A COMPARISON OF INTRAORAL VERSUS EXTRAORAL BITEWING RADIOGRAPHY TO DETECT PROXIMAL CARIES AND LOSS OF ALVEOLAR BONE

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Micah Chan

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Mansur Ahmad, BDS, Ph.D.

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Dedication

I dedicate this thesis to my family and my small group (The Ditches and Holes) for their support and their patience with my groaning throughout this whole process. I also dedicate this to Émilie and Winston, who have constantly been by my side (emotionally and physically) for the last three years.

Abstract

Objective and Background: Proper diagnosis is integral in effective and efficient treatment in dentistry. While clinical examination provides important information in the diagnosis of periodontal disease and caries, bitewing radiography is one of the tools used for the examination of structures that cannot be readily seen with the naked eye. The ProMax S3 panoramic unit from Planmeca offers a True Bitewing program that can obtain bitewing images without the use of intraoral sensors. The aims of this study was to compare the diagnostic accuracy of intraoral bitewings and extraoral bitewings for the detection of

1. interproximal caries
2. interproximal bone loss

Methods: Patients from the University of Minnesota School of Dentistry who recently received intraoral bitewings were recruited for extraoral bitewings. Five examiners (two board certified radiologists, one radiology clinical assistant professor, one general dentist and one graduate periodontics resident) evaluated both images for interproximal bone loss and interproximal caries as well as a consensus diagnosis was made.

Results: The study population was one hundred sixteen patients. There was statistically significantly greater caries detection with extraoral radiographs (46.26% of surfaces) compared to intraoral radiographs (21.12% of surfaces) at $p<0.0001$. Assuming that the intraoral bitewing is the gold standard, for caries diagnosis, the extraoral bitewings had a sensitivity of 71.91% and a specificity of 61.99% with a false positive rate of 38.01%. When evaluating the bone loss detection, there was statistically significantly greater detection with extraoral bitewings (90.19% of teeth) compared to intraoral bitewings (77.95% of teeth) at $p<0.0001$. Assuming that the intraoral bitewing is the gold standard, for bone loss diagnosis, the extraoral bitewings had a sensitivity of 94.5% and a specificity of 26.86% with a false positive rate of 73.14%.

Conclusions: The caries detection rate with extraoral bitewings was significantly greater than intraoral bitewings. The false-positive rate for caries detection with extraoral bitewings was 38.01%. The bone loss detection rate with extraoral bitewings was also significantly greater than intraoral bitewings. The false-positive rate for bone loss detection with extraoral bitewings was 73.14%. While extraoral bitewings provide efficient imaging with more patient comfort, it appeared to have more false positives, which would warrant cross-examination with clinical exams and re-evaluation with follow up exams.

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Introduction

Importance of proper diagnosis

In the field of health care, proper diagnosis is fundamental for successful treatment. Proper diagnosis includes the determination of the presence of disease, the type, severity, distribution and any underlying causes. In dentistry, clinical diagnoses can be made via visual inspection with the aid of lighting, probes, explorers and mouth mirrors. However, there are certain facts and findings that cannot be determined simply through clinical examination. The use of radiography provides the clinician with crucial information of anatomic structures needed for proper diagnosis, which may not be apparent clinically.

Periodontal disease epidemiology

Periodontitis is one of the most widespread oral diseases in mankind (Borrell and Papapanou 2005). It has been estimated that over 47% of American adults have periodontitis (Eke, Dye et al. 2012). Although subgingival pathogenic bacteria are required for the induction of periodontitis, a susceptible host response is also necessary (Pihlstrom, Michalowicz et al. 2005).

Periodontal disease etiology

At sites with clinically healthy periodontal tissues, the tissue appears pink, firmly attached to the underlying bone with minimal bleeding on probing. In health, the gingival crevice around the tooth harbors a microbial flora composed mainly of gram-positive facultative organisms. Infiltration of the tissues with chronic inflammatory cells can be seen histologically in response to bacterial plaque. In the sites of periodontal health, the physical mechanisms of the host defense function adequately to clear bacteria and their products from the subgingival environment (Page and Schroeder 1976). Within 2-4 days of plaque accumulation, a low-grade chronic inflammatory response can be observed in gingival tissues. This is characterized by increased vascular permeability and vasodilation, increased gingival crevicular fluid production from the sulcus and migration of leukocytes through the gingival connective tissue and into the sulcus (Page and Schroeder 1976). Following 1 week of plaque accumulation, the gingiva appears erythematous secondary to continued proliferation of capillaries and increased vascular permeability. Infiltrating leukocytes increase in numbers and are accompanied by degeneration of fibroblasts and collagen occurs. The junctional and sulcular epithelium of the gingiva begin to proliferate into areas of collagen depletion. This is clinically observed as early gingivitis. When early gingivitis has been allowed to persist, it can progress to chronic gingivitis. Histologically, this is characterized by a predominance of plasma cells and a dense inflammatory cell infiltrate in the connective tissue. Significant collagen depletion and proliferation of the epithelium occur. Although gingivitis and periodontitis both share clinical features of inflammation, periodontitis can be distinguished by the destruction of periodontal ligament and bone (Page and Schroeder 1976). When the process has progressed to periodontitis, in order to prevent bacterial invasion into the bone, the bone retreats from the inflammatory front through osteoclastic bone resorption. The junctional epithelium of the sulcus follows this collagen depletion and a periodontal pocket is formed. The periodontal pocket then provides an environment that favors proliferation of periodontal pathogens. According to Socransky et al.

(Socransky, Haffajee et al. 1998), Gram-negative bacteria of the "Red complex," *Porphyromonas gingivalis, Tannerella forsythia* and *Treponema denticola* have been proposed to be largely associated with periodontitis. These periodontal pathogens along with other microorganisms form a subgingival biofilm in the periodontal pocket, and their microbial virulence factors initiate and perpetuate the host inflammatory response (Socransky and Haffajee 1991). The virulence factors of the pathogenic bacteria can either enable bacteria to colonize and invade host tissues or directly or indirectly cause host tissue damage. Although the host response to bacteria and their virulence factors are essentially protective, hyper-responsiveness or hypo-responsiveness of the host immune system leads to local tissue destruction (Preshaw, Seymour et al. 2004).

Diagnosis of periodontal disease

The diagnosis of periodontal disease is made with clinical and radiographic examination of the periodontal tissues. Clinically, measurements are taken of the periodontal pockets (the distance from the gingival margin to the depth of the gingival sulcus) (Armitage 2004) and attachment levels (the distance from the cementoenamel junction of the tooth to the depth of the gingival sulcus) (Savage, Eaton et al. 2009). In areas of health, the periodontal pockets usually measure 1-3 mm in depth and the attachment level measures less than or equal to 0mm (Pihlstrom 1992). There are certain features of periodontal disease that may not be apparent clinically. Radiographs can provide information on the extent of alveolar bone resorption, local attributing factors, and identify characteristics of the dentition and alveolar structures, which may affect the prognosis of teeth. Although radiographs do not reveal the exact extent of alveolar bone loss (van der Linden and van

Aken 1970), bitewings offer an accurate image for this because the x-ray is directed perpendicular to the teeth through the interproximal spaces.

