การเปรียบเทียบการประเมินสภาวะปริทันต์บริเวณง่ามรากฟันกรามด้วยภาพรังสีในช่องปากและภาพรังสีโคนบีมคอมพิวท์โทโมกราฟี

นางสาวเมธิยา นิมิตรปัญญา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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ปีการศึกษา 2557

COMPARISON BETWEEN INTRAORAL RADIOGRAPHY (IOR) AND CONE BEAM COMPUTED TOMOGRAPHY (CBCT) FOR THE ASSESSMENT OF MOLAR FURCATION INVOLVEMENT

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Periodontics
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Thesis Title	COMPARISON BETWEEN INTRAORAL RADIOGRAPHY (IOR) AND CONE BEAM COMPUTED TOMOGRAPHY (CBCT) FOR THE ASSESSMENT OF MOLAR FURCATION INVOLVEMENT
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เมธิยา นิมิตรปัญญา : การเปรียบเทียบการประเมินสภาวะปริทันต์บริเวณง่ามรากฟันกรามด้วยภาพรังสีในช่องปากและภาพรังสีโคนบีมคอมพิวท์โทโมกราฟี (COMPARISON BETWEEN INTRAORAL RADIOGRAPHY (IOR) AND CONE BEAM COMPUTED TOMOGRAPHY (CBCT) FOR THE ASSESSMENT OF MOLAR FURCATION INVOLVEMENT) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ทพญ. ดร.กนกวรรณ นิสภกุลธร, 48 หน้า.

ที่มาและความสำคัญ การทำลายกระดูกบริเวณง่ามรากฟันกรามมักจะถูกบดบังจากภาพถ่ายรังสีในช่องปาก ภาพรังสีโคนบีมคอมพิวท์โทโมกราฟีซึ่งแสดงข้อมูลเป็นภาพสามมิติอาจจะมีประโยชน์ในการประเมินสภาวะปริทันต์บริเวณง่ามรากฟันกราม การวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบระหว่างภาพรังสีในช่องปากและภาพรังสีโคนบีมคอมพิวท์โทโมกราฟีในการประเมินการทำลายกระดูกบริเวณง่ามรากฟันกรามและเลือกแนวทางการรักษา นอกจากนี้ยังประเมินความน่าเชื่อถือของเฟอร์เคชั่นแอร์โรว์ในแง่ของการเป็นตัวทำนายการทำลายกระดูกบริเวณง่ามรากฟันกราม

วัสดุและวิธีการ การวิจัยนี้มีอาสาสมัคร 25 คน ที่เป็นโรคปริทันต์อักเสบระดับปานกลางถึงรุนแรง อาสาสมัครทุกคนจะได้รับการตรวจทางคลินิก การตรวจทางภาพรังสีในช่องปากและทางภาพรังสีโคนบีมคอมพิวท์โทโมกราฟีทั้งช่องปาก ผู้ประเมิน 3 คน จะให้การประเมินระดับการทำลายกระดูกบริเวณง่ามรากฟันกรามและการมีเฟอร์เคชั่นแอร์โรว์โดยใช้ข้อมูลทางภาพรังสี และเลือกแนวทางการรักษาโดยใช้ข้อมูลทางภาพรังสีร่วมกับข้อมูลทางคลินิก อีกทั้งยังประเมินความสอดคล้องกันระหว่างผู้ประเมินในการประเมินสภาวะปริทันต์ด้านต่างๆด้วย

ผลการศึกษา การวิเคราะห์ข้อมูลประกอบไปด้วยฟันกรามจำนวน 168 ซี่ (ฟันกรามบน 81 ซี่ และฟันกรามล่าง 87 ซี่) พบว่า ภาพรังสีในช่องปากและภาพรังสีโคนบีมคอมพิวท์โทโมกราฟีมีความสอดคล้องกันที่ดีในการประเมินการทำลายกระดูกบริเวณง่ามรากฟัน (77.3-80.5%) และการเลือกแนวทางการรักษา (80.3%) ซึ่งภาพถ่ายรังสีในช่องปากมีแนวโน้มให้การประเมินต่ำกว่าการประเมินด้วยภาพรังสีโคนบีมคอมพิวท์โทโมกราฟี ในแง่ของการเลือกแนวทางการรักษาพบว่า กลุ่มการรักษาด้วยวิธีไม่ผ่าตัดมีความสอดคล้องกันสูงมาก (94.6%) มีความสอดคล้องกันปานกลางในกลุ่มถอนฟัน (71.9%) ในขณะที่มีความสอดคล้องกันต่ำในกลุ่มการรักษาด้วยวิธีผ่าตัด (56.8%) การประเมินด้วยภาพรังสีโคนบีมคอมพิวท์โทโมกราฟีมีค่าความสอดคล้องกันระหว่างผู้ประเมิน (เฟลิสคัปปา) และค่าเปอร์เซ็นต์ความสอดคล้องกันทั้งหมดของผู้ประเมินทั้งสามคนสูงมากและสูงกว่าการประเมินด้วยภาพรังสีในช่องปากในการประเมินทุกประเภท นอกจากนี้ยังพบว่า เฟอร์เคชั่นแอร์โรว์มีความสัมพันธ์กับการทำลายกระดูกบริเวณง่ามรากฟันกรามอย่างมีนัยสำคัญโดยมีความไว ความจำเพาะ ค่าทำนายผลบวกและค่าทำนายผลลบเท่ากับ 0.42 0.86 0.76 และ 0.60 ตามลำดับ

สรุป ภาพถ่ายรังสีในช่องปากเป็นเครื่องมือที่มีความเหมาะสมเมื่อต้องการประเมินว่ามีการทำลายกระดูกบริเวณง่ามรากฟันกรามหรือไม่ อย่างไรก็ตาม ภาพรังสีโคนบีมคอมพิวท์โทโมกราฟีมีความเหนือกว่าเมื่อต้องการประเมินระดับการทำลายกระดูกบริเวณง่ามรากฟันกรามและการเลือกแนวทางการรักษาด้วยวิธีผ่าตัด อีกทั้งยังมีความสอดคล้องกันสูงมากระหว่างผู้ประเมิน เฟอร์เคชั่นแอร์โรว์อาจใช้เป็นตัวทำนายการทำลายกระดูกบริเวณง่ามรากฟันได้

ภาควิชา	ปริทันตวิทยา	ลายมือชื่อนิสิต	....
สาขาวิชา	ปริทันตศาสตร์	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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KEYWORDS: CONE BEAM COMPUTED TOMOGRAPHY (CBCT) / FURCATION BONE LOSS / TREATMENT DECISION / FURCATION ARROW

METHIYA NIMITPANYA: COMPARISON BETWEEN INTRAORAL RADIOGRAPHY (IOR) AND CONE BEAM COMPUTED TOMOGRAPHY (CBCT) FOR THE ASSESSMENT OF MOLAR FURCATION INVOLVEMENT. ADVISOR: ASSOC. PROF. KANOKWAN NISAPAKULTORN, Ph.D., 48 pp.

Background: Furcation bone loss is often obscured in intraoral radiograph (IOR). Cone beam computed tomography (CBCT) provides three-dimensional data, which may be beneficial for furcation assessment. The aim of this study was to compare the assessment of molar with furcation bone loss and furcation treatment by IOR and CBCT. In addition, the reliability of the furcation arrow as a predictor of furcation bone loss was evaluated.

Method: There were twenty-five subjects with moderate to advanced periodontitis. All patients received complete clinical examination, full-mouth intraoral radiographs, as well as CBCT. Three periodontists assessed the degree of furcation bone loss and the presence of furcation arrows, based on radiographic data. The treatment of furcation-involved teeth was determined, based on radiographic and clinical data. The examiner agreement on the assessment was also evaluated.

Results: One-hundred and sixty-eight molars (81 upper molars, 87 lower molars) were included in the analysis. The concordance between IOR and CBCT for the presence of furcation bone loss (77.3-80.5%) and furcation treatment (80.3%) were good, with a trend towards under-estimation. IOR and CBCT had excellent agreement on non-surgical treatment (94.6%). The agreement on tooth extraction was fair (71.9%) whereas the agreement on surgical treatment was low (56.8%). The inter-examiner agreement (Fleiss's kappa) and percentage of complete agreement of CBCT was excellent and higher than IOR for all categories of assessment. The presence of furcation arrow was significantly associated furcation bone loss with the sensitivity, specificity, positive predictive value and negative predictive value of 0.42, 0.86, 0.76 and 0.60, respectively.

