone has been lost in the furcation. If density increases at +25°, then bone loss is mainly vestibular; if it increases at −25°, then bone loss is mainly oral (Orban T.R. and B.J., 1960). The reverse applies to the maxilla.

The floor of a pocket can be visualized radiographically if necessary. For this purpose radiopaque material has to be introduced into the pocket (e.g. a gutta-percha point, pocket probe, Hirschfeld point or bismuth solution).

3.4.4 Classification of periodontal bone loss on the radiograph

There is a need for a classification of periodontal bone lesions by severity.
Sheppard (1936) proposed a gradation of alveolar bone loss on periapical radiographs scored on a scale from 0 through 10: 1 indicating sufficient bone loss to be radiographically visible, 5 indicating loss of half the bone, and 10 indicating loss of the entire alveolar bone (alveolar crest at apex).
Millar and Seidler (1940) proposed a gradation on a scale from 0 through 5: 0 indicating no bone loss, 3 indicating loss of half the bone and 5 indicating bone loss as far as the apex of the alveolar crest.
Schei et al. (1959) developed a method to measure bone height as percentage of maximum bone height. Lindhe and Nyman (1975) related the degree of bone loss to tooth length. After a clinical diagnosis of inflamed pockets they used the following classification:

- periodontitis levis: pocket depth measurements and/or radiography indicate marginal bone loss of no more than one-third of the normal bone height.
- periodontitis gravis: horizontal bone loss of more than one-third of the normal bone height.
- periodontitis complicata: radiographic evidence of angular bone loss and/or discernible involvement of the furcation or mobility of the tooth involved.

3.5 Conclusions and discussion

A physiological recession of gingiva and alveolar bone (aging) occurs around every tooth (vestibular, oral and proximal aspects). No consensus about physiological recession can be found in the literature (Van der Velde, 1982). Consensus probably cannot be achieved because corresponding evidence of physiological aging elsewhere in the skeleton (osteoporosis, diminished vascularization and recuperation) are clinically not readily distinguishable from pathological resorption processes due to the frequently observed plaque formation. Clinical as well as radiographic findings are indispensable in making a diagnosis. For evaluation of therapeutic results, radiography is the most objective instrument (before, after and years after treatment).
Radiographs can record:

- the height of the vestibular alveolar crest (marginal).
- the height of the oral alveolar crest (marginal).
- the height of the proximal alveolar crest (end-teeth).
- the height of the interproximal alveolar crest.

They warrant conclusions about:

a. horizontal bone loss.
b. vertical bone loss, intrabony and angular.

In actual fact it might be better to refer to height reduction and lateral reduction of alveolar bone.

CHAPTER 4

EXPERIMENTAL BONE LESIONS

4.1 Introduction

By inducing experimental bone lesions, more information can be obtained on the radiographic features of bone structures and changes in these structures. Such experimental lesions can be induced under carefully standardized conditions with a predetermined shape and size. Moreover, their localization can be determined exactly and varied if necessary. In this way it is possible both to imitate the presence of a lesion in the bone structure and to simulate its changes in the course of time.
Such experiments demand detailed knowledge of the anatomy and of the radiographic features of the anatomical structures. The same applies to pathological affections and their radiographic features. With special reference to periodontal lesions, the following aspects merit attention:

- the clinical features of periodontal lesions.
- the radiographic representation of periodontal lesions.
- morphological factors which influence the radiographic representation of periodontal lesions.

The first two factors have been discussed in chapters 2 and 3. The third factor will be discussed in this chapter.

4.2 Review of the literature

In order to obtain more information on the radiographic representation of the alveolar process, several investigators studied the anatomical relation between the radices and cortical bone in mandibles and maxillae, and the structure of the alveolar bone (Bender and Seltzer, 1961), for instance by means of cross-sections through cadaver jaws.
Other investigators removed parts of the bone and studied the influence of this removal on the radiographic features. Goldman et al. (1957) removed the buccal and oral cortical bone of the maxilla and mandible. This had no effect on the trabecular pattern on the radiograph, but the optical density increased. In the maxilla the increase in optical density was less marked because the maxillary cortical bone is thinner than that of the mandible. Removal of the vestibular and oral alveolar bone had no effect on the radiographic image of the lamina dura of the alveolus, nor on that of the periodontal ligament space.
According to Bender and Seltzer (1961), extensive bone destructions are radiographically invisible under certain conditions. Their experiments warranted the conclusion that lesions were visible only if there had been perforation of the cortical bone or extensive destruction on the outside. Removal of bone on the inside of the cortical layer had the same effect as its removal on the outside. Lesions and perforations of the cortical bone produced a radiolucency which depended on the depth of the lesion. Lesions involving only the cancellous bone were not radiographically visible. Loss of the trabecular pattern on the radiograph was caused by removal of bone on the inside of

the cortical layer, at the junction between cancellous and cortical bone (junction area). Excavation of large amounts of cancellous bone was possible without any evidence on the radiograph. This implies that the trabecular pattern on the radiograph is formed in the junction area. The experiments were performed in periapical and periodontal bone, and the conclusions apply to both.

Ramadan and Mitchell (1962), too, experimentally induced bone lesions in a dry skull. Lesions in the alveolar crest did not become visible until they were 3 mm deep. As in the experiments of Bender and Seltzer, removal of oral or vestibular cortical bone was not radiographically visible. Lesions which left the buccal and lingual alveolar wall and the junction area intact, were not visible. These findings warranted the conclusion that infrabony pockets are not visible radiographically. The trabecular pattern did not change upon removal of the central cancellous bone of maxilla and mandible if the junction area remained intact. In the maxilla, removal of the junction area alone did not affect the trabecular pattern either. Joint removal of both junction area and cancellous bone did change the trabecular pattern. The editor's note added to this article points out that the soft tissues and the bone marrow influence the radiographic image. Moreover, the cancellous bone may have more effect if the cortical bone is thinner. The use of dry bone fragments contributes to more high contrasts in the film, which reduce minor differences in density in the representation of hard tissues. Soft tissues reduce the high contrasts in the radiograph. This would imply that soft tissues more rapidly reveal differences in optical density on the radiograph. It was therefore recommended to repeat the experiments with bone fragments to which a soft tissue substitute had been added. The above is at odds with the findings reported by Ardran (1951), who induced lesions in vertebral bodies filled with water and found that this in fact reduced the visibility of the lesions: more than 1 cm^3 cancellous bone had to be removed before they became visible.

Pauls and Trott (1966) likewise demonstrated that lesions in mandibular bone became visible upon perforation of the cortical bone or extensive removal of bone from the outer or inner surface of the cortical layer. Lesions involving only the cancellous bone did not become radiographically visible. The loss of trabecular pattern in a radiolucent area was largely a result of removal of bone in the junction area.

Schwarz and Foster (1971) also concluded that removal of sufficient cancellous bone to form an infrabony pocket was not radiographically visible. At odds with this conclusion they stated that removal of a large amount of cancellous bone resulted in increased density.

Rees et al. (1971) studied a number of skulls with periodontal bone lesions. The knowledge thus obtained was audited with the aid of radiographs of 11 intact mandibles and 9 intact maxillae from cadavers. Proximal bone lesions, interproximal craters and buccal and lingual furcation lesions were radiographically identifiable with great certainty. Lesions of the vestibular or oral surface at the sites of the teeth, however, could not be readily located or identified on the radiograph.

Shoha et al. (1974) concluded that lesions around the root apex of premolars and molars are always larger than the radiograph suggests. This applies in particular to the molar region. Changes in the premolar region were already visible before the junction area and cortical bone were involved in the lesion.

There is no well-defined strategy in these studies, which lack a high level of standardization and quantitation. Van der Stelt (1979) corrected this in a more systematic approach to the radiographic representation of bone and bone lesions. He performed standardized studies of the visibility of experimentally induced bone lesions. After inducing lesions in cortical and cancellous bone and in the junction area, he confirmed that a lesion is visible as a radiolucency if cortical bone has been removed. He, too, concluded that the radiographic trabecular pattern is formed in the junction area, which he defined as "the area in which a cross-section through the bone shows spaces visible to the naked eye (unlike those in cortical bone), which, however, have not yet attained the dimensions of spaces observed elsewhere in the bone (most of the cancellous bone)". Lesions limited to the cancellous bone had no discernible effect on the radiographic image. A lesion of the junction area changed the trabecular pattern but did not cause a radiolucency. Van der Stelt demonstrated both mathematically and empirically that a lesion of cortical bone should have at least a diameter of 0.6 mm and a depth of 1.2 mm to produce a visible radiolucency. In that case there was no visible change in the trabecular pattern.

Most of the experiments reported by the various investigators revealed that:
- removal of cancellous bone has no effect on the trabecular pattern and the radiographical density.
- removal of bone in the junction area causes a change in the trabecular pattern.
- a lesion of the cortical bone correspond with an increasing chance of a visible radiolucency.

Most investigators focused on the periapical region or removed the entire vestibular or oral cortical bone. Only Bender and Seltzer (1961) and Ramadan and Mitchell (1962) induced vertical lesion in the alveolar crest with a fissure bur, while Schwarz and Foster (1971) used a round bur for this purpose. Rees et al. (1971) examined lesions in skulls without themselves inducing lesions.

4.3 Study design

In view of the above it seemed useful to simulate the various periodontal bone lesions with their intermediate phases in experimental bone lesions induced step by step in the alveolar process. The purpose is to establish which morphological factors influence the radiographic image of bone lesions, in order thus to contribute to an improved interpretation of these bone lesions.

4.4 Materials and methods

Round burs were used to induce lesions in the interdental bone of the alveolar crest. Using burs of increasing diameter, the lesions were enlarged step by step in that 1, 2 3 or 4 walls cut away (Goldman and Cohen, 1958) (fig. 3.3). This procedure was used to imitate:
- a three-wall bone lesions bounded by the mesial, oral and vestibular walls.
- a two-wall bone lesion bounded by the mesial and the oral wall.
- a one-wall bone lesion bounded by the mesial wall.

Standardized reproducible radiographs were made of these lesions. The extent and type of extension of the lesion were recorded in writing, and impressions were made of all phases for subsequent identification of the changes induced in the bone fragment, and for comparison.

4.4.1 The radiographic procedure

The mandible was mounted on an optical bench (Micro Contrôle). The mandible was first cut in the midline. A resin lock fixed to the underside, fitted exactly in a holder of the object table on the optical bench. Thus ensuring that the object could always be replaced in exactly the same position. The focus-object distance was adjustable with the aid of a movable rider carrying the object. Using a system of object tables which enables translation in x and y direction rotation on a horizontal axis and rotation on a vertical axis, the object could be placed in any position desired (accuracy up to 0.1°). A compound leverage jack was used to adjust the height (Z-direction) (fig. 4.1). A light beam diaphragm on the roentgen apparatus was used to aim the roentgen beam. The reticle of the light beam diaphragm was aimed at the point of contact between the first and second premolar in the madible. The optical bench adjustment was noted down for subsequent reproduction (fig. 4.2).

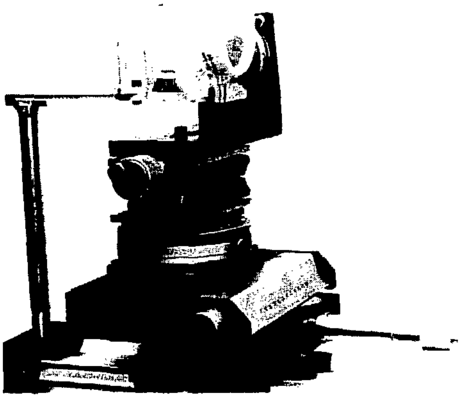


Fig. 4.1 Set-up of object table, compound leverage jack, mandibular fragment with soft tissue phantom and holder for roentgen films.

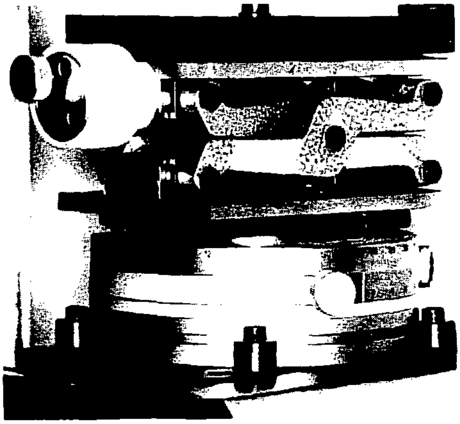


Fig. 4.2 Object table with gradation for positioning.

Fig. 4.3 Set-up for making reproducible radiographs.

As a substitute of soft tissues and bone marrow a phantom was placed on front of the mandible; this phantom consisted of 8 mm polymethylmetacrylate and 22.5 mm water, corresponding with 3 cm soft tissues and bone marrow (Van der Stelt, 1979). With the object table, a film holder and a roentgen apparatus (Philips Practix) were mounted on the optical bench (fig. 4.3). Tube voltage varied between 50 and 90 kVp, and tube current was 25 mA. The focus-object distance was 40 cm. The beam width of the roentgen apparatus could be adjusted with the aid of the light beam diaphragm, thus ensuring that the beam diameter corresponded with the film dimension. The object-film distance was 2 cm. The film was always positioned perpendicularly to the roentgen beam. This imaging geometry results in a neglectable radiographic magnification. An aluminium step wedge mounted on the film holder was used to standardize the optical film density. The film used was Kodak Ultra Speed DF 57, the developer was Kodak DX 80 and the fixer was Kodak FX 40. Developing time was 4 minutes at 20°C as stipulated by the manufacturer.

Van der Linden and Van Aken (1970) demonstrated in a test model that voltage and exposure time influence the width of the peridontal space on the radiograph by changing the film density. It was therefore imperative to perform the experiments with a correctly determined voltage and exposure time in combination with an appropriate developing technique in order to ensure constant film density. In order to determine the proper exposure time and correct voltage, series of films were exposed during 0.2 through 1.6 second at 60, 70 and 80 kVp and 25 mA. The exposure times were increased by steps of 25%. The exposed films were examined to select the film which optimally showed the pattern of the smallest bone trabeculae between the radices of the first and second bicuspid without an unfavourable influence of surrounding radiolucent areas. This proved to be the one exposed at 70 kVp and 25 mA.

In order to obtain films of the same density, the developer was tested with the aid of an Agfa Gevaert Curix RP test film before the films were developed. This test film is a pre-exposed film showing several series of grey values. Optical densities of the films exposed in the experiment can also be compared with the aid of the aluminium wedge mounted on the film holder. Using a digital density meter (Macbeth TD520 and TP78, fig. 4.4), the densities of the aluminium step wedges on the radiographs were measured and plotted in density curves. Only when the test films showed the appropriate density the exposed films were developed.

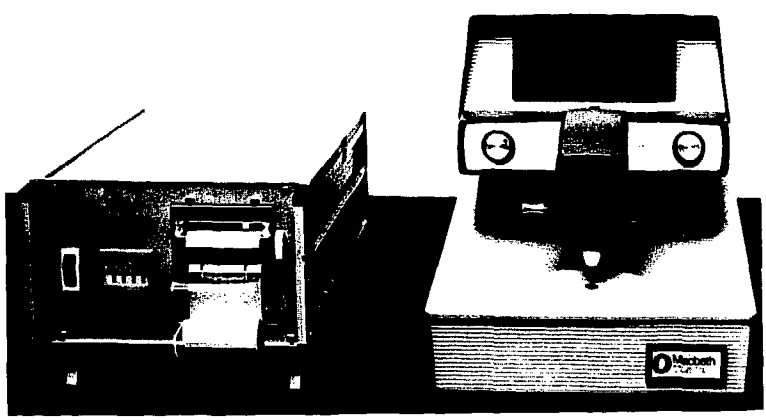


Fig. 4.4 Macbeth TD502 and TP78 digital density meter and printer.

4.4.2 The lesions

Using round burs (table 4.1), bone was removed from the interproximal alveolar crest in a mandible.

Table 4.1 Number and diameter of the burs used to remove bone

Bur number	Bur diameter (mm)
1/006	0.6
1/008	0.8
1/010	1.0
1/012	1.2
1/014	1.4
1/016	1.6
1/021	2.1
1/023	2.3
1/027	2.7

First experiment

In the first series of induced lesions efforts were made to keep them in accordance with the diameter of the bur used.
In the second series the lesions were enlarged in bucco-lingual direction and deepened until only the vestibular and the oral wall were still intact.
Subsequently these walls were likewise removed successively, and finally the bone vestibularly and orally to the premolars was removed.

Second experiment

To begin with, the round burs 1/008 through 1/016 were used to induce lesions between the cuspid and the first premolar. Next, the lesion in the alveolar crest was enlarged up to twice and thrice the diameter of a round bur 1/016.

Third experiment

The third experiment was performed between the second premolar and the first molar. Lesions were induced mesially to the first molar. Using round burs increasing from 1/006 through 1/012, the lesion was enlarged in bucco-lingual direction and deepened. Next, a bur 1/010 was used for step-by-step enlargement of the lesion in bucco-lingual direction, the buccal and the lingual wall were removed and bone was also removed buccally and lingually to the molar. Contrary to the first experiment (in which all bone between the first and second bicuspid was removed), the bone bounding the second bicuspid distally was left intact from the midline between the second bicuspid and the first molar on. The following phases can be distinguished in the extension of the lesion:

- one wall has been removed; the mesial, oral and vestibular walls are still intact.
- two walls have been removed; the mesial and oral walls are still intact.
- three walls have been removed; only the mesial wall is still intact.

4.4.3 Registration by means of impressions

Impressions of the lesions were made in the successive phases, using as tray a perforated piece of aluminium (Flexico, J and S Davis Ltd). This tray was adjusted to the shape of the jaw. Such that the distance between tray and mandible was about 2 mm throughout. Rubberjel Syringe Type I (Stolk, 1977) which was squirted onto the model with a Coeflex impression syringe, was used as impression material. Next, the tray (likewise filled with impression material) was placed on the model and the material was allowed to set. After removal of the impression from the model, it was poured out with Vel-mix Stone (Kerr Manufacturing Co).

4.4.4 Assessment of the registrations

The radiographs were projected on a screen at tenfold magnification and a tracing was made. The tracing comprised the bone area to be examined and the demarcation of the adjacent teeth. To begin with, the bone level of the initial radiograph was drawn on each tracing, followed by the size of the observed radiolucency caused by the lesion. In addition, a composite tracing was made on which all successive phases of the lesion were drawn. This provided an overall picture of the course of the extension of the lesion. At this stage radiographs, plaster casts and tracings were available for comparison, together with a description of the situation after each enlargement of the lesion. For each phase the size of the lesion was measured on the plaster cast and compared with that on the radiograph. For this purpose calipers with a 0.1 mm gradation (British Indicators Ltd) were used to measure the lesion on the plaster cast in vestibulo-oral and in mesio-distal direction. The depth of the lesion was measured with the aid of a gauge. Moreover, the intensity of the radiolucencies and the changes in the trabecular pattern on the radiograph were compared. On the basis of the tracing on which all visible boundaries had been drawn, the lesions could be divided into groups, each group comprising lesions showing roughly the same extension and density on the radiograph.

4.5 Results

The radiographic features of the lesion can be divided into:
- an increase in radiolucency.
- an extension of the radiolucent area.
- a gradual disappearance of the trabecular pattern.

The plaster casts of the poured impressions and the descriptions of the activities performed provided methods of registration for subsequent identification and comparison of the size of the lesion in the various phases.

First experiment

– *First series*

In this experiment lesions were induced between the first and second bicuspid of a mandible. Table 4.2 lists the diameters of the round burs used, the sizes of the lesion on the plaster cast, the sizes of the lesion on the radiographs and the sizes of the lesion on the traces of the radiographs. The descriptions of the various phases of the bone lesion, give a more complete impression of the changes induced in the bone.

Table 4.2 The various phases in the size of the bone lesion between the first and the second premolar as measured on the plaster cast, on the radiograph and on the tracing of the radiograph.

Phase	Round bur diameter (mm)	Size on the plaster cast (mm)	Size on the radiograph (mm)	Size on the tracing (mm)
0	–	–	–	–
1	1/008	b-l:0.8		
		m-d:0.8	b:0.8	b:0.8
		d:0.8	d:0.4	d:0.2
2	1/010	b-l:0.7		
		m-d:0.9	b:1.0	b:0.9
		d:0.7	d:0.6	d:0.3
3	1/012	b-l:1.3		
		m-d:1.0	b:1.0	b:0.8
		d:0.8	d:0.6	d:0.4
4	1/014	b-l:1.5		
		m-d:1.4	b:1.5	b:1.5
		d:1.2	d:1.3	d:1.0
5	1/016	b-l:2.3		
		m-d:2.2	b:1.4	b:1.8
		d:1.4	d:1.4	d:1.5
6	1/018	b-l:2.3		
		m-d:2.1	b:1.4	b:1.8
		d:1.4	d:1.6	d:1.1
7	1/021	b-l:2.1		
		m-d:2.1	b:1.5	b:1.9
		d:2	d:1.6	d:2.0
8	1/023	b-l:2.1		
		m-d:2.3	b:2.3	b:2.5
		d:2.1	d:1.7	d:2.1
9	1/016	b-l:2.8		
	2x	m-d:2.3	b:2.3	b:2.4
		d:2.1	d:2.0	d:2.5
10	1/016	b-l:3.5		
		m-d:2.3	b:2.2	b:2.4
		d:2.3	d:2.3	d:2.5
11	1/016	b-l:3.8		
		m-d:2.3	b:2.3	b:2.4
		d:2.3	d:2.3	d:2.5
12	1/016	b-l:3.8		
		m-d:2.3	b:2.3	b:2.5
		d:2.5	d:3.2	d:2.9
13	1/016	b-l:4.0		
		m-d:2.3	b:2.7	b:2.7
		d:2.8	d:4.0	d:4.2
14	1/016	b-l:4.2		
		m-d:2.3	b:2.7	b:2.7
		d:3.0	d:4.2	d:4.2
15	1/016	b-l:5.0		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.3	d:4.3

Phase	Round bur diameter (mm)	Size on the plaster cast (mm)	Size on the radiograph (mm)	Size on the tracing (mm)
16	1/016	b-l:6.2		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.2	d:4.1
17	1/016	b-l:6.2		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.4	d:4.2
18	1/016	b-l:6.3		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.3	d:4.2
19	1/016	b-l:6.9		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.2	d:4.4
20	1/016	b-l:7.1		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.2	d:4.2
21	1/016	b-l:7.7		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.2	d:4.1
22	1/016	b-l:8.8		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.5	d:4.2
23	1/016	b-l:8.8		
		m-d:2.3	b:2.7	b:2.7
		d:3.1	d:4.5	d:4.4

The numbers in the first column refer to the various phases in the size of the bone lesion, which can be defined as follows.

0 In this phase, no lesions have as yet been induced. Examination of plaster cast and phantom reveals that the alveolar crest has a depression with a depth of 0.8 mm and measuring 1.5 mm in mesio-distal direction and 1.4 mm in bucco-lingual direction. This is not visible on the radiograph (fig. 4.5).

Fig. 4.5 Radiograph of the object (without experimentally induced lesions)

1 Using round burs 1/008, 1/010 and 1/012, a lesion is induced with a diameter
2 which equals the diameter of the bur used. The above-mentioned depres-
3 sion and the lesion with the size of the round bur are visible on the plaster

cast. The lesions are radiographically visible (fig. 4.6): the radiolucency increases and the trabecular pattern is disappearing. On the tracing the radiolucencies of 1, 2 and 3 are roughly of equal size (fig. 4.7). The size of the radiolucent area on the tracing is less than that of the lesion on the plaster cast.

Fig. 4.6 Radiograph of a lesion induced with round bur 1/012.

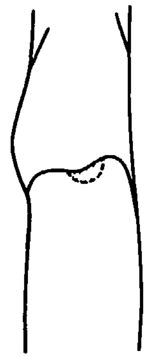


Fig. 4.7 Tracing of the radiograph of a lesion induced with round bur 1/012.

4 A lesion is induced using round burs 0/014 and 0/016 respectively.

5 Two radiolucent areas are visible on the radiograph: the radiolucency of the upper area roughly equals that of the interproximal space; the lower area shows less marked, evenly distributed density and practically no trabecular pattern. On the tracing, 4 and 5 are about equally large but larger than 3. At 4 and 5 the lesion and the radiolucency are roughly of equal size; at 5, the lesion is slightly larger than at 4.

6 A lesion has been induced using round bur 1/018. The plaster cast shows the depression and the lesion as roughly of the same size as the bur diameter. The radiolucency has increased again, and the trabeculae are virtually invisible. As compared with 5, the lesion on the tracing (fig. 4.9) has become deeper and the size in mesio-distal direction has also increased. Yet the lesion on the radiograph is narrower than the lesion on the cast. The depth of the lesion is roughly the same on cast and radiograph (fig. 4.8) but the width of the lesion is less on the radiograph.

Fig. 4.8 Radiograph of a lesion induced with round bur 1/018.

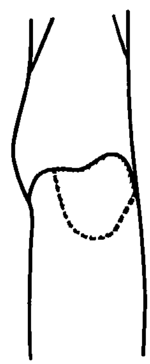


Fig. 4.9 Tracing of the lesion induced with round bur 1/018.

7 The lesion has been enlarged using round bur 1/021. The plaster cast shows the depression and the lesion as roughly the size of the bur diameter.
There are two distinguishable areas on the radiograph:
- one showing disappearance of the trabecular pattern and no radiopacity.
- the other showing a cervico-apical increase in radiopacity and apically a slight indication of a trabecular pattern.

On the tracing, 6 and 7 are about equally large.
The size of the lesion on the cast exceeds that on the radiograph.

8 A bur 1/023 has been used because larger burs no longer fit between the teeth. Lesion and depression are beginning to fuse. The radiolucency is like that described in 7, but significantly larger (fig. 4.10). On the tracing, 8 is significantly larger than 7 (fig. 4.11).
The lesion on the radiograph is smaller than that on the cast.

Fig. 4.10 Radiograph of a lesion induced with round bur 1/023. The lesion has a depth of 2.1 mm and measures 2.3 mm in mesio-distal direction. On the radiograph the depth is 1.7 mm and the diameter is 2.3 mm. The visibility of the trabecular pattern is reduced.

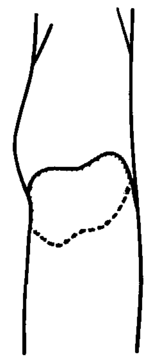


Fig. 4.11 Tracing of the radiograph of the lesion induced with round bur 1/023.

Second series

9 Using bur 1/016, the lesion has been enlarged in vestibulo-oral direction to twice the size of the bur. Lesion and depression have virtually fused; the lesion measures 2.8 mm in vestibulo-lingual and 2.3 mm in mesio-distal direction.

Fig. 4.12 Radiograph of a lesion induced with round bur 1/023 and enlarged in vestibulo-lingual direction to twice the size of bur 1/016.

As compared with 8, the radiolucency in the bone mesially to the second premolar increases and the trabecular pattern changes at this site (fig. 4.12). On the tracing, 8 is larger than 9.
The lesion on the radiograph is significantly smaller than that on the cast.

10 The lesion has been enlarged in buccal and lingual direction until only the buccal and lingual bone walls are still intact. The radiograph shows a well-defined radiolucency without trabecular pattern distally to the first premolar. Mesially to the second premolar the radiolucency has increased and the trabecular pattern is still present but has changed. The tracings of 9 and 10 are equally large. The lesion on the cast is of the same size as that on the radiograph in mesio-distal direction (fig. 4.13).
From phase 10 on, enlargement can take place only in apical, buccal and lingual direction while removing the walls.

Fig. 4.13 Radiograph of the lesion with only the buccal and the lingual wall still intact.

11 The entire lesion has been deepened using bur 1/016. There are two sharply defined radiolucent areas. Distally to the first premolar trabeculae are no longer present, and mesially to the second premolar the trabecular pattern is fading. The deepening of the size of bur 1/016 is not visible. Distally to the first premolar the periodontal space is still present; mesially to the second premolar it is disappearing. On the tracing, the deepening of the size of bur 1/016 is not visible.

12 After further deepening with 1/016 the radiolucency in the cervival part of

Fig. 4.14 Radiograph of the lesion deepened with round bur 1/016.

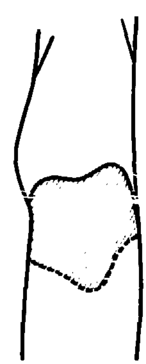


Fig. 4.15 Tracing of the radiograph of the lesion deepened with round bur 1/016.

the lesion has increased. The trabecular patterns of 11 and 12 are about the same (fig. 4.14). The excavation is visible on the tracing of the radiograph (fig. 4.15). The lesion on the cast is about equally deep as that on the radiograph.

13 Using bur 1/016, the lesion has been excavated in apical direction; at 14 and
14 15 it has been enlarged buccally and part of the cortical layer has been remo-
15 ved until, at 16, the buccal wall has been removed. The lingual wall is still
16 quite intact. The cast shows that the lesion has become deeper at 13. At 14 and 15 the buccal wall is becoming thinner and at 16 about half this wall has been removed.

The radiolucency increases at 14 and 15. At 16 there is still a dinstinctly increasing radiolucency in the area where the buccal wall has broken. At 13, the trabecular pattern distally to the first premolar has disappeared. At 14 the boundary between the mesial and the distal part of the radiolucency starts fading; at 15 it has virtually disappeared. At 14 and 15 the remaining trabecular pattern is beginning to disappear; at 15, a trabecular pattern is still visible at the bottom of the lesion. The tracings are about equal, but at 13 size has significantly increased as compared with 12 (fig. 4.17).

The size of the lesion on the cast is about the same as that of the more radiolucent area on the radiograph (fig. 4.16).

Fig. 4.16 Radiograph of the lesion after removal of part of the buccal wall.

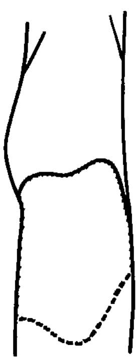


Fig. 4.17 Tracing of the radiograph of the apically deepened lesion.