Radiographic diagnosis of periodontal disease

Radiographically, the normal alveolar bone in the absence of periodontal disease appears at a level 0.5-2.0mm below the level of the cementoenamel junction (CEJ) of adjacent teeth (Hausmann, Allen et al. 1991). In the average human, 1.07mm of space coronal to the alveolar crest is occupied by connective tissue and 0.97mm of space is coronal to the connective tissue is occupied by the junctional epithelium apical to the base of the gingival sulcus. The combination of these two measurements constitutes 2mm of space for biologic width (Gargiulo, Krajewski et al. 1995). The crest of the alveolar bone has a lamina dura, a thin radiopaque outline consistent with the thin layer of cortical bone. The interproximal alveolar bone appears as a peak between anterior teeth (Greenstein, Polson et al. 1981). Between posterior teeth the alveolar bone is well defined, has a similar density as the lamina dura and is parallel to a line connecting the cementoenamel junctions of adjacent teeth. With the progression of periodontal disease, there is resorption of the alveolar bone and loss of bone mineral content. These morphological changes of the alveolar bone become apparent on radiographic images and the alveolar crest is positioned apically further than 2.0mm from the CEJ. Other morphological changes associated with periodontal disease include osseous deformities in the furcations of multirooted teeth and changes to the internal density and trabecular pattern of bone.

Dental caries pathophysiology

Dental caries is a chronic infectious disease affecting 80-90% of the world population (Petersen 2004). *Streptococcus mutans* is largely considered to be the causative agent of dental caries (Loesche, Rowan et al. 1975). However, recent advances in DNA- and RNA-based studies from carious lesions have observed a comprehensive survey of bacterial species in the oral cavity that act collectively in the caries disease progression (Simon-Soro and Mira 2015). Colonization of the tooth surface by cariogenic bacteria is established soon after eruption of the tooth. Upon exposure to fermentable carbohydrates, there is increased metabolic activity from the bacterial plaque colonizing the tooth surface. The acidic by-products of the bacterial metabolic activity results in a persistent pH drop (Loesche, Rowan et al. 1975). When the critical pH, around pH 5.0-5.5, is reached, demineralization of the tooth structure begins (Stephan 1944). During the demineralization, calcium phosphate and carbonate are lost from the tooth surface. At early stages, re-mineralization can occur as the tooth's natural repair mechanism with the capture of calcium, phosphate and fluoride (Marsh, Moter et al. 2011). Left untreated, a carious lesion can lead to irreversible demineralization and cavitation of the tooth surface (Featherstone 2004). Left untreated, cavitation and further progression of the carious lesion can lead to extension of the lesion into the pulp and endodontic infection. Extensive loss of tooth structure can result in un-restorable teeth and the need for extraction.

Proximal caries

The process of dental caries can occur at different discrete areas of the teeth (Berman and Slack 1973). Sites most prone to caries are usually fissures, proximal contact points and smooth surfaces (Berman and Slack 1973). While careful clinical examination may identify caries on smooth and occlusal tooth surfaces, clinical access is often limited to proximal surfaces in contact. Clinical diagnosis of caries often relies on the tactile sensation of a lesion that has progressed to a cavitated lesion (Bertella, Moura dos et al. 2013). However, carious lesions on proximal surfaces are less likely to cavitate than those on occlusal surfaces and buccal and lingual pits (Ferreira Zandona, Santiago et al. 2012). With greater depths of the carious lesion, there is greater likelihood of cavitation (Bille and Thylstrup 1982). If cavitation of the carious lesion has yet to occur, proximal caries have the potential to be arrested. However, if cavitation has occurred, the carious lesion will always be active as bacteria colonize within the cavity. Carious lesions limited to the enamel rarely present with surface cavitation. When a carious lesion extends about half-way into dentin, about 50% of the carious lesions have surface cavitation (Bille and Thylstrup 1982). Cavitated lesions require operative therapy. Since access to the proximal surfaces is often limited, the depth of the carious lesion is often a main deciding factor for treatment.

For carious lesions limited to the enamel, progression can often be arrested with conservative interventions including reductions in sugar intake, improved oral hygiene and topical fluoride treatment (Mjor, Holst et al. 2008). For carious lesions extending into the dentin, operative treatment may be prescribed depending on previous caries history, age, site of the lesion and evidence of progression (National Institute of Health Consensus Development 2001).

Diagnosis of proximal caries

The difficulties associated with clinical examination in diagnosis of interproximal caries results in a sensitivity of 0.52 and a specificity of 0.98 (Bader, Shugars et al. 2001). Because of this, different modes of examination have been employed for diagnosis of proximal caries. While the histological examination of the tooth structure is considered to be the "gold standard" for caries diagnosis (Bader, Shugars et al. 2001), the invasive nature of this diagnostic test renders it unusable in a clinical setting. Furthermore, because of the dynamic nature of the caries process with demineralization and remineralization periods, there is difficulty with the histological examination to reveal the true state of the caries lesion (Baelum, Heidmann et al. 2006).

Bitewing radiography

The most frequently used mode for imaging and diagnosing interproximal carious lesions is intra-oral radiography (Wenzel 2006). The images from these radiographs aid the clinician to examine and assess structures that may not be visible upon clinical inspection. Following the caries process, there is demineralization of enamel and dentin. The demineralized structures absorb less x-ray photons and appear radiolucent compared to unaffected adjacent structures. Demineralization of enamel structures on proximal surfaces classically appears as a radiolucent triangle with its base on the tooth surface (Hintze, Wenzel et al. 1999). This shape is caused by the spread of the carious lesion along the enamel rods. Once the demineralization reaches the dentin, it first spreads along the dentoenamel junction before progressing towards the pulp of the tooth. This demineralization of the dentin forms a second triangle with its base at the dentoenamel junction. The use of bitewing radiographs allows the clinician to evaluate the depth of the carious lesion as well as the progression of the lesion as multiple bitewing radiographs are taken over time. Bitewing radiographs are accepted to be valuable for caries diagnosis (Kidd and Pitts 1990). However, a systematic review (Bader, Shugars et al. 2001) has shown bitewing radiography to have a sensitivity of 0.66 and a specificity of 0.95 in interproximal caries detection.

Bitewing technique

For the bitewing radiograph, the x-ray beam is aligned between the teeth parallel with the occlusal plane +10 degrees to minimize overlapping of the opposing cusps. The receptor is positioned lingual to the teeth to be examined and the patient is instructed to bring the maxillary and mandibular teeth together in occlusion (Iannucci and Howerton 2011). With the parallel placement of the receptor along the vertical axis of the teeth and the perpendicular direction of the x-ray beam, the bitewing radiograph provides accurate images with minimal overlapping of contact points, distortion or magnification. Horizontal bitewing radiographs usually depict the crowns of maxillary and mandibular teeth as well as the alveolar crest. For adult patients, two posterior bitewing radiographs are recommended for each side. The premolar bitewing radiograph should include the distal half of the canine and the crowns of the premolars. The molar bitewing radiograph should extend 1 to 2 mm beyond the most distally erupted molar. As a technique sensitive imaging method, the diagnostic quality of the bitewing radiograph can be affected by improper angulation and receptor placement leading to overlapping contact points (Pitts, Hamood et al. 1991). However, optimization of the receptor positioning for minimal overlapping contacts has been seen using film holders with a beam-aiming device (Pitts, Hamood et al. 1991). The use of bitewing radiographs may be limited in patients with partial edentulism where holding the film or sensor in a proper position may be difficult. Furthermore, infection in the orofacial structures can cause subsequent edema and trismus. In such cases, intraoral radiography may be too uncomfortable for the patient. Another limitation to bitewing radiographs is with patients who manifest a gag reflex (Iannucci and Howerton 2011), particularly with stiff CCD or CMOS receptors. The sensitivity is triggered as the receptor is placed into the oral cavity and even more so when the posterior dorsum of the tongue or soft palate is stimulated.