Conclusions: IOR is a reasonable tool to identify whether there is furcation bone loss or not. However, CBCT is superior to IOR for assessing the extent of furcation bone loss and surgical planning of furcation treatment. CBCT provides excellent agreement among examiners on furcation assessments. A furcation arrow may be used to predict furcation bone loss.

Department: Periodontology
Field of Study: Periodontics
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Student's Signature ....
Advisor's Signature ....

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CHAPTER I

INTRODUCTION

Background and significance

Diagnosis and treatment of molars with furcation bone loss has always been a challenge. Furcation bone loss is defined as loss of periodontal bone support in the inter-radicular area of multi-rooted teeth. It is generally presented in advanced stage of periodontitis. At the age of 30, approximately 50% of molars showed at least 1 site with furcation invasion (Svardstrom and Wennstrom, 1996). Presence of furcation bone loss poses a risk of further periodontal attachment loss and it is considered an important parameter that worsens tooth prognosis (McGuire and Nunn, 1996). Molars with furcation bone loss also respond less favorable to both non-surgical and surgical treatment (Kalkwarf et al., 1988, Nordland et al., 1987, Pihlstrom et al., 1984). Long term studies showed that approximately 30% of furcation-involved molar were lost even when supportive periodontal therapy was provided (Hirschfeld and Wasserman, 1978, McFall, 1982).

Periodontal examination is important for achieving accurate diagnosis, prognosis and treatment plan. For clinical assessment of furcation-involved molars, a Naber's probe is used to measure horizontal depth in the furcation area. Furcation bone loss is classified by the extent of horizontal bone loss into the furcation. Two commonly used furcation's classification are Hamp's (Hamp et al., 1975) and Glickman's classifications (Glickman, 1958). According to Hamp's classification, Grade I has 3 mm of probable horizontal depth or less whereas Grade II has > 3 mm horizontal depth. For Glickman's classification, Grade I refers to an anatomic fluting of the root without inter-radicular bone loss and Grade II refers to any probable horizontal depth into furcation without a through and through bone loss. Grade III in both classifications defines as a complete bone loss in the furcation or a through and through lesion. Grade IV in Glickman's classification is similar to Grade III but the furcation is clinically seen. Furcation bone loss is also further classified by the extent of vertical bone loss at furcation into subclass A, B, and C, with probable vertical depth of 1-3 mm, 4-6 mm, and >7 mm, respectively (Tarnow and Fletcher, 1984). The classification of furcation bone loss is important for treatment planning, however the reliability of the measurement should be considered.

Several factors influence the accuracy of clinical furcation assessment (Muller and Eger, 1999). The linear horizontal depth of a furcation is measured by a curved Naber's probe, which may result in a slight discrepancy when compared to the intra-surgical or radiographic measurement. The depth of probe penetration depends on the condition of gingival tissue. Inflamed tissue results in a deeper probe penetration. The soft tissue thickness over the furcation entrance also influences the horizontal depth measured. The alignment of the teeth and the location of the furcation entrance sometimes limit the access of the probe. Moreover, the furcation entrance is usually in the subgingival location and the furcation assessment relies on tactile sensation of the operator. Studies showed that clinically assessed furcation bone loss was 20-40% overestimated when compared to the intra-surgical finding. The furcation classification used also affect the degree of overestimation (Zappa et al., 1993).

Periodontal bone loss is the hallmark of periodontal diseases. Therefore, radiographs are considered an important source of information, which complement the data obtained from the clinical examination. At present, intraoral radiography (IOR) including periapical and bitewing radiographs is commonly used because it is simple, relatively low-cost and low radiation dose (Mol, 2004). For furcation assessment, IOR provide information on the level and extent of furcation bone loss as well as root and furcation morphologies. One of the radiographic sign for furcation bone loss is the presence of furcation arrow. A furcation arrow is defined as a small triangular radiolucency over the mesial and distal proximal areas of maxillary molars (Hardekopf et al., 1987). It was shown that 30-44% and 52-55% of furcation arrows was associated with Hamp's grade II and grade III furcation bone loss, respectively. In addition, furcation arrow was shown to predict 38.7% of proximal furcation bone loss presented in the intra-surgical finding. The specificity and sensitivity of a furcation arrow for detection of furcation bone loss was 92.2% and 38.7%, respectively (Deas et al., 2006). Approximately, 7-18% of furcation arrows were found in uninvolved proximal furcations (Deas et al., 2006, Hardekopf et al., 1987).

Although, IOR provides valuable diagnosis information, there are some limitations. The major limitation is the two-dimensional nature of the images. To accurately represent the bone level, the radiographic receptor must be placed parallel to the tooth and the central ray of the X-ray beam is aimed at the right angle relative to the tooth and the receptor (White et al., 2001). However, limited space in both maxilla and mandible may not allow correct receptor placement and result in the distortion of the true bone level. Anatomical structures such as the roots of the maxillary molars and bony exostosis may superimpose with the crestal bone on the radiographic film and conceal the actual bone morphology in the inter-radicular area (Cattabriga et al., 2000). In the mandibular molars, buccal and lingual furcations always superimpose in both periapical and bitewing radiographs. Therefore, IOR may not provide sufficient information for diagnosis and treatment planning of the furcation-involved molars.

Cone beam computed tomography (CBCT) is a new generation of CT that generates three-dimensional data at a lower cost and lower absorbed doses than conventional CT used in medical radiology. CBCT provides high-resolution imaging with high diagnostic reliability (Hirsch et al., 2008). The radiation dose of CBCT for dentoalveolar protocols is 28-265 microsievert (μSv) (Pauwels et al., 2012), as compared to 1320-3324 μSv of conventional CT systems (Scarfe et al., 2006). The CBCT radiation dose was higher than that of a full-mouth intraoral radiograph (40 μSv) and panoramic radiograph (24.5 μSv) (Loubele et al., 2009, Ludlow and Ivanovic, 2008). The worldwide average natural radiation dose to humans is about 2.4 millisievert (mSv) per year, which is four times more than the worldwide average artificial radiation exposure of 0.6 mSv per year (UNSCEAR 2008). It should be noted that the effective dose of CBCT increase significantly as the size of the field of view (FOV), particularly its height, increases (Pauwels et al., 2014). Although, the radiation risk is relatively small, the clinician should select the appropriate FOV size and weight the risk-benefit between risk of radiation exposure and diagnostic data.

It has been shown that CBCT provides an accurate measurement and morphological description of periodontal bone defects (Mengel et al., 2005, Misch et al., 2006, Mol and Balasundaram, 2008, Noujeim et al., 2009, Vandenberghe et al., 2008). Regarding furcation assessment, degree of furcation bone loss evaluated by CBCT and intra-surgical finding was compared (Qiao et al., 2014, Walter et al., 2010). The result showed that 82.4-84% of CBCT data was confirmed by the intra-surgical finding with 11.7-14.7% underestimation and 1.3-5.9% overestimation. The value of CBCT for decision making for furcation surgery was also evaluated (Walter et al., 2009). The study showed that clinical examination and IOR was insufficient in decision making for furcation surgery and resulted in 59-82% discrepancy of teeth studied. On the other hand, with additional information from CBCT, the examiners could make a more definite surgical decision. Moreover, CBCT can provide additional information such as root perforation, root fusion, and root proximity, which offers significant benefits over conventional IOR, especially in buccal and lingual defect (Noujeim et al., 2009). This superior information may justify the use of CBCT in diagnosis and treatment planning of furcation-involved molar teeth. At present, the evidence for the benefit of CBCT in furcation diagnosis and treatment planning is still limited. Therefore, the aim of this study is to compare the use of CBCT and IOR for diagnosis and treatment planning of furcation-involved molar teeth.

Objectives

1. To compare IOR and CBCT for the assessment of molar with furcation bone loss.
2. To compare IOR and CBCT for treatment decision of molar with furcation bone loss.
3. To determine the reliability of a furcation arrow as a predictor of furcation bone loss of maxillary molars.

Hypothesis

1. There are differences between IOR and CBCT in diagnosis of molar with furcation bone loss
2. There are differences between IOR and CBCT in the treatment decision of molar with furcation bone loss.
3. A furcation arrow is a reliable predictor of furcation bone loss in maxillary molars.

