Factors influencing the radiographic appearance of bony lesions

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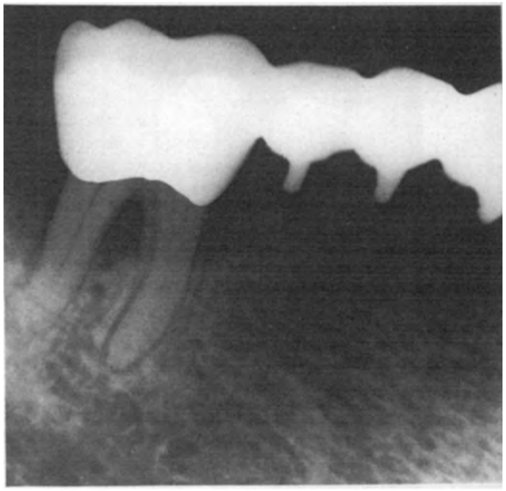
Part I

The X ray is a tool of inestimable value in establishing a diagnosis and in follow-up studies. However, the radiographic findings do not always accurately reflect the existence of normal or pathogenic conditions at the apexes of teeth, or in the mandible and maxilla, represented by metastatic or certain systemic lesions. A considerable body of confirming literature has accumulated since we first showed that experimental bone lesions, created within the cancellous structure and not encroaching on the junction region between cancellous and inner surface of cortical bone, cannot be visualized on radiographs.[1-6] The aforementioned studies emphasize that routine clinical radiographs may not detect the presence of inflammatory lesions or neoplasms causing bone destruction. Whereas minute or small lesions[7] have been acknowledged to go undetected, it has not been recognized that large lesions may also go undetected (Fig 1).

Besides the experimental evidence, there is also histologic and clinical evidence of apical and periodontal disease without correlative radiographic manifestations.[3] Human necropsy material has shown that, in many instances, radiographic examinations had negative results when cancellous bone was diseased and sometimes when cortex was involved. Furthermore, necrotic pulps invariably cause periapical inflammation with different degrees of bone destruction without appearing in a radiographic visualization; this is a common observation.[8]

Further evidence of discrepancies in X-ray and morphologic studies of inflammatory processes within bone has been shown, using a high-resolution cadmium telluride probe by measuring ^{99}technetium polyphosphate (Tc-PP) uptake. Acute abscesses were induced in dog molars by sealing fresh dog fecal matter in mechanically exposed vital pulps. Diagnostically significant increases in Tc-PP uptake were detected in the abscessed teeth within one to two weeks after infection compared with intraoral radiography, which required four weeks for positive detection.[9] Recently, the clinical use of ^{99}Tc-PP uptake to detect occult dental lesions in the mandible was also reported.[10,11]

It was also shown that changes in angulation of the X-ray beam produced an increase, a decrease, or an elimination of radiolucent areas[10,12] (Fig 2). A decrease in vertical angulation produced an elongated tooth with a subsequent increase in the size of the radiolucent area; whereas, an increase in vertical angulation produced a foreshortened tooth with a subsequent decrease in the size of the radiolucent area (Fig 3). Wengraf[13] showed that a difference of 15 degrees in the horizontal angulation often discloses a region of rarefaction; whereas, a change in the vertical plane is not significant in



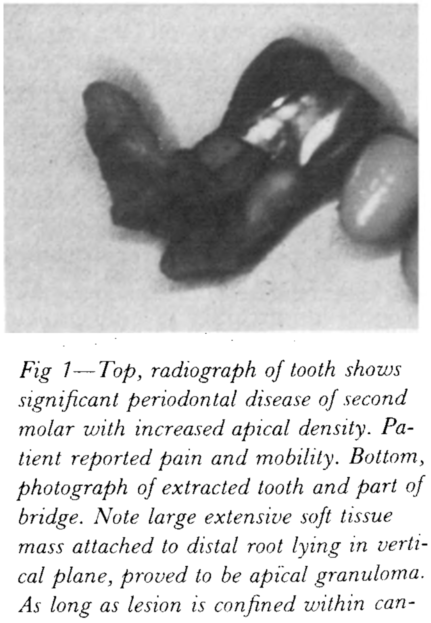


Fig 1—Top, radiograph of tooth shows significant periodontal disease of second molar with increased apical density. Patient reported pain and mobility. Bottom, photograph of extracted tooth and part of bridge. Note large extensive soft tissue mass attached to distal root lying in vertical plane, proved to be apical granuloma. As long as lesion is confined within cancellous bone and not encroaching on junctional trabeculae and masked by thick cortical bone, no radiographic visualization will occur.

