6-2014

Novel Approach to Assess Periodontal Disease Severity Using Volumetric Analysis

Meera George Maveli

LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

Novel Approach to Assess Periodontal Disease Severity Using Volumetric Analysis

by

Meera George Maveli

A Thesis submitted in partial satisfaction of
the requirements for the degree
Masters of Science in Periodontics

June 2014

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Masters of Science.

______________________________, Chairperson
Martyn Green, Associate Professor of Periodontics

____
Jeffrey Henkin, Professor of Periodontics

____
Erik Sahl, Assistant Professor of Periodontics

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Dr. Green, Dr. Sahl and Dr. Henkin for their advice and direction regarding the research as part of the Research Guidance Committee (RGC). Also special thanks to Dr. Walter and Dr. Jaramillo for reviewing the research protocol.

I would like to give a special thanks to my husband who has been my cheerleader from the beginning. And finally, I would like to thank God for providing me the undeserved opportunity to study His creation and marvel in its complexity.

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

CBCT	Cone Beam Computerized Tomography
DICOM	Digital Imaging and Communications in Medicine
L1	Total length of root
L2	Length of the apical half of the root
V1	Total volume of the root
V2	Volume of the apical half of the root
W1	Width of root at half the root length
CEJ	Cemento-Enamel Junction

ABSTRACT OF THE THESIS

Novel Approach to Assess Periodontal Disease Severity Using
Volumetric Analysis

by

Meera George Maveli

Masters of Science, Advanced Specialty Education Program in Periodontics
Loma Linda University, June 2014
Dr. Martyn Green, Chairperson

The purpose of this study was to evaluate if the absolute change in linear measurements of bone loss on the facial plane of a maxillary central incisor at full and half root length along the vertical axis is directly proportional to volumetric change. The secondary aim was to evaluate if the variation of root volume is influenced by difference in root morphology.

Three dimensional digital models of 70 random patients were obtained from DICOM CBCT files using volumetric software, InVivoDental (Anatomage, San Jose, CA). One central incisor of average root length was selected per patient and total length (L1) and the apical half of the root (L2) were measured. Corresponding volumes were obtained for the total length of tooth root (V1) and the apical of the root (V2). The absolute change in root volume was compared with the corresponding length of root to determine a direct correlation. The sample was then divided into two groups (Thick and Thin) based on the median value of root width (W1) at half the root length and the co-relation between root morphology and the percent change in root volume was compared.

The change in linear measurements along the facial plane of a maxillary central incisor was not directly related to corresponding volumetric changes. In fact, for the

similar change in linear measurement, there was great variation in the rate of volumetric change.

Root shape could not account for the lack of correlation probably due to the small sample size and variation in segmentation between the examiners. However, the root shape showed a significant influence in the change in volume from the coronal to the apical half. The variation was greater for the thinner root group signifying there was greater loss of volume along the root for similar level of bone loss compared to thick roots.

Within the limitations of the study, we conclude that linear measurements along the length of a maxillary central incisor root do not correlate with corresponding volumetric change. Nevertheless, the variation of root volume was influenced by difference in root morphology.

CHAPTER ONE

INTRODUCTION

The prognosis of a tooth diagnosed with periodontitis depends mainly on the amount of tooth remaining within the bone. Variation in root morphology with respect to the width or shape of the root can greatly affect the remaining bony housing and thereby the periodontal prognosis of the tooth. For example, a thicker cylindrical root may show better periodontal prognosis compared to a slender conical root with similar bone levels. Radiographs, a two dimensional mapping of a three-dimensional tooth, are commonly used to assess root length as a means of estimating the bone loss. Since root length is a one-dimensional linear measurement of bone height along the root surface, it can result in statistically significant errors by overestimating or underestimating the remaining bone level (Goldman, Schluger and Fox, 1956). These errors are compounded due to the lack of information of the bone level on the buccal and lingual side of the tooth (Theilade,1960).

The linear measurement of a vertical defect does not carry any information with regard to the width of the defect. Likewise, the same amount of linear disease progression in the coronal third versus the apical third may entail large differences in actual bone loss due to root tapering. Therefore, root morphology must be considered as a clinical parameter for periodontal disease prognosis as it can greatly affect the bony support of the tooth.

