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Furcation Measurements: Realities and Limitations

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Abstract

Furcation involvement is a common sequela of severe chronic periodontal disease. Its effective management has a profound influence on the outcome of periodontal therapy. For the efficient clinical management of furcation defects, it is necessary to have a reliable diagnostic tool that can accurately measure and quantify the furcation defect. This article addresses the various diagnostic methods available and assesses their limitations. Further, it also highlights some new frontiers in the field of furcation diagnosis and measurements.

Keywords: Furcation, measurement, periodontal disease, diagnosis, periodontal defect

Introduction

Reliable measurement of the degree of furcation in multi-rooted teeth offers a unique and challenging task, and remains an unresolved problem for the periodontist in clinical practice (Eickholz, 1995; Al-Shammari *et al*., 2001). The furcation area creates situations in which routine periodontal procedures are limited and special procedures are generally required because of various confounding factors such as the size and shape of the tooth, roots and their alveolar housing, and the varied nature and patterns of periodontal destruction (Al-Shammari *et al*., 2001; Lekovic *et al*., 1998).

Since the early description and classification of furcation involvement by Glickman, it is a known fact that the measurement process has a profound influence on the detection and assessment of the furcation defect (Zappa *et al*., 1993; Lindhe, 1983; Mealey *et al*., 1994). It is believed that furcation measurements influence the prognosis of the involved tooth, which helps with the insurance claim, time and money spent to retain the tooth, and to determine the strategic importance of the tooth for the overall rehabilitation of the patient and allow development of a surgical treatment plan (Lindhe, 1983; Mealey *et al*., 1994; Muller and Eger, 1999). Further, the decisions regarding treatment are vastly dependent on the severity of destruction, the strategic importance of the tooth, and the level of patient motivation, for which accurate diagnosis of the extent of involvement is a key factor. There are various traditional diagnostic tools to detect and evaluate the extent of the disease. However, inherent limitations exist in determining accurate measurements, especially in the horizontal direction, due to interference from the furcation anatomy, the need for the sound technical skills and compliance of the patient. Because of these factors there is always a quest for newer diagnostic tools and modern treatment modalities for accurate furcation diagnosis and treatment (Muller and Eger, 1999).

The objective of this review is to bring the reader up-to-date on the realities and limitations of the various traditional methods used for the diagnosis of furcation involvement and, in addition, the various advanced methods in furcation measurements are briefly discussed.

Call for accurate furcation measurement

There exists a compelling need to accurately diagnose the extent of furcation involvement, as these defects represent a formidable problem in the treatment of periodontal disease, principally related to the complex and irregular anatomy of furcations (Marcaccini *et al*., 2012; James *et al.,* 2013). One of the key points the clinician should keep in mind while measuring furcation involvement is that not much of an "inaccuracy" is acceptable because it may significantly alter the treatment plan (Mealey *et al*., 1994). This highlights the great need for accurate furcation measurements, which can be summarized as follows:

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1. Furcation defects serve as risk factors for progressive loss of connective tissue attachment, alveolar bone resorption and tooth mobility (Bowers *et al.*, 2003).
2. After periodontal treatment, monitoring of the furcation lesion has to be done to ensure that there is no disease progression (Cortellini *et al.*, 1993).
3. Different therapeutic approaches are chosen based upon clinical determination of severity of involvement. Therefore, any discrepancy between pre- and intra-surgical findings may lead to an alteration in the surgical treatment (Mealey *et al.*, 1994; Muller and Eger, 1999).

Limitations in furcation measurements

Influence of furcation anatomy

Knowledge of the anatomy of multi-rooted teeth is essential in order to correctly identify the presence of furcation involvement. The furcation area can be divided into 3 parts; namely, the roof, the surface immediately coronal to the root separation (flute), and the area of root separation (Goldman and Cohen, 1988). There are some anatomical variations that are often encountered in the furcation area such as enamel pearls, bifurcation ridges, cervical enamel projections and fused roots, which limit the ability to manipulate the probe in negotiating the furcation to its vertical probing depth (VPD) and horizontal probing depth (HPD) (Shiloah and Kopczyk, 1979; Moskow and Canut, 1990; Hou and Tsai, 1997; Everett *et al.*, 1958; Bower, 1979). This is especially the case with distal furcations of maxillary molars that generally lie in a plane directly apical to the contact area, which is further exacerbated by the presence of a second or third molar distal to the tooth in question. In addition, this issue is worsened due to the lack of reliability of different diagnostic aids (Bower, 1979). With respect to the maxillary first premolars, bifurcation is generally present 40% of the time and the mean root trunk length is 8 mm on both mesial and distal aspects, a feature that further complicates access to the furcation involvement with respect to these teeth (Joseph, 1996). The variations in the normal anatomy with regard to furcations of different teeth are listed in *Table 1*.

Influence of investigator experience

Investigator experience in various furcation measurements influences the accuracy and reproducibility of the diagnostic performance. Moriarty *et al.* (1988) investigated inter-examiner reliability of furcation measurements using a TPS (true pressure-sensitive) probe, and reported that the HPD measurements were not consistently recordable, and that the reproducibility of the facial and lingual furcation sites decreased with an increase in probing pocket depth and an increased degree of root separation. Greatz *et al.* (2014) showed that operator experience in interpretation of radiographs enhances the predictability of radiographic measurements and therefore the right diagnosis. Hence, to avoid investigator bias, the intra- and inter-examiner should be calibrated for the grade of agreement using the weighted kappa coefficient for open flap surgery, which is considered a gold standard for probing and radiographs.

