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DIAGNOSIS OF DENTAL EROSION USING INTRAORAL SCANNER IN COMPARISON TO 3D CONFOCAL LASER MICROSCOPE

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ABSTRACT:

INTRODUCTION: Many in vitro and in vivo techniques to diagnose and measure dental erosion are included in the literature, but none of the in vivo techniques could detect the early erosive enamel wear in microns.

OBJECTIVES: The aim of this study was to determine if intraoral scanners could diagnose dental erosion when compared to a 3D confocal laser microscope.

METHODOLOGY: Thirty six 1 mm thick enamel samples were luted to labial surfaces of sound extracted anterior teeth. Baseline scans of the specimens were made by intraoral scanner (Carestream 3700) and 3D confocal microscope (KEYENCE VK-X100). Each enamel sample had a reference area created by applying a protective tape then the teeth were immersed in citric acid of 1% concentration (ph.: 2.7). After 1, 3and 6 hours teeth were removed and brushed with an electrical tooth brush for 2 minutes. To determine the enamel loss each follow-up scan was superimposed with the baseline scan and measured with the tools of the intraoral scanner's software. Same procedures were performed under the 3D confocal laser microscope where height difference between eroded and reference surfaces was measured. Values obtained were statistically analyzed.

RESULTS: 3D laser microscope detected enamel loss at each time point, while the intraoral scanner detected the erosion only at 3h and 6h, values of loss varied between both methods. Bland Altman test was statistically significant.

CONCLUSIONS: Intraoral scanner was able to diagnose erosive dental wear on the samples after erosive acidic challenge with its internal software tools.

KEYWORDS: dental erosion, intraoral scanner, diagnosis, 3D laser microscope.

RUNNING TITLE: Early diagnosis of enamel erosion by intraoral scanner.

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INTRODUCTION

Erosive dental wear may be regarded as a significant oral concern (1). Sensitive techniques and technologies for detection and monitoring are in great demand (1). Several approaches have been proposed and employed in the literature to qualify and quantify dental erosion, but the majority of them were only applicable on an in vitro scale (2).

The most widely used method for assessing erosion in vivo is the use of indices, which typically include a mix of diagnostic criteria and a scoring system to rate the severity of the lesions (2). Despite the existence of various index systems, none of them have gained widespread recognition (2). The Basic Erosive Wear Examination is a more recent idea for a standardized, validated index and a basic tool for clinical practice (3). It has been used as well to monitor erosive wear on study casts and associated photos (3). However, because all of these index methods are semi quantitative, it is difficult to quantify and monitor early erosive tooth attrition in the micrometer range (2).

A more appropriate way would be to collect 3-D images with extraoral scanners, which have already been proposed as the preferred method for measuring tooth wear (4). However, dimensional variations in the impression materials may influence accuracy, particularly at the micrometer level (2). Furthermore, this indirect measurement necessitates a sophisticated laboratory setup, including a model scanner, inspection software and expert knowledge (2).

Meanwhile, intraoral scanners (IOS) systems have evolved from the restorative sector to diagnostic devices, with some manufacturers incorporating an additional software program that allows chair side alignment of two datasets into the IOS software (5,6). The use of intraoral scanners has been recently suggested for the early detection of the dental wear, its quantification and monitoring based on some *in vitro* and *in vivo* studies that examined 3D data obtained either directly from patients or from cast models (5). Studies conducted to the evaluation of visual detection of early erosive dental wear demonstrated higher sensitivity using meticulous visual

examination with BEWE index on digital 3D models in comparison to the traditional visual examination technique on patients. (7)

Confocal laser scanning microscopy is a well-established approach for detecting and measuring dental erosion in various in vitro research. Its technology involves concentrating a laser beam on the surface of a specimen using an objective lens (8). The image is obtained by recording the in-focus light and suppressing the out-of-focus light with confocal apertures, resulting in clearer images (8). Although confocal laser scanning microscopes are commonly used to get qualitative results, 3D laser microscopy could be utilized to quantitatively detect erosive tissue loss by analyzing surface loss depth at the micro- or nanometer scale (2).

However, intraoral scanning has yet to be comprehensively validated for the detection and monitoring of minute amounts of tissue loss associated with erosive tooth wear.

As a result, the primary aim of the current study was to determine if IOS can detect the evolution of tissue loss following successive phases of acid etching. The conventional way for comparison was to use a 3D confocal laser microscope to quantify step surface loss and then compare the readings from both methods for statistical analysis. The hypothesis was that the intraoral scanner will be capable of diagnosing and monitoring dental erosion in comparison to the 3D confocal laser microscope.

