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In Vitro Detection Of Proximal Caries With High Resolution Ultrasound (US) In Comparison To Bitewing Radiography In Deciduous Teeth

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Abstract: *We evaluated the performance of high resolution Ultrasound imaging in detecting proximal caries in primary posterior teeth, compared to bitewing (BW) radiography. A total of 64 deciduous molar teeth with proximal dentin caries (32 primary caries and 32 secondary caries under restorations) and 64 primary molar teeth without caries were used. All teeth were randomly placed in the |alveolar sockets of a dry skull in groups of 8. Digital intraoral bitewing radiographs were obtained by photostimulable phosphor plate (PSP) detector. US examinations were performed by using high-resolution ultrasonography (US). Finally, 2 image sets were obtained: 1) PSP bitewing radiography, and 2) HD US images. Images were viewed by 2 observers. Histology was considered as gold standard. Intraclass correlation coefficients (ICCs) were calculated to assess observer agreement. The areas under the ROC curves (AUC - Area Under Curve - values) and chi-square tests were utilized (α = 0.05). Higher intra-and inter-observer coefficients were found for primary caries compared to secondary caries and for bitewing radiography when compared to Ultrasound images. In general, excellent ICC values were calculated. Highest AUC values were found for bitewing radiography images for primary caries detection and lowest for Ultrasound images for secondary caries detection. Dual Diagnostic Performance Comparison between Ultrasound and bitewing radiography showed no statistically significant difference (P=0,329). Again, no statistically significant difference was found for diagnostic performance between primary and secondary caries detection (P=0,545). High resolution ultrasound imaging has the potential to be utilized in the detection of proximal dental caries in deciduous teeth.*
Keywords: *Caries Detection, Dental Caries, Primary Teeth, Radiography, Ultrasonography*

1. INTRODUCTION

Caries is basically a pathological process that occurs when the demineralization-remineralization balance between the enamel surface and the plaque fluid shifts towards demineralization, resulting in decreased mineralization of the enamel. It is considered as an oral health issue in which the enamel layer on the surface of the teeth erodes over time, creating cavities on the surface of the tooth which occurs specifically as a result of acids produced by bacteria in the oral environment.[1,2] The clinical criterion for tooth caries is cavity formation which is difficult to detect by current diagnostic methods until the caries progresses and becomes a cavity that is known as the late stage of caries pathogenesis. Due to lack of early diagnostic techniques clinical cases requiring restoration are encountered especially in children. Restoration of the tooth is a troublesome practice for the child and costly for the family. Therefore, it is of paramount importance for the clinician to diagnose caries at an early stage and prevent it from becoming a large cavity with the necessary protective measures. After the eruption of the first permanent molar, the possibility of caries on the proximal surface of the teeth increases with the closure of physiological diastemas. As the contact area between the primary 1st and 2nd molars is a wide and flat surface, the occurrence of caries on the distal surface of the primary 1st molars and the mesial surface of the primary 2nd molars is high. The lesions start slightly below the contact area, however; due to the large surface area of the contact area, it is not possible to examine the interface with a probe.[1-5]

If a cavity occurs, the lesion should be diagnosed as soon as possible, taking into account the health of the pulp, and in order to keep the tooth healthy and functional in the mouth until it falls out normally. Tooth with caries should be included in the treatment program and the appropriate treatment option should be created according to the condition of the caries. The most commonly used methods in caries diagnosis are mirror-probe, visual examination and radiography.[6,7] There are many clinically unnoticed caries lesions which make the use of radiography mandatory, especially in proximal caries. Bitewing technique is important in detecting interdental caries that are not noticed in the early stages. It has been reported that an average of 30-40% loss of mineralization in the enamel tissue is required for radiographic identification of the enamel

tissue.[8] Radiography is the most useful and frequently used method for diagnosing proximal and recurrent caries in conjunction with clinical examination. Solid-state detectors are either a charge-coupled device (CCD), or a complementary metal oxide semiconductor (CMOS). Photostimulable phosphor plates (PSP) absorb and gather energy from X-rays and thereafter this energy is released as phosphorescent upon detection by a photomultiplier. The two-dimensional (2D) nature of the bitewing images limits the information that can be obtained, and their versatility is affected by projection geometry, beam angulation, superimposition of anatomical structures, position of teeth in the arch, and patient-related factors.[9-13] Ultrasound (US) imaging was proposed for dental use due to concerns over hazardous effects of ionizing radiation to dental patients and especially to children. High-frequency sound waves are transmitted into the region of interest by use of a transducer and echoes from tissue interface are detected and monitored on a screen. Main disadvantages of US are limited penetration into bone structures, less spatial resolution at deep tissues and lack of expertise in dentistry. Therefore, its application in dentistry is limited to superficial dento-maxillofacial soft and hard tissue structures since high-resolution, small-sized and intraoral probes were not available for dental health. In dentistry, diagnostic ultrasonography is used in salivary gland diseases, vascular pathologies of the head and neck region, ultrasound-guided interventions, detection of metastatic lymph nodes, imaging of soft tissue lesions such as cystic lesions, benign lesions, malignant lesions, lodge infections and abscesses, and lymphadenopathies. Ultrasound imaging of dental hard tissues and detection of enamel demineralization were studied previously. Ultrasonography is increasingly used in dentistry because it provides on-site, user friendly, low-cost, real-time imaging without ionizing radiation.[13,14]
This study aimed to evaluate the performance of high resolution Ultrasound in detecting proximal caries in primary posterior teeth, compared to bitewing (BW) radiography.