Influence of diagnostic methods

Furcation defects can be detected and measured using various clinical and radiographic techniques as discussed below:

Clinical methods of furcation measurements

Furcation probing

Traditionally, furcation defects have been measured with the help of probes like the straight periodontal probe (a variant of which is the TPS probe), automated probes, such as the Florida probe with disc attachment, and with certain other probes specially designed for furcations called furcation probes, such as the Nabers, ZA2, ZA3, HO2, NS2, NP2C and ACE probes (*Figure 1)*. Using these probes, various classification systems have been proposed that help to arrive at a fairly accurate diagnosis (*Table 2*). However, there is no one classification system that is accepted and followed universally.

Table 1. Significance of various anatomic variables of different teeth.

Tooth	Cross-section of different roots	Incidence of different root trunk types	Incidence and depth of concavity	Root trunk length	Furcation entrance diameter
Maxillary molars	Mesio-buccal: ovoid, elongated in bucco-palatal direction Disto-buccal: circular Palatal: circular, wider in mesio-distal dimension	Type A: 34.9% Type B: 61.8% Type C: 3.3%	Mesio-buccal: 94% and 0.3 mm Disto-buccal: 31% and 0.1 mm Palatal: 17% and 0.1 mm	Mesial: 3mm Distal: 3.5mm Palatal: 5mm	Buccal: 0.5 to 1.5 mm Mesial: 0.5 to 2 mm Distal: 0.5 to 2 mm
Mandibular molars	Mesial: hour-glass, wider in bucco-lingual direction Distal: circular	Type A: 62.5% Type B: 37.5% Type C: 0%	Mesial:100% and 0.7 mm Distal: 99% and 0.5 mm	Buccal: >3 mm Lingual: >4 mm	Buccal: <0.75 mm Lingual: >0.75 mm

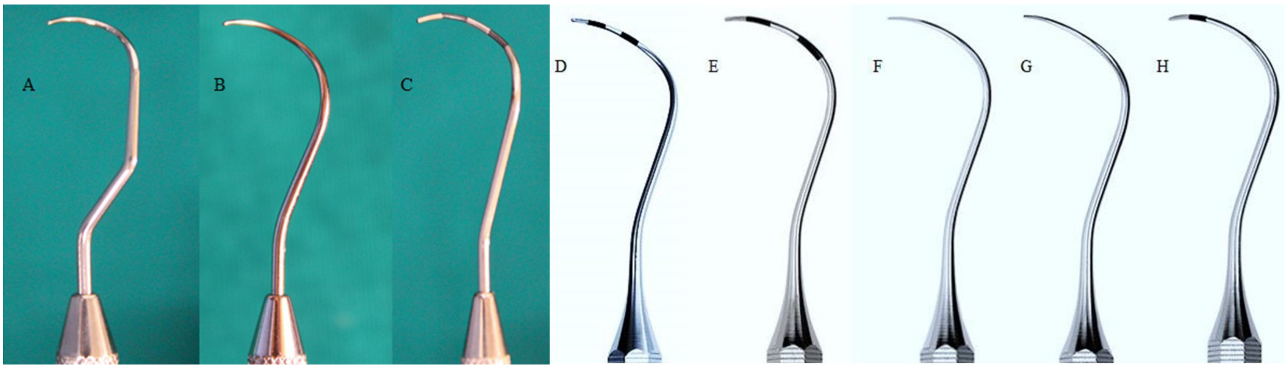

Figure 1. Types of furcation probes: A) Nabers 1N, with smooth non-calibrated surface, and sharper, more defined curves/angles used for measuring mesial and distal furcations on maxillary molars; B) Nabers 2N, with smooth non-calibrated surface, has a shallower curve at the working end and accesses all buccal and lingual furcations; C) Nabers Q2N, color-coded variant of the 2N with color coding at 3, 6, 9 and 12 mm; D) ZA2 probe, with a diameter of 0.5 mm and graduations at 2, 4, 6 and 8 mm; E) ZA3 probe, with a diameter of 0.5 mm and graduations at 3, 6, 9 and 12 mm; F) HO2 probe is non-graduated and has a diameter of 0.4 mm; G) NS2 probe is non-graduated and has a diameter of 0.5 mm; H) NP2C probe has a diameter of 0.5mm and graduations at 3-5 mm.

To measure the depth of furcation involvement, a straight probe, like the UNC-15 probe with 1 mm markings, is inserted into the periodontal pocket along the root surface to locate the initial fluting of the furcation. Once located, the distance from the gingival margin to the opening of the furcation is noted. The probe is then advanced apically until resistance is felt and the distance from the gingival margin to the vertical depth of probing is noted. The VPD of the furcation is recorded to the nearest millimeter as the difference between the two values. Similarly, the HPD of the furcation defect can be determined by measuring the horizontal extent of probe penetration into the furcation (Mealey *et al.*, 1994). To detect furcation involvement with a furcation probe, the tip of the probe is moved towards the presumed location of the furcation and then curved into the furcation area. For the mesial surfaces of maxillary molars this is best done from a palatal direction, as the mesial furcation is located palatal to the midpoint of the mesial surface. The distal furcation of maxillary molars is located more towards the midline, and may be detected from a buccal or palatal approach (Lindhe *et al.*, 2008).