MATERIALS AND METHODS

Sample size was estimated assuming 5% alpha error and 80% study power. According to Witecy et al, (9) the mean (SD) enamel loss was 34.2 µm and 23.75 µm for non-contacting profilometry (PRO) and Intraoral scanners (IOS), respectively. The IOS measurement can be ±15 µm of the PRO measurement. Based on difference between dependent means, the sample size was to be 35 samples, increased to 36 samples to make for processing errors. Sample size was based on Rosner's method (10) calculated by G*Power 3.1.9.7.

Flat square shaped samples of human enamel (n=36) were prepared by using a microtome (Micracut 150, Metkon Metallography, Bursa, Turkey) from the smooth parts of extracted molars collected from the outpatient clinic of Faculty of dentistry, Alexandria university (9). The thickness of the samples was 1 mm and the dimensions were 4x3 mm (9). Four grooves were made at each enamel sample for standardization (Fig.1). (9)

In aim to simulate the clinical conditions the square shaped samples were bonded to extracted anterior teeth (n=36) that were collected from the outpatient clinic of Faculty of Dentistry, Alexandria university, the teeth were cleaned by an ultrasonic scaler, inspected to be caries and crack free, and stored in deionized water (7). The protocol was approved by the Institutional Ethical Committee, Faculty of Dentistry, Alexandria University (IRB NO 0561-12/2022) and registered under registration number IORG0008839. These anterior teeth were flattened at the center of their labial surfaces and the enamel samples were luted using flowable composite (Tetric N Flow) (9), and the teeth were then mounted on a dimensionally stable silicone impression material (Zetaplus condensation silicone, Zhermack, Badia Polesine (RO) Italy) (7). The intraoral scanner (CS 3700, Carestream Dental LLC, Atlanta,GA, USA) and the 3D confocal laser microscope (Keyence VK-X100, Keyence Co., Osaka, Japan) were used to register the baseline scans for the specimens.

The enamel samples were assigned into an eroded area and a protected area by applying an adhesive tape (9), then the specimens were immersed in citric acid solution of concentration 1% and pH (pH= 2.7), and were extracted out of the acid at time points of 1h, 3h and 6h to measure height loss using both methods (7).

Each specimen's entire surface was scanned with an intraoral scanner (CS 3700) at 1h, 3h, and 6h (11).The intraoral scanner's internal software was used to superimpose each follow-up scan at 1h, 3h, and 6h with the baseline scan. Measurements were made in the transition zone between the eroded area and the reference area of each sample using the assigned measuring tools (preparation check tool and measurement tool) in the software (DEXIS IS ScanFlow) (Fig.2) (9). The enamel loss was determined in millimeters (mm) and converted to micrometers (µm) for comparison with the 3D confocal laser microscope (9).

Each specimen was additionally measured using a 3D confocal laser microscope (Keyence VK-X100) at three different time points (1h, 3h, and 6h), with the transition zone between the eroded and reference areas of the sample at the middle of the microscope's field of view (8). The surface of each sample was converted into a 3D image (Fig.3), and the height difference between the eroded and reference surfaces was determined in micrometers (µm) (8).

Statistical analysis

The normality of the data was tested using the Shapiro-Wilk test and Q-Q plots, and a non-normal distribution was confirmed; thus, the data are presented using the median, interquartile range (IQR) and minimum and maximum values, in addition to the mean and standard deviation. Comparisons between the intraoral scanner and 3D confocal laser microscope data were performed using the Wilcoxon Sign Rank test, while changes across time intervals were analyzed using the Friedman test, followed by a post hoc test with Bonferroni correction. All tests were two tailed

and the significance level was set at p value≤0.05. Data were analyzed using IBM SPSS, version 23, Armonk, NY, USA.

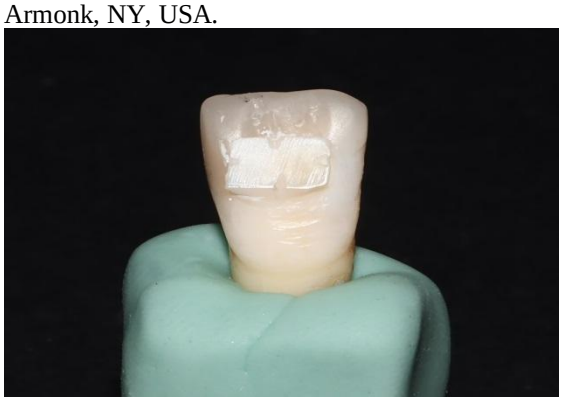

Figure 1 an enamel sample attached to an anterior tooth.

