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TECHNICAL REPORT

The role of stationary intraoral tomosynthesis in reducing proximal overlap in bitewing radiography

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Objectives: This study examined the utility of stationary intraoral tomosynthesis (s-IOT) in opening proximal contacts in bitewing radiography.
Methods: 11 DENTSPLY Rinn Dental X-ray Teaching and Training Replica mannequins (Model #546002, Elgin, Ill) were imaged with a prototype s-IOT device (Surround Medical Systems, Morrisville, NC) and standard bitewing (SBW) technique. Premolar and molar bitewings were acquired with each system. Image receptor holders were used to position receptors and aid in the alignment of the position indicating devices. An expert operator (having more than 5 years of experience in intraoral radiography) acquired the images with the s-IOT prototype and standard intraoral X-ray devices. Images were assessed to analyze percentage overlap of the proximal surfaces using the tools available in ImageJ (NIH, Bethesda Maryland).
Results: 253-paired surfaces were included in the analysis. The difference in overlap was statistically significant with standard bitewing (SBW) images resulting in a median overlap of 13%, a minimum of 0%, a maximum of 100% and an interquartile range of 40%. s-IOT resulted in a median overlap of 1%, a minimum of 0%, a maximum of 37% and an interquartile range of 0%. The s-IOT prototype substantially reduced proximal surface overlap compared to conventional bitewing radiography.
Conclusions: The use of s-IOT reduced proximal contact overlap compared to standard bitewing radiography for an experienced radiographer. Stationary intraoral tomosynthesis may be a potential alternative to SBW radiography, reducing the number of retakes due to closed contacts.
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Keywords: Digital; tomosynthesis; Carbon nanotube (CNT); proximal caries; closed contacts

Introduction

Standard bitewing (SBW) radiography is considered the preferred method for caries diagnosis.[1] When combined with a thorough clinical examination, SBWs are deemed to be a valuable diagnostic tool. However, like most radiographic procedures, SBWs are technique-sensitive and rely strongly on the skill of the operator. Unfortunately, caries detection may be hampered by poor technique and unequally trained operators.[2–4] Adding to the challenge of correctly exposing SBWs, a systematic review of the literature by Bader et al reported that the median sensitivity value for proximal caries was 49%.[5] One of the primary goals of SBW radiographic technique is to open the proximal contacts so that no superimposition of the tooth surfaces occurs. Techniques to accomplish this goal have ranged from the use of innovative receptor holders to the development of an extraoral panoramic bitewing radiography-like feature. However, several of the research studies comparing these techniques have failed to show a significant improvement

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Figure 1 Intraoral tomosynthesis prototype.

over SBW technique that used a tab with the X-ray source positioned free-handed.[6,7] In our study, we examined whether stationary intraoral tomosynthesis (s-IOT), an experimental technology invented at the University of North Carolina,[8] could reduce proximal surface overlap in bitewing (BW) radiography. We used a prototype s-IOT device manufactured by Surround Medical Systems, Morrisville, NC (Figure 1). The development of s-IOT was made possible by the invention of the carbon nanotube (CNT) field emission X-ray source array technology[9] and a collaborative effort between researchers from the Department of Physics and Astronomy and the Department of Diagnostic Sciences Section of Oral and Maxillofacial Radiology at the University of North Carolina Adams School of Dentistry.[10] The s-IOT prototype device uses an array of seven X-ray focal spots ("sources") that are linearly positioned at different angles achieving a total angular disparity of 12 degrees (Figure 2). The sources fire in sequence while a Complementary Metal–Oxide–Semiconductor (CMOS) digital sensor captures the images. The captured images are reconstructed to produce three-dimensional information using Surround Medical Systems' proprietary algorithms. The reconstructed images are parallel to the detector allowing the clinician to scroll through the generated stack of images and view the anatomy free of superimposition (Figure 3). The

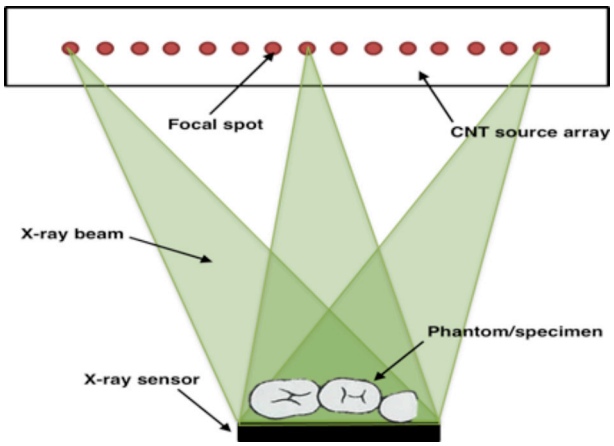

Figure 2 Drawing depicting a 15-beam array in linear configuration. CNT, carbon nanotube.