The use of probes bears similarity to the difficulties encountered when the clinician measures the periodontal pocket, where probe penetration and probe tip position are affected by force, tip diameter, angulation, and tissue quality variability, especially while probing a furcation defect with inflammation (Freed *et al.*, 1983; Durwin *et al.*, 1985; Anderson *et al.*, 1991). Further, reading error may result due to interference from calculus on the tooth/root surface, presence of an overhanging restoration or crown contours (Ramachandra *et al.*, 2009). These limiting factors in turn affect the reliability and reproducibility of the measurements. The type of probe used is another factor affecting the recording of accurate values, as shown in a study comparing Nabers probes with the TPS probe, the results of which showed that the TPS probe underestimated furcation degrees significantly (Kim *et al.*, 1996).

Table 2. Classifications proposed for furcation involvement.

1. Glickman classification (1953)	Grade I. Pocket formation into the furcation, but intact interradicular bone. Grade II. Loss of interradicular bone and pocket formation but not extending through to the opposite side. Grade III. Through-and-through lesion. Grade IV. Through-and-through lesion with gingival recession, leading to a clearly visible furcation area.
2. Goldman *et al.* classification (1958)	Grade I. Incipient. Grade II. Cul-de-sac. Grade III. Through-and-through.
3. Staffileno's classification (1969)	Based on surface location, number of bony walls, degree of furcation exposure, as follows: Class I. Furcations with a soft tissue lesion extending to furcal level but with minor degree of osseous destruction. Class II. Furcations with a soft tissue lesion and variable degree of osseous destruction but not a through-and-through communication through the furca. Class II F. Furcations with osseous destruction from facial aspect only. Class II L. Furcations with osseous destruction from lingual aspect only. Class II M. Furcations with osseous destruction from mesial aspect only. Class II D. Furcations with osseous destruction from distal aspect only. Class III. Furcations with osseous destruction that present with through-and-through communication from buccal to lingual aspect or mesial to distal aspect.

Table 2 continued overleaf...

...Table 2 continued

4. Easley and Drennan (1969)	Class I. Incipient involvement, fluting coronal to furcation entrance is involved, but there is no horizontal component to the furca. Class II. Divided further into Types 1 and 2 Type 1. A definite horizontal loss of attachment into the furcation, but pattern of bone loss remains horizontal. Type 2. There is a buccal or lingual bony ledge and a definite vertical component to the furcation. Class III. Through-and-through loss of attachment into the furcation, and the pattern is horizontal in Type 1 and vertical in Type 2.
5. Hamp *et al.* (1975)	Degree I. Horizontal loss of periodontal tissue support not exceeding one third of the width of the tooth. Degree II. Horizontal loss of periodontal support exceeding one third of the width of the tooth, but not encompassing the total width of the furcation area. Degree III. Horizontal through-and-through destruction of the periodontal tissue in the furcation.
6. Rosenberg (1978)	*Horizontal* Degree I. When the result of probing is not greater than 4 mm. Degree II. When probing shows a value greater than 4 mm (i.e., the bifurcation lesion has already passed the center of the trifurcation). Degree III. Two or three furcations classified as degree II are found. *Vertical* Shallow. Slight lateral extension of an interradicular defect, from the center of the trifurcation in a horizontal direction, toward one or both adjacent furcations. Deep. Internal furcation involvement denotes the greater lateral extension of the interradicular defect into but not penetrating the adjacent furcation.
7. Ramfjord & Ash (1979)	Class I. Beginning involvement. Tissue destruction <2 mm (1/3 of tooth width) into the furcation. Class II. Cul-de-sac, tissue destruction >2 mm (>1/3 of tooth width), but not through-and-through. Class III. Through-and-through involvement.
8. Goldman and Cohen (1980)	Degree I. Involves furcation entrance. Degree II. Involvement extends under the roof of furcation but not through-and-through. Degree III. Through-and-through involvement.
9. Ricchetti (1982)	Class I. 1 mm of horizontal measurement; the root furrow. Class Ia. 1–2 mm of horizontal invasion; earliest damage. Class II. 2–4 mm of horizontal invasion. Class IIa. 4–6 mm of horizontal invasion. Class III. >6 mm of horizontal invasion.
10. Tal and Lemmer (1982)	The degree of severity of the furcation defects affecting each molar is assigned to one of four groups designated 1, 2, 3 and 4, referred to as furcation involvement index (FII) scores. Furcal rating 1. Depth of the furcation is 0 mm. Furcal rating 2. Depth of the furcation is 1 to 2 mm. Furcal rating 3. Depth of the furcation is 3 mm. Furcal rating 4. Depth of the furcation is 4 mm or more.
11. Tarnow & Fletcher (1984)	Each grade of furcation is further subdivided into three subgroups, based on the degree of vertical involvement. Subclass A. 0–3 mm. Subclass B. 4–6 mm. Subclass C. >7 mm.

Table 2 continued overleaf...

