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Accuracy of the Intraoral Scanner for Detection of Tooth Wear

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ABSTRACT

Objective: The aim of this work was to study the accuracy of the intraoral scanner for detection of tooth wear in natural teeth by using micro-computed tomography (micro-CT) as a gold standard.

Materials and methods: Twenty premolars were prepared, fixed in acrylic blocks, and scanned with an intraoral scanner (iTero Element® 2) and micro-CT for baseline reference images before artificial tooth wear induction. The samples were then scrubbed with abrasive sandpaper 20 times and scanned with the intraoral scanner. They were then superimposed with the reference images utilising the "TimeLapse" feature of the scanner until the abraded area appeared yellow, indicating tooth surface loss in the 50-200 μm range. The same samples were then rescanned by micro-CT to measure the actual tooth surface loss. This procedure was repeated for the subsequent experimental tooth surface loss of 200-400 μm range (orange areas) and 400-750 μm range (red areas). The collected data were analysed for sensitivity, positive predictive value (PPV), and accuracy. Level of statistical significance was set at .05.

Results: In the detection of experimental tooth surface loss, the specificity, PPV, and accuracy of the intraoral scanner were 98%, 98%, and 97%, respectively.

Conclusions: The iTero® intraoral scanner can be recommended to be a suitable screening tool for tooth wear in routine dental practice.

Introduction

Tooth wear is a prevalent issue commonly encountered in the oral health care system.[1,2] It is a general condition caused by many factors such as ageing, behaviour, and socioeconomic status, leading to the loss of dental hard tissue (enamel and dentine).[3] The aetiology of tooth wear can be classified into mechanical wear, which encompasses abrasion, attrition, and abfraction, and chemical wear in the form of erosion.[4]

Abrasion is a type of extrinsic mechanical wear caused by non-tooth objects. It is usually due to incorrect or excessive oral hygiene practices, a coarse diet, or habits such as nail or pen biting.[5,6] The clinical characteristics of abrasion are scooping or pitting of the tooth surface, most often seen in the cervical areas. Normally, functional cusps (ie, palatal cusps of upper molars and buccal cusps of lower molars) are more likely to be worn out from function faster than other surfaces.[7]

Conversely, attrition is a form of intrinsic mechanical wear, caused by tooth-to-tooth contact during clenching and/or bruxism,[1] resulting in the loss of dental hard tissue.[6] Clinical characteristics of attrition appear as flat occlusal surfaces corresponding to the morphology of an opposing tooth, without a cupping or scooping pattern.[8]

Abfraction, another form of intrinsic mechanical wear, propagates from flexural stresses at the cervical area of tooth structure. It is exacerbated by harmful occlusal forces that do not pass through the long axis of the tooth.[5,9] Abfraction may

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be either supragingival or subgingival at the cemento-enamel junction. Clinically, these lesions appear wedge-shaped and a sharp line angle or crack line is often seen. It commonly affects the elderly and those with parafunctional habits such as sleep bruxism and habitual clenching. Teeth that are susceptible to abfraction are those that are rotated or maligned, as they tend to be subjected to lateral deformation from repeated horizontally directed forces.[9]

Chemical tooth wear presents as erosion, which can be caused by extrinsic factors such as acidic foods and drinks, or intrinsic factors related to systemic conditions like gastroesophageal reflux disease. These factors cause a reduction in the pH levels of the oral cavity, directly resulting in tooth surface demineralisation or indirectly worsening mechanical tooth wear due to the already softened tooth surface.[3,6,10] The initial stages of erosive tooth wear can be observed as smooth, shiny, or glazed surfaces, which would progress into flattened areas or concavities, called a “cupping” appearance.[11] If patients presenting with these lesions also complain of tooth hypersensitivity, it could indicate that the process of erosion is active. The depth of the erosion cavities in these cases tend to be increased as well.[8]