17 The entire buccal wall has been removed. There is a well-defined evenly distributed radiolucency. The radiolucency has increased again. A trabecular pattern is still visible at the bottom of the lesion (fig. 4.18). The tracing is about the same as that of 16 (fig. 4.19). The size of the lesion on the cast roughly equals that of the well-defined radiolucency on the radiograph.

18 Bucally to the second premolar the bone has been removed to halfway the buccal surface. The cast shows the removal of a thin layer of buccal bone. On the radiograph the floor of the lesion takes a more horizontal course in distal direction. Otherwise the radiograph is the same as at 17 (fig. 4.20). The bone removed bucally to the tooth (cast) is not visible on the radiograph.

Fig. 4.18 Radiograph of the lesion after removal of the entire buccal wall. The lesion has two walls. In the remaining wall no trabecular pattern is visible.

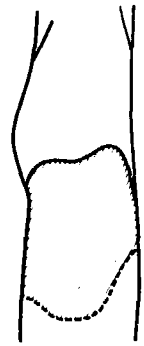


Fig. 4.19 Tracing after removal of the buccal wall.

Fig. 4.20 Radiograph of the lesion after partial removal of the buccal bone at the second premolar.

19 Lingually, bone has been removed to the size of bur 1/016; the lingual wall
20 becomes thin at 19. At 20, another thickness of bone equal to the size of bur
21 1/016 has been removed. At 21, part of the lingual wall equal to the size of
22 bur 1/016 has been removed, and at 22 the entire lingual wall has been removed. On the cast, the lingual bone wall is visibly excavated at 19. At 20 this process has advanced and part of the wall has disappeared. At 21 about half the wall has been removed, and at 22 the entire wall has gone. The radiolucency at 19 slightly exceeds that at 18. The trabecular pattern, too, has become slightly less distinct. The upper part of the radiolucency at 20 has an optical density which equals that of the interproximal space. The remainder practically no longer causes radiopacity (fig. 4.21). The radiograph clearly shows the removal of bone at 21. At careful examination of the bone at the site of the second premolar, two bone levels are visible superposed on the tooth. The boundary of the buccally removed bone is visible, as is the course of the lingual level (fig. 4.22). The boundary of the bone removal is sharply defined on the radiograph at 22.

The tracings of 18, 19, 20, 21 and 22 are virtually the same (fig. 4.23).

At 19 the excavation visible on the cast is represented by a radiolucency. The size of the lesion on the model after removal of part of the lingual wall (phase 20) is represented by an additional radiolucency of the same size as the part removed. This situation continues until at 21 and 22 the entire lingual wall has been removed (cast). The extent of the radiolucency on the radiograph equals that of the lesion on the cast.

Fig. 4.21 Radiograph of the lesion after partial removal of the lingual bone.

Fig. 4.22 Radiograph of the lesion after removal of most of the lingual bone. The buccal and the lingual bone level are both visible.

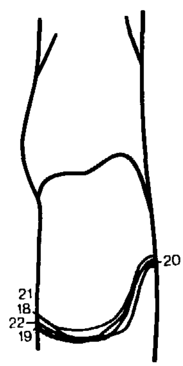


Fig. 4.23 Tracing of phases 18, 19, 20, 21 and 22.

23 Bone has been removed lingually to the second bicuspid. The bone thickness shows a marked cervico-apical increase. The radiograph shows a marked increase in radiolucency over the radix of the second bicuspid. The boundary of bone removal buccally and lingually to the tooth is clearly visible (fig. 4.24).

Fig. 4.24 Radiograph of the lesion after partial removal of the lingual bone at the second premolar.

The tracing of 23 equals that of 22 (fig. 4.25). However, over the radix of the second bicuspid it shows a well-defined boundary of bone removal. The clear demarcation of the lesion is probably due to the fact that the lower part of the removed lingual bone is fairly thick.
The size of the lesion on the cast after removal of bone lingually to the tooth roughly equals that of the radiographically visible lesion.
Fig. 4.26 presents an overview of the tracings from phase 0 through phase 23.

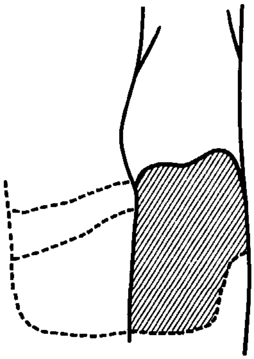


Fig. 4.25 Tracing of the lesion after partial removal of the lingual bone at the second premolar.

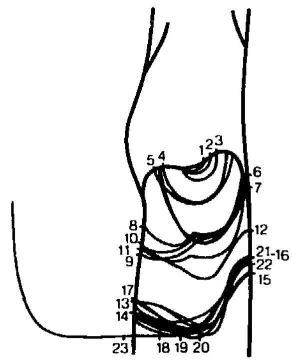


Fig. 4.26 Overview of the tracings from phase 0 through phase 23.

Second experiment

The second experiment was confined to inducing only small lesions in the alveolar crest between cuspid and first premolar. Examination of the still intact cast shows that the intact surface of the alveolar crest between cuspid and premolar is fairly smooth. The radiograph, however, already reveals a well-defined radiolucency without a trabecular pattern.
Table 4.3 lists the various phases in the size of the lesion with the corresponding bur diameters and lesion sizes measured on the plaster cast, on the radiograph and on the tracing of the radiograph. The descriptions of the various phases of the bone lesion give a more complete impression of the changes induced in the bone.

The phases indicated by the numbers in the first column can be defined as follows.
1 Round burs 1/006, 1/008 and 1/010 are used to induce an incipient lesion.
2 Once it is through the crest, the bur sinks away. The impression shows that
3 the alveolar process contains a cavity (fig. 4.27). On the plaster cast the
phantom shows an aperture the size of the round bur. The radiograph shows
no change in density (fig. 4.28).

4 The lesion has been enlarged using burs 1/012 and 1/014 respectively. The
5 cast shows an aperture the size of the bur used. The radiograph shows a
slightly increasing radiolucency in the alveolar crest, which is more distinct
at 5 (fig. 4.29). The tracings of 4 and 5 reveal the change in radiolucency
(fig. 4.30).
6 After using bur 1/016, the features are about the same as in 5.

Fig. 4.27 Rubberjel impression of the phantom showing the cavity in the bone.

Fig. 4.28 Radiograph of the lesion between cuspid and premolar.

Fig. 4.29 Radiograph of the lesion induced with round bur 1/014.

Fig. 4.30 Tracing of the lesion induced with round bur 1/014.

7 The lesion has been enlarged with bur 1/016. On the cast, the aperture in the crest has become much larger. The radiograph shows increased radiolucency. The tracing indicates a slightly larger radiolucent area. A large lesion is visible on the cast, but this causes but little change in density on the radiograph.

8 The lesion has again been enlarged with bur 1/016. The cast shows that only the buccal and the lingual wall are still intact. Comparison of the radiograph with those of previous phases does not permit the prediction that the lesion on the cast is so extensive. The radiograph shows a well-defined radiolucency (fig. 4.31). The tracing reveals that the size of the lesion has increased (fig. 4.32).
Fig. 4.33 presents an overview of the tracings from phase 0 through phase 8.

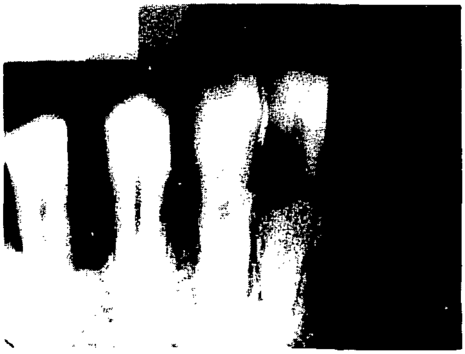


Fig. 4.31 Radiograph of the lesion between cuspid and premolar with the buccal and the lingual wall still intact.

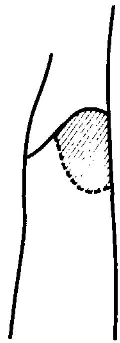


Fig. 4.32 Tracing of the lesion with the buccal and the lingual wall still intact.

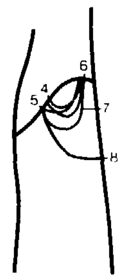


Fig. 4.33 Overview of the tracings from phase 0 through phase 8.

Table 4.3 The various phases in the size of the bone lesion between cuspid and first premolar as measured on the plaster cast, on the radiograph and on the tracing of the radiograph.

Phase	Round bur diameter (mm)	Size on the plaster cast (mm)	Size on the radiograph (mm)	Size on the tracing (mm)
0	–	–		
1	1/006			
2	1/008			
3	1/010	b-l:0.9		
		m-d:1.1		
		d:n.d		
4	1/012	b-l:1.0		
		m-d:0.9	b:0.6	b:0.7
		d:n.d.	d:0.5	d:0.5
5	1/014	b-l:1.0		
		m-d:1.0	b:0.7	b:0.7
		d:1.4	d:0.7	d:0.8
6	1/016	b-l:1.3		
		m-d:1.0	b:0.7	b:0.9
		d:1.0	d:0.7	d:0.7
7	1/016	b-l:2.5		
	2x	m-d:1.0	b:0.9	b:1.0
		d:1.4	d:0.9	d:1.0
8	1/016	b-l:1.2		
	3x	m-d:3.6	b:1.3	b:1.3
		d:2.4	d:1.7	d:1.9

Third experiment

In the third experiment, bone lesions were induced in the alveolar crest between the second premolar and the first molar, in the bone adjacent to the latter. The bone adjacent to the second premolar remained intact.

Table 4.4 lists the various phases of the third experiment with the corresponding measurements. The table is followed by a detailed description of the various phases.

The phases indicated by the numbers in the first column can be defined as follows.

1 Lesions 1 through 4 have been induced with burs 1/006, 1/008, 1/010 and
2 1/012 respectively. The cast shows that the lesion is gradually increasing in
3/4 size. At 4 it is not yet quite certain whether a radiolucency is visible.

5 The lesion has been enlarged and deepened in buccal direction, using bur 1/012. The radiograph shows an ill-defined radiolucency. The trabecular pattern seems to be fading (fig. 4.34). On the cast, the lesion has a depth of about 1.7 mm (bur diameter); it measures 2.8 mm in vestibulo-lingual and 1.8 mm in mesio-distal direction.

Fig. 4.34 Radiograph of the lesion after buccal and apical enlargement with round bur 1/012.

6 The lesion is further enlarged in buccal and lingual direction.
7 The cast shows enlargement of the lesion until ample buccal and lingual
8 walls are still intact (at 9). The demarcation on the radiograph becomes more
9 distinct: increasing radiolucency and gradual disappearance of the trabecular pattern. At 9, the trabecular pattern has virtually disappeared and the lesion is sharply defined (fig. 4.35). The tracing is more or less unchanged (fig. 4.36). The radiograph seems to show further extension in apical direction than the cast.

10 Buccal and lingual bone has been removed, but the walls are still-standing.
11 The radiograph shows incipient disappearance of bone structure, a trabecular pattern still being visible only in the lower part of the radiolucent area. The tracing has remained more or less unchanged. The still-present walls produce a radiopacity with a very slight trabecular pattern.

12 The buccal wall has been removed. The cast shows that the floor of the buccal wall has been removed in its entirety. Only on the floor of the lesion does the radiograph still show a bone radiopacity (fig. 4.37). The tracing shows about the same size as that in 11. The still-present lingual wall appears to contribute but little to the radiopacity.

Table 4.4 The various phases in the size of the bone lesion between the second premolar and the first molar as measured on the plaster cast, on the radiograph and on the tracing of the radiograph.

Phase	Round bur diameter (mm)	Size on the plaster cast (mm)	Size on the radiograph (mm)	Size on the tracing (mm)
0	–	–	–	–
1	1/006	b-l:0.8 m-d:0.8 d:0.8		
2	1/008	b-l:1.2 m-d:1.6 d:1.0		
3	1/010	b-l:1.8 m-d:1.2 d:0.9		
4	1/012	b-l:2.3 m-d:1.4 d:1.1		
5	1/012	b-l:2.8 m-d:1.8 d:1.7	 b:1.3 d:2.3	 b:1.0 d:2.3
6	1/012	b-l:4.9 m-d:1.7 d:1.7	 b:1.3 d:2.5	 b:1.2 d:2.3
7	1/010	b-l:6.4 m-d:1.8 d:1.9	 b:1.3 d:3.0	 b:1.3 d:3.0
8	1/010	b-l:6.8 m-d:1.7 d:2.3	 b:1.3 d:2.9	 b:1.5 d:2.7
9	1/010	b-l:6.9 m-d:1.7 d:2.5	 b:1.3 d:3.0	 b:1.4 d:2.8
10	1/010	b-l:7.5 m-d:1.8 d:2.5	 b:1.4 d:3.1	 b:1.3 d:3.0
11	1/010	b-l:7.8 m-d:1.8 d:2.5	 b:1.3 d:3.2	 b:1.4 d:2.8
12	1/010	b-l:8.8 m-d:1.6 d:2.7	 b:1.4 d:3.3	 b:1.3 d:2.8
13	1/010	b-l:9.3 m-d:1.8 d:2.5	 b:1.3 d:4.5	 b:1.3 d:4.5
14	1/010	b-l:10.8 m-d:1.8 d:2.4	 b:1.3 d:4.5	 b:1.3 d:4.6
15	1/010	b-l:11.3 m-d:1.8 d:2.5	 b:1.3 d:4.6	 b:1.4 d:4.6

Fig. 4.35 Radiograph of the lesion between the second premolar and the first molar after enlargement of the cast in vestibulo-lingual direction.

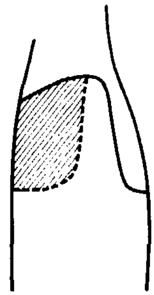


Fig. 4.36 Tracing of the lesion between the second premolar and the first molar.

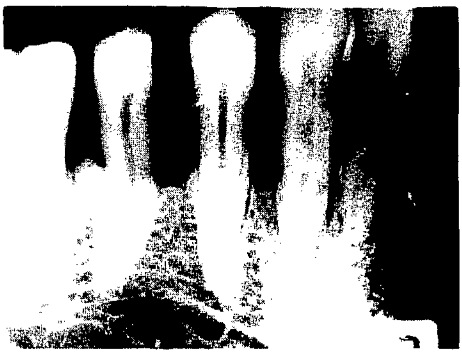


Fig. 4.37 Radiograph of the lesion after removal of the buccal wall.

13 The lingual wall has been removed. As compared with 12, an additional radiolucency in apical direction has developed (fig. 4.38). Although only lingual bone has been removed, the radiolucency is extended in apical direction. The tracing shows a significant apical increase in depth (fig. 4.39).

Fig. 4.38 Radiograph of the lesion after removal of the lingual wall.

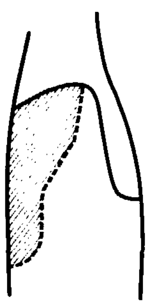


Fig. 4.39 Tracing of the lesion after removal of the lingual wall.

14 Buccal bone has been removed at the site of the molar, the bone removed having a thickness of about 1 mm. The radiolucency buccally to the tooth

has increased, and a periodontal space is still visible in the area of increased radiolucency.

15 Lingual bone has been removed at the site of the molar, the bone removed being thinner than that on the buccal side. Buccal and lingual bone has now been removed to the same level. Yet the radiograph shows two entirely differently demarcated radiolucencies (fig. 4.40). A periodontal space is no longer visible in the radiolucent area. The demarcation extends as far as the level of lingual wall removal. Fig. 4.41 presents an overview of the tracings from phase 0 through phase 15.

Fig. 4.40 Radiograph of the lesion after removal of buccal and lingual bone at the first molar.

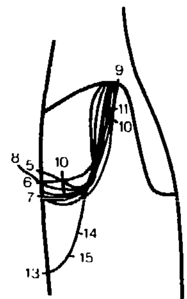


Fig. 4.41 Overview of the tracings from phase 0 through phase 15.

4.6 Conclusions

The first experiment started by inducing a bone lesion in the centre of the interdental septum. Invariably, the true size of the bone lesion was found to exceed its radiographic size. Example: a bone lesion with a depth of 2.1 mm on the plaster cast and a width of 2.3 mm produced a radiolucency with a depth of 1.7 mm and a diameter of 2.3 mm, with diminished visibility of the trabecular pattern (phase 8) (fig. 4.10).
Removal of the buccal wall caused a lesion in which the lingual wall was still intact. A sharp demarcation between lesion and normal bone was visible on the radiograph. No trabecular pattern was visible over the lingual wall (phase 17) (fig. 4.18).
Removel of the lingual wall caused a lesion with a lower level of the entire interdental septum. Buccal and lingual bone were also removed at the site of the tooth. The lower bone demarcation was clearly visible on the radiograph and also on the root of the tooth (phase 23) (fig. 4.24).
In the first experiment, removal of cancellous bone in the alveolar crest of the alveolar process was almost immediately manifested radiographically as an increase in radiolucency and disappearance of the trabecular pattern. In small lesions, the size of a radiolucency was somewhat smaller than the size of the lesion induced. Larger lesions caused a radiolucency of about the same size as the lesion induced. Removal of cancellous bone thus resulted in increased radiolucency and, with an increase in the size of the lesion, in diminished visibility of the trabecular pattern. **Larger lesions** caused a **sharply defined** radiolucency on the radiograph.
Removal of the cortical layer was followed by a marked increase in radiolucency. Removal of only buccal or lingual bone at the site of a tooth was invisible or virtually

invisible on the radiograph. Removal of both buccal and lingual bone, however, was visible.

In the second experiment a bone lesion was induced in the centre of the interproximal septum. A lesion with a depth of 2.4 mm and measuring 3.6 mm in vestibulo-lingual direction was radiographically hardly visible (phase 8) (fig. 4.31).

The second experiment demonstrated that a large lesion may be induced in the bone before it becomes evident radiographically. It should be borne in mind that the bone at this site is of very low density, as already apparent from the wider spacing of the bone trabeculae while the lesions were being induced.

The third experiment started by inducing a lesion with one wall removed (the mesial, oral and vestibular walls remaining intact); this lesion was radiographically visible if it had a depth of 1.7 mm and measured 2.8 mm in vestibulo-lingual and 1.8 mm in mesio-distal direction (phase 5) (fig. 4.34). After enlargement of the lesion by removal of two walls (the mesial and oral walls being still intact), the radiograph no longer showed visible bone at the site of lingual bone removal (phase 12) (fig. 4.37). After removal of the lingual wall, leaving only the mesial wall intact, the radiograph showed an apical increase in radiolucency when compared with the previous lesion. This was caused by the slope of the interdental bone in relation to the axis of the roentgen beam (phase 13) (fig. 4.38). Removal of buccal and lingual bone at the site of a tooth was radiographically visible (phase 15) (fig. 4.40). In the third experiment the lesion was already fairly large before it became radiographically visible. Enlargement of the lesion resulted in gradually increased radiolucency.

The cortial bone can be regarded as a structure with a very dense trabecular structure. The trabeculae are slightly wider spaced in the area of transition from cortical to cancellous bone (the junction area), and in cancellous bone they are spaced even wider or very far apart. This is schematically represented in fig. 4.42a (Van der Stelt, 1979). The experiments warrant the conclusion that the difference in trabecular density between cortical and cancellous bone is less marked in the coronal than in the apical region (fig. 4.42b).

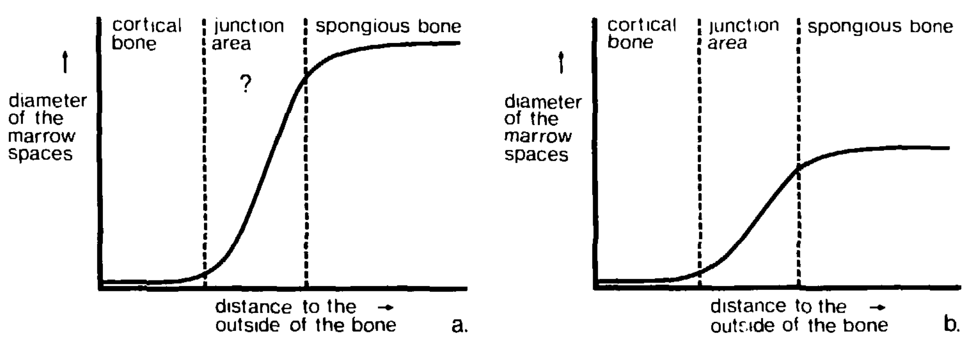


Fig. 4.42 Schematic [illegible]esentation of the junction area between cortical and cancellous bone in relation to the spacing of the trabec[illegible] a periapical region; b periodontal region (after Van der Stelt, 1979).

In summary, it can be stated that:

- a radiolucency of the coronal aveolar process can be caused by a lesion in the cancellous bone, the junction area or the cortical bone.
- the trabecular pattern is formed in the cancellous bone and the junction area.
- the density of the various structures plays an important role.

With regard to periodontal lesions this implies that:

- destruction of the cancellous bone of the alveolar process influences the radiolucency and the trabecular pattern on the radiograph.
- affection of the junction area influences the trabecular pattern.
- affection of the cortical bone influences the radiolucency.

With regard to the radiographic visibility of periodontal structures, the following can finally be stated:

- bucco-lingual enlargement of a lesion with removal of one wall causes an increase in radiolucency which, however, is not immediately visible as an increase in the size of the lesion.
- after removal of two walls, bone is still visible with virtually no trabecular pattern and markedly increased radiolucency.
- removal of three walls is clearly visible by the absence of radiopaque structures.

Tracings permit comparison of lesion sizes but are not suitable for comparison of the optical density of radiolucencies. Comparison of the lesion on the cast with the image on the radiograph shows that the true size of the lesion exceeds the size suggested by the radiograph. The angulation of the roentgen beam in relation to the alveolar crest can make the depth of a lesion seemingly deeper.

4.7 Discussion

The radiographic visualization of an experimental bone lesion appears to differ in the three experiments performed. The lesion was rapidly visualized in the first experiment but not in the second and the third. However, these differences can be explained by differences in the structure and thickness of the bone involved.

A lesion becomes visible once a particular amount of bone has been removed. According to Van der Stelt (1979) a lesion in the cortical bone of the corpus mandibulae becomes visible when it has a depth of 1.2 mm and a diameter of 0.6 mm. This implies that a lesion in cancellous bone with its less dense structure must measure 9.2 mm before it becomes detectable. Owing to the difference in structure between apical and coronal bone, especially the relative amounts of cortical and cancellous bone, these values are not directly applicable to periodontal lesions.

In the first experiment a lesion rapidly became visible when only little cortical bone was present or when the cancellous bone of the alveolar process was of dense structure. In that case the lesion was visible even if it was still confined to the cancellous bone. The structure of the junction area seems to be virtually identical to that of the cancellous bone.

In the second experiment the alveolar process was of low structural density. This meant low visibility of the lesion induced because removal of low-density cancellous bone is not radiographically visible.

In the third experiment a lesion became visible (at the site of the first molar) when it had a depth of 1.7 mm and measured 1.7 mm in mesio-distal direction. This suggests that the structure of the alveolar process at this site is fairly compact. Again, the postulate that a bone lesion does not become visible as radiolucency until the cortical bone is affected, is contradicted here.

A study of severed bone fragments containing teeth reveals that the coronal cancellous bone of the alveolar process is of denser structure than that near the apices of the teeth. The cortical bone, however, is cervically thinner than apically. More extensive research into this subject would be welcome. In any case, the relative amounts of cancellous bone and cortical bone and the corresponding spatial dimensions is not the same in the coronal as in the apical region. Moreover, the position and thickness

of the alveolar process in the dental arch also plays a role. It is the bone density that determines the rate of its visualization. All this requires insight into and knowledge of the anatomy of the alveolar process and its radiographic representation.
Bender and Seltzer (1961), Ramadan and Mitchell (1962) and Pauls and Trott (1966) observed in general that the trabecular pattern on the radiograph is formed in the junction area. The results of the study described here do not seem to confirm this. However, Ramadan and Mitchell noted that removal of bone from the junction area in the maxilla did not influence the trabecular pattern, whereas removal of bone from both the junction area and the cancellous bone did. The thinner cortical layer and the correspondingly greater influence of cancellous bone on the image formation in the maxilla are in agreement with what our study revealed in the coronal part of the alveolar bone. Shoha et al. (1974) found that a radiolucency can develop in the lower premolar region although the junction area remains unaffected. The same factors may have played a role in this finding. According to Van der Stelt (1979) a lesion in the cancellous bone is visible if the removed trabeculae represent the minimum amount of material required to produce a discernible difference in grey values. This in fact provides a general description of the problem of the visibility or invisibility of bone lesions in that the occurrence of radiolucencies and changes in the trabecular pattern is related to the amount of bone material. Our findings confirm a difference in the distribution of cortical and cancellous bone between the coronal and the apical region, resulting in a difference in occurrence of radiolucencies and changes in the trabecular pattern between these regions.
The radiographic trabecular pattern of the alveolar process at the site of the alveolar crest is not formed solely by the junction area, for it disappears even before a lesion reaches the boundary of the cortical bone (junction area).
Responsible interpretation of radiographs of periodontal lesions demands a detailed knowledge of image formation, and this requires:
- a study of skulls with periodontal bone lesions on radiographs of these lesions (Rees et al., 1971).
- a study of serial radiographs of bone lesions induced step by step.
- comparison of radiographs of bone lesions with radiographs made after bone resection during surgical treatment.

Visual determination of changes in the radiolucency of the alveolar process and changes in the trabecular pattern is both difficult and rather imprecise. Development of more exact technique for this purpose is therefore recommendable.
In summary it can be stated that the relation between cancellous and cortical bone in the interproximal region of the alveolar process differs from that in the periapical region. The influence of cancellous bone over cortical bone is more pronounced in the coronal region than in the more apical areas. Consequently the effects of bone lesions in this region differ from the effects of lesions in the more apical bone of the jaw.

STANDARDIZATION OF THE RADIOGRAPHIC TECHNIQUE

5.1 Introduction

Radiographs are a widely used aid in dentistry in longitudinal studies. For instance the diameter of periapical lesions can be followed on radiographs made at certain regular intervals (Eggink, 1964; Duinkerke, 1976; Klevant, 1981). Bite-wing radiographs made at regular intervals provide a good impression of the rate of progression of caries in a given individual (Axelsson and Lindhe, 1978, 1981). In periodontology only radiographs make it possible to determine the amount of bone loss in the course of time in periodontitis and juvenile periodontitis (Theilade, 1960; Baer, 1971, Liljenberg and Lindhe, 1980).

Standardized, reproducible radiographs are of importance in obtaining information on a lesion at different times. **Standardized** radiographs are those made according to fixed rules which ensure a predictable result and enable comparison of the situations at different points of time. Radiographs are **reproducible** if in the course of time they have been made by a standardized technique which keeps variations within a certain limit.

5.2 The radiograph of the alveolar bone

Van Aken (1969) explained why the bite-wing technique is the one most suitable to obtain information on periodontal bone loss. Image formation is influenced by tube length, film position and the angle between beam axis and object. These factors all influence magnification, which may differ in one, two or three dimensions. Magnification manifests itself in the relation between the true length of the tooth and its length on the radiograph; an anisotropic magnification results in a difference in the distance between the projections of the buccal and of the palatal part of the cemento-enamel junction and the crown of a tooth; or a disproportionate magnification of some parts (e.g. crown or radix) of the tooth (fig. 5.1).

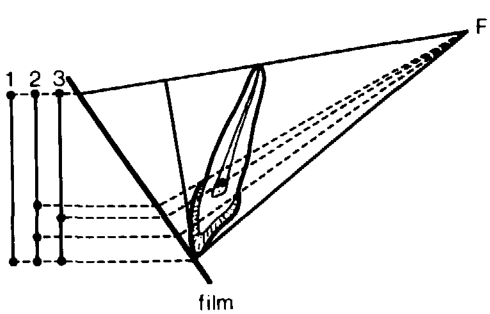


Fig. 5.1 Schematic drawing of a tooth, x-ray beam and film, showing magnification in all directions (1) and in one (2) or two (3) dimensions.

In this study efforts were made to obtain radiographs which fulfilled the following criteria:

1) the true length of the tooth is depicted.
2) there is no difference in the relation between the size of the crown and radix of a tooth and the anatomical situation.
3) the projections of the buccal and palatal parts of the cemento-enamel junction coincide optimally.

This can be achieved if:

- the film is positioned parallel to the tooth.
- the roentgen rays are parallel.
- the roentgen beam (passing through the cervical part of the tooth) is perpendicular to the tooth axis.

When the film is positioned parallel to the tooth axis in a maxilla with a flat palate it is impossible to visualize the entire tooth, particularly if in addition the beam has to be perpendicular to the cervical part of the tooth axis. To visualize the entire tooth, under these circumstances, as a compromise the beam has to be at an angle with the tooth axis. Fig. 5.2 shows that the height of the palate determines this angle.

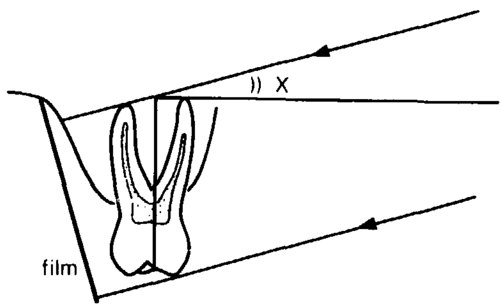


Fig. 5.2 The influence of the shape of the palate on the angle between x-ray beam (X) and tooth axis.

Theoretically, a beam of parallel rays is obtained at an infinite focus-object distance, which is not feasible. Van Aken (1969) reported that magnification begins to approximate 1 at a focus-object distance of 30 cm. In that case the abovementioned disadvantages remain within acceptable limits.

Reed and Polson (1984) compared the alveolar bone height shown on bite-wing radiographs with that shown on periapical radiographs, making measurements in 210 patients. In 50% of cases they found a significant difference in bone height between the two types of radiograph (parallel-film technique and Rinn aiming devices). In 94% of cases the bone level was lower on the bite-wings. They explained this difference on the basis of the anatomy of the palate and the difference in vertical angulation of the roentgen apparatus.