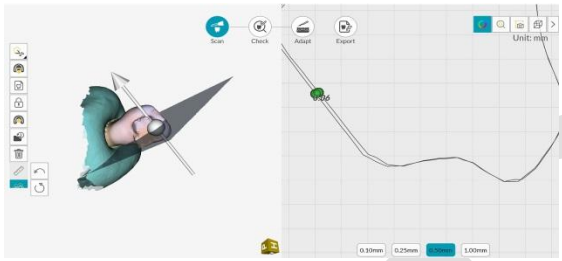

Figure 2 measurement of the erosion using the software of the intraoral scanner.

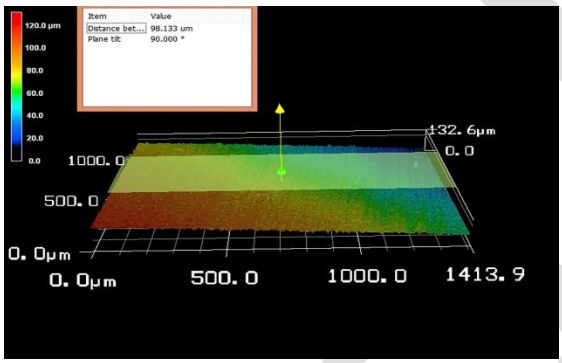

Figure 3 measurement of the erosion using the 3D confocal laser microscope.

RESULTS

A comparison of enamel loss in micrometers between the intraoral scanner and the 3D confocal laser microscope at different time points (1h, 3h and 6h).The Mean ± SD for the IOS at 1h is 0.00± 0.00 µ, at 3h is 34.17± 13.39 µ and at 6h is 71.11± 26.70, while the median at 1h, 3h and 6h is 0.00 µ, 30.00 µ and 65.00 µ respectively. The Mean ± SD for the 3D laser microscope at 1h is 67.53± 18.28 µ, at 3h is 131.42± 24.81 µ and at 6h is 209.72± 28.76 µ, while the median at 1h, 3h and 6h is 69.50 µ, 128.50 µ and 209.50 µ respectively. The data for the cumulative enamel tissue loss obtained from 3D confocal laser microscope as a measuring method revealed a significant increase in enamel tissue loss after each erosive challenge ($p \leq 0.0001$ each). Similar results were obtained with the intraoral scanner at each time point ($p \leq 0.0001$ each). Table 1 shows the mean ± SD, median and minimum and maximum values for both methods at each time point, it also shows the T test (p value) and pairwise comparisons for each method at each time point.

Comparison between intra oral scanner and 3D confocal laser microscope was done using Wilcoxon Sign Rank test while changes across time intervals was analyzed using Friedman test followed by post hoc test with Bonferroni correction. The differences between the consecutive etching steps were all significant (p<0.0001) as shown in Figure 2

The Bland Altman analysis evaluating the agreement between the enamel tissue loss as measured by the 3D confocal laser microscope and the intraoral scanner at 95% limits of agreement ((-173.16) – (-29.1)) and bias (mean difference) equals (-101.13) and standard deviation of bias equals (36.75) was statistically significant ($p \leq$ 0.0001).

Table 1: Comparison of enamel loss (µm) between intra oral scanner and 3D confocal laser at different time points

		Scanner (n=36)	**Laser (n=36)**	**Test (p value)**
1 hour	Mean ± SD	0.00 ± 0.00	67.53 ± 18.28	5.232 (<0.0001*)
	Median (IQR)	0.00 (0.00)	69.50 (29.25)	
	Min – Max	0.00 – 0.00	33.00 – 98.00	
3 hours	Mean ± SD	34.17 ± 13.39	131.42 ± 24.81	5.232 (<0.0001*)
	Median (IQR)	30.00 (20.00)	128.50 (42.50)	
	Min – Max	20.00 – 70.00	100.00 – 190.00	
6 hours	Mean ± SD	71.11 ± 26.70	209.72 ± 28.76	5.232 (<0.0001*)
	Median (IQR)	65.00 (37.50)	209.50 (46.00)	
	Min – Max	40.00 – 160.00	170.00 – 272.00	
Test (*p* value)		72.00 (<0.0001*)	72.00 (<0.0001*)	
Pairwise comparisons		p_1<0.0001*, p_2<0.0001*, p_3<0.0001*	p_1<0.0001*, p_2<0.0001*, p_3<0.0001*	

*Statistically significant at $p \leq 0.05$, p_1: comparison between T1 and T2, p_2: comparison between T1 and T3, p_3: comparison between T2 and T3

DISCUSSION

The primary aim of this study was to experiment the capability of IOS for diagnosing and tracking the course of extremely minute quantities of erosive tissue loss when compared to a 3D confocal laser microscope as a reference method.