prototype device built by Surround Medical Systems is comparable in size to current two-dimensional (2D) intraoral X-ray systems and uses identical image geometry. The images are high resolution and the total radiation dose used to acquire the images is comparable to the dose of D-speed film with rectangular collimation.[11–13]

Methods and materials

This study was conducted at the University of North Carolina at Chapel Hill, Adams School of Dentistry, Oral and Maxillofacial Radiology Clinic. 11 DENTSPLY Rinn Dental X-ray Teaching and Training Replica mannequins (Model #546002, Elgin, Ill) were used as test subjects and exposed using each device. The Dental X-ray Teaching and Training Replica model #546002 is made with natural teeth and cadaver material and is often used for teaching radiographic imaging techniques to dentists, dental hygienists, dental assistants and clinical staff. SBW images (a premolar and molar on each side) were acquired using a single Instrumentarium Focus™ intraoral X-ray unit with rectangular collimation (Charlotte, NC). The following exposure parameters were used for each projection, 70 kilovoltage peak (KVp), 7 milliamps (mA) and 320 ms. A Rinn XCP-ORA Universal Sensor Holder (York, Pa) was used with a Schick 33 CMOS detector (Sirona Dental, IN, Long Island City, NY) for image acquisition. Bitewing tomosynthesis images (a premolar and molar on each side) were acquired using the s-IOT prototype.

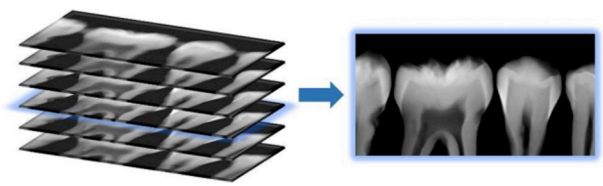

Figure 3 Example of generated images using software reconstruction.

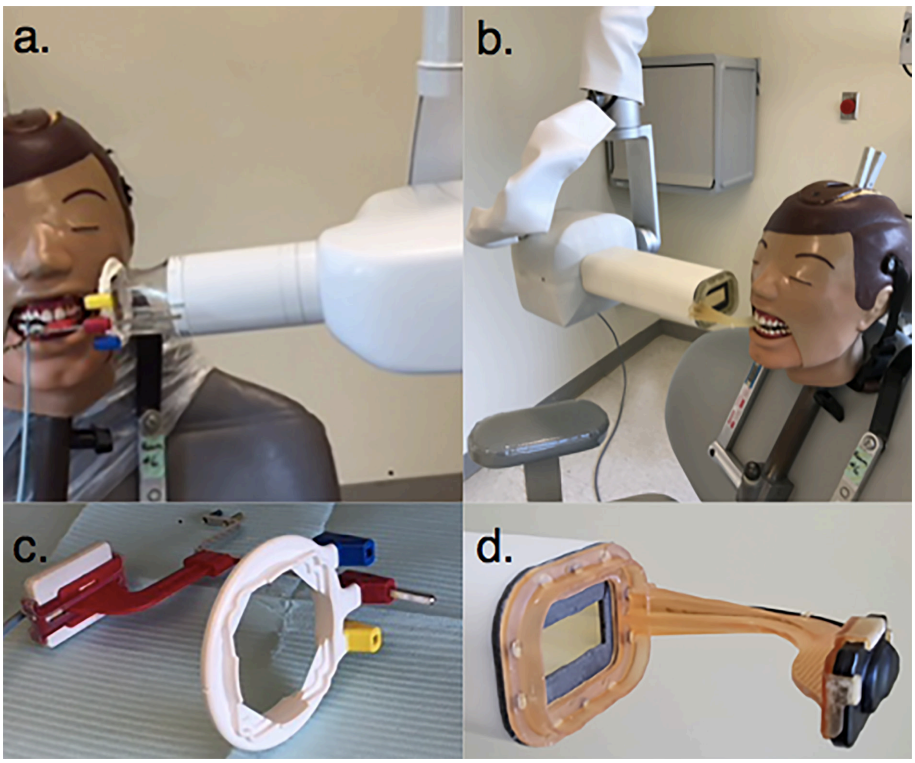

Figure 4 Image acquisition with standard device (a) tomosynthesis (b) Universal XCP (c) and s-IOT receptor holder (d). s-IOT, stationary intraoral tomosynthesis.

