Endodontic Topics 2002, 1, 3–25
Printed in Denmark.

ENDODONTIC TOPICS 2002
1601-1538

Radiological aspects of apical periodontitis

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The diagnosis and management of periapical pathosis requires a thorough clinical and radiographic examination. As chronic apical periodontitis often develops without subjective symptoms, the radiological diagnosis is particularly important. However, radiography is not a perfect diagnostic tool, partly because radiographs are two-dimensional representations of three-dimensional structures, and partly because particular clinical and biological features may not be reflected in radiographic changes. The presence of a lesion may not be directly evident and its real extent and the spatial relationships to important anatomical landmarks are not always easily visualized. This paper reviews the usefulness and limitations of the radiological examination in periapical diagnosis.

Apical periodontitis

Apical periodontitis is inflammation of the periodontium at the portals of entry of the root canal system. The etiology of apical periodontitis is an infection of the tissues in the root canal system and of the surrounding dentin, in some cases also of tissues outside the apical foramen or other portals of entry. Typically, the lesion is located at the root apex, but communications may exist at various levels along the root surface, and lesions may develop at lateral and furcal locations. The disease shows the classical features of inflammation. One or more of the clinical symptoms – pain, swelling, redness, increased temperature and impaired function – characterize acute apical periodontitis. Chronic apical periodontitis shows replacement of adjacent tissue with an inflammatory cell infiltrate. Due to the encasement of the root in bone and the relatively greater resistance of the root to resorption, the production of an inflammatory infiltrate usually occurs at the expense of the surrounding bone. The changes in mineralization and structure of the bone adjacent to the site of inflammation form the basis of radiographic diagnostic procedures for the detection and monitoring of chronic apical periodontitis.

Apical periodontitis develops as a response to infection, and in the chronic form a *granuloma* is formed with characteristics peculiar to the location and anatomy. In addition to the inflammatory cells, it typically contains fibrous tissue and often cholesterol crystals, as well as proliferating strands of epithelium derived from the cells of Malassez. It may or may not develop a cyst cavity, which is lined in part or in full by epithelium. If the lumen of this *radicular cyst* is continuous with the infectious source at the pulpal entry, it may not be self-sustained (a 'bay' or 'pocket' cyst) and will heal following elimination of the infectious source (1, 2). On the other hand, if the cyst is completely encased by epithelium and removed from the source of infection, it may be self-sustained (a 'true' cyst) and refractory to treatment except by surgical excision (1, 2).

The stages in development and also in healing of chronic apical periodontitis, granulomas and cyst are, to a degree, reflected by changes in the radiographic appearance of the periapical area. These changes are of decisive importance in diagnosis and choice of treatment. As they are presented on a background of superimposed, normal osseous and other structures, the changes can be interpreted properly only with consideration given to these structures, as outlined below.

Anatomical considerations

Bone structure

In the maxilla, the facial cortex is thin as far posterior as the disto-buccal root of the first molar. Sometimes, the buccal roots tips are uncovered by bone. The buccal cortex of the second and third molars is thicker. Generally, the palatinal cortex of the alveolar process is thicker than the facial one, although it is paper-thin over the palatinal alveolus of the first molar and rather thin over the palatinal alveoli of the second and third molars. The cancellous bone is thick over the deeper portions of the alveoli palatinal of the anterior teeth and premolars. The apex of the lateral incisor, however, is frequently located in apposition to the palatinal cortical bone (Fig. 1).

In the mandible, the alveolar process is very thin in its anterior portion around the roots of incisor teeth, but thicker in the molar region. The lingual walls of the alveoli of the second and third molars are relatively thin near the bottoms of the sockets, whereas the bone on the facial aspect is somewhat thicker and very compact. This is caused by the mandible being undercut at this point for the submaxillary fossa below the mylohyoid ridge. The bone buccal to the last two molars is very thick, being reinforced by the external oblique ridge. The labial cortex surrounding the incisor apices is often thin or even absent, exposing the root tips. The canine alveolar process, how-

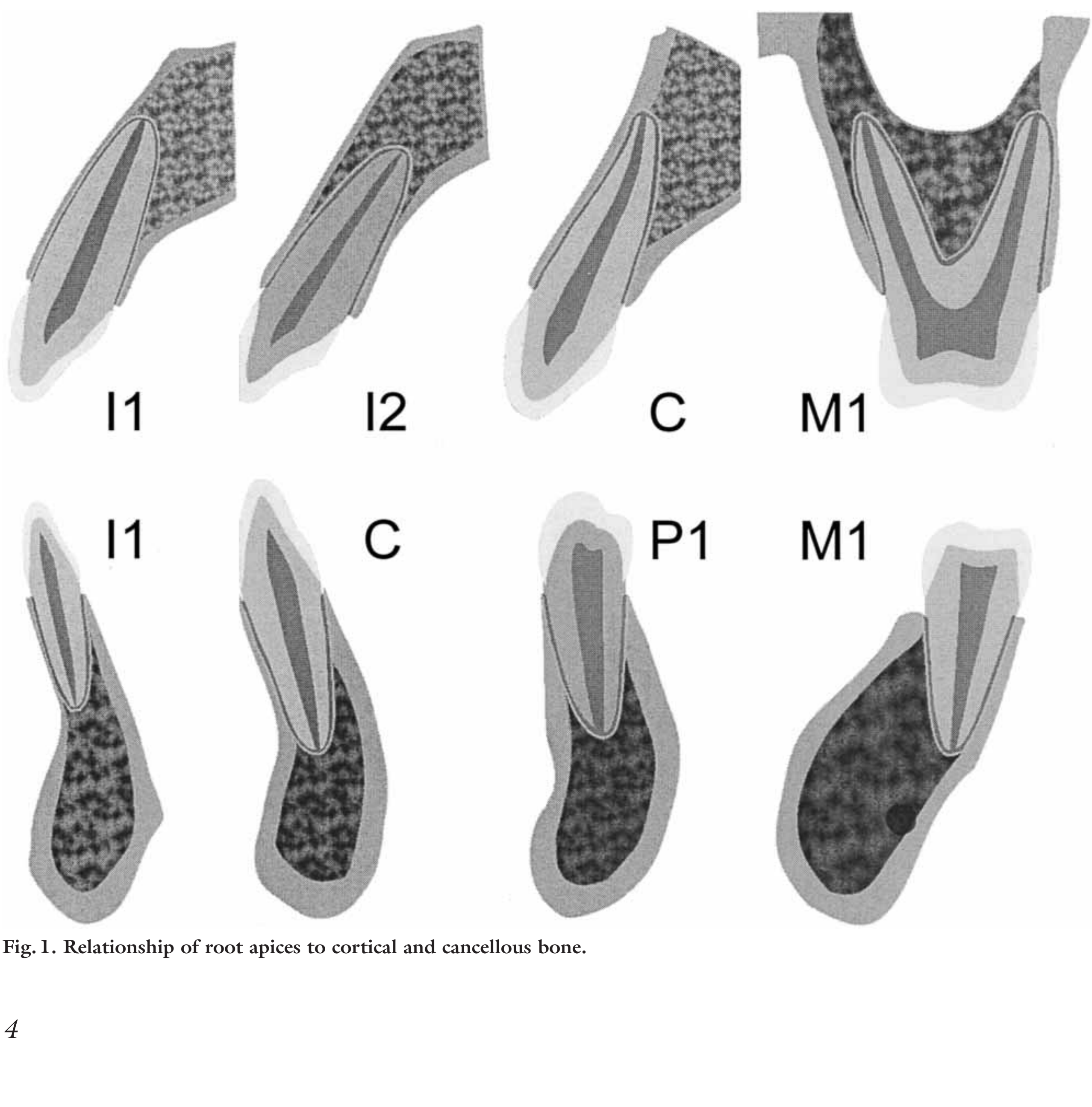

Fig. 1. Relationship of root apices to cortical and cancellous bone.

ever, is stronger and heavier than over the incisors. The buccal cortex of the alveoli is relatively thin, whereas the lingual cortex is rather thick (Fig. 1).

The trabeculae in the anterior maxilla are typically thin and numerous, forming a fine, granular dense pattern, and the marrow spaces are consequently small and numerous. In the posterior maxilla, the trabecular pattern is usually quite similar to that in the anterior maxilla, although the marrow spaces may be larger (Fig. 2A).

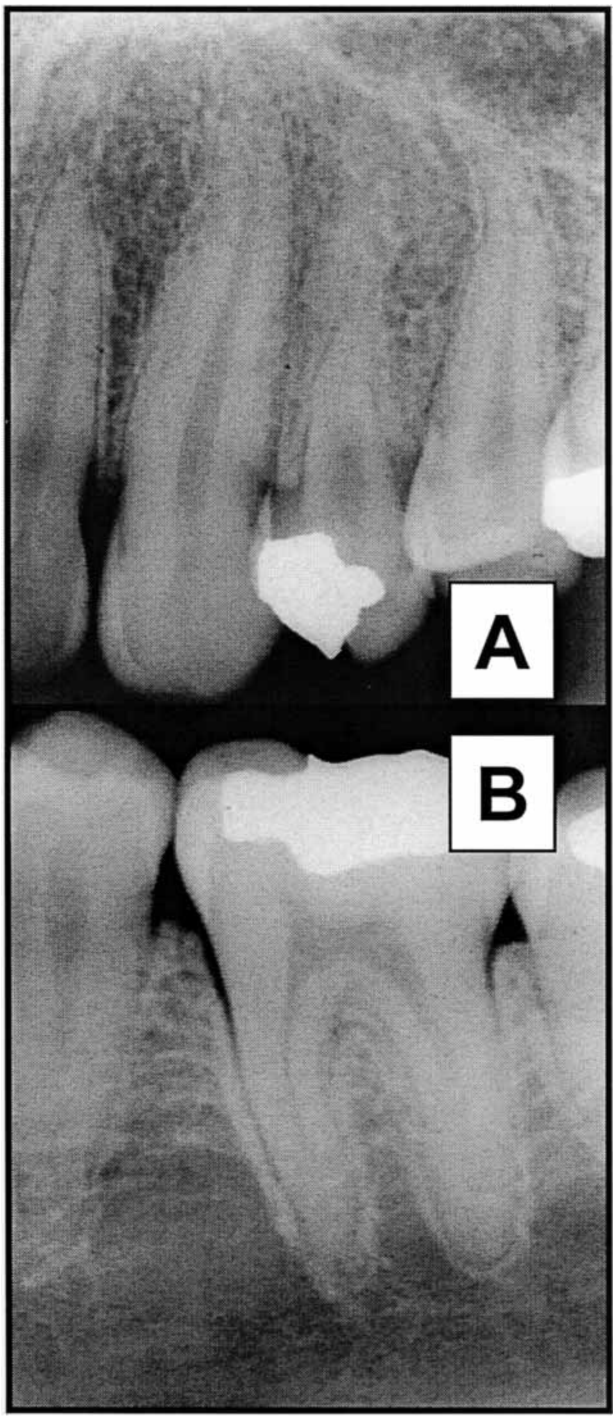

Fig. 2. A) Fine granular pattern of maxillary bone from canine/premolar area. (B) Coarse mandibular bone structure around first molar. Apically, the trabeculae are apparently absent, giving the impression of a radiolucent area.