Field of research

Cross-section, clinical study

CHAPTER II

LITERATURE REVIEW

Prevalence and significance of molars with furcation bone loss

A furcation is defined as “the anatomical area of multirooted tooth where the roots are separated”. Maxillary molars usually have three root cones, a mesio-buccal, disto-buccal and palatal. Three roots frequently diverge in apical direction, which have three furcation areas locating on buccal, mesial and distal sites. Mandibular molars usually consists of two root cones, mesial and distal, which the inter-radicular area at buccal and lingual is buccal and lingual furcation, respectively. The furcation bone loss is defined as loss of periodontal bone support in the inter-radicular area of multi-rooted teeth and it is generally related to an advanced stage of periodontal disease. The epidemiologic study of periodontal disease in the United States from the third National Health and Nutrition Examination Survey during 1988 to 1994 (NHANES III) reported that 14% of population at the age of 30 to 90 years old had furcation bone loss in one or more teeth (Albandar et al., 1999). A study in 222 Swedish patients (mean age 44.9 years, range 14-73 years) referred for periodontal treatment reported that a half of maxillary molars showed at least 1 site of furcation bone loss at 30 years but the similar prevalence of mandibular molar was observed at 40 years (Svardstrom and Wennstrom, 1996). Cattabriga et al. (2000) reviewed the prevalence of furcation involvement in periodontitis subjects who were referred for periodontal treatment in long-term studies and reported that the prevalence of furcation bone loss in maxillary molars was higher than mandibular molar. It ranged from 25-52% for maxillary molars and 16-35% for mandibular molars (Table 1) (Cattabriga et al., 2000).

Table 1. The prevalence of molars with furcation bone loss (%) in long-term studies of periodontitis subjects

Authors	Upper molar (%)	Lower molar (%)
Hirschfeld and Wasserman (1978)	38.7	29.0
McFall (1982)	25.1	15.9
Goldman et al. (1986)	52.2	19.5
Wood et al. (1989)	42.4	35.9

The furcation bone loss is an important parameter that significantly influences prognosis and treatment plan. According to McGuire and Nunn (1996), the presence of furcation bone loss is considered as a factor that worsens tooth prognosis (McGuire and Nunn, 1996). Moreover, it increases a risk of further attachment loss and tooth loss even when supportive periodontal therapy has been regularly performed (Goldman et al., 1986, Hirschfeld and Wasserman, 1978, McFall, 1982).

Clinical assessment of furcation bone loss

Prognosis and treatment decision of molars depends on the degree of furcation bone loss. Clinically, furcation bone loss is detected by a Naber's probe, which is a curved probe, to measure the horizontal depth. The probe tip is moved toward the furcation entrance and curved into the furcation area. The buccal and lingual furcation are easily detected by a probe because they locate on mid-buccal and mid-lingual side. For the mesial furcation of maxillary molars, a probe should be assessed from a palatal direction since the furcation is palatal to the midpoint of mesial surface. The distal furcation of maxillary molars is near the midpoint so a probe can be inserted from either buccal or palatal direction. For the vertical depth measurement, a straight periodontal probe is normally used. Commonly used classifications to define furcation bone loss are listed in Table 2.

Table 2. Classification of furcation bone loss

Classification	Definitions
Horizontal depth measurement	
Glickman (1958)	*Grade I*: an anatomical fluting of the root without inter-radicular bone loss
	Grade II: any probable horizontal depth into furcation without through and through bone loss
	Grade III: a complete bone loss in the furcation
	Grade IV: a complete bone loss in the furcation, but clinically seen
Hamp et al. (1975)	*Degree I*: less than 3 mm of probable horizontal depth
	Degree II: more than 3 mm of probable horizontal depth
	Degree III: a complete bone loss in the furcation
Vertical depth measurement	
Tarnow & Fletcher (1984)	*Subclass A*: 1-3 mm
	Subclass B: 4-6 mm
	Subclass C: >7 mm

Several factors influence the accuracy of clinical furcation assessment (Muller and Eger, 1999). Alignment of the teeth and the location of the furcation entrance sometimes limit the access of the probe. The soft tissue thickness, the condition of soft tissue over the furcation area, and probing force also affects the horizontal depth measured. The operator experience also influences the validity of the measurement because the probing relies on tactile sensation of operators, especially when the furcation entrance is at sub-gingival location. In addition, the linear horizontal depth of a furcation is measured by a curved probe, which results in a slight discrepancy when compared to the intra-surgical measurement. Zappa et al. (1993) compared clinical and intra-surgical measurement of furcation bone loss in 42 maxillary and 36 mandibular molars. They found that clinical assessment agreed with intra-surgical measurement at 58.3% with an underestimation of 27.8% and overestimation of 13.9% (Zappa et al., 1993) (Table 3).

Assessment of furcation bone loss by intraoral radiography

Conventional radiographs for furcation assessment are IOR including periapical and bitewing radiographs. IOR is commonly used because it is simple, relatively low-cost and low-radiation dose (Mol, 2004). The characteristic of furcation bone loss observed from IOR is a radiolucent area between roots. For maxillary molars, a radiographic sign called "a furcation arrow" can be observed (Figure 1). A furcation arrow is defined as a small triangular radiolucency over the mesial and distal areas of maxillary molars (Hardekopf et al., 1987). This sign has been associated with furcation bone loss. Hardekopf et al. (1987) studied the relationship between furcation arrows and proximal furcation bone loss in dried skull. Of 282 sites of maxillary molars, the prevalence of furcation arrows on the mesial furcation was 44% for degree II and 55% for degree III, and the distal furcation was 30% for degree II and 52% for degree III, according to Hamp's classification. Deas et al. (2006) studied the relationship between furcation arrows and furcation bone loss from the intra-surgical finding. Of 111 proximal sites, furcation arrows can predict 38.7% of proximal furcation bone loss. The specificity and sensitivity of a furcation arrow for the detection of furcation bone loss was 92.2% and 38.7%, while the positive predictive value and negative predictive value was 71.7 and 74.6, respectively. Furcation arrows had false positive about 7-18% in uninvolved furcation (Deas et al., 2006, Hardekopf et al., 1987).

Figure 1. A furcation arrow over a distal furcation of an upper left molar

IOR has been shown to improve the clinicians' ability to detect furcation bone loss. The combination of clinical examination and IOR could improve the detection of furcation bone loss from 3% of maxillary molars and 9% of mandibular molars by clinical examination alone to 65% and 18% of maxillary molars and mandibular molars, respectively (Ross and Thompson, 1980). However, there are some limitations of IOR. The major limitation is the two-dimensional nature of the images. To represent the bone level accurately, the radiographic receptor must be placed parallel to the tooth and the central ray of the X-ray beam is aimed at the right angle relative to the tooth and the receptor (White et al., 2001). Limited space in both maxilla and mandible may not allow correct receptor placement and result in the distortion of the true bone level. Anatomical structures such as the roots of the maxillary molars and bony exostosis may superimpose with the crestal bone on the radiographic film and conceal the actual bone morphology in the inter-radicular area (Cattabriga et al., 2000). In the mandibular molars, buccal and lingual furcations always superimpose in both periapical and bitewing radiographs. Therefore, IOR may not provide sufficient information for diagnosis and treatment planning of molars with furcation bone loss.

Cone beam computed tomography

Computed tomography (CT) is a radiographic technique that enables cross-sectional and three-dimensional (3D) analysis. This 3D imaging technique has been shown to overcome the superimposition problem of the 2D image. An application of CT in periodontal field showed that CT could detect all periodontal bone defects and the deviations of bone level ranged from 0.2 to 0.41 mm, compared to intra-surgical measurement (Naito et al., 1998). However, the use of CT in dentistry has been limited because of the high equipment cost, availability, and radiation dose consideration.

Cone beam computed tomography (CBCT) is an advance in CT imaging that has emerged as a potentially low dose cross-sectional technique for visualizing bony structures in the head and neck region (Miracle and Mukherji, 2009). The first CBCT system became commercially available for the maxillofacial imaging in 1998. Contrary to the conventional CT, it consists of a conical radiographic source and a high performance digital panel detector. The x-ray source and detector rotate around a patient, which acts as a fulcrum. Most CBCT machines are similar in size to a conventional panoramic machine. The CBCT allows the creation of accurate images, not only in the axial planes but also two-dimensional images in the coronal, sagittal, and even oblique or curved image planes. The process referred to the multiplanar reformation (MPR). The CBCT provides clear images of high contrast structures and is well suited for evaluating bone. An effective dose in the broad range of 19-368 μSv can be expected, depending on exposure parameters and the selected field of view (FOV) size. Most CBCT scans have effective doses between 28 and 265 μSv (Pauwels et al., 2012). In comparison, standard panoramic radiography delivers 24.5 μSv and conventional CT with a similar FOV delivers 474-1160 μSv (Loubele et al., 2009, Ludlow and Ivanovic, 2008). Images acquired with higher radiation exposure often produce better image quality (Loubele et al., 2005). In addition, the CBCT image resolution can be as small as 0.08 mm, compared to 0.5-1 mm for the conventional CT (White, 2008). In periodontics, CBCT has been shown to provide an accurate measurement and morphological description of periodontal bone defects. CBCT could detect all defects with mean deviation of 0.13 – 1.67 mm (Braun et al., 2014, de Faria Vasconcelos et al., 2012, Fleiner et al., 2013, Mengel et al., 2005, Misch et al., 2006, Vandenberghe et al., 2008).