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12. Eskow and Kapin (1984)	Furcation involvement is classified as grade I subclasses A, B, and C. Sub-classification to classifications is based on the degree of vertical involvement and includes: Subclass A. Vertical destruction up to one third of total interradicular height. Subclass B. Vertical destruction reaching two-thirds of the interradicular height. Subclass C. Vertical destruction beyond apical third of interradicular height.
13. Fedi (1985)	Combined Glickman and Hamp classifications: Grades are same as Glickman's grades I through IV, but grade II is subdivided into degrees I and II. Degree I. The furcation bone loss possesses a vertical component of >1 but <3 mm Degree II. The furcation bone loss possesses a vertical component of >3 mm, but still does not communicate through-and-through.
14. Grant *et al.* (1988)	Class I. Involvement of the flute only. Class II. Involvement partially under the roof or dome. Class III. Through-and-through loss of furcation bone and attachment.
15. Basaraba (1990)	Class I. Initial/incipient furcation involvement. Class II. Partial/patent furcation involvement. Class III. Patent furcation involvement that communicates with 2nd or 3rd furcation opening; *i.e.* communicating furcation involvement.
16. Carnevale *et al.* (1997)	Modified Hamp *et al.* (1975) classification wherein the horizontal depth of furcation involvement is expressed in terms of 3 mm instead of thirds.
17. Nevins and Capetta (1998)	Class I. Incipient or early loss of attachment. Class II. A deeper invasion and loss of attachment that does not extend to a complete invasion. Class III. Complete loss of periodontium extending from buccal surface to lingual surface. Diagnosed radiographically and clinically.
18. Hou *et al.* (1998)	Classification based on root trunk length and horizontal and vertical bone loss. Types of root trunk: Type A. Furcation involving cervical third of root length. Type B. Furcation involving cervical third and cervical two thirds of root length. Type C. Furcation involving cervical two thirds of root length. The different classes of furcation are: Class I. Horizontal loss of periodontal tissue support <3 mm. Class II. Horizontal loss of support >3 mm, but does not encompass the total width of the furcation area. Class III. Horizontal " through-and-through" loss of periodontal tissue in the furcation. Subclasses of furcation involvement relate to alveolar bone loss from the furcation roof apically to the root apex by radiographic assessment of the periapical view. Sub-class 'a'. Suprabony defect. Sub-class 'b'. Infrabony defect. Classification of furcation: AI, AII, AIII. Type A root trunks with class I, class II and class III furcations. BI, BII, BIII. Type B root trunks with class I, class II and class III furcations. CI, CII, CIII. Type C root trunks with class I, class II and class III furcations.
19. Glossary of periodontal terms (2001)	Class I. Minimal but notable bone loss in furcation. Class II. Variable degree of bone destruction but not extending completely through furcation. Class III. Bone resorption extending completely through furcation.
20. Walter *et al.* (2009)	Modification of the Hamp *et al.* classification, wherein degree II is divided into degrees II and II–III. Degree II. Horizontal loss of support >3 mm, but no more than 6 mm. Degree II–III. Horizontal loss of support >6 mm, but no detectable '' through-and-through'' destruction.

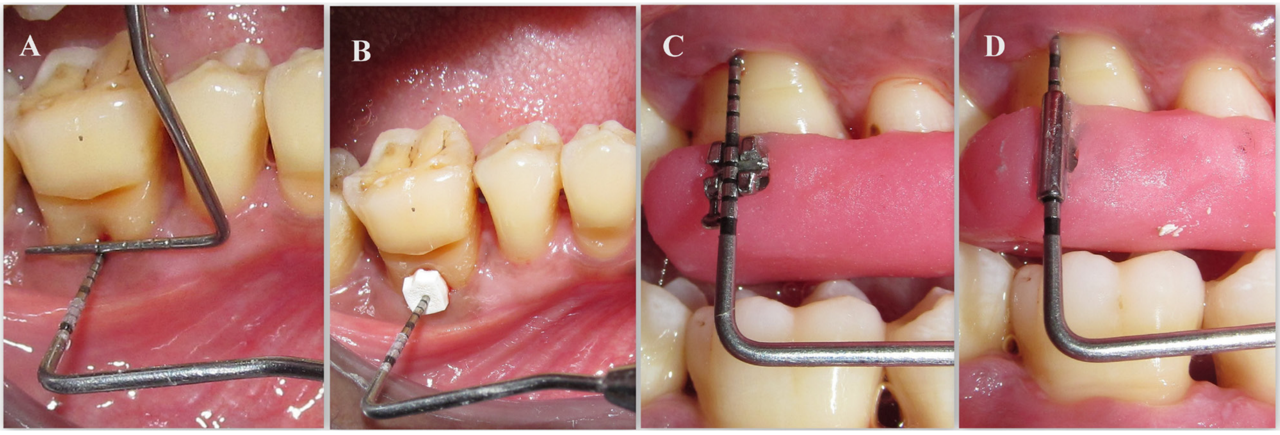

Figure 2. Clinical furcation measurement techniques: A) Furcation measurement using intersection of two periodontal probes; B) Rubber stop placed on a periodontal probe acting as a reference point for depth of penetration; C) Stent with an orthodontic bracket acting as a reference point both for probe penetration and measurement of depth of furcation involvement; D) Stent with an orthodontic molar tube acting as a reference point both for probe penetration and measurement of depth of furcation involvement.

To measure the depth of furcation involvement, a straight probe, like the UNC-15 probe with 1 mm markings, is inserted into the periodontal pocket along the root surface to locate the initial fluting of the furcation. Once located, the distance from the gingival margin to the opening of the furcation is noted. The probe is then advanced apically until resistance is felt and the distance from the gingival margin to the vertical depth of probing is noted. The VPD of the furcation is recorded to the nearest millimeter as the difference between the two values. Similarly, the HPD of the furcation defect can be determined by measuring the horizontal extent of probe penetration into the furcation (Mealey *et al.*, 1994). To detect furcation involvement with a furcation probe, the tip of the probe is moved towards the presumed location of the furcation and then curved into the furcation area. For the mesial surfaces of maxillary molars this is best done from a palatal direction, as the mesial furcation is located palatal to the midpoint of the mesial surface. The distal furcation of maxillary molars is located more towards the midline, and may be detected from a buccal or palatal approach (Lindhe *et al.*, 2008).