In the anterior mandible, the trabeculae are somewhat thicker than in the maxilla, resulting in a coarser pattern, with trabecular striae that are oriented more horizontally. The trabeculae are also fewer than in the maxilla, and the marrow spaces are correspondingly larger. In the posterior mandible, the periradicular trabeculae and marrow spaces may be comparable to those in the anterior mandible but are usually somewhat larger. The trabeculae are oriented mainly horizontally in this region. Below the apices of the mandibular molars the number of trabeculae is reduced even more. In some cases, the area from just below the molar roots to the inferior border of the mandible may appear to be almost devoid of trabeculae (Fig. 2B).

Lamina dura

The lamina dura is a continuation of the jawbone cortex, which encases the root in a socket of cortical bone. Its appearance in radiographs varies. When the X-ray beam is directed through a relatively long expanse of the structure, the lamina dura appears radiopaque and

Fig. 3. Septum in maxillary sinus; apparent loss of lamina dura of first molar roots.

well defined. When the beam is directed more obliquely, however, the lamina dura appears more diffuse and may not be discernible. This means that the appearance of the lamina dura is determined as much by the shape and position of the root in relation to the X-ray beam as by the density and integrity of the lamina dura itself. In addition, small variations and disruptions in the continuity of the lamina dura may represent superimpositions of trabecular pattern and small nutrient canals passing from the bone to the periodontal ligament. The thickness and density of the lamina dura on the radiograph may also vary with the amount of occlusal stress to which the tooth is subjected. A lesion in lamina dura may produce radiographic detection more readily than in cancellous bone because more minerals is removed at that site (3).

Although loss or diminution of the lamina dura has long been considered an indication of local or systemic disease, e.g. Paget's disease (4), or hyperparathyroidism (5), there is a considerable intra- and interindividual range in its thickness and density. Often, the lamina dura at the apex of the maxillary canines will be almost impossible to discern. This is because the bone is frequently thin in this region. In the same patient, the periapical lamina dura of the other teeth may be very distinct. Furthermore, it is important to realize that some patients characteristically have a prominent well-defined lamina dura, whereas in other patients, the lamina dura may be generally faint.

Maxillary sinus

The border of the maxillary sinus appears on radiographs as a thin, radiopaque line that seems continuous but has small interruptions. The deepest part of the sinus is usually at the level of second premolar and first molar teeth.

The distance from the apices of the roots of the first molar tooth to the sinus floor is 0.5 mm or even less in one third of all cases, and sometimes there is no bone between the root apex and the sinus. Therefore, a periapical radiograph may fail to show lamina dura covering the apex (Fig. 3). When the second molar tooth is three-rooted, its apices are located even closer to the maxillary sinus. It has also been found that the apices of single-rooted molars may be located in the immediate vicinity of the maxillary sinus (6). The thin layer of bone covering the root may also be seen as a fusion of the lamina dura and the floor of the sinus.

Often in the image of the maxillary sinus one or several radiopaque lines are seen. These so-called septa represent folds of cortical bone projecting a few millimeters away from the floor and wall of the sinus. They are usually oriented vertically, although horizontal bony ridges also occur, and it is not uncommon for them to vary in number, thickness and length. These septa may sometimes circumscribe radiolucent areas mimicking periapical pathosis (Fig. 3).

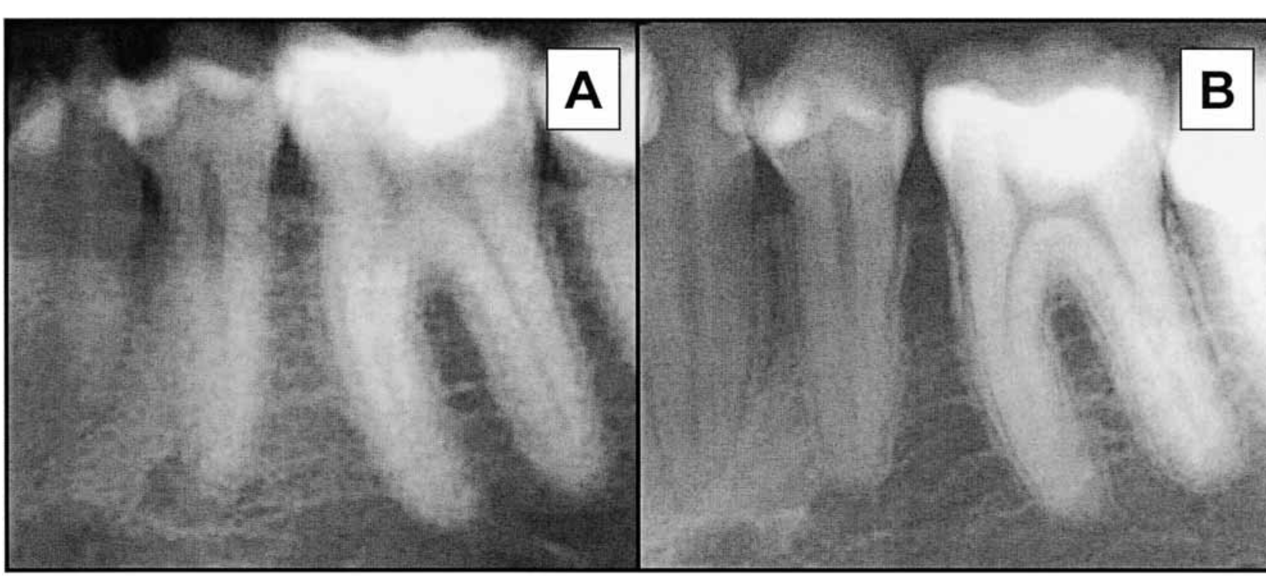

Fig. 4. Radiolucent structure in panoramic radiograph (A) may give a false impression of apical periodontitis. A periapical film (B), exposed at a different angle, does not show the radiolucency, which is probably the mental foramen.

Incisive and mental foramen and mandibular canal

The incisive foramen is the opening of the incisive canal onto the roof of the hard palate, located often just behind and above the roots for the central incisors. It may cause diagnostic problems, appearing on radiograph as a radiolucent area related to the apex of the maxillary central incisors. Following the lamina dura or taking a subsequent angled radiograph may shift the lucency in relation to apex, and reveal its true nature.

The mental foramen opens on the facial aspect of the mandible in the region of the premolars. When it is projected over one of the premolar apices, it may mimick periapical disease (Fig. 4). In such cases, evidence of the mandibular canal extending to the suspected radiolucency or a lamina dura traceable around the root apex would suggest the true nature of the radiolucency. However, the lamina dura superimposed on the radiolucent foramen may be of too low a density to be recognized in the image ('burn out').

The relationship of the mandibular canal to the posterior tooth roots may vary from one in which there is close contact with all molars and the second premolar, to one in which the canal has no intimate relation to any of the posterior teeth. When the apices of the molars are projected over the canal, the lamina dura may be overexposed, again conveying the impression of missing lamina dura or a thickened periodontal ligament space that is more radiolucent than apparently normal to the patient. Because the canal is sometimes located just inferior to the apices of the posterior teeth, altering the vertical angle for a second film of the area will not necessarily separate the images of the apices and canal.

Visualization of lesions in bone

There is a marked variation in the thickness of the cortices in the same patient. Therefore, a lesion of a