In general dental practice a bite-wing radiograph is made as follows. A bite-wing holder or loupe is slipped round the film, which is then placed lingually against the teeth in the mandible. When the patient occludes on the wing, the operator should use his index finger to push the upper posterior part of the film slightly away from the teeth to prevent the patient from biting on the film edge when he occludes. The roentgen apparatus is so aimed that the vertical plane through the axis of the beam is perpendicular to the dental arch. As already mentioned, the horizontal plane through the

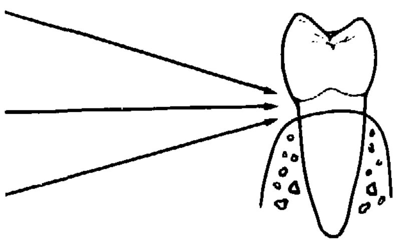


Fig. 5.4 Influence of the angulation of the beam on the distance between the alveolar bone and the cemento-enamel junction.

Selikowitz et al. (1981) studied the possible use of unstandardized bite-wings in determining the rate of alveolar bone loss over a longer period. In a group of 100 patients they determined bone loss over a 10-year period. This approach proved to warrant conclusions about the mean bone loss in the group, but not about individual bone loss.

5.3.1 Criteria to be met by standardized reproducible radiographs

Many methods to ensure reproducibility of radiographs have been described. Most are based on the use of an aiming device for fixation of the relative positions of film, roentgen apparatus and patient.
According to Van Aken (1969) a standardized radiographic technique should fulfil a number of requirements (5.2). Gilbert and Hanan (1968) listed a number of factors to be controlled in a standardized reproducible radiographic technique:
- film position in relation to tooth axis.
- horizontal and vertical beam angulation in relation to film and tooth axis.
- object-film distance.
- focus-object distance.
- film density.
- film contrast.

5.3.2 Applications in the literature

Medwedeff et al. (1962) and Wege (1967) described aiming devices for making long-cone parallel radiographs. Gilbert and Hanan (1968) modified the device developed by Medwedeff for use in making reproducible radiographs. Disposable styrofoam bite-blocks were modified to individual bite-blocks with the aid of Stent's mass. The link between roentgen apparatus and aiming device was not reproducible.
Plotnick et al. (1971) linked the aiming device to the roentgen tube and used a bite-block adapted to the relation with the mandible with self-polymerizing resin. The relation of bite-block to maxilla was established using impression material on a thiocol rubber base. Variations were assessed on the basis of reference points in the trabecular pattern. Even if the block was not optimally positioned, only a small error was observed. A dislocation of 2-3 mm resulted in an angulation error of about 1°.
Brown and Owings (1973) used methylmetacrylate to modify Rinn posterior bite-blocks to individual bite-blocks. The film holders were used in combination with a Rinn aiming device and horizontal and vertical angulation was achieved in a manner which Brown described as "controlled", without further defining it. The standard deviation of the two measuring techniques described in the article was 0.07 mm and 0.23 mm respectively.
Kirkegaard and Zeuner (1974) likewise used bite-blocks adapted with self-polymerizing resin to ensure reproducible positioning of the film holder in relation to the teeth to be radiographed. A bar attached to the film holder fitted in six different

ways in two wings mounted on the tube. The radiographs were regarded as identical if two radiographs superposed on the light box appear to cover each other completely. The relative error of this technique was 0.28 ± 0.06%.
Adolph et al. (1975) also used an individual bite-block linked to the roentgen apparatus. The radiographs were scanned photometrically and the results fed into a computer. The coefficient of correlation of measurements on two radiographs made of an object at different time points provided a standard of reproducibility (0.81-0.93).
Rosling et al. (1975) used an individualized bite-block of the entire jaw on which the patient occluded. An indicator rod attached to the roentgen apparatus fitted into the bite-block. The standard deviation of this technique was between 0.024 mm and 0.0917 mm.
In their animal experiments Kastle and Klein (1976) applied a technique using bite-blocks made of Stent's mass. The radiographs were required to be so reproducible that comparison on the light box revealed an identical image and that subtraction with television was possible.
Duinkerke (1976) developed an aiming device for standardized reproducible periapical radiographs. The bite-block was adapted to maxilla or mandible with the aid of rubber impression material. The standard deviation of the positioning error was determined to be 0.032 mm.
The abovementioned investigators all performed longitudinal studies using a standardized reproducible radiographic technique. It is justifiable to conclude that longitudinal studies of the periodontal bone should be performed with a standardized reproducible radiographic technique in order to avoid variations in bone level on different radiographs due to variations in angulation. The bite-wing technique is to be preferred for an optimally faithful visualization of the anatomical structures. While the technique has the disadvantage of not depicting the entire tooth, it does visualize the region of importance: that of the alveolar crest.

5.4 Reason to design a new aiming device

The aiming devices used by the various investigators are often modifications of devices used in general dental practice. This may be a source of inaccuracy (Gilbert and Hanan, 1968; Brown and Owings, 1973). Many reports do not clearly define the method used to determine the degree of reproducibility. Moreover, most aiming devices were designed primarily for periapical radiographs. A possible source of error lies in placing the roentgen tube parallel to the indicator rod "by eye". These facts led to the decision to design an aiming device especially for studies of interdental bone. This device was to be based on:
- the bite-wing radiographic technique.
- a semi-fixed link between roentgen apparatus and patient.

5.4.1 Criteria to be met by the aiming device

The criteria to be met by the aiming device were defined as follows:
1) it should be possible to place roentgen tube, object and film in exactly the same relative positions for radiographs made at intervals in time.
2) enlargement and deformation should be minimal.
3) it should be possible to measure bone level differences as small as 0.1 mm.
4) it should be possible to place the bite-wings in a vertical position to neutralize the image loss caused by the bite-block and to ensure visualization of the largest possible part of the alveolar process.

5.4.2 Design of the device

The aiming device (fig. 5.5) consists of several detachable components.

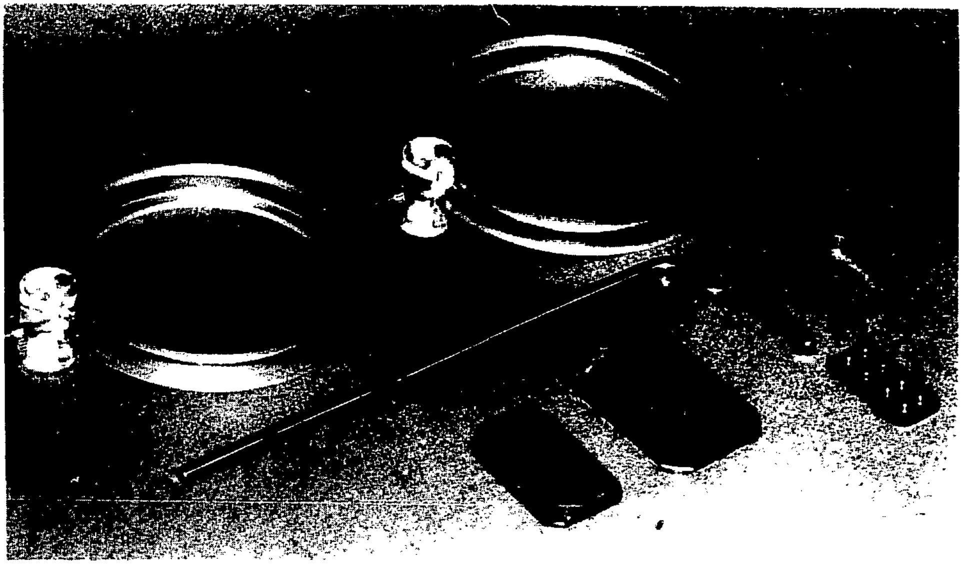


Fig. 5.5 Aiming device for making reproducible intraoral bite-wing radiographs. The disassembled device consists of an indicator rod, two locator rings of synthetic material, an aluminium bite-block, a film holder for format 2 films and a film holder for format 1 films.

1. A stainless steel bar with a milled groove and a holder for the bite-block.
2. Two locator rings of synthetic material.
3. An aluminium bite-block.
4. A film holder.

re 1: The indicator rod (fig. 5.6) is the basis of the aiming device. A groove milled in the bar makes it possible to fix the two plastic locator rings in line. The part to be positioned in the mouth has two cross-arms into which the bite-block fits (fig. 5.7).

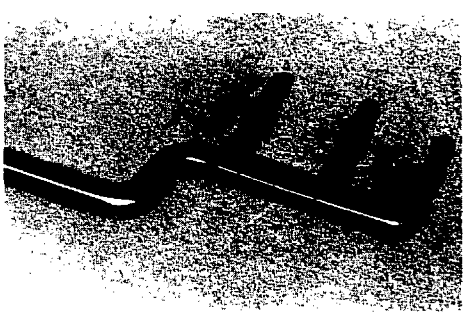


Fig. 5.6 The indicator rod with its milled groove for fixation of the plastic rings.

Fig. 5.7 The part of the indicator rod to be inserted into the mouth, with two cross-arms to accommodate the individual bite-block.

re 2: The diameter of the locator rings is sufficient to accommodate the tube of a General Electric 1000. The locator ring closer to the film holder, moreover, has a flange to arrest the tube (fig. 5.8) as it is passed through the locator rings. The indicator rod fits into depressions in the locator rings. A screw fitting into the groove of the indicator rod is tightened to fix each ring to the bar, always in the same way.

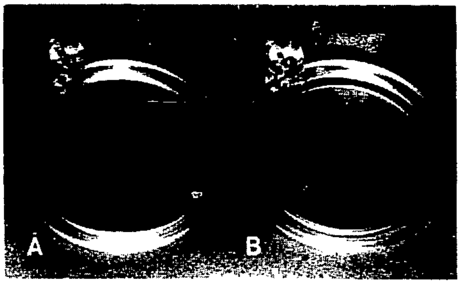


Fig. 5.8 The plastic rings into which the roentgen tube fits. A. locator ring through which the tube passes. B. ring with a flange which arrests the tube.

re 3: A perforated aluminium bite-block is inserted into the device, which is then fitted into the mouth. Next, resin (Formatray of Kerr Manufacturing Company) is prepared. Stolk (1977) has demonstrated that this material is not deformed under the influence of such factors as humidity and time lapse. Two metered-dose gelatin capsules with Formatray are used, to which 11 drops of monomer are added, with subsequent mixing for 10 seconds in a Silamat mixer (Vivodent). The resin is then applied to either side of the block, pressed firmly into the perforations and built up conically.
The aiming device is inserted into the mouth and the patient is asked to occlude on the bite-block with resin for two minutes (the block should be parallel to the dental arch). After two minutes the block is removed from the mouth and the resin is allowed to set further. The individual bite-block then shows an impression of the cusps of the teeth in maxilla and mandible. An aiming device which can be re-inserted into the mouth in a reproducible way is now available.

re 4: The edges of a metal plate the size of a dental film are bent so as to hold the film. Slots in the reverse side of the plate serve to attach the film holder to the indicator rod. Although the device has been designed especially for bite-wing radiography, more grooves have been milled in the reverse side of the film holder (fig. 5.9). This makes it possible to mount the film holder on the indicator

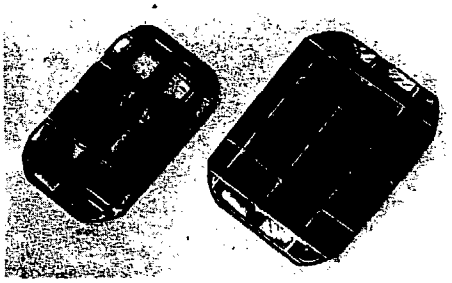


Fig. 5.9 The film holder with in its reverse side a number of grooves into which the indicator rod can be fitted in several ways.

rod in several different ways, permitting the use of this instrument for different types of radiographs without necessarily changing the angulation of the beam, for example:

- horizontal bite-wing radiographs.
- vertical bite-wing radiographs.
- radiographs of three-quarters of a tooth.
- periapical radiographs.

Less space is available in the frontal region, and for this region a smaller film holder is therefore used, which can accommodate films of format 2.5 x 4 cm.

5.5 The positioning error and the error of observation

In a longitudinal study, radiographs of a given area in the same patient are made at intervals over a certain period of time. Inaccuracies may be introduced in restoring the aiming device to the mouth and in slipping the roentgen tube into the rings of the aiming device. These inaccuracies are called positioning error. In this study all measurements on radiographs were performed at 10-fold magnification. This, too, provides a possible source of error. The above indicates that various errors can be divided into two groups.

1. Errors in angulation technique: **positioning errors.**
2. Errors made in processing and measuring on radiographs: **errors of observation.**

The following procedures were used to determine the effect of the various errors on the results obtained:

- measurements on radiographs made with the aid of an optical bench, to determine the error of observation.
- measurements on radiographs of patients, to determine the positioning error.

Determination of the error of observation will be discussed in subsection 5.5.1, and that of the positioning error in subsection 5.5.2. The tolerance of the method is discussed in subsection 5.5.3, and subsection 5.5.4 provides information on the techniques of measurement and magnification employed.

5.5.1 Measurements on radiographs made on an optical bench to determine the error of observation

The error of observation was determined by measurements on radiographs (fig. 5.10)

Fig. 5.10 Radiograph made on the optical bench.

of teeth on a phantom with marking points. The intact teeth in a mandible severed in the midline were provided with marking points. For this purpose a round bur 1/012 was used to drill holes the depth of the bur (1.2 mm), and ball bearings with a diameter of 1 mm were glued into these holes. This was done mesio-buccally and disto-buccally and in the centre of the lingual surface in the first molar, and in the centre of the buccal surface and mesio-lingually and disto-lingually in the second molar (fig. 5.11).

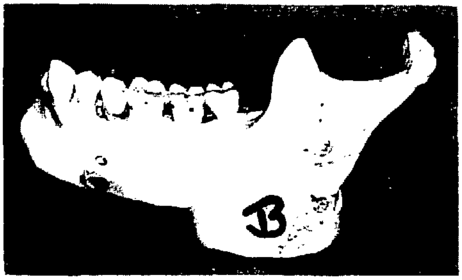


Fig. 5.11 Severed mandible with the teeth containing marking metal balls with a diameter of 1 mm (buccal aspect).

The set-up of roentgen apparatus, devices on the optical bench, phantom and film have been described in subsection 4.4.1, and the same applies to the radiographic procedure (fig. 4.1).
The measurements were performed using automatic coordinate-locating equipment (Summagraph Corporation, I.D. Data Tablet/Digitizer series 2000). The accuracy of this electronic X-Y tablet is better than 0.1 mm according to the manufacturer.
Because the error introduced with the X-Y tablet is relatively less important in measurements over longer distances, the intra-oral radiographs were enlarged. The inaccuracies of this enlargment were also determined.
The radiographs were photographed using an intermediate-negative film Ilford Pan-F 135-36. The film was developed in undiluted Promicrol fluid during 5 minutes at 20°C, while the film was intermittently moved. The fixation fluid used was Super Amfix diluted 1:4. The film was enlarged with the aid of a Leitz Focomat II C Colar enlarger. The objective was a Focotar 50 mm/f4.5. Prints were made on Agfa Gevaert 0 81p 30x40. Tray developing was done in Suprol diluted 1:9 during 1.5 minute at 40°C. The fixation fluid was Super Amfix diluted 1:4.
In order to determine the printing error, five registers (reticles) Mecanorma S26 were applied to a transparent film, which was then photographed. Ten prints were made. Thus the marking points on the object, with a diameter of 1 mm (the metal balls glued onto the teeth), had a diameter of 10 mm on the print. The centre of the circle formed by the outline of the balls was constructed. These points were used as marking points, from which the various distances were measured. The error of observation is a combination of:
1. measuring error.
2. printing error.
3. marking error.
4. magnification error.

Errors 1 and 3 are caused by the observer, and errors 2 and 4 are due to the photographic procedure.
The following experiments were performed:
- to determine the measuring error, the distance between the marking points on the print of the same enlarged radiograph was measured ten times.
- on the ten prints of the transparent film with the reticles, the distance between the marking points (reticles) was measured.
  From the measured error, which comprises:
  - the measuring error and.
  - the printing error.

The printing error can be deduced.

- to determine the marking error, the radiograph was enlarged ten times over and photographic prints were made ten times. The marking points on these ten photographs were determined.
  From the measured error, which comprises
  - the measuring error.
  - the printing error and.
  - the marking error (the accuracy with which the marking points have been placed).

  The marking error can be deduced.
- to determine the magnification error, the enlarger was set at ten-fold enlargement ten times over and a print was made of the same photograph.
  From the measured error, which comprises
  - the measuring error.
  - the printing error.
  - the marking error and.
  - the accuracy of the enlarger adjustment.

  The magnification error can be deduced.

These experiments thus provide us with the total error of the technique described and with the separate errors.

5.5.2 Measurements on radiographs of patients to determine the positioning error

The positioning error of radiographs of patients (fig. 5.12) was determined by making ten vertical bite-wing radiographs of the same area in the same patient (fig. 5.13), using the aiming device described. The ten radiographs were photographically enlarged 10x and printed.

Fig. 5.12 Aiming device and roentgen apparatus in situ for making reproducible intraoral radiographs.

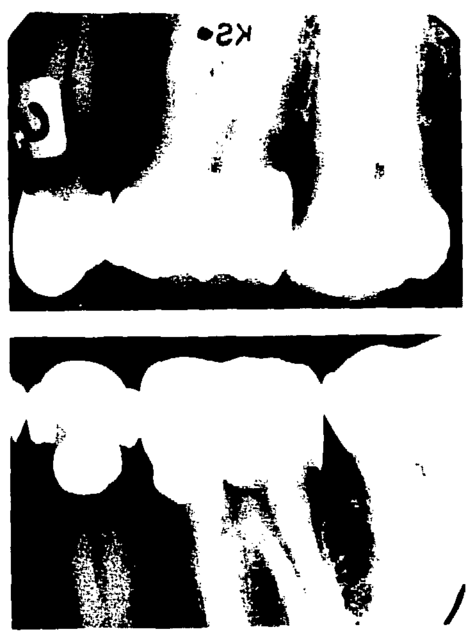


Fig. 5.13 Bite-wing radiograph made with the aiming device described.

The total error of this method comprises the positioning error of the radiographic technique and the error of observation (error in the way measurements were made on the enlarged and printed radiographs). Since the error of observation is already known, the positioning error can thus be deduced.

5.5.3 Determination of the magnitude of acceptable positioning errors

In an effort to determine the influence of small positioning errors of the operator on the results, the phantom was radiographed several times, each time rotating the object over an angle of 1° with the aid of the optical bench. Both on the horizontal and on the vertical axis, the phantom was thus rotated from −10° through +10°.
The total error was determined at each angulation. The results were examined to determine over how many degrees the object could be rotated before the positioning error exceeded 5% (5% being taken as still acceptable).

5.5.4 Measuring method and determination of the accuracy of the magnification technique

In the various experiments, measurements were made with the aid of three points on the print of the radiograph which form a triangle. In this triangle a perpendicular was drawn. The example (fig. 5.14) is a triangle PQR in which the lengths of PQ, QR, PR and RU were measured. The mean of a line segment was calculated (Dixon and Massey, 1969) as

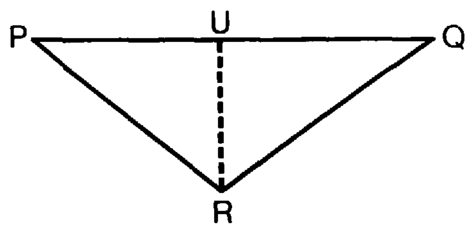


Fig. 5.14 Drawing of Δ PQR in which the length of the line segments PQ, QR and PR and the perpendicular RU is measured.

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad 1$$

where $\bar{X}$ is the mean and N is the number of measurements;
i = 1; i = 2; i = 3.....i = N.

The standard deviation was calculated using the equation:

$$S = \sqrt{\frac{\sum_{i=1}^{N} (X-\bar{X})^2}{N-1}} \qquad 2$$

The mean of the standard deviations (S) was used to determine the standard error (S_A) in mm.

$$S_A = \sqrt{\frac{\sum_{i=1}^{N} S^2}{N}} \qquad 3$$

The total error equals the square root of the sum of the squares of the separate errors.

$$S = \sqrt{S^2\text{magn. err.} + S^2\text{mark. err.} + S^2\text{meas. err.} + S^2\text{pos. err.}} \qquad 4$$

5.6 Results

5.6.1 The measuring error

The marking points were situated as follows. In the first molar points P and Q were in the buccal surface and point R was in the lingual surface. In the second molar point Y was in the buccal surface and points X and Z were in the lingual surface (fig. 5.15).

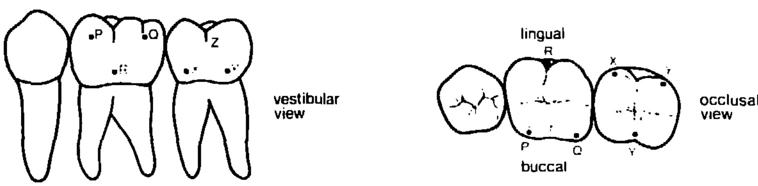


Fig. 5.15 The buccal aspect of the mandible with the location of the measuring points (balls) in the buccal and the lingual surface. The occlusal aspect also shows their location in the buccal and the lingual surface.

Of Δ PQR and Δ XYZ (fig. 5.16) the sides and the perpendicular were measured ten times. Results, mean, standard deviation and standard error of the line segments are presented in table 5.1.

Fig. 5.16 Tenfold magnification of the radiograph of the teeth, with the measured line segments PQ, PR, QR and RU of Δ PQR and line segments XY, XZ, YZ and YT of Δ XYZ indicated.

Table 5.1 Mean ($\bar{X}$), standard deviation (S) and standard error (S_A) of the measurements of the line segments of Δ PQR and Δ XYZ.

Line segment	Mean $\bar{X}$ (mm)	Standard deviation S (mm)
PQ	81.0	0.098
PR	30.77	0.149
QR	58.5	0.139
RU	17.52	0.127
XY	69.5	0.175
XZ	73.22	0.113
YZ	35.87	0.152
YT	33.37	0.225
S_A		0.152

The measuring error is 0.152 mm.

5.6.2 The error in the photographic printing of the radiograph.

Of the reticles A, B, C, D and E (fig. 5.17) the line segments AB, BC, CD, AE, EC, BE, AD and ED were measured. Mean, standard deviation and standard error of the line segments are presented in table 5.2.

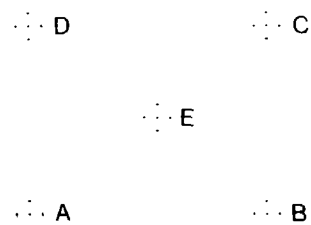


Fig. 5.17 Print of the film with reticles A, B, C, D and E.

Table 5.2 Mean ($\bar{X}$), standard deviation (S) and standard error (S_A) of the measurements of the line segments AB, BC, CD, AE, EC, BE, AD and ED.

Line segment	Mean $\bar{X}$ (mm)	Standard deviation S (mm)
AB	107.98	0.26
BC	105	0.16
CD	108	0.19
AE	74.98	0.42
EC	75.52	0.43
BE	75.71	0.5
AD	104.4	0.01
ED	75.02	0.23
S_A		0.316

The standard error is 0.316 mm.

$$\text{The printing error} = \sqrt{\text{standard error}^2 - \text{measuring error}^2}$$

$$= \sqrt{0.316^2 - 0.152^2} = 0.277 \text{ mm.}$$

The printing error is 0.277 mm.

5.6.3 The marking error

The marking error is determined by the accuracy with which the marking points are placed. The radiograph was printed ten times without changing angulation. The same marking points were applied to each of the ten prints, and measured. The accuracy of this procedure is determined by the observer's measuring error, the printing error, the marking error and the total standard error of this experiment. Mean, standard deviation and total standard error of the line segments are presented in table 5.3.

Table 5.3 Mean ($\bar{X}$), standard deviation (S) and standard error (S_A) of the measurements of the line segments of Δ PQR and Δ XYZ for determination of the marking error.

Line segment	Mean $\bar{X}$ (mm)	Standard deviation S (mm)
PQ	80.89	0.348
PR	31.04	0.344
QR	58.33	0.431
RU	17.68	0.236
XY	69.77	0.217
YZ	35.81	0.369
YT	33.47	0.311
S_A		0.315

The total standard error is 0.315 mm.

$$\text{The marking error} = \sqrt{\left(\text{total error}^2 - (\text{measuring error}^2 + \text{printing error}^2)\right)}$$
$$= \sqrt{\left(0.315^2 - (0.152^2 + 0.277^2)\right)}$$
$$= 0.025$$

The marking error is 0.025 mm.

5.6.4 The magnification error

Enlargements were made ten times after separate setting and each time a print was made. Table 5.4 lists mean, standard deviation and standard error of the line segments.

Table 5.4 Mean ($\bar{X}$), standard deviation (S) and standard error (S_A) of the measurements of the line segments of Δ PQR and Δ XYZ for determination of the magnification error.

Line segment	Mean $\bar{X}$ (mm)	Standard deviation S (mm)
PQ	81.2	0.460
PR	31.04	0.279
QR	58.51	0.441
RU	17.6	0.301
XY	69.54	0.311
XZ	73.09	0.274
YZ	35.75	0.435
YT	33.39	0.357
S_A		0.364

The magnification error $= \sqrt{\text{total measured error}^2 - (\text{measuring error}^2 + \text{marking error}^2 + \text{printing error}^2)}$

The magnification error $= \sqrt{0.364^2 - (0.152^2 + 0.277^2 + 0.025^2)}$
$= 0.18$ mm.

The magnification error is 0.18 mm.

All factors which determine the accuracy of the method play a role in the total error of this last experiment. These factors are: measuring error (0.152 mm), printing error (0.277 mm), marking error (0.025 mm) and magnification error (0.18 mm).
The total error of the measurements performed on radiographs by the above described method is the square root of the sum of the squares of the errors described in the experiments. This amounts to an absolute error of 0.364 mm, which corresponds with 0.036 mm on the original radiograph.

5.6.5 The positioning error in radiographs of patients

The positioning error in bite-wing radiographs of patients comprises the positioning error of the radiographic technique and the total error of the method, which we have called error of observation. The marking points on the radiographs were so chosen as to be recognizable accurately on each radiograph and on its ten times enlarged print. Suitable points for marking were bevels or sharp edges of restorations (fig. 5.18). These points formed the triangles MNO and UVW. In Δ MNO, M and N are sharply defined bevels of inlays and O is a readily recognizable sharp point of the occlusal part of a restoration, while NQ is the perpendicular in the triangle. In Δ UVW, V and W are readily identifiable extensions of the bevels and VS is the perpendicular in the triangle. The sides and the perpendiculars of Δ MNO and Δ UVW were measured ten times over. Mean, standard deviation and standard error of the line segments were calculated (table 5.5).

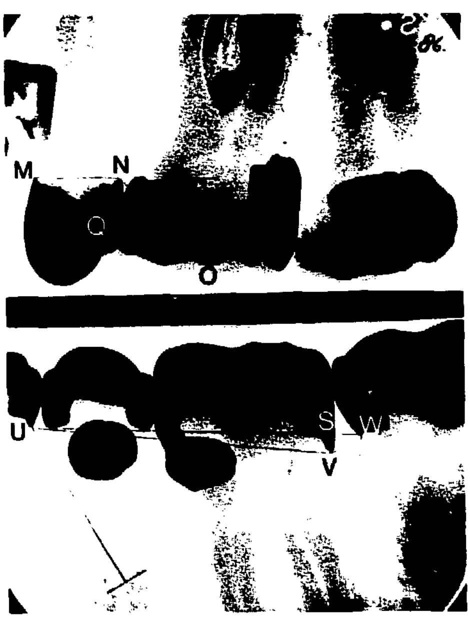


Fig. 5.18 Tenfold magnification of the bite-wing radiograph of a patient on which the sides and the perpendiculars of Δ MNO and Δ UVW were measured to determine the positioning error.

Table 5.5 Mean ($\bar{X}$), standard deviation (S) and standard error (S_A) of the measurements of the line segments of Δ MNO and Δ UVW for determination of the positioning error.

Line segment	Mean $\bar{X}$ (mm)	Standard deviation S (mm)
MN	52.8	0.297
NO	74.17	0.614
MO	117.76	0.501
NQ	23.16	0.373
UW	205.51	0.621
UV	187.31	0.486
VW	22.29	0.648
VS	11.45	0.26
S_A		0.496

The positioning error $= \sqrt{\text{total error}^2 - \text{magnification error}^2}$

$$= \sqrt{0.496^2 - 0.364^2}$$

The positioning error is 0.337 mm.