The following exposure parameters were used: 70 KVp, 7 mA and 50 ms. Image acquisition was accomplished with a CMOS detector that was part of the system and programmed to acquire the images in the proper sequence for image reconstruction. Both detectors (XCP and experimental device) were secured in holders with beam alignment devices. The s-IOT detector holder was specifically designed to facilitate accurate alignment with the X-ray source. This is achieved using magnets embedded at the end of the holder and position indicating device to facilitate coupling. Accurate alignment was essential for achieving optimal image reconstruction (Figure 4).

44 molar and premolar images were acquired with each modality and the relative amount of proximal enamel overlap was measured. One expert operator (having more than 5 years of experience exposing intraoral radiographs) acquired all of the images. The exposure order and sequence of manikins was random per modality. The SBW and s-IOT generated images were analyzed by a calibrated clinician who measured the percentage of overlap of adjacent surfaces for each image using the tools available in ImageJ (NIH, Bethesda, MD). Each s-IOT data set was reconstructed into 45 slices of 0.5 mm that were parallel to the sensor plane. For each proximal surface, the percentage horizontal overlap between the enamel and the enamel of the adjacent proximal surface was calculated by dividing the amount of surface overlap by the maximum thickness of the enamel. (Figure 5.) The percentage overlap was recorded and analyzed. Proximal surfaces overlap exceeding 33% compromises caries detection and are considered a technical error (UNC Adams School of Dentistry SBW performance criteria). 10 randomly selected paired images with 52 surfaces were selected for reassessment in order to determine the intrarater reliability using the intraclass correlation coefficient. A Wilcoxon signed rank test was used for comparison analysis of the two devices to determine statistical significance.

Results

A total of 265 conventional tooth surfaces and 350 test tooth surfaces were imaged and evaluated. 12 conventional surfaces and 97 test surfaces were excluded from analysis as a result of those surfaces not being captured with both modalities. Thus, a total of 253-paired surfaces were included in the analysis. Figure 6 is an examples of a SBW image and the paired s-IOT images comprised of three slices of the same area. Measures of the SBW images resulted in a median overlap of 13%, a minimum of 0%, a maximum of 100% and an interquartile range of 40%. s-IOT images resulted in a median overlap of 1%, a minimum of 0%, a maximum of 37% and an interquartile range of 0%. The difference was statistically significant between the two devices ($p < 0.0001$) by

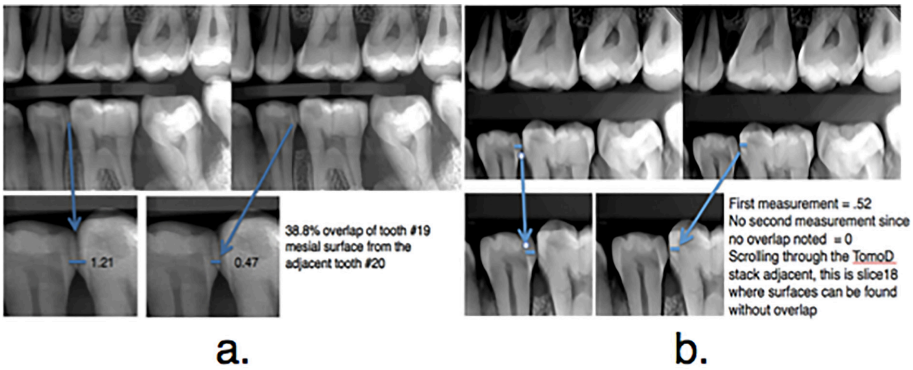

Figure 5 Example measurement for of standard bitewing and s-IOT generated images. s-IOT, stationary intraoral tomosynthesis.

the Wilcoxon Signed Rank test. (Figure 7.) Intrarater reliability for the test device (s-IOT) was perfect with an intraclass correlation of 1.0. For the conventional device reliability, the R-square value was 0.73 and had an Intraclass correlation of 0.84.