Regardless of the aetiology and clinical presentation of each type of tooth wear, all of them essentially lead to structural loss of the tooth surface and changes in the basic tooth anatomy. According to Hanif et al, physiologic tooth wear in human teeth naturally occurs at an average rate of 0.02 to 0.04 mm a year, but this rate would be increased in people with pathologic factors.[12] The latter group of patients could be identified if they have other reported symptoms such as dental hypersensitivity and/or dental or orofacial pain.[13]

Besides the potential discomfort pathologic tooth wear may cause, it is an irreversible phenomenon that may increase the complexity and cost of treatment.[12,13] Early detection and diagnosis would therefore be beneficial in order to take the necessary preventive or therapeutic measures to alleviate the condition.[14]

Tooth wear is typically diagnosed from clinical inspection and supplemented by a review of the patient’s history. However, these may not be enough to detect the early signs of tooth wear. With the introduction and development of intraoral scanners for dental applications, it might become a useful tool for this purpose.

Over the past decade, the capabilities of digital hardware and software for dental and medical use have much improved. They are now much faster, more reliable, and more compatible.[15] Digital radiographs, cone-beam computed tomography, computer aided design-computer aided manufacturing, and 3-dimensional (3D) intraoral scanners are just a few devices that are increasingly being used in the dental clinic these days.[16-18]

In order to obtain intraoral dental records, conventional impressions with hydrocolloids or polyvinylsiloxanes have been the standard practice up until now. The drawbacks such as technique-sensitivity, distortion, and polymerisation shrinkage have encouraged dentists to turn to digital impressions instead. Patients have reported significantly less discomfort from digital impression taking compared to the conventional methods.[15] Other advantages of digital impressions include ease of use, reduction of storage space for physical dental models, portability, and environmental friendliness.

Because of this, digital impressions can be taken during each patient visit to compile multiple records. The digital 3D images from different points in time can then be superimposed,[19] either in the scanning unit itself or by using an external software. This function can potentially be applied to monitor and detect changes in tooth structure at the chairside to aid in maintaining and updating the treatment plan for the oral health benefit of the patient.

Whilst digital impressions are able to record surface characteristics, micro-computed tomography (micro-CT) is a separate form of digital imaging that visualises the internal structures of a sample without damaging it. The sample is imaged in sections and captured as 2-dimensional slices, which can then be reconstructed to be a 3D image for analysis in all 3 planes. In the detection of tooth morphologic changes, the information obtained from the micro-CT images can be used as a calibration tool for measuring and analysing tooth structure loss from the surface scans of the digital impressions.

Hence, the aim of our study is to evaluate the suitability of intraoral scanning in the detection of early tooth surface loss from tooth wear. The null hypothesis is that the intraoral scanners are not sufficiently accurate to be able to detect tooth surface changes.

Materials and methods

Twenty extracted sound human first upper premolars were collected and stored in 0.1% thymol solution in order to retain the moisture in the tooth structure to maintain the natural biomechanical properties. Each sample was fixed and stabilised in a resin block with self-cured acrylic. This study was granted the Certificate of Exemption by the Institutional Review Board of the Faculty of Dentistry/Faculty of Pharmacy, Mahidol University, COE No. MU-DT/PY-IRB 2019/053.0509.

All samples were initially imaged with a micro-CT scanner (SkyScan 1173, Bruker) and an intraoral scanner (iTero Element 2, Align Tech., Inc.) to be the reference data.

To simulate tooth wear, the buccal surface and lingual cusp tip of each tooth was abraded with 200-grit silicon carbide paper for 20 strokes. The sample was rescanned with the intraoral scanner, and the “TimeLapse” feature was used to superimpose this record with the reference scan. If no surface changes were detected, the abrasion process, scan, and superimposition was repeated until the software could detect a surface change, which appeared as a yellow area that represents a 50- to 200-μm surface difference. When both abraded areas on all samples were detected as yellow, all samples were then imaged with the micro-CT scanner.