Occasionally, if the patient has moderate to severe alveolar bone loss, an image of the alveolar crest may not be present on a horizontal bitewing radiograph. In such situations, bitewing radiographs are employed the length of the receptor is positioned vertically to capture an image of the alveolar crest. With vertical bitewing radiographs the vertical field captured in the image is increased and structures further apical than the CEJ of the teeth are visible.

Film based radiography

Before the last decade, dental radiography was largely film based. Upon exposure of the x-ray film by photons exiting an object to be imaged, the silver halide crystals of the x-ray film become irradiated and interact with bromide ions forming silver bromide crystals. These silver bromide crystals form an invisible latent image on the film. Through film processing, this latent image is converted into a visible image. Immersion of the exposed film in the developer solution reduces silver ions in the exposed silver halide crystals to metallic silver grains. Following the development of the film, it is immersed in a fixing solution. The fixing solution aids to dissolve and remove any undeveloped silver halide crystals, which if left would cause the film to be opaque. The fixing solution also aids to harden and shrink the film emulsion (Eikenberg and Vandre 2000). Although film based radiography has been used by dental practices for decades, it is often associated with multiple shortcomings. Diagnostic quality of the film can be influenced by sources of light in the darkroom, depletion of developer or fixer solutions, insufficient washing of films between solutions, contamination of solutions, issues with automatic processing rollers and many others (Eikenberg and Vandre 2000). Films that are developed also require adequate drying time after processing and to be correctly placed into a film mount for proper maintenance and radiographic interpretation.

Digital radiography

In the last decade, digital intraoral radiographs have become increasingly common for dental examinations. Previously, digital radiography was achievable only by indirectly digitizing a film radiograph using a scanner or digital camera. To date, there are two main methods for direct digital image acquisition, solid-state detectors and photostimulable phosphor systems. One of the solid-state detectors is the charge-coupled device (CCD). A silicon wafer is used for image recording with CCD. Radiation exposure causes covalent bonds between silicon atoms to be broken forming electron-hole pairs. The electrons form “charge packets” that correspond to pixels. Each row of pixel charges is transferred and transmitted as a voltage and converted to a computer readout (Sanderink and Miles 2000). Another solid-state detector is the complementary metal oxide semiconductor (CMOS). They differ from CCDs in the reading of the pixels from the sensor. Electron hole pairs are formed following radiation of silicon-based semiconductors similar to CCDs, however, the charge from the electron hole pairs is transferred to a transistor as a small voltage and each transistor is read separately then displayed as a digital image (Sanderink and Miles 2000). Although associated with sensor bulk, solid-state detectors provide rapid availability of the image after exposure. However, most solid state detectors incorporate some form of electronic cable to transfer the data to the computer.

Photostimulable phosphorplates (PSP) do not have the same bulk as solid-state detectors and can be manufactured in standard intraoral sizes. PSP plates are composed of “europium-doped” barium fluorohalide (Couture and Hildebolt 2000). Upon exposure to x-rays, valence electrons of europium absorb the energy of the radiation and migrate to halogen vacancies in the fluorohalide (Couture and Hildebolt 2000). The energy stored from the x-rays is released as light when stimulated by another light source of appropriate wavelength. The light emitted from the PSP plate is converted into electrical energy and converted into a voltage output, which can be displayed as a digital image on a computer (Couture and Hildebolt 2000). Unlike solid-state detectors, PSP systems do not require electronic cables attached to the sensors. However, they require stationary plate scanners for reading and converting the latent image into a digital read out. Also, before each use, PSP plates require erasing of the prior exposures with exposure to bright light. Exposure to ambient light can lead to image fading prior to processing.

Advantages of digital radiography

Numerous advantages have been shown with direct digital radiography compared to conventional film based radiography (Wenzel 1993): the contrast and brightness can easily be adjusted, wet solutions are no longer required for processing, less radiation dose is required compared to conventional film based radiography, working time is significantly reduced and image storing and transferring is greatly facilitated. When comparing the diagnostic quality between film based radiography and digital radiography, the image quality of radiographic films was found to be similar to CCD systems (Nair and Nair 2001) and to PSP plate systems (Conover, Hildebolt et al. 1996). When comparing the diagnostic accuracy between the system for detection of non-cavitated interproximal caries, digital images were found to be similar to conventional film-based radiography(Abesi, Mirshekar et al. 2012).

Fiber-optic transillumination

Fiber-optic transillumination is an alternative method used for the diagnosis of interproximal caries. In contrast to radiography, it is a minimally invasive diagnostic tool. When transilluminated, the carious lesion scatters and absorbs visible light and are observed as a darker area at the interproximal surface of the tooth. When compared to bitewing radiography, fiber-optic transillumination has been shown to have comparable specificity but lower sensitivity in interproximal caries diagnosis (Vaarkamp, ten Bosch et al. 2000). The main advantage of fiber-optic transillumination over radiographs for caries diagnosis is the lack of need for radiation exposure to attain a diagnosis.

Panoramic radiographs

While intraoral radiographs are mainly used for the diagnosis of caries and bone loss, panoramic radiographs provide a simple and convenient overview of the dentition and the surrounding structures (Rushton, Horner et al. 2002). With panoramic radiographs, both the x-ray source and the receptor are kept outside of the patient's mouth. This induces less discomfort to the patient compared to intraoral radiographs. The panoramic machine functions with the x-ray tube head rotating around one side of the patient's head, while the receptor moves at the same rate around the other side of the patient (White and Pharoah 2013). The structures on the side of the patient nearest the receptor are displayed clearly on the panoramic radiograph. A curved focal trough is created where only structures present in the three-dimensional zone appear well defined on the panoramic radiograph. Structures outside of this focal trough appear blurred, magnified and distorted.

Panoramic image receptors

In order to reduce the amount of radiation used for panoramic radiographs, intensifying screens are regularly used. The use of regular intensifying screens at low tube potential or medium intensifying screens while increasing tube potential make it possible to reduce the radiation dose required for a diagnostic image (Kaeppler, Dietz et al. 2007). However, while the visible light emitted by the intensifying screens aid in the reduction of radiation dose, the scattering of the light emitted results in the decreased image sharpness often associated with panoramic radiographs. Similar to intraoral radiographs, digital panoramic radiography can be obtained either with CCD sensors or PSPs. The use of digital panoramic radiography provides multiple advantages over conventional film-based panoramic radiography; reduction in the amount of radiation required for imaging, elimination of the need for a dark room, ability to enhance and adjust images and facilitated archiving and consulting between colleagues (Farman and Farman 2001, Farman, Levato et al. 2008). It has been shown that when comparing the diagnostic quality of conventional and digital panoramic radiography, the two modes of panoramic radiography have equivalent quality for evaluation of borders of the maxillary sinus, periodontal bone levels, periapical bone structures, trabecular bone, mandibular canal and mental foramen (Molander, Grondahl et al. 2004).