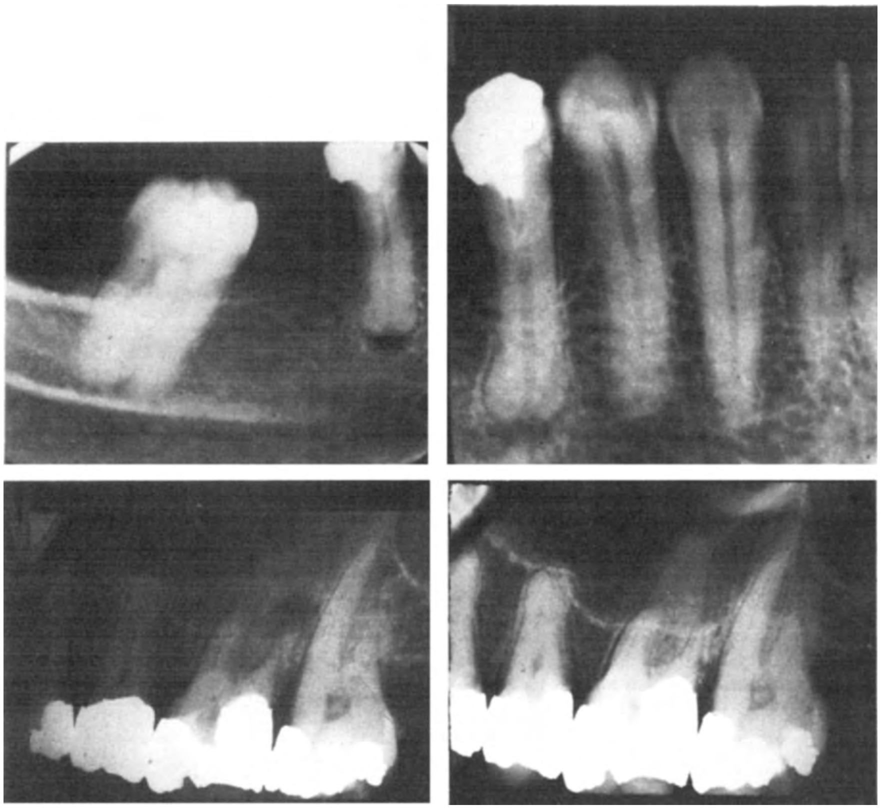


Fig 2—All four X rays were taken at same time before treatment. After intentional change in angulation, there was apparent decrease in size of lesion in radiograph at top right, and complete disappearance in radiograph bottom right. Change in angulation produces reduction or increase in bone thickness in path of X-ray beam. Significance of use of more than one film becomes evident in diagnosis and follow-up studies.

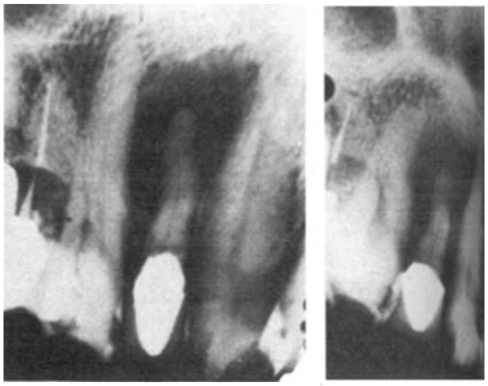


Fig 3—Left, elongation causes enlarged shadow; whereas foreshortening in radiograph on right reduces radiolucent area. Radiolucency is due to anatomic depressions with variations in bone thickness on labial aspect in maxilla. Tooth is vital.

detecting a radiolucent area. This observation often occurs, inadvertently, when a full-mouth X ray is taken; a rarefaction appears on the mesial maxillary root of the first molar during the examination of the premolar segment of films, although the molar segment shows no evidence of rarefaction. The significance of using more than one film for diagnosis or follow-up studies, particularly in endodontics, is emphasized by Brynolf.[14] She reports that accuracy in radiographic interpretation can be increased from 74% to 90% after using a single film, when radiographs are taken from three different angles.[14]

The significance of changes in horizontal and vertical angulation is well documented in caries detection studies[15] (Fig 4). Vertical zero degree angulation of the X ray, with the film placed tangentially to the crowns of teeth, detects caries more readily and accurately than a 30-degree angulation. That is precisely why bitewing radiographs are used in the detection of caries. Horizontal angulation is also a consideration in attempting to prevent an overlapping image of adjacent teeth. Correct angulation is essential; the X ray should pass directly through the interproximal spaces. To mitigate the error that may be produced by the curvature of the jaws, the use of two bitewing films of each side of the tooth has been accepted as standard practice.

Although carious lesions can be detected clinically, whether they are located occlusally, interproximally, or buccally, the radiographs often fail to disclose the lesion, notwithstanding correct angulations.[15] Similarly, the radiograph also fails to disclose occult lesions located within cancellous bone.[12,16] Why these phenomena occur in the oral hard structure and what amount of mineral bone loss (MBL) is necessary to produce a radiographic contrast are the purpose of this article.

REVIEW

Principles concerning mineralized structures need to be reviewed before explanations can be offered. Differences in radiographic shadows in bone or other mineralized tissues depend on variations in thickness of hard structure, constancy of composition according to mineral per unit volume of tissue, and the direction in which the X ray traverses the object, in other words, the angulation. It is also essential to consider the three-dimensional aspect of radiographs of bone because, before the shadow is cast, all parts must be accumulated and evaluated. In addition, X-ray films are read according to the contrast in shadows.

Differences in radiographic shadows in the same bone depend on the variations of thickness in bone. Radiodensity will vary from the high degree of opacity in thick bone to low index of opacity in thin bone (Fig 5). In regions of the same bone where the thickness of cortex decreases, radiolucent areas increase. Variations in shadows also can be affected by the position of the plane of bone at right

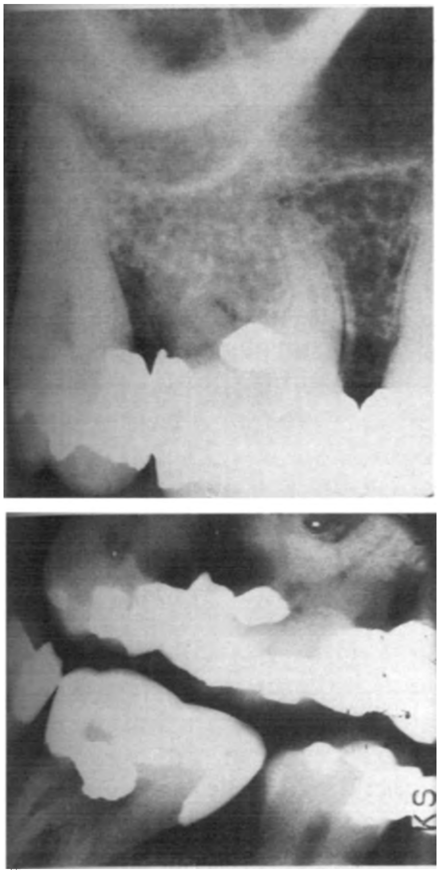


Fig 4—Top, these films illustrate value of bite-wing to enhance diagnosis. Conventional radiographs taken at 30° angulation show nothing unusual; periodontal disease, moderate depth metallic fillings, and slight rarefaction at base of proximal fillings, simulate cervical burn-out radiolucency. Bottom, bite-wing taken at 0° angulation shows extensive decay, which was masked by metallic fillings.