These were in turn superimposed with the initial reference micro-CT scan using the scanner’s DataViewer software (Version 1.5.6.5 [Pre-release] 64-bit, Bruker). The superimposed images were adjusted both automatically by the software and then refined manually. Two methods were employed to verify image superimposition. First, the image margins should blend completely with the background, and if any black or white areas appeared at the margins, it would indicate improper superimposition. The other method is by analysing the graph in the software. Despite applying these 2 methods, complete superimposition could not be obtained due to reasons that will be discussed later.

Once the superimposition process was completed, the buccal surface differences of each sample were measured. In the coronal view, the x-axis (blue reference line) and z-axis (red reference line) were set to be parallel and perpendicular to the actual plane of tooth surface loss, respectively. In the transaxial view, the x-axis and y-axis (green reference line) were set to be parallel and perpendicular to the actual plane of tooth surface loss, respectively (Figure 1). The images of the coronal and transaxial views were gradually rotated until the image in the sagittal view appeared as a symmetrical doughnut-shape, which would signify that the planes were truly parallel/perpendicular to the actual plane of tooth surface loss. This was done as it was not feasible to create a flat plane by abrasive paper unlike that in the clinical situation. The depth of tooth surface loss was then measured and the entire process was replicated for the abraded area of the lingual cusp.

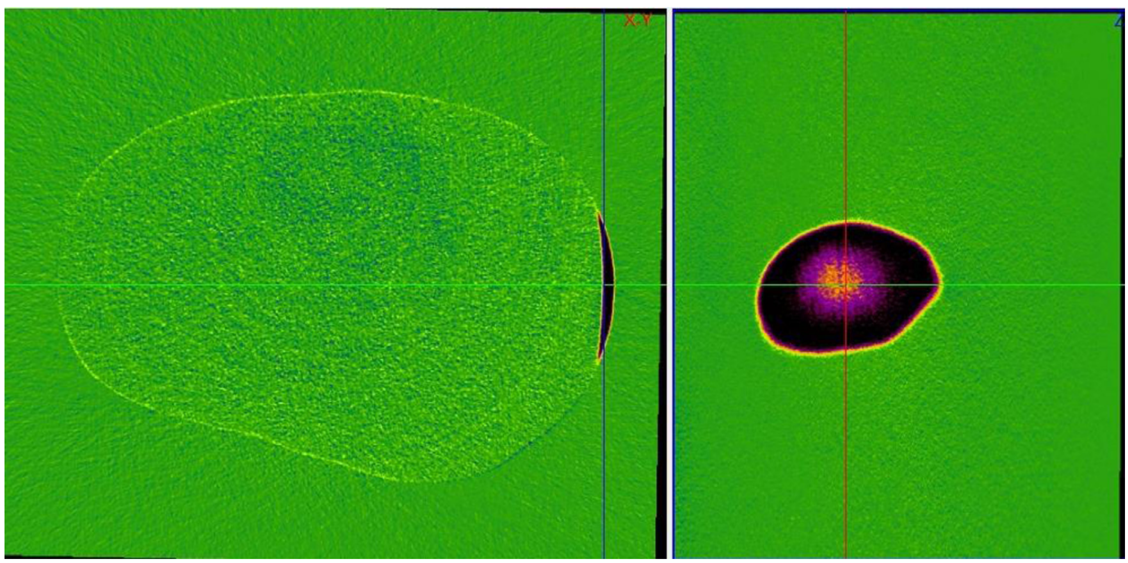

Fig. 1 – Micro-computed tomography image cross-section of a representative sample in the coronal view showing the reference planes: x-axis (blue line), y-axis (green line), and z-axis (red line).