In order to arrive at a realistic prognosis and treatment plan for a periodontally involved dentition, an accurate determination of the amount of remaining bone support is necessary. Most studies quantify root surface areas as a means to identify the remaining bone support using variations on one of three methods: (1) division planimetry, (2) weight conversion, or (3) the membrane technique. With division planimetry, the root is sectioned perpendicularly or longitudinally to the tooth vertical axis, and each section surface area is calculated by multiplying that section circumference by its thickness (Jepsen et al. 1963). With the weight conversion method, the tooth roots are coated with a uniform thickness of benzene, silver plate, or other coating agent; the weight change is then converted to a surface area (Luthra et al. 1974). The membrane technique was the most commonly used technique. With this technique, the root surfaces are covered with thin material such as tin foil, polyvinyl chloride, or thin paper (Brown et al. 1950). Subsequently, the material is peeled off and the surface area of the material measured with devices such as a planimeter, grid paper, or grid slides. These techniques were cumbersome, inaccurate for multi-rooted teeth and required the tooth to be extracted (Klock et al. 1993).

Considering that the tooth is a three dimensional structure, the volume of the root may be a better measure of the bone support as opposed to the surface area. The volume gives information of the bone displaced by the root in contrast to the surface area that measures only the attachment offered by the Sharpey's fibers. It also would account for the differences in root morphology in comparison to linear or area measurements.

To date the physical volume of a tooth has been measured using the water displacement method based on the Archimedes principle. With the use of the volumetric

3D software, the teeth can be analyzed using a routine CBCT and does not necessitate the extraction of the tooth.

Liu et al. (2010) evaluated the accuracy of in-vivo volumetric measurements using CBCT images and compared them with the physical volume of the tooth. The measurements slightly deviate from the physical volumes within -4% to 7%. With the widespread use of CBCT, the use of a three dimensional software that is primarily used in implant treatment planning may be convenient to volumetrically assess the tooth remaining in bone support. The software also allows for individualized determination of the actual bone support and not the extrapolated bone loss from linear measurements.

This study aims to question whether the linear measurement along the long axis of the root is directly proportional to the volumetric measurement following the root morphology. The null hypothesis is that the maxillary central incisor will not show a direct proportional relationship in the linear and volumetric measurements of remaining bone at full and half the root length. Moreover, the linear and volumetric measurements will not be influenced by the root morphology.

CHAPTER TWO

LITERATURE REVIEW

Clinical evaluation focuses on pocket probing depth as a means to estimate the loss of attachment. In order to obtain an index of the amount of bone remaining about a tooth root, the alveolar bone height is often expressed as a percentage/ratio of total root length. (Marshall et al. 1949, Schei et al. 1959, Bjorn et al.1966 and 1969, Suomi et al. 1971, Sjolien & Zachrisson 1973, Lavstedt 1975, Williams et al. 1979, Greenfield et al. 1981). However, since no absolute measurement (in millimeters) of bone loss is obtained, a small amount of bone loss from a short rooted tooth may be expressed as the same percent bone loss as a large amount of bone loss from a long rooted tooth. Since both clinical and radiographic levels are calculated by linear measurements and teeth are three dimensional, critical information may be lost.

Linear methods do not take into account root shape in determining the percent of remaining alveolar bone. For instance, 50% bone loss around a thick, conical root has better prognosis than around a slender, tapered root. Also, the estimation error in predicting supported root surface area from either root length or projected area is greater at the cervical area where initial alveolar bone destruction took place (Chen et al. 2004). This is explained by the relatively larger diameter of the root in this region. The authors also reported that the overestimation of remaining attachment increased from the alveolar crest at CEJ region and reached a peak at about half the length of the root, then gradually decreased down to the apex.

Klock et al. (1993) found a positive correlation between linear and area attachment loss in single and multi-rooted teeth. The correlation was lower for multi-rooted teeth (probably due to more complex root anatomy) and in teeth with moderate loss (25- 50%) of attachment. Roots with greater bone boss (> 50%) showed no significant correlation. The authors also mentioned that a similar amount of linear loss in the coronal third versus more apically may entail differences in real loss due to root tapering.

Yamamoto et al. (2006) estimated the remaining periodontal attachment from attachment level measurements using a computer-aided membrane technique applied to each tooth type (excluding third molars). The teeth with longer roots showed greater co-relation with remaining attachment level measured in a linear manner and therefore current linear measurements in use, such as probing attachment level, may accurately reflect the amount of remaining periodontal supporting tissue.

Jeffcoat et al. (1984) utilized a digitizer-computer assembly to determine linear, curvilinear and area measurements of radiographic bone levels in pre-molars of beagle dogs. They found no significant difference between straight line or curvilinear measurements and with area measurements when there is little loss of alveolar bone (<15%). However, when there was moderate to severe bone loss (>15%), area measurements were significantly lower than linear measurements. This overestimation of linear measurement in roots with greater bone loss can be explained by root anatomy. Each root tapers as it approaches the apex so that there is less area to be lost as bone loss approaches the apex. A similar change in volume may be considered with respect to root taper in single rooted teeth but in multi-rooted teeth, the surface area increases from the CEJ to the apex but the root volume may decrease.