2. MATERIALS AND METHODS

A total of 64 deciduous molar teeth with proximal dentin caries (32 primary caries and 32 secondary caries under restorations) and 64 primary molar teeth without caries extracted for periodontal and orthodontic reasons were stored in 1% thymol solution after extraction. For secondary caries, Class 2 cavities were prepared and caries were left on the pulpal or axial walls, and the teeth were restored with conventional resin composite (Filtek Z250, Z250/3M ESPE, Seefeld, Germany). Scotchbond Universal adhesive (3M ESPE, Seefeld, Germany) without prior etching was used as bonding. For imaging procedures, each tooth was placed in the appropriately prepared maxillary and mandibular molar sockets of a dry child skull along with its mandible. The dry skull along with its mandible was covered with 2 cm red wax as a soft tissue equivalent material. All teeth were randomly placed in the alveolar sockets in groups of 8 ensuring an equal number of maxillary and mandibular deciduous teeth (two molars on left and right hemi-mandibles and hemi-maxillae). Digital intraoral bitewing radiographs were exposed by using an X-ray unit (Gendex Digital Systems, Hatfield, PA, USA) operated at 70 kVp and 7mA with a size 2 photostimulable phosphor plate (PSP) detector (GXPS-500 PSP, Gendex Digital Systems, Bensheim, Germany). Image recording was set at 64 μm (high) pixel size and 32-bit color. Imaging was performed with a focus-receptor distance of 20 cm and an image-exposure time of 0.05 s. Pulpal root canal, dentine and enamel visibility were determined as indicators of optimal image quality. US examinations were performed by using an ACUSON S 2000 (Siemens, Munich, Germany) high-resolution ultrasonography. A 18L6 MHz HD linear probe covered with ultrasonography gel was placed on the transversal plane, with the probe position altered constantly to obtain adequate cross-sectional images. The transducer was positioned perpendicular to alveolar crest in order to enable cross-sectional assessment of the teeth. For the caries evaluation, restorative materials and enamel seen as hyperechogenic image with an echogenic shadow was used for decision-making reference. A total of 2 image sets were obtained as follows: 1) PSP bitewing radiography, and 2) HD US images. A specific calibration session by using 5 images was conducted prior to image reading. Image sets were viewed separately by 2 blinded and calibrated observers (between 10 and 20 years of experience in dental and caries imaging) in a dimly lit room without time restrictions. The image sets were viewed at one-week intervals, and evaluations of each image set were repeated one week after the initial viewings. For bitewing images, the observers were asked to assess the presence or absence of proximal caries on a diagnostic monitor (NEC, Tokyo, Japan) that had a 21.3'' screen and 2048 × 1536 resolution by using built in software of the imaging system. US assessments were conducted by using Siemens system's own software and monitor. The 5-point rating scale determined the presence or absence of

caries as: (1) almost definitely present, (2) probably present, (3) unsure, (4) probably not present and (5) almost definitely not present. Histological gold standard status of teeth was performed by serially sectioning each tooth mesiodistally in parallel to the long axis of the crown. Each section was examined under a stereomicroscope (610) (Stemi 2000; Carl Zeiss, Jena, Germany) in which a caries was defined as a demineralized white or yellowish-brown discolored area in the dentine.

3. Iii. Statistical Analysis

Intraclass correlation coefficients were calculated to assess the intra- and inter-observer agreement for each image type according to the following criteria: <0.40= poor agreement; 0.40–0.59 = fair agreement; 0.60–0.74 = good agreement; 0.75–1.0 = excellent agreement. The estimated ICC values were based on absolute agreement, two-way mixed effects model.[15] Obtained scores from 2 different image types and 2 different caries types were compared with the gold standard by using the receiver operating characteristic (ROC) analysis in order to evaluate the observers' ability to differentiate between teeth with and without caries. The areas under the ROC curves (AUC - Area Under Curve - values) were calculated and the tests for the equality of AUCs for each image type and caries were compared using chi-square tests. Significance level was set at $\alpha = 0.05$.