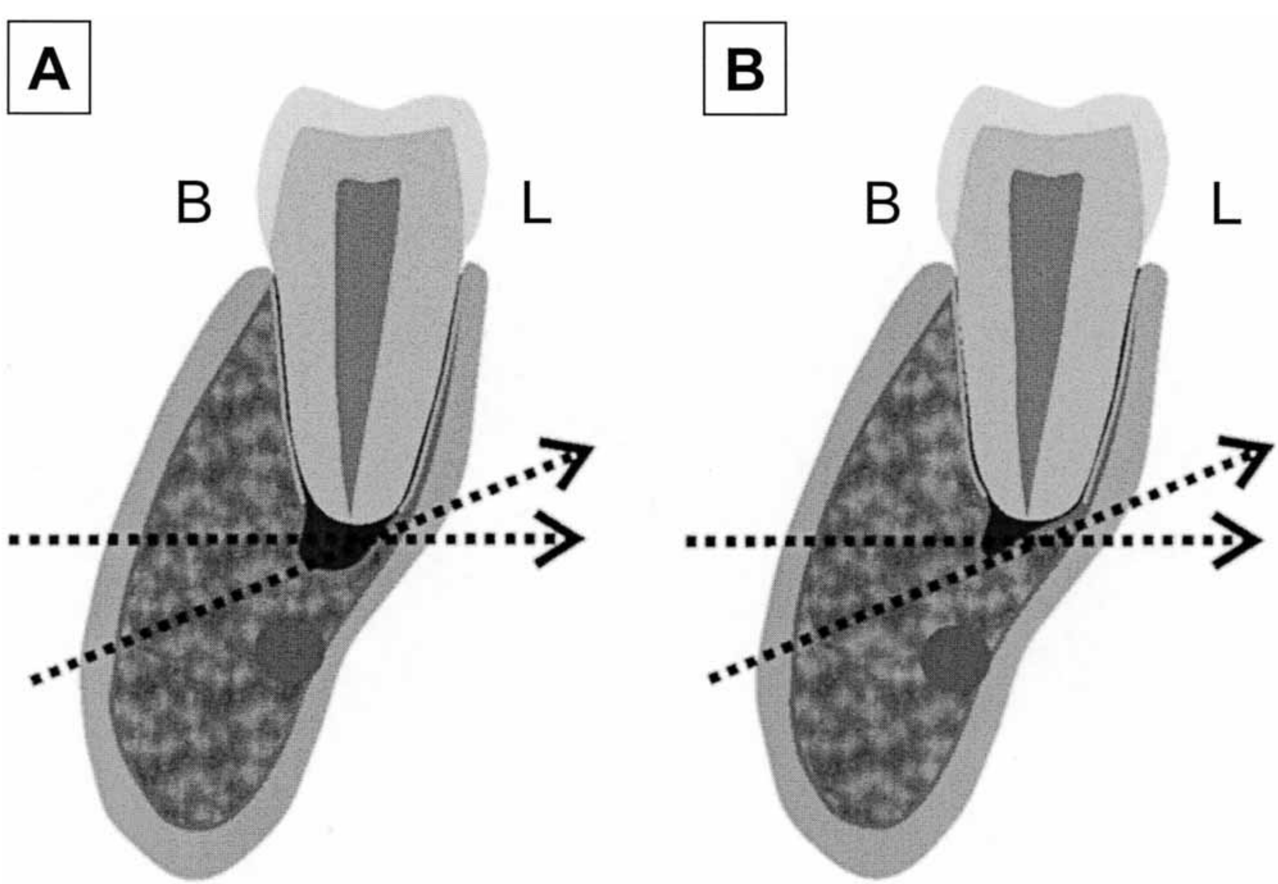

Fig. 5. Effects of beam angulation and lesion size on appearance of lesion in radiographs. The larger lesion in (A) is visible in different angles, whereas the smaller and more buccally oriented lesion in (B) disappears when the beam is from an oblique angle.

given size can be detectable in a region covered by a thin cortex; the same size lesion, in a region covered by thicker cortex, will not be seen. Radiographic visualization of lesions is also influenced by the location of the lesions in different types of bone. Because there are more minerals per unit volume in cortical than cancellous bone, the resorption or demineralization process will manifest radiolucent changes, i.e. enough minerals are lost to create contrast, sooner and more readily in the more calcified tissue than in the less calcified tissue.

Several *in vitro* studies have addressed the issue of visualization of periapical lesions. It appears that the lesion may be visualized more readily when it is near (7, 8), or in the cortex (7, 9). It may not be (10) or is less likely to become apparent in the cancellous bone (11). The size at which the periapical lesion becomes radiologically detectable varies between the different regions of the mandible. Isolated spongiosa lesions, being larger than 3 mm in diameter, are most often easily detectable at the mandibular front teeth and premolars. Isolated spongiosa lesions at mandibular molars are generally non-detectable. Atypical lesions, e.g. discontinuities of bony structures, are particularly difficult to detect radiologically (12).

The percent of mineral loss within the path of the central X-ray beam perpendicular to the object may be more critical than the size of the lesion which produces the radiographic visualization. This may explain why a change in angulation in the X-ray or that of the object can cause the disappearance of a lesion. The shape of the lesion is also frequently a deciding factor as to whether it will show on the radiographs or not. For instance, a lesion that has an oblong shape may not become visible on the radiographs if the exposure is at an angle through the narrowest dimension of the lesion. However, if the radiograph is taken with the beam passing directly through the longest dimension of the lesion, a prominent lesion might appear on the radiographs (Fig. 5).

Radiological features of apical periodontitis

The radiographic diagnosis of apical periodontitis is based on deviations from the normal periapical anatomy. Resorptive and bone remodeling activities in response to the inflammation are the main causes of changes that become visible on the radiograph. The periodontal ligament, the lamina dura, cancellous and cortical bone, and the root itself may all be affected by the biological activities of apical periodontitis.

Periodontal ligament

The soft tissue of the periodontal ligament provides the space for the initial cell infiltration. It serves as the starting point for resorptive processes as well as an end-station of healing processes. A widened periodontal space is associated with such initial or residual inflammation, and it appears to be a sign of chronic inflammation. Andreasen & Rud (13) found that if the periodontal membrane is more than doubled in width, moderate or severe inflammation is likely present. When a widened periodontal ligament reflects apical periodontitis, there is often a fairly sharp transition to the unaffected adjacent periodontal ligament, with a step up in size to the apical periodontal ligament affected by the infection. On the other hand, the periodontal ligament space may vary in width from patient to patient, from tooth to tooth in the individual, and even from location to location around one tooth. Teeth with increased mobility due to marginal periodontitis or bruxism may also have a large periodontal space, but in the case of apical periodontitis, widened periodontal space is limited to the infected area near the apex (14). A widened periodontal ligament may also be associated with a slight excess of root filling material, but such surplus material is often in turn the source of inflammatory changes due to either persistent toxicity or via bacterial colonization (15, 16), and the reaction may be viewed as pathological. Histological analyses of cases that are radiographically described as having a widened periodontal ligament around surplus material repeatedly demonstrate extensive granuloma formation and resorption of the surrounding bone (14).

Lamina dura

While the lamina dura is frequently cited in textbooks as a target for radiographic change in apical periodontitis, a critical review of the literature fails to establish a clear association. Changes to the radiographic integrity of the lamina dura may indicate early evidence of periapical lesion pathogenesis (11) and this may be radiographically visible (Fig. 6A) (3) . A collar-shaped increase in the thickness of the lamina dura lateral to the root was found more often in cases with moderate to severe inflammation than in cases with no or mild inflammation (13). Unfortunately, normal variations in thickness and continuity of lamina dura make the diagnosis by this criterion uncertain. The lamina dura may be described as irregular, indistinct or serrated (14), but none of these changes is pathognomonic in the early or healing phases of apical periodontitis. In fact, characteristics of the lamina dura may offer little help in the distinction between stages or degrees of inflammation (14). In more advanced stages, other radiographic changes (in bone structure and in the form of an easily recognizable radiolucent area) become prominent as signs of apical periodontitis.

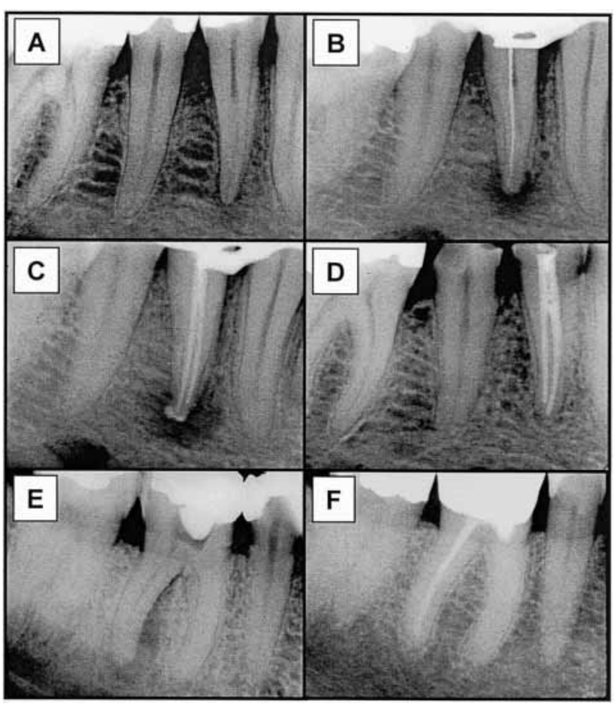

Fig. 6. Appearance of apical periodontitis and features of healing. In (A) through (D), the mandibular first premolar shows features of lamina dura disruption and bone structural changes in (A); 2 weeks later, there is a clear radiolucency confirming an established lesion (B); the root filling 1 week later shows a surplus (C); at the 3-year recall, healing is complete except for some discontinuities in the lamina dura and minor structural disorganization of the apical bone. The distal root of the mandibular first molar in (E) shows chronic apical periodontitis with signs of exacerbation; 24 years after endodontic treatment, there is complete restitution of the periapical bone (F).

Cancellous bone

Changes in the structure of cancellous bone, rather than overt mineral loss, may be a primary sign of apical periodontitis. In the presence of a root canal infection, a less functionally oriented pattern replaces the normal trabecular pattern of cancellous bone (Fig. 6A). The diagnosis becomes easier when mineral loss becomes evident. The radiolucency may be seen clearly adjacent to the root apex but may blend with the surrounding bone at the periphery of the lesion. The bone structure peripheral to the lamina dura or apical radiolucency may be rarefied, indicating moderate or severe inflammation (Fig. 6B, E), whereas minor alterations in bone structure may occur in cases with mild inflammation (13, 14). These changes most likely take place during granuloma formation, as part of a process of sequestering the infected tissues from the body interior. Sometimes the area of disorganization may be traced and separated from the surrounding bone, but it may also have a diffuse transition to normal bone (Fig. 6B). Such changes are probably of greater importance when the lesion only marginally, or not at all, affects cortical bone, either because the lesion has not increased sufficiently in size or because the root tip is at a distance from either cortical plate (see above). Mild inflammatory processes may at times cause the formation of *condensing apical periodontitis*, mostly involving the mandibular first molar (17). This inflammatory process appears as a radiopacity, either well circumscribed or blending diffusely with the surrounding normal bone, involving the apical region of the teeth. Sometimes a small radiolucent area can be seen at the apex of the root and surrounded by an area of increased radiopacity. After endodontic treatment, condensing apical periodontitis may show regression with rebuilding of bone structures to normal appearance (18).

Cortical bone

Lesions in cortical bone are easy to detect and assume prominence for their clarity and size in radiographs. Based on *in vitro* experiments (3, 9), it was widely held that an apical periodontitis could indeed not be discerned until and unless the cortical plate was resorbed. With greater attention to detailed changes in the bone structure (see above), one may be able to visualize changes also with limited or no cortical involvement. It should also be noted that most root tips, and probably most periodontitic lesions, lie in close apposition to either the facial or oral cortical plate.

Root surface

The root surface may be affected by resorption following damage to the cementum surface. Resorption of the root tip may follow a transient inflammation in combination with physical trauma, as seen in cases of orthodontic tooth movement or external physical trauma (19), and it may occur following long-standing apical periodontitis in root filled teeth as well as in apical periodontitis without periapical treatment. While root resorption in apical periodontitis may stop spontaneously or following treatment, it leaves a scar in the sense that the shape of the root tip is permanently altered.