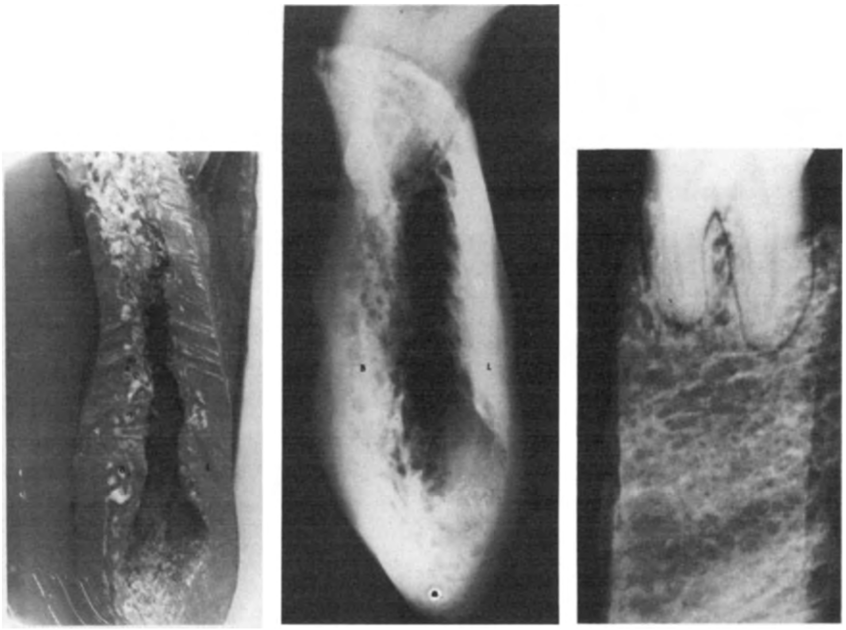


Fig 5—Left, photograph of section of mandible displaying variations in thicknesses of periosteal and endosteal cortices and curvilinear nature of bone. Notched area of inner region of lingual cortex is space for mandibular canal. Note difference in composition of bone in endosteal and cortical bone. Fine trabeculae of cancellous bone have been removed to demonstrate negative effect of radiographic visualization on cancellous bone; B, buccal; L, lingual. Middle, radiograph of same section taken mesiodistally. Note intracortical porosity of buccal cortex and thicker endosteal trabeculae; lingual cortex appears more compact than buccal cortex. Indented area, which lodges mandibular canal, is devoid of junctional trabeculae and endosteal bone. It is junctional trabeculae that form the trabecular patterns as visualized on radiograph; B, buccal; L, lingual. Right, radiograph of specimen taken buccolingually. Different shadow densities are due to different thicknesses of cortices and junctional trabeculae that mask lesion created in cancellous bone. Visualization of mandibular canal is due to reduced cortical thickness in different bone sites. Sometimes canal cannot be seen; location of canal determines visualization. If canal is located completely within cancellous bone and not surrounded by fine cortical bone, canal cannot be seen.

angles to the path of the X ray; on the vertical plane, the bone trabeculae may be thin; whereas, on the horizontal plane, the same bone may be very thick (Fig 6). Furthermore, different shadows will occur when curvatures of bone are present or when there are different directions in which the X ray traverses the bone. Thus, by the simple rule of summation of thickness, variations in shadows can occur, and the extra thickness can mask trabecular detail of the cancellous bone.

Variations in shadows occur when composition of mineralized tissues varies. The greater the content of calcium (hydroxy apatite crystal) in a given volume of tissue, the greater the absorption of the rays—hence, a higher potential index of opacity. For example, enamel has more calcium per unit volume and less organic structure than dentin. Thus, if the thickness is kept constant while composition of structure varies, the radiodensity will vary.

Mineral content per unit volume of bone varies greatly in the different types of bone and even in the same bone (Fig 5). Periosteal cortical bone has more mineral per unit volume than the region of the endosteal cortex, and cancellous bone has the least mineral per unit volume. Bone is not pure calcium. It has a physiologic structure with holes and spaces to accommodate body fluids. It is composed of an organic matrix into which the complex bone mineral is precipitated. Gradations of radiographic shadows are controlled by the mineral content per unit volume, with the highest amount of mineral occurring in enamel, and the lowest occurring in cancellous bone.

Anteroposterior and lateral projections, or purposeful changes in angulation are additional views that are designed to disclose a particular lesion in a particular patient. This multiview disclosure confirms the diagnosis of fractures that would otherwise go unnoticed (Fig 7). In patients with tori (palatinus, mandibularis, or buccalis), numerous angulations are used to remove the superimposed thickness of bone and to determine the presence of periapical lesions (Fig 8).

Optical limitations permit the resolution of the shadows of only those coarser trabeculae, those most likely to occur near the junctional areas, those which have more mineral per unit volume. The myriads of the finer trabeculae are not noticed as defined white shadows. Thus, destruction of bone by an inflammatory process cannot be detected (Fig 1). Moreover, in radiographs, when slight movements occur during exposure, trabeculae cannot be seen distinctly, or observed in tomographs, or in films taken of extremities in plaster.[17]

Radiographic lesions or shadows of different normal mineralized tissues are seen according to the contrast in bone densities, and visualization depends on how much mineral is removed from the calcified tissues in the path of the X-ray beam. Because there is more mineral per unit volume in cortical than in cancellous bone, the resorptive or demineralization process will manifest radiolucent changes sooner and more readily in the more calcified tissue than in the lesser calcified tissue. When a resorptive lesion occurs in the cancellous structure, a region that has the least amount of mineral per unit volume, no difference in radiodensity can be radiographically visualized; not enough mineral is lost to create a contrast. However, when the lesion begins to spread toward the junction of the inner surface of the cortex involving bone that has more mineral per unit volume, the radiolucent area becomes observable.