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Various reference points have been routinely employed to measure the HPD of furcation defect using straight probes. One such approach uses two probes (*Figure 2A*), wherein the first periodontal probe is inserted into the furcation until its horizontal depth is reached, followed by placement of a second probe held against the furcation such that the point of intersection of the two probes indicates the depth of the horizontal component of the defect (Reddy and Jeffcoat, 2000). The disadvantage with this technique is that holding the reference probe at exactly the same point and the point of probe intersection is not easily reproducible, especially in the posterior regions of the mouth (Laxman *et al.*, 2009; Black *et al.*, 1994). Likewise, polyvinyl chloride (PVC) stops can provide fairly accurate defect depth values when positioned on the probe and inserted into the furcation in such a way that the stop would rest at the root surface concavity at the furcation entrance (*Figure 2B*). However, with this method the coronal position of the gingiva in some cases may obstruct the visual control (Zappa *et al.*, 1993). Further, the initial fluting of the furcation entrance can be used as a fixed reference point from which the VPD and HPD measurements can be made (Mealey *et al.*, 1994): while this can be done to standardize the reference point, the presence of the soft tissue covering the furcation fluting interferes with visualization and it is a subjective method, limiting its use (Zappa *et al.*, 1993; Mealey *et al.*, 1994). Also, an imaginary plane can be drawn tangential to the external root surface as a reference from which measurements can be taken (Pontoriero and Lindhe, 1995). This technique too has a lower reliability when used for measurements of distolingual furcations due to the impossibility of direct vision and difficulties probing this remote location (Pontoriero and Lindhe, 1995; Cortellini *et al.*, 1993; Eickholz and Staehle, 1994). Alternatively, custom stents can be used as fixed reference guides to measure the depth of probe penetration, which has been found to be a more promising method (Laxman *et al.*, 2009; Suh *et al.*, 2002).

Suh *et al.* (2002) fabricated stents that had vertical grooves made on the buccal and lingual extensions to the stent, which guided accurate probe placement. Similarly, Laxman *et al.* (2009) designed a stent that had a hole corresponding to the furcation entrance on the buccal plate of the stent which extended to the attached gingiva; the outer surface of the hole served as a reference point for measurements.

For vertical measurements, orthodontic brackets and molar tubes can be fixed to the acrylic stents such that the upper or lower margins serve as reference points for recordings. Further, such stents would permit consistently accurate and reproducible slots for placement of the probes, as shown in *Figure 2C* and *2D*.

These studies confirm that the various clinical methods of furcation evaluation by probing provide only an arbitrary clue to the severity of furcation involvement (Darby *et al.*, 2014), that the chances of misinterpreting the values remain high because of the inherent limitations of probes, and that specialized furcation probes have proved to be better than straight probes. With respect to the referencing system, custom stents have been shown to be fairly precise and reliable in monitoring the real time changes in the HPD of the furcation.

Furcation bone sounding

This method is a trans-gingival probing technique that is used, under anesthesia, to plot the morphological outline of the furcation defect (Laxman *et al.*, 2009; Black *et al.*, 1994). Various studies have shown that furcation bone sounding measurements are very close to open bone measurements. The average difference between furcation bone sounding measurements and surgical measurements is 0.4 to 0.5 mm (Mealey *et al.*, 1994). Additionally, in another study, Suh *et al.* (2002) reported vertical and horizontal open bone levels to be 0.9 to 1.1 mm deeper than probing bone levels.

Because furcation bone sounding gives consistent measurements that are equivalent to open bone measurements, and in addition avoids a re-entry procedure, it can be considered as a good substitute for open bone measurements.

Surgical measurements

Various methods have been proposed for direct measurements following surgical exposure of the furcation defect, which gives the most accurate values.

Open bone measurements with probes

Following the reflection of the facial and lingual flaps, and the debridement of the defect area, measurements of the vertical attachment level (VAL) can be made to the nearest millimeter with a UNC-15 probe from the furcation fluting to the base of the defect. Similarly, horizontal attachment level (HAL) can be measured with a furcation probe from the furcation fluting to the horizontal extent of the defect. As the measurements of the defect are carried out directly, this method is considered to be the gold standard against which other methods are compared (Mealey *et al.*, 1994).

Comparison of clinical measurements using the Nabers probe, TPS probe and UNC-15 probe with intra-surgical measurements showed that for all probes, a statistically significantly smaller measurement error was observed in buccal and lingual sites than in mesial and distal furcations, and no significant differences were noted between pre- and intra-surgical HAL using the Nabers probe (Eickholz and Kim, 1998). Similarly, other studies have reported no significant difference between furcation degrees as assessed pre-surgically and intra-surgically with the Nabers probe and concluded that clinical furcation diagnosis provides reliable and valid information for prognosis and therapy of molars exhibiting furcation involvement (Eickholz, 1995; Eickholz and Staehle, 1994). However, controversial results have also been reported in others studies where clinical probing values varied significantly from surgical furcation measurements (Zappa *et al.*, 1993; Graetz *et al.*, 2014).