Kay et al. (1954) considered root length volume relationship in anterior teeth and concluded that changes in surface area are directly proportional to changes in volume. However, he did not determine if there was a correlation between linear measurements and the remaining volume of root within bone.

The recent advent of volumetric imaging via cone-beam computed tomography (CBCT) in dentistry, in vivo three dimensional (3D) anatomical structure information is available for measurement and analysis. The use of a CBCT reduces the limitations in x-ray beam angulation or geometric distortion of the image. It also reduces variations in contrast and density of radiographs caused by film processing that can lead to errors in image analysis.

Naito et al. (1998) showed good correlation between bone levels from CBCT and the denuded bone levels (R= 0.75) compared to standardized intraoral radiographs (R=0.47). However he recommends that the CBCT be applied when its benefits clearly outweigh the risk of radiation exposure and expense.

The primary purpose of this study was to evaluate if the percent change in linear measurements of bone loss on the facial plane of a maxillary central incisor at full and half root length along the vertical axis is directly proportional to volumetric change. The secondary purpose was to evaluate if the variation of root volume is influenced by difference in root morphology. The null hypothesis is that the maxillary central incisor will not show a direct proportional relationship in the linear and volumetric measurements of remaining bone at full and half the root length. Moreover, the linear and volumetric measurements will not be influenced by the root morphology.

CHAPTER THREE

MATERIALS AND METHODS

Study Sample

CBCT records of 70 consecutive patients from Department of Periodontics, LLUSD was retrospectively reviewed. The first 70 CBCT's fulfilling the following inclusion criteria was selected - (1) presence of at least one maxillary central incisor, (2) the tooth must be free of caries, restorations, endodontic treatment, periapical lesions or the evidence of root resorption, (3) the cement-enamel junction (CEJ) must be intact and easy to identify (4) average root length of 13mm ± 1mm (Ash, 2003). In order to observe the independence of the observations only one tooth per patient was included in the study. The CBCT images were converted into DICOM files and the DICOM files were adapted into 3D images using the volumetric software, In Vivo Dental (Anatomage, San Jose, CA) (Figure 1).

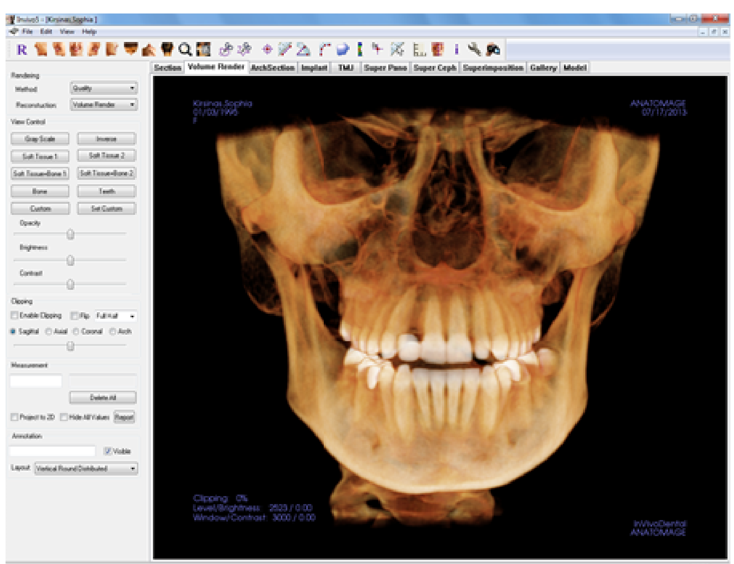
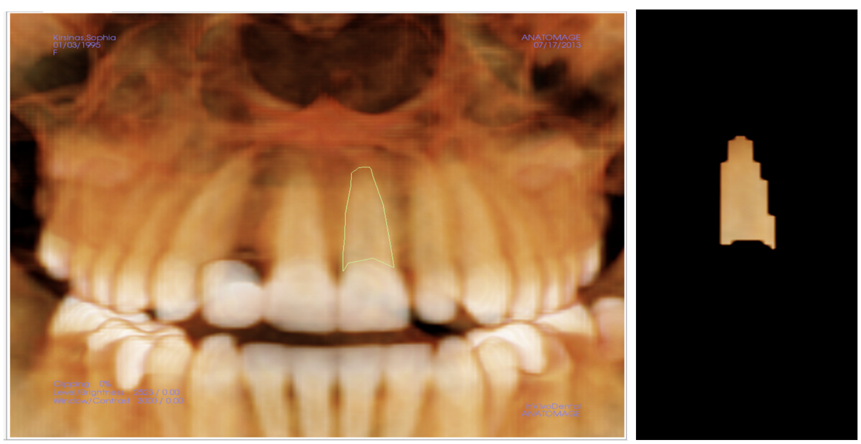