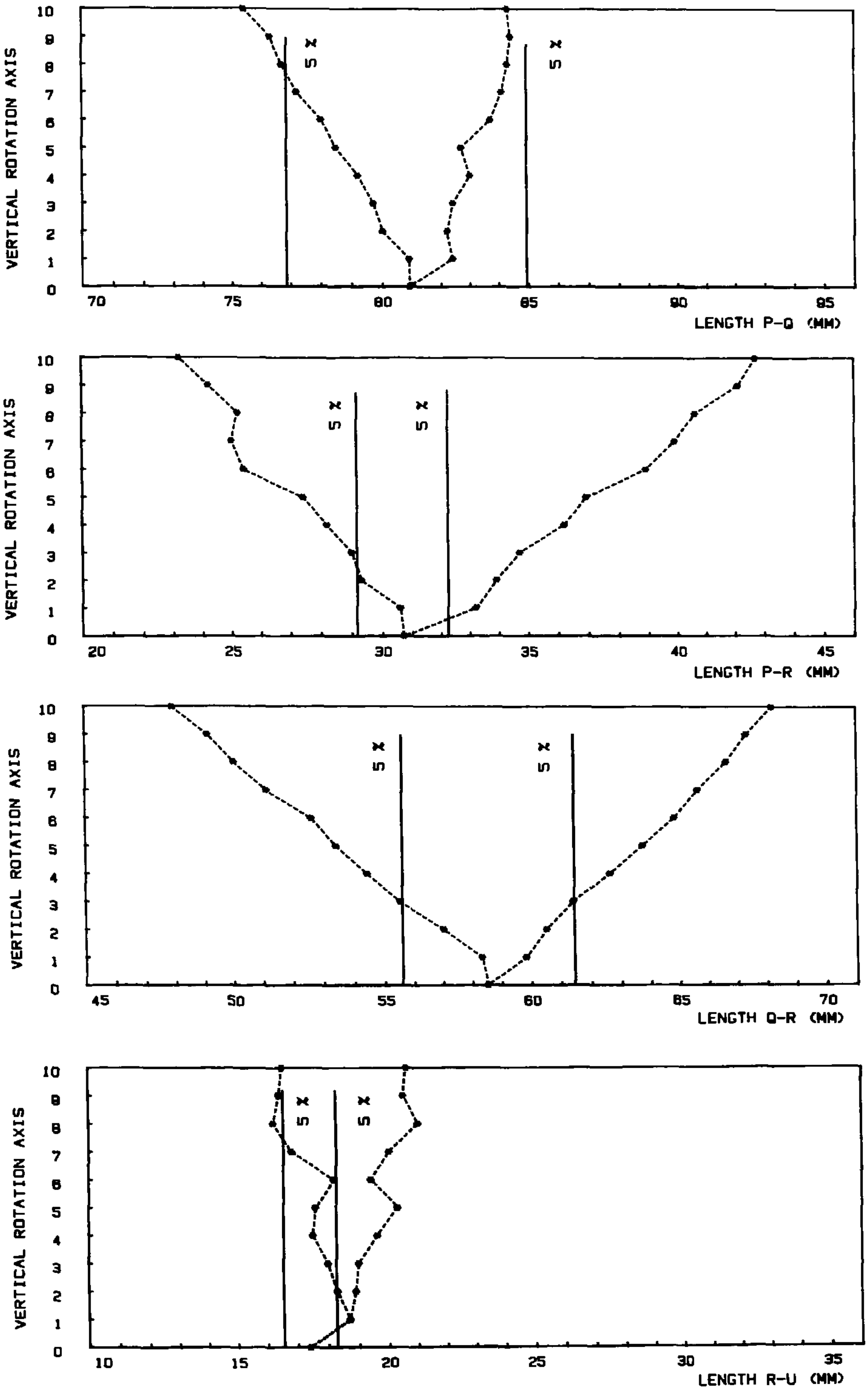
This amounts to an absolute error of 0.337 mm, which corresponds with 0.034 mm on the original radiograph.

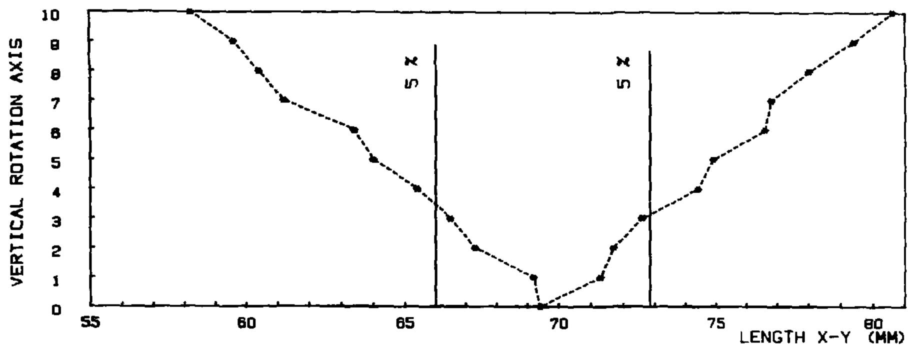
5.6.6 The magnitude of acceptable positioning errors

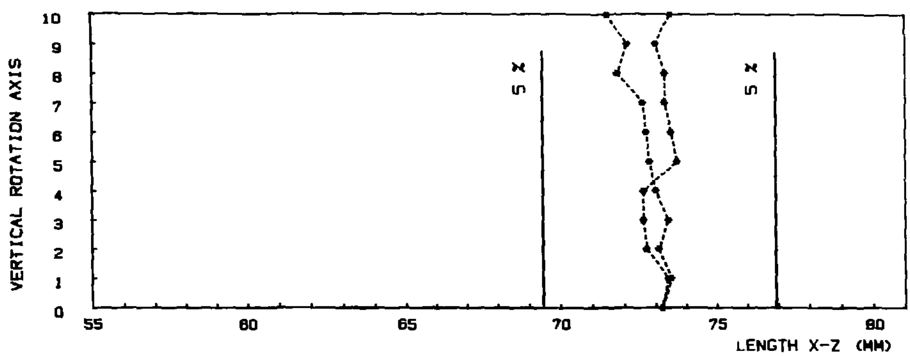
The mean of the line segments of Δ PQR and Δ XYZ was determined at each angulation angle. The resulting values are shown in table 5.6 and fig. 5.19.
The 5% limit of the error was calculated, whereupon the amount of rotation possible before the 5% limit was exceeded was determined for rotation on a horizontal axis (vertical angulation) and for rotation on a vertical axis (horizontal angulation) (table 5.6 and fig. 5.19).

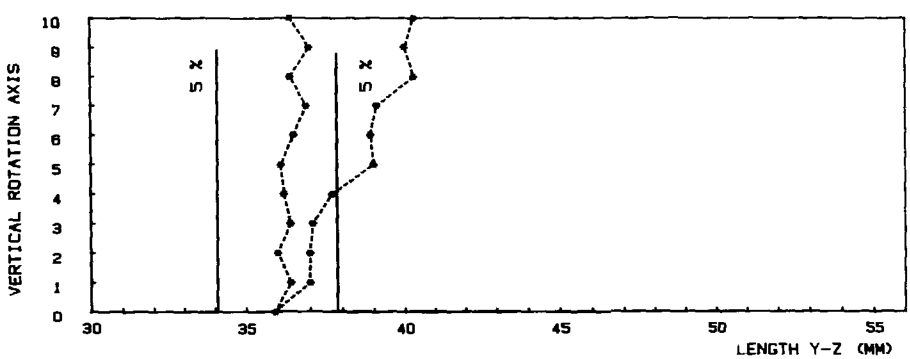
Table 5.6 Mean ($\bar{X}$) of the line segments of Δ PQR and Δ XYZ (fig. 5.16), the calculated 5% level ($R_{5\%}$) and the maximum positive and negative rotations on the horizontal and the vertical axis at $R_{5\%}$.

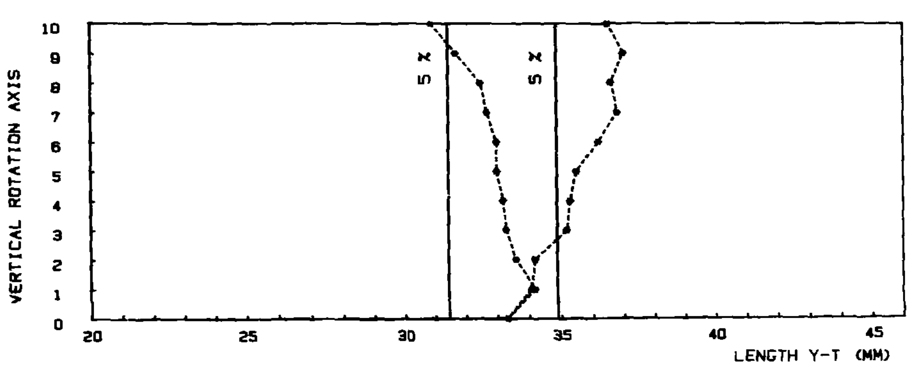
Line segment	Mean $\bar{X}$ (mm)	Calculated $R_{5\%}$ (mm)	Horizontal axis of rotation		Vertical axis of rotation	
			max. pos. rotation	max. neg. rotation	max. pos. rotation	max. neg. rotation
PQ	81.0	4.05	> 10°	> 10°	> 10°	< 8°
PR	30.77	1.54	< 3°	< 2°	< 1°	< 3°
QR	58.5	2.92	> 10°	> 10°	< 3°	3°
RU	17.52	0.87	< 2°	< 1°	< 8°	< 1°
XY	69.5	3.47	> 10°	< 9°	< 4°	< 4°
XZ	73.22	3.66	> 10°	> 10°	> 10°	> 10°
YZ	35.87	1.79	< 2°	< 1°	< 4°	> 10°
YT	33.37	1.67	< 2°	< 1°	< 10°	< 3°

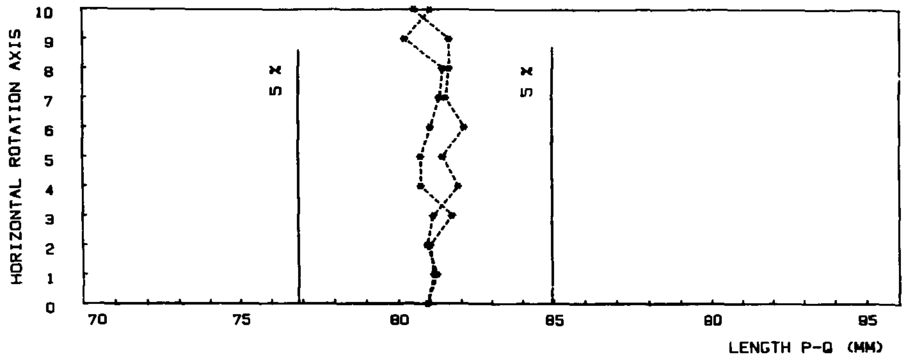

VERTICAL ROTATION AXIS
LENGTH P-Q (MM)
5 %
5 %
VERTICAL ROTATION AXIS
LENGTH P-R (MM)
5 %
5 %
VERTICAL ROTATION AXIS
LENGTH Q-R (MM)
5 %
5 %
VERTICAL ROTATION AXIS
LENGTH R-U (MM)
5 %
5 %

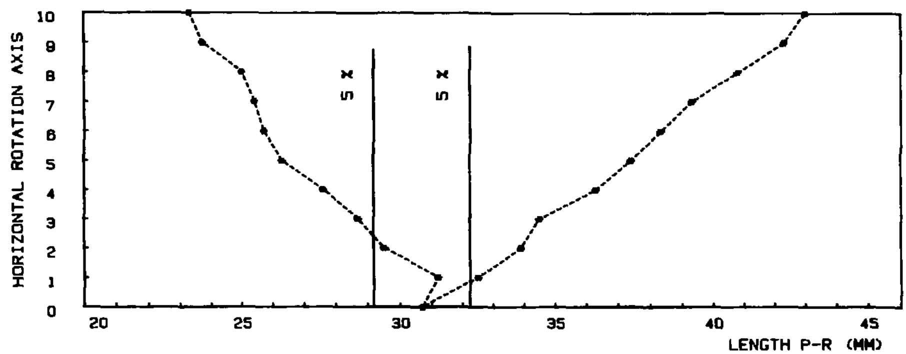

VERTICAL ROTATION AXIS
5 %
5 %
LENGTH X-Y (MM)

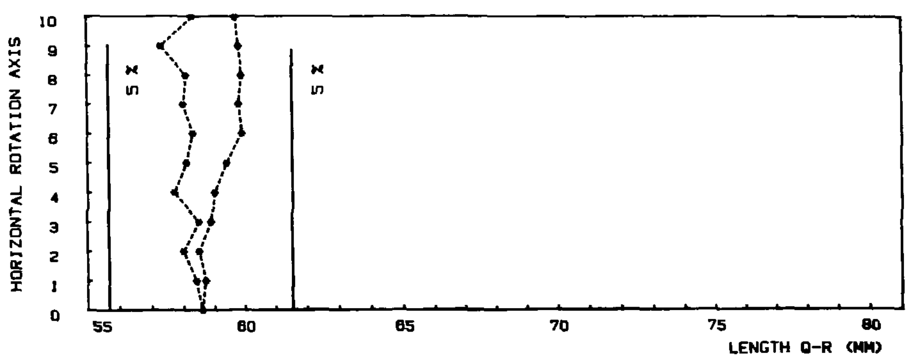

VERTICAL ROTATION AXIS
5 %
5 %
LENGTH X-Z (MM)

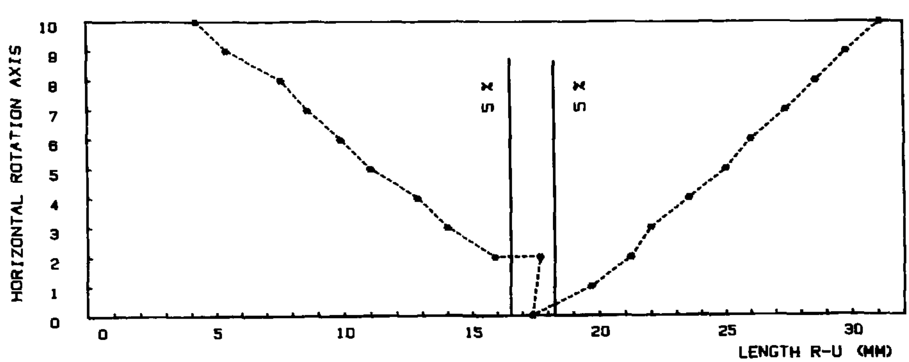

VERTICAL ROTATION AXIS
5 %
5 %
LENGTH Y-Z (MM)


VERTICAL ROTATION AXIS
5 %
5 %
LENGTH Y-T (MM)


HORIZONTAL ROTATION AXIS
LENGTH P-Q (MM)
5 %
5 %


HORIZONTAL ROTATION AXIS
LENGTH P-R (MM)
5 %
5 %


HORIZONTAL ROTATION AXIS
LENGTH Q-R (MM)
5 %
5 %


HORIZONTAL ROTATION AXIS
LENGTH R-U (MM)
5 %
5 %

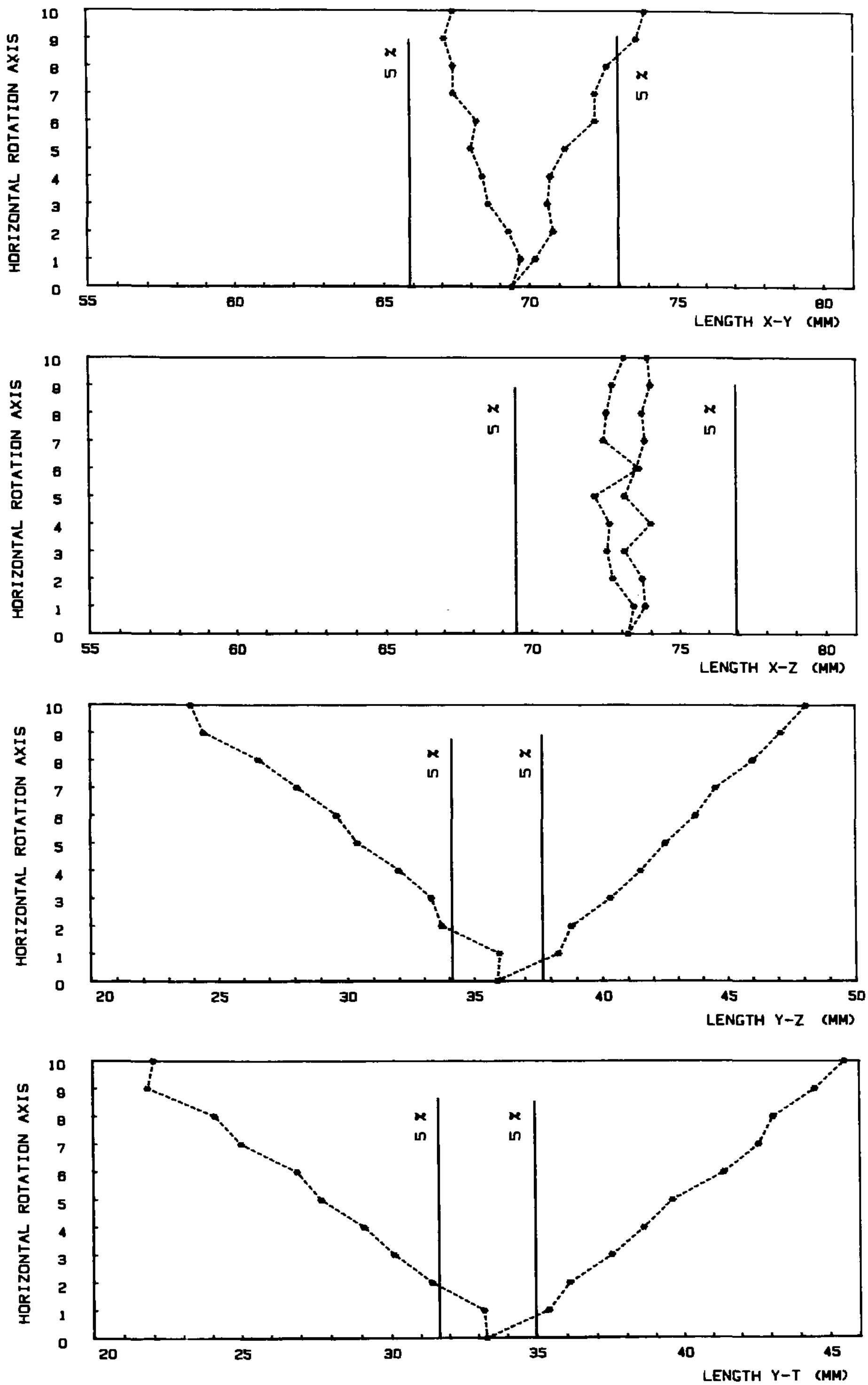


Fig. 5.19 Graph showing the lengths of the line segments of Δ PQR and Δ XYZ at horizontal and vertical rotations of the object (mandible), with the 5% limit of inaccuracy indicated.

On the horizontal axis of rotation the aim can rotate about 20° for the horizontal lines and less than 3° for the vertical lines before the error exceeds 5%. On the vertical axis of rotation the aim can rotate 13° to 20° for the horizontal lines and 4° to 13° for the vertical lines.
In Δ PQR, points P and Q are in the buccal and point R is in the lingual surface. However, rotation is not measured in Δ PQR but on the projection of Δ PQR on the film. This means that PR and RQ, which extend from the buccal to the lingual surface, are more influenced by a rotation.
The projection of line segment YT in Δ XYZ takes a vertical course on the radiograph, but in space YT extends from the buccal to the lingual surface, and Y is localized more occlusally than T. If YT were vertical in the object, then rotation on a vertical axis would have little effect; as a result of the actual rotation of YT, however, the projection of YT lengthens and only a small degree of rotation is possible.

5.7 Conclusions

1. The error of observation of the positioning technique was 0.036 mm. The positioning error was 0.034 mm. The total error of the technique used was 0.05 mm.
2. For a maximum error of 5% the object may rotate 3° on a horizontal axis and 4° on a vertical axis. Larger rotations may in some cases be possible, dependent on the direction of the projected line segments.

One of the criteria formulated in subsection 5.4.1 was that it should be possible to measure bone level differences of 0.1 mm. The total error (error of observation and positioning error) was 0.05 mm. This means that the technique demonstrated in this chapter is sufficiently standardized to ensure reproducible radiographs of dental structures in longitudinal studies, on which the expected changes in bone level with increasing time can be found.

5.8 Discussion

To avoid differences in the horizontal as well as the vertical angulation of the roentgen apparatus in the course of longitudinal studies of changes in the calcified structures of the alveolar process, the need arises for a positioning technique which makes it possible to obtain standardized reproducible radiographs. Because the bite-wing radiograph provides the most realistic depiction of the coronal part of the alveolar process and because devices so far described consist of disposable bite-blocks or have been designed especially for periapical radiographs, an aiming device with a semi-fixed link to the roentgen apparatus was designed for bite-wing radiographs. In longitudinal studies of large numbers of patients the preparation of the bite-blocks for the aiming device and the procedure for accurate positioning are very time-consuming. A striking finding is that investigators trying to determine the accuracy of the positioning technique make measurements on radiographs at a magnification which ranges from 3 through 11.6 x. The positioning error determined in this study (0.034 mm) is equal to or lower than the values described in the literature. Kirkegaard and Zeuner (1974) reported a relative error of 0.28% (s.d. 0.06 or s.d. = 0.07 mm).
Rosling et al. (1975) reported a positioning error with a standard deviation ranging between 0.024 mm and 0.0917 mm, while Duinkerke (1976) mentioned a standard deviation between 0.032 mm and 0.11 mm. Stolk (1977) maintained that the migration of teeth may be more pronounced than is usually assumed. This is apparent from

the fact that the bite-blocks no longer fit snugly even though no restorations have been made. However, he did not quantify the possible degree of migration.
In order to determine the positioning error of the radiographic technique, the error of observation was also determined in the experiments described in this chapter. To ensure optimal angulation of the roentgen apparatus, an experimental set-up involving the use of an optical bench was chosen.
In an effort to determine the influence of possibly inadvertent variations in the angulation of the roentgen apparatus on the accuracy of positioning, the phantom used was rotated on a horizontal and a vertical axis. It was found that rotations exert little influence on line segments extending mesio-distally in a horizontal plane. Bucco-lingually extending line segments are more influenced by rotations (table 5.6). The alveolar crest extends from the buccal to the lingual surface. This means that rotations exert an unfavourable influence on its projection on the radiograph. In making reproducible radiographs, therefore, variations in horizontal and/or vertical angulation should be avoided. This means that a link between roentgen apparatus and film holder is a stringent requirement in a reproducible radiographic technique.

CHAPTER 6

MEASURING THE BONE LEVEL OF THE ALVEOLAR CREST IN PATIENTS

6.1 Introduction and aim

In periodontal diagnosis the radiograph is an aid in the detection and temporal comparison of untreated bone lesions. Patients whose periodontium has been treated can also be followed, for it is important to establish how the periodontal bone responds to the therapy. Clinical and radiographic findings, however, do not always lead to an unequivocal conclusion (Hollander et al., 1966; Ainamo and Tammisalo, 1973).
This discrepancy between clinical and radiographic features led to the study described in chapter 4, in which an attempt was made to determine the relation between the true and the radiographic dimensions of a periodontal bone lesion. It was also demonstrated in chapter 4 that, given an accurate technique, minute lesions induced in the alveolar crest with a round bur are already demonstrable if they have a depth of about 1 mm and a diameter of about 1 mm.
Diagnostic radiographs of a patient should be made in a standardized way (Van Aken, 1969). For longitudinal studies radiographs are suitable only if they are reproducible as well (see subsection 5.3.1) (Gilbert and Hanan, 1968). Without standardization and reproducibility the scope of radiographic research is substantially reduced. The aiming device described in subsection 5.4.2 was designed to ensure both standardization and reproducibility. The results in terms of positioning error and error of observation show that this device can be used in longitudinal studies of the bone level and of periodontal lesions.
Lindhe and Nyman (1975) and Nyman et al. (1975) reported on research based on reproducible periapical radiographs. Boyle et al. (1973) and Röhner et al. (1983) used non-reproducible periapical radiographs, while Selikowitz et al. (1981) based themselves on non-standardized bite-wing radiographs (table 1.1). On the periapical radiographs the bone loss was determined in percents of the tooth length. On the bite-wing radiographs the distance between the cemento-enamel junction and the alveolar crest was measured to determine differences in bone level.
The purpose of this particular part of the study was to develop a measuring method which can be used for reproducible registration of changes in the bone level of the alveolar crest shown on standardized reproducible radiographs in the course of time. This was done because the relevant literature on this subject is not entirely clear. Bone level measurements in patients were first performed in accordance with views formulated in the literature. The reproducibility of this approach is discussed in sections 6.2 - 6.5. An improved method is proposed in section 6.6.

6.2 Materials and methods

6.2.1 The patients

Bone level measurements were performed in patients with an intact periodontium. The teeth had intact approximal surfaces or surfaces with restorations with a correct marginal fit or a gingival overhang. These patients were selected from the group of patients involved in the Amalgam Project (1985). This project focused on quality aspects of amalgam restorations and was carried out at the University of Nijmegen and the Free University, Amsterdam (Letzel and Van Reenen, 1978). Some of the aims of this project were:

- to determine the relation between the durability of amalgam restorations and the material characteristics of amalgam.
- to determine the quality of amalgam restorations.

The patients who volunteered for this project had to meet the following criteria:

- good general health.
- good oral hygiene.
- no intraoral lesions other than caries.
- undisturbed continuity of maxillary and mandibular dental arches.
- age between 15 and 40 years.
- requiring at least 4 but no more than 12 multiple-surface restorations of standard size (Advokaat et al., 1985).

In the course of this longitudinal study, annual bite-wing radiographs were made for the purpose of caries diagnosis.

Classification of the patients

Our study concerned 15 patients of whom radiographs made after 0 and 4 years were available. Table 6.1 shows the age distribution of these patients at the start of the study.

Table 6.1 Patient ages at the start of bone level measurements (0 year evaluation).

Age	Number
16 through 20 years	4
21 through 25 years	9
26 through 30 years	2
31 through 35 years	0
35 through 40 years	0
Total	15

These age categories are analogous to those distinguished in the Amalgam Project (Advokaat, Akerboom and Borgmeijer, 1985).

On these radiographs the distance between the measuring points was measured on 333 surfaces; 116 were bounded by an intact surface, 110 were adjacent to a restoration with a correct marginal fit and 107 were adjacent to a restoration with an overhanging (94 with 0.4 mm or less and 13 with more than 0.4 mm overhang on the radiograph) (table 6.2).

Table 6.2 Condition of the surfaces adjacent to the periodontal interdental bone at the time of measurement.

Intact	116
Correct marginal fit	110
Restoration overhanging $\leq$ 0.4 mm	94
Restoration overhanging $>$ 0.4 mm	13
Total	333

6.2.2 The radiographic technique

Schei et al. (1959) developed a method to determine the bone level with the aid of periapical radiographs. This method was further developed and improved by Björn and Holmberg (1966) and Björn et al. (1969). The method is based on recording the bone level in relation to the length of the tooth. According to these investigators the optimal bone level was about 65% of the total tooth length.
Research done by Regan and Mitchell (1963) indicated measurements on periapical radiographs correlate better with clinical measurements in the mandible than in the maxilla. The explanation is that, in the mandible, the bisecting angle technique they used approximates the parallelling technique, whereas in the maxilla the projection according to the bisecting angle technique deviates more from that according to the parallelling technique.
Reed and Polson (1984) compared the bone level on periapical radiographs made with the parallelling technique with that on bite-wing radiographs. The distance between cemento-enamel junction and bone level proved to be smaller on periapical than on bite-wing radiographs, a finding in agreement with observations reported by Björn et al. (1975) and Håkansson et al. (1981). The differences resulted from the fact that in the maxilla it was usually impossible with the parallelling technique to aim perpendicularly to the tooth axis.
It has been explained in chapter 5 that the beam should be perpendicular to the tooth axis for optimally reliable visualization of the anatomical structures. The bite-wing radiograph best meets this requirement. In terms of radiation protection, too, the bite-wing is preferable because it simultaneously depicts part of the teeth in maxilla and mandible. On the other hand, it has the disadvantage that not the entire tooth is depicted. This is why many investigators nevertheless resort to periapical radiographs. However, Duinkerke (1976) reported that it is difficult to determine the measuring point of the apex exactly, which may be a source of inaccuracy. Periapical radiographs are therefore of only relative value in this context.
Consequently bite-wing radiographs were used in our study. Vertical bite-wings were used for measurement of extensive bone loss, using the aiming device described in subsection 5.4.2. This ensures reproducibility. The beam angle was adjusted by the parallelling technique.

6.2.3 The making of the radiographs

Bite-blocks were prepared (5.4.2) after completion of each patient's treatment. At that time the first bite-wing radiograph for this part of the study (0 year) was made. Further radiographs were made after 1, 2, 3 and 4 years. This was done using Kodak Ultra Speed films (DF 57) and a General Electric 1000 roentgen apparatus (70 kVp, 15 mA). The exposure time was 0.4 sec for the premolar bite-wing (6 mAs) and 0.5 sec for the molar bite-wing (7.5 mAs). The films were developed in a Siemens Pantomat 10, using Siemens Cronex 90 MD developer and Siemens Cronex 90 MF fixer. The temperature of the developer bath was 28°C.
Van der Linden and Van der Stelt (1980) demonstrated that a good film quality is attained when an adequately maintained developing machine is used. In that case radiographs are obtained which in density and detail are comparable with hand-developed radiographs. The developer for the developing machine was checked with the aid of Agfa Curix test film.

6.2.4 The evaluation of the radiographs

Engelberger et al. (1963) made their measurements on true-size radiographs placed

on a light box. Björn et al. (1969) chose a set-up involving 5x linear magnification by projection. The radiograph was so projected that the approximal contour of the tooth extended parallel to the vertical lines of the gradation (fig. 6.1). The bone level - defined as the distance between bone margin and apex - was compared with the total length of the tooth. Kelly et al. (1975) also used a magnification (5x) in measuring the radiographs. For our study, vertical bite-wing radiographs were mounted in a slide frame and projected onto a plane with a gradation in millimetres.
The magnification was adjusted with the aid of a film on which a circle with a diameter of 1 cm had been drawn. The film was perforated at the centre of the circle and at four points on its circumference which were determined by constructing a horizontal and a vertical line through the centre.
Five magnifications (1, 4, 6, 8 and 10x) were tried in order to determine which magnification gave an optimal image, with special reference to the depiction of the lamina dura, the cortical bone of the alveolar crest, the periodontal ligament space and the trabecular pattern.

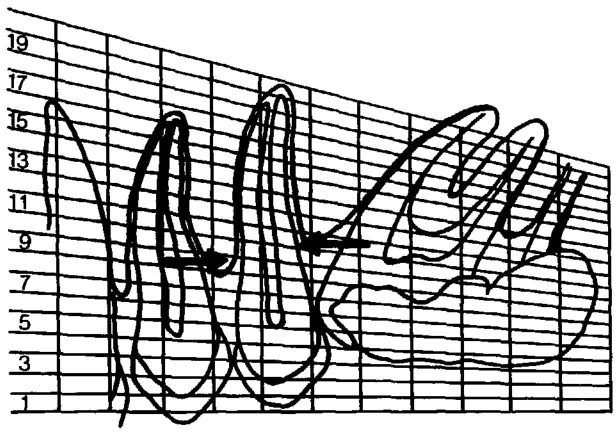


Fig. 6.1 Schematic representation of the method used by Björn et al. (1969) to determine bone height. This was done along the root surface as indicated by arrows. The bone score in this case was 10 mesially and 11 distally.