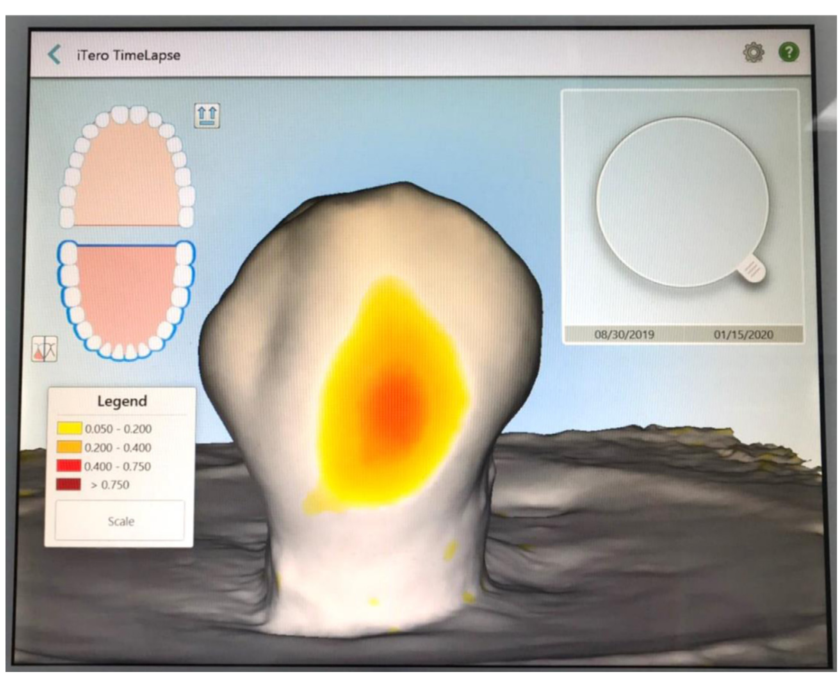

Fig. 2 – Image superimposition of a representative sample on the iTero® intraoral scanner showing the different colour scales with corresponding depth ranges.

Table 1 – Equations for calculation of sensitivity, specificity, positive predictive value, and accuracy.

Sensitivity	$= \frac{TP}{TP+FN}$
Specificity	$= \frac{TN}{FP+TN}$
Positive predictive value	$= \frac{TP}{TP+FP}$
Accuracy	$= \frac{TP+TN}{n}$

TP, true positive; FP, false positive; TN, true negative; FN, false negative.

The process of abrasion, scanning, superimposition, and analysis with both intraoral and micro-CT devices for each sample was carried out again for the following 2 conditions as detected on the image superimposition in the intraoral scanner: (1) abraded areas changed from yellow to orange (representing 200 to 400 μm surface difference) and (2) abraded areas changed from orange to red (representing 400- to 750-μm surface difference (Figure 2).

The data were grouped according to abrasion location and depth in 2 × 2 tables, and the sensitivity, specificity, accuracy, and positive predictive values (PPV) were calculated for each data set according to the equations in Table 1. The data were further analysed using Statistical Package for Social Sciences (IBM Corp.).

True positives (TPs) were recorded when the micro-CT measurement of the area corresponded with its respective range of surface loss as detected by the intraoral scanner, and it would be a false positive (FP) if the measurement did not correspond. There would not be any true negative (TN) or false negative (FN) expected, as all areas had to reach the predetermined colour range before bring measured in the micro-CT.

The pilot trial for micro-CT image analysis were carried out to obtain the interrater reliability. The Kappa statistic value above 0.7 was obtained before continue with the subsequence experiment.

Results

Twenty samples were abraded in 2 areas in 3 different depths; hence, a total of 6 groups of raw data were obtained. From the first 20 abrasion strokes, the lingual cusps of 2 samples were unintentionally abraded over 200 μm which exceeded the yellow range, so only 18 readings were available for the yellow and orange range groups. Some measurements of the lingual cusp were repeated and showed as red areas; hence, more than 20 data were collected for the red lingual cusp group. One measurement was excluded as the abraded area appeared maroon (50- to 750-μm surface difference) on the image superimposition. In total, 119 measurements were available for statistical analysis.