Issues with panoramic radiographs

Panoramic radiographs are often associated with image distortions. These distortions are influenced by the distance from the x-ray source to the object, the distance from the object to the receptor, the position of the object in the focal trough and the path of the rotation center. The amount of distortion and magnification present can vary among different panoramic units and even among different regions of the jaw. The distortions associated with panoramic radiographs result in unreliable linear measurements (Choi 2011). When comparing the diagnostic quality of intraoral and panoramic radiographs, panoramic radiographs have been shown to be less diagnostic for caries (Hurlburt and Wuehrmann 1976, Kidd and Pitts 1990). These studies were based on film-based panoramic radiographs. For evaluation of bone changes in periodontal disease, panoramic radiography has been shown to be similar to intraoral radiography (Muhammed, Manson-Hing et al. 1982, Douglass, Valachovic et al. 1986).

Latest innovation in panoramic radiography

The ProMax S3 from Planmeca (PLANMECA USA, INC., 100 NORTH GARY AVENUE, SUITE A, ROSELLE, IL 60172) was chosen for the purposes of this study based on the claim by the manufacturer of a unique mechanical design of the panoramic unit to alter the tube head rotation for different imaging programs. The patented SCARA (Selectively Compliant Articulating Robotic Arm) technology uses a fully programmable 3-axis robot to control the rotation and angles of the radiographic beam. The precise free-flowing arm movements allow for a wider variety of imaging programs not possible with other X-ray units.

Fig 1. Planmeca ProMax S3

True Bitewing Program

One of the options available for the ProMax S3 is the True Bitewing program of the panoramic unit. This program allows clinicians to take routine bitewing radiographs without any intraoral sensors. With the True Bitewing Program, following programming for the individual patient size and dental arch shape, the tube head moves closer to the patient to reduce the distance between the radiation source and the image. The specific rotational path of the ProMax S3 allows the x-ray beam to be aimed perpendicularly with the long axis of the patient's teeth. Bilateral bitewing images are taken within one movement of the machine. The diagnostic area captured in the extraoral bitewing includes canines to third molars and from the crowns of the teeth to the apices.

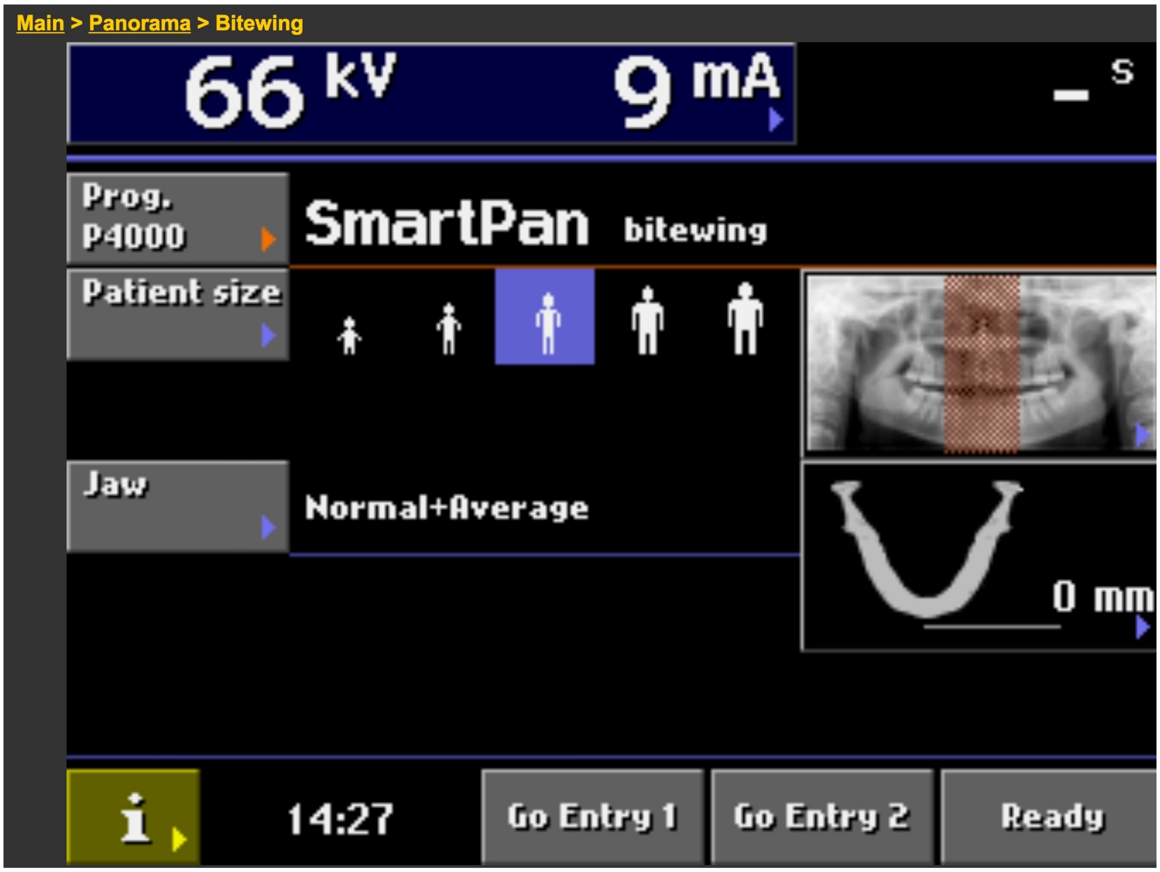

Fig. 2 – Settings in the True Bitewing program. Customizable according to the patient's stature and jaw characteristics

Hypothesis

Few studies have compared diagnostic accuracy of intraoral and extraoral bitewing radiography *in vivo*. To date, there have not been any studies published to the best of our knowledge evaluating the accuracy of extraoral bitewings for the diagnosis of bone loss. The hypothesis for this study is that the diagnostic accuracy of the extraoral bitewing radiography is not inferior to intraoral bitewing radiography.

Specific Aims

The aims of this present study are:

1. *To compare the diagnostic efficacy of intraoral bitewings and extraoral bitewings for interproximal caries*
2. *To compare the diagnostic efficacy of intraoral bitewings and extraoral bitewings for interproximal bone loss*

Material and Methods

This prospective clinical study will compare the diagnostic ability of horizontal and vertical digital intraoral bitewing radiography with digital extraoral bitewing radiography for caries and bone loss.

Patient enrollment

New patients from the University of Minnesota School of Dentistry were screened to identify those who have radiographic evidence of caries or bone loss. Patients included in the study were required to have posterior dentition present, normal tooth alignment and contacts between posterior teeth. Exclusion criteria included orthodontic or prosthetic appliance compromises interproximal views of teeth, severe posterior crowding, and pregnancy. Each patient received intraoral bitewings (horizontal or vertical) using Schick intraoral digital X-ray sensors with the Schick Aimright adhesive positioning system (Sirona Dental, Inc., 30-30 47th Avenue, Long Island City, NY 11101 USA), and extraoral bitewings using Planmeca ProMax S3 with the True Bitewing Program.

Radiographic examination

Five examiners examined the radiographs: two board certified oral radiologists, one general dentist, one radiology clinical assistant professor and one periodontal resident. Images were viewed on individual Dell 22 Monitors (Dell Inc., TX 75075 USA) in a dimly lit room.

