REVIEW ARTICLE

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Exploring the third dimension in root resorption

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Structured Abstract
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Objective – To review and investigate the validity of various 2D quantitative measurement techniques, and to explore the third dimension of root resorption.
Design – A review of the literature involving various quantitative evaluation of root resorption.
Results – Quantitative evaluation of resorption using radiographs has proven to be highly inaccurate because of magnification errors and their inability to be readily repeated and reproduced. Studies using histology sections of samples have proven to be laborious and technique sensitive. Inherent parallax errors and loss of material in data transfer have denied the true understanding of this 3D event.
Conclusion – With the evolution in computing technology and digital imaging, the vision of evaluating the extent of root resorption in 3D has materialized. It was demonstrated that 3D volumetric quantitative evaluation of root resorption craters was feasible and its accuracy and repeatability was high.

Key words: 2D and 3D measurements; root resorption; scanning electron microscope (SEM)

Introduction

Root resorption in orthodontics has been described as an idiopathic and unpredictable adverse effect of orthodontic treatment (1). While extensive post-orthodontic root resorption compromises the benefits of an otherwise successful orthodontic outcome, most root loss resulting from orthodontic treatment does not decrease the longevity or the functional capacity of the involved teeth. It commonly manifest as apical root shortening or surface resorption. Histological studies

Dates:
Accepted 20 February 2004

To cite this article:
Orthod Craniofacial Res **7**, 2004; 64–70
Chan EKM, Darendeliler MA:
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have reported high incidences while clinical studies have revealed a more varied incidence (1). Although most root resorption studies attempt to investigate the etiologic factors and predictability of this phenomenon, its origins remain obscure. Individual susceptibility, hereditary predisposition, systemic, local and anatomic factors associated with orthodontic mechanotherapy are commonly cited components.

The detection of root resorption has been mainly through radiographs (2), light microscope (3) and scanning electron microscope (SEM) (4–6). Although the literature has stated the importance of identifying high-risk cases and their various ways of management, quantitative evaluation of root resorption is still relatively poor. There remain several flaws in 2-dimensional (2D) surface measurements for this 3-dimensional (3D) phenomenon. This paper is a review paper with commentary of the accuracy of 2D quantitative root resorption measurements in previously published papers.

Radiologic detection

Numerous reports have documented root resorption using radiographs (7–10). While this is clinically relevant in detecting root shortening before, during or after orthodontic treatment, because of varying degrees of magnification, the quantitative value of radiographs still remains questionable. Root resorption seen on radiographs could often only detect root shortening. Surface resorption could only be detected if they are mesiodistally placed, facing in direct right angles to the focal beam of the X-rays or if resorption has progressed to a severe or advanced stage. The common radiographs requested for diagnosis are orthopantomogram (OPG), periapical and lateral cephalometric radiographs.

The OPG is a sectional radiograph and only structures that are within the section will be captured on the film. This in-focus section or focal trough is approximately the shape as the dental arch and is created by a narrow slit of X-ray beam aimed upwards at approximately 8° to the normal (11). Relative positioning of the dental arch in this pre-determined focal trough may lead to images there are foreshortened, magnified and/or out of focus. In addition, normal anatomical structures can appear as radiolucent or radiopaque shadows superimposed over the teeth as either real or actual shadows or as ghost or artifacts of which can degrade the quality of the final image (12). In orthodontic cases, in markedly class II or III patients, or patients with excessively proclined or retroclined teeth, it may not be feasible to position the upper and lower labial segments or the maligned teeth within the focal trough. Roots may hence be magnified or foreshortened (11). Sameshima and Asgarifar (8) compared the use of periapical radiographs and OPGs to assess morphology and quantify the amount of root shortening present in a human sample. They found that the description of root morphology differed greatly between the two detecting modes. It was found that OPGs overestimated the amount of root loss by 20% or more when compared with periapical radiographs. This could easily be explained by the relative position of the focal trough to the dental arch during imaging. The narrow focal trough in the anterior portion of the maxilla presents particularly as a problem in patients with maligned incisors. The apices are often misdiagnosed as root resorption from root foreshortening (11). Does this however mean that periapical radiographs would be adequate for accurate quantitative measurements?