Studies on bone have indicated that clinical radiographs are a crude indication of disease, and significant loss of mineral must occur before definite changes can be detected by simple inspection of X-rays films.[18] A number of references state that specific amounts, 30% to 50%, of the mineral content of bone, have to be lost before radiographic visualization can occur.[19-22] These amounts were determined on osteoporotic bone using a Norland-Cameron[23] bone mineral analyzer, which determines the mineral content of bone by measuring the absorption of bone of a low-energy photon beam originating from ^{125}I. This photon absorptiometry method has the advantage of detecting variations in mineralization or in intracortical porosity with an accuracy of 97%.[24]

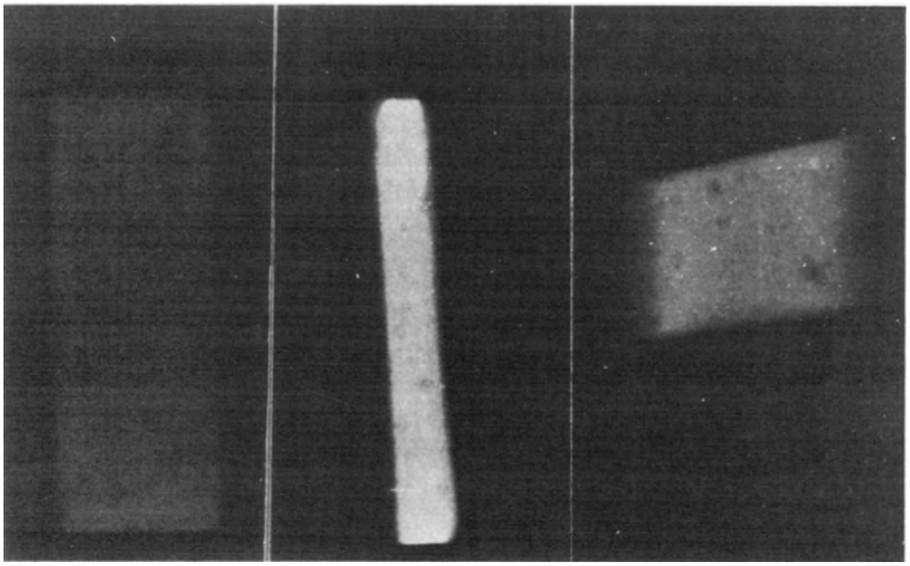


Fig 6—Note difference in densities of same specimen X rayed in different planes. Left, vertical plane, 4 mm thick; middle, horizontal plane, the same specimen becomes 20 mm thick; right, taken at 45° angle. This specimen gives the appearance of different thickness. Identical exposures and developing times were used.

As more than 30% of the mineral content of bone must be lost before a diagnosis of osteoporosis can be made on a radiograph, it becomes apparent that early and extensive demineralization may go undetected. Similarly, local inflammatory lesions in bone can go undetected especially in the early stages, even in the late stages, and depending on the type of bone, such as cancellous or cortical (Fig 1). Also, compactness and thickness of bone influences X-ray visualization. Many absorptiometric, morphometric, and densitometric studies have repeatedly confirmed that more than a 30% decrease in mineral content is required for radiographic detection; however, these amounts are not applicable to periapical or other local resorptive lesions. The results obtained from osteoporotics have been extrapolated with an implication that the same percentage of mineral content has to be lost in local lesions before radiographic visualization can occur. This deduction is specious.

In osteoporosis, there is a generalized mineral content loss of 30% or more throughout the entire skeletal mass, including both cancellous and cortical bone, before radiographic contrast can occur. In local resorptive lesions, almost complete mineral and collagen loss is localized within a given size lesion. Thus, the higher mineral loss within the localized lesion, which is surrounded by normal calcified tissue, gives a more distinct radiographic contrast.[25]

Radiographic visualization is not directly related to loss of volume of calcified tissue. The amount of involved tissue necessary to produce a radiographic lesion depends on the mineral per unit volume of tissue, specifically, composition. Hence, the higher the mineral content of calcified tissue, the smaller the volume of tissue that needs to be destroyed for X-ray visualization. For example, when a radiographic carious lesion within the enamel that has the highest mineral content (97%),[26] is compared with a lesion of similar size in cortical bone that has 50% to 55% volume of mineral,[27] the latter lesion will not be visible. Not enough mineral has been lost to create a contrast on the radiograph.

However, if the content of mineral per unit volume of tissue is low, such as in cancellous bone, a larger volume of this tissue needs to be destroyed before radiographic changes can be seen. Furthermore, because the contrasting image on the radiographic film is the summation of thicknesses of both cortical plates of the mandible, the thicker trabeculae of the endosteal region, and the finer trabeculae of the central medullary area, the lesion located in cancellous bone may not be observed. The cortices, particularly of the mandible, have a masking effect on the lesion within the cancellous bone similar to dentin superimposition over a periapical lesion (Fig 9).

Because there is marked variation in the thickness and in the curvilinear nature of the cortices in the same patient, a particular size lesion can be seen in a region covered by thin cortex; yet, 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

