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Radiographic ratios for classifying furcation anatomy. Proposal of a new evaluation method and an intra-rater and inter-rater operator reliability study.

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Abstract

Objectives: Few studies in literature evaluate the "mean measure" of root divergence. Most of them are linear measurements, they hardly describe the dental furcation conformation. It is left to the subjectivity of the operator deciding whether a furcation is convergent or divergent. The goal of this study is to create a visual evaluation method to overcome these problems giving a conformation of the entire interradicular space.

Material and methods: A user-friendly software (Paint®, Windows10®) was used to measure endo-oral radiographs of upper and lower molars. Three kinds of measurements were taken. Three operators used the software to measure 20 radiographs, then the technique was repeated on 250 radiographic images to identify an average measurement. The ratio of these three measurements allowed to develop a new visual evaluation method of the interradicular space.

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Results: Intra and inter-operator reproducibility was statistically assessed on a sample of 20 anonymous endo-oral radiographs measured by 3 blind operators. Then, a sample of 250 anonymous endo-oral radiographs were measured by a blind operator and were statistically evaluated to identify an average value to define a main conformation of the interradicular space. Measurements made by the 3 operators on the 20 radiographic images showed that the technique is reproducible, and a mean value of the interradicular space was obtained.

Conclusions: A new anatomical evaluation of the interradicular space in its entirety, which could help the clinicians in the therapy of furcated molars, can be obtained.

Clinical relevance: diagnostic evaluation of furcation defects

Key words: furcation anatomy, furcation measurement, furcation evaluation

1. INTRODUCTION

Regenerative therapy of furcation defect is considered one of the main challenges in periodontal surgery. The proposed strategies aiming to improve the prognosis of the tooth with furcation involvement are different, according both to the severity of the defect and the anatomy of soft and hard tissues, including the conformation of the tooth. Several non-surgical (debridement and management of the radicular surface with powders and polishing) and surgical (resective and regenerative) strategies have been proposed. While Class I furcations are generally maintainable with non-surgical therapy alone[1], Class II furcations can be successfully treated with regenerative approaches, leading to a reduction in horizontal and vertical probing and a clinical attachment gain[2-5]. There are different regenerative techniques, but the efficacy of regeneration has been demonstrated with amelogenins[6], guided tissue regeneration techniques (GTR)[2], and the use of bone grafts[7]. Defects do not always completely heal in the case of class II furcations but decreasing the probing depth and improving from a class II to a class I furcation is considered a success as it changes the prognosis of the tooth over time[8-9]. This is relevant since, from a biological point of view, the regenerative potential within the furcation area is limited, and it seems to be conditioned by several anatomical factors that may harden the regenerative procedure. The proportion of keratinized gingiva on the affected tooth, the phenotype of the patient[10-11], and the severity of the bone defect, both horizontal (degree I, II, III)[12] and vertical (A,B,C according to Tarnow, 1984[13] and subclasses A,B,C Tonetti 2007[14]). Finally, the root anatomy (both the divergence of the furcation and the length of the root trunk) has been repeatedly demonstrated influential[15-16-17-18], although some authors do not consider it a success/failure factor[19]. In literature there are only few studies evaluating the “mean measure” of root divergence, either of the amplitude of the inter-root septum. In their study, Bowers et al, measured the divergence as root divergence at crest of the bone (RDCB)[16]. Another method of evaluation of the divergence was proposed in the study of Caesarin et al[20], after flap elevation and bone defect debridement. In this case the authors intended divergence the distance

between the roots 2 mm under the fornix of the furcation. With this measure we can't describe the divergence coronal or apical to the measuring site. For example, if a tooth has convergent root cones in its apical portion this will not be considered. Moreover, these are intraoperative clinical measures, therefore they do not allow to establish before the surgery the divergence of the furcation and again these are single measures. It is therefore left to the subjectivity of the operator to decide whether a fork is convergent or divergent. The goal of this study is to create a visual evaluation method that can overcome these problems giving a conformation of the entire area of the interradicular space. Therefore, in this study the root conformation is described by the width of the roof of the furcation and the width of the space between the two roots[16-22]. The larger the width of the furcation roof the easier the debridement of the area will be, but at the same time it will be more difficult obtaining a complete closure of the defect due to an inability of the clot to effectively fill the area. For the same reason, increased root divergence is associated with a larger furcation defect, which may result in reduced horizontal bone gain, reduced furcation closure, and unfavorable regenerative outcome[21]. Putting together these two parameters (transversal width and diameter of an osculating circle) related to the interradicular septum length, gives us two ratios which describe the anatomy of the interradicular space in its entirety. Also, since the measurements are ratios, they are not subjected to image scale errors of measurements.
Therefore, the aim of the present study is to propose a method for describing roots conformation and to test its intra- and inter-rater reliability.