Discussion

SBW radiography has been the preferred imaging modality to assess the presence of proximal caries. The success of the procedure is highly dependent on the ability of the operator to use correct angulation in order to image the proximal contacts free of superimposition. When improper technique is used, proximal surfaces may be overlapped, compromising caries detection, requiring retakes that are time consuming, resulting in additional radiation exposure to the patient. In the past, several efforts have been made to develop positioning devices to increase accuracy of receptor position. These have included the Precision Instrument, Universal XCP's, the True Align and others. However, one the most promising efforts was accomplished by Richard Webber in the early 1990s by his development of Tune Aperture Computer Tomography (TACT), a form of tomosynthesis. His invention resulted in an extensive research effort that generated a body of academic publications reporting that in many cases TACT was superior to 2D imaging in the diagnosis of several common oral diseases because of its ability to display slices of anatomical details free of superimposition.[14] Unfortunately, research of TACT waned due to the lack of promise in developing a viable device for clinical use. Manufacturers of panoramic radiographic units have also incorporated a bitewing radiography-like feature in some of their units in an effort to improve the outcome of the technique, but results have failed to show that Panoramic BW-type radiographs are superior to conventional methods being used. In this study, SBW radiographic images were compared to bitewing images acquired with an s-IOT prototype device. The results showed that s-IOT substantially reduced proximal surface overlap compared to SBW radiography. As a result, s-IOT likely maintains diagnostic quality for caries detection and could reduce the need for retakes even when the horizontal angulation is suboptimal. This study demonstrates that this is true for an experienced radiographer taking a large number of BW radiographs, minimizing the probability that the difference between the modalities was caused by a

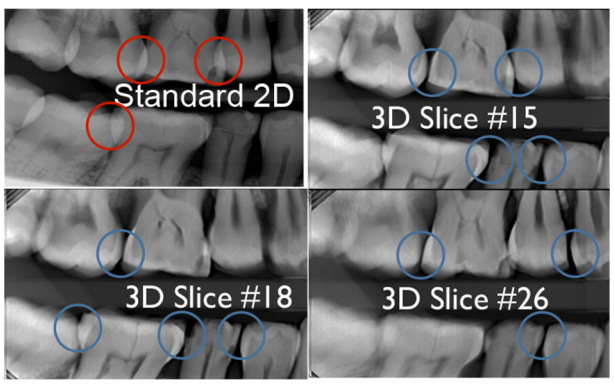

Figure 6 Comparison of standard bitewing image with s-IOT reconstructions showing contacts free of superimposition. 2D, two-dimensional; 3D, three-dimensional.

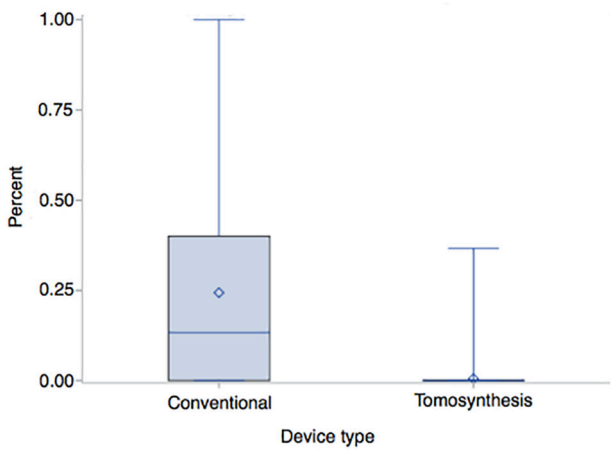

Figure 7 Distribution of percentage overlap by device.

particular projection or a particular manikin. Images produced with s-IOT provided excellent visualization of anatomic structures since it gives the user the ability to scroll through the reconstructed images. The s-IOT prototype did not require additional operator training for receptor position or tube alignment resulting in a seamless transition for operator use. As the technology advances, the authors recommend performing additional studies to assess the usefulness of the s-IOT in clinical practice. In an earlier bench top study at the UNC Adams School of Dentistry comparing dental tomosynthesis to 2D imaging, dental tomosynthesis showed a 36 percent increase in sensitivity in the diagnosis of proximal caries. These results were presented at the American Academy of Maxillofacial Radiology meeting in Indianapolis, Indiana.[15] Other studies underway at the UNC Adams School of Dentistry include dosimetry comparing the effective doses of s-IOT BW and SBW radiography and a clinical trial comparing conventional BW radiography to s-IOT in the diagnosis of proximal caries.[16] Currently, the main limitations of s-IOT are the lack of clinical data validating its efficacy in the diagnosis of common oral conditions, optimization of the technology and the availability of information to clinicians and patients.

Conclusion

The use of the s-IOT prototype reduced proximal contact overlap compared to SBW radiography for an experienced radiographer. This new technology may be a potential alternative to SBW radiography. Also, its role in the diagnosis of common oral diseases should be investigated and any studies performed with the s-IOT prototype should be repeated with commercial units to validate reported results.

Acknowledgment

Surround Medical Systems, Morrisville, NC Enrique Platin, André Mol, Jianping Lu and Otto Zhou are listed as inventors on the patent. Enrique Platin, Jianping Lu and Otto Zhou have financial interest in Surround Medical Systems.