Impression method

Furcation measurements can also be obtained by taking an impression of the furcation area, as reported by Zappa *et al.* (1993). In this method rubber base impression material is injected into the furcation defect with a syringe, following reflection of full thickness buccal and lingual flaps to expose the furcation area. The impression is then used to calculate the dimensions in terms of the volume of the furcation defect using a Leitz stereomicroscope. This equipment enables three-dimensional visualization of the sample and overlaps macrophotography for recording and examining solid samples with complex surface topography. Zappa *et al.* (1993) reported a mean absolute error for surgical probing measurements as 0.07 mm, and for the impression method as 0.02 mm. However, there are no subsequent studies to validate this. Further, this method is technically demanding, as it requires precisely injecting the impression material into narrow furcations, and limiting the flow of the material to within the furcation area. Also, the distortion caused while drawing out the set impression can be a challenge. Adding to this is the calculation of the volume of the impression material, for which the authors have suggested employing a stereomicroscope, the use of which requires prior training and sound knowledge of the technicalities, which further limits the feasibility of its practical application.

Mathematical algorithm

Calculation of the volume of a furcation defect can also be carried out using a mathematical algorithm following the reflection of facial and lingual flaps and direct linear measurements of the defect morphology, as given by Bowers *et al.* (2003). The algorithm used was:

$$\frac{(\text{ROF-BOD})^2 (\text{RDCB}) (\text{HBOD-F})}{2(\text{ROF-COB})}$$

ROF-BOD denotes roof of furcation to base of defect, RDCB denotes root divergence at crest of bone, HBOD-F denotes horizontal extent (base) of defect at level of crest of bone, ROF-COB denotes roof of furcation to crest of bone at furcation entrance. Even though this method appears promising, there are no further studies to validate it.

From evidence in the literature, it can be concluded that the clinical method of bone sounding and clinical probing with furcation probes such as the Nabers probe can be simple, practical and reliable approaches for assessing the HAL and VAL dimensions of furcation involvement, without the need for surgical exposure of the furcation defect. When comparing furcation probing clinically and intra-surgically, it has been shown that clinical measurements underestimate the values compared to intra-surgical measurements because clinical probing assesses only horizontal tissue attachment, whereas intra-surgical probing assesses up to the bone level, which can be simulated with furcation bone sounding.

Radiographic diagnosis

Traditionally, radiographic assessments in conjunction with clinical probing have been the chief diagnostic methods for detecting and characterizing furcation involvement. If radiographs are taken properly and processed, they can be used as a valuable supplementary tool in periodontal disease diagnosis to reveal the morphologic characteristics of alveolar bone (Gusmao *et al.*, 2014). Conventional radiographs are intra-oral peri-apical (IOPA) radiograph and orthopantomograms (OPG).

Conventional radiography is a 2-dimensional interpretation of a 3-dimensional object and is a mainstay in periodontal diagnosis because of its user-friendly image acquisition, cost effectiveness and ready accessibility. An OPG showing furcation involvement is shown in *Figure 3A*. Furcation involvement has been reported to be detected more frequently by conventional periapical radiographs compared to clinical measurements. The incidence of detection by IOPA was 22% in maxillary molars and 8% in mandibular molars, whereas for clinical examination it was 3% and 9% in maxillary and mandibular molars respectively (Ross and Thompson, 1980). Further, furcation involvement can be correctly identified with accuracy of 40.4% with panoramic radiographs, 43.7% in intra-oral dental radiographs and 54% with clinical probing alone (Topoll *et al.*, 1988).

The use of radiographs to diagnose proximal maxillary molar furcation involvement has always been a matter of debate. Hardekopf *et al.* (1987) proposed the term "furcation arrow" for a "subtle shadow" in the radiographs of maxillary first molars over the mesial root. The sensitivity of the furcation arrow image as a diagnostic marker was shown to be just 38.7% (Topoll *et al.*, 1988). It can be extrapolated that radiographs are more reliable in assessing furcation involvement in maxillary molars than by clinical examination, which is the opposite compared to the mandible. In addition, it can be inferred that the precision of conventional radiographs improves as the severity of the furcation involvement increases (Gusmao *et al.,* 2014). Thus, the shortcomings in traditional radiographs include an inability to detect initial alveolar bone changes, leading to variability in the perception of furcation involvement, distortions and variability in image quality due to processing errors, and overlapping of structures due to their 2-dimensional nature, further limiting the reliability in diagnosis (Jeffcoat, 1992; Furhmann *et al.*, 1997; Young *et al.*, 1996).

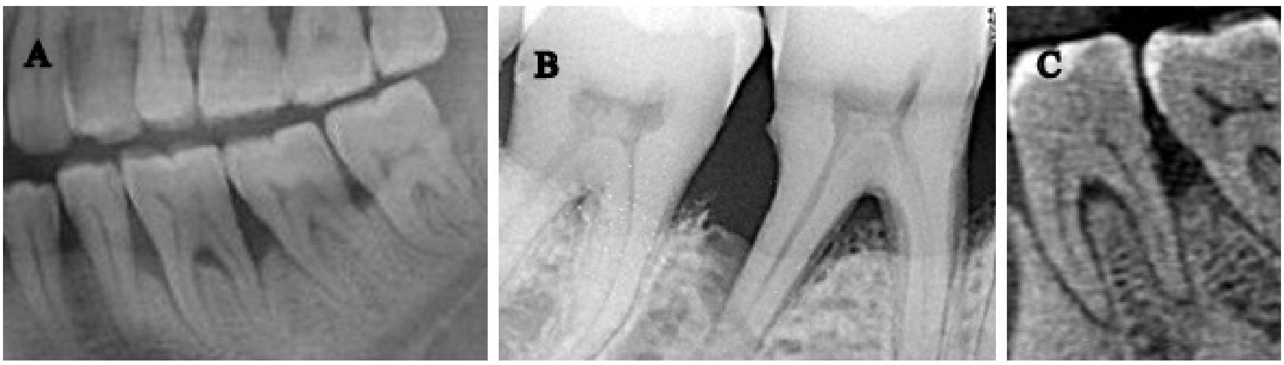

Figure 3. Radiographic techniques of furcation measurement: A) A section of an orthopantomograms (OPG) showing furcation involvement with respect to a mandibular molar; B) A radiovisiograph (RVG) showing furcation involvement with respect to a mandibular molar; C) A cone beam computed tomograph (CBCT) of a mandibular molar with furcation involvement.