Figure 1. Anatomage software interface

The software was used to determine the location of the CEJ, the root outline and the root apex. Root segmentation is carried out along the coronal and sagittal plane by outlining the root along the periodontal ligament space (Figure 2). All teeth were segmented twice by the two independent examiners. Once the root was segmented, linear measurement tool was used to measure total length of root (L1), length of apical half of the root (L2) and width of root at half the root length (W1) along the coronal plane. Then volume rendering tool was used to measure volume of total length of the root (V1) and volume of apical half of the root (V2) was measured after segmentation of the coronal half was completed. Hounsfield threshold value was reduced to minimum for every volume rendered to minimize variation in sampling.



A. B.

Figure 2. A&B - Segmentation of the maxillary central incisor root along the facial plane.

Root length was measured along the long axis of the root from the defined CEJ to the most apical point of the root. Root volume was measured at total root length (V1) and at half the root length (V2). Based on the reference points used in the pilot study, the width at half the root length (W1) was measured on 70 teeth to evaluate the influence of root morphology.

Clinical Measurements

All the measurements were performed by two calibrated examiners and independent duplicate measurements will be carried out. Prior to taking measurements, the two examiners participated in a calibration session on the first 5 CBCT's. During the calibration session, each examiner measured all of the parameters on one central maxillary incisor per patient, and the intra-examiner and inter-examiner reliability were assessed using intra-class and inter-class correlation coefficients. Intra-examiner and intra-examiner error was also calculated. All linear measurements were recorded to the nearest 0.2mm. The mean of the two sets of measurements were used for further statistical comparison. The absolute volume change between the coronal and apical halves of the root was compared at corresponding length L1/L2 to determine if there is linear correlation between the values. Volume change was calculated as V1-V2/V2 and linear change was calculated as L1-L2/L2. Statistical tests were also run to determine if the change in volume is influenced by the shape of the roots as determined by the width at half the root length (W1).

Statistical Analysis

Intra-examiner and inter-examiner reliability were calculated using intra-class correlation coefficient. Spearman's rho correlation coefficient test was used to determine correlation between absolute change in linear measurements along the facial plane of the sample teeth at full and half root length along the vertical axis with corresponding volumetric change. Mann-Whitney U Test was used to compare mean change in volume along the root with the two groups of root shape (thick vs thin) as determined by the mean width at half the root length (W1). Hypotheses was tested at an alpha level of 0.05 and 95% confidence intervals were constructed. All analyses were performed with SAS version 9.2.3 (SAS institute in Cary, North Carolina).

CHAPTER FOUR

RESULTS

Intra-examiner and inter-examiner reliability was calculated using intra-class correlation coefficient (Table 1). Intra-class correlation coefficients were high, with the intra-class correlation coefficient for examiner 1 being 0.936, and the intra-class correlation coefficient for examiner 2 being 0.988. The inter-class correlation coefficient was lower, being 0.537. This demonstrates consistency within each examiner but not as much between examiners. The lack of inter-class reliability can be explained by the differences between the examiners in visualizing the root outline and thereby the segmentation. Table 2 shows calculated linear/volumetric intra-examiner and inter-examiner error.

Table 1. Intra-examiner and inter-examiner reliability.

Correlation	Coefficent	95% CI
Intra-class 1	.936	.842 - .973
Intra-class 2	.988	.968 - .995
Inter-class between examiners	.537	.202 - .763

Table 2. Intra-examiner inter-examiner error.

Examiner	Linear error (mm)	Volumetric error (cu.mm)
Examiner 1	1.02	64.6
Examiner 2	1.80	26.2
Inter-examiner	0.78	38.4

Table 3 shows means for each variable measured. Mean total length of the root was 12.45 ±1.12mm and half the length was 6.21±0.56mm. Corresponding mean volume as obtained by volumetric conversion was 347.19±78.87mm^3 and 114.94±34.06mm^3. The entire sample was then divided into two groups (thin vs thick) based on the mean W1 which was 4.30±0.89mm.

Table 3. Mean and standard deviation of the variables measured.

MEASURED VALUES N = 70	MEAN	STANDARD DEVIATION	RANGE
L1 (mm)	12.45	1.12	10 .00 – 14.50
L2 (mm)	6.21	0.56	5.00 – 7.30
W1 (mm)	4.30	0.89	2.70 – 8.45
V1 (cu. mm)	347.19	78.87	178.00 – 646.00
V2 (cu. mm)	114.94	34.06	41.00 – 248.00

The change in linear vs volumetric measurement at full and half the root length was evaluated to detect a linear correlation. The correlation was found to be non-linear but it did not reach statistical significance (Spearman's rho Test, $p = 0.09$) (Table 4). The scatterplot shows that most of the volume values segregated along certain linear measurements (Figure 3). The correlation did not reach significance even when the sample was adjusted for the total length of root, L1 or when the sample was split between the two root groups (Figure 4).