It has been described that when using intra-oral imaging techniques such as periapical radiography in detection of root resorption, the tooth/teeth under investigation and the film packet should be in contact or, if not feasible, as close together as possible. The long axis of the tooth/teeth and the film packet should be parallel to each other. The X-ray tubehead should be positioned so that the beam meets the tooth and the film at right angles in both the vertical and horizontal planes. The positioning should be reproducible, particularly if the films are to be used for comparative purposes. Unless all these criteria are met, accurate quantitative measurements could not be recorded (11). Remington *et al.* (13), used a non-standardized bisecting angle technique for periapical radiograph imaging of root lengths. They concluded that root lengths could not be measured directly from periapical radiographs. Although the paralleling technique has been described as the technique of choice for detecting root shortening, it has also been shown to be geometrically inaccurate as well (11). The authors have noted that although the paralleling technique is of a higher diagnostic value for root shortening, it may not always be feasible to obtain an absolute straight-on view. In the bisected angle technique, it is often difficult to standardize the position of the tubehead. Foreshortening

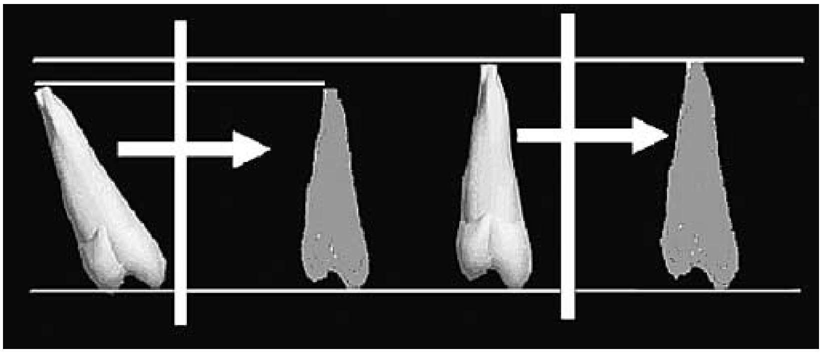

Fig. 1. Illustration demonstrating the parallax error easily manifested in X-ray radiography. The tooth in focus has to be parallel to the film to obtain a good quantitative evaluation of the tooth length.

and elongation is common and widespread (Fig. 1). This does not allow reproducible views and are not ideal for comparative studies (11). A study by Costopoulos and Nanda (14) documented the amount of root shortening of upper incisors after orthodontic intrusion. They devised a jig to standardize the taking of periapical radiographs before and after the experimental period. They claimed that with a worked formula, they could eliminate magnification and distortion errors and accurately deduce the amount of root lost. It has however been reported (15) that despite meticulous control of magnitude and direction of force, there is still no absolute guarantee in predicting the distribution of resorption. Hence it would be reasonable to assume that in Costopoulos and Nanda's study, there could be resorption evident in the buccal and/or palatal surfaces around the apex but not involving the apex. This does not contribute to actual root shortening by radiographic analyses and hence may not accurately demonstrate the true extent of resorption.

The lateral cephalogram provides an accurate and reproducible view of the length of the upper incisors. However, this is likely to be subjected to a 5–12% enlargement factor as a result of the radiographic set-up. In addition, overlapping of the left and right sides may make the image unclear (11).

Digital radiography has been used in recent times to study root resorption (16–18). It has been demonstrated that digital radiography has a similar degree of sensitivity to film-based radiography in the detection of resorption, but with a lower radiation dose (16). However the geometric relationship of the digital receptor, tooth and X-ray beam is just as important as in conventional radiography if geometric distortion is to be avoided (11).

The literature has demonstrated with optimal application, radiography, which is 2D may be a good diagnostic tool in detection of root resorption. However quantitative measurements of root resorption in 3D are relative poor and should be avoided.

Serial sectioning and light microscopy

A series of publications on root resorption were published from 1995–2000. They looked at the effects of different types of orthodontic forces on root resorption (19), magnitude of force on root resorption (20–23), repair of root resorption craters (24, 25), risks of allergens to root resorption (26), hyalinization in early resorption (27) and root resorption in relation to the time factor (21). They described the method of using embedding and serial sectioning to document the extent of root resorption. Using a light microscope, they quantified the craters using arbitrary units measured from the eyepiece. The samples were serially-step sectioned longitudinally in a bucco-lingual direction for half the tooth into three parts with a microtome set to 4 μm. The other half was further sectioned into another three parts mesio-distally, longitudinally (Fig. 2a, b). In the illustrations shown, one can visualize how craters on the root surfaces could easily be missed. We also understand that resorption craters could vary excessively in size and depth. It would then be reasonable to assume that some irregularly C-shaped craters and/or smaller craters could be partially or totally missed; or miscalculated. Moreover, their studies examined samples of human maxillary first premolars. These teeth do vary quite extensively in root morphology and anatomy (Fig. 3). Given this variation in root morphology, it would be even more difficult to achieve an absolute longitudinal cut along the long axis of the tooth (Fig. 4), which could lead to apical or even some mid-root craters being missed. The micrometer