6.2.5 The measuring points for determination of the bone height

In this study the absolute distance was determined between the bone level and the cemento-enamel junction or a recognizable point on the approximal part of a restoration. The latter is of use only if changes in bone level are examined in a longitudinal study (figs. 6.2 and 6.3).
To begin with, the measuring points to be used for bone level determination will have to be clearly defined. Since there may be some uncertainty about the exact position of the measuring point of the top of the interdental bone, such investigators as Schei (1959), Engelberger (1963) and Kelly (1975) tried to define the site used as measuring point.
Schei et al. (1959) measured the bone level at a site where the periodontal space was of normal or approximately normal width; but they failed to define the term "normal". Coolidge (1937) reported on postmortem measurements of the width of the periodontal membrane showing that this varies widely. Engelberger et al. (1963) and Kelly et al. (1975) formulated additional guidelines for determination of the bone

Fig. 6.2 Radiograph of teeth and alveolar process with the site of normal width of the periodontal ligament space marked. The arrow indicates the measuring point.

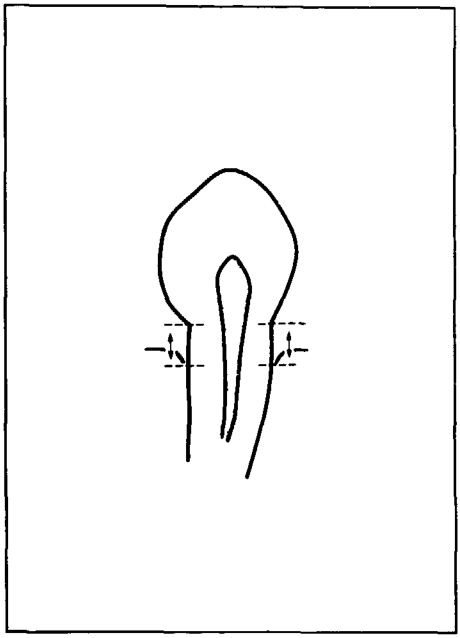


Fig. 6.3 The method used to measure bone height.

height. In view of these reports, the following criteria were formulated primarily for the site of the measuring point of the bone level:

- one should measure from the most coronal site where the periodontal space is of constant normal width, i.e. the site of transition from the cervical widening of the space to that part which shows no marked fluctuations in width (figs. 6.2 and 6.3).
- one should measure from the top of the bone level immediately adjacent to the tooth if the alveolar bone shows the normal radiolucency and the periodontal space extends to the top of the alveolar crest or is invisible (fig. 6.4).

In our study, the following criteria were applied for comparison of bone heights measured as the distance between the interdental bone and the cemento-enamel junction or the cervical margin of the restoration:

- as measuring point for the cemento-enamel junction that point was taken at which the cervical enamel was still just visible.
- as measuring point for the restoration the most cervical point of the restoration was taken. If the site was doubtful, then the point taken as measuring point was noted separately for future reference.

Both measuring methods were applied whenever possible; otherwise one of the two was used. Moreover, the degree of overhanging of any restoration present was noted (Van Amerongen, 1980). The measurements were performed by two observers experienced in interpreting radiographs. In the case of inter-observer differences about the site of the measuring points, attempts were made to reach agreement. If this was impossible, the two observers recorded different bone height measurements.

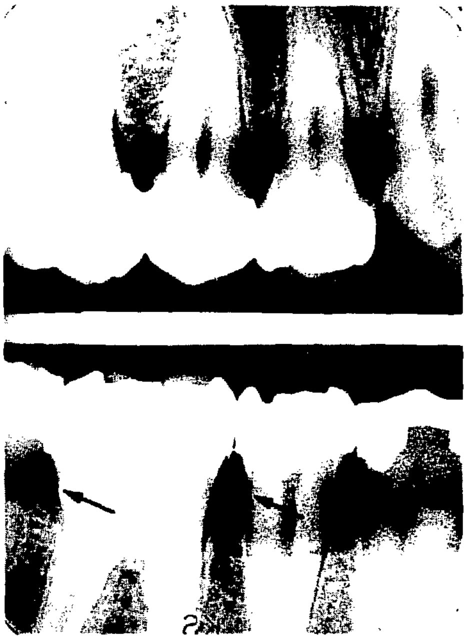


Fig. 6.4 Radiograph showing the alveolar process immediately adjacent to the tooth. The arrow indicates the measuring point.

6.2.6 The reliability of the magnification of radiographs

As described in the literature (6.2.4), the radiographs were magnified in order to make measurements by projection on graph paper. Transport and focusing might lead to deviations which influence reproducibility. This is why first of all an attempt was made to establish the degree of reliability of magnification of radiographs. To check this, the film used for adjustment of the magnification was adjusted to ten-fold magnification ten times over. The centre of the test circle with its diameter of 1 cm and the perforations on the circle were adjusted to the centre of a line of the gradation of the graph paper. The distances between the inside on one side and the outside on the other side of the projected perforations, visible as points of light on the graph paper, were measured. This was repeated after transport and focusing ten times over. Moreover, the degree of accuracy was determined by the method described in subsection 5.5.4.

6.2.7 Analysis of the measurement data

The two observers measured the bone level at 333 sites as described in subsection 6.2.5. When the distance between the measuring points diminished, the difference between measurements was marked with a positive sign; and when the distance increased the difference was marked with a negative sign; a no-difference finding was recorded as 0.

A comparison was made of bone level measurements made on interdental bone adjacent to a tooth with an intact approximal surface, adjacent to a restoration with a correct adapted cervical margin, and adjacent to a restoration with an overhanging cervical margin.

The differences between the measurements made by the two observers at 0 and 4 years in relation to the cemento-enamel junction and the cervical margin of the restoration were compared with the aid of the mean ($\bar{X}$) and the standard deviation (s.d.)

of the measurements. The standard deviation of the mean of the differences between the measurements was determined:

$$S_A = \frac{s.d.}{\sqrt{n}}$$

6.3 Results

6.3.1 Magnification of the radiographs

The radiographs were compared at magnification 1, 4, 6, 8 and 10x. It was found that the lamina dura, the alveolar crest and the trabeculae of the cancellous bone of the alveolar process were clearly visible at magnification 10x. Consequently a ten-fold magnification was used throughout this study.

6.3.2 Adjustment of the magnification

In order to determine the accuracy of adjustment the test object (circle with a diameter of 1 cm) was used to adjust to ten times magnification ten times over (transport and focusing). The results are listed in table 6.3. Adjustment of the magnification amounted to 100.84±0.13 mm, and transport and focusing to 100.77±0.07 mm. Adjustment, transport and focusing therefore hardly exerted any influence on the accuracy of the measuring method.

Table 6.3 The mean ($\bar{X}$), standard deviation (s.d.) and standard error (S_A) due to adjustment of the magnification and transport and focusing of the test slide.

Adjustment of 10x magnification (mm)	Transport and focusing (mm)
101.0	100.8
100.9	100.7
100.9	100.7
100.8	100.7
101	100.8
100.9	100.8
100.8	100.8
100.7	100.8
100.6	100.9
100.8	100.7

$\bar{X}$ = 100.84 mm	$\bar{X}$ = 100.77 mm
s.d. = 0.126	s.d. = 0.067
S_A = 0.04	S_A = 0.02

6.3.3 Measurements on radiographs of patients

Measurements at 0 and 4 years.

The observers K and L measured bone levels on radiographs of patients at 0 and 4 years. Differences between the bone level measurements are listed in table 6.4. Because in a number of instances the observers were unable to agree about the visibility of the surfaces, the totals differ from the number of surfaces evaluated.

Table 6.4 Differences between bone level measurements at 0 and 4 years for intact surfaces (A), surfaces adjacent to a restoration with correct adaption (B) and surfaces adjacent to an overhanging restoration (C) (n = 325).

Difference (mm)	A Observer K		A Observer L		B Observer K		B Observer L		C Observer K		C Observer L	
	nr.	%	nr.	%	nr.	%	nr.	%	nr.	%	nr.	%
−1.6/−2.0	1	1							1	1		
−1.1/−1.5	2	2	1	1	7	6	3	3	4	4	2	2
−0.6/−1.0	10	8	9	8	13	12	7	6	8	8	7	7
0 /−0.5	52	44	43	38	42	38	42	39	32	33	43	41
0	7	6	15	13	10	9	20	18	11	11	16	15
0 /+0.5	35	30	34	30	28	26	34	31	35	36	33	31
+0.6/+1.0	10	8	9	8	7	6	3	3	7	7	2	2
+1.1/+1.5	1	1	2	2	2	2	1	1			2	2
Total	118		110		109		110		98		105	

The changes in the differences between measurements after 0 and 4 years in table 6.4, are summarized in table 6.5; this shows that observers K and L found a diminished distance between the measuring points on the intact surfaces in 39% and 40% of cases respectively. For surfaces with a correct marginal adaptation the respective values were 34% and 35%, and for surfaces with an overhanging restoration they were 43% and 35%.

The number of cases in which a diminished distance between the measuring points was measured was strikingly large. This raises the question whether this was caused by some uncertainty on the choice of measuring points.

Table 6.5 Differences between bone level measurements at 0 and 4 year evaluation of 325 surfaces, in percents.

	Condition of the surfaces adjacent to the bone: Intact		Restoration with correct marginal fit		Overhanging restoration	
Observers	K	L	K	L	K	L
Increased bone level	39	40	34	35	43	35
Reduced bone level	55	47	56	48	46	50
Unchanged bone level	6	13	9	18	11	15

For this reason the agreement between the measurements made by K and L was studied. Table 6.6 lists the differences between K and L in measurements made from the cemento-enamel junction and the restoration after 0 and 4 years. Table 6.6 shows that the mean of the measurements from the cemento-enamel junction at 0 year evaluation was 0.12 ± 0.32 mm. This means that observer K measured a higher value (0.12 mm) on the average than observer L. The standard deviation of the mean difference was 0.02 mm (table 6.7). Table 6.7 also lists the values of the measurements after 4 years and the measurements at 0 and 4 year evaluation in relation to the cervical margin of the restoration. The magnitude of the standard deviation was in part due to a few marked differences between the observers as to the location of the measuring points.

Table 6.6 Differences (n) between measurements made by observers K and L at 0 and 4 years from the cemento-enamel junction (CEJ) and the cervical margin of the restorations.

Differences K-L (0.1 mm)	CEJ 0 year n	rest. 0 year n	CEJ 4 year n	rest. 4 year n
25	0	0	0	0
24	0	0	0	0
23	0	0	0	1
22	0	0	0	0
21	0	0	1	1
20	0	0	1	0
19	1	0	1	1
18	1	1	0	1
17	0	1	1	0
16	1	0	1	0
15	1	0	2	1
14	2	2	0	1
13	1	0	2	0
12	1	0	2	0
11	0	3	6	7
10	6	2	0	0
9	1	2	1	1
8	2	2	3	1
7	3	4	4	5
6	6	4	8	7
5	7	6	9	5
4	8	3	12	8
3	12	7	10	5
2	12	13	16	10
1	50	43	61	48
0	164	93	145	84
− 1	34	18	29	17
− 2	5	0	3	0
− 3	2	1	0	0
− 4	0	0	1	0
− 5	1	0	0	1
− 6	0	0	2	0
− 7	0	0	0	0
− 8	0	0	0	0
− 9	0	0	0	0
−10	0	0	0	0
	n: 321	n: 205	n: 321	n: 205
	$\bar{X}$: 0.12	$\bar{X}$: 0.15	$\bar{X}$: 0.16	$\bar{X}$: 0.19
	s.d.: 0.32	s.d.: 0.32	s.d.: 0.36	s.d.: 0.4
	s.d.$_{\bar{X}}$: 0.018	s.d.$_{\bar{X}}$: 0.022	s.d.$_{\bar{X}}$: 0.020	s.d.$_{\bar{X}}$: 0.028

Table 6.7 Standard deviations (s.d.) and standard errors (S_A) of the mean difference between observers K and L.

Bone height	Mean difference (mm)	Standard deviation (mm)	Standard error (mm)
cemento-enamel junction			
0 year	0.12	0.32	0.02
4 years	0.16	0.36	0.02
restoration			
0 year	0.15	0.32	0.02
4 years	0.19	0.4	0.03

6.4 Summary and conclusions

Measurements were made on radiographs magnified ten times. Magnification, transport and focusing did not contribute in a major way to the inaccuracy of the method. The standard deviation of magnification was 0.126 mm and that of transport and focusing 0.067 mm. The error of magnification and that of focusing were 0.04 mm and 0.02 mm.

Radiographs of patients were assessed by two observers. The difference in distance measured between the measuring points was more often increased than diminished. There was no obvious difference between measurements adjacent to teeth with intact surfaces and those adjacent to teeth with multiple-surface restorations. Diminution of the difference was measured in many instances (34-43% of cases). This applied to measurements from the cemento-enamel junction as well as to those from the restoration.

The mean of the differences in measurements between K and L, the standard deviation and the standard error of the mean were determined in order to establish the accuracy of the measuring method (table 6.7). In the cases in which the observers could not agree, there were marked differences in the localization of the measuring points.

6.5 Discussion

Rohner et al. (1983) measured alveolar bone loss on radiographs made at different times. More correctly, they measured the change in bone height. Suomi et al. (1968) compared bone level measurements on radiographs with measurements made during periodontal surgery, and found that the radiographs gave a relatively faithful impression of the actual situation. This warrants the conclusion that bone level changes or differences between the distances from the measuring points involve bone gain or bone loss.

The method developed by Schei et al. (1959) and improved by Engelberger et al. (1963) for longitudinal studies of the bone level proved to pose problems as to the localization of the measuring points for the bone level. It is difficult, for instance, to indicate exactly the correct bone height, the vestibular or lingual level and the boundaries of normal radiopacity (fig. 6.5). The same applies to the site at which the periodontal ligament space is of normal width. In our study these measuring points led to discussion.

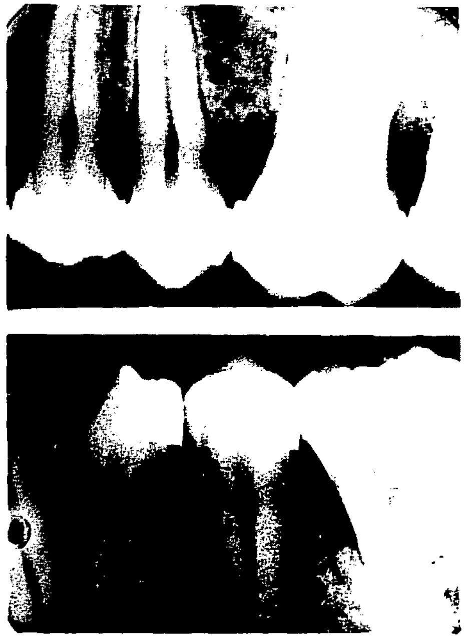


Fig. 6.5 Radiograph of teeth and alveolar process; the latter has two bone levels: a radiolucent level and a more radiopaque level. The arrow indicates the boundary between the two levels.

In a striking number of cases observers K and L measured the same bone height but differed in their measurements of changes in bone height on the basis of their 0 year and 4 year measurements. This seemed to suggest that the observers had difficulty in localizing always the same measuring points.

The findings of the two observers with regard to differences in bone level after 4 years showed an unchanged or increased bone height in 43-54% of cases. In the literature, only Al-Kufaishi et al. (1984) reported bone gain in a study of juvenile subjects. During the first two years of a study covering a three-year period a slight (non-significant) increase in bone height was found. In the course of the third year there was significant bone loss. In view of other data from the literature, bone degeneration would be more in the line of expectation. The conclusion is therefore that it is questionable whether the measuring points are suitable for measuring bone degeneration, because the points are not reproducible. It would consequently be useful to develop a method with improved recognizability of measuring points for subsequent measurements.

For this purpose a study was designed for two groups of patients in whom the determination of the measuring points were so modified that their localization was less controversial to the observers. This study will be discussed in the following subsections concerning a simple procedure by which accurate measurements could be made. This method was tested by two observers (P and L) (subsection 6.6.4).

6.6 Materials and methods

6.6.1 The patients

One observer performed bone level measurements in two groups of patients:

- patients with intact approximal surfaces and surfaces with correct marginal fit or with overhanging restorations (group A).
- patients with juvenile periodontitis (group B).

Group A

This group consisted of the patients of the Amalgam Project already mentioned in subsection 6.2.1. This study included 13 patients. Of the 69 bone level differences assessed, 18 were adjacent to an intact surface, 27 to a surface with a restoration with correct marginal fit, and 24 to a surface with an overhanging restoration (0.4 mm or less in 10 and more than 0.4 mm in 14) (table 6.8).

Table 6.8 Condition of the surfaces adjacent to the periodontal interproximal bone at the time of measurement (group A).

Intact	18
Restoration with correct marginal fit	27
Restoration overhanging $\leq$ 0.4 mm	10
Restoration overhanging > 0.4 mm	14
Total	69

Group B

Another part of the study was performed in patients with juvenile periodontitis presenting for treatment at the Department of Periodontology of the Free University, Amsterdam. Juvenile periodontitis is characterized by marked local bone loss, particularly in the incisor and at the first premolar area, in juvenile patients. Treatment of these patients was a combination of medication and surgery:

1) tetracycline 4 x 250 mg daily during two weeks.
2) surgical elimination of granulation tissue using the modified Widman flap technique.

This therapy, previously described by Liljenberg and Lindhe (1980), may be rapidly followed by osteogenesis in the lesion treated, which is discernible only by means of radiographs. In 4 patients vertical bite-wings made at the start of treatment and 3 and 6 months later were used to determine and follow the formation of bone. Bone height measurements were made at a total of 32 approximal surfaces.

6.6.2 The radiographic technique, the making and the evaluation of the radiographs

Radiographic equipment:	
Film	Kodak Ultra Speed (DF 57)
x-ray apparatus	General Electric 1000
Tube voltage	70 kVp
Milliamperage	15 mA
Exposure time	premolars 0.4 sec (6 mAs)
	molars 0.5 sec (7.5 mAs)
Developer	Siemens Cronex 90 MD
Fixer	Siemens Cronex 90 MF
Developer temperature	28°C

As described in subsection 6.2.2, vertical bite-wing radiographs were made using the aiming device described in subsection 5.4.2. This device ensures reproducible radiographs. The roentgen apparatus was adjusted by the parallelling technique. As mentioned in subsection 6.2.3, bite-blocks have to be made for reproducibility in patients. The first bite-wings in group A were made at time 0. Subsequent bite-wings were made after 1, 2, 3 and 4 years. In group B, bite-wings were made at the start of therapy and after 3 and 6 months.

Vertical bite-wings mounted in a slide frame were evaluated as described in subsection 6.2.4. They were projected at ten-fold magnification onto a surface with a gradation in mm.

6.6.3 The measuring points for determination of the bone height

In order to eliminiate the influence of a variation in the width of the periodontal ligament space and the density differences in the alveolar bone (what is normal?), a different procedure was used. Rather than using the measuring points for bone level determination described in subsection 6.2.5, the following method was developed for this part of the study.

Before evaluation the projected radiograph was so oriented that the image of the metal bite-block of the aiming device took a horizontal course. Next a line connecting the highest mesial with the highest distal point of the alveolar crest between two teeth was drawn. Lines were drawn parallel to the bite-block: one through the lowest point of the cemento-enamel junction and the cervical margin of the restoration (if present), and the other through the point of intersection between the line connecting the highest mesial with the highest distal point of the alveolar crest, and the tooth root. The bone height could then be measured in two different ways (fig. 6.6):

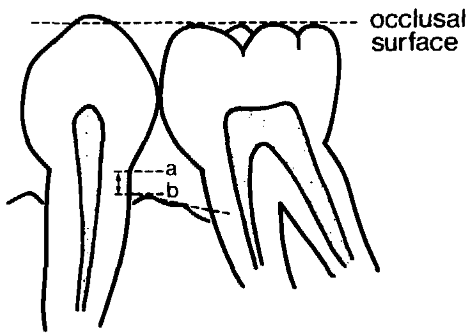


Fig. 6.6 Schematic drawing of a radiograph on which a line has been drawn which connects the highest mesial with the highest distal point of the alveolar crest. Lines a and b are parallel with the bite-block. The bone height is the perpendicular distance between a and b.

- as perpendicular distance between the line through the cemento-enamel junction and the line through the point of intersection with the tooth root.
- as perpendicular distance between the line through the cervical margin of the restoration (if there is an approximal restoration in the tooth) and the line through the point of intersection with the tooth root.

For more accurate measurements and better interpretation of the measured data, the following points were taken into account or noted down in writing:

- when there was doubt about the cervical margin of the restoration, the point from which the measurement was made was noted on the form to ensure that the same measuring point would be used in the next measurement.
- if a restoration extended so far cervically as to include the cemento-enamel junction, then only the cervical margin of the restoration was used.
- the degree of overhanging of the restoration was determined (Van Amerongen, 1980) in order to establish its influence on bone height.

Juvenile periodontitis involves angular bone loss, as described in chapter 3. Dependent on the local presence of plaque and the mesiodistal width of the interdental sep-

tum, part of the septum may remain intact or at least show less resorption. The depth of the (local) lesion should be distinguished from the height of the bone level surrounding the lesion. This is why we decided that, in the case of angular bone loss, we should measure the distance from the cemento-enamel junction to the floor of the lesion as well as that from the junction to the more cervical bone level.
For determining the depth of the lesion a perpendicular was drawn from the deepest point of the lesion to the bite-block of the aiming device. The perpendicular distance between the bone level measuring point and the deepest point of the lesion is the depth of the lesion (fig. 6.7). This measurement was not performed if the lesion was no longer radiographically visible after 3 or 6 months.

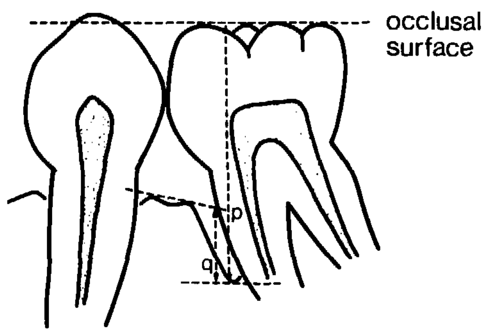


Fig. 6.7 Schematic drawing of a radiograph with a line drawn on the alveolar crest (fig. 6.6). From the deepest point of the bone lesion line p is perpendicular to the bite-block. Line q indicates the depth of the bone lesion.

6.6.4 The reliability of the measurements

The reliability of the measurements depends on the accuracy with which measuring points can be localized on the radiograph and on the inter-observer agreement in localizing measuring points. To determine the reliability of the measurements an additional study was performed using standardized reproducible radiographs of 4 patients made at 0, 1, 2, 3 and 4 years. On these radiographs the bone level was measured at 11 surfaces and the accuracy of the method was determined. The measurements were made in two different ways:
- measuring radiographs per patient in chronological order.
- measuring radiographs in random order as to patient and chronology.

The results will be further discussed in subsection 6.7.1. In any case, however, they led to the decision to have each observer perform each measurement twice for the same observation.

6.6.5 Applications of the measuring method developed

The above described measuring method was applied in the abovementioned patients, using the mean of two measurements for further analysis. Measurements made at 0 year and 4 years can be used to establish the influence of intact surfaces, surfaces with correct margins and surfaces with overhanging restorations on the bone level. The bone level was measured at 69 surfaces, and a distinction was made between restorations overhanging up to 4 mm and those overhanging more than 4 mm.
As already mentioned in subsection 6.2.7, an increase in bone height was marked with a positive and a decrease with a negative sign. The difference between measurements at 0 year and at 4 years was tested with the aid of the sign test.
The distances from the cemento-enamel junction to the bone and from the cervical

margin of the restoration to the bone were plotted in a graph against the time of measurement. The linear regression through these points was determined using the equation y = mx + b (fig. 6.8), in which

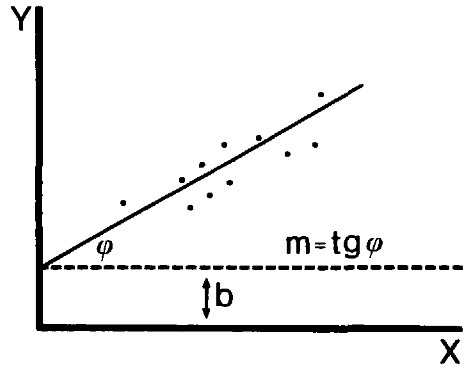


Fig. 6.8 Schematic drawing of the linear regression.

y = the values measured,
x = the year of measurement,
b = the y-value of the intersection of the straight line with the y-axis for x = 0,
m = the tangent of the best fitting straight line through the points.
The slope of the line (tg gamma) is a measure of the degree of bone loss or bone formation. A positive tg gamma indicates bone loss (the wider the angle, the faster the process). A negative tg gamma indicates bone gain. These measurements make it possible to predict the bone level after, say, 10 years - assuming that a decrease in bone height is a continuous process and that an increase in bone height cannot progress further than 1 mm from the cemento-enamel junction.

6.7 Results

6.7.1 The reliability of measuring differences in bone height

The two observers evaluated the radiographs in two different ways: in chronological order and in random order. The results of the bone level measurements were plotted in graphs, of which fig. 6.9 is an example. Further examination of the graphs shows

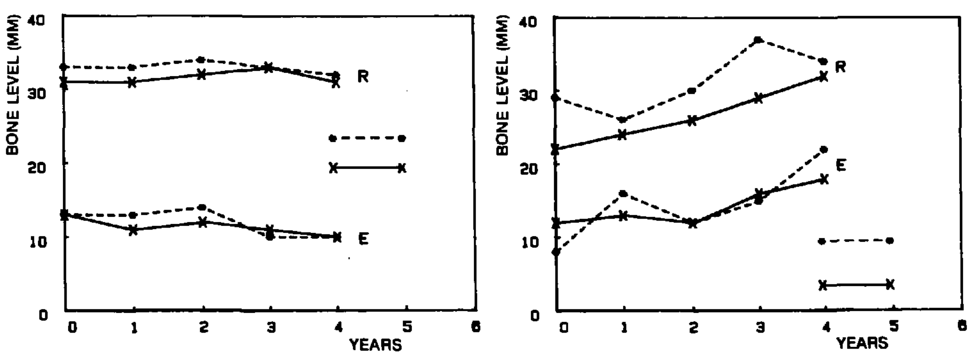


Fig. 6.9 Bone level measurements made by observers P and L.
• = measurements by observer P.
x = measurements by observer L.

that the bone level measurements after 0, 1, 2, 3 and 4 years can be divided into four combinations of observations:

a. the bone level measurements by the two observers coincide.
b. the bone level remains the same but the measurements by the two observers show a constant difference.
c. the bone level fluctuates but the inter-observer difference in measurements has a constant value.
d. the observations are close but one year observer P measures higher bone levels than L, and the next year the reverse is true.

Efforts were made to determine the degree of concurrence between the two observers at measurements after 0, 1, 2, 3 and 4 years. Because relative bone level differences rather than real bone levels were measured, the following simplifications can be applied:

- a constant inter-observer difference means that one observer consistently localized his measuring points differently from the other. For determination of the accuracy of bone level differences after a given interval, the bone levels were shifted parallel to each other until the difference between the observations was the smallest possible.
- when the inter-observer differences were not constant, one of the levels was shifted parallel to the other until the bone level differences were minimal.
- there was no interdependence between the measurements in the different years: P might measure higher values than L, or vice versa. Because the correct value was probably in between, the absolute value of the differences between the observers was taken.

If a difference of 0.1 mm in measuring bone level difference is considered acceptable, then observations in chronological order showed concurrence in 82%. The concurrence of observations in random order was 72% (table 6.9).

Table 6.9 Frequency of differences in measuring bone height between two observers. Radiographs evaluated per patient in chronological and in random order.

Differences between observations by P and L (mm)	0	0.1	0.2	0.3	0.4	0.5	total	% (0 and 0.1)
chronological	36	38	11	4	1		90	82
random	39	26	16	7		1	90	72

Table 6.10 Mean, standard deviation and standard error of the mean of the differences between observers P and L.

Differences between P and L (mm)	Chronological	Random
mean	0.08	0.12
standard deviation	0.09	0.11
standard error of the mean	0.01	0.01

As in subsection 6.3.3, the agreement between the observations by P and L was examined in detail. Table 6.10 shows that the mean of the difference between observations in chronological order was 0.08 ± 0.09 mm. This means that observer P on average measured 0.08 mm higher than L. The standard error of the mean of the difference was 0.01 mm. For observations in random order the mean of the difference was 0.12 ± 0.11 mm, and the standard error of the mean difference was 0.01 mm.

6.7.2 The accuracy of bone height measurements made by a single observer

Each measurement to determine the bone height was made twice, measuring from the cemento-enamel junction and from the cervical margin of the restoration to the bone level. The differences between measurements made for determination of the bone height are presented in table 6.11.

Table 6.11 Frequency of measuring differences in determination of the bone height per surface (1 observer, 2 measurements). Radiographs evaluated per year per patient in random order.

Difference between the two measurements (mm)*	E**	%	R**	%
+0.7			1	0.4
+0.6				
+0.5	2	0.7		
+0.4	3	1		
+0.3	7	2.4	5	2
+0.2	33	11.4	23	9.2
+0.1	76	26.2	74	29.6
0	84	30	88	35.2
-0.1	54	18.6	42	16.8
-0.2	23	7.9	13	5.2
-0.3	4	1.4	4	1.6
-0.4	2	0.7	1	0.4
-0.5	2	0.7		
Total	290	100	250	100

* First measurement higher: positive. First measurement lower: negative.
** E is the distance from the cemento-enamel junction to the bone and R is that from the cervical margin of the restoration to bone.