2. MATERIALS AND METHODS

2.1 Study design

The study has as its main objective assessing the reliability and the repeatability of a visual evaluation method of the root conformation.

2.2 Inclusion criteria

Periapical radiographs of upper and lower molars were retrieved.
Radiographs were included in the present study if they met the following inclusion criteria:

i) Radiographs made with paralleling technique
ii) Good image definition (clearly distinguishable roots margins)
iii) Complete view of the interradicular space
iv) Complete view of root apices

2.3 Novel method for classifying the furcation divergence in mandibular molars

The novel method is based on the assessment of the following parameters on periapical x-rays:

- Furcation roof width (D)
- Interradicular furcation width (T)
- Interradicular septum length (L) (Figure 1).

Intraoral radiographs made with paralleling technique of upper and lower molars are studied. In upper molar only the vestibular furcation is considered. Using a graphic software (Paint®, Windows10®), a vertical line is drawn from the roof of the furcation to the midpoint of an imaginary line passing through both root tips. This line should reflect the vertical length of the interradicular septum. A second horizontal line is drawn within two thirds coronal of the interradicular septum, where the interradicular septum has got the maximum width. Lastly, an "osculating circle" is traced along the curvature of the furcation roof. This circle overlaps as much as possible the shape of the roof of the furcation. Its definition is the maximum overlap on which to yearn half the circumference of the circle, that is that the rope connecting the two points where circle and curvature of the root divers get as close as possible to the diameter of the circle. In case of a furcation roof with two overlapping curvatures, the mean curvature will be selected.

The diameter and the lines are measured on the same graphic program (Paint®, Windows10®). Ratios are created: between the diameter of the circle (D) and the length of the line from the roof of the furcation to the midpoint of an imaginary line passing through the tips of the roots (L); between the line drawn in the maximum width of the interradicular septum (T) and the line from the roof of the furcation to an imaginary line passing through the tips of the roots (L) (Figure 1).

The D/L ratio express the roof furcation width (RFW), and the T/L express the interradicular furcation width (IFW).

2.4 Intra-rater and inter-rater operator reliability assessment of the new method for characterizing furcation divergence

Three dentists (E.L., A.L., P.B.), without previous knowledge of the selected cases, assessed furcation divergence with the proposed evaluation system on a sample of 20 periapical x-rays. The 3 operators carried out the measurements of D, T and L and calculated their ratios at time 0 (T0). After 30 days (T1) the operators repeated the same evaluation on the same 20 cases.

2.5 Determination of the "mean furcation conformation/configuration"

A sample of 249 periapical radiographs was collected by a pre-calibrated operator (A.C.), who measured D, T and L and the ratios D/L (RFW) and T/L (IFW). The ratios were then statistically analyzed and an average measure of the reports, reflecting the interradicular space, was created, based on the statistical distribution of the measurements collected.

2.6 Statistical analysis

The reliability of the novel evaluation of furcation divergence was explored among the same examiner at different timepoints (intra-reliability) and between different examiners (inter-reliability) on 20 periapical x-rays. Bland-Altman plots were constructed to investigate the intra-rater and inter-rater operator reliability. A generalized linear model was used to evaluate the repeatability of the two measurements in relation to the operators (fixed effects) and the measurements carried out the same objects (random effects).

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3. RESULTS

3.1 Intra-rater and inter-rater operator reliability assessment

The linear generalized model for RFW as dependent variable showed a variability (R-square) of 83.4% and that the operator seems to have a significant role in determining the measurements ($p<0.01$). Examiner 1 was found to give statistically significantly different measurements compared to operator 2, however, the difference between the two operators, and overall, among each operator, are < 5%.

The linear generalized model for IFW as dependent variable showed a variability (R-square) of 94.8%, with the operator having a significant role in the model ($p<0.05$). A statistically significant difference between examiner 1 and 3 was observed ($p<0.05$), however, this difference was within 5%.

Overall, the two linear generalized models showed that are no differences the two sets of measurements performed by the same operators at T0 and T1 ($p>0.05$). Although a statistically significant different was found between the measurements of two examiners for RFW and IFW, these differences were within 4 hundredths of a millimeter (< 5% of the original measurements) and can therefore be considered not clinically relevant and negligible (Figure 2).

3.2 Determination of the "mean furcation conformation/configuration"

Based on 249 periapical x-rays, the mean furcation conformation/configuration was characterized in terms of RFW and IFW. The average RFW and IFW were 0.163 and 0.307, respectively. Table 1 shows the quintile division of the obtained distribution.