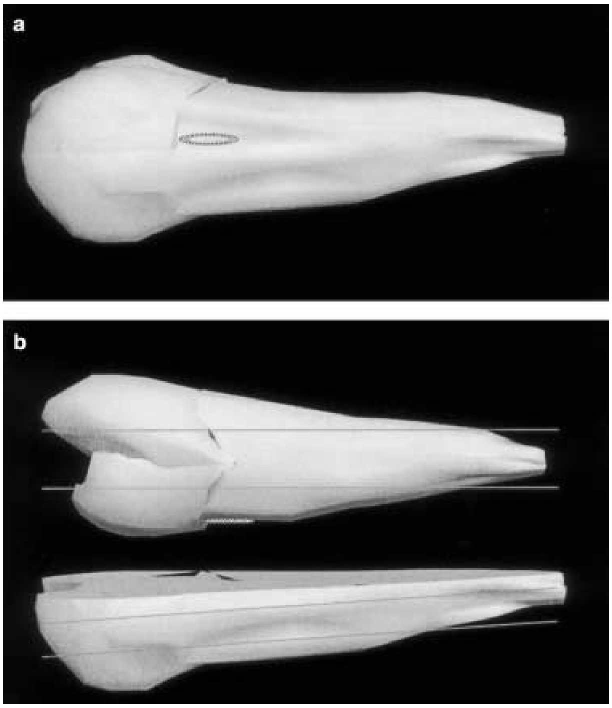

Fig. 2. Illustration demonstrating a resorption crater on the buccal cervical region of a specimen (a). Once the tooth has been serial sectioned, it could be demonstrated that the crater in focus could easily be missed (b).

mounted on the eyepiece of the microscope used in the study would encourage parallax errors and measurements might again be distorted. Furthermore, only arbitrary units were used. Based on these arguments, the true quantitative value of this exercise is questionable and their conclusions have to be taken with some reservation.

Repair of root resorption craters were studied under the transmission electron microscopy (TEM) after serial sectioning and 3D reconstruction (28). The authors removed a 2 mm buccal sliver of cementum and dentine from maxillary first premolars using a jeweler's hacksaw blade, and further divided that sliver into three cervical, three middle and three apical sections. After making fiducial reference scribe lines, the sliver-specimen was sectioned for light microscope imaging. Serial 35 mm photomicrographs were taken and enlarged 250 times for digitization. The final images were photographed directly from the computer screen in a darkened room and stereo pairs were made by rotating the screen through 6°. After this laborious attempt, the authors could only obtain an illusion of the third