The table shows that the difference between the two measurements per surface was between +0.1 mm and −0.1 mm in 74% of cases if the observer measured from the cemento-enamel junction (E) and in 82% of cases if he measured from the cervical margin of the restoration (R). Some bone height differences in relation to the cemento-enamel junction and in relation to the restoration are shown in fig. 6.10. Table 6.12 shows the mean difference between the two measurements, the standard deviation and the standard error of the mean. The accuracy of the method with a single observer can be deduced from these data.

Table 6.12 Standard deviations and standard errors of the mean difference between the two measurements made by the same observer.

Bone height	Mean difference (mm)	Standard deviation (mm)	Standard error (mm)
Cemento-enamel junction	0.02	0.15	0.009
Restoration	0.02	0.13	0.008

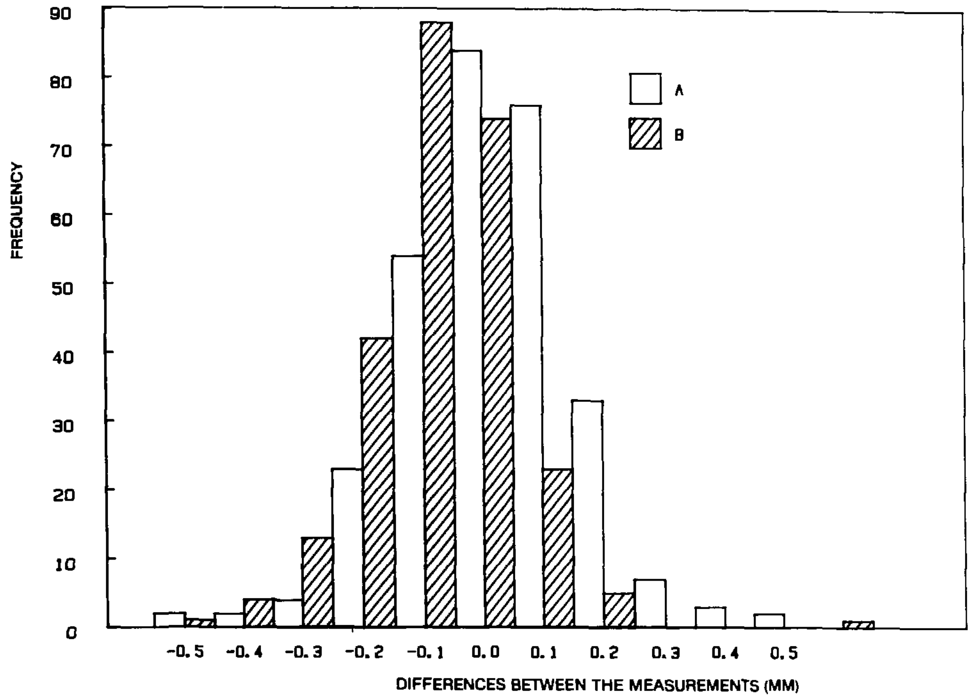


Fig. 6.10 Histogram of the differences between two bone level measurements made by a single observer at the same plane.
A = measurement from the cemento-enamel junction.
B = measurement from the cervical margin of the restoration.

Table 6.13 Differences in bone height over a period from 0 to 4 years at intact surfaces (A), surfaces with a restoration with a good marginal fit (B), surfaces with an overhanging restoration (C) and the total number of surfaces with a restoration (D), n = 69.

	A		B				C				D			
Difference (mm)	number of surfaces	%	number of surfaces		%		number of surfaces		%		number of surfaces		%	
	E*	E*	E*	R*	E*	R*	E*	R*	E*	R*	E*	R*	E*	R*
-1.1/-2.0														
-0.6/-1.0	1	5.5	1		3.8		1	3	7	12.5	2	3(2)	5	5.9
0 /-0.5	8	44.4	14	21	53.8	77.7	9	14	64	58.3	23	35(6)	57.5	68.6
0	4	22.2	5	2	19.2	7.4	1	3	7	12.5	6	5(2)	15	9.8
0 / 0.5	4	22.2	6	4	23	14.8	3	4	21	16.6	9	8(1)	20	15.7
0.6/ 1.0	1	5.5	0											
1.1/ 1.5														
Total	18		26	27			14	24			40	51		

* E: measurements from the cemento-enamel junction to the bone level. R: measurements from the cervical margin of the restoration to the bone level.

( ): measurements with the cemento-enamel junction encompassed in the restoration.

6.7.3 Determination of the bone height by means of the tangent on the alveolar crest (group A)

In 13 patients of group A the bone height was measured by the method described in subsection 6.6.3. In this part of the study the bone height was measured after 0, 1, 2, 3 and 4 years. The measurements after 0 and 4 years were used to determine bone height differences. The data measured on radiographs at five different times are presented in table 6.17 (page 113).
Table 6.13 shows a decrease in bone level in 50% and an increase in 27.7% of cases in category A (intact surfaces). In category B (restorations with a good marginal fit) a decrease was found in 57.6% and 77.7% respectively, and an increase in 23% and 14.8% respectively. In category C (overhanging restorations) a decrease was measured in 71% and 70.8% respectively, and an increase in 21% and 16.6% respectively.

Table 6.14 Percentages of the differences in bone height over a period from 0 to 4 years at intact surfaces, surfaces with a restoration with a good marginal fit and surfaces with an overhanging restoration.

	Bone level unchanged (0)		Bone level increased (+)		Bone level decreased (−)	
	E	R	E	R	E	R
Intact surface	22.2		27.7		49.9	
Restoration with a good marginal fit	19.2	7.4	23	14.8	57.6	77.7
Overhanging restoration	7	12.5	21	16.6	71	70.8

Table 6.15 Differences in bone level over a period from 0 to 4 years at intact surfaces, surfaces with a restoration with a good marginal fit, surfaces with an overhanging restoration and the total number of surfaces with a restoration.

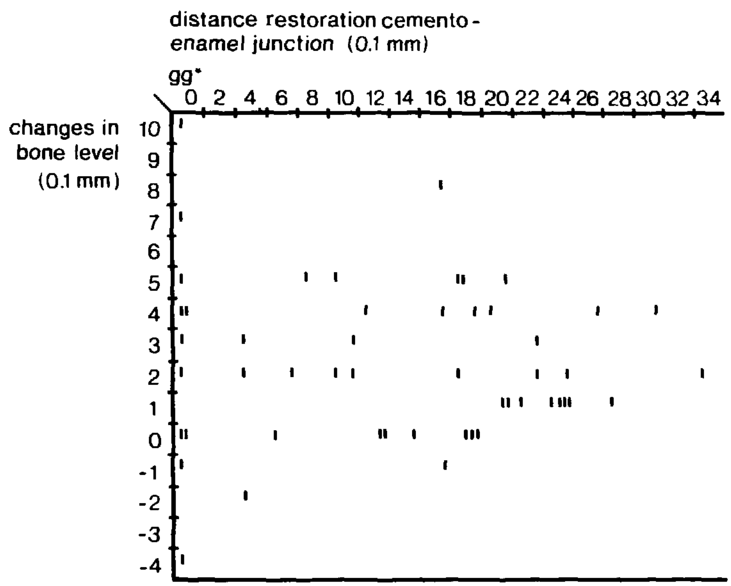
	Condition of the surfaces adjacent to the bone						
	Intact (a)	With restoration with a good marginal fit (b)		With overhanging restoration (c)		Total number with restorations (b+c)	
	E*	R*	E*	R*	E*	R*	E*
Bone level increased (+)	5	4	6	4	3	8	9
Bone level decreased (−)	9 NS*	21 S*	15 NS*	17 S*	10 NS*	38 S*	25 S*
Bone level unchanged (0)	4	2	5	3	1	5	6
Total	18	27	26	24	14	51	40

* R: measurements from the cervical margin of the restoration to the bone level. E: measurements from the cemento-enamel junction to the bone level. NS: not significant ($p > 0.05$). S: significant ($p < 0.05$).

Table 6.13 gives the difference in bone level after 4 years for the three different categories (A, B, C), and table 6.14 summarizes the results of the measurements, listing

the percentages of bone level changes at intact surfaces, surfaces with a restoration with a good marginal fit and surfaces with an overhanging restoration. At intact surfaces, decreased bone levels were measured as frequently as intact and increased levels together. At surfaces with a restoration with a good marginal fit the percentage of decreased bone levels increased; this increase was even more marked at surfaces with an overhanging restoration. Moreover, the differences in bone level after 4 years were tested with the sign test (table 6.15).
Further analysis of the data in this table shows that there was no significant decrease in bone level adjacent to intact surfaces. Measurements from the cervical margin of the restoration revealed a significant decrease in bone level adjacent to restorations with a good marginal adaptation and overhanging restorations. Differences in measurements made from the cemento-enamel junction just escaped significance, but after summation of the surfaces with restorations with a good marginal adaptation and overhanging restorations the difference was indeed significant. Table 6.14 shows that bone loss was more frequently found in the presence of a restoration than adjacent to intact surfaces. It is of importance to establish whether the location of the cervical margin of the restoration in relation to the cemento-enamel junction influenced the degree of bone loss (table 6.16).

Table 6.16 Evaluation of changes in 51 bone levels adjacent to approximal surfaces with restorations.



*gg: Cemento-enamel junction encompassed in the restoration.

The table reveals a considerable range of changes in bone height. These data do not warrant the conclusion that a smaller distance from the cervical margin of the restoration to the interproximal bone increased the degree of bone loss. When the entire cemento-enamel junction was encompassed in the restoration there was no demonstrable difference.
The data so far discussed concern changes in bone level after 0 year and after 4 years. However, measurements were also made after 1, 2 and 3 years (table 6.17).

Table 6.17 Bone height measurements after 0, 1, 2, 3 and 4 years.

Patient	Site of bone height measurement	Distance measured (0.1 mm)									
		0		1		2		3		4	
		E*	R**	E*	R**	E*	R**	E*	R**	E*	R**
1	14 dist	8		11		14		13		15	
	15 mes	8	31	8	31	8	31	10	32	8	32
	16 mes	10		11		12		11		11	
	36 mes	3	19	3	19	3	20	5	20	4	19
	45 mes	10		9		10		9		10	
	45 dist	13	15	11	15	11	15	10	16	13	17
2	25 mes	10	33	11	35	11	35	8	31	11	34
	25 dist	13	20	11	19	10	18	12	18	13	24
	27 mes	7		7		7		7		7	
	35 mes	9		8		8		8		11	
	46 mes	8	28	9	29	9	27	9	28	9	27
	46 dist		12		11		11		11		11
3	15 mes	18	29	18	32	12	30	13	32	14	34
	15 dist	14	29	14	29	15	31	15	33	17	34
	35 dist	11	34	15	35	16	35	15	36	15	35
	45 dist	10	24	11	25	16	30	18	31	17	32
4	14 dist	15	30	12	30	14	30	14	31	15	34
	16 mes	9	32	11	34	9	34	8	35	9	34
	46 dist	12	30	12	32	10	32	10	32	11	33
	47 mes	3	27	5	30	5	30	6	30	5	31
5	16 mes		12		13		19		20		23
	25 mes	4	15	5	16	5	16	4	16	3	15
	36 mes		2		6		8		9		9
	36 dist		10		10		13		12		12
6	16 dist	7	23	6	23	6	25	5	25	4	22
	34 dist	11		11		11		12		11	
	35 dist	9		11		12		11		11	
	36 mes	7	21	8	26	10	26	9	27	9	26
	36 dist	6	19	6	22	6	21	5	24	7	23
	45 dist	13	17	12	17	12	16	11	16	12	17
	46 mes	6	33	7	35	8	34	7	35	10	34
	46 dist	11	28	11	29	10	27	10	29	12	30
7	46 mes	10	28	9	26	9	27	10	27	11	27
	46 dist	11	19	12	19	13	20	14	21	15	21
8	15 dist	4	32	5	33	7	33	5	33	5	33
	25 mes	6	26	6	27	7	26	7	26	7	27
	26 mes	12	28	7	25	10	30	12	28	9	27
	26 dist		16		15		20		19		21
	37 mes	3		3		4		1		2	
	46 dist		18		20		21		22		22

Patient	Site of bone height measurement	Distance measured (0.1 mm)									
		0		1		2		3		4	
		E*	R**	E*	R**	E*	R**	E*	R**	E*	R**
9	14 dist	9	12	8	13	8	13	8	12	7	10
	25 dist		11		9		11		11		11
	26 mes	11	19	9	17	11	19	12	20	12	21
	35 mes	8		8		7		7		10	
	36 mes	8		8		5		5		7	
	36 dist	11		10		9		9		14	
	45 dist		17		19		17		19		20
10	15 mes	6		3		2		2		2	
	16 mes	10		6		4		5		3	
	26 mes	13	15	16	19	14	16	15	18	15	18
	36 mes	-5	27	-6	28	-5	27	-5	28	-4	29
	37 mes	4		6		7		7		7	
	46 mes	8	17	11	19	12	22	12	22	9	19
11	15 mes	9		9		10		10		10	
	15 dist		13		11		11		10		9
	25 mes	11	29	12	31	10	30	14	33	15	33
	26 mes	15	37	16	37	13	35	16	38	17	38
	45 mes	7		10		7		9		11	
	46 mes	10	38	10	39	11	40	11	43	12	42
12	15 mes	11	22	9	23	12	24	10	24	11	24
	15 dist	8	16	10	17	15	22	10	19	12	21
	25 dist		0		3		4		2		4
	26 mes	6	26	11	28	15	33	10	27	3	27
	26 dist	1		5		5		5		1	
	45 mes	1	11	2	10	11	19	3	12	9	16
	46 dist	7	18	8	19	10	20	9	21	11	21
13	15 dist	8	22	8	20	7	21	8	22	10	22
	16 mes		10		9		10		11		10
	46 mes	7		5		6		7		6	

* E: measurements from the cemento-enamel junction to the bone level.
**R: measurements from the cervical margin of the restoration to the bone level.

It can be deduced from this table that bone levels may be decreased, unchanged or increased, and that bone level changes may fluctuate. This means that bone loss may be measured one year, that the bone level remains the same the next year, and that bone regeneration occurs after yet another year. There are many possible combinations of findings and the degree of bone level change can vary widely.

6.7.4 Patients of group B (juvenile periodontitis)

In four patients of group B bone height was measured by the method described in subsection 6.6.3. Bone levels were determined after 0, 3 and 6 months adjacent to a total of 32 surfaces. Table 6.18 lists bone level measurements at the time of treatment as well as 3 and 6 months later; the table also mentions the differences.

Table 6.18 Depths of bone lesions and bone levels after 0, 3 and 6 months and differences of bone levels after 3 and 6 months in patients treated for juvenile periodontitis.

Patient	Site of bone level measurement	Distance measured (0.1 mm)						Difference in bone level (0.1 mm)			
		months						months			
		0		3		6		3		6	
		*D	*N	*D	*N	*D	*N	*D	*N	*D	*N
20	25 dist	53	43		53		56		−10		−13
	26 mes	67	55		45		58		+10		− 3
	35 dist		24		29		33		− 5		− 9
	36 mes	30	26		26		25		0		+ 1
	15 dist	41	33		36		29		− 3		+ 4
	16 mes	50	25		37		32		−12		− 7
	45 dist		13		23		22		−10		−11
	46 mes	50	14	24	22		25	+26	− 8		−11
21	47 mes		16		21		14		− 5		+ 2
	46 dist	58	20	43	25		24	+15	− 5		− 4
	44 dist	32	18	28	22	20	13	+ 4	− 4	+ 8	+ 5
	45 mes		14		15		15		− 1		− 1
	35 dist	31	11		15		12		− 4		− 1
	36 mes	55	3		8		8		− 5		− 5
	36 dist	53	30		53		36		−23		− 6
	37 mes	6			13		15		− 7		− 9
22	25 dist	22	6	28	10	26	11	− 6	− 4	− 4	− 5
	26 mes	43	8	40	22	41	13	+ 3	−14	+ 2	− 5
	35 dist		3		4		5		− 1		− 2
	36 mes	41	16	42	18		20	− 1	− 2		− 4
	15 dist		18		10		29		+ 8		−11
	16 mes	65	47	59	41		36	+ 6	+ 6		+11
	45 dist		19		25		25		− 6		− 6
	46 mes	34	20		26		27		− 6		− 7
	46 dist	41	29		31		25		− 2		+ 4
	47 mes		11		12		13		− 1		− 2
23	15 dist	70	50	49	48		51	+21	+ 2		− 1
	16 mes	76	44		51		52		− 7		− 8
	47 mes	35	17		16		12		+ 1		+ 5
	46 dist	88	50	78	55	70	65	+10	− 5	+18	−15
	46 mes	98		80		82	60	+10		+16	
	45 dist		18		18		23		0		− 5

*D: depth of lesion measured from its floor to the highest point of the alveolar crest (fig. 6.7).
*N: distance between highest point of crest and cemento-enamel junction (fig. 6.6).

Of the 32 bone levels measured, 23 were adjacent to surfaces of teeth bounded by a lesion and 9 were adjacent to surfaces of teeth not bounded by a lesion. Table 6.19 shows that:

- 23 lesions were radiographically visible at time 0.
- 10 lesions were visible after 3 months.
- 5 lesions were still visible after 6 months.

Table 6.19 Radiographic image of the lesions in the interproximal bone after 0, 3 and 6 months.

Time (months)	Lesion visible	Lesion invisible	Total
0	23		23
3	10	13	23
6	5	18	23

Table 6.20 presents data on the depth of the lesions, showing that:
- after 3 months 2 lesions had increased in depth, 2 had remained unchanged and 19 had decreased in depth.
- after 6 months the depth measured was increased in 2 and decreased in 21 lesions.

Table 6.20 Radiographic evidence of the difference in depth of interproximal bone lesions after 3 and 6 months.

Time (months)	No change	Increased depth	Decreased depth	Total
3	2	2	19	23
6		2	21	23

Table 6.21 shows that the level of the alveolar crest:
- was unchanged in 2, decreased in 24 and increased in 5 cases after 3 months.
- was decreased in 24 and increased in 7 cases after 6 months.

Table 6.21 Radiographic evidence of the difference in the level of the alveolar crest after 3 and 6 months.

Time (months)	Level unchanged	Level decreased	Level increased	Total
3	2	24	5	31
6		24	7	31

Finally, table 6.18 shows that there were 21 surfaces at which a decrease in bone level was persistently measured after 3 and 6 months, versus 10 surfaces (32%) at which either an increase or a decrease in level was measured.

6.8 Conclusions

This chapter describes a method to measure the interproximal bone height on radiographs of patients. The measurements performed warrant the following conclusions.

The method:
- the measurements made by two observers showed a high degree of agreement upon evaluation in chronological order (82%). The agreement between observations in chronological order exceeded that between observations in random order. Yet these observations, too, differ but little (72%). The percentages given pertain to a maximum difference of +0.1 mm or −0.1 mm.

- the mean difference between the measurements made by the two observers was 0.08 mm upon evaluation in chronological order and 0.12 mm upon evaluation in random order.
- the two measurements made by a single observer were concurrent in 74% of cases if he measured from the cemento-enamel junction (random order) and in 82% if he measured from the cervical margin of the restoration.
- the mean difference between the two measurements made by a single observer was 0.02 mm if he measured from the cemento-enamel border and 0.02 mm if he measured from the cervical margin of the restoration.

Radiographs in group A evaluated after 0 and 4 years:
- adjacent to intact surfaces decreased levels were found as frequently as unchanged and increased levels together. Adjacent to restorations with a correct marginal fit the bone level was more frequently decreased than unchanged or increased. The same applied to the bone level adjacent to surfaces with an overhanging restoration.
- after 4 years the patients in this group showed a significant decrease in bone level adjacent to restorations, but not in that adjacent to intact surfaces.
- it was not demonstrable that a smaller distance from the cervical margin of the restoration to the interproximal bone led to a greater decrease in bone level.

Radiographs in group A evaluated after 0, 1, 2, 3 and 4 years:
- the bone level might show a decrease one year, remain unchanged the next year, or show an increase another year. Various combinations were observed and the degree of change varied.

Radiographs in group B evaluated after 0, 3 and 6 months:
- of the 23 lesions, 13 were no longer radiographically visible after 3 months, and 18 were invisible after 6 months.
- of the 31 bone levels measured, 24 showed a decrease after 3 and 6 months.
- after 3 and 6 months there were 10 bone levels (32%) which had meanwhile showed either an increase or a decrease.

6.9 Discussion

As already mentioned in section 6.5, the recognizability of the measuring points on the basis of the criteria mentioned in the literature seemed debatable. Consequently a method was developed which ensured better recognition of the site of a measuring point.
It is difficult to determine the exact location of the cemento-enamel junction on a radiograph. This is why the cemento-enamel junction and the cervical margin of the restoration, if present, were taken as starting-points. In a number of cases the measurements from the cemento-enamel junction and from the margin of the restoration were not concurrent. Due to the highly absorptive character of the filling material the radiographs showed the most cervical point of the restorations, and it was from this point that the measurements were made. A minor change in beam angulation or in the shape of the restoration must have been of much greater influence here than at the far less absorptive cemento-enamel junction (Advokaat, 1985) and the interproximal bone. The agreement of observations in this study compares favourably with the

data in the literature. In the study of Björn et al. (1969) the inter-observer agreement was 86% if the bone score was plus or minus 1 (a bone score is comparable with 1 mm). Sjölien and Zachrisson (1972) reported 97% concurrence of measurements on duplicate radiographs (plus or minus 1 bone score). The agreement in measuring tooth lengths was 76% at a difference of +0.5 mm or −0.5 mm. Boyle et al. (1973) found that single-observer measurements of bone level from the cemento-enamel junction showed a mean difference of 0.32 mm.
According to Duinkerke (1976) the reproducibility of the measurements depends on the definition of the measuring point. He used sharply defined measuring points in determining the accuracy of his method. The standard error of his method was ± 0.14 mm. In our study the standard deviation of the mean difference of measurements by two observers was ± 0.11 mm, and that of the mean difference between two measurements by the same observer was ± 0.15 mm. However, the measuring points were not sharply defined (cemento-enamel junction and interproximal bone). A survey of some measuring methods is presented in table 6.22.

Table 6.22 The accuracy of some measuring methods for longitudinal studies of intraoral radiographs

Investigators	Mean difference	Standard deviation	Standard error	Number of observers
Björn et al. (1966)	0.1596 BS*	0.1122	0.0023	2
Björn et al. (1969)	0.16 BS**		0.04	2
Boyle et al. (1973)	0.23 mm			1
Duinkerke (1976)			0.14 mm	1
Kirkegaard and	0.28%	0.25	0.06	?
Zeuner (1974)	0.41 mm	0.07 mm		
Sjölien and				
Zachrisson (1973)	0.32 BHS***			
Van der Linden				
(this study)	0.12 mm	0.11	0.01	2
	0.02 mm	0.15	0.01	1

* BS = bone score = about 2.5 mm.
** BS = bone score = about 1 mm.
*** BHS = bone height score = about 0.5 mm.

Comparison of the measuring method developed in this study with the methods described in the literature shows that it can be used in longitudinal studies of patients. Socransky et al. (1984) reported that loss of periodontal tissue support is a process characterized by periods of latency and of increased activity. Our study goes even further: it shows that there are periods of bone loss, unchanged bone level and bone formation. According to Socransky, periods of destruction of periodontal tissue may last from a few days to a few months. It is therefore advisable to obtain radiographs at intervals of less than 1 year in order to establish whether these changes can also be registered in bone tissue.
According to Van der Stelt and Webber (1985) subtraction images of radiographs shows three situations:
1) a dark zone indicative of bone loss.
2) a light zone indicative of bone formation.
3) a clouded region indicating both bone formation and bone loss at the same site.
Their conclusion is that a dynamic process is involved.

Despite this observation the predicted bone level after 10 years was calculated on the basis of linear regression. This was prompted by a report published by Hirschfeld and Wasserman (1978) showing that loss of periodontal tissue support more rapidly leads to loss of molars than to loss of premolars. Table 6.23 distinguished between the predicted bone level at molars and at premolars after 10 years.

Table 6.23 Bone level after 10 years predicted on the basis of the regression curve from 0 to 4 years. Frequencies and percentages at molars (M) and at premolars (P).

Bone loss or bone gain (mm)	M		P	
	predictions		predictions	
	number	%	number	%
-3.1/-3.5	1	2.7		
-2.6/-3.0				
-2.1/-2.5	1	2.7	1	3.1
-1.6/-2.0			1	3.1
-1.1/-1.5	5	13.5	5	15.6
-0.6/-1.0	10	27	7	21.8
0 /-0.5	10	27	11	34.8
0	2	5.4	1	3.1
0 /+0.5	6	16.2	4	12.5
+0.6/+1.0				
+1.1/+1.5			2	6.25
+1.6/+2.0	2	5.4		

The bone level at the molars was decreased in 72.9% of cases, and that at the premolars in 78.4%. The degree of bone loss was less at molars than at premolars. Our findings therefore do not confirm the conclusion of Hirschfeld and Wasserman, but their study covered a period of some 22 years while our study covered 4 years with predictions calculated up to 10 years. The question is whether clinical findings may be compared with calculated data on bone loss from radiographs. In the discussion of the results conclusions were formulated concerning a 4-year period. In spite of the results reported by Socransky et al. (1984) it is interesting to compare the mean changes in bone level per patient per year. The conversions of bone levels after 4 years to changes per year are presented in table 6.24. These data can be compared with data from the literature (table 1.1).

Lindhe and Nyman (1975) and Nyman and Lindhe (1975) concluded that the bone level does not change with time. Bone level changes were expressed in a Bone Score (1 BS is about 1 mm). Assuming that bone level changes amount to about 0.07 mm per year (table 1.1), it will take about 7 years before 0.5 BS bone loss is measured. Consequently their measuring method was probably the cause of the reported absence of changes in bone level.
In our study the influence of an overhanging restoration did not become clear because the dentists who had made the restorations had worked so accurately that only slight overhangings occurred (no more than 0.6 - 0.7 mm).
The presence of an approximal restoration causes increased plaque retention. The less distance between the cervical margin of the restoration and the gingiva and bone, the more likely is an unfavourable influence of the restoration (the plaque) on the interproximal bone level, resulting in a decrease of this level.

Table 6.24 Percentages of mean differences in bone level over a period of 4 years at intact surfaces, surfaces with a restoration with a good marginal adaptation and surfaces with an overhanging restoration. Percentages of differences in bone level calculated over a one-year period.

Condition of the adjacent surface	Number of surfaces and degree of change in bone level	Mean bone level change after 4 years (mm)	Mean bone level change per year (mm)
Intact	E* 9 (−)*	0.27 ± 0.18	0.07 ± 0.05
	4 (0)*		
	5 (+)	0.28 ± 0.27	0.07 ± 0.07
Good marginal fit	E 15 (−)	0.28 ± 0.19	0.07 ± 0.05
	R* 21 (−)	0.28 ± 0.14	0.07 ± 0.04
	E 5 (0)		
	R 2 (0)		
	E 6 (+)	0.12 ± 0.04	0.03 ± 0.01
	R 4 (+)	0.13 ± 0.05	0.03 ± 0.01
Overhanging	E 10 (−)	0.22 ± 0.19	0.06 ± 0.05
	R 17 (−)	0.37 ± 0.26	0.09 ± 0.06
	E 1 (0)		
	R 3 (0)		
	E 3 (+)	0.23 ± 0.12	0.06 ± 0.03
	R 4 (+)	0.18 ± 0.15	0.05 ± 0.04

* E = measurements from cemento-enamel junction to bone level
* R = measurements from cervical margin of restoration to bone level
(−) = bone level decreased
(0) = bone level unchanged
(+) = bone level increased.

Since the above statement cannot be confirmed, we have reason to refer to a study by Stolk (1977). He concluded that, within an observation period of 15 months, there is no return to the original morphology of the interproximal gingiva due to the influence of the entire restoration procedure. He ascribed this more to the procedure of preparation/restoration than to the material used for the restoration. On the basis of similar considerations one could explain that no difference in bone level change was demonstrable between surfaces with a good marginal fit and those with an overhanging restoration. The mere presence of a restoration seems more important in connection with bone loss than its good adapting or overhanging margin. The number of patients in whom differences in bone height were measured, was relatively small. It would be advisable to perform a study which would meet the following requirements:

- larger numbers of patients in order to ensure a better overview of bone level changes.
- patients with good as well as with moderate and with poor oral hygiene in order to determine its influence on bone level changes.
- patients with markedly overhanging restoration in the approximal surfaces.
- a longer period of observation.

In surgical patients it is possible by means of radiography to determine exactly the degree of bone remodelling in a lesion and the degree of change in bone level. Thus the radiographs provide a good impression of the effect of therapy.

The method described in this chapter is a good aid in quantitative determination of bone levels. The new method can be used to obtain information on changes in bone level per surface per tooth in the individual patient.
In studies of large groups of patients, a degree of accuracy is often sacrificed in that reproducible vertical bite-wing radiographs are omitted in order to save time and money. As a result, the measurements and the conclusions reported in these studies are less reliable.
It is not only local factors such as micro-organisms from the plaque that play a role in the aetiology of periodontal disease. As Groen (1972) pointed out, general factors may play a role as well. This is why research into the degree of influence exerted by general factors is desirable.

It can be stated in summaiy that:
- the measuring method developed for this study proved to be suitable for clinical application.
- changes in bone level often fluctuated, unchanged as well as decreased or increased bone levels being measured.
- most cases showed a mean annual bone loss of 0.06 mm.
- bone gain also occurred in a number of cases.
- patients given surgical treatment and medication for juvenile periodontitis generally showed a decrease in bone level; bone remodelling was observed after 3-6 months at sites with an angular lesion.

CHAPTER 7

IMAGE PROCESSING AND PATTERN RECOGNITION ON RADIOGRAPHS OF PERIODONTAL BONE LESIONS

7.1 Introduction and problem definition

The interpretation of radiographic images is unfavourably influenced by a number of factors:

1. The extent of radiolucencies such as those caused by carious lesions seems smaller than the actual lesions (Van Aken, 1964). It has been pointed out in chapter 4 that the same applies to periodontal lesions.
2. Observer subjectivity influences radiographic interpretation (Barr, 1961; Goldman et al., 1974). The observer's visual adaptation, visual acuity and ability to concentrate affect the observation.
3. The lesion has to be located and observed in a region in which the trabecular pattern causes a structural noise in the image. The signal-noise ratio is therefore unfavourable.