Table 4. Correlation of change in linear vs volumetric measurement at full and half the root length

	Correlation coefficient	Significance	N
LINEAR AND VOLUMETRIC CHANGE AT FULL AND HALF ROOT LENGTH	.141	.097	140

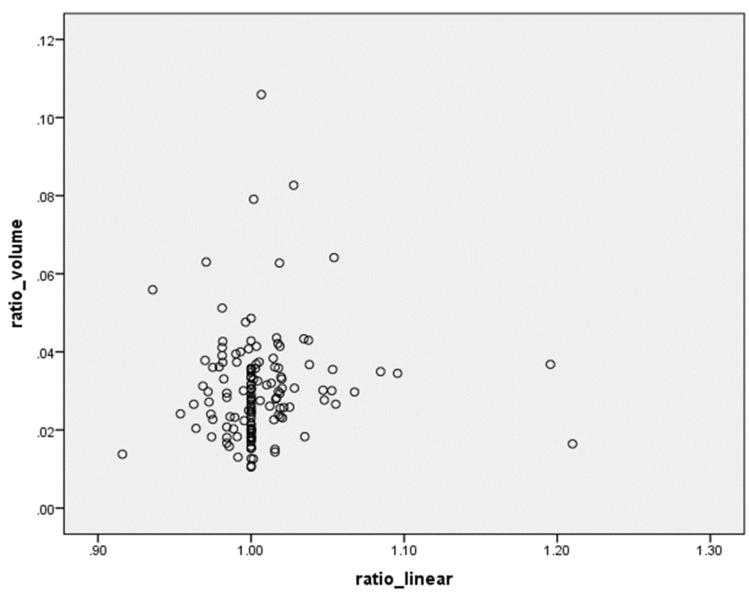
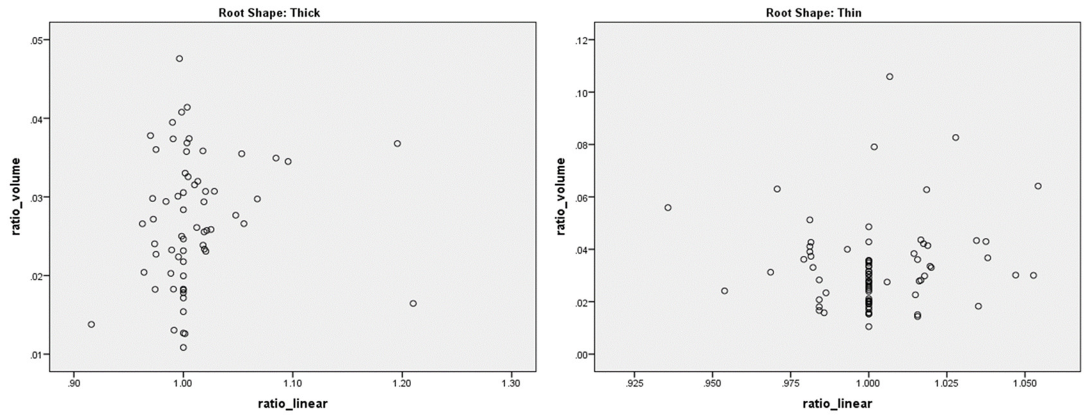


Figure 3. Scatter plot of the correlation of change in linear vs volumetric measurement at full and half the root length.



A. B.

Figure 4. Scatter plot of the correlation of change in linear vs volumetric measurement at full and half the root length by examiner 1 (A) and examiner 2 (B).

Mean change in volume along the root length was evaluated for correlation with the root morphology. Mean W1 was used to split the sample into thin (W1<) and thick (W1>) root groups. The correlation was found to be highly significant for both groups ($p<0.04$). The variation in volume was seen to be higher in the thin root group when compared to the thick root group. The significance remained when the sample was split for the two examiners.