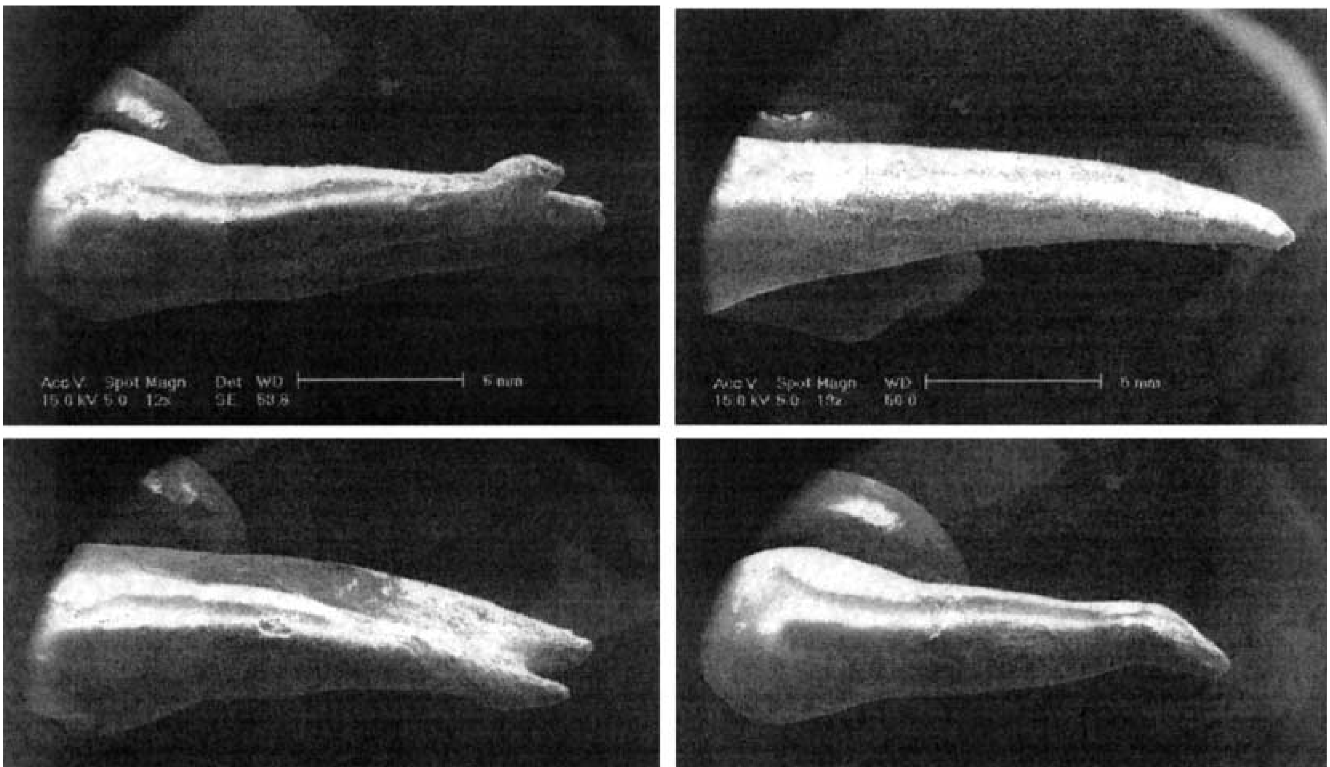

Fig. 3. Typical root morphology of upper first premolars demonstration the variation in size, contour and number of roots.

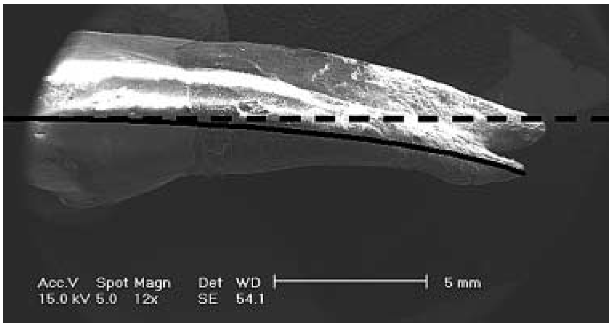

Fig. 4. A closeup view of a typically curved first premolar root demonstrating that an absolute longitudinal section may not necessary yield two half cuts. Solid line: true long axis of tooth. Dotted line: longitudinal cut through the mid-buccal region taking reference from the crown.

dimension of the resorption crater. Although the study design was not for quantitative analysis, it could be demonstrated that the technical difficulty in handling the sectioned pieces and using the computer software to piece it all together is time consuming and potentially inaccurate.

Scanning electron microscope studies

It has been reported that SEM provides enhanced visual and perspective assessment of root surfaces, and when recorded in stereo pairs, they provide resolution and detail not attainable with histological models reconstructed from serial sections (3). Kvam was one of the first to document root resorption craters after tooth movement with the SEM (5, 6). Later studies on root resorption using the SEM measured resorption craters using surface area landmarks obtained from micrographs (29–31). However, we know that the surfaces of these premolar teeth are curved (Fig. 5a) and an absolute straight-on view is difficult to obtain. Parallax error in 3D (Fig. 5b) could easily manifest and would induce errors in measurement. Moreover, the composite micrographs obtained were physically pieced together and resorption craters then measured with a digitizer. There would also be further inherent error in measurements if the craters were along the edges of the micrographs that were pieced together. It has to be noted that the micrographs obtained could only provide a straight-on 2D view of the root surfaces and resorption craters as well. Thus it seems that the quantitative value of 2D measurements of root resorption performed in the past may not be adequate.

The difficulty in obtaining 3D quantitative measurement of root resorption has much prevented the true understanding of this phenomenon in its entirety. The volumetric measurements of these irregularly shaped