Assessment of furcation bone loss by cone beam computed tomography

CBCT has been shown to provide an accurate assessment of furcation bone loss. Vandenberge et al. (2008) compared furcation bone loss assessed by IOR and CBCT to the direct measurement from one cadaver and one dry skull. They showed that CBCT was able to detect and correctly classify 100% of the furcation defects. In contrast, IOR could not detect 44% of the furcation defects and it was not possible to differentiate buccal and lingual furcation involvement (Vandenberghe et al., 2008). Furcation bone loss of periodontitis subjects was evaluated by CBCT and compared to those of intra-surgical measurement (Qiao et al., 2014, Walter et al., 2010). Hamp's classification was used. CBCT assessment was in concordance with intra-surgery assessment at 82-84%, with an underestimation of 12-15% and overestimation of 1-6%. An agreement between CBCT and intra-surgical measurement (weighted kappa) ranged from 0.88 to 0.96. Therefore, CBCT might be used as a standard reference for furcation assessment in order to avoid intra-surgery measurement.

Furcation assessment by conventional means including clinical examination and IOR, have been compared to those using 3D imaging techniques. Fuhrman et al. (1997) use a high-resolution computed tomography (HR-CT), which is a conventional CT with high resolution, to study molar furcation. They found that HR-CT could identify all of the artificial furcation defects created in dry skulls while IOR identified only 21%. Furthermore, HR-CT could classify the degree of furcation bone loss in both horizontal and vertical depth. Several studies showed low concordance on the degree of furcation bone loss between clinical examination and 3D images. Walter et al. (2009) compared clinical examination and CBCT. They found that clinical examination agreed with CBCT at 27%, underestimated at 44%, and overestimated at 29%. Darby et al. (2014) also found that clinical examination agreed with CBCT at 22%, underestimated at 20%, and overestimated at 58%. Laky et al. (2013) compared the degree of furcation bone loss between clinical examination and a low-dose CT. A low-dose CT is a medical CT which has a low-dose mode resulting in a remarked reduction in the radiation dose compared with the conventional CT. They found that clinical examination agreed with low-dose CT at 57%, underestimated at 23%, and overestimated at 20% of the sites. Assessment of furcation bone loss by clinical examination and intra-surgery was also compared (Qiao et al., 2014). Clinical examination was in agreement with intra-surgery only 21.6%. The underestimation was up to 45.1% and the overestimation was 33.3%. It appeared that clinical examination and IOR did not give accurate assessment of furcation bone loss. Studies comparing different modalities of furcation assessment were summarized in Table 3.

Treatment of molars with furcation bone loss

Treatment of molars with furcation bone loss is challenging. The presence of furcation bone loss complicates treatment because they respond less favorably to both nonsurgical and surgical treatment (Kalkwarf et al., 1988, Nordland et al., 1987, Pihlstrom et al., 1984). For nonsurgical treatment, success depends on the accessibility of the instrument to remove local factors. However, 81% of the furcation entrance is 0.75 -1 mm in width, which is narrower than the blade width of a standard curette (Bower, 1979). The difficulty in gaining access to the furcation entrance results in significant more residual calculus (Caffesse et al., 1986, Matia et al., 1986). For periodontal flap surgery, the rationale is to gain access for root planing. Many studies found less residual calculus after flap elevation than closed debridement, especially in deep furcation defects (Caffesse et al., 1986, Fleischer et al., 1989, Matia et al., 1986). Hence, scaling and root planing with or without flap surgery is recommended for molars with shallow furcation defects (Svardstrom and Wennstrom, 2000). Surgical treatment approaches such as tunneling procedure, root resection, root amputation, and regenerative approaches are recommended when the furcation defects are at advanced stage.

Many factors are likely to influence the treatment decision. Tunneling procedure is suitable for mandibular molars with wide furcation entrance and short root trunk (Cattabriga et al., 2000). However, tunneled teeth appear to be at a higher risk for the development of root caries (Hamp et al., 1975, Hellden et al., 1989, Little et al., 1995). For root resection and root amputation, the degree of furcation bone loss, the degree of root separation, residual bone support of an affecting root and endodontic condition is considered a key to successful treatment (DeSanctis and Murphy, 2000, Svardstrom and Wennstrom, 2000). For regenerative procedures, degree of furcation bone loss and tooth position in the jaw are important factors for case selection. Degree II of furcation bone loss was more favorable than degree III (Pontoriero et al., 1987). Proximal furcation of maxillary molars had poor response to periodontal regeneration (Pontoriero and Lindhe, 1995). Tooth extraction is considered when there is inadequate attachment to support the tooth. Therefore, it is important to identify the degree of furcation bone loss and related anatomical factors to determine the most appropriate treatment (Svardstrom and Wennstrom, 2000).

Studies on the value of CBCT for periodontal treatment decision are scarce. Walter et al. (2009) studied 22 maxillary molars in 12 patients with clinical furcation bone loss and deep probing depth. Treatment recommendations, which are no surgical treatment, apically repositioned flap, root separation, root amputation, trisection and extraction, based on clinical examination and IOR were compared to data with additional CBCT. The study showed that clinical examination and IOR was insufficient in decision making for furcation surgery and resulted in 59-82% discrepancy of teeth studied. Intra-surgical changes of the treatment may be required in cases with no additional CBCT data. On the other hand, with additional information from CBCT, the examiners could make a more definite surgical decision. In addition, CBCT provides additional information such as root perforation, root fusion, root proximity, endodontic conditions of the roots, which offers significant benefits over conventional IOR. A cost analysis showed that CBCT data facilitated a reduction in treatment cost and time for maxillary molars with furcation bone loss when compared to treatment recommendations from conventional periodontal method (clinical examination together with IOR), especially when more invasive treatment such as extraction or implant placement are planned (Walter et al., 2012). This superior information may justify the use of CBCT in diagnosis and treatment planning of furcation-involved molar teeth.

Table 3. Studies comparing different modalities of furcation assessment

Authors	Model	Study design	Results and comments
Zappa et al. (1993)	12 patients (42 maxillary molars and 36 mandibular molars) - Mean age 40.5 years - Moderate to severe chronic periodontitis	6 examiners performed clinical examination and 1 examiner performed intra-surgical measurement Furcation assessment - Clinical examination vs. intra-surgical measurement - Hamp's classification Reference: intra-surgical measurement	Clinical vs. intra-surgery - 58.3% concordance* - 27.8% underestimated - 13.9% overestimated * Recalculated from available data
Qiao et al. (2013)	15 Patients (11 first molars, 9 second molars, 51 furcations) - Mean age 43.5 years - Generalized chronic periodontitis	2 calibrated examiners performed clinical examination, 2 examiners performed CBCT evaluation and 2 calibrated examiners performed intra-surgical measurement Furcation assessment - Clinical examination vs. intra-surgical measurement - CBCT vs. intra-surgical measurement - Hamp's classification Reference: intra-surgical measurement	Clinical vs. intra-surgery - 21.6% concordance - 45.1% underestimated - 33.3% overestimated CBCT vs. intra-surgery - 82.4% concordance - 11.7% underestimated - 5.9% overestimated An agreement between CBCT and intra-surgical measurement (weighted kappa) - 0.96 on buccal - 0.88 on mesial - 0.94 on distal

Authors	Model	Study design	Results and comments
Walter et al. (2009)	12 patients (22 maxillary molars) - Mean age 57.5 years - Generalized chronic periodontitis	2 calibrated examiners performed clinical examination, CBCT evaluation, and treatment decision Furcation assessment - Clinical vs. CBCT - Modified Hamp's classification Degree I: < 3 mm probable horizontal depth Degree II: 3-6 mm probable horizontal depth Degree II-III: >6 mm probable horizontal depth but no "through and through" Degree III: a complete bone loss in the furcation Furcation treatment - Clinical and IOR vs. clinical and IOR and CBCT - 11 different treatments was ranked based on invasiveness - 2 examiners decided for treatment together - Several treatments can be selected Reference: CBCT	Furcation diagnosis Clinical vs. CBCT - 27% concordance - 44% underestimated - 29% overestimated Furcation treatment Clinical and IOR vs. clinical and IOR and CBCT - Significant difference in treatment decision - Discrepancy in 59–82% of the teeth