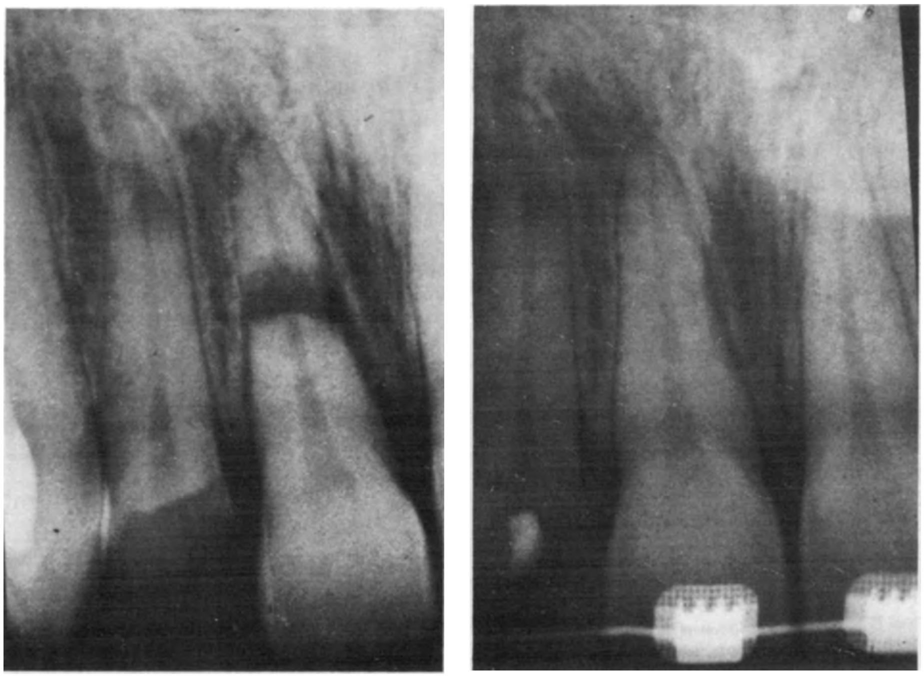


Fig 7—Left, radiograph taken before treatment shows fractured root of central and crown of lateral tooth. Radiograph taken immediately after treatment with different angulation shows no evidence of fracture after opposition and stabilization. This case illustrates need of taking radiographs from different angulations or views.

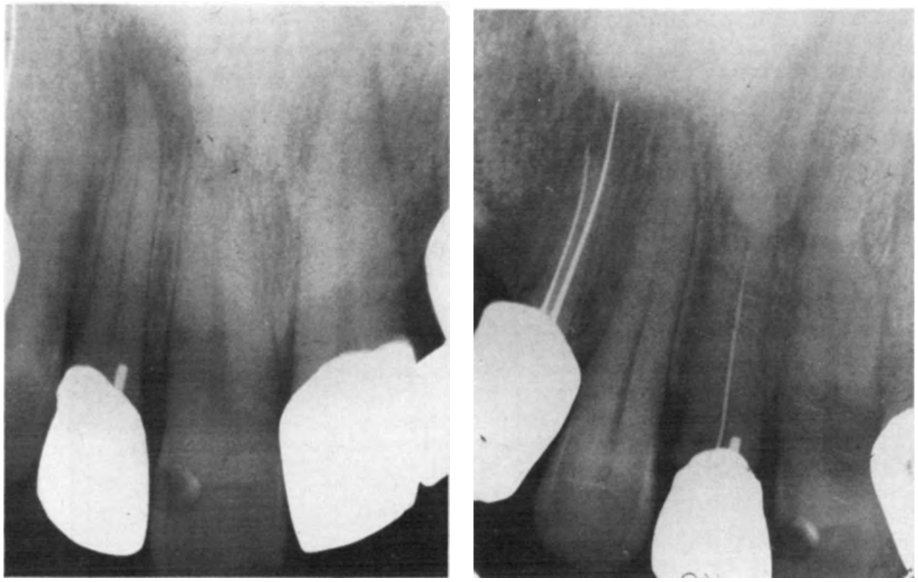


Fig 8—Shows effects of adding or subtracting mineral bone content in establishing radiolucency. Left, apical lesion in maxillary second incisor becomes obliterated in radiograph on right because of superimposition of torus palatinus. Increase in thickness and higher bone density of torus has masking affect on lesion in left radiograph, by increasing amount of mineral in path of X-ray beam, thereby reducing percentage of MBL.

bone. The lesion is radiographically visualized most readily when it is near or in the cortex, less likely when it is located in the endosteal region, and least likely when it is in the region of the cancellous structure. Image visualization of high bone density can be enhanced by increasing the time of exposure of KV_p.

It is not so much the size of the lesion that produces the radiographic visualization; the percent of mineral loss within the path of the central X-ray beam perpendicular to the object is the critical aspect. This may explain why a change in angulation in the X ray or a change in position of the object can cause the disappearance of radiographic lesion on film. From one angle, more calcified tissue is picked up within the path of the X-ray beam and gives the impression of increasing bone thickness or added mineral content (Fig 8); from another angle the radiograph gives the impression of decreasing bone thickness or subtracting mineral. Thus, because of the curvilinear nature of the mandible with the variations in compactness and thickness, different X-ray angulations are essential to improving diagnostic acumen and to adding more variety to follow-up studies.

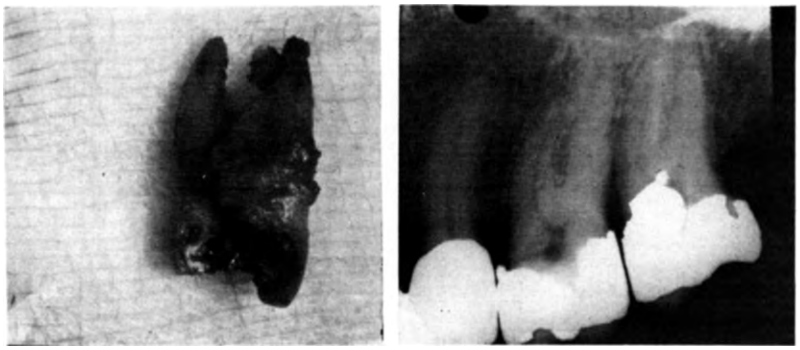


Fig 9—Left, photograph of an inter-radicular lesion in first molar seen from mesiodistal direction, can't be visualized in radiograph at right. Dentin with its high mineral density is masking lesion. It is doubtful whether lesion, because of its position, could be seen radiographically by changing angulations.

Part II
RADIOGRAPHIC STUDY

Whereas the aforementioned were explanations of why these phenomena occur, the proceding radiographic study was done to determine the percentage of mineral bone loss that is required to produce a radiolucent area.

METHODS AND MATERIALS

Sections of bone from five different cadaver mandibles were cut, selecting a particular flat segment that was not curvilinear either on the periosteal or endosteal side. Radiographs were taken of cortical and trabecular bone at varying thicknesses at 65 KV_p, 10 mA, exposed for 0.4 seconds, and developed in an automatic processor at 28 C for 3.7 minutes using Kodak film D-568. A millimeter rule, calipers, and a 5-diopter magnifying glass were used for measuring bone thickness. High-speed burs no. 556, a no. 4 round bur at low speed, and endodontic files of different sizes were used to make bone lesions.