Although in principle the information on a bone lesion is contained in the radiograph, the abovementioned factors may prevent the observer from observing or recognizing it as such. It is therefore of importance to develop a method for more effective utilization of the information available on the radiograph, in order thus to enhance its diagnostic value. The study described in this chapter was performed in an effort to establish whether image processing and pattern recognition with the aid of computer techniques can overcome the abovementioned disadvantages.

The computer can be valuable aid in pattern recognition because:

- its great capacity makes it possible to process a large amount of information and perform extensive calculations within a short time.
- the indefatigability and objectivity of the computer guarantee **reproducible** and **standardized** results.

Several techniques of digital image processing have been described in recent literature. Most of these techniques involve processing of the entire image (global processing). For dental application Gröndahl et al. (1983) described a technique of visualizing minute bone lesions in a longitudinal study by means of digital subtraction analysis. The structural noise in the image is eliminated or reduced by subtraction.

A disadvantage of the subtraction technique is that two radiographs are always required which should be identical or be made in projection (Jeffcoat et al., 1984).

However, digital image processing also permits the use of other procedures to enhance the amount of information obtained, e.g. contrast enhancement and contour detection (Nieman, 1979, 1981) (local processing). Because the irregular structure of the trabecular pattern acts as a structural noise for a lesion of similar spatial structure, contrast enhancement alone does not lead to improve interpretation. After all, background and lesion have the same spatial frequency and are therefore enhanced to the same degree, sot that the signal-noise ratio does not improve. More advanced image

processing techniques are therefore required for recognition and isolation of areas and structures in the radiographic image. The purpose of our study was to develop a technique which, by digital image processing, could facilitate the diagnosis of small bone lesions and more especially of angular interproximal bone lesions on radiographs.
In view of the exploratory nature of this study it was performed on radiographs of experimentally induced bone lesions.

7.2 Materials and methods

Using round burs, a bone lesion was induced in a mandible between the second premolar and the first molar (fig. 7.1) as described in chapter 4. Reproducible radiographs of the relevant part of the mandible were obtained by the method also described in chapter 4. Radiographs were made before induction of the lesion and after each extension of that lesion.

Fig. 7.1 Radiograph with the region to be digitized indicated.

The following steps in image processing are commonly discerned:
a) image encoding: registration of the image and storing in the computer memory.
b) preprocessing: enhancement of the characteristic features of the image.
c) image segmentation: demarcation of significant structures of the image.
d) feature extraction: registration of the significant features.
e) classification of the features, e.g. as normal or abnormal.
In our study these steps were carried out as follows.

A. Image encoding

The radiograph was scanned via an epidiascope with a Quantimet 720-D and stored in the computer by means of an analog-digital converter (fig. 7.2). The conversion of an analogous to a digital image should be imagined as follows. The radiographic image is considered to be divided into small areas (pixels). Each pixel is substituted by a digital value which corresponds with the mean density of the area of that pixel. These digital values are arranged in a matrix which corresponds with the location in the original image.
With a view to more efficient analysis and processing of the data, only the region between two adjacent teeth with part of the adjacent teeth was scanned. This corresponds with a matrix of 100 x 120 pixels (i.e. 100 x 120 rows and columns of figures). A pixel represents an area of about 0.1 x 0.1 mm, and the entire region scanned therefore measured 10 x 12 mm.

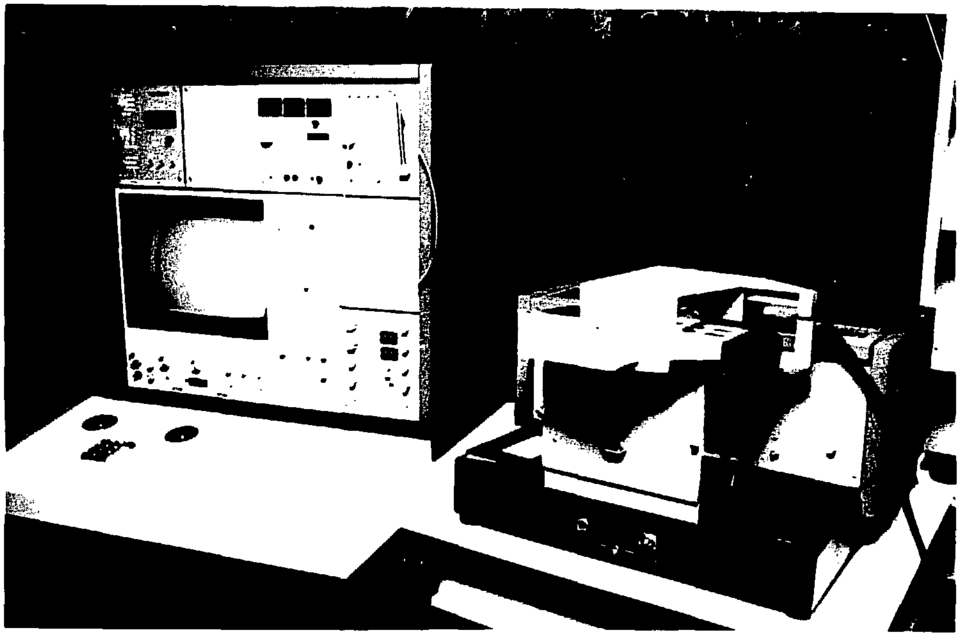


Fig. 7.2 Epidiascope and Quantimet 720-D for scanning the intraoral radiographs.

The analogous density values were converted to digital values from 0 to 64. This number of steps proved to be sufficient to reflect the radiographic image. The digital image thus obtained was stored in a PDP 11/40 computer (Digital Equipment Corporation).

B. Preprocessing

The digital image was subjected to several mathematical procedures in order to suppress the noise and intensify the contrast. **Noise reduction** was effected by means of a so-called convolution filter. The effect of a convolution filter is that the original value of a pixel is substituted by the result of a mathematical operation of a group of, say, 3 x 3 pixels. The pixel to be substituted lies in the centre of the group of 3 x 3 pixels. The entire group is called a 3 x 3 window or kernel (fig. 7.3).

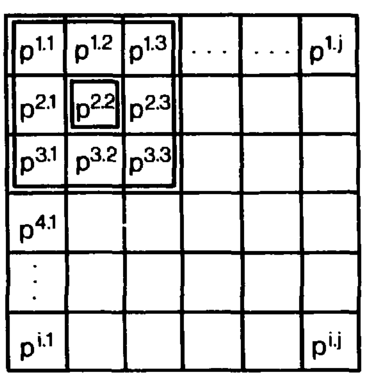


Fig. 7.3 3x3 window. The pixel in the centre of the group is substituted by the result of a mathematical procedure applied to the other elements of the kernel.

The procedure is consecutively applied to all pixels. There are several possible kernels. In our study the following operator was applied:

$$\begin{matrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{matrix}$$

This means that the central pixel was substituted by the difference between five times the value of this central pixel and the sum of the pixels indicated by "−1".
Contrast enhancement aims at the detection of the contours of the teeth.
The boundaries of the teeth extend virtually parallel to each other in vertical direction over a large distance in the image. Some procedure must therefore be chosen to account for this. Differentiation of pixels lying side by on a horizontal line accounts for the direction of the tooth boundaries, for the density transitions are most marked in that direction (tooth → periodontal ligament space → bone). The following convolution filters were applied for the differentiations:

$$\begin{matrix} 0 & 0 & 0 \\ 1 & -2 & -1 \\ 0 & 0 & 0 \end{matrix} \quad \text{and} \quad \begin{matrix} 0 & 0 & 0 \\ 1 & -1 & 0 \\ 0 & 0 & 0 \end{matrix}$$

C. Image segmentation

Segmentation techniques had to be used to isolate the interdental bone, including the periodontal ligament space and the lamina dura, from the tooth.
The results of contrast enhancement were subjected to **treshold filtering.** This means that pixel values below a certain limit in the processed image (after contrast enhancement) were equated to 0. In this way the areas with the most marked differences in contrast could be found. These could be proved to correspond with the tooth boundaries.

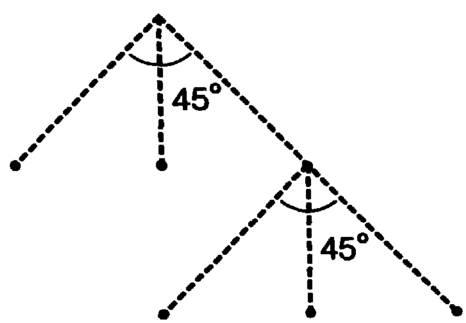


Fig. 7.4 Schematic example of the contour detection technique.

The maximum value of the group of pixels in supertreshold areas per row was then taken in order to determine the exact tooth contour. Once the starting-point of the contour was detected on the first row of the matrix (corresponding with the coronal part of the interproximal region), the remainder of the contour could be detected by searching for the nearest highest value from this point, and so on in an **iterative search process.** Criteria were included in the programme to ensure discontinuation of contour detection when no further pixels were eligible as parts of the contour. At that point the apical region could be assumed to have been reached. Also included in the programme were clues to ensure that the contour was sought primarily in vertical direction and that, upon failure of an attempt to detect the next pixel, the search was continued "looking a few pixels ahead". The next pixel on the contour to be detected was never to deviate more than 45° from the vertical. A schematic example is given in fig. 7.4.

The region between the two tooth contours thus detected is the interdental bone. It is precisely here that periodontal lesions are localized. The region between the contours was subjected to further processing, to make sure that the procedures concerned only the interdental bone and to make the procedure less computationally expensive.

D. Feature extraction

There is a considerable variation in the shape and size of trabeculae even in regions without abnormalities. In order to eliminate inter-patient variations in the trabecular pattern, the trabecular pattern of a region in which a lesion was suspected was compared with that in an intact region in the same patient. This was done by comparing the mesial and the distal half of the interproximal region (fig. 7.12).

A difference in density between these two regions denotes the presence of a lesion in one of them. The region containing the lesion can be deduced from the mean density of the two regions.

Another method of detecting interproximal bone lesions (which was also used) is based on the fact that angular lesions develop from a region along the tooth root and the alveolar crest. Analysis of a narrow zone of pixels along the tooth contour thus enabled us to detect the presence of periodontal bone lesions. In the second method the pixel values in the central part of the interproximal bone in the same patient served as standard. The narrow zone along the contour of the tooth root was called P-area (periodontal area); the remainder of the adjacent interproximal bone - minus a symmetrical zone along the neighboring adjacent tooth as wide as the P-area investigated - was called I-area (interdental area) (fig. 7.14). The presence of a bone lesion can be established by comparing the mean density in the P-area with that in the I-area. The width of the P-area corresponds with a zone of about 1 mm along the tooth contour. To eliminate an interference effect from the periodontal ligament space, the first two pixels in the interproximal area (counting from the contour) were not included in the procedure.

7.3 Results

A. Image encoding

Fig. 7.5 shows the printout of the digitized region investigated with, for elucidation, lines drawn between points of the same density: the so-called isodensity lines. On the basis of isodensity lines (which in this example are three digital values apart) the original image of the tooth with its pulp cavity and the interdental bone is reasonably recognizable. The picture already clearly demonstrates the difference between human observation and "computer observation". The digital image corresponds with the absolute grey values of the original radiograph; a human observer is more inclined to interpret the image in terms of structures and shapes. Obviously in this step isodensity lines and contours do not coincide exactly.

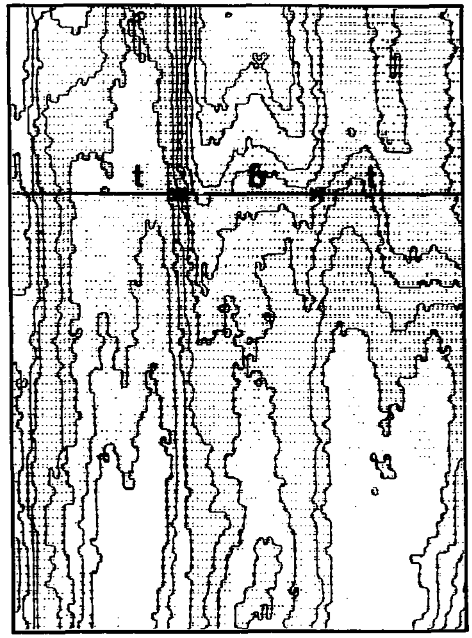


Fig. 7.5 Part of the printout of the digitized image with isodensity lines drawn on it for elucidation.
t = tooth; b = interdental bone.

B. Preprocessing

Fig. 7.6 presents the results of a noise reduction procedure applied to the digital image.

Contrast enhancement was effected by two different differentiations. The results are shown in figs. 7.7 and 7.8. The second filtering gave the better results. After treshold filtering the region comprising the tooth contour remains (fig. 7.9).

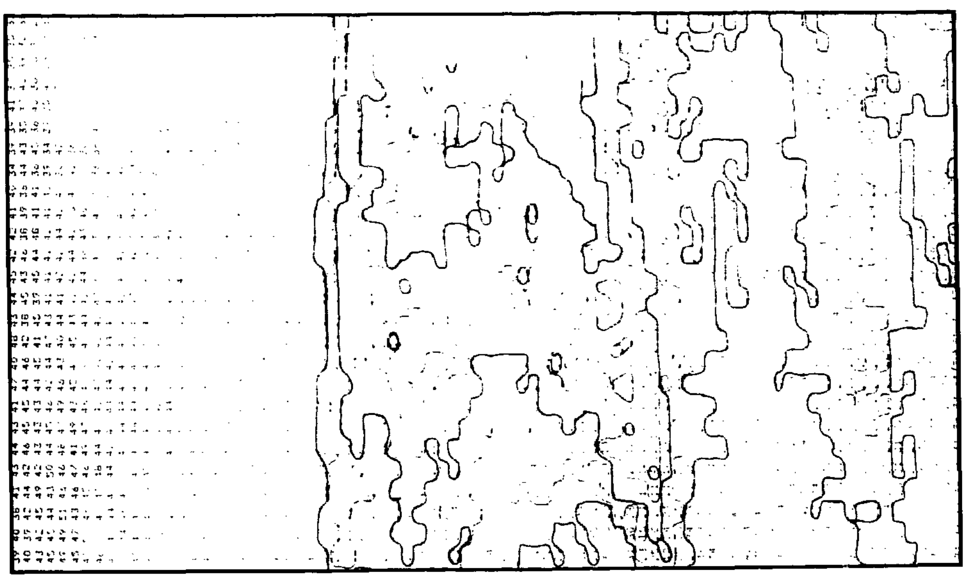


Fig. 7.6 Part of the digitized image after noise reduction.

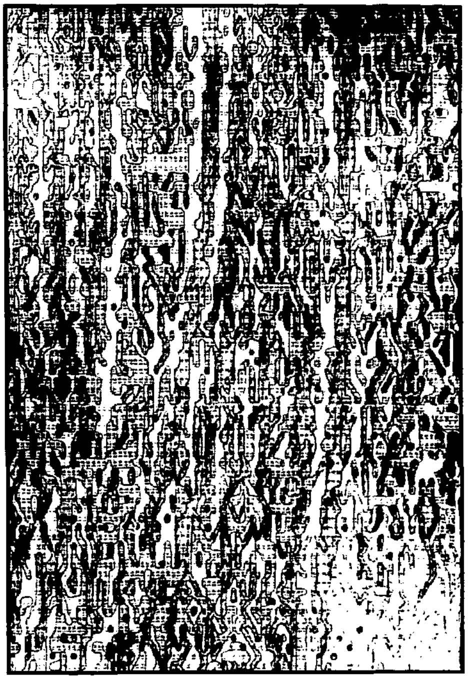


Fig. 7.7 Part of the digitized image after contrast enhancement, differentiation 1.

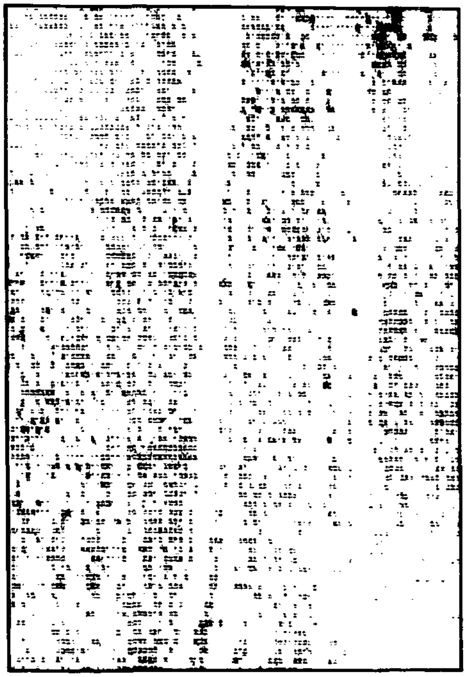


Fig. 7.8 Part of the digitized image after contrast enhancement, differentiation 2.

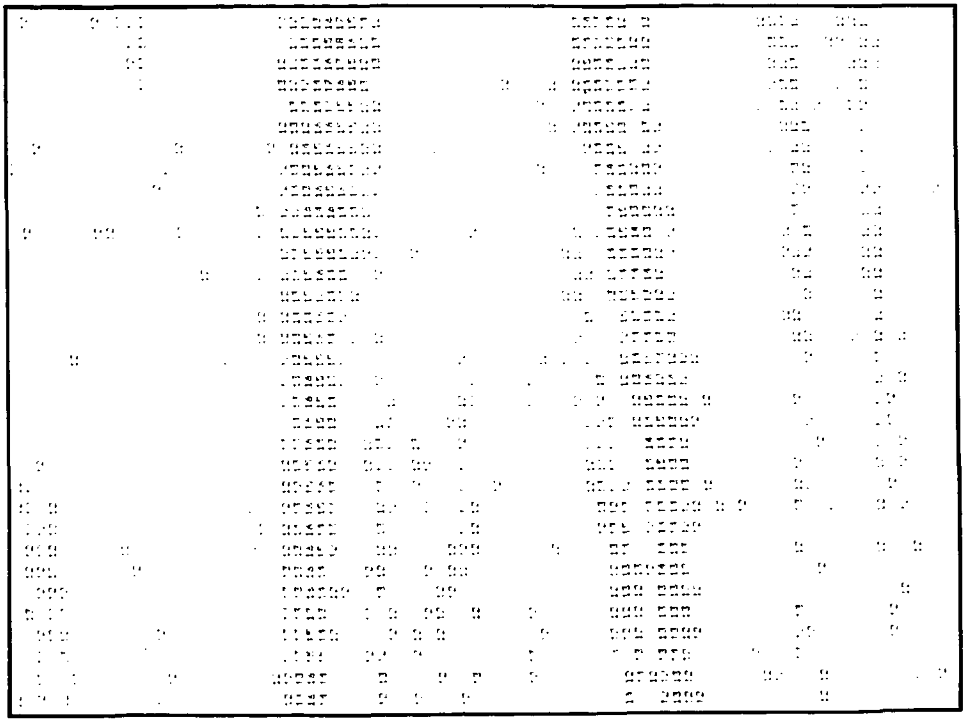


Fig. 7.9 Part of the digitized image after treshold filtering.

C. Image segmentation

Fig. 7.10 shows the results of contour detection. Comparison of the pixels on the detected contour and their locations in the original analogous image shows that the contour detected corresponds with the transition from the tooth to the periodontal ligament space. The region of the interproximal bone therefore also comprises the lamina dura and the periodontal ligament space.

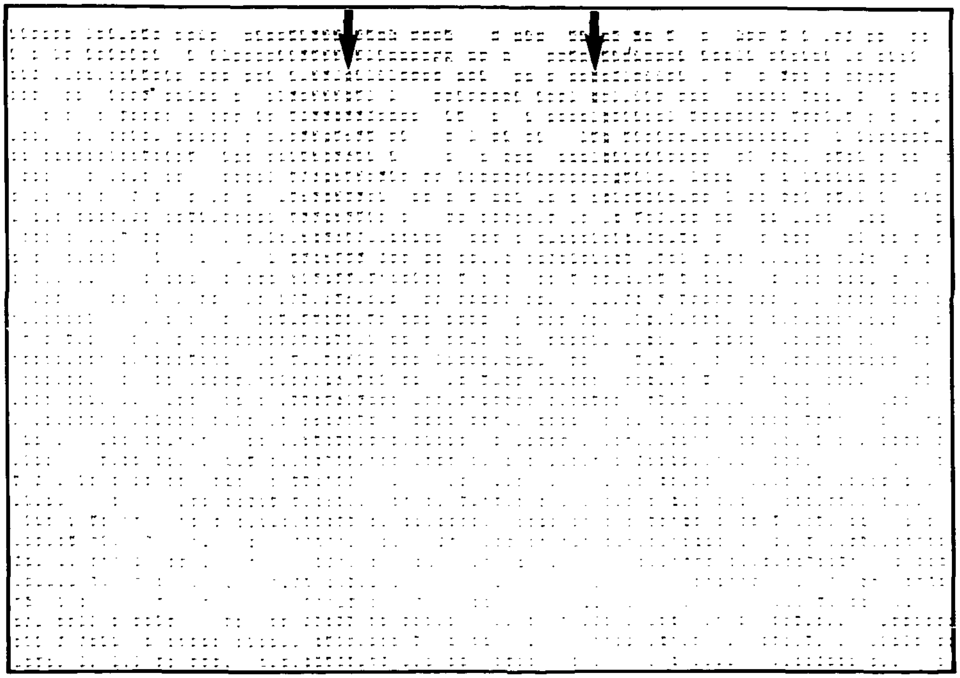


Fig. 7.10 Part of the digitized image after contour detection.
xxx = the contour of the tooth.

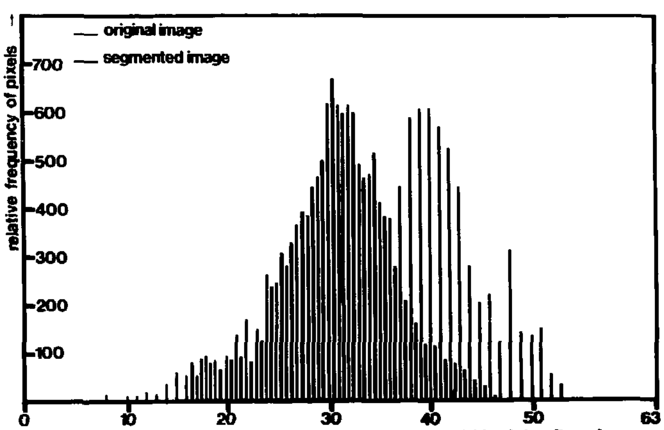


Fig. 7.11 Frequency curve of the digitized density values of the radiographic image before and after image segmentation.

The frequency function of the digital density values is a curve with two distinct peaks (fig. 7.11): one corresponding with the bone structures of the interproximal region and one corresponding with the teeth. The frequency curve after image segmentation shows only one peak, which corresponds with that denoting the bone structures in the original function (fig. 7.11). Consequently it is evident that segmentation has been adequately performed.

D. Feature extraction

The detection of a periodontal bone lesion was first of all effected by comparing the mean densities of the areas indicated in fig. 7.12. Fig. 7.13a shows the curve of the mean densities in a region without defect, while fig. 7.13b shows the curve of the same region after induction of a lesion. We find that, in the presence of a lesion, the curves of the left and of the right half do not entirely coincide but are a certain distance apart. Yet the curve is not quite satisfactory due to interference from the trabeculae, which are localized partly in the interproximal region and in part are projected superposed on the tooth contour. When such a situation prevails in the mesial or in the distal region, this also causes a deviation in the "normal" curve.

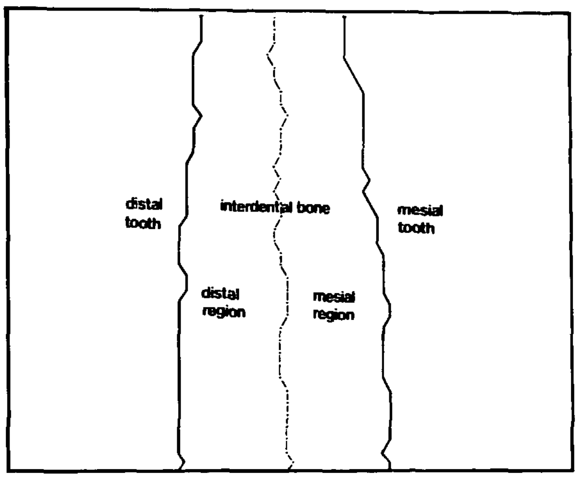
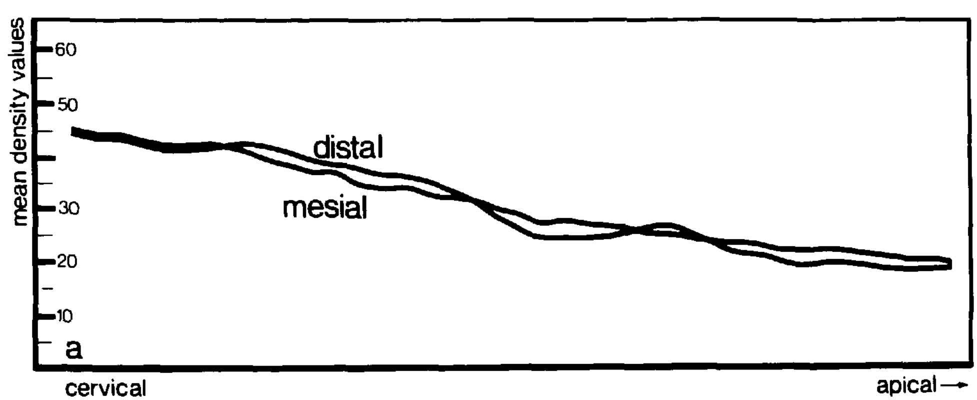


Fig. 7.12 Schematic representation of the division of the interdental bone into a mesial and a distal region for comparison of the mean density values.



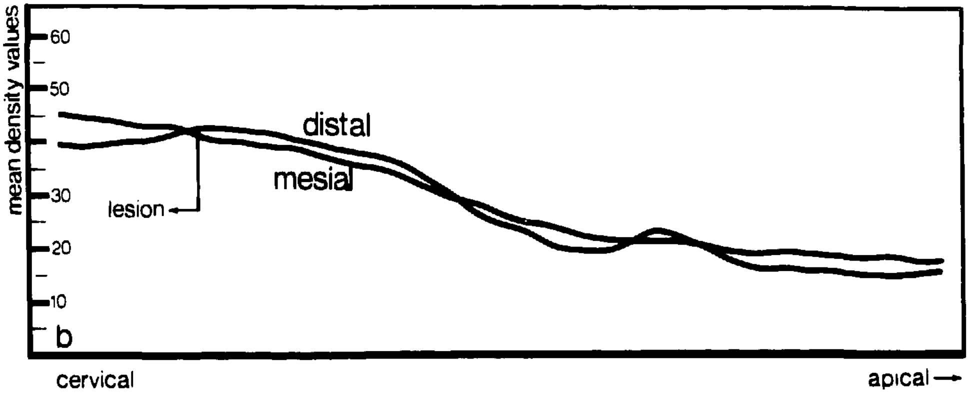


Fig. 7.13 Curves of the mean density values of the pixels of the mesial and the distal part of the interdental bone.
a. No periodontal lesion.
b. Periodontal bone lesion.

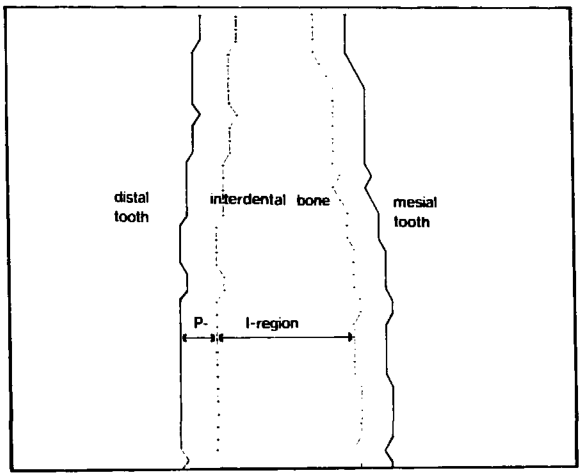
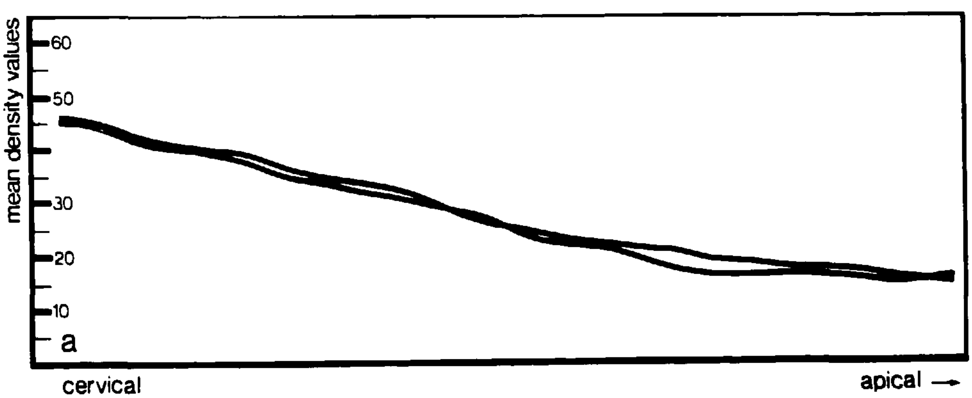


Fig. 7.14 Schematic representation of the division of the interdental bone into a P-area and an I-area for comparison of the mean density values.