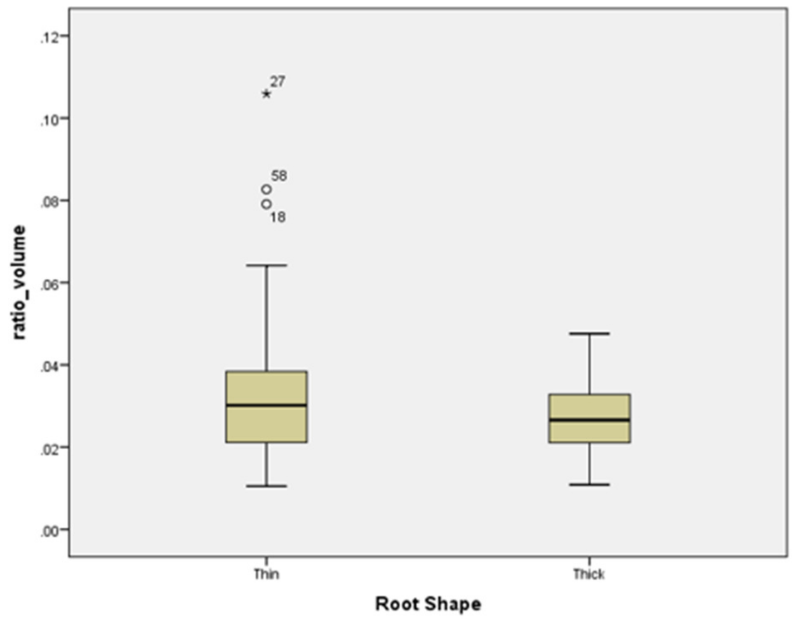


Figure 5. Correlation of change in volumetric measurement at the full and apical halves of the root length with root morphology.

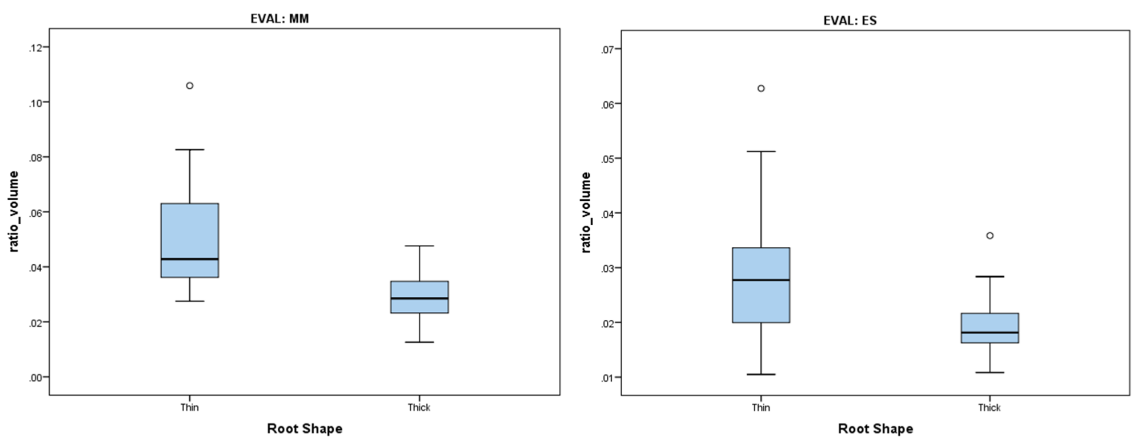


Figure 6. Correlation of change in volumetric measurement with root morphology when split by examiner.

Based on our results, we cannot reject our primary null hypothesis that the change in linear and volumetric measurements at full and apical halves of the root length on a maxillary central incisor is not directly proportional. The secondary null hypothesis that the volumetric measurements will not be influenced by the root morphology is rejected.

CHAPTER FIVE

DISCUSSION

In this study, we tried to determine a correlation between the linear and volumetric measurements made along the coronal plane of a maxillary central incisor using 3D CBCT software. Furthermore, we wanted to assess whether variation in root morphology can influence the change in volumetric measurement along teeth of similar root lengths. The results show that there is considerable variation in the volumetric measurements when compared with corresponding linear measurement along the root and the two measurements do not seem to be correlated. The non-linear pattern may be affected by many factors which have not been assessed in this study. Therefore, we cannot conclude on a definite pattern of behavior between the two parameters. The form of distribution nevertheless shows that the relationship is not directly proportional, meaning that for similar changes in linear measurement, the volumetric changes are diverse. Thus, the clinical parameters used at present does not represent the true values of bone loss as this study indicates that linear measurements are not proportionate for volumetric changes.

These volumetric changes are however related to the root morphology as seen by the high significance ($p<0.04$) when these parameters are compared. The correlation is significant for both the thick and the thin roots but greater variation is seen with the thin roots. This finds clinical application in that roots with similar linear measurement of bone loss may show great variation in volumetric measurement of remaining bone support and this variation is steeper for slender conical roots.

In recent years, several studies have focused on the linear and volumetric accuracy measurements of CBCT images, but the results are controversial. Baumgaertel et al, Damstra et al, Ballrick et al, Lascala et al, Periago et al, and Brown et al. reported that CBCT linear measurements had a tendency to underestimate the reference values. But Lagravere et al. found that CBCT linear and angular measurements showed no statistically significant differences between the coordinate measuring machine and CBCT, which can produce a 1-to-1 image-to-reality ratio. Fourie et al. applied the method of superimposed models and found that the CBCT models tended to be larger than the reference models.