Authors	Model	Study design	Results and comment
Vandenberghe et al. (2008)	1 human cadaver and 1 dry skull (11 molars)	3 examiners performed IOR and CBCT evaluation and direct measurement Detection and classification of furcation bone loss - IOR vs. direct measurement - CBCT vs. direct measurement Reference: direct measurement	IOR - 56% furcation bone loss detection - 20% correctly classified furcation bone loss CBCT - 100% furcation bone loss detection - 100% correctly classified furcation bone loss
Walter et al. (2010)	6 patients (25 maxillary molars) - Mean age 57.0 years - Generalized chronic periodontitis	2 calibrated examiners performed clinical examination, CBCT evaluation and intra-surgical measurement Furcation assessment - CBCT vs. intra-surgical measurement - Hamp's classification Reference: intra-surgical measurement	CBCT vs. intra-surgery - 84% concordance - 14.7% underestimated - 1.3% overestimated An agreement between CBCT and intra-surgical measurement (weighted kappa) - 0.94 on buccal - 0.89 on mesial - 0.95 on distal

Authors	Model	Study design	Results and comment
Laky et al. (2013)	75 Patients (upper and lower molars; 582 furcations) - Mean age 47.8 years - Severe chronic periodontitis	Unknown examiners performed clinical examination and low-dose CT evaluation Furcation assessment - Clinical examination vs. low-dose CT - Hamp's classification Reference: low-dose CT* * Tomoscan SR-600, Philips Medical system, Best, The Netherlands	Clinical vs. low-dose CT - 57% concordance - 23% underestimated - 20% overestimated
Darby et al. (2014)	27 Patients (upper and lower molars; 154 furcations) - Aged between 18-85 years - Moderate to severe chronic periodontitis	Unknown examiners performed clinical examination and 3 examiners performed CBCT evaluation Furcation assessment - Clinical examination vs. CBCT - Hamp's classification Reference: CBCT	Clinical vs. CBCT - 22% concordance - 20% underestimated - 58% overestimated

CHAPTER III

MATERIALS AND METHODS

Study subjects

The subjects were recruited from new patients who visited the Graduated Periodontology clinic between October 2013 to January 2014. Of 104 patients, 25 patients met the inclusion criteria and agreed to participate in the study. The inclusion criteria were the followings: 1) had moderate to advanced chronic periodontitis 2) had at least 14 remaining teeth and 3) had at least one molar with separate roots on an intraoral radiograph. The subjects were excluded if they were pregnant or lactating at that time of the study or had medical conditions that did not allow conventional periodontal treatment.

Clinical examination

The subjects received full-mouth periodontal examination and periodontal charts were recorded by one operator (K.T.). Probing depths and clinical attachment levels were recorded at 6 sites/ tooth using a UNC-15 probe (Hu-Friedy, Chicago, Illinois, USA). Degree of furcation bone was determined using a Naber's probe and recorded according Glickman's classification (Glickman, 1958) as followed: F1-the anatomic fluting between the roots could be felted with a probe, but cannot engage the furcation, no furcation bone loss, F2-partial furcation bone loss, the furcation can be probed, but not through-and-through, F3-total furcation bone loss with through-and-through opening of the furcation. Tooth mobility was evaluated using two blunt instruments and classified according to the Miller's index (Miller, 1938) as followed: Grade I: slightly more than normal (<1 mm horizontal movement); Grade II: moderately more than normal (1-2 mm horizontal movement); Grade III: severe mobility (>2 mm horizontal movement or any vertical movement).

Radiographic image acquisition

All subjects received intraoral radiographs comprising full-mouth periapical radiographs and vertical bitewings of the posterior teeth, using the parallel long cone technique. The radiographs were taken with an intraoral radiographic machine (Kodak 2200 intraoral X-ray system, Carestream Dental LLC, Atlanta, USA) at 70 kV, 7 mA, exposure time 0.2-0.4 s, using F-speed, size 2 films (Kodak Insight, Carestream Dental LLC). Each intraoral radiograph was digitally converted on a flatbed scanner with transparency adapter (Expression 10000XL, Epson, California, USA) at 600 dpi and saved as a JPEG file. The CBCT scans were performed using the 3D Accuitomo 170 machine (J. Morita, Kyoto, Japan). Cylindrical volumes of 100x100 mm, 80 kV, 5 mA, exposure time 17.5 s, and a voxel size of 0.25 mm was used.

Determination of furcation bone loss by IOR and CBCT

Radiographic assessment of furcation bone loss was performed without clinical data. For IOR, furcation bone loss was classified as followed: absence-no radiolucent area within a furcation; presence-had a radiolucent area within a furcation (corresponded to F2 and F3). For upper molars, three furcation sites on buccal (B), mesial (M), and distal (D) was individually assessed. For lower molars, buccal and lingual furcations were assessed together, due to the superimposition of both furcations. In addition, the presence/ absence of a furcation arrow was evaluated at M and D furcations of upper molars. A furcation arrow was defined as a small, triangular radiographic shadow that points toward the furcation entrance on the proximal sides of maxillary molars (Hardekopf et al., 1987). For CBCT, the degree of bone loss was classified as followed: absence-no inter-radicular bone loss; F2-had inter-radicular bone loss but not through-and-through lesion; F3-total inter-radicular bone loss, through-and-through lesion.

Determination of furcation treatment

Furcation treatment was determined based on clinical and radiographic data. The treatment was categorized as 1) non-surgical treatment, 2) surgical treatment, and 3) extraction. Surgical treatment encompassed both resective and regenerative therapy. General guidelines for each treatment were as followed: non-surgical treatment-no or partial furcation bone loss, <5 mm PD at furcation; surgical treatment-presence of furcation bone loss, ≥5 mm PD at furcation; extraction- inadequate attachment to support the tooth (Al-Shammari et al., 2001, Cattabriga et al., 2000, Svardstrom and Wennstrom, 2000).

Furcation assessment

Three periodontists performed furcation assessment of molar teeth. The radiographic images were displayed on a 22-inch LCD monitor (ThinkVision L2250p, Lenovo, Quarry Ba, Hong Kong) at a screen resolution of 1680 x1050 pixels. The digitized intraoral radiographs were put into a PowerPoint presentation to facilitate viewing. Each PowerPoint slide contained the periapical and bitewing radiographic images of one tooth sextant. An example of a PowerPoint slide showing an upper left posterior sextant was shown in Figure 1.

The CBCT images were reconstructed using the OneVolumeViewer software (J. Morita, Kyoto, Japan) and displayed on two monitors. One monitor displayed a simulated panoramic image of the upper and lower teeth, created by the Ray Sum method (Figure 2). Another monitor displayed the CBCT images in the axial, sagittal, coronal, and 3D views (Figure 3). A facilitator, trained by an experienced radiologist, used the software to show the CBCT image of each tooth, one plane at a time, to the examiners. The tooth was first orientated in 3D to make the intersection between the sagittal and coronal planes coincide with the long axis of tooth. The slice scroll-bar was used to display the images of each tooth from the coronal to the apical direction, the mesial to the distal direction, and the buccal to the lingual direction, respectively. The procedure could be repeated as requested by the examiners. All examiners viewed the radiographic images together. First, the examiners were asked to determine the degree of furcation bone loss and the presence of furcation arrows from the radiographic data only. Then, the clinical data were given and the examiners made treatment decision. Each examiner gave his/ her periodontal assessment, independently. An agreement of at least 2 out 3 examiners was considered as a consensus. An agreement of 3 out 3 examiners was considered as a complete agreement. When each examiner gave a different assessment, a discussion was required to reach consensus. There was no time restriction for image viewing and assessment. All examiners were blinded to the identity of the study subjects. Intraoral radiographic images of each subject were evaluated at least one week prior to CBCT image evaluation.

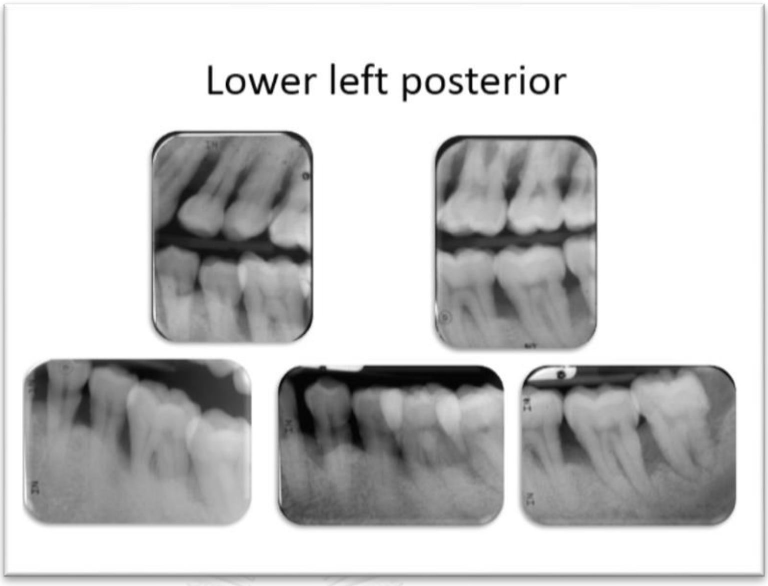

Figure 2. A screen capture of a Power Point slide showing a lower left posterior teeth.