4.DISCUSSION

It has been well established that the anatomy of the roots, both in terms of furcation divergence and length of the root trunk, is associated with outcomes of periodontal regeneration[15-16-17-18-20-22]. Nevertheless, only few studies have focused on measuring parameters related to anatomy of the roots/furcation, including fork divergence, root trunk length, radicular roof width and interradicular width[16-21-22]. Previous evaluation systems introduced in the past for describing furcation involvement often lack reliability assessment.

The aim of the present study was to propose a visual evaluation method of assessing furcation/root anatomy and, in line with the goals of contemporary literature, to test the intra-rater and inter-rater reliability of the newly introduced system. We described an objective method of identification and measurement of the interradicular space in two dimensions. Results from the reliability study demonstrated that this method is reliable and consistent among the same operator at different time point and among different examiners. Therefore, this novel method can be easily performed by all clinicians. Furthermore, the measurements on radiographic images can be obtained by using basic and "user-friendly" graphic software compatible with all kinds of hardware.

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To the best of the authors' knowledge, a similar evaluation characterizing the entire radicular space has not been described in the literature so far. This may have a positive impact on future investigations exploring the impact of RFW and IFW on the treatment outcomes of periodontal regeneration.

There are individual parameters such as divergence, degree of separation and separation coefficient, that however, failed to provide an overview of the radicular space, when taken individually investigated. For example, the method proposed by Bowers et al, to measure the divergence as root divergence at crest of the bone (RDCB)[16], doesn't provide a pre-operative way to analyze the root divergence. Another method of evaluation of the divergence was proposed in the study of Caesarin et al[20], who, after flap elevation and bone defect debridement, calculated the distance between the roots 2 mm under the roof of the furcation. These linear measures do not provide complete information on the entire root space. There are, indeed, several cases in which furcated molars have a large roof and converging roots, or a narrow roof and diverging roots, where it is difficult to determine whether the interradicular space is large or narrow. The predictability in the regenerative therapy could be obtained with pre-operative measures. In this study the measurements are ratios between lines drawn by a basic graphic software. The advantage of the proposed evaluation is the fact that the common problem of image magnification on x-rays are overcome by the calculation of ratios, that are independent from the scale of measurement and do not suffer of scale errors. Magnifications caused by the position of the sensor relative to the tooth and by the manipulation of the digital image by the operator do not affect the accuracy of the proposed evaluation. When these lines are examined together, they give the operator the shape of the interradicular space. The proposed evaluation allows to have a global vision of the interradicular space, as well as a pre-operative method to examine it.

Subdivision in quintiles of the range of measurements of RFW and IFW (table1), showed a higher percentage of population, for both ratios, in the second and third quintiles.

Among the limitations of the present study, the lack of standardization of the periapical x-rays utilized to conduct the reliability study and the determination of the "mean furcation configuration" must be mentioned. In addition, the sample size is relatively limited and represent a specific population only and therefore further studies are needed to explore the generalizability of this method in other populations. Lastly, although this preliminary study provides the basis for utilizing this evaluation system in everyday case scenarios, clinical studies are needed to evaluate whether the root/furcation anatomy, described with the proposed method and ratios, affects the outcomes of periodontal therapies.

5 CONCLUSIONS

The present study introduced a new anatomical evaluation of the interradicular space, which could help clinicians and researchers when searching for an objective quantitative description of the furcation configuration/anatomy. This visual evaluation method, created by measuring the width of the roof of the furcation and the width of the space between the two roots, and the relationship of these two measurements with the radicular length, was proved to be reliable and consistent among the same operators and different examiners. This evaluation can be effectively applied by all clinicians, and it is not affected by the problems

of magnification of the radiographic images that are overcome by the ratios. The ability to measure these values and to classify them objectively may allow to weigh their influence on bone regeneration and improve the way we manage bone defects. Subdivision in quintiles of the range of measurements could establish a classification of the interradicular area based on the value of more representative interradicular space.
Further studies are needed to establish a possible positive correspondence with the regenerative potential.

Compliance with ethical standards

Conflict of interest. The authors do not have any financial interests, either directly or indirectly, in the products or information listed in the paper.

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Informed consent. Due to the retrospective nature of the study, informed consent was not required by the local ethic committee.