Inter-examiner calibration

Prior to examining the radiographs, examiners reviewed 20 vertical intraoral bitewings, 20 horizontal intraoral bitewings and 20 extraoral bitewing radiographs to reach ≥90% inter-examiner reproducibility on identification for presence of interproximal caries and interproximal bone loss.

Examiners evaluated each patient's intraoral bitewings and finalized a consensus diagnosis for each tooth and each interproximal surface with regards to caries and bone loss. Following the evaluation of the intraoral bitewings, examiners evaluated the corresponding extraoral bitewings for each patient. For the diagnosis of caries, observations included:

0. The absence of caries and the extent of caries when present,
1. Caries less than ½ way through the enamel,
2. Caries more than ½ way through the enamel but not into dentin
3. Caries into dentin but less than ½ way through the dentin
4. Caries more than ½ way through the dentin.
5. Overlapping contacts
6. Missing teeth
7. Defective margin of a restoration.

If multiple characteristics were observed (i.e. overlapping contacts, yet evident carious lesion), the most critical observation were recorded (presence of caries).

For the diagnosis of bone loss, observations to be recorded included:

0. Interproximal bone not visible on image
1. Presence of bone loss evident (greater than 2 mm distance from alveolar crest to cementoenamel junction)
2. Normal bone level.
3. overlapping contacts
4. Missing teeth

Observations for bone loss were designated for a single tooth regardless of side (mesial or distal) and severity.

Statistical Analysis

Counts and percentages were used to summarize the caries and bone loss assessments. For the subset of locations where caries (or bone loss) could be assessed on both intraoral and extraoral images, percent agreement along with a 95% confidence interval was calculated using a generalized estimating equations (GEE) model. This model takes into account within-subject correlation. Sensitivity, specificity, and false positive rates were also calculated. Similar models were used to compare caries detection (or bone loss) rates between images. SAS V9.3 (SAS Institute Inc., Cary, NC) was used for the analyses.

The primary outcome for this study was the level of agreement between examinations of the intraoral bitewings and extraoral bitewings in the diagnosis of caries and bone loss.

Secondary outcomes evaluated were presence of overlap, number diagnostic surfaces and observations of pathologies.

Results

For this study, 116 patients from University of Minnesota School of Dentistry that presented for conventional intraoral bitewings were recruited into the study and received extraoral bitewings. For each subject's images, 52 locations were assessed for caries and 28 locations were assessed for bone loss.

Caries

A total of 4056 proximal surfaces were examined for caries in intraoral and extraoral bitewings. Table 1 depicts the different diagnoses for the proximal surfaces. Examination of the intraoral bitewings revealed 1437 proximal surfaces (35.43%) with no radiographic signs of caries, 49 proximal surfaces (1.21%) with carious lesions extending less than ½ way through the enamel, 97 proximal surfaces (2.39%) with carious lesions extending more than ½ way through the enamel but not yet into dentin, 179 proximal surfaces (4.41%) with carious lesions extending into the dentin but less than ½ way through the dentin and 60 proximal surfaces (1.48%) with carious lesions extending more than ½ way through the dentin. A total of 918 proximal surfaces (22.63%) of teeth to be evaluated were not visible on the intraoral bitewings but were visible on extraoral bitewings.

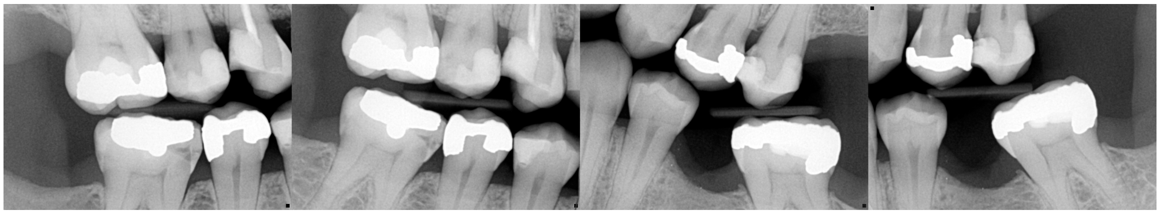

Fig. 3 – Intraoral Bitewings Revealing Interproximal Caries

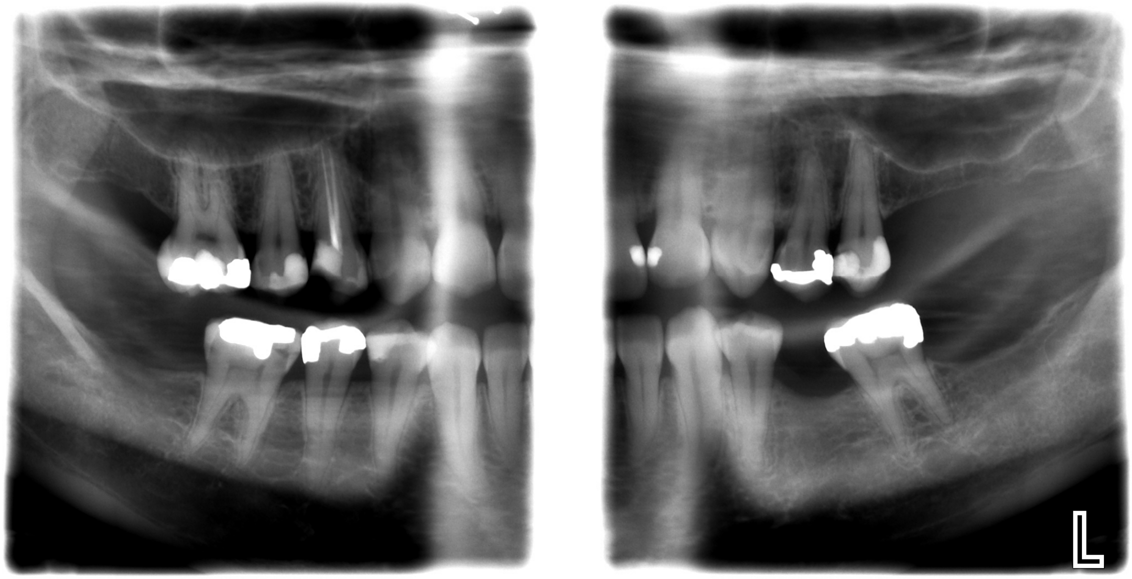

Fig. 4 – Extraoral Bitewing Revealing Interproximal Caries

Table 1 – Distribution of Diagnoses for Interproximal Caries

Code	**Intraoral n=4056**	**Extraoral n=4056**
0 = None	1437 (35.43%)	1364 (33.63%)
1 = Less than 1/2 way through enamel	49 (1.21%)	431 (10.63%)
2 = More than 1/2 way through enamel, not to DEJ	97 (2.39%)	177 (4.36%)
3 = Into DEJ but less than 1/2 way to pulp	179 (4.41%)	321 (7.91%)
4 = Over half way to pulp and further	60 (1.48%)	128 (3.16%)
5 = Overlap Contact	473 (11.66%)	538 (13.26%)
6 = Tooth Missing	553 (13.63%)	742 (18.29%)
7 = Surface not seen on image	918 (22.63%)	55 (1.36%)
8 = Defective Margin/restoration	186 (4.59%)	195 (4.81%)
Missing/x	104 (2.56%)	105 (2.59%)

Percent Agreement† (95% confidence interval) = 58.52% (55.25%, 61.72%)

†From a GEE model for binary outcome. The GEE model takes into account potential within subject correlation (i.e. multiple locations per subject).