Bone thickness was measured to the nearest 0.25 mm, and, depending on the size of the bone specimen, 3 to 6 grooves of different depths were cut into specific periosteal cortical bone samples. Serial cuts, 5-mm deep, were made in varying widths and lengths in cancellous bone. Photographs of the experimental lesions were recorded before and after they were cut.

The cuts or grooves in cortical bone on the periosteal side varied in depth from 0.5 to 1.25 mm; experimental lesions or cuts were also made on the endosteal side at the junctional region with the cancellous bone. The thicknesses of cortical bone were determined by measuring the widths of the two cortical plates. The combined widths varied from 3 to 8 mm. The width of the experimental lesions in cancellous bone was measured 0.5 mm from the inner surfaces of both cortices and these widths varied from 1.0 to 7.0 mm.

Measurements and differences in the visualization of radiolucent areas were recorded by three observers. When there was agreement among the three evaluators, the result was marked "plus," if there was disagreement, it was marked "minus."

Calculations to determine percentages of mineral bone loss (MBL) were based on a report that specified "pure bone tissue consists of 50 to 55 volume per cent of mineral, 30 to 35 per cent organic material and 10 to 15 per cent of water."[27] The volume percent of mineral, 50% to 55%, was averaged and expressed as 52.5%. This number (52.5%) was multiplied by the percentage of cortical bone loss in the experimental lesion to give the approximate percentage of MBL in the lesion as radiographically visualized.

Radiolucent areas were classified according to four categories characterized by the degree of lucency: distinct visualization with a definite pronounced region of rarefaction showing shades of grayish black to black in color (DV); visualization of distinct regions of rarefaction that are gray in color (V); visualization is questionable in agreements as to presence of shadows (RV); no visualization of any radiolucent areas (NV).

RESULTS

The results, based on 20 observations of different thicknesses and variations in depths cut in cortical bone, indicated that the lowest percentage of cortical bone loss producing a radiolucent area was 12.5% with a 6.6% MBL. Distinct radiographic visualization with greater rarefaction was reported by all observers at 14.3% or more than 12.5% bone loss, with an average of 7.1% MBL. All three observers were in agreement regarding the latter result; whereas, in the former result, disagreement occurred in four observations. It was also reported that the thicker cortex needed a deeper cut to produce a radiographic visualization. Although different bone specimens were used with a variety of densities, the results were mainly the same. The slight differences were in degree of the clarity of radiolucent areas, ranging from distinct image to a reduced visualization.

The sizes of the experimental lesions measured on the endosteal side were not too accurate. The division between endosteal cortex and cancellous bone becomes less distinct as the endosteal spaces enlarge. The increase in porosity is greatest in the endosteal region; however, there is a decrease in porosity toward the periosteal side (Fig 5). Many of the cuts were approximated due to the irregularities of the inner surface. Nevertheless, the range of distinct to reduced visualization was 8.7% to 6.6%, with an average of 7.1% MBL. If the periosteal and endosteal averages are considered, then any MBL above 6.6% is enough to produce a radiolucent area (Table).

Experimental lesions in cancellous bone were made in 18 specimens. Lesions from 1 to 7 mm in most cancellous bone produced no radiolucent areas in cortical bone specimens 8 mm thick. One specimen had a 0.75 mm cut in cortical bone 8 mm thick, with no apparent radiolucent area; however, when a 6-mm experimental lesion in the cancellous bone was imposed between the X-ray beam and both lesions, visualization of radiolucent area did occur. In two specimens, experimental lesions 4 and 6 mm wide in cancellous bone showed radiolucent areas, notwithstanding the fact that the cortical bone was 8 mm thick; in these two samples, the trabeculae throughout the cancellous bone was dense. In two others, visualization was apparent when the cortical bone was 2 to 4 mm thick, with the cancellous lesion 4 to 6 mm wide; these did not encroach on the region of the endosteal trabeculae. The percentage of MBL in cancellous bone could not be determined directly by using this method.

DISCUSSION

Although numerous methods have been used in estimating mineral bone content, most of the procedures that were used were applied to study MBL in osteoporosis, in bone changes for different age groups, in racial differences, and in diseases of generalized demineralization. Because our problem was concerned mainly with local resorptive processes limited to the maxilla and mandible, we chose to

Table • Determinations of percentage of cortical bone loss and mineral bone loss before radiographic visualization (20 lesions studied).

Thickness of cortices	Depth of cut	Bone loss (%)	Mineral loss (%)	Visualization§	Agreement
3.0	0.5	16.6	8.7	DV	+
3.0	0.5	16.6	8.7	DV	+
3.5	0.5	14.3	7.5	V	+
4.0	0.5	12.5	6.6	RV	−
4.0	0.5	12.5	6.6	RV	−
4.0	0.5	12.5	6.6	NV	+
4.5	0.5	11.1	5.8	NV	+
4.5	0.75	16.6	8.7	DV	+
4.5	0.75	16.6	8.7	DV	+
6.0	0.75	12.5	6.6	NV	−
8.0	0.75	9.4	4.9	NV	+
8.0	0.75	9.4	4.9	NV	+
8.0	1.0	12.5	6.6	RV	−
8.0	1.0	12.5	6.6	V	+
8.0	1.25	18.1	9.5	DV	+
4.0	0.5*	12.5	6.6	RV	+
6.0	0.5*	8.3	4.4	NV	+
6.0	0.75*	12.5	6.6	RV	−
8.0	1.0*	12.5	6.6	V	+
8.0	1.25*	18.1	9.5	DV	+

*Cut on endosteal side

+All observers agree.