For areas that appeared yellow in the intraoral scanner, the mean surface loss was 94.31 μm and 144.00 μm for the buccal contour and lingual cusp, respectively. For the surfaces with orange areas, the average buccal surface loss was 232.57 μm, whilst the lingual cusp was 299.11 μm. In the red data group, surface loss averaged at 457.77 μm and 510.37 μm for the buccal surface and lingual cusp, respectively. (Figure 3)

From the histograms of the data, a normal distribution was seen; hence, parametric statistical tests were used. In all 3 colour ranges, the average measured surface loss was consistently significantly higher at the lingual cusp compared to the buccal surface as confirmed from the t tests ($P < .001$ for yellow, $P < .001$ for orange, $P = .022$ for red; Figure 2). A possible explanation would be that the lingual cusp was more accessible and convenient to abrade compared to the buccal surface, leading to higher surface loss in the former.

The 119 measurements were grouped according to abrasion location and depth in 2 × 2 tables, and the sensitivity, specificity, accuracy, and PPV were calculated for each data set (Table 2).

From the 119 measurements, 115 had micro-CT readings which corresponded to their respective colour group. Two data from the lingual cusps recorded as yellow in iTero had tooth surface loss of more than 200 μm which should have appeared as orange areas. On the other hand, another 2 data collected from the buccal surface appeared as orange areas in

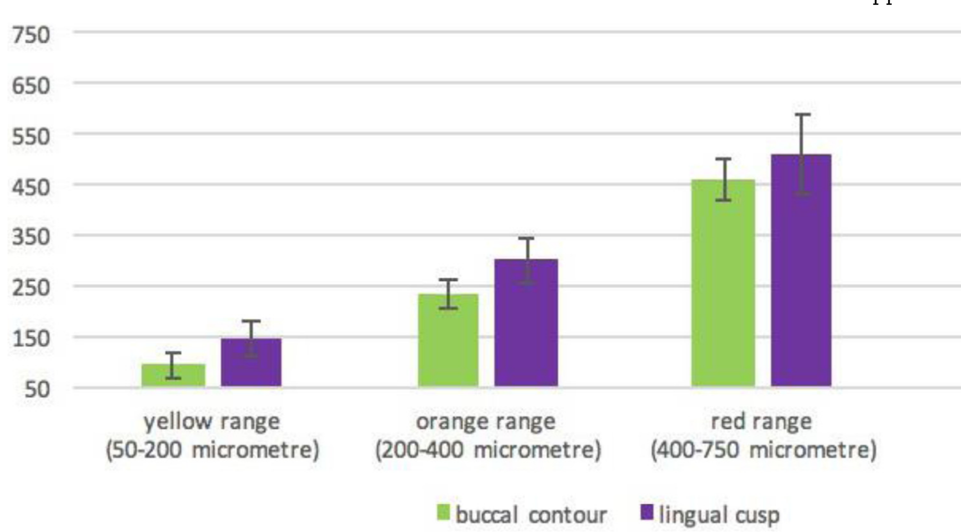

Fig. 3 – Comparison of average experimental tooth surface loss between buccal cervical area and lingual cusp area according to abrasion depth as detected by the intraoral scanner.

Table 2 – Results of sensitivity, specificity, accuracy, and positive predictive value as calculated from 2 × 2 tables.

	50-200 μm					200-400 μm					400-750 μm					Combined depth ranges(50-750 μm)				
	N	Sen.	Spec.	Acc.	PPV	N	Sen.	Spec.	Acc.	PPV	N	Sen.	Spec.	Acc.	PPV	N	Sen.	Spec.	Acc.	PPV
Buccal contour	20	1	NC	1	1	20	1	0	0.9	0.9	20	1	NC	1	1	60	1	0	0.97	0.97
Lingual cusp	18	1	0	0.89	0.89	18	1	NC	1	1	23	1	NC	1	1	59	1	0	0.97	0.97
Combined buccal contour and lingual cusp	38	1	0	0.95	0.95	38	1	0	0.95	0.95	43	1	NC	1	1	119	0.98	0	0.97	0.97

Sen., sensitivity; Spec., specificity; Acc., accuracy; PPV, positive predictive value; NC, not calculated.

iTero, but were measured to be less than 200 μm in the micro-CT, indicating the yellow range instead.