4. RESULTS

Intra-observer and inter-observer agreements for both readings for both observers are given in **Table 1**. Higher intra-and inter-observer coefficients were found for primary caries compared to secondary caries and bitewing radiography when compared to Ultrasound images. In general, excellent ICC values were calculated for all diagnostic image type and caries type assessments.

Table 1. ICC Observer Correlation

Caries Type	Image Type	Intraobserver (R1 vs R2)		Interobserver	
		Observer1	Observer 2	1.Reading	2. Reading
1. Primary Caries	Ultrasound	0,842	0,861	0,711	0,763
	Bitewing	0,849	0,875	0,725	0,795
2. Seconder Caries	Ultrasound	0,811	0,819	0,701	0,712
	Bitewing	0,835	0,878	0,717	0,725

Table 2 shows Caries Type and Diagnostic Method related Diagnostic Performance as defined by AUC. Highest AUC values were found for bitewing radiography images for primary caries detection and lowest for Ultrasound images for secondary caries detection.

Table 2. Caries Type and Diagnostic Method related AUC Diagnostic Performance

Caries Type	Diagnostic Method	AUC	Std. Err.	95% Confidence Interval	
				L.B	U.B
1- Primary Caries	Ultrasound	0,717	0,0441	0,829	0,966
	Bitewing	0,781	0,0727	0,881	0,891
2- Secondary Caries	Ultrasound	0,621	0,061	0,249	0,551
	Bitewing	0,669	0,074	0,349	0,776
AUC: Area under curve, L.B: Lower bound, U.B: Upper Bound					

Table 3 shows general diagnostic performance for both methods suggesting higher AUC values for bitewing radiography. Dual Diagnostic Performance Comparison between US and bitewing radiography showed no statistically significant difference (P=0,329). Again, no statistically significant difference was found for diagnostic performance between primary and secondary caries detection (P=0,545).

Table 3. General Diagnostic Performance

Diagnostic Method	AUC	Std. Err.	95% Confidence Interval	
			L.B	U.B
Ultrasound	0,625	0,0234	0,662	0,791
Bitewing	0,666	0,0362	0,701	0,737
AUC: Area under curve, L.B: Lower bound, U.B: Upper Bound				

5. DISCUSSION

The aim of this study was to develop an evaluation procedure for the ultrasonographic detection of dental caries in deciduous teeth. When ultrasound hits between two interfaces with high acoustic impedance, it moves back and forth between these interfaces. Tissues may be observed as echogenic or anechogenic, with echogenic, or hypergenic, tissue reflected with high intensity to produce light screen images, such as restorative materials. On the other hand, dental hard tissue and anechogenic, or hypoechogenic, tissue reflected with low intensity tend to produce dark screen images such as caries. Ultrasound imaging and assessment is an observer and patient dependent modality which needs certain amount of expertise. In the present study, our observers were well trained about dental diagnostic procedures with Ultrasound imaging. Patient related factors such as tissue characteristics, weight and side bones were not an issue for this in vitro research.[13,14]

We found high repeatability and agreement for all diagnostic image types for both observers. Higher AUC values were obtained for proximal primary caries in the evaluation of deciduous teeth for bitewing images without statistical significance. No statistically significant difference was found between imaging methods and observers in terms of primary and secondary caries detection. The high resolution ultrasound imaging system and technique used in our study have the potential to be used in proximal caries detection of deciduous teeth. More studies should be conducted in different populations to increase the versatility of diagnostic methods in the attempt of proximal primary and secondary caries diagnosis in deciduous teeth. Ultrasound imaging has the potential to revolutionize dentistry and therefore this technique has been proven to be accurate, time and cost effective and consistent for generating informative maxillofacial diagnostic analytics. Nowadays, researchers have become increasingly enthusiastic about conducting ultrasound imaging research related dental diagnostic tasks. Caries are common chronic oral diseases affecting most adolescents and adults worldwide. A dataset of high-quality dental bitewing radiographs was used to support the detection of both primary and secondary caries, and a technique to visualize proximal caries via ultrasound probe was developed. The performance of the diagnostic models was determined by the diagnostic performance of experienced observers. With the help of the methods used in this experimental design, we believe that ultrasound imaging will increase the accuracy and consistency of the assessment of dental caries simultaneously and on patient site. Bitewing images revealed higher diagnostic performance when compared to Ultrasound in the detection of proximal caries in deciduous in vitro without statistical significance. Currently, ultrasound may provide supplementary information without ionized radiation but it is not a substitute for bitewing radiography in the detection of proximal caries with deciduous teeth. Specific attention should be directed towards developing specific intraoral dental ultrasound probes and software for dentistry in order to detect subtle changes in teeth.

6. CONCLUSION

Within the limitations of the present study, high resolution ultrasound imaging has the potential to be utilized in the detection of proximal dental caries in deciduous teeth.

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