−One or two disagree

§DV, distinct visualization, V, visualization, RV, reduced visualization, NV, no visualization

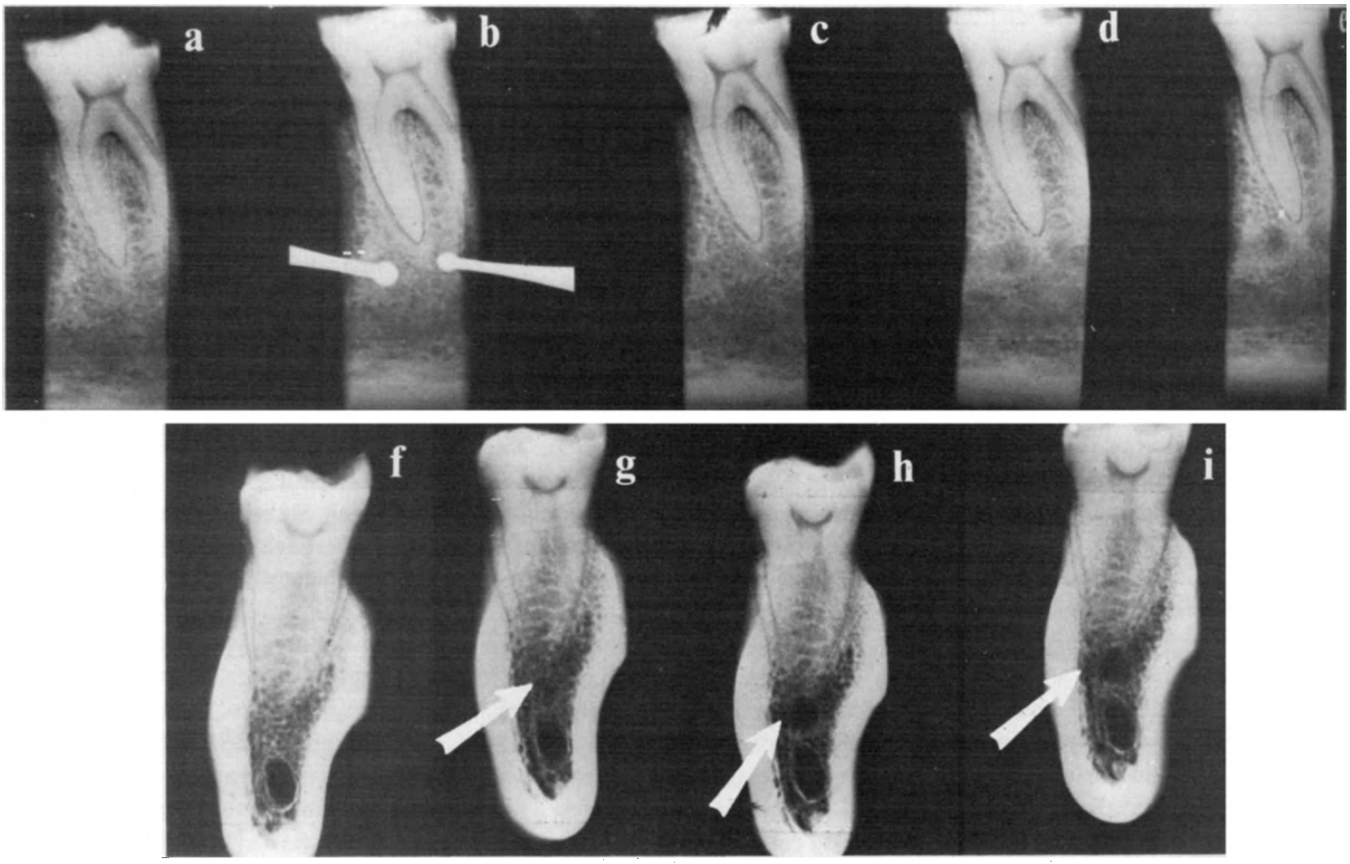


Fig 10—X rays a,b,c,d,e were taken buccolingually; and X rays f,g,h,i were taken mesiodistally and show effects of experimental lesions created in different parts of mandible as to radiographic visualization. Before creating lesions, a and f were controls; b shows position of burs in cancellous bone; c and g depict bone after creating lesion, lesion cannot be detected in c and can barely be visualized in g (arrow). In h and d cancellous lesion is enlarged in depth and width, through hole, engaging junctional trabeculae and endosteal cortex by changing direction of bur towards inner surface (arrow). In i and e, bur is directed deeper into inner more compact cortex, which has higher mineral content per unit volume. Arrow in i points to distinct resorptive lesion in inner cortex (1.0 mm deep) with radiographic visualization in e, Classification 1 (Table). Different degrees of radiolucent areas in d and e show different depths of experimental lesions created in inner cortex. Apparent apical lesion created in cancellous bone h and i is not seen in d and e. The apical cancellous and inner cortical lesions lie in different planes and in different locations of bone. Lower mineral content per unit volume of cancellous bone and masking effect of cortical bone, 6 mm thick, in this specimen, precludes any visualization of lesions within cancellous bone.

study the mandible because of its availability, the control of X-ray angulation, and the ease of measuring the variety of thicknesses of cortical and cancellous bone. Furthermore, we chose a radiographic method that most simulates clinical interpretations of evaluating radiolucent areas. Although densitometric readings may have fewer flaws, the overall errors of our method were minimized by using three different observers; however, the final measurements and interpretations were performed by the same observer. Admittedly, the method was based on individual judgments of radiolucent visualization, and the mathematical calculations were based on the conclusion that "pure bone tissue consists of 50-55 volume percent of mineral, 30-35 per cent of organic material, and 10-15 per cent of water."[27]

Classification 3, which involved reduced visualization, caused disagreements among the three clinicians who interpreted the images during the evaluation of radiographs. This response was the most expected. Judgmental bias in recording radiographic changes was often made by each clinician when he was asked to detect radiolucent areas. The clinicians often overlooked the experimental lesion as visualized on the radiograph. However, when they were shown the experimental lesion in the bone, they responded somewhat more accurately. Subsequent inspections of the radiographs were often inaccurate, as each claimed detection of nonexistent experimental lesions. However, no discrepancies occurred in interpreting radiolucent areas in categories 1, 2, and 4.

The visual radiographic inspections in this study were more critical than those performed under in vivo conditions. In clinical situations, there is superimposition of periosteum, muscle tissue, fat and body fluids in the path of the X-ray beam. Thus, slightly more bone loss would be necessary to produce a visible contrast on the radiograph. This consideration would suggest that higher levels of MBL would occur under clinical conditions; perhaps 7.1% should be considered the amount that can produce radiolucent areas.