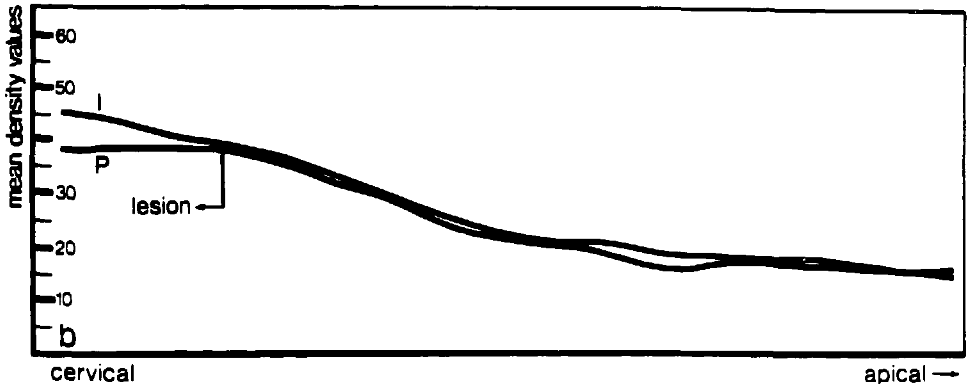


Fig. 7.15 Curves of the mean density values of the pixels of the P-area and the I-area of the interdental bone.
a. No periodontal lesion.
b. Periodontal bone lesion.

The other technique used - comparing the P-area with the I-area - proved to be less marred by interference from the trabecular pattern (fig. 7.14). The curves of the mean density in the P-area and in the I-area for the intact bone and for the bone with a lesion are presented in figs. 7.15a and 7.15b.
In the presence of a periodontal bone lesion the mean density curves of the P-area and the I-area are divergent. In the other case these curves virtually coincide. The disturbing influence of the trabeculae has now been eliminated. The degree of divergence is related to an increase in density and thus demonstrates the severity of bone destruction.

7.4 Conclusions

The regions representing the bone and the teeth on a radiograph can be separated by means of digital image processing techniques. The frequency function of the density values after image processing shows that the segmentation results in a distinct separation between the pixels of the interdental bone and those of the tooth. This makes it possible to confine further processing to the interproximal bone without interference from other structures. The boundary of the segmented region proves to correspond with the transition from tooth to periodontal ligament space. This is important because periodontal bone lesions develop precisely in that region of the periodontal ligament space and lamina dura that is adjacent to the tooth. These structures are comprised in the segmented interproximal bone. Angular bone lesions can be diagnosed by comparing the P-area and the I-area of the segmented bone. The degree of divergence of the curves is a parameter of the severity of bone destruction. Results obtained by comparing only the mesial and the distal part of the interproximal region are less good.

7.5 Discussion

Comparison of the mean density values of the P-area and the I-area proved to be a good technique to detect angular periodontal bone lesions on radiographs.
However, further investigations will be needed to determine what width of the P-area gives an optimal result. Moreover, methods to assess the extension of periodon-

tal bone lesions will have to be developed. This can be done by applying, per row, an iterative variation in the width of the P-area which yields the maximum difference between the P-value and the I-value.

Larger series of radiographs will have to be studied in order to determine what improvement this processing technique provides in the interpretation of radiographs and as a supplement to clinical diagnosis. This can be done by constructing ROC curves and by means of other forms of statistical analysis based on data from human observers in comparison with the results of the computer aided lesion detection.

CHAPTER 8

DISCUSSION

In the oral cavity, many causes may lead to changes in the hard and soft structures of the alveolar process. If oral hygiene is insufficient, for instance, periodontal lesions may develop due to micro-organisms in the plaque. The resulting effects may be reinforced by inadequate dental treatment, e.g. overhanging restorations, insufficient points of contact, an inappropriate contour, malocclusion, etc. Other factors such as nutritional deficiencies, hormonal disorders and systemic diseases also exert an influence.

Micro-organisms from the plaque may also play a role in infections elsewhere in the body, e.g. subacute bacterial endocarditis, acute rheumatic fever, eye inflammations, etc. Prevention of periodontal lesions is therefore important, not only to preserve the teeth but also in a general medical sense.

Changes in the form and structure of the alveolar bone can only be identified and followed up radiographically. Soft tissue changes are diagnosed by other means. Due to the importance of the alveolar bone as structure supporting the teeth, radiography has a prominent place in the diagnosis of periodontal disease and the follow-up of therapeutic results.

The study described in this thesis was aimed at determination of the accuracy with which radiographs are used and at improving some aspects of their use.

– *The importance of the study*

A rather detailed discussion of the morphology and pathology of the alveolar process is presented in chapters 2 and 3. The author considers the aspects discussed important for correct interpretation of the normal radiographic image and for recognition of lesions. It cannot be emphasized enough that a profound knowledge of the normal radiographic image is a prerequisite to correct interpretation of pahtological radiographic findings.

Ramadan and Mitchell (1962) and Schwarz and Forster (1971) stated that it is difficult to identify a periodontal bone lesion radiographically. This applies in particular to infrabony pockets and lesions involving two bony walls.

In view of the importance of early detection and classification of lesions in the alveolar process, the radiographic image of bone lesions experimentally induced in the mandible was studied as described in chapter 4. Unlike the image formation of the periapical region, the density of the image is influenced not only by the cortical but also by the cancellous bone. The radiographic trabecular pattern proves to be formed not only in the junction area, as it is in the periapical region, but also in the cancellous bone. One may therefore presume that periodontal lesions are radiographically visible at an relatively earlier stage than periapical bone lesions.

The site of the lesion, the dental arch and the bone mineralisation play an important role in recognizing the lesion. Early recognition of bone lesions is important because lesions treated early have a more favourable prognosis.

In order to follow periodontal lesions caused or promoted by the abovementioned factors in the course of time, an aiming device was developed with which changes in

periodontal bone can be determined with great accuracy (0.1 mm). This is described in chapter 5. By means of a newly developed radiographic and evaluation technique it was found possible to gain insight into changes in bone height and the degree of bone remodelling in patients. The technique was applied in patients in whom teeth with amalgam restorations were followed over a period of 4 years, and in patients given surgical therapy and medication for juvenile periodontitis. This is described in chapter 6.
In subjective evaluation of lesions, marked variations in size may occur (Eggink, 1964; Duinkerke, 1976). Visual assessment of changes in density, shape and structure of the trabeculae is not very exact. This is why efforts were made to find techniques for an objective approach. Digital image processing and pattern recognition on the radiographic image is a technique of diagnosing bone lesions more objectively. Although these techniques are still in the process of development, encouraging results could be obtained with regard to angular bone lesions (chapter 7). It is to be expected that the great advances in digital image processing in other fields will also be of value in dentistry.

– *Problems encountered in the study*

The knowledge concerning the recognition of bone lesions gained in the studies described in chapters 2, 3 and 4, was tested in a few surgical patients. Since clinical assessment of the size of the lesions in these patients was found to be insufficiently exact for comparison with radiographs, these attempts are not further discussed in this thesis.
The method developed for determination of the positioning error and the error of observation, is very cumbersome. It seems advisable to look for a technique which makes it possible to measure electronically on an enlarged intraoral radiograph. The same applies to the measuring method described in chapter 6.
It proved difficult to determine the measuring points on radiographs of the alveolar bone by the methods described by Schei et al. (1959) and Engelberger et al. (1963). The same applies to the reproducibility of the measuring points in bone and at the cemento-enamel junction. The method used in this study involved drawing a tangent on the most coronal mesial and distal interproximal bone. When a restoration was present, its cervical margin was taken as measuring point because this could be located more readily than the cemento-enamel junction. Comparison of measurements made from the cemento-enamel junction with those made from the cervical margin of a restoration revealed no difference in accuracy. The use of individualized bite-blocks proved to be essential in this method.
The use of aiming devices with bite-blocks can pose problems in longitudinal studies when new restorations are made or existing restorations are replaced in the region studied. The fit can become less exact. The same applies to changes in the position of the teeth. A disadvantage in studies of large groups of patients is that bite-blocks have to be prepared for each individual patient; this is time-consuming and often too expensive to be feasible. In our study these problems were not insurmountable because it was confined to a limited period and a small group of patients.
Changes in bone height adjacent, to overhanging restorations were studied. No extremely overhanging restorations (> 0.6 mm) were present in the patients concerned. If there had been, larger differences would probably have been found. Further investigation of the effects of markedly overhanging restorations seems desirable. In this context the question may be raised whether it is ethically justifiable to maintain restorations of poor quality over longer periods.

The number of patients in groups A and B was small. It would be desirable to study bone lesions more extensively in larger groups of patients. However, it is difficult to form large groups of patients with juvenile periodontitis because this disease is fairly rare. An improvement would be to have the operative and the radiographic part of a study performed by the same investigator. It should be borne in mind, however, that the purpose of our study was not to do extensive research into bone lesions but to develop and test a method to obtain standardized, reproducible radiographs suitable for longitudinal studies of periodontal lesions.
Bone height changes were measured on the radiographs. According to Suomi et al. (1968) the radiographic image makes it possible to decide whether bone loss or bone formation is present. It should be borne in mind, however, that radiographic diagnosis of a lesion never provides information on the location of the attachment level base. A single radiograph never reveals whether a disease process is active or inactive. It is important to realize these limitations of radiography in the diagnosis of periodontal disease.

– *New studies*

Because changes in bone height are a dynamic process in which inactive periods alternate with periods of bone formation and bone loss, studies should be continued over longer periods. Four years are a relatively brief period in which to diagnose changes in bone level. Socransky et al. (1984) reported that the active period within which changes in periodontal tissue support take place, ranges from a few days to a few months. This is why one annual radiograph is probably insufficient. This statement is in agreement with the results obtained in our patients treated for juvenile periodontitis, in whom bone remodelling in the lesion was already observed after 3 months. In most cases, however, a decrease in bone height was observed as well. Finally, it should be established whether this is a transient or a persistent process.
The effects of "genuine" overhanging restorations should be investigated although, as previously pointed out, certain objections may be raised to such studies. Even an experienced observer finds it very difficult to assess differences in radiographic density of alveolar bone and to establish the presence of a lesion and of changes in form and structure. Angular bone lesions can be measured more objectively by digitized image processing and pattern recognition.
In the digitized image of the radiographs of experimentally induced bone lesions (chapter 4) the size of the lesions can now be registered automatically. It is also possible to relate the amount of bone removed to the corresponding radiographs. These procedures should be further refined and used to study the morphometry of the changing trabecular pattern. Moreover, the technique can subsequently be adapted to the study of bone lesions elsewhere in the human body. The further development and refinement of this technique may give us an improved insight into the dentomaxillary region and other parts of the human body.
In periodontology, much attention is focused on the influence of local factors (microorganisms) on the pathogenesis of periodontal diseases. Social, economic and nutritional factors and the influence of systemic diseases on changes in the periodontium receive far less attention. Since there are strong indications that systemic diseases influence the condition of the periodontium, further investigation of these factors seems desirable.

SUMMARY AND CONCLUSIONS

In the course of life the periodontium is subject to changes which may be physiological or pathological. Intraoral radiographs give insight into the hard structures of the dentomaxillary region and provide information on lesions in the bone of the periodontium in that they show radiopacities and radiolucencies caused by such lesions. These facts led to the three aims of the studies described in this thesis (chapter 1):
- to gain insight into the relation between the true shape and dimensions of periodontal bone lesions and their radiographic image.
- to develop and test a method of making standardized and reproducible radiographs suitable for longitudinal studies of periodontal lesions.
- to develop an objective and reproducible method of interpretation of the radiographic characteristics of periodontal bone lesions.

Chapter 1 also presents a survey of the literature on longitudinal studies of the periodontium as such or in relation to a particular treatment. The conclusions from this survey are:
- failure to treat an unhealthy periodontium leads to loss of teeth.
- carefully guided patients show little or no bone loss.
- each therapy instituted contributes to improve periodontal health; shallow pockets should preferably be treated by scaling and root planing, whereas very deep pockets require surgical treatment.
- much research focuses on changes in pocket depth and level of epithelial attachment; but far less research concerns the degree of bone loss manifested on radiographs.
- the influence of micro-organisms on the periodontium receives much attention, whereas that of systemic diseases is largely ignored.

Chapter 2 presents a brief description of the structure of the periodontium and its radiographic image, with special reference to the hard structures of the alveolar process. The radiographic image of the periodontium and other structures of the alveolar process is determined by the density and the chemical composition of the various tissues. The shape and size of the periodontal ligament space and the influence of several factors on the visual width of the periodontal membrane are described. Also discussed are the structure of the alveolar crest, the lamina dura (lamina cribriformis), the cortical and the cancellous bone and their radiographic characteristics. The significance of the junction area on the radiograph is discussed with reference to the available data from the literature.

Chapter 3 discusses periodontal lesions, and more especially those which occur in periodontitis and juvenile periodontitis, with reference to the clinical and radiographic characteristics of both forms of periodontitis. This chapter also describes the mechanism of bone loss with reference to several factors which influence the radiographic image and should therefore be taken into account in interpretation.

Chapter 4 discusses a number of experiments in which round burs were used to remove, step by step, 1, 2, 3 and 4 walls of the bone between a cuspid, a premolar and a molar in a mandible. Of each lesion thus induced, impressions and radiographs were made. The radiographs, their tracings and the casts of the impressions were evaluated. The conclusions from this part of the study are:

- removal of cancellous bone is manifested radiographically by increased radiolucency; further extension of the induced lesion leads to a change in the radiographic trabecular pattern.
- the radiographic trabecular pattern proves to be formed not only in the junction area (the junction between cortical and cancellous bone) but also in the cancellous bone.
- removal of cortical bone causes a marked increase in radiolucency.
- removal of bone on the vestibular or lingual side of a tooth is not radiographically visible; removal of bone on both sides may be visible.

These experiments have demonstrated a significant difference in image formation between the alveolar bone and the bone in the apical region.
In a number of experiments even a relatively small lesion of the cancellous bone caused an increase in radiolucency. According to Van der Stelt (1979) and others removal of cortical bone in the apical region causes increased radiolucency. In this region removal of cancellous bone has far less effect on the radiographic image. In the coronal interproximal region, however, the influence of cancellous bone is more pronounced than in the apical region. This is due to the fact that the anatomical relation between cortical and cancellous bone in the cervical region differs significantly from that in the apical region.

Chapter 5 describes a method to obtain standardized reproducible radiographs suitable for longitudinal studies of changes in bone height. The requirements to be met by an aiming device for this purpose are:

- it should be possible to return x-ray machine, object and film to the same relative positions for radiographs made of a certain region at certain intervals.
- enlargement and image distortion should be minimal.
- it should be possible to measure bone level differences of 0.1 mm.
- it should be possible to place the bite-wings vertically to ensure that the largest possible part of the alveolar process is radiographed.

A special aiming device meeting these requirements was designed for radiography of the periodontium. Measurements were made on radiographs obtained with the aid of this device. The influence of each of the factors contributing to the error in inpretation of the radiograph was thus determined. These factors were called error of observation and positioning error. To begin with, radiographs were made of a fragment of mandible in a test set-up involving the use of an optical bench. The error of observation was determined by measurements on enlargements of these radiographs.
In patients, the positioning error was determined on enlargements of ten radiographs made with the aid of the aiming device.
The influence of minute positioning errors was determined by rotating the object on the optical bench in 1° steps in horizontal and vertical direction and establishing the acceptable rotations up to a maximum error of 5%.
The conclusions are:

- the error of observation of the technique proved to be 0.036 mm.
- the positioning error was 0.034 mm.

- the positioning technique is therefore sufficiently reproducible to determine bone level changes of 0.1 mm.
- within a maximum positioning error of 5% the object may be rotated 3° horizontally and 4° vertically.

Chapter 6 describes a method of measuring the height of the interproximal septum on radiographs of patients. It was ensured that the measuring points used were readily recognizable.
Periodontal changes were studied in two groups of patients: one group of patients whose teeth had intact approximal surfaces or surfaces with correctly adapted or overhanging restorations (group A) and one group of patients given surgical treatment and medication for a lesion in the interproximal bone (juvenile periodontitis, group B). The aiming device described in chapter 5 was used to obtain radiographs on which the bone height was measured after 0, 1, 2, 3 and 4 years in group A and before treatment and after 3 and 6 months in group B.
The conclusions are:
The measuring method:
- the method developed is suitable for clinical application. The mean difference between two single-observer measurements was 0.02 mm, regardless of whether he measured from the cemento-enamel junction or from the cervical margin of the restoration.
- the two single-observer measurements concurred in 74% of cases when he measured from the cemento-enamel junction and in 82% when he measured from the cervical margin of the restoration.

Radiographs in group A:
- at intact surfaces a decreased bone level was observed as frequently as an unchanged and an increased bone level together; at surfaces with correctly adapted restorations the bone level was more frequently decreased than unchanged or increased.
- after 4 years the bone level adjacent to a restoration was significantly decreased; the bone level adjacent to intact surfaces was not.
- the bone level might be decreased one year and the next year show no change or even an increase. Several combinations were possible and the degree of change was variable.
- after conversion to mean bone loss per year, the amount of bone loss after 4 years was 0.05 - 0.07 mm per year. This is in agreement with the amounts of bone loss reported in the literature.

Radiographs of group B (juvenile periodontitis):
- bone remodelling was observed adjacent to most surfaces with a lesion.
- the bone level adjacent to most surfaces was decreased.

Chapter 7 describes a technique of using digital image processing and pattern recognition to separate the regions which represent the bone and the teeth on the radiograph. In the segmented image the interdental bone (including the periodontal ligament space) was separated from the tooth. Periodontal lesions often develop in the region of the periodontal ligament. Segmentation was therefore such as to include this space in the evaluation of the interproximal bone. Angular bone lesions can be diagnosed by comparing a zone along the contour of the tooth (periodontal area or P-area) with the interdental area (I-region). The divergence between the curves of mean density of the P- and the I-area provides a parameter for the severity of the lesion.

The conclusions from this study can be summarized as follows:

- experimentally induced lesions in the cancellous bone of the interproximal bone are fairly quickly visible on the radiograph. In terms of radiographic image formation, therefore, the structure of the interproximal bone differs from that of the periapical alveolar bone.
- the aiming device developed for this study makes it possible to measure bone heights with an accuracy of 0.1 mm.
- in patients with a healthy periodontium slight bone loss was found to alternate with periods of inactivity or bone remodelling. Restorations overhanging no more than 0.6 mm proved to have no distinct unfavourable effect on the bone level.
- in a group of patients treated for juvenile periodontitis bone remodelling was demonstrable in angular lesions, together with a decrease in bone level.
- by means of digital image processing and pattern recognition, angular bone lesions could be objectively diagnosed and described.

SAMENVATTING EN CONCLUSIES

Gedurende het leven vinden er in het parodontium veranderingen plaats die fysiologisch of pathologisch kunnen zijn. De intraorale röntgenfoto geeft inzicht in de harde structuren van het dentomaxillaire gebied. De röntgenfoto is daarmee het hulpmiddel om radiopaciteiten of radiolucenties ten gevolge van afwijkingen in het bot van het parodontium op te sporen. Dit heeft geleid tot de in hoofdstuk 1 geformuleerde drie doelstellingen van dit proefschrift:

- het verkrijgen van inzicht in de relatie tussen de werkelijke vorm en afmeting van parodontale defecten en de röntgenologische afbeelding daarvan.
- het ontwikkelen en toetsen van een methode voor het vervaardigen van gestandaardiseerde en reproduceerbare röntgenopnamen, geschikt voor longitudinaal onderzoek van parodontale defecten.
- het ontwikkelen van een objectieve en reproduceerbare interpretatie van parodontale botdefecten op röntgenopnamen.

In hoofdstuk 1 wordt eveneens een overzicht gegeven van de literatuur betreffende longitudinaal onderzoek, waarin het parodontium is bestudeerd al dan niet in samenhang met een bepaalde behandeling. De conclusies hieruit zijn:

- het niet behandelen van het niet-gezonde parodontium leidt tot verlies van gebitselementen.
- nauwgezet begeleide patiënten vertonen geen of weinig botverlies.
- elke ingestelde therapie draagt bij tot een gezonder parodontium; bij ondiepe pockets geniet behandeling door middel van scaling en rootplaning de voorkeur en bij zeer diepe pockets een chirurgische behandelmethode.
- veel onderzoek vindt plaats naar veranderingen in pocketdiepte en epitheliaal aanhechtingsniveau; veel minder onderzoek wordt verricht naar de mate van botverlies, zoals deze zich op de röntgenfoto manifesteert.
- erg veel aandacht wordt besteed aan de invloed van microorganismen op het parodontium; aan die van systeemaandoeningen daarentegen wordt weinig aandacht besteed.

In hoofstuk 2 wordt de bouw van het parodontium en het röntgenbeeld ervan in het kort beschreven. Aandacht wordt speciaal besteed aan de harde structuren van de processus alveolaris. Het beeld van het parodontium en van andere structuren van de processus alveolaris wordt bepaald door de dichtheid en chemische samenstelling van de verschillende weefsels. De vorm en de grootte van de periradiculaire ruimte en de invloed van een aantal factoren op de visuele breedte van de parondontale spleet worden beschreven. De bouw en de structuur van de crista alveolaris, de lamina dura (*lamina cribriformis*), het corticale en het spongieuze bot en het beeld ervan op de röntgenfoto worden besproken. De betekenis van de z.g. junction area - het overgangsgebied tussen corticalis en spongiosa - op het röntgenbeeld wordt nagegaan voorzover hierover gegevens uit de literatuur beschikbaar zijn.

In hoofdstuk 3 worden parodontale defecten, in het bijzonder die voorkomen bij parodontitis en juveniele parodontitis, besproken. Aan de klinische kenmerken en het röntgenologische beeld van deze beide vormen van parodontitis wordt aandacht besteed.
Het mechanisme van botafbraak wordt beschreven. Tevens wordt een aantal factoren genoemd die het röntgenbeeld beïnvloeden en waarmee bij de interpretatie rekening dient te worden gehouden.

In hoofdstuk 4 wordt een aantal experimenten besproken, waarbij met ronde boren stap voor stap 1, 2, 3 of 4 wanden van het bot tussen de cuspidaat, de premolaar of de molaar van een mandibula werden verwijderd. Van de ontstane defecten werden telkens röntgenfoto's en afdrukken vervaardigd. De röntgenfoto's, de tracings ervan en de modellen van de uitgegoten afdrukken werden beoordeeld. De conclusies hieruit zijn:

- verwijdering van spongieus bot manifesteert zich op de röntgenfoto als een zwartingstoename; verdere vergroting van het aangebrachte defect leidt tot een verandering van de trabekelstructuur in het röntgenbeeld.
- de trabekelstructuur in het röntgenbeeld blijkt niet alleen in de junction area te worden gevormd, maar ook in het spongieuze bot.
- verwijdering van corticaal bot veroorzaakt een sterke toename in de zwarting.
- wordt er vestibulair of linguaal van een gebitselement bot verwijderd dan is dit niet zichtbaar; indien op beide plaatsen bot wordt verwijderd kan dit wel het geval zijn.

Uit deze experimenten is een belangrijk verschil in beeldvorming gebleken tussen het alveolaire bot en het bot in het apicale gebied.
In een aantal experimenten veroorzaakte een betrekkelijk klein spongieus defect reeds een toename in de radiolucentie. Volgens Van der Stelt (1979) en anderen veroorzaakt verwijdering van corticaal bot in het apicale gebied een zwartingstoename en heeft aantasting van spongieus bot hier veel minder gevolgen voor de beeldvorming. De invloed van de spongiosa blijkt in het coronaire interdentale gebied echter sterker te zijn dan in het apicale gebied. Dit verschil wordt veroorzaakt door de anatomische verhouding van corticaal en spongieus bot, welke in het cervicale gebied anders is dan in het apicale.

In hoofstuk 5 is de methode beschreven om op een gestandaardiseerde, reproduceerbare wijze röntgenopnamen te vervaardigen voor longitudinaal onderzoek naar veranderingen van het botniveau. De eisen waaraan een instelapparaat voor dit doel dient te voldoen, zijn de volgende:

- het moet mogelijk zijn het röntgenapparaat, het object en de film in een zelfde positie ten opzichte van elkaar te plaatsen bij opnamen die met tijdsintervallen van een bepaald gebied worden gemaakt.
- de vergroting en de vertekening dienen minimaal te zijn.
- er dienen bothoogteverschillen van 0.1 mm te kunnen worden gemeten.
- de bitewings moeten vertikaal geplaatst kunnen worden om een zo groot mogelijk deel van de processus alveolaris af te beelden.

Er is een instelapparaat ontworpen, dat speciaal voor opnamen van het parodontium aan deze eisen voldoet. Er zijn metingen uitgevoerd aan opnamen vervaardigd met deze apparatuur. Hiermee is de invloed bepaald van elk van de factoren die een bijdrage leveren aan de beoordelingsfout van de röntgenopname. Deze factoren zijn de "waarnemingsfout" en de "instelfout" genoemd.

Eerst werd met een proefopstelling op een optische bank van een stuk mandibula röntgenopnamen vervaardigd. Aan de hand van metingen aan vergrotingen van de vervaardigde foto's werd de waarnemingsfout vastgesteld; deze bleek 0.036 mm te bedragen.
Bij patiënten werd bij een tiental met het instelapparaat vervaardigde röntgenfoto's op vergrotingen de instelfout bepaald. Deze bedroeg 0.034 mm. Verder werd de invloed van kleine instelfouten nagegaan door een object op de optische bank telkens over een hoek van 1° in horizontale en verticale richting te draaien en na te gaan welke rotaties bij een fout van maximaal 5% nog toelaatbaar zijn. Voor een maximale instelfout van 5% bleken horizontale rotaties van het object van 3° en verticale rotaties van 4° toelaatbaar. De insteltechniek is dus voldoende reproduceerbaar om veranderingen in het botniveau van 0.1 mm te kunnen waarnemen.

In hoofdstuk 6 is een methode ontwikkeld om op röntgenfoto's van patiënten de bothoogte van het interdentale septum te meten. Voor de plaats van de meetpunten zijn gemakkelijk te herkennen meetpunten gekozen.
De parodontale veranderingen zijn bij twee groepen patiënten onderzocht. De ene groep betrof patiënten die gebitselementen hadden met gave approximale vlakken of met vlakken voorzien van aansluitende en overstaande restauraties (groep A). De andere groep bestond uit patiënten bij wie een defect in het interdentale bot chirurgisch en medicamenteus was behandeld voor juveniele parodontitis (groep B). Met de in hoofdstuk 5 beschreven instelapparatuur zijn röntgenopnamen vervaardigd. In groep A werd de bothoogte na 0, 1, 2, 3 en 4 jaar gemeten, in groep B vóór de behandeling en na 3 en 6 maanden.
De conclusies luiden
t.a.v. de meetmethode:
- de ontwikkelde meetmethode is toepasbaar. Tussen twee metingen van een waarnemer bedroeg het gemiddelde verschil 0.02 mm, zowel bij metingen vanaf de glazuurcementgrens als vanaf de cerviale rand van de restauratie.
- in 74% van de gevallen bestaat bij de twee metingen door een waarnemer overeenstemming wanneer vanaf de glazuurcementgrens wordt gemeten; bij metingen vanaf de cervicale rand van de restauratie bedraagt het percentage 82.

t.a.v. de röntgenfoto's uit groep A:
- bij gave vlakken komt een verlaging van het botniveau even vaak voor als een verhoging en een gelijk blijven tezamen; bij vlakken met aansluitende restauraties is er vaker verlaging van het botniveau dan een gelijk blijven en verhoging.
- in de onderzochte groep vindt na vier jaar een significante verlaging van het bot plaats als het bot door een restauratie wordt begrensd; bij gave vlakken is dat niet het geval.
- het botniveau kan het ene jaar een verlaging vertonen, het jaar daarop gelijk blijven respectievelijk een verhoging vertonen; er zijn allerlei combinaties mogelijk en de mate van verandering kan variëren.
- wordt het botverlies na vier jaar omgerekend naar gemiddeld botverlies per jaar dan bedraagt dit 0.05 - 0.07 mm per jaar. Dit is in overeenstemming met de in de literatuur vermelde hoeveelheid botverlies.

t.a.v. de röntgenfoto's uit groep B (juveniele parodontitis):
- bij de meeste vlakken met een defect vindt ingroei van bot plaats.
- bij de meeste vlakken vindt een verlaging van het botniveau plaats.

In hoofdstuk 7 wordt een methode beschreven om met digitale beeldverwerkingstechnieken en patroonherkenning de gebieden die het bot en de gebitselementen op de röntgenfoto vertegenwoordigen van elkaar te scheiden. In het gesegmenteerde beeld wordt het interdentale bot inclusief de parodontale spleet gescheiden van het gebitselement. Parodontale defecten ontstaan vaak in het gebied van de parodontale spleet. De segmentatie is dus zodanig dat deze bij de beoordeling van het interdentale bot betrokken wordt. Angulaire botdefecten kunnen worden gediagnostiseerd door vergelijking van het P- en I-gebied overeenkomend met een strook langs de contour van het gebitselement (P(arodontaal))gebied) en het interdentale bot (I(nterdentaal))gebied). Bij vergelijking van de curves van de gemiddelde zwarting van de P- en I-gebieden is divergentie een parameter voor de ernst van het defect.

De conclusies van dit onderzoek zijn als volgt samen te vatten:
- in het interdentale bot zijn kunstmatig aangebrachte laesies in de spongiosa op de röntgenfoto vrij snel zichtbaar; de structuur van het interdentale bot verschilt dus van die van het periapicale alveolaire bot voor wat betreft de röntgenologische beeldvorming.
- het ontwikkelde instelapparaat maakt het mogelijk botniveaus met een nauwkeurigheid van 0.1 mm te meten.
- bij patiënten met een gezond parodontium blijkt licht botverlies plaats te vinden afgewisseld met perioden van rust of botaanmaak; vullingen die maximaal 0.6 mm overstaan blijken geen duidelijk nadelige invloed op het botniveau te hebben.
- bij een groep patiënten behandeld voor juveniele parodontitis is bij angulaire botdefecten ingroei van bot aan te tonen, samen met een verlaging van het botniveau.
- door middel van digitale beeldverwerking en patroonherkenning zijn angulaire botdefecten objectief vast te stellen en te beschrijven.

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