Examination of the extraoral bitewings revealed 1364 proximal surfaces (33.63%) with no radiographic signs of caries, 431 proximal surfaces (10.63%) with carious lesions extending less than ½ way through the enamel, 177 proximal surfaces (4.36%) with carious lesions extending ½ way through the enamel but not yet into dentin, 321 proximal surfaces (7.91%) with carious lesions extending into the dentin but less than ½ way through the dentin and 128 proximal surfaces (13.26%) with carious lesions extending more than ½ way through the dentin. Fifty five proximal surfaces (1.36%) were not visible on the extraoral bitewings.

Table 2 represents the subset of proximal surfaces, which were diagnostic in both intraoral and extraoral bitewings. When evaluating the caries detection rate between intraoral and extraoral bitewings, there was statistically significantly greater caries detection with extraoral radiographs, 655 proximal surfaces (46.26%), compared to intraoral radiographs, 299 proximal surfaces (21.12%), at $p<0.0001$.

Table 2 – Caries Detection Rates

Code	**Intraoral n=1416**	**Extraoral n=1416**
0 = None	1117 (78.88%)	761 (53.74%)
1-4 = any severity of caries	299 (21.12%)	655 (46.26%)

The caries detection rates of 21% and 46% are statistically significantly different for this subset ($p<0.0001$).

Table 3 represents the detection rate between caries within the enamel and caries extending into the dentin and further. With intraoral bitewings, 188 surfaces (13.28%) were diagnosed with caries extending into the dentin and further. With extraoral bitewings, 295 surfaces (20.83%) were diagnosed with caries extending into the dentin and further. The difference in detection of caries extending into the dentin was statistically significant at $p<0.0001$.

Table 3 – Caries Detection at Different Levels of Caries Progression

Code	**Intraoral n=1416**	**Extraoral n=1416**
0-2	1228 (86.72%)	1121 (79.17%)
3-4 = carious lesions into dentin and deeper	188 (13.28%)	295 (20.83%)

The caries detection rates are statistically significantly different between the methods ($p<.0001$).

On a site to site level, table 4, there was 63.95% agreement (95% confidence interval) between caries detection from intraoral and extraoral bitewings. Assuming the gold standard is the intraoral bitewing and the truth, the extraoral bitewings have a sensitivity of 71.91% and specificity of 61.99% with a false positive rate of 38.01%. Assuming the gold standard is the extraoral bitewing, the intraoral bitewings have a sensitivity of 33.71% and a specificity of 89.06% with a false positive rate of 10.94%.

Table 4 – Site-to-Site Comparison Between Intraoral and Extraoral Caries Diagnosis

n=1416	**Intraoral, 1-4 n=299**	**Intraoral, 0 n=1117**
Extraoral, 1-4; n=655	219 (73.24%)	436 (39.03%)
Extraoral, 0; n=761	80 (26.76%)	681 (60.97%)

Percent Agreement (95% confidence interval) = 63.95% (60.56%, 67.19%)
†From a GEE model for binary outcome. The GEE model takes into account potential within subject correlation (i.e. multiple locations per subject).
Assuming intraoral is the gold standard:
Sensitivity=71.91%; Specificity=61.99%, False positive rate=38.01% (These are also from a GEE model.)
Assuming extraoral is the gold standard:
Sensitivity=33.71%; Specificity=89.06%, False positive rate=10.94% (These are also from a GEE model.)

The surfaces represented in table 5 include the subset of 918 proximal surfaces that were not seen on the intraoral bitewing, but were diagnostic on the extraoral bitewing. Four hundred surfaces (43.57%) were diagnosed as free of caries radiographically. Overlapping contacts on extraoral bitewings affected 120 surfaces (13.07%). One hundred sixty five surfaces (17.78%) not seen on the intraoral bitewings appeared to have caries when observed on extraoral bitewings.

Table 5 - Subset of Surface Locations Not Seen On Intraoral Bitewings

Code	**Extraoral n=918**
0 = None	400 (43.57%)
1 = Less than 1/2 way through enamel	86 (9.37%)
2 = More than 1/2 way through enamel, not to DEJ	30 (3.27%)
3 = Into DEJ but less than 1/2 way to pulp	32 (3.49%)
4 = Over half way to pulp and further	17 (1.85%)
5 = Overlap Contact	120 (13.07%)
6 = Tooth Missing	166 (18.08%)
7 = Surface not seen on image	33 (3.59%)
8 = Defective Margin/restoration	14 (1.53%)
Missing/x	20 (2.18%)

Bone loss

A total of 2184 teeth were examined for bone loss in intraoral and extraoral bitewings. Bone loss was radiographically evident with 981 teeth (44.92%) when evaluated with intraoral bitewings. The crestal bone level was not visible with 166 teeth (7.6%) and 442 teeth (20.24%) could not be seen on the intraoral bitewings. With the extraoral bitewings, bone loss was radiographically evident with 1474 teeth (67.49%). The crestal bone was not visible with 83 teeth (3.08%) and 15 teeth (0.69%) could not be seen on the extraoral bitewings.

Fig. 5 – Intraoral Bitewings Revealing Interproximal Bone loss (note cone cut in images)

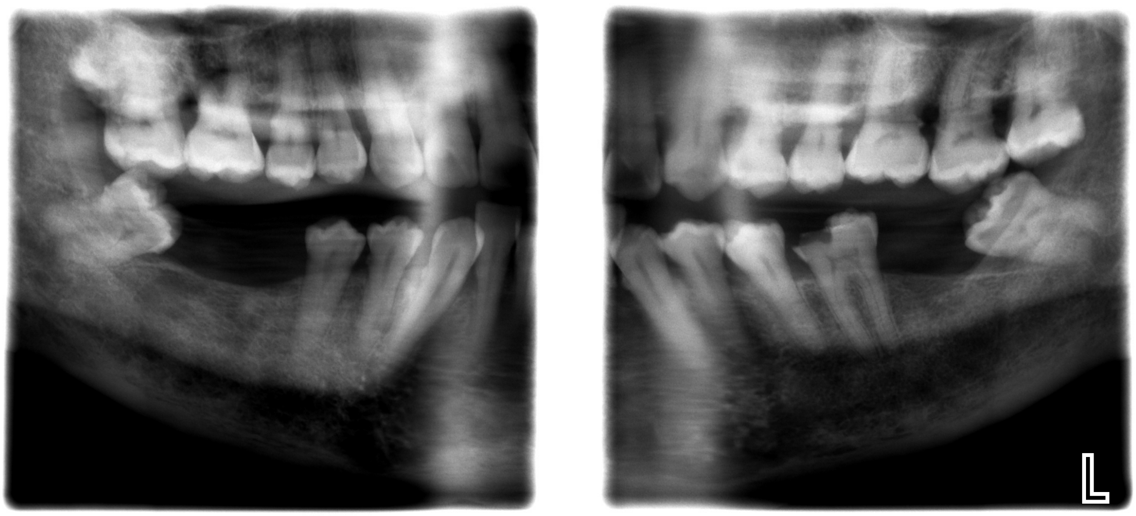

Fig. 6 – Extraoral Bitewing Revealing Interproximal Bone loss (note ghosting in image)