In studies of volumetric accuracy measurements of CBCT images, Wang et al and Maret et al. found that CBCT volume measurements of teeth were similar to those with microcomputed tomography. In their studies, they used as the reference standard microcomputed tomography, which is also an x-ray scan machine and can cause artifacts in high-density tissues. The microcomputed tomography scan parameters they used were 0.037mm (Wang) and 0.041 mm (Maret), which were close to the CBCT scan parameters - 0.08 mm in (Maret) and 0.125 mm in (Wang). The higher the resolution, the less the volume discrepancy might be between the microcomputed tomography and the CBCT scans. But Liu et al. found that the CBCT volume measurements deviated slightly from the physical volumes, by about –4% to 7%.

In clinical practice, volume accuracy is important and can be fundamental to the study’s limitations. There are many factors that affect the accuracy of CBCT measurements. If the Hounsfield unit threshold is set too high, the tooth contour cannot be obtained completely and tooth volume tends to be smaller. If the Hounsfield unit threshold id set too low, the surrounding tissues will have a significant impact on tooth contour and the tooth volume tends to be larger. In this study, to obtain tooth measurements as intact as possible, we set the threshold segmentation to the minimum for all the samples to keep the inter-examiner values unaffected by the setting.

For high-precision volume applications (ie, 3D computer-aided design model development, dental measurement, periodontal bone level assessment, predicting the diameters of unerupted teeth, and evaluation of root resorption), voxels of 0.125, 0.20, and 0.25 mm are better. In small voxel scans, the periodontal membrane (0.3- to 0.4-mm thickness) between the root and the alveolar bone can be obtained clearly; this could help for root segmentation. But in larger voxel scans, the periodontal membrane cannot be displayed clearly, so it is difficult to segment the root completely from the jaw; this could cause greater deviations for volume measurements. Ye et al.

in their study found that the tooth volumes tended to be larger with increased voxel sizes and artifacts around teeth causing a halation effect.

At present, there is no standard for tooth segmentation. This can cause deviations between different operators. There will be a learning curve on using the software and it's applications. This may affect the accuracy of the projected vs the absolute measurements. A follow-up clinical study evaluating the accuracy of volume measurements by comparing values obtained through the software with absolute physical measurements can assess the accuracy of the software used in this study.

The clinical implications of this study include:

i. Individualized determination of periodontal prognosis based on a root morphology and not just the linear change in remaining bone level.

ii. Determination of dental root morphology and volume is of great in orthodontics for biochemical considerations. Changes in root resorption and bone volume during treatment can be monitored in progress.

iii. Immediate implant placement can be assisted by understanding the volume of the bone displaced by the root. The size of the implant can be determined prior to the extraction of the tooth especially as CAD-CAM implant use is becoming more prevalent.

iv. Assist in developing a prognostic criteria relating to the effect of root morphology on bone loss, loss of attachment, mobility etc.

V. Annual changes in bone may be more sensitive as volumetric measurements as opposed to linear measurements on peri-apical radiographs.

CHAPTER SIX

CONCLUSION

Within the limitations of this study, we conclude that linear measurements along the length of a maxillary central incisor root do not correlate with corresponding volumetric change. In fact, for the similar change in linear measurement, there was great variation in the rate of volumetric change. Root shape could not account for the lack of correlation probably due to the small sample size and variation in segmentation between the examiners. When grouped into thin vs thick root groups, a significant correlation was noted between volumetric changes along the coronal and apical halves the root. The deviations were greater for the thinner root group signifying there is greater loss of volume along the root for similar level of bone loss compared to thick roots.

REFERENCES

Ash, Major M. and Stanley J. Nelson. Wheeler's Dental Anatomy, Physiology, and Occlusion. 8th edition. 2003

Ballrick JW, Palomo JM, Ruch E, Amberman BD, Hans MG. Image distortion and spatial resolution of a commercially available cone-beam computed tomography machine. Am J Orthod Dentofacial Orthop 2008;134:573-82.

Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop 2009;136:19-25.

Bjorn, H. & Holmberg, K. 1966: Radiographic determination of periodontal bone destruction in epidemiological research. Odontologisk Revy 17: 232-250.

Bjorn, H., Hailing, A. & Thyberg, H. 1969. Radiographic assessment of marginal bone loss. Odontologisk Revy 20: 165-179.

Brown AA, Scarfe WC, Scheetz JP, Silveira AM, Farman AG. Linear accuracy of cone beam CT derived 3D images. Angle Orthod 2009;79:150-7

Damstra J, Fourie Z, Huddleston Slater JJ, Ren Y. Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes. Am J Orthod Dentofacial Orthop 2010;137:16.e1-6.