The sensitivity, PPV, and accuracy of the yellow and orange groups was 100%, 95%, and 100% respectively, whilst the red group showed 100% in all aspects. The overall sensitivity of the iTero scanner in detecting tooth wear was 98%, suggesting that the iTero scanner would not be able to detect 2% of pathologic tooth wear (FNs). The overall PPV of the scanner was also 98%, indicating that 2% of measurements on the iTero scanner were incorrect (FPs). The PPV measures the probability of participants with a positive value truly having tooth wear within the detected range. The accuracy of the scanner was 97%.

Discussion

It is well known that choosing or developing a proper diagnostic test to detect the presence of any disease or deviation from the normal is a challenging and crucial matter. Whilst tests or investigations should ideally have both 100% sensitivity and specificity, such standards are likely to be unrealistic. It is more often found that a test with high sensitivity tends to have low specificity and vice versa.[20]

At present, reliable methods to detect early tooth wear are yet to be available. Tooth wear is often discovered when it has progressed to such an extent that it can be observed clinically. At this point, though, more conservative or preventive measures to halt its progression are usually no longer feasible. Though tooth wear is not life-threatening and does not progress rapidly, its effects are irreversible and can be severe if left untreated. Moreover, treatment complexity increases with the advancement of tooth wear. For these reasons, a diagnostic test of high sensitivity would be preferable for the detection of tooth wear.[21]

A recent study by Kumar et al indicated the potential of using an intraoral scanner in detecting early erosive tooth wear, but they found that the scans had low precision and may not be able to distinguish minimal surface differences.[22] Our results are in agreement as the minimum limit of the device in our study was 50 μm. In their methodology, instead of superimposing the scanned files in the scanning unit itself, an external software, Geomagic, was used. The drawback of this method is that it would be more difficult to produce a real-time chairside result.[7]

The additional advantages for this method in clinical practice that warrants further study is the improvement of patient practicality as supported by the findings by Siqueira et al.[23] In contrast, Grünheid et al found that the entire conventional process took longer than that of intraoral scanning.[24]

Micro-CT is a highly reliable and popular equipment in the study of materials and health sciences. micro-CT was chosen to be the gold standard in this study because of its low discrepancy and small voxel size of 18.313 μm. Cone-beam computed tomography would not be suitable, as its lowest voxel size is 70 μm which would not be sufficiently sensitive to detect minute differences. Even so, the voxel size of the micro-CT in our study possibly contributed to a small proportion of measurement errors. For example, one lingual cusp sample that appeared as a yellow area on the iTero scanner, which corresponds to a scale of 50 to 200 μm, was measured to be 201.439 μm from the micro-CT. Due to the limitation of voxel size though, it is not unlikely that the surface loss did not actually exceed 200 μm, but we could not verify this theory as a finer voxel size was not available.

Intraoral scanners are steadily becoming an essential asset in dental practices today. Intraoral scanning is a noninvasive and convenient method, so patients can easily be scanned during a routine dental visit, which is generally advised to be every 6 months. If the rate of tooth wear that is higher than the average physiologic rate of approximately 0.02 to 0.04 mm per year is discovered,[12] the dentist can promptly conduct a more thorough examination and update of the patient's history and oral habits. Once the cause can be defined, a comprehensive course of management can be offered to the patient, such as behaviour modification, occlusal splints, and orthodontic treatment. From our study, as the intraoral scanner has shown high sensitivity, accuracy, and PPV, we can safely recommend its use as a diagnostic screening tool for detecting and monitoring tooth wear.

Conclusions

In the detection of experimental tooth surface loss, the specificity, PPV, and accuracy of the intraoral scanner was 98%, 98%, and 97% respectively. The iTero® intraoral scanner can be recommended to be a suitable screening tool for tooth wear in routine dental practice.

Conflict of interest

None disclosed.

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