Figure 3. A screen capture of the CBCT images showing a simulated panoramic image created by Ray Sum method.

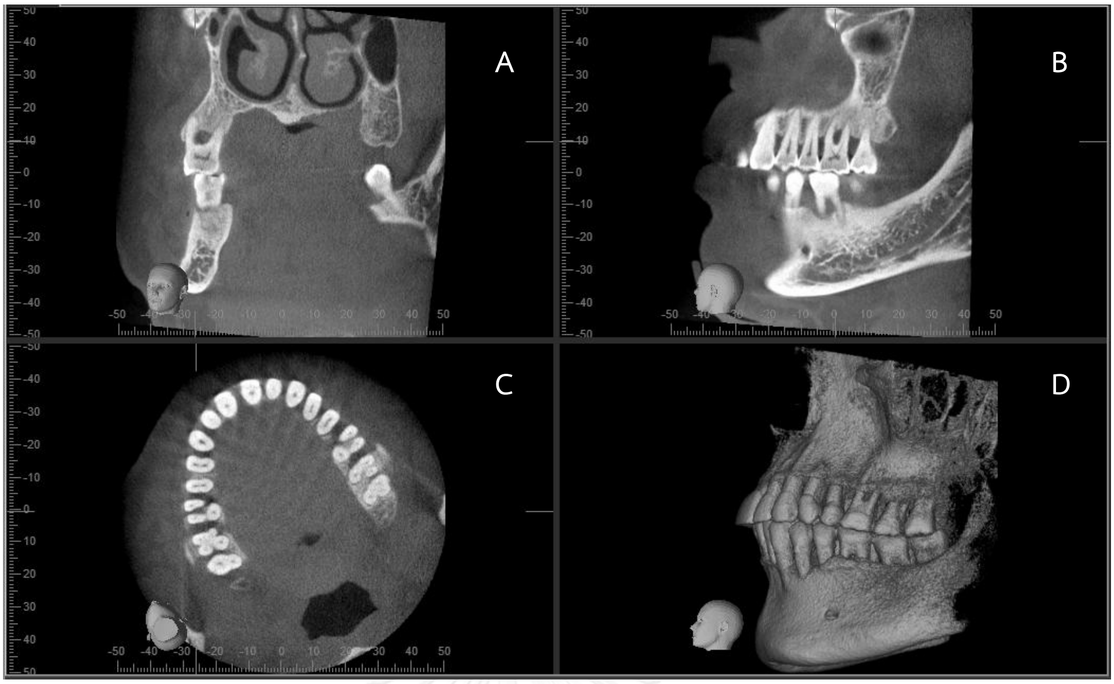

Figure 4. A screen capture of the CBCT images showing the furcation bone loss of upper left first molar in (A) sagittal, (B) coronal, (C) axial, and (D) 3D view.

Statistical analysis

Commercially available statistical software (SPSS, IBM Corp, New York, USA) was used to analyze the data. The radiographic modalities (IOR and CBCT) were independent variables whereas periodontal assessments (degree of furcation bone loss, furcation arrow, and furcation treatment) were dependent variables. The concordance of furcation assessment between IOR and CBCT are calculated. The inter-examiner agreement of furcation assessment was analyzed using Fleiss' kappa (Fleiss, 1971). The association between furcation arrow and degree of furcation bone loss was analyzed using Chi-squared test. Statistical differences with a *P*-value < 0.05 were considered significant.

CHAPTER IV

RESULTS

Twenty-five subjects with an average age of 48.8 years old (range 34-75 years old) participated in this study. Of 192 molars, 24 teeth with fused root were excluded. A total of 168 molars were included in the analysis (81 upper and 87 lower molars).

The prevalence of furcation bone loss assessed by IOR and CBT was comparable. For IOR, the prevalence was 41.6% for upper molars and 37.9% for lower molars (Table 4). The buccal and lingual furcations of lower molars were not separately assessed due to the superimposition of both furcations by IOR. For CBCT, the prevalence was 45.3% for upper molars and 34.5% for lower molars (Table 5). However, clinical examination showed a lower prevalence of furcation bone loss compared to those of IOR and CBCT (Table 6).

Table 4. Prevalence of furcation bone loss assessed by IOR

Furcation location		N	%
Upper	B	28	34.6
	M	28	34.6
	D	45	55.6
	All	**101**	**41.6**
Lower	**B-L**	**33**	**37.9**

Table 5. Prevalence of furcation bone loss assessed by CBCT

Furcation location		F2	F3	Total	
		N	N	N	%
Upper	B	16	13	29	35.8
	M	17	21	38	46.9
	D	21	22	43	53.1
	All	**54**	**56**	**110**	**45.3**
Lower	B	13	13	26	29.8
	L	21	13	34	39.0
	All	**34**	**26**	**60**	**34.5**

We showed that IOR had a good concordance to CBCT for the assessment of furcation bone loss and furcation treatment, with a trend towards underestimation (Table 7). The concordance between clinical examination and CBCT was also good. Clinical examination was very likely to underestimate furcation bone loss, compared to CBCT (Table 8).

IOR and CBCT assessment of furcation treatment is shown in Table 9. IOR and CBCT had excellent agreement on non-surgical treatment (94.6%). The agreement on tooth extraction was fair (71.9%) whereas the agreement on surgical treatment was low (56.8%). It should be noted that out of 36 teeth planned for surgical treatment by IOR, 7 teeth (19.4%) was considered extraction by CBCT.

Table 6. Prevalence of furcation bone loss assessed by clinical examination

Furcation location		F2	F3	Total	
		N	N	N	%
Upper	B	8	7	15	18.5
	M	13	14	27	33.4
	D	22	15	37	45.7
	All	**43**	**36**	**79**	**32.5**
Lower	B	10	4	14	16.0
	L	12	4	16	18.3
	All	**22**	**8**	**30**	**17.2**

Table 7. Concordance on the presence or absence of furcation bone loss between IOR and CBCT on furcation assessment and furcation treatment

		Concordance[*] (%)	Under-estimation[†] (%)	Over-estimation[‡] (%)
Furcation bone loss[§]	Upper	77.3	13.2	9.5
	Lower	80.5	14.9	4.6
Furcation treatment		80.3	13.7	6.0

[§] Furcation bone loss was classified as absence or presence.

[*] The assessment agreed with CBCT.

[†] The assessment was underestimated compared to CBCT.

[‡] The assessment was overestimated compared to CBCT.

Table 8. Concordance between clinical examination and CBCT on furcation assessment

		Concordance* (%)	Under-estimation† (%)	Over-estimation‡ (%)
Furcation bone loss§	Upper	78.6	20.2	1.2
	Lower	75.9	22.4	1.7

§ Furcation bone loss was classified as absence, F2, and F3.

* The assessment agreed with CBCT.

† The assessment was underestimated compared to CBCT.

‡ The assessment was overestimated compared to CBCT.

Table 9. Furcation treatment assessed by IOR and CBCT

		CBCT		
		Nonsurgical	Surgical	Extraction
IOR	Nonsurgical	87	14	2
	Surgical	4	25	7
	Extraction	1	5	23
	Total	**92**	**44**	**32**

The inter-examiner agreement and the percentage of complete agreement on furcation assessment is shown in Table 10. Overall, CBCT showed excellent agreement among examiners whereas IOR had good agreement. However, IOR assessment of upper mesial furcation bone loss had significantly lower agreement than other furcation sites.

We also determined the value of a furcation arrow as a predictor of furcation bone loss. The prevalence of furcation arrows was 27.8% (Table 11). The prevalence at the distal site (40.7%) was much higher than that of the mesial site (14.8%). We observed a higher prevalence of furcation arrows at sites with furcation bone loss (13.6% vs. 42.5%). Presence of a furcation arrow at distal furcations had a much higher false positive rate compared to the mesial furcations (26.3% vs. 2.3%). We found that the furcation arrow was significantly associated with the presence of furcation bone loss using Chi-squared test ($p<0.05$) (Table 12). However, we did not find a positive correlation between the prevalence of furcation arrows and the degree of furcation bone loss (Table 13). Overall, we showed that the presence of a furcation arrow was significantly associated furcation bone loss with the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of 0.42, 0.86, 0.76, and 0.60, respectively (Table 14).