Table 6 – Distribution of Diagnoses for Bone loss

Code	**Intraoral n=2184**	**Extraoral n=2184**
0 = Bone level not visible	166 (7.60%)	83 (3.80%)
1 = Bone loss evident	981 (44.92%)	1474 (67.49%)
2 = Normal bone level	280 (12.82%)	197 (9.02%)
3 = Tooth not in image	442 (20.24%)	15 (0.69%)
4 = Tooth missing	252 (11.54%)	358 (16.39%)
Missing/x	63 (2.88%)	57 (2.61%)

Table 7 represents the subset of teeth that appeared diagnostic in both intraoral and extraoral bitewings for the evaluation of bone loss. The percent agreement between the two types of bitewings was 80.86% (95% confidence interval). The bone loss detection rate was greater for extraoral bitewings with 1076 teeth (90.19%) compared to intraoral bitewings with 930 teeth (77.95%). This difference was statistically significant at $p<0.0001$. Assuming the gold standard is the intraoral bitewing and the truth, the extraoral bitewings have a sensitivity of 94.50% and specificity of 26.86% with a false positive rate of 73.14% for diagnosis of bone loss. Assuming the gold standard is the extraoral bitewing, the intraoral bitewings have a sensitivity of 90.78% and a specificity of 64.40% with a false positive rate of 35.60%.

Table 7 Site-to-Site Comparison Between Intraoral and Extraoral Bone loss Diagnosis

Code	**Intraoral n=1193**	**Extraoral n=1193**
1 = Bone loss evident	930 (77.95%)	1076 (90.19%)
2 = Normal bone level	263 (22.05%)	117 (9.81%)

Percent Agreement (95% confidence interval) = 80.86% (75.75%, 85.10%)
Assuming intraoral is the gold standard:
Sensitivity=94.50%; Specificity=26.86%, False positive rate=73.14% (These are also from a GEE model.)
Assuming extraoral is the gold standard:
Sensitivity=80.78%; Specificity=64.40%, False positive rate=35.60% (These are also from a GEE model.)

Table 8 represents the 422 teeth that were not visible on the intraoral bitewings. When evaluated on the extraoral bitewings, 224 teeth (55.2%) had radiographic bone loss evident. Eighty-nine teeth (20.14%) were diagnosed as missing.

Table 8 - Subset of Surface Locations Not Seen On Intraoral Bitewings

Code	**Extraoral n=442**
0 = Bone level not visible	24 (5.43%)
1 = Bone loss evident	244 (55.20%)
2 = Normal bone level	63 (14.25%)
3 = Tooth not in image	13 (2.94%)
4 = Tooth missing	89 (20.14%)
Missing/x	9 (2.04%)

Discussion

In this study, we found that the caries detection rate with extraoral bitewings was significantly greater than intraoral bitewings. The false-positive rate for caries detection with extraoral bitewings was 38.01%. The bone loss detection rate with extraoral bitewings was also significantly greater than intraoral bitewings. The false-positive rate for bone loss detection with extraoral bitewings was 73.14%.

Diagnostic accuracy for caries

Exposure to ionizing radiation is not without biologic risk and economic costs. It is advantageous for the clinician to provide patients with a mode of radiography that provides the highest level of diagnostic accuracy with minimal radiation exposure, discomfort and time required for imaging. Because extraoral radiographs can be taken with minimal discomfort and time, this study compared the diagnostic accuracy of intraoral and extraoral bitewings for interproximal caries and bone loss. This study revealed that for the diagnosis of interproximal caries, extraoral bitewings had greater caries detection rate compared to intraoral bitewings. Assuming intraoral bitewings to be the gold standard for interproximal caries, extraoral bitewings had a false positive rate of 38%. This is consistent with the findings of Kamboroglu et al. (Kamburoglu, Kolsuz et al. 2012), who observed that extraoral bitewing radiography was inferior to intraoral bitewing radiography with respect to accuracy of interproximal caries detection and higher false-positive ratios with extraoral radiography. In their study, the investigators evaluated the detection of interproximal caries using intraoral bitewings, extraoral bitewings and panoramic radiography. The diagnoses made with the aid of the radiographs were validated using histological diagnoses for the true presence of caries. 80 crowns of extracted premolar and molar teeth were mounted on wax blocks and placed in a dry human skull. Similar to the present study, the investigation conducted by Kamboroglu et al. also used a Planmeca Promax Digital Panoramic X-ray unit. One draw back of the mentioned study is that the extracted teeth were mounted in a cadaver skull prior to examination between the three types of radiography, making this an *ex-vivo* study. Furthermore, because only the crowns of the teeth were used for the study, periodontal bone loss could not be evaluated.

Similar results were observed in studies evaluating the accuracy of extraoral and intraoral radiography in diagnosis of interproximal caries. In the study by Flint et al. (Flint, Paunovich et al. 1998), the diagnostic accuracy was compared between panoramic radiographs and intraoral radiographs. Intraoral radiographs were film based by means of a Gendex GX1000 intraoral dental radiography unit and processed in an Allied System 30Dx automatic processor. Film based panoramic images were obtained from the subjects' previous panoramic survey. This *in vivo* study evaluated the accuracy of diagnosing different dental pathoses including caries and bone loss in air force personnel. The radiographs of 30 subjects were read singly and in various combinations: panoramic radiographs alone, periapical and bitewing radiographs, panoramic and bitewing radiographs, and panoramic with bitewings and periapical radiographs. When panoramic radiographs were used alone for diagnosis of caries, it was shown to have the lowest correlation with the consensus radiographic standard (Flint, Paunovich et al. 1998).

In the study by Akkaya et al. (Akkaya, Kansu et al. 2006), the diagnostic accuracy of panoramic and intraoral radiographs were evaluated for the interproximal caries of different dental regions (maxillary and mandibular incisor, canine, premolar and molar). The radiographs were evaluated by three observers and diagnoses of interproximal caries were made and compared between observers. The authors concluded that full mouth series were most efficient in diagnosis of caries for incisor and canine teeth. For the diagnosis of caries with posterior teeth, similar diagnostic accuracy was found for full mouth series and using a combination of panoramic radiographs and intraoral bitewings. When using panoramic radiographs alone, the images were insufficient for the diagnosis of interproximal caries of the entire dentition (Akkaya, Kansu et al. 2006). In order to provide diagnostic accuracy for interproximal caries of the entire dentition comparable with full mouth series, panoramic radiographs would need to be supplemented with anterior periapical radiographs (Akkaya, Kansu et al. 2006).

In the studies by Akkaya et al. (Akkaya, Kansu et al. 2006) and Flint et al. (Flint, Paunovich et al. 1998), it was concluded that extraoral radiographs by themselves were insufficient for diagnosis of proximal caries of the entire dentition. The studies recommend a combination of extraoral radiographs and intraoral bitewings for optimal diagnosis. However, unlike the present study, extraoral bitewings were not used. The studies only compared panoramic radiographs with intraoral bitewings.

One possible reason for inferior diagnostic accuracy of extraoral radiographs is the presence of overlap. Overlapping of the tooth crowns in panoramic radiography is often observed making diagnosis of interproximal caries difficult (Scarfe, Nummikoski et al. 1993). This may have been responsible for the inferior diagnostic accuracy of extraoral bitewings in other studies. However, in the present study, the presence of overlap was similar between intraoral bitewings (11.66%) and extraoral bitewings (13.26%).