Adjacent structures: maxillary sinus, nasal cavity

On occasion, the apical periodontal lesion may involve the maxillary sinus or nasal cavity and cause displacement of the floor or wall of the cavity. Periapical inflammation may also cause odontogenic maxillary sinusitis. Destruction, by localized inflammation, of the often extremely thin bone lamella between the sinus floor and the root apex can result in a local mucous membrane reaction in the form of membrane swellings (Fig. 7), pseudocysts or, sometimes, in chronic maxillary sinusitis (20, 21).

Granulomas and cysts

The differentiation of cysts and granulomas is difficult if at all possible by traditional radiographic techniques (22, 23). On the assumption that cyst cavities may have lower densities than granulomas, studies utilizing computer tomography (24) or densitometry (25) have shown some promise in differentiating cysts from granulomas. Several radiographic features have been proposed to make this distinction, including lesion size and the presence of a radiopaque rim demarcating the cystic lesion. While the probability of a lesion being a cyst may increase with lesion size (26), such rules of thumb have little basis in histological studies. A reliable diagnosis therefore remains based on histology (27).

Development

Systematic approaches to the description of how chronic apical periodontitis develops as reflected in radiographic change are scarce. Frequent radiographic assessment of intact teeth for the sole purpose of detecting and monitoring early signs of apical periodontitis is normally not indicated for reasons of radiation safety. However, studies on traumatized teeth and on root filled teeth with no preoperative signs of apical periodontitis may be looked at in the context of rate and course of chronic apical periodontitis in radiographs.

Luxated teeth are normally followed clinically and radiographically for months to years after the trauma. Particularly when there is a negative sensitivity test the teeth are monitored closely for apical changes indicative of periodontitis. There are three possible outcomes for such teeth: they may regain sensitivity due to revascularization and innervation (28); they may remain insensitive and have an aseptic pulp necrosis without apical periodontitis; they may become infected and develop chronic apical periodontitis (29). It is the latter outcome that is of interest in the present context. The time to develop necrosis, infection and radiographic change may, however, vary widely from one case to the next, which means that the start-

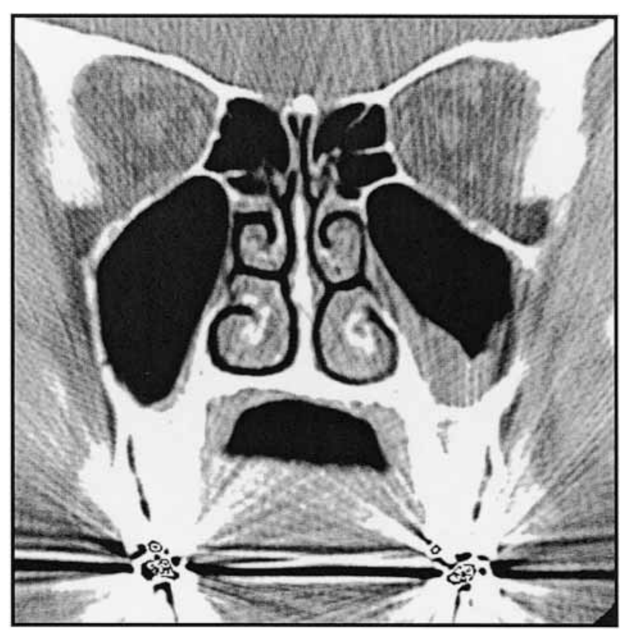

Fig. 7. Computer tomogram of the maxillary sinus and nasal structures. Mucosal swelling of the left sinus adjacent to the first molar is evident.

ing point for chronic apical periodontitis becomes hard or impossible to define. Whereas follow-up periods of up to and more than 1 year are recommended, this will not mean that the starting point for an apical periodontitis to develop is at the time of trauma. Signs of necrosis are generally evident within 3 months of the traumatic incident in luxation injuries to permanent teeth (30, 31). However, the use of discoloration, sensitivity and other markers, in addition to radiographic signs of apical periodontitis, as criteria is a confounding factor.

It appears that apical periodontitis without endodontic treatment mainly present with characteristics of established radiolucencies (14). By inference, this means that the time spent in the intermediate categories of bone structural changes and rarefaction without demonstrable radiolucency must be short, but there are no data from humans to establish the actual time frame of lesion development (Fig. 8).

The treatment outcome of root filled teeth in the absence of a lesion at the time of treatment may also be used to study the development of apical periodontitis. The majority of teeth that developed disease after root filling did so within the first year (32). At 2 years, the risk of a tooth developing disease was reduced to the general level for any root filled tooth, and at 3 and 4 years afterwards, the risk was actually less and approached that of any tooth, root filled or not. Even though radiographic signs may be seen at any time after the filling procedure, the actual starting point of the disease process may not be known. It may occur at any given time before, during or long after treatment. A further complicating factor is that the root filling itself creates a totally different microenvironment for the root canal infection (33–35), with space limitations and chemical ecological pressures by the filling materials, which may modify the infection and associated inflammatory changes. Many root filled teeth are also associated with bone structural changes or minor rarefactions; this may be related to either a low-grade infection or tissue reaction to the filling material (14).

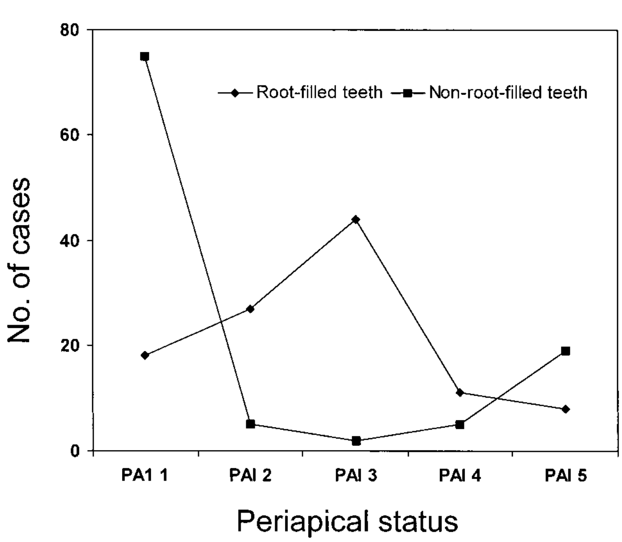

Fig. 8. Distribution of teeth according to periapical and root filling status. Reproduced with permission from (39).

In reviewing such follow-up studies with regard to lesion development, there are also systematic differences in the amount of tissues susceptible to infection. In trauma cases, the teeth are mostly young and have large pulp spaces; whereas in endodontic cases, the teeth are usually older and the root canals smaller, leaving less room and substrate for infection. The quantitative and qualitative nature of the flora will therefore vary. Standardized and controlled conditions for development of apical periodontitis may be possible only in experiments in animals (see below).

Healing

Healing after endodontic therapy is monitored by interpretation of periodic recall radiographs. Little is known about the radiographic characteristics of healing apical periodontitis. Repair of periradicular tissues consists of a complex regeneration involving bone, periodontal ligament and cementum. Following instrumentation and filling of a tooth, there may be a transient increase in radiolucency. It may be due to chemical and/or mechanical irritation resulting from the root canal treatment and will usually revert to normal (36). Temporary periapical breakdown for periods of years has also been indicated (37).

The area of mineral loss gradually fills with bone and the radiographic density increases. The structure of the newly formed bone may differ from normal, often being less organized (Fig. 9). The contours, width and structure of the periodontal ligament return to normal. It has been assumed that the periodontal ligament may remain widened mainly around excess filling material (37), but it may be questioned whether complete healing has indeed occurred in such cases (14). The course and width of the lamina dura also return to normal. If the cortical plate is perforated, healing begins with the regeneration of the external cortical plate and proceeds from the outside

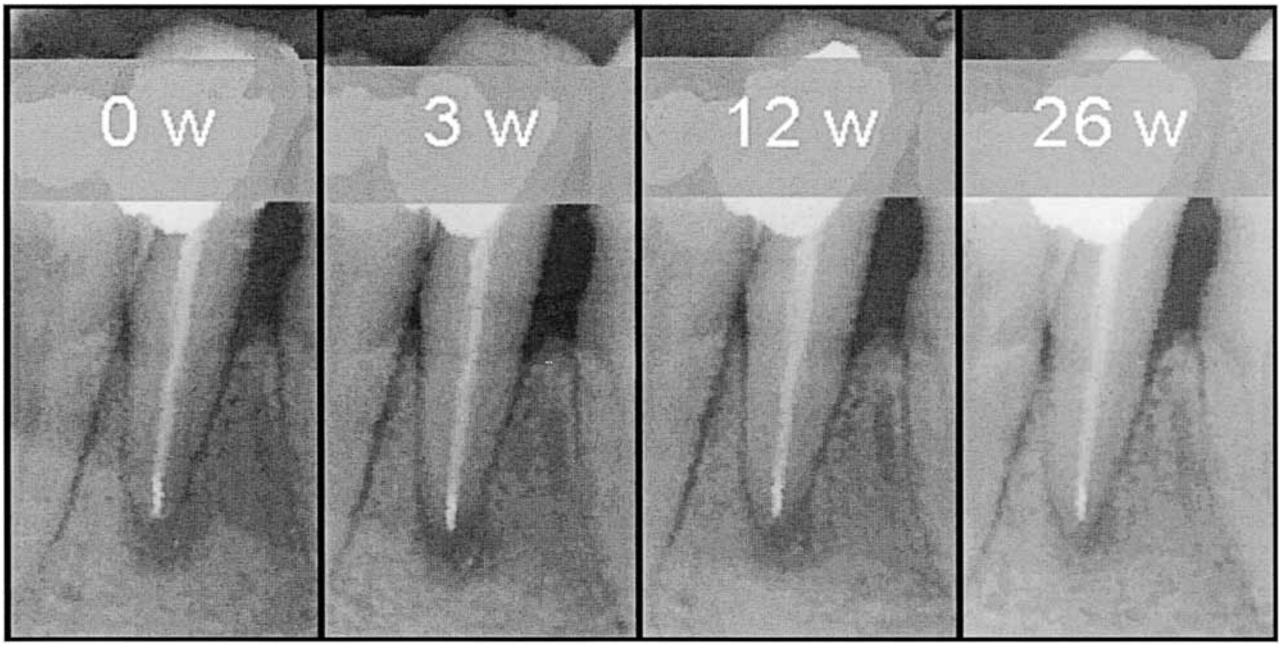

Fig. 9. Radiographic changes during healing of chronic apical periodontitis.

of the lesion toward the inside (27, 38). A majority of root-filled teeth show some indication of bone structural change or minor rarefaction; this may be related to a protracted healing phase (14, 39).