REFERENCES

1. Gaalaas L, Tyndall D, Mol A, Everett ET, Bangdiwala A. Ex vivo evaluation of new 2D and 3D dental radiographic technology for detecting caries. *Dentomaxillofac Radiol* 2016; **45**: 20150281. doi: https://doi.org/10.1259/dmfr.20150281
2. Sewerin I. Frequency and distribution of proximal overlappings on posterior bitewing radiographs. *Community Dent Oral Epidemiol* 1981; **9**: 69–73. doi: https://doi.org/10.1111/j.1600-0528.1981.tb01031.x
3. McDonald SP. A method to reduce interproximal overlapping and improve reproducibility of bitewing radiographs for use in clinical trials. *Community Dent Oral Epidemiol* 1983; **11**: 289–95. doi: https://doi.org/10.1111/j.1600-0528.1983.tb01896.x
4. McDonald SP. Investigation into the relationship between deviations in X-ray angulation and images of proximal overlapping on bite-wing radiographs. *Community Dent Oral Epidemiol* 1984; **12**: 173–6. doi: https://doi.org/10.1111/j.1600-0528.1984.tb01433.x
5. Bader JD, Shugars DA, Bonito AJ. Systematic reviews of selected dental caries diagnostic and management methods. *J Dent Educ* 2001; **65**: 960–8.
6. Ulusu T, Bodur H, Odabaş ME. In vitro comparison of digital and conventional bitewing radiographs for the detection of approximal caries in primary teeth exposed and viewed by a new wireless handheld unit. *Dentomaxillofac Radiol* 2010; **39**: 91–4. doi: https://doi.org/10.1259/dmfr/15182314
7. Terry GL, Noujeim M, Langlais RP, Moore WS, Prihoda TJ. A clinical comparison of extraoral panoramic and intraoral radiographic modalities for detecting proximal caries and visualizing open posterior interproximal contacts. *Dentomaxillofac Radiol* 2016; **45**: 20150159. doi: https://doi.org/10.1259/dmfr.20150159
8. Zhou OZ, Lu J, Shan J, Tucker A, Chtcheprov P, Platin E, et al. Methods and computer readable media for intraoral dental tomosynthesis imaging. *United States Patent. US* 2017; **9**: 9,782,136 B2.
9. Zhou OZ, Lu J. X –ray generating mechanism using electron field emission cathode. *United States Patent. US* 2005; **6**: 6850595B2.
10. Shan J, Tucker AW, Gaalaas LR, Wu G, Platin E, Mol A, et al. Stationary intraoral digital tomosynthesis using a carbon nanotube X-ray source array. *Dentomaxillofac Radiol* 2015; **44**: 20150098. doi: https://doi.org/10.1259/dmfr.20150098
11. Inscoe CR, Platin E, Mauriello SM, Broome A, Mol A, Gaalaas LR, et al. Characterization and preliminary imaging evaluation of a clinical prototype stationary intraoral tomosynthesis system. *Med Phys* 2018; **45**: 5172–85. doi: https://doi.org/10.1002/mp.13214
12. Puett C, Inscoe C, Hilton R, Mol A, Platin E, Lu J, et al. Stationary digital intraoral Tomosynthesis: demonstrating the clinical potential of the first-generation system. *Physics of medical Imaging* 2018;10573OESPIE 10573, Medical imaging.
13. Inscoe CR, Wu G, Soulioti DE, Platin E, Mol A, Gaalaas L, et al. Stationary intraoral tomosynthesis for dental imaging. *Physics of Medical Imaging,* 2017; **1013203**Proc. SPIE 10132, Medical Imaging.
14. Webber RL, Horton RA, Tyndall DA, Ludlow JB. Tuned-aperture computed tomography (TACT). theory and application for three-dimensional dento-alveolar imaging. *Dentomaxillofac Radiol* 1997; **26**: 53–62. doi: https://doi.org/10.1038/sj.dmfr.4600201
15. Mol A, Gaalaas L, Tucker A, Shan J, Wu G, Platin E, et al. Intraoral Tomosynthesis using carbon nanotube (CnT) X-ray technology: primary caries detection. *66th Annual Session of the American Academy of Oral and maxillofacial Radiology* 2015;Indianapolis, Indiana, September 30.
16. University of North Carolina, Chapel Hill protocol record, conventional bite wing radiography versus stationary intraoral Tomosynthesis, a comparison study. *ClinicalTrials.gov Identifier*NCT02873585.