Flat enamel samples were prepared to be measured on the order of micrometers under the 3D confocal laser microscope, as flat surfaces are required for the 3D confocal laser microscopy (2). These enamel samples were subsequently attached to the labial surfaces of anterior teeth to simulate erosion conditions due to extrinsic factors usually caused by the consumption of different types of acidic beverages and due to a lack of scientific evidence of the ability of intraoral scanners to scan, recognize and apply different features of their software to flat disc-shaped samples. The use of a whole tooth model mounted in jaw model was not feasible for the testing procedures under the 3D confocal microscopy, however scanning a single tooth is reported in previous in vitro studies (12).

The citric acid of the given PH and concentration were chosen to simulate the commonly used drinks (13). The time points at 1, 3 and 6 hours were chosen to simulate follow-up visits clinically at 1, 3 and 6 months periods respectively (11). The intraoral scanner (CS 3700) was the device of choice because it has proven to be associated with a very high level of trueness (the first place among 12 intraoral scanners) (14). 3D confocal laser microscopy was the standard method for comparison, as it is considered a well-established method for measuring dental wear in in vitro studies and obtaining accurate presentable quantitative values of tissue loss (8).

The magnitude of enamel loss varied among the specimens due to differences in the susceptibility of enamel material taken from different donors. This allowed us to get a clinically significant range in enamel tissue loss data, which served as a good substrate for the analysis.

The 3D confocal laser microscope detected tissue loss with each acid immersion (1h, 3h and 6h), the intraoral scanner detected the loss only after 3h and 6, in addition the values measured differed between the 3D confocal laser microscope and IOS, and the hypothesis was accepted. These results correspond with those reported by Witecy et al. (9) who also found that the IOS (CS 3600) couldn't detect the dental tissue loss after the first acid etching period, and discovered that intraoral scanners could detect progression of dental tissue loss when consecutive datasets were analyzed with external or internal software, but the loss values obtained differed from those obtained with a non-contact profilometer.

This could be due to the measurement uncertainty of IOS especially when measuring minute loss in the micrometer range is addressed. Several studies have experimented with the scanning resolution of some types of intraoral scanners and reported discrepancy related to accuracy when measurement in the micrometer scale was required (15, 16). In addition, certain registration and analysis methods in the intraoral scanner's software may result in measurement inaccuracies (17). Most intraoral scanners use registration algorithms to minimize the distance between comparable locations in successive scans (5). The software normally reduces the detected tissue loss by getting the two subsequent images as near as possible, this results in registration inaccuracy and underestimating of the value of the measured wear (5, 18). This may explain the variation between the values measured by the intraoral scanner from those obtained by the 3D confocal laser microscope for the same specimens.

Because of these problems in scan registration, no intraoral scanner software can currently detect tissue loss less than 50 microns correctly (18). This wear rate may be higher than that observed by modern in vitro equipment, but the use of intraoral scanners is a viable and therapeutically practical technology.

However, the aim of this paper was to evaluate the diagnostic ability of intraoral scanners in detection and monitoring of erosive dental wear which includes distinguishing a difference in tissue loss from consecutive observations; which was approved after 3 and 6 hour time points successfully.

The limitations of this study include the in vitro setting of the experiment, which may not have duplicated the oral conditions. Moreover, the intraoral scanner is a device originally designed for in vivo use.

In the light of the findings of this study it is recommended to design further in vitro studies using other types of intraoral scanners and software and in vivo studies that can benefit from the results of this in vitro study.

CONCLUSIONS:

In a setting of clinical simulation, the intraoral scanner was not able to detect the minute erosive lesions below 50-60µ after the first hour of acid immersion, but it could use its internal software tools to detect erosive dental wear after 3 and 6 hours of acidic challenge in comparison to the 3D laser microscope, which was used as the reference method.

STATEMENT OF CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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