The time frame of the healing process is also poorly known. Clinical practice and follow-up studies have shown that a large proportion of treated cases of chronic apical periodontitis show signs of healing within 1 year of treatment, and in many instances as early as 2–4 months (32, 40). However, arguments have been presented to follow root filled teeth until complete healing is seen on radiographs, sometimes up to 7 or more years, and 4 years has been proposed as a standard (37).

Animal experiments

There are few experimental studies of radiographic signs of apical periodontitis. Radiolucencies were demonstrated 6 months after infection of the pulps in monkeys (41). When the animals had been immunized against the infecting microbes, the lesions were more clearly circumscribed with a condensed demarcation against the surrounding bone, while non-immunized monkeys had lesions that were diffuse and usually more extended. In baboons, subtraction radiography has been reported to allow identification of changes in the bone architecture as early as 7 days after infection of the pulp (42). In sealed infected teeth, inducing periapical pathosis, minor radiographic changes were seen at 2 months, becoming more visible after that time (43).

In dogs, initial signs of apical periodontitis may be visible on radiographs as early as 3 weeks after infection of root canals. Lesions keep developing at 6 weeks, and become extensive at 11 and 14 weeks (Fig. 10) (44). Radiographic examination may more often show variable agreement with histological analysis in the characterization of disease than in the characterization of normal bone structure, and the radiographic diagnosis may be more reliable at longer time intervals because the disease has become more extensive and there has been more time for changes in mineralization to occur (45).

In rats, periapical lesions develop rapidly after pulp exposure, with a maximum rate of bone loss occurring within the first 2 weeks. The bone loss becomes visible in radiographs after these 2 weeks (46–48). This period may represent the most active phase of periapical lesion pathogenesis, whereas the period of relative size stability after 2 weeks may be considered to be a more chronic phase in which expansion occurs at a much slower rate. At first, the periapical lesion extends mesio-distally with the resorption of spongy bone and then vertically with the resorption of cortical bone and cementum (47).

Special situations

Split teeth

The clinical and radiographic diagnosis of the split or fractured teeth is difficult because the radiographic features may imitate those of apical as well as marginal periodontitis, and there is a variety of radiographic manifestations in proximity to the affected roots (49). Cracks may occur without any radiographic signs, or it may take months or years for the radiographic and clinical features to become evident (50). There are several radiographic features found more often in split or fractured teeth than with apical periodontitis. There may be a 'halo' appearance, where the radiolucency extends from the periapical area to the mid-root level or even more coronally on one or both sides of the root. Sometimes, angular marginal bone loss is found on one or both sides of root (51), characteristic of a cracked tooth. Lateral and apical radiolucencies may also sometimes indicate cracked teeth (52). However, only 30–60% of cracked or vertically fractured teeth can be diagnosed radiographically (51, 52).

Periapical scars

Scar tissue can also develop after conventional endodontic treatment as well as after periapical surgery (22), and may cause diagnostic problems of periapical lesions (Fig. 11). In the case of scar tissue after surgery, the rarefaction may decrease in size, and have one or more of the following characteristics: bone structures are recognized within the rarefaction; the periphery of the rarefaction may be irregular and may be demarcated by a compact bone border; the rarefaction is often located asymmetrically around the apex; the connection of the rarefaction with the periodontal space may be angular. Isolated scar tissue areas in the bone may also be found, but this is probably a later stage of healing in some cases (53).

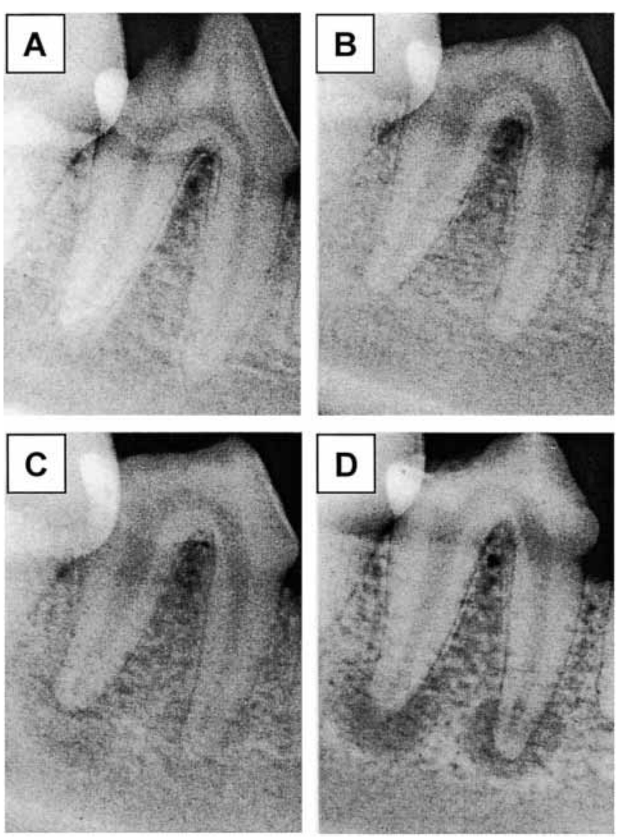

Fig. 10. Radiographs of a dog's mandibular premolar (A) before induction of apical periodontitis 3 (B), 11 (C) and 14 (D) weeks after pulpal inoculation with dental plaque. Reproduced with permission from (44).

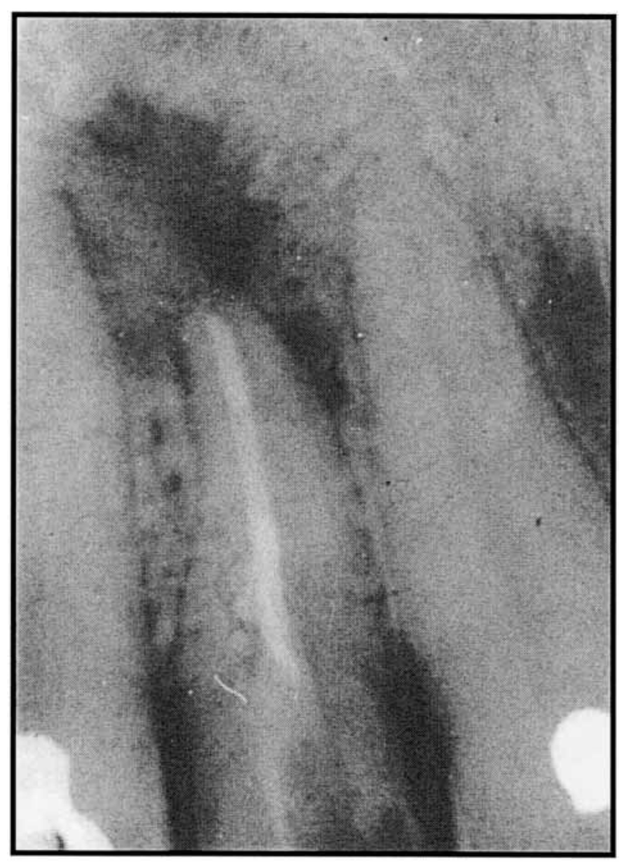

Fig. 11. Scar formation during healing. Reproduced with permission from (72).

Interpretation in clinical practice and research

Problems in interpretation: bias, consistency

The stages and extent of chronic apical periodontitis may be seen as steps on a continuum from complete health to overt and easily recognizable disease. Where signs of disease are large and striking, problems of interpretation hardly exist: a droplet-shaped radiolucency at an apex, with a periodontal ligament tapering into the normal areas at the lateral aspects of the root and the lamina dura absent, strongly suggests chronic apical periodontitis. When associated with findings confirming a necrotic pulp, it is pathognomonic (54). Problems arise in the transition between normal periapical structures and minor signs of disease, and it has been documented repeatedly that there is great variability within and among observers in radiographic diagnosis of lesions in bone (Table 1) (55–59). Several factors contribute to this variability, many of which may not be related to the apical radiographic findings (59, 60): for example, observer bias may be related to concepts regarding the need for treatment, the finding of a defect root filling, knowledge of the apical status in other radiographs of the same tooth at the same or other points in time.

Clinicians do not approach evaluation of endodontic treatment results as just a task of detecting the presence or absence of periapical radiolucency. One hypothesis of dentists' behavior may be to assume that they operate along a health continuum (61). Assigning various periapical conditions to different stages on a continuous scale, they may consider larger lesions to be more serious. Variation between dentists in decision-making may then be looked upon as the result of choosing different cut-off points for prescription of treatment. Such variation may help explain variations in dentists' attitude to treatment of asymptomatic periapical lesions in endodontically treated teeth: general dental practitioners and endodontists differed substantially in their treatment decisions and also in their assessment of the probabilities of disease and future complications (62, 63). It was also noted that the endodontists were more prone to treat smaller and medium-sized lesions than were general practitioners.

Treatment outcome assessments in endodontics

There is a long tradition in endodontics of long-term follow-up assessment of treatment outcome. While clinical as well as radiographic data are used to monitor cases, the relative absence of clinical symptoms in chronic apical periodontitis makes the assessment primarily a radiographic one. Table 2 lists a commonly used set of criteria for the radiographic assessment of success and failure (37). Such criteria include a number of considerations in addition to the radiographic information, and it is primarily a system designed to detect changes in radiographic appearance rather than significant signs of disease. Even though the periapical conditions are viewed as a continuous process of healing or developing periodontitis, the system is strictly dichotomous, i.e. there is no middle ground between success and failure. If the radiograph were able to reflect adequately the presence or absence of infection, this might be acceptable, but there is little evidence to support that it does. It is somewhat unfortunate that such assessment schemes for endodontic success and failure have taken the place of disease diagnosis in endodontic practice and research.

Despite its limitations, success–failure assessment has been an essential tool in the documentation of endodontic materials and clinical methods (37, 64–

Table 1. Interexaminer agreement on periapical conditions after endodontic treatment (59)

Diagnosis	All observers in agreement (%)
Normal periapical condition	40
Increased width of periodontal membrane space	9
Periapical radiolucency	27

In all, 119 roots were diagnosed radiographically by six observers.

66). The concept of success and failure is also a strong didactic and quality-assurance tool, which places (wrongly or rightly) blame or praise on the operator. This is a strong motivation for improved performance. Moreover, it has some value in the decision-making as to whether and when treatment is to be initiated.