Overall, in the present study, the extraoral bitewings resulted in a high sensitivity (71.91%) and moderate specificity (61.99%) for the diagnosis of interproximal caries. Although a false positive rate of 38% was observed, the diagnosis of made for "treatable carious lesions" was higher for extraoral bitewings (20.83%) compared to intraoral bitewings (13.28%). Furthermore, if a more conservative approach is taken to observe initial carious lesions prior to treatment, a false positive lesion will not progress upon re-evaluation unlike an actual carious lesion. Because of the slow progression of carious lesions, a delay in treatment of 6 months will unlikely result in extensive advancement of the true positive carious lesion (Benn 1994).

Diagnostic accuracy for bone loss

For the diagnosis of bone loss, extraoral bitewings had a percent agreement of 80.86%. This was greater than the percent agreement observed by Molander (Molander 1996). In their study comparing panoramic radiography with intraoral radiography, the two types of panoramic radiographs used (rotational and intraoral x-ray tube technique) resulted in 55% and 49% agreement in marginal bone height. They concluded that the agreement was insufficient to use panoramic radiography alone to diagnose marginal bone loss (Molander 1996). When a combination of panoramic radiography followed by intraoral radiographs considered necessary, there was a sensitivity of 80-96% and a specificity of 50-92%.

In a study conducted by Akesson et al. (Akesson, Rohlin et al. 1989), the diagnostic quality of panoramic radiographs was compared to that of intra-oral bitewings and periapical radiographs. The study focused on the ability to interpret and measure marginal bone level. Panoramic and full mouth radiographs were taken for each patient and although measurements were not taken and diagnoses of bone loss were not made, the image quality of each site was classified as excellent, acceptable or unacceptable. The panoramic radiographs from this study had less diagnostic quality compared to intraoral radiographs. The main reason for this was due to overlapping of teeth seen in the panoramic radiographs, but not in the intraoral bitewings (Akesson, Rohlin et al. 1989). In the present study, there was minimal overlapping that resulted in inability to properly assess bone levels with extraoral bitewings (3.80% of teeth). This was even less than the proportion of teeth that could not be properly assessed with intraoral bitewings (7.06%).

Alternative study designs

Although extraoral bitewings had a higher percent agreement for bone loss compared to caries detection, 80.86% and 63.95%, and higher sensitivity compared to caries detection, 94.5% and 71.91%, extraoral bitewings had a much higher false positive rate of 73.14% compared to caries diagnosis 38.01%. One possible explanation for this is the magnification commonly observed with extraoral radiographs. With a greater distance between the object and the sensor with extraoral radiographs, there is greater magnification compared to intraoral radiographs. As a result, the linear measurement from the cementoenamel junction of the tooth to the alveolar crest may appear falsely greater than in reality, which could lead to overtreatment. This magnification may not have affected the accuracy of caries diagnosis as much since the severity of the carious lesions was measured based on proportion of the tooth involved instead of the linear measurement of the carious lesion. This is reflected in the lower false positive rate in caries diagnosis. An alternative would have been to diagnose and classify bone loss as percent of attachment loss for each tooth on top of its presence and absence. Just as caries diagnoses are not made solely from radiographic examinations, the diagnosis of bone loss and periodontal disease is made from both clinical and radiographic examinations. In the diagnosis and treatment planning of periodontal disease, the bone loss observed from extraoral bitewings can easily be verified by cross examining the measurements from the clinical periodontal exams to rule out false positives.

Another alternative in study design could have been the use of cone beam computed tomography and to compare with the diagnoses from both extraoral bitewings and intraoral bitewings. In a study by Young et al. (Young, Lee et al. 2009), extracted premolar and molar teeth were mounted and imaged using a cone beam CT and a CCD sensor. This *ex vivo* study compared the two methods of imaging for the diagnosis of interproximal and occlusal caries. For interproximal caries extending into the dentin, cone beam CT images had twice the sensitivity (61%) compared to CCD images (33%)

and the difference was significantly different (Young, Lee et al. 2009). It could be concluded that conventional radiographic imaging may underestimate the presence of caries (Young, Lee et al. 2009). Implementing the use of cone beam CT images would aid in the evaluation of sites that were false positives. However, the disadvantage of this alternative mode of imaging in an in-vivo study is the increased radiation associated with cone beam CT images and the image artifacts from metallic restorations. As the x-ray beam passes through the teeth, photons of lower energy are absorbed in higher preference to photons of higher energy. This differential absorption leads to distortion of metallic structures on the cone beam CT image.

A third alternative would be to evaluate the diagnoses made from intraoral and extraoral images with histology. An investigation could be conducted ex-vivo, similar to Kamboruglu et al. (Kamburoglu, Kolsuz et al. 2012) or in-vivo with teeth treatment planned for future extraction.

Limitations of the study

For the purposes of this study, intraoral bitewings were assumed to be the truth and extraoral bitewings were compared to intraoral bitewings. However, without histological evaluation, the gold standard, the actual truth of interproximal caries and bone loss is unknown. Because the setting of the current study was at a University teaching environment, the intraoral bitewing radiographs were obtained by dental students under the supervision of radiology technicians. This had a large impact on the diagnostic quality of the intraoral bitewings. There would have been more standardization if all the intraoral and extraoral bitewings were taken by one operator. Two of the examiners had travelled from out of town and out of state for examination of the radiographs. Because the examiners had come from long distances, all the radiographs were read and evaluated within two days. Fatigue could have affected the diagnoses made. Lastly, because of limitations in time we did not evaluate all the images that were taken.

Costs

The use of extraoral bitewings in dentistry does offer certain advantages over intraoral bitewings including increased patient comfort, decreased time required for multiple images and an increased field of view. However, the use of extraoral bitewings comes with equipment costs. The practicing dentist already owns and frequently employs equipment required for intraoral bitewings. In order to supplement their dental radiography with extraoral bitewings, the dentist would require purchasing the ProMax S3 from Planmeca because of its patented SCARA technology for its True Bitewing program. With the SCARA technology, the panoramic unit offers a fully programmable 3-axis robot arm to reduce the distance between the radiation source and the image and to ensure that the x-ray beam is perpendicular with the long axis of the patient's teeth. Implementing this method of radiography would also require training in use of the machine as well as in reading the images.

Future studies

In a future study, the diagnoses made from the intraoral and extraoral bitewings of the present study could be evaluated based on dental therapy provided to any returning patients at the School of Dentistry. The diagnoses could also be evaluated for progression of caries and bone loss as patients receive recall examinations and bitewings in the future.

Conclusions

Based on the results of our study, we concluded that

- The number of overlapping contacts with extraoral bitewings was not significantly greater than intraoral bitewings
- The caries detection rate with extraoral bitewings was statistically significantly greater than intraoral bitewings
- The false-positive rate for caries detection with extraoral bitewings was 38.01% assuming intraoral bitewings are the gold standard
- The percent agreement between intraoral and extraoral bitewings for bone loss diagnosis was 80.86%
- For the diagnosis of bone loss, the sensitivity with extraoral bitewings was high (94.5%), but the false positive rate was also high (73.14%)
- It may be prudent to diagnose bone loss as a percentage of attachment loss for future studies and to clinically re-evaluate radiographic findings
- The use of extraoral bitewings provides numerous advantages over intraoral bitewings, but comes with a financial cost of purchasing new equipment and training both support staff and clinicians

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