The results apparently can vary depending on the location of the experimental lesion in the different bone sites, such as periosteal cortex, cancellous and junctional, or endosteal bone. The most consistent results with the least variations occurred in periosteal cortical bone. The measurements indicate a distinct linear relationship between radiolucent areas, between bone and thickness, and depth of experimental lesion; the thicker the cortex, the deeper the cut has to be before radiographic visualization can occur. There is also a relationship between the percent of MBL and cortical bone volume loss: the estimates of MBL of the cortex correlate significantly with similar estimates at other sites in the same bone and in different mandibles. Apparently, the percentage of cortical bone loss determines more accurately the percentage of MBL and the degree of radiographic visualization.

Experimental lesions created in cancellous bone produced varied results. Although the lesions varied from 2 to 7 mm wide, 3 to 5 mm long, and 5 mm deep in the path of the X-ray beam, no radiographic visualization occurred. This finding was especially significant when the combined cortices were 6 to 8 mm thick. Evidently, thick cortical bone has a masking effect. The cancellous lesion, although large in volume, produced no visible changes on the radiograph, especially in mandibles with wide trabecular spaces and thin trabeculae. The volume of cancellous bone is mainly marrow spaces with bone mineral content significantly less than cortical bone. The increased reduction in volume of bone tissue and the high volume of organic content in the cancellous bone do not lend themselves to analysis of mineral content with the use of the present method, except that a large percentage of bone loss must occur before a radiographic contrast can be detected. For radiographic visualization to occur, cortical thickness has to be reduced.

A radiographic contrast can be created in cancellous bone that has a large lesion by reducing cortical thickness. This is shown in bone sections with thin cortices and in a modified specimen of cortical bone 8 mm thick. In the latter, a 0.75-mm lesion in cortex created no radiographic visualization, but when a 6-mm lesion in the cancellous region of the same specimen was imposed on the 0.75-mm lesion in cortical bone directly in the path of an X-ray beam, a contrast was visualized. Hence, in that specific bone, a 6-mm lesion of cancellous bone has the equivalent mineral content per unit volume of a 0.25-mm periosteal cortical bone. By extrapolation, 0.25 mm of cortical or 6 mm of cancellous bone has 1.65% mineral contents; thereby verifying the fact that cortical bone, because of its compactness, has more mineral per unit volume than cancellous bone.

Bone loss or mineral bone content in the endosteal area, or the region of junctional trabeculae, is difficult to measure. It is the junction where cortical bone joins the endosteal cortex with the endosteal trabeculae. Each one of these regions has different porosities or densities with a different mineral content per unit volume of tissue. The periosteal cortex is most dense, and the endosteal cortex is more porous than the former; and the endosteal trabeculae, which establish the trabecular pattern as seen on the radiograph, are more dense than cancellous trabeculae. Thus, different degrees of radiolucencies can be seen, depending on the location of the lesion; the image can range from no radiographic visualization to distinct visualization (Fig 10). Furthermore, a lesion in cancellous bone is not detected radiographically until it reaches a certain depth in the endosteal region.

Because the periosteal cortex in these mandibles have the least porosity with the highest mineral content per unit volume and the measurements were more accurate than in the endosteal cortex, the results obtained in the periosteal cortex can be considered more reliable in determining the relationship between radiolucent areas and percentage of MBL. Thus, the estimated 7.1% MBL, directly in the path of the central X-ray beam, reflects the amount that is approximately necessary to produce a visual detection of a radiolucent area. Furthermore, the percentage of MBL is consistent, irrespective of the size of the lesion or cortical thickness. The relationship between the size and location of the lesion in different bone sites determines the MBL and the ultimate radiographic visualization.

Lesions in bone with higher mineral content per unit volume can be smaller and still be detected radiographically. This difference in mineral content per unit volume can be illustrated clinically when the lamina dura is affected by a resorptive process. The lamina dura, being less fibrillar[27] and more compact, has more mineral per unit volume than the adjoining cancellous bone. Thus, a lesion in the lamina dura could produce radiographic detection more readily because more mineral was removed at that site.

The time needed to detect occult lesions under clinical conditions and how quickly radiographic lesions can be visualized depend on the initial location. For example, if a root apex is in juxtaposition to the junctional area, a subsequent resorptive process can be detected early; whereas, a root apex located in the center of the cancellous bone would appear later. The resorptive process would have to expand to the endosteal region to remove more mineral and to produce a radiographic visualization. The aforementioned example can be illustrated with clinical observations in mandibular first molars. The mesial root has a higher incidence of apical rarefactions than the distal root because the apex of the distal root is located more often in the central portion of the cancellous bone.

The observations in this study may explain the differences in sizes often found between morphologic and radiographic lesions. The latter are always smaller. The morphologic lesion, as represented by a cyst or granuloma, is spherical in shape with the deepest diameter in the central path of the X-ray beam representing a higher MBL. At the periphery of the sphere, as a result of a lessened resorptive process, there is less MBL although not enough loss to create a radiolucent area.

CONCLUSIONS

The mandible proved to be well-suited for this study because there were variations in cancellous and cortical bone thickness. These could be measured in millimeters with subsequent radiographic estimation of percent of volume bone loss and percentage of MBL to produce radiographic visualization.

The results indicate that the highest concentration of mineral per unit volume is located in the periosteal cortex, with slightly less in the endosteal cortex, and the least amount in the cancellous bone. The amount of MBL in cancellous bone does not significantly affect the radiographic results. Although experimental lesions were made in three different bone sites, the radiographs as visualized included the summation of the entire thickness of the mandible.

The lowest percent of MBL in the direct path of the X-ray beam to create a radiolucent area in cortical bone was 6.6%. It is suggested that a 7.1% MBL average be considered, to compensate for soft tissue X-ray absorption under clinical conditions and for consistency in radiographic visualization.

Although there was general agreement that 30% to 50% mineral loss is required before radiographic rarefaction is visualized in osteoporotic bone, these percentages do not apply in local resorptive lesions.

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