Other methods of assessment have also been applied for the dichotomous decision of treatment outcome. Area measurements of the radiographic lesion may be done by direct visual inspection (67), based on optical densitometry (68) or after digital manipulation of serial radiographs of the same case (69).

A probability assessment of the presence or absence of apical periodontitis has been proposed (Table 3) (60). This is a more disease-oriented approach to chairside diagnosis than the conventional success–failure analysis, and it accepts the bias of the observers. While it may have limited use in clinical practice, it is relevant for research purposes.

Another approach is the 'periapical index' (PAI) (39) (Fig. 12), which provides an ordinal scale of five scores ranging from 'healthy' to 'severe periodontitis with exacerbating features'. The PAI is based on reference radiographs with verified histological diagnoses originally published by Brynolf (14). It has been designed for and used both in clinical trials (70–74) and in epidemiological surveys (75), and it may be transformed into criteria for success and failure by defining cut-off points on the scale for a dichotomous outcome assessment. However, the use of a graded scale provides statistical power in comparative studies that is easily lost in the transformation.

The use of receiver-operating-characteristic (ROC) curves is an appropriate statistical approach to radiological data generated as scores. ROC analysis has been advocated in imaging studies in preference to sensitivity and specificity reporting (76). The area under the ROC curve obtained from a rating scale method represents the probability that an abnormal subject is rated higher on the scale than a non-diseased subject (77). ROC analysis accounts for the bias in sample population and the limitations of the observer's tendency to over- or under-read an image (76). It has been shown that extensive calibration and training in scoring periapical pathosis is necessary to produce adequate ROC curves (39, 62).

Surveys and epidemiology

The assessment of the incidence and prevalence of chronic apical periodontitis in different populations is important for many reasons. It may help to define treatment needs and to relate treatment outcome to various technical and clinical factors of endodontic intervention (78). There seems to be no standard criteria for the registration of apical periodontitis in such surveys, either for periapical radiographs or panoramic radiographs.

The PAI scoring system has been modified and applied to epidemiological and clinical comparative studies of treatment outcome. The possibility of comparisons among studies carried out with calibrated observers makes this system attractive (79–81).

Table 2. Radiographical criteria for the results of endodontic treatment (37)

Success:	
(a)	the contours, width and structure of the periodontal margin are normal;
(b)	the periodontal contours are widened mainly around the excess filling.
Failure:	
(a)	a decrease in the periradicular rarefaction;
(b)	unchanged periradicular rarefaction;
(c)	an appearance of new rarefaction or an increase in the initial.
Uncertain:	
(a)	there are ambiguous or technically unsatisfactory control radiographs which could not for some reason be repeated;
(b)	the tooth is extracted prior to the 3-year follow-up owing to the unsuccessful treatment of another root of the tooth.

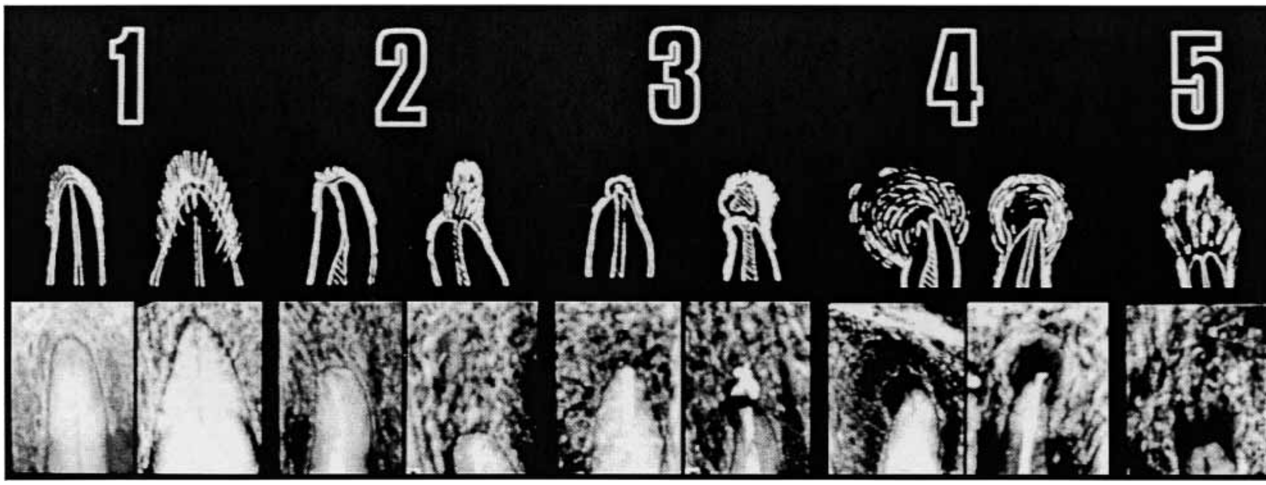

Fig. 12. The periapical index. 1, Normal periapical structures 2, Small changes in bone structure. 3, Changes in bone structure with some mineral loss. 4, Periodontitis with well-defined radiolucent area. 5, Severe periodontitis with exacerbating features. Reproduced with permission from (54)

Radiographic techniques

Bisecting angle and parallel techniques

In the clinical situation, anatomical conditions often determine the position of film and the alignment of the X-ray tube. The technique of placing the film parallel to the root axis is frequently recommended, and it often gives images of good quality. In follow-up studies of individual cases, identical or at least similar conditions for exposure are essential. Changes in the angle of the beam may produce an increase, decrease or elimination of periapical lesions. A decrease in vertical angle produces an elongated tooth and may increase the size of the radiolucent area, whereas an increase in vertical angle produces a foreshortened tooth and may decrease the size of the radiolucent area (Fig. 13).

Bisecting angle and paralleling techniques have been developed to minimize image distortion. The paralleling technique provides images with a minimum of geometric distortion, but with some enlargement of structures. The bisecting angle technique introduces some image distortion, particularly in the bucco-lingual direction. With the angulation of the central beam differing between the two methods, different anatomical structures may overlap the apical area resulting in a different radiographic appearance of the lesion. Forsberg & Halse (82) did not find differences between the two techniques in assessment of lesion size, but they recommended the paralleling technique due to the better reproducibility of repeated exposures.

Table 3. Interexaminer variation range in scoring periapical conditions according to a probability classification (60)

Diagnosis	Range (%)
Periapical destruction of bone definitely not present	19–77
Periapical destruction of bone probably not present	12–28
Unsure	0–30
Periapical destruction of bone probably present	2–18
Periapical destruction of bone definitely present	8–25

In all, 119 roots were diagnosed radiographically by six observers.

Multiple exposures

The use of more than one film for diagnosis or follow-up studies is likely to give more information than only one. If two or three films at different angulations are used, the accuracy in radiographic interpretation is increased (83). The overlapping of structures may be avoided by changing the angulation of the X-ray beam. The possible advantage of use of several films must be considered in each case separately.

It is sometimes important to know the spatial or bucco-lingual relation of an object in the jaw or alveolus, e.g. to locate anatomic landmarks in relation to the root apex. The technique most widely used to identify the spatial relation is the tube shift technique, employing the 'buccal object rule', which makes use of the fact that objects closer to the buccal surface appear to move more in the direction opposite the movement of the tube head, when compared to the first film. Objects closer to the lingual surface appear to move in the same direction as the cone.

Panoramic radiography

Panoramic radiographs (Fig. 14) have become popular in dental diagnosis because of improved quality, low radiation dose and ease of use. As an extra-oral method it may be more comfortable for the patient and may allow a more vertical alignment of the structures than do periapical intraoral radiographs.

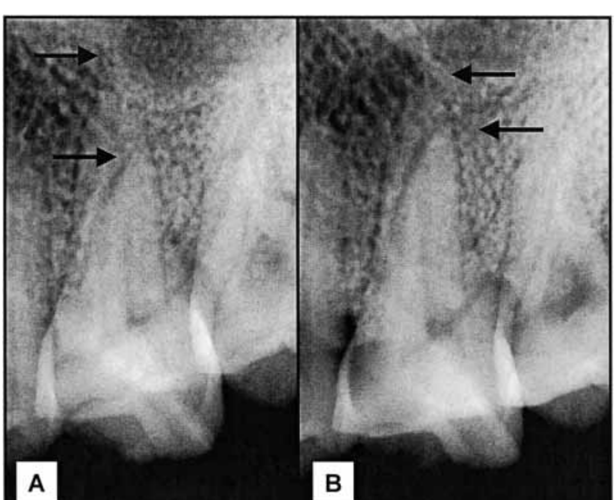

Fig. 13. Shortening of facial roots and lengthening of palatal root in bisecting angle exposure (A) compared with paralleling technique (B).

Panoramic radiography may underestimate periapical lesions compared to periapical radiography (84). On the other hand, the overall accuracy of these two techniques has been shown to be similar (85, 86). Molander et al. (87) compared sensitivity and specificity of panoramic X-rays with respect to periapical lesions and to the type of teeth. In panoramic radiographs, lesions were detected in 60–83% of cases found with periapical film for most tooth types, but for mandibular incisors and canines this sensitivity was only 29%. A false positive diagnosis was seldom made with panoramic radiographs; the specificity was over 95% for all types of teeth.

Digital radiography

Advances in digital systems include a 50–80% reduction in radiation exposure, wider exposure latitude, immediate image generation and manipulation and elimination of chemical processing of radiographs. Disadvantages include the size, shape and stiffness of the sensor and lower image resolution.

Conventional intraoral films have a spatial resolution exceeding 20 line pairs per millimeter (88), while the corresponding resolution for photostimulable phosphors is less than 7 line pairs per millimeter (89), and that of the newest charge-coupled devices (CCD) up to 20 line pairs per millimeter (90). This difference of resolution of details may have an effect on subtle features such as thin trabeculae, the lamina dura and the periodontal ligament.

Digital radiography systems have given the clinician the ability to rapidly acquire and manipulate intraoral images (Fig. 15). Density and gray-scale changes in radiographs are important visual features that the clinician uses to evaluate changes in bone pattern. In endodontics, researchers have examined the effects of enhancement on periapical lesion detection and the application of measurement algorithms for dimensional assessment. *In vitro,* digital systems have been shown to be more sensitive when the lesions involved lamina dura and cancellous bone, but no difference was found between films and digital image of lesions that involved cortical bone (91). Others have not found differences between digital and conventional images (92).