Table 10. Inter-examiner agreement and percentage of complete agreement on furcation assessment by IOR and CBCT

		Inter-examiner agreement (Fleiss' kappa)		Complete agreement (%)	
		IOR†	CBCT ‡	IOR	CBCT
Furcation bone loss Upper	B	0.73	0.91	81.5	92.6
	M	0.59	0.97	71.6	97.5
	D	0.80	0.97	85.2	97.5
Furcation bone loss Lower	B-L	0.86	-	96.3	-
	B	-	0.90	-	96.6
	L	-	0.96	-	93.1
Furcation treatment	Upper	0.86	0.90	86.4	90.1
	Lower	0.79	0.93	86.2	94.3

† For IOR, furcation bone loss classified as absence or presence

‡ For CBCT, furcation bone loss classified as absence, F2, and F3.

Table 11. Prevalence of furcation arrows

Furcation location	Prevalence (%)
M	14.8
D	40.7
All	**27.8**

Table 12. Association between furcation arrows (%) and the presence or absence of furcation bone loss assessed by CBCT

Furcation site	Furcation bone loss	
	No	Yes
M	2.3	29.0
D	26.3	53.8
All*	**13.6**	**42.5**

*Furcation arrow was significantly associated with the furcation bone loss using Chi-squared test (p<0.05)

Table 13. Prevalence of furcation arrows (%) according to the degree of furcation bone loss assessed by CBCT

Furcation site	Furcation bone loss		
	Yes	F2	F3
M	29.0	29.4	28.6
D	53.8	66.7	40.9
All	**42.5**	**50.0**	**34.9**

Table 14. Association between furcation arrows and furcation bone loss assessed by CBCT

Furcation location	Sensitivity[*]	Specificity[§]	PPV[†]	NPV[‡]	P-value
M	0.29	0.98	0.92	0.61	<0.005
D	0.54	0.74	0.70	0.58	<0.05
All	**0.42**	**0.86**	**0.76**	**0.60**	**<0.001**

[*]Sensitivity (true positive rate) is the proportion of furcations with furcation bone loss that have furcation arrows.

[§]Specificity (true negative rate) is the proportion of furcations without furcation bone loss that do not have furcation arrows.

[†]Positive predictive value (PPV) is the proportion of furcations with furcation arrows that have furcation bone loss.

[‡]Negative predictive value (NPV) is the proportion of furcations without furcation arrows that do not have furcation bone loss.

CHAPTER V

DISCUSSION

We compared the IOR and CBCT assessment of molar furcation, in term of furcation bone loss and furcation treatment, in order to identify the potential benefit of CBCT over the conventional IOR in routine periodontal treatment. At present, CBCT is considered the best tool to assess the bone morphology of the maxillo-facial region. It is well established that CBCT gave an accurate measurement of periodontal bone loss when compared to a direct measurement from cadavers (Fleiner et al., 2013, Vandenberghe et al., 2008), dry skull (Misch et al., 2006, Mol and Balasundaram, 2008, Noujeim et al., 2009, Vandenberghe et al., 2007), and intra-surgery (Feijo et al., 2012, Grimard et al., 2009). In addition, CBCT was able to identify correctly periodontal bone defects and root morphology (Darby et al., 2014, Qiao et al., 2014, Walter et al., 2009, Walter et al., 2010). Therefore, we used CBCT assessment as a reference, to which the IOR assessment was compared.

We found that the prevalence of furcation bone loss, identified as presence or absence, obtained from IOR and CBCT was comparable. It should be noted that the 2D nature of IOR has a major limitation in discriminating the extent of bone loss, especially those involved in bucco-lingual view (Mengel et al., 2005, Misch et al., 2006, Vandenberghe et al., 2007). It was also impossible to identify separately the degree of bone loss between the superimposed buccal and lingual furcation of lower molars. Therefore, IOR assessment of furcation bone was simply classified as presence or absence. In addition, buccal and lingual furcation of a lower molar were assessed as one furcation. In contrast, we found that CBCT was able to show clearly the morphology and extent of furcation bone loss as well as the root morphology. Therefore the degree of furcation bone loss assessed by CBCT was further classified as partial (F2) or complete (F3) furcation bone loss. Since the ability to detect furcation bone loss of IOR was cruder than that of CBCT, we could only compare IOR and CBCT assessment on the presence or absence of furcation bone loss. When IOR and CBCT assessment of each furcation was matched and compared, we found that IOR and CBCT had good concordance on identifying the presence of furcation bone loss. The concordance was approximately 80% with a trend towards under-estimation. At present, there have been no studies that compared directly the assessment of furcation bone loss between IOR and CBCT. Vanderberghe et al. (2008) studied 11 molars in one human cadaver and one dry human skull. They compared the degree of furcation bone loss assessed by IOR and CBCT to the direct measurement. They showed that CBCT was able to detect and correctly classify 100% of the furcation defect. In contrast, IOR could not detect 44% of the furcation defects and it was not possible to differentiate buccal and lingual furcation involvements.

Clinical examination has also been a useful tool for furcation assessment. Using a Naber's probe, furcation bone loss was classified into no furcation bone loss, partial furcation bone loss and complete furcation bone loss. Compared to CBCT, clinical examination showed a lower prevalence of furcation bone loss for all furcations. The concordance between clinical examination and CBCT on the degree of furcation bone loss was quite good (76-79%) with a clear trend towards under-estimation (20-22%). Our findings were different from previous studies that showed poor concordance between clinical and CBCT assessment. Darby et al. (2014) found that 22% of furcation involvement assessment from clinical examination and CBCT were in agreement. Fifty-eight percent of clinical recordings were over-estimated, and 20% were under-estimated when compared to CBCT analysis. Walter et al. (2009) showed that the estimated degree of furcation bone loss based on clinical findings was confirmed in 27% of the sites, while 29% were overestimated and 44% revealed an under-estimation, according to CBCT analysis. It should be noted that our study graded furcation bone loss as no, partial, and complete loss, which was equivalent to F0/ F1, F2, and F3 of Glickman's classification, respectively. The other two studies graded furcation bone loss as no, <3 mm, >3mm but not complete loss, and complete loss, which was equivalent to F0, F1, F2, and F3 of Hamp's classification, respectively. The difference in the criteria of furcation bone loss may account for the discrepancies. They also found that clinical F1 showed very high degree of over-estimation (50-70%), whereas F2 and F3 had under-estimation, compared to CBCT. We found that it is difficult to differentiate between Hamp's F1 and F2 with accuracy. In addition, comparing clinical measurement to CBCT measurement posed some problems. Using a Naber's probe, clinical measurement included furcation bone loss and soft tissue thickness at the furcation entrance. However, CBCT measurement started at the external surface of furcation, which excluded the soft tissue. Moreover, a Naber's probe is slightly curve whereas the CBCT measurement is linear. Using a 3 mm cut-off, the soft tissue thickness and the curve of a probe can significantly influence the furcation grading. Therefore, we chose not to use Hamp's classification in this study.

We showed that CBCT and IOR had an overall concordance of 80% on furcation treatment. We categorized furcation treatment into three groups: non-surgical treatment, surgical treatment, and extraction. When each treatment type was analyzed, we found excellent agreement (94%) between IOR and CBCT on non-surgical treatment. However, the agreement on surgical treatment was poor. Of 44 furcations planned for surgical treatment by CBCT, IOR decision on treatment was non-surgical, surgical, and extraction at 32%, 57%, and 11% respectively. Regarding tooth extraction, the agreement was 72%. Approximately 20% of teeth planned for surgical treatment by IOR were decided for extraction by CBCT. It is clear that IOR was not effective in providing surgical treatment decision of furcations and the treatment assessed by IOR was likely to be under-estimated. Walter et al. (2009) also showed that treatment decision for upper molar furcation surgery assessed by IOR and CBCT was different. They studied 22 upper molars that required furcation surgery. They compared the treatment recommendations based on IOR and clinical data (conventional approach) versus CBCT and IOR and clinical data. Various treatment options (11 types) were available and two examiners were able to select more than one treatment options. They found discrepancies of treatment between conventional approach and the additional of CBCT in 59–82% of the teeth. Conventional approach indicated more than one treatment option in most teeth whereas the additional CBCT analysis. This same group of investigators (Walter et al., 2012) also determined whether CBCT provided financial benefit for treating upper molar with furcations. They found that CBCT facilitates a reduction in treatment costs and time, especially those involved invasive treatment. Therefore, CBCT appears to be a valuable tool treatment decision of molar furcation surgery.