Digital radiographs

Radiovisiography (RVG) uses a digital detector to capture the radiographic image, which eliminates the chemical processing, reduces radiation exposure and offers tools for precise measurements (Mouyen and Benz, 1989; Bragger *et al.*, 1988). An RVG showing furcation involvement is shown in *Figure 3B*. Radiographic evidence of interproximal bone loss can be considered as a fairly reliable indicator of possible initial interradicular bone loss. Grover, *et al.* (2014) reported a common association of early interradicular bone loss with an interproximal bone loss of around 4 mm. Comparison of images of digital intraoral radiographs (IOR) with cone beam computed tomography has shown that over- and underestimations of furcation defects are both 50% for the digital IOR, with a mean of 0.56 mm for the overestimations and 0.55 mm for the underestimations. Also, there is a 49% chance that a furcation defect may be left undetected in a digital IOR (Vandenberghe *et al.*, 2008). Another study (Young *et al.*, 1996), reported large underestimation of furcation lesions by 67% using RVG, showing that considerable variation may result in either underestimation or overestimation of bone loss.

Subtraction radiography

This technique permits visualization of change in image densities at different time intervals and allows detection of mineral changes as little as 5%. Subtracted images of furcation lesions, when compared to physical measurements of the area and volume of interest, showed an overall 67% underestimation of the bone loss; however, in deeper lesions, the underestimation was only about 4%, which could be due to structured noise of the image produced by inadequate alignment of the radiographs (Young *et al.*, 1996). At present, this imaging system is not sufficiently accurate to determine furcation bone loss, and it involves time and effort, which could limit its usefulness as a diagnostic tool (Young *et al.*, 1996). However, computer-assisted densitometric image analysis (CADIA), has shown favorable results over digital subtraction radiography when used to study alveolar bone density changes in furcations (Bragger *et al.*, 1988; Bragger *et al.*, 1989).

Digital image ratio

This method is based on computation of the mass ratio of digitalized radiographs. It directly shows changes in alveolar bone mass, and thus avoids some of the drawbacks of quantitative digital subtraction radiography. Further, it takes the advantage of low X-ray machine voltage [50 kilovolts (Kv)] at short exposure times, making it possible to study several sites on the same patient with a low radiation dose (Jean *et al.*, 1996a; 1996b). However, there are no subsequent studies to further substantiate this method as being effective for accurate measurements of furcation involvement.

Computed tomography (CT)

Computed tomography is a sophisticated X-ray procedure used to view cross-sectional images of the furcation without superimpositions. It uses X-rays emitted from a fan-shaped X-ray source to produce sectional images of the area of interest that are captured by crystal or gas detectors, then the intensity of the X-ray beam emerging from the patient is measured and converted into digital data, which are further converted into a gray scale representing different tissue densities, allowing three dimensional visual images to be generated. It has been reported that CT can identify 100% of HAL and VAL furcation involvement (Furhmann *et al.*, 1997). Further, another study (Mengel *et al.*, 2005), showed the possibility of measurements of all furcations in three planes and a clear-cut differentiation between Class I, II, and III furcations; these measurements of the radiographic images, when compared to histologic sections, have a mean deviation of 0.16 ± 0.10 mm.

Similarly, a recent study (Laky *et al.*, 2013) compared clinical probing using a Nabers probe with CT scans, and reported that the degree of furcation involvement on clinical findings was confirmed by CT in 56% of the sites, whereas clinically 21% were overestimated and 23% underestimated. Only 32% of Class III furcations detected by CT scan were detected clinically. However, despite the attractive features, it also has certain drawbacks: firstly, it has a high radiation dose, high cost, unfavorable cost-benefit ratio, and low resolution (Schuller *et al.*, 1992; Vandenberghe *et al.*, 2007), and secondly, CT scans can be degraded in patients with apically extended fixed restorations and metallic fillings, limiting the CT image quality (Vandenberghe *et al.*, 2007).

Cone beam CT (CBCT)

CBCT is also known as digital volume tomography (DVT). The working principle of CBCT is similar to CT, except that it employs a cone-shaped X-ray beam instead of the flat fan-shaped beam used in CT, which helps to record the patient volume in a single rotation, thereby lowering the radiation dose and saving on cost. A CBCT image showing a Class III furcation involvement is shown in *Figure 3C*. Various authors (Mengel *et al.*, 2005; Vandenberghe *et al.*, 2007) have reported that furcation involvement can be differentiated into Class I, II and III furcations clearly with both CT and CBCT. However, in terms of image quality the CBCT scans were superior to the CT scans, with the periodontal ligament space in particular being represented exactly in all three planes, and that CBCT resolution can be as small as 0.2 mm, as compared to 0.5-1 mm for CT. In comparison with intraoral radiographs, studies have shown a significant advantage of CBCT owing to its high resolution and three dimensional capabilities to assess buccal and lingual surfaces, which makes it a very reliable tool for detecting incipient furcation involvement (Umetsubo *et al.,* 2014; de Faria Vasconcelos *et al.,* 2012; Misch *et al.,* 2006).