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Tables and figures

Figure 1. Peri-apical x-ray shows a lower molar. Figure B shows the visual evaluation method. The osculating circle, the trasversal width and the longitudinal length are drawn on the rx. D: Diameter of the Osculating Circle (Red); T: Trasversal Width (light Blue); L: Longitudinal length (Yellow)

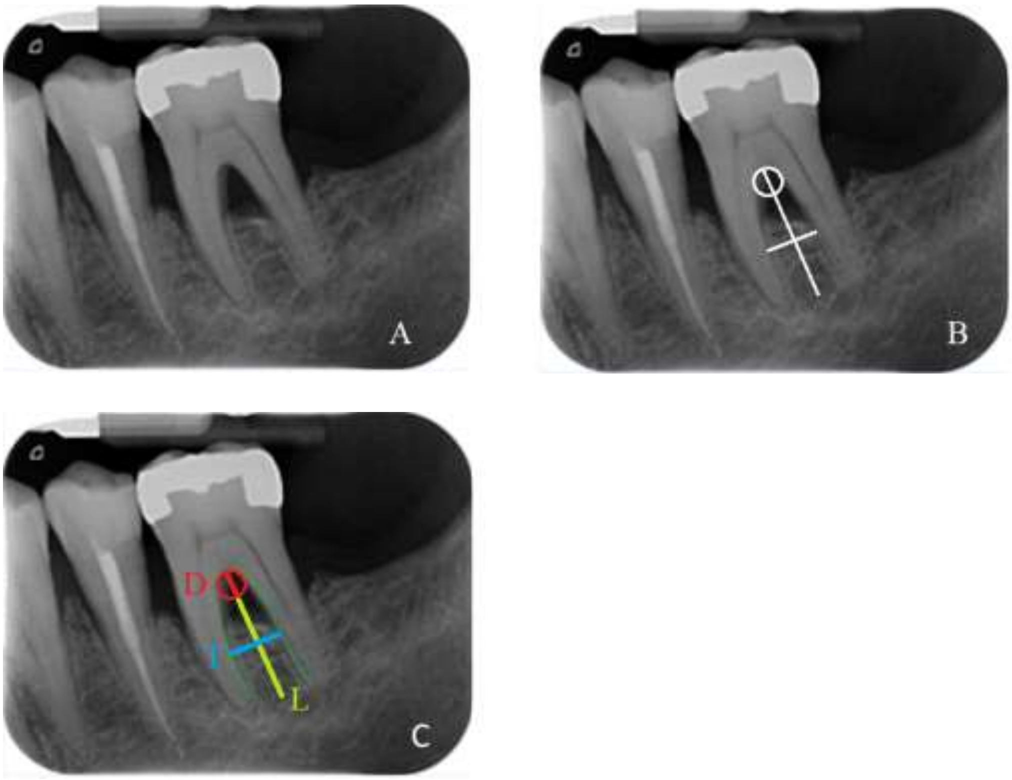

Figure 2. Graphs from the linear generalized model using the RFW ratio (A) and the IFW ratio (B) as dependent variables, showing the mean differences in measuring these ratios obtained by the operators. The graphs show negligible differences among the examiners, less than 5%, confirming that the described method is reproducible and consistent.

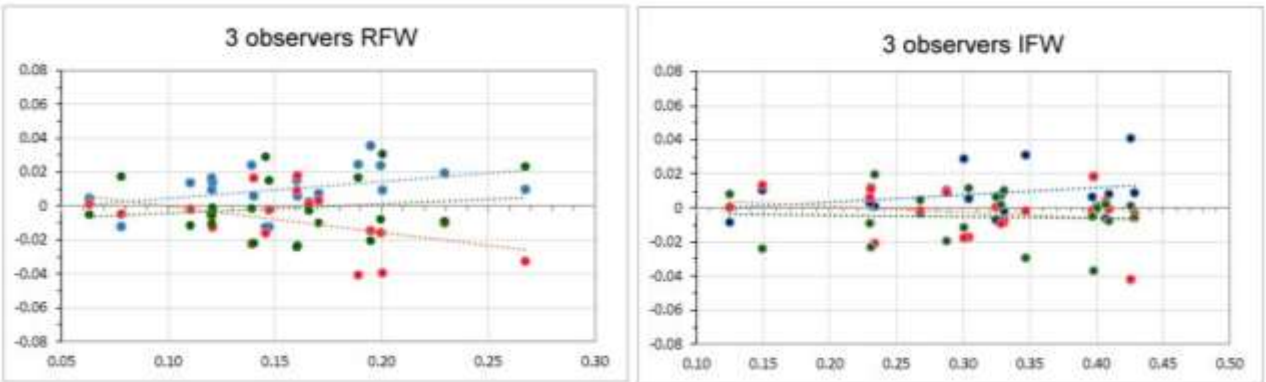

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Table 1. Distribution of subjects for every quintile for RFW and IFW.

Quintiles RFW	N
1 (0.01-0.07)	11
2 (0.07-0.15)	110
3 (0.15-0.22)	96
4 (0.22-0.30)	26
5 (0.30-0.38)	4
Quintiles IFW	N
1 (0.06-0.14)	20
2 (0.14-0.29)	102
3 (0.29-0.43)	95
4 (0.43-0.58)	29
5 (0.58-0.73)	4