We showed that CBCT provided excellent agreement among examiners both in term of assessing the degree of furcation bone loss and furcation treatment. Fleiss' kappa value ranged from 0.90-0.97 whereas the percentage of complete agreement was 90.1-97.5%. For IOR, Fleiss' kappa of furcation bone loss was 0.59-0.86 and the percentage of complete agreement was 71.6-96.3%. Overall, the agreement was good. The highest agreement was on bucco-lingual furcation bone loss of lower molars. This may be because buccal and lingual furcations were superimposed in IOR and we assessed both furcations as one value. The lowest agreement was on mesial furcations of upper molars. Poor agreement may be due to the anatomy of upper molars. The position of the mesio-buccal root and the mesial of palatal root are in straight line, whereas the disto-buccal root and the distal of palatal root is inclinated to a varying degree (Svardstrom and Wennstrom, 1988). Therefore, it is more difficult to observe furcation bone loss of mesial furcations than distal furcations. Contrary, CBCT assessment showed excellent examiners' agreement for both mesial and distal furcations. It should be noted that furcation bone loss was classified into 2 groups for IOR assessment, but 3 groups for CBCT assessment. Nonetheless, the examiner's agreement of CBCT was higher than IOR for all types of assessments. Previous studies from Walter et al. (2010) and Qiao et al. (2014) evaluated the accuracy of CBCT in assessing the furcation bone loss compared to intra-surgical measurement. These findings confirmed that the agreement between CBCT and intra-surgical measurement in the furcation diagnosis of upper molars were excellent with the weighted kappa 0.917-0.926. However, two studies also found that mesial furcation of upper molars was the lowest agreement with the weighted kappa 0.88-0.89. Therefore, our findings suggested that CBCT is a reliable tool to determine furcation bone loss and furcation treatment because it gave highly consistent results among examiners.

We showed that the presence of furcation arrows was associated with furcation bone loss assessed by CBCT. In this study, the prevalence of furcation arrows was 27.8%. However, the prevalence of furcation arrows was almost 3 times higher at the distal sites than the mesial sites. As mentioned earlier, the inclination between the disto-buccal root and the distal of the palatal root might be a factor that makes it easier to observe furcation arrows at distal furcations. Although the distal sites had high prevalence of furcation arrows, the false positive value was also high. Furcation arrows were found at 26.3% of intact distal furcations, but only at 2.3% of intact mesial furcations. Hardekopf et al. (1987), however, found similar prevalence of furcation arrows at mesial and distal furcations. They studied the association between furcation arrows and furcation bone loss in dry skulls and showed that furcation arrows were significantly associated with furcation bone loss. The furcation arrow as a diagnostic marker in our study had a sensitivity of 42% and a specificity of 86%. The positive predictive was 76% and the negative predictive value was 60%. These values were in agreement with those of Deas et al. (2006). They found that the sensitivity, specificity, positive predictive value, and negative predictive value were 39%, 92%, 72%, and 75%, respectively. However, they commented that it was difficult to obtain a consensus on the presence of furcation arrows among five examiners who were experienced periodontists. In addition, a large number of furcation with bone loss did not have furcation arrows. Therefore, the furcation arrow may have limited usefulness as a diagnostic marker of furcation invasion.

Although we showed that CBCT was superior to IOR for furcation assessment, the routine use of CBCT may be limited from several factors. Compared to IOR, CBCT interpretation was more time-consuming and required additional skills to use the software. The radiation dose of CBCT was also a major concern. Most CBCT scans have effective doses between 28-265 μSv (Pauwels et al., 2012). In comparison, a panoramic radiograph delivered 24.5 μSv and a full-mouth periapical radiographs with bitewings delivered 40 μSv (Loubele et al., 2009, Ludlow and Ivanovic, 2008). The effective dose of CBCT depends largely on the field of view (FOV) size and the image quality required. Therefore, we suggested that CBCT should be used in a limited area of interest for evaluation of surgical treatment of molar furcations.

In conclusion, we showed that IOR is a reasonable tool to identify whether there is furcation bone loss or not. However, IOR is not effective for assessment of furcation treatment especially those involve surgical treatment. CBCT is superior to IOR for assessing the extent of furcation bone loss and planning of furcation treatment. CBCT also provides excellent agreement among examiners on furcation assessments. A furcation arrow may be used to predict furcation bone loss.

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APPENDIX

Study protocol and consent form approval

No. 025/2015

Study Protocol and Consent Form Approval

The Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand has approved the following study to be carried out according to the protocol and patient/participant information sheet dated and/or amended as follows in compliance with the **ICH/GCP.**

Study Title	: Comparison between intraoral radiography (IOR) and cone beam computed tomography (CBCT) for assessment of molar furcation involvement
Study Code	: HREC-DCU **2015-006**
Study Center	: Chulalongkorn University
Principle Investigator	: Dr. Methiya Nimitpanya
Protocol Date	: February 10, 2015
Date of Approval	: April 7, 2015
Date of Expiration	: April 6, 2017

V. Lertchirakarn

....

(Associate Professor Dr. Veera Lertchirakarn)
Chairman of Ethics Committee

K. Bhalang

....

(Assistant Professor Dr. Kanokporn Bhalang)
Associate Dean for Research

*A list of the Ethics Committee members (names and positions) present at the Ethics Committee meeting on the date of approval of this study has been attached (upon requested). This Study Protocol Approval Form will be forwarded to the Principal Investigator.

Approval is granted subject to the following conditions: (see back of the approval)

All approved investigators must comply with the following conditions:

1. Strictly conduct the research as required by the protocol;
2. Use only the information sheet, consent form (and recruitment materials, if any) bearing the Human Research Ethics Committee's seal of approval ; and return one copy of such documents of the first subject recruited to the Human Research Ethics Committee for the record;
3. Report to the Human Research Ethics Committee any serious adverse event or any changes in the research activity within five working days;
4. Provide reports to the Human Research Ethics Committee concerning the progress of the research upon the specified period of time or when requested;
5. If the study cannot be finished within the expire date of the approval certificate, the investigator is obliged to reapply for approval at least one month before the date of expiration.

นักวิจัยทุกท่านที่ผ่านการรับรองจริยธรรมการวิจัยต้องปฏิบัติดังต่อไปนี้

1. ดำเนินการวิจัยตามที่ระบุไว้ในโครงร่างการวิจัยอย่างเคร่งครัด
2. ใช้เอกสารแนะนำอาสาสมัคร ใบยินยอม (และเอกสารเชิญเข้าร่วมวิจัยหรือใบโฆษณาถ้ามี) เฉพาะที่มีตราประทับของคณะกรรมการพิจารณาจริยธรรมการวิจัยเท่านั้น และส่งสำเนาเอกสารดังกล่าวที่ใช้กับผู้เข้าร่วมวิจัยจริงรายแรกมาที่สำนักงานคณะกรรมการพิจารณาจริยธรรมการวิจัย คณะทันตแพทยศาสตร์ เพื่อเก็บไว้เป็นหลักฐาน
3. รายงานเหตุการณ์ไม่พึงประสงค์ร้ายแรงที่เกิดขึ้นหรือการเปลี่ยนแปลงกิจกรรมวิจัยใดๆ ต่อคณะกรรมการพิจารณาจริยธรรมการวิจัย ภายใน 5 วันทำการ
4. ส่งรายงานความก้าวหน้าต่อคณะกรรมการพิจารณาจริยธรรมการวิจัย ตามเวลาที่กำหนดหรือเมื่อได้รับการร้องขอ
5. หากการวิจัยไม่สามารถดำเนินการเสร็จสิ้นภายในกำหนด ผู้วิจัยต้องยื่นขออนุมัติใหม่ก่อนวันสิ้นสุดการอนุมัติ อย่างน้อย 1 เดือน

VITA

Miss Methiya Nimitpanya was born on March 14, 1986 in Bangkok, Thailand. She graduated the high school education from Suksanari School, Bangkok. In 2010, she earned her Doctor of Dental Surgery degree with second class honor from Chulalongkorn University. She worked as a general dentist at Chumpholburi Hospital, Surin (2011-2012), and at Ekkachai Hospital (2012-2013). Presently, she attends the Master of Science Program in Periodontics, Department of Periodontology, Faculty of Dentistry, Chulalongkorn University.