Color-coding has been proposed as a means of detecting differences between sequential images by means of image addition to detect bone changes (93).

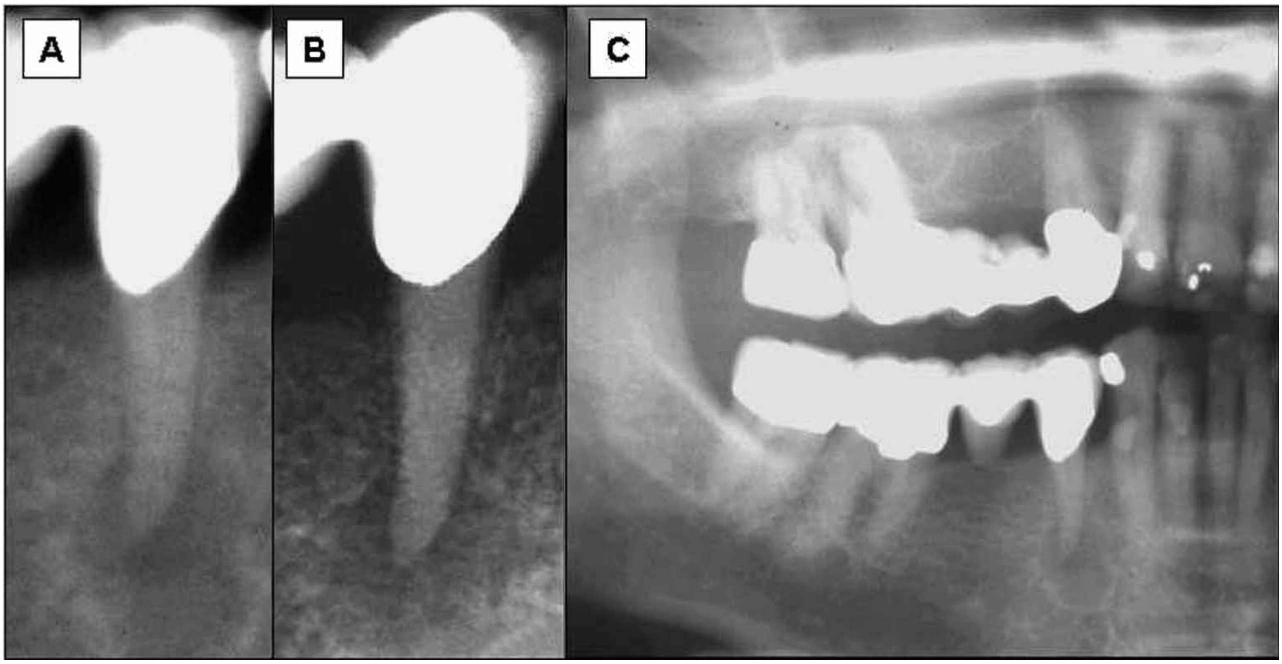

Fig. 14. Comparison of image quality in panoramic radiograph (A and B) and in periapical film (C).

Assigning a color to a range of grays creates colorized images, but the process may discard some information. Color-coding may also visualize normal anatomical structures, and it can be used to help to find possible lesions; in diagnosis, however, a gray-scaled image seems preferable (94).

Texture analysis has been developed to identify the trabecular bone pattern and systemic or local changes caused by pathologic processes (95), but this method has not yet been applied to clinical work.

Densitometric methods and subtraction

Subtraction radiography and densitometric image analysis have been applied to enhance the detection of small osseous changes over time. The radiographic images may be acquired by direct digital radiography, or conventional film may be digitized for further analyses. The purpose of subtraction radiography is to eliminate, or even out, all unchanging structures from a pair of radiographs, displaying only the area of change. In

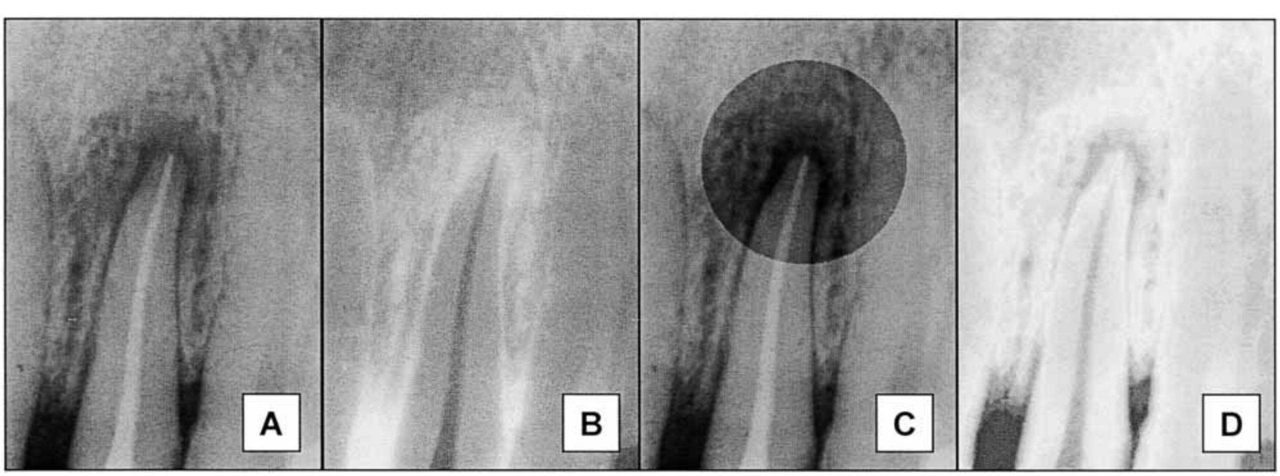

Fig. 15. Computer-assisted enhancement of periapical radiograph (A). (B) Negative image; (C) contrast enhancement; and (D) pseudocolor application.

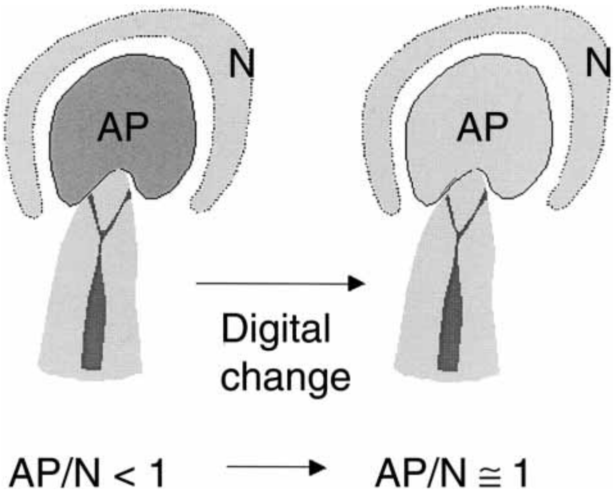

Fig. 16. Measurement of density changes with time in apical periodontitis lesion (AP) in relation to the relatively stable density of an unaffected area (N). Reproduced with permission from (72).

practice, this leaves the area of bone gain or loss standing out against a neutral gray background. In densitometric image analysis, the images may not be displayed, but the numeric density values are analyzed to quantify osseous changes in areas of interest.

The use of subtraction radiography requires that the radiographs be taken with similar contrast, density and angulation. Thus, exquisite attention to detail is critical when exposing radiographs for use in subtraction radiography. Computer algorithms have been developed that can correct for variation in radiograph image density and contrast (96).

The standardization of image geometry, which presents one of the most serious challenges to the successful implementation of digital subtraction radiology, has been achieved using one of several methods. Stents may stabilize the relationship of the teeth, film and X-ray source (97). Alternatively, the relationship between the X-ray source and the teeth may be stabilized using a cephalostat (98), and the computer can be used to correct image distortion caused by film placement (99). Reference points may be used to aid in the superimposition of sequential radiographs in digital subtraction radiography (36, 100, 101). Algorithms have been introduced that align the serial images as well as manual alignment (102). Other methods used in research include specialized computer software and a video camera to superimpose follow-up radiographs (40, 70, 103).

Densitometric analysis with digital subtraction has been correlated with histological evaluation of healing of apical periodontitis at 6 months after apicoectomy in dogs (104). The average gray value of the surgical area on the subtraction images was significantly correlated with the histological evaluation of healing and the relative percent of trabecular bone.

Contrast enhancement of the subtraction image may result in better visualization of some structures. Reddy et al. (105) used pseudocolor enhancement for the detection of small periodontal bone lesions, but they found that coloring did not add new information to the image. However, it may allow increased speed and efficiency for interpretation of subtraction images with greater confidence.

A more robust method of comparing images over time has been proposed (103). By relating the density of the lesion area to a peripheral, normal bone area, a density ratio measure is obtained that may be monitored over time as a marker for development or healing of chronic apical periodontitis (Fig. 16).

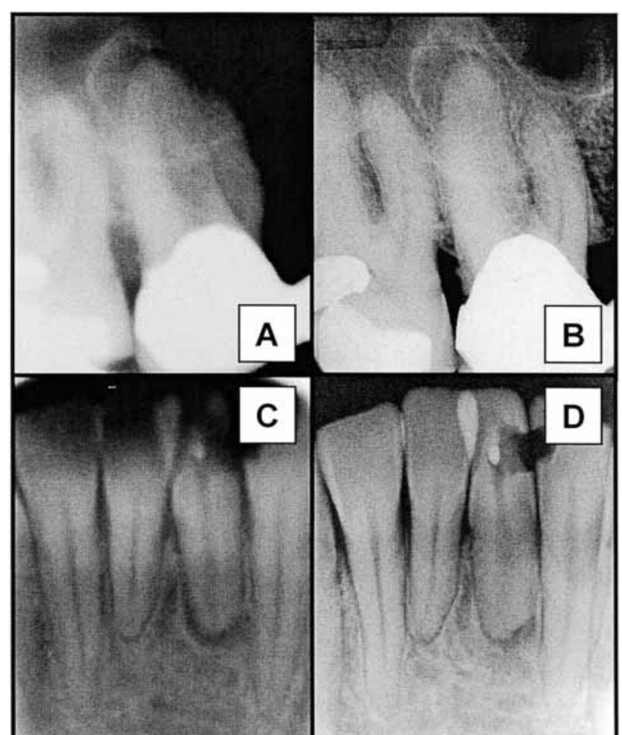

Fig. 17. Tomographic images (A, C) in comparison with periapical radiographs (B, D). The tomographic images appear more blurred, but show a section of the tooth/jaw segment rather than the whole traverse that creates the periapical image.