Fourie Z, Damstra J, Schepers R, Gerrits P, Ren Y. Segmentation process significantly influences the accuracy of 3D surface models derived from cone beam computed tomography. Eur J Radiol 2012;81:e524-30

Goldman, Henry M., Schluger, Saul, and Fox,Lewis: Periodontal Therapy. The C. V. Mosby Company,St. Louis, 1 956. Page 66.

Greenfield, D. S., Williams, R. C. & Goldhaber, P. 1981. Radiographic measurement of alveolar bone loss: a perspective in vitro. Journal of Clinical Periodontotogy 8: 474-^80.

Jepsen, 1963. Root Surface Measurement and A Method for X-Ray Determination of Root Surface Area. Acta Odontologica Scandinavica Vol. 21, Pages 35-46

Jørgen Theilade. An Evaluation of the Reliability of Radiographs in the Measurement of Bone Loss in Periodontal Disease. Journal of Periodontology April 1960, Vol. 31, No. 2, 143-153

Klock KS, Gjerdet NR, Haugejorden O. Periodontal attachment loss assesses by linear and area measurements in vitro. Journal of Clinical Periodontology 1993; 20: 443-447

Lagravere MO, Carey J, Toogood RW, Major PW. Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. Am J Orthod Dentofacial Orthop 2008;134:112-6

Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol 2004;33:291-4.

Lavstedt, S. 1975. A methodological-roentgenological investigation of marginal alveolar bone loss. Acta Odontologica Scandinavica 33 (Supplement 67)

Liu Y, 2010. The validity of in vivo tooth volume determinations from cone-beam computed tomography. Angle Orthod. 80(1):160-166.

M. K. Jeffcoat. Relationship between linear and area measurements of radiographic bone levels utilizing simple computerized techniques. Journal of Periodontal Research 1984: 19: 191-198

Maret D, Molinier F, Braga J, Peters OA, Telmon N, Treil J, et al. Accuracy of 3D reconstructions based on cone beam computed tomography. J Dent Res 2010;89:1465-9.

Marshall-Day, C. D. & Shourie, K. L. 1949. A roentgenographic survey of periodontal disease in India. Journal of the American Dental Association 39: 572-588.

Niansong Ye, Fan Jian, Junjie Xue Accuracy of in-vitro tooth volumetric measurements from cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2012;142:879-87

Periago DR, Scarfe WC, Moshiri M, Scheetz JP, Silveira AM, Farman AG. Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. Angle Orthod 2008;78:387-95.

R. Brown, 1950. A Method of Measurement of Root Area. Journal of Canadian Dental Association 16:130-132

S P Luthra, 1950. Root surface area measured by the benzene adsorption method. J Prosthet Dent 31:185-189

S. Kay. Tooth root length volume relationships, an aid to periodontal prognosis I – Anterior teeth. Oral Surgery, Oral Medicine, Oral Pathology Volume 7, Issue 7, July 1954: 735–740

Schei, O., Waerhaug, J., Lovdal, A. & Arno, A.1959. Alveolar bone loss as related to oral hygiene and age. Journal of Periodontology 30:7-16.

Sjolien, T. & Zachrisson, B. U. 1973. A method of radiographic assessment of periodontal bone support following orthodontic treatment. Scandinavian Journal of Dental Research 81:210-217.

Ssu-Kuang Chen. Calculation of simplified single root surface area from simulated x-ray projection. Journal of Periodontology 2002; 73:906-910.

Suomi, J. D., West, T. D., Chang, J. J. & McCIendon, B. J. 1971. The effect of controlled oral hygiene procedures on the progression of periodontal disease in adults: radiographic fmdings. Journal of Periodontology 42: 562-564.

Toru Niato, Ryuji Hosokawa, Makoto Yokota. Three Dimensional alveolar bone morphology analysis using computed tomography. Journal of Periodontology 1998; 69:584-589

Wang Y, He S, Yu L, Li J, Chen S. Accuracy of volumetric measurement of teeth in vivo based on cone beam computer tomography. Orthod Craniofac Res 2011;14:206-12.

Williams, R. C, Sandier, M. B., Aschaffenburg, P. H. & Goldhaber, R. Preliminary observations on the inhibitory effect of tetracycline on alveolar bone loss m beagle dogs. Journal of Periodontal Research 1979. 14: 341-351.

Yamamoto T, Kinoshita Y, Tsuneishi M, Umemura O, Watanabe T. Estimation of the remaining periodontal ligament from attachment level measurements: Journal of Clinical Periodontology 2006; 33: 221-225