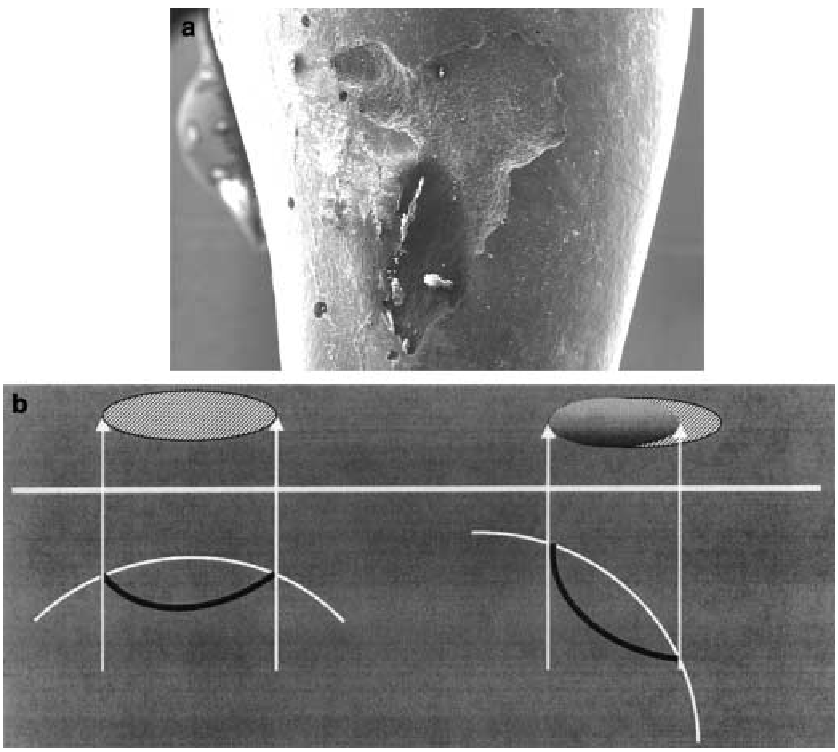

Fig. 5. A Scanning electron microscope view of typical craters seen on the surface of root cementum demonstrating the curvature of the root surface (a). Illustration demonstrating the difficulty in obtaining an absolute straight-on view with parallax errors easily manifested if a slight rotation is present. The true size of the craters measured may not be accurate (b).

open craters are further complicated by the innate curvature of the cementum root surface. The authors have devised a new methodology to overcome this handicap and have also demonstrated that volumetric measurements of such craters are possible (32). Using SEM as a capturing device, stereo images of resorption craters were taken and analyzed. The images were captured at eucentric point as close to zero-degree horizontal as possible. After converting the pair of stereo images into an 8-bit grayscale depth map, a further shading correction was carried out to eliminate any distortion of the craters evidenced by the presence of the innate curvature of the root surface. Volumetric measurements were calculated utilizing a specially written software *AnalySIS Pro 3.1* (Soft Image System, SIS, Münster, Germany). The planar area of the crater, obtained by segmenting the corrected depth profile image was multiplied by the average depth of the nominated crater to give the volume. This new methodology was also further calibrated using a Vickers hardness tester indenting on four cylindrical metallic rods (33). The calculated volumes of these pyramidal indentations were correlated to the estimated volumes of the same indentations obtained by the software. The results obtained have shown that the volumetric measurements obtained using the software was both highly accurate and reproducible.

This further allowed us to quantify the extent of root resorption in a sample of 36 teeth (34). Light (25 g) and heavy (225 g) levels of orthodontic forces were activated on maxillary or mandibular first premolars over an experimental period of 28 days with the contra-lateral teeth serving as controls. It was demonstrated that the mean volume of the resorption in the light-force group was 3.49-fold more than the control group, and the heavy-force group 11.59-fold more than control group ($p < 0.001$). The heavy force group had 3.31-fold more total resorption volume then light force group ($p < 0.001$).

These 3D volumetric measurements were also correlated to 2D surface area measurements obtained from the same sample (Chan *et al*, unpublished data). It was further demonstrated that 2D measurements were strongly correlated with 3D measurements ($r = 0.991$, $p < 0.01$). Within the light and heavy force groups, the measurements were also strongly correlated ($r = 0.978$, $p < 0.01$ and $r = 0.994$, $p < 0.01$, respectively). We concluded that in a 28-day experimental period, 2D measurements of root resorption craters could be as reliable as 3D measurements if they were conducted adequately.

Conclusion

Previous studies on human (19, 20, 22–26, 30, 35) and animal (36, 37) subjects reporting force magnitude in correlation to resorption have demonstrated conflicting results. Sample collection, data transfer and material analysis could be a very sensitive process. Any error in planning as well as executing these steps could easily cause results to be distorted. This present series of studies have highlighted the fact that quantitative evaluation of root resorption if not conducted adequately, will have an impounding effect on the correlation between the magnitude of force and extent of tissue destruction.

Although the comparison of 2D vs. 3D measurements of the root resorption craters over 28 days did not demonstrate any significant differences, forces applied for a longer duration may form deeper craters and may thus render 2D measurements inadequate. Further studies with an increase in experimental duration are in progress. With the inclusion of the fourth dimension: time, we could hopefully shed further light on this root resorption phenomenon.

Acknowledgements: We thank Drs Allan S Jones and Ian J Kaplin from the Electron Microscopic Unit, University of Sydney, for their invaluable assistance.

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