Tomography and computer tomography

In tomography, structures in a selected object layer, or transversal plane, are sharply described, whereas those outside it are blurred. The blurred structures appear on tomographs as homogeneous, low contrast shadows allowing the detection of lesions in the object layer (Fig. 17). Dental radiography units have been developed that include a tomographic imaging mode, which visualizes dento-alveolar structures in detail. The sensitivity of tomography in visualizing periapical bone lesions was markedly higher for premolar and molar regions compared with periapical films. Differences in the anterior regions were smaller (106). The better detection rate in the posterior regions is mainly attributable to the ability of tomography to eliminate structural noise arising from the thick alveolar bone. When examining multirooted teeth, the use of multiple projections may increase the rate of detection of periapical lesions. Stereoscopic viewing also may improve the visualization of details.

Computer tomography has previously been used clinically to detect and diagnose a variety of intrabony lesions. Its use for the routine diagnosis is still hampered by the high radiation exposure and lack of resolution. Cotti and coworkers (107) used computer tomography in the follow-up of an extensive periapical lesion. They found that computer tomography was superior to panoramic radiography in obtaining detailed information of the size of the lesion and its spatial relationship to anatomical landmarks. Also, the healing was better visualized in computer tomography than in panoramic radiographs.

A high-resolution computed tomography, which uses a small conical beam and reconstructs images in any direction by means of a software program that runs on a personal computer, has been developed for dental applications. This imaging technique may also be useful for depicting periapical lesions (108).

Currently, the use of microcomputer tomography technology in humans is restricted to samples of no larger than a few millimeters, e.g. biopsies from the iliac crest (109), or as an *in vitro* non-invasive method for three-dimensional reconstruction of root canals (110). Ideally, one would prefer to have a system with microstructural resolution, which would allow for measurement of whole bones in patients *in vivo*. A recent study indicates that this goal may be feasible (111).

Tuned-aperture computed tomography

Tuned-aperture computed tomography is a relatively new type of imaging that may have advantages over

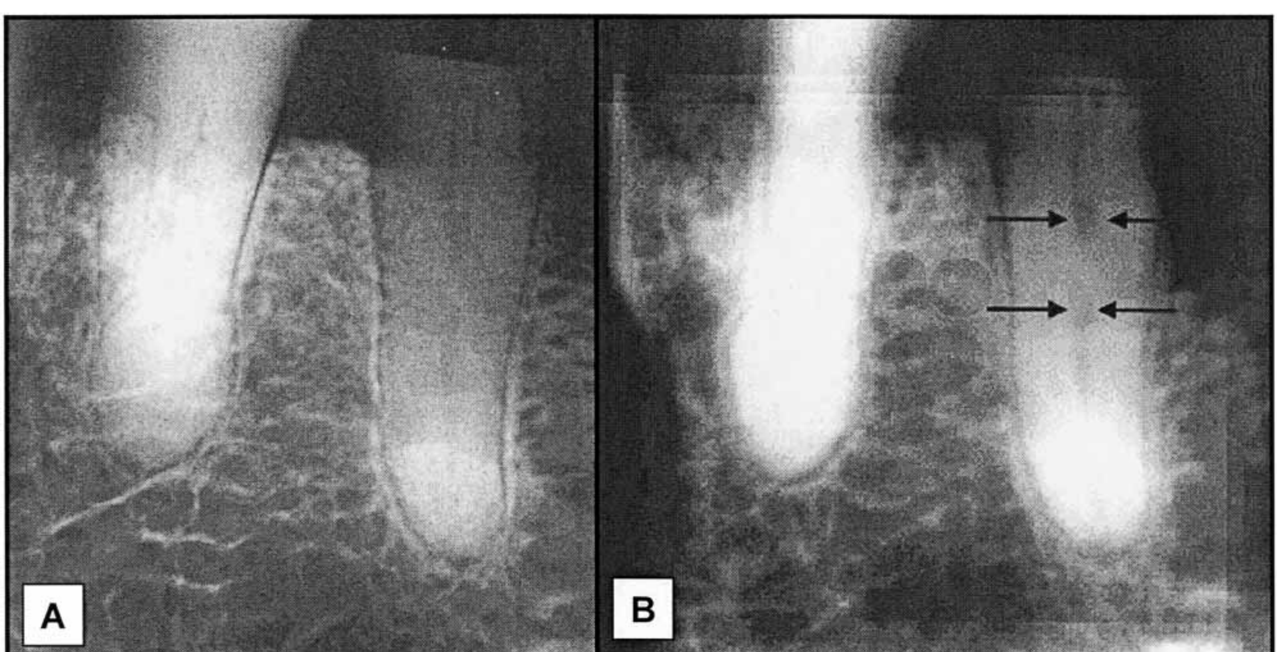

Fig. 18. The tuned-aperture-computed tomogram (arrows in B) shows the details of the root canal more clearly than the periapical radiograph (A). Reproduced with permission from (115).

current radiographic modalities in viewing an object while decreasing the superimposition of the overlying anatomical structures (112–114). The system uses digital radiographic images and the software collates the individual images of a subject and forms a layering of images that can be viewed in 'slices'. The resulting image is made from a series of eight digital radiographs that are assimilated into one reconstructed image. Preliminary studies have shown that the system may have advantages over conventional film in the visualization of root canals (Fig. 18) (115). It has also been shown to be an effective diagnostic tool for evaluating dental caries and simulated osseous defects (112–114). A clinically useful system would consist of a standard radiographic unit, digital image acquisition device, and the necessary software to reconstruct the acquired images.

Magnetic resonance imaging

The signal strength of magnetic resonance imaging depends on the hydrogen content of the tissue. When, for example, fatty bone marrow is replaced by inflammation, the strength of the signal is altered and in this way inflammation becomes visible. Magnetic resonance imaging was found to show periapical edema at the apex of teeth with inflamed pulps, dentigerous cysts and their relation to surrounding tissues (116). Magnetic resonance imaging has been applied to the differential diagnosis of ameloblastoma and odontogenic keratocysts (117). Magnetic resonance imaging has the advantage of revealing septa chiefly made of soft tissue with few or thin bone structures, and it may be superior to conventional radiography and computer tomography in demonstrating multilocularity in some cases (118).

Ultrasound

Ultrasound is a real time imaging technique recently introduced to periapical diagnostics (119). Sound waves do not pass through bone, but are reflected back to the sensor on the surface; therefore, only lesions uncovered by bone can be examined. It is possible to discriminate fluid, soft tissue, small mineral particles and blood flow. In practice, ultrasound would be a safe and perhaps easy method to use, if suitable sensors were available.

Nuclear techniques

Bone scanning is generally considered to be a highly sensitive, but non-specific, imaging procedure, which is used in a wide range of medical situations to detect and monitor a variety of osseous lesions. Scintigraphic images are obtained after introducing a radionuclide to the patient. Within a short time it is possible to measure the uptake of radionuclide in different parts of body as a gamma camera counts the amount of radiation emitted from tissues. The uptake of the radionuclide depends on the metabolic activity of the tissues, e.g. it is increased in inflamed areas (Fig. 19). The advantage of scintigrams is that changes in bone can be seen earlier than in conventional radiographs.

A number of common dental pathoses, such as pulpitis and apical periodontitis, have resulted in

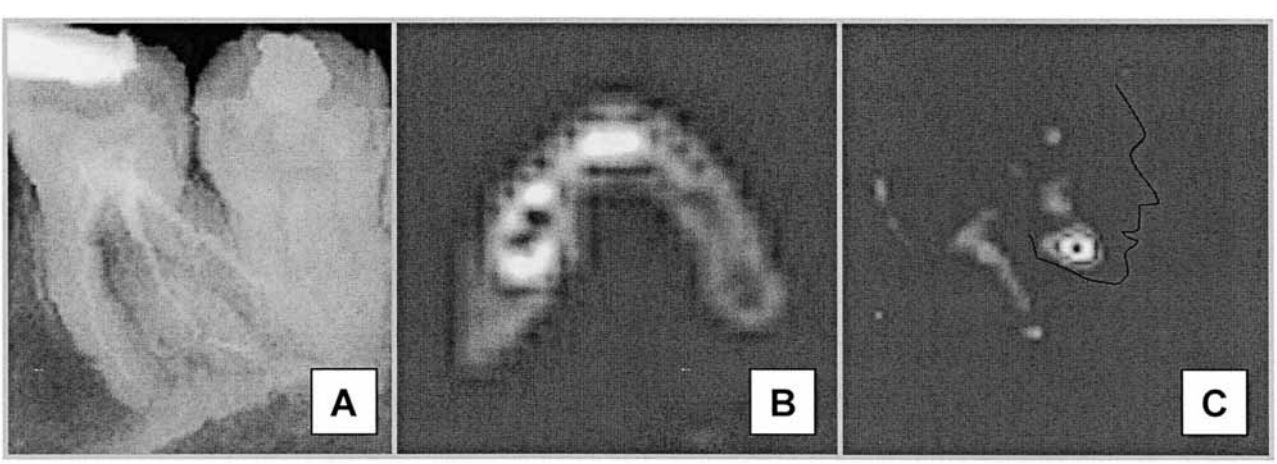

Fig. 19. Scintigraphic images of the acute lesion in (A) show 'hot spots', i.e. high intake of radionuclides in the tissues, in the horizontal section (B) and in profile (C).

abnormal uptake on skeletal images. The abnormal findings on scans may appear before clinical evidence of the inflammatory disease is actually present (120). A case of poorly localized pain was diagnosed as an active root canal infection by scintigraphy (121).

Concluding remarks

This review has dealt with some aspects related to apical periodontitis. The characteristics of this condition in children are hardly mentioned in the literature. The monitoring of patients following surgical treatment of apical periodontitis has many particular features related to the consequences of the operation itself, and little is known of the balance between residual activity of a periodontitic lesion and the healing processes induced by the operation.

Radiographic diagnosis of chronic apical periodontitis is a complex task, which is confounded by several anatomical and biological variables. Between the extremes of well-defined, normal periapical structures and pathognomonic radiolucencies, detection and grading of radiographic signs of chronic apical periodontitis may be difficult. Systems for training and calibration of observers may be used to improve diagnostic performance, and digital manipulations have great potential for the detection of subtle changes indicating disease. The impact of more sophisticated radiographic techniques is still in the future.

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