When clinical probing measurements versus CBCT were compared to diagnose furcation involvement, it was shown that clinical probing either over- or underestimated the actual extent of furcation involvement. This was especially so in the case of Class I furcation involvement, where it was commonly overestimated (Darby *et al.,* 2014). Similarly, surgical and CBCT measurements have been shown to be equivalent about 82-84% of the time, and very rarely over- and underestimated, which makes CBCT measurements a reliable alternative to surgical measurements (Qiao *et al.*, 2014; Walter *et al.*, 2009; Umetsubo *et al.,* 2012).

With the advent of digital technology, the diagnostic efficacy of radiographs are improved. Even though, CBCT is more accurate compared to other techniques in diagnosing furcation involvement, the evidence is not compelling enough to recommend a CBCT scan to diagnose furcation involvement in view of its high radiation levels.

We should understand the strengths and weaknesses of diagnostic imaging, and weigh the costs and benefits, with due consideration to the amount of radiation exposure, before prescribing it (Darby *et al.,* 2014; Walter *et al.,* 2012). It has also been emphasized that radiographs are not superior to clinical findings and are only ancillary tools to diagnosis (Payot *et al.,* 1987; Waerhaug, 1980). These points imply that clinical diagnosis should be combined with radiographic findings for improving the precision in diagnosis (Gusmao et al., 2014).

New frontiers

The quest for accurate and reliable diagnosis of furcation defects has led to the evolution of newer diagnostic tools, which can improve our ability to diagnose more precisely and accurately.

Natural frequency analysis

Natural frequency is the dynamic response of a vibrating object related to the material properties and boundary conditions of the structure. This method requires the placement of an electronic transducer on the area of interest, and the passing of a low-voltage current through the transducer. The resistance to the vibration of the transducer in the surrounding bone is digitally registered. Originally, it was used for evaluating stability of natural teeth and implants. It has recently been shown to have higher identification rate of furcation involvement than traditional diagnostic methods, and it has been suggested that it be combined with traditional methods to overcome inaccuracies in measurements (Wang *et al.*, 2009). Similar to the digital image ratio study, there have been no subsequent studies carried out to validate its usefulness in measurement of furcation involvement.

Ultrasonography

Ultrasonography is a non-invasive investigation technique that uses a very high frequency (7.5-20 MHz) pulsed ultrasound beam to produce high-resolution images of structures. As the ultrasound waves travel through the tissues, some of them are reflected back by tissue interfaces to produce echoes that are picked up and converted into electrical signals, which in turn are converted into black, white and grey images and are displayed on a computer screen. Using ultrasound in furcation diagnosis, a study by Chandrashekhar *et al.* (2014) showed that it was 76% accurate as compared to surgical measurements (clinical measurements showed 70% accuracy). Further studies, however, are required to substantiate its effectiveness in furcation measurements.

Optical coherence tomography (OCT)

The optical coherence tomography system uses a white light that is able to penetrate into the tissues without biologically harmful effects. Differences in the reflection of the light are used to generate a signal that corresponds to the morphology and composition of the underlying tissues. It has been reported to be a new diagnostic tool and as a sensitive method for detecting periodontal defects (Otis *et al.*, 2000). Colston *et al.* (2000) reported that OCT can be used for precise measurement of both volumes and distances, and used to interpret both soft and hard tissues. This system is alleged to be able to provide both 2- and 3-dimensioal intraoral images with good lateral and axial optical resolution and good microstructural detail. Also, using this new technology, visual recordings of periodontal tissue contour, sulcular depth and connective tissue attachment are possible. However, presently there are no studies conducted to assess the efficacy of OCT in furcation measurements.

Fiberscopes

Fiberscopes are based on fiberoptic endoscopy technology, and they are minimally invasive miniature periodontal endoscopes with which a magnification of 24-48X can be achieved. Fiberscopes, when applied clinically as reported by Ozawa *et al.* (1999), allowed visualization of the fields involved in periodontal disease. When inserted through a fistula, the extent of bone loss, the soft tissues and root surfaces involved in periodontal lesions could be differentiated. It can also be applied to furcation diagnosis; however, to date there are no studies conducted to assess the efficacy of fiberscopes in furcation measurements.

Conclusion

In spite of the availability of an array of diagnostic aids, accurate measurement of the degree of furcation involvement in periodontal disease still remains a potential challenge to the practitioner. Clinical probing provides a fairly accurate picture of the extent of destruction within the furcation; it is simple, practical and the least expensive compared to all other methods. Bone sounding and advanced radiography seem to provide values that are closest to the actual existing bone levels. Modern digital radiography like CBCT have been shown to be very reliable and promising gauges; however, the high cost and lack of availability limits it primarily to use as a research tool, and its large scale clinical usage is still far from a reality in diagnosing furcation involvement. In addition, other parameters, such as the diagnostic experience of the examiner, tooth anatomy and the type of diagnostic aid, adds to the complexity in diagnosing furcation involvement. Hence, it can be concluded at this time that the present furcation diagnostic techniques do not have sufficient long-term controlled documentation to substantiate the diagnostic advantage of one technique over the other, and that no single method is totally accurate and reliable. A combined assessment with one or more techniques may prove to be a better guide.

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