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In Vitro Assessment of Dimensional Alterations of Worn Human Incisors

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ABSTRACT

Tooth wear is recognized as an increasing clinical problem due to increases in life expectancy and the duration of tooth retention. The aim of this study was to assess various methods for evaluating dimensional changes in worn human incisors over different time periods. In total, 100 extracted human incisors were divided into two groups, termed "enamel" and "enamel-dentin." The incisal edges of the teeth were abraded gradually four successive times in a specially modified mechanical two-body surface grinder. Before and after each grinding, the dimensional changes in the teeth were evaluated by an ultrasonic system, digital radiography, digital photography, and digital modeling. Digital micrometer was used as the control method.

Control method and ultrasonic system were able to diagnose worn enamel accurately and reproducibly in both the laboratory and clinical practice over different time periods to a depth of 50µm ($p<0.01$). Digital radiography, digital photography, and digital modeling methods could only diagnose dimensional differences at 100µm or greater ($p>0.05$).

As a non-destructive, sensitive and accurate method ultrasonic system seems to be a promising diagnostic tool for measuring early stages of tooth wear and tracking dimensional changes.

KEYWORDS Worn incisors, tooth wear, ultrasonic system, digital modeling

Introduction

Tooth wear is a non-carious, multifactorial, irreversible physiologic or pathologic loss of dental hard tissues (Kelleher and Bishop, 1999). It is recognized as an increasing clinical problem due to the increase in life expectancy and the longer retention of teeth (Lee et al., 2012). Tooth wear is becoming important in aging populations (Holbrook et al., 2003) and the occurrence and pattern are associated with educational, cultural, dietary, occupational, and geographic factors in the population (Hattb ve Yassin, 1999). It is considered as pathologic when the loss of dental tissue exceeds what is perceived to be normal (Al-Omiri et al., 2005).

Tooth wear is classified as attrition, abrasion, erosion, and abfraction (Şener and Türker, 2009). Dental attrition is defined as a gradual loss of the dental hard tissue from occlusal or incisal surfaces of two opposing teeth or restored dentition (Hattb ve Yassin, 1999). In dental attrition, two opposing teeth have equal and matching wear facets clinically. Parafunctional habits such as bruxism may accelerate attrition. In severe cases, total loss of dental enamel and exposure of dentin is unavoidable (Litonjua et al., 2003). Dental abrasion is the loss of dental hard tissue, mostly in the cervical surfaces, caused by abrasive tooth pastes, rough tooth brushing, pipe smoking, or nail biting (Grippo et al., 2004; Bishop et al., 1997). Dental abfraction is the loss of dental hard tissue on cervical surfaces as a result of crack formation during flexure of the tooth. Some authors have proposed that tensile and compressive stresses produced by mastication play a major role in the formation of wedge-shaped abfraction lesions (Lewis and Dwyer-Joyce, 2005). Dental erosion is the loss of dental structure by a nonbacterial chemical process (Litonjua et al., 2003). Gastroesophageal reflux and bulimia nervosa as intrinsic factors and acidic foods and drinks as extrinsic factors can cause irreversible chemical damage in hard dental tissues.

Any kind of pathological tooth wear can cause several harmful effects on dental hard tissues, periodontal tissues, and the masculatory system (Milosevic, 1993). Due to the general absence of early symptoms, it is difficult to diagnose pathological tooth wear. Tooth sensitivity, poor esthetics, and lack of masculatory function are the main reasons for dissatisfaction, and may motivate patients to seek dental treatment (Al-Omiri et al., 2005; Hemmings et al., 1995). More conservative dental approaches are preferred due to irreversible loss of hard dental tissues caused by pathological tooth wear. An accurate early diagnosis and appropriate preventive measures can protect dental hard tissues from irreversible damage (Bartlett, 2003). Moreover, treatment of is easier and cheaper with early-diagnosed potential tooth wear than it is when the process has advanced (Holbrook et al., 2003).

Tooth wear can be measured by quantitative and qualitative methods. Quantitative methods tend to rely on objective physical measurements such as depth of the groove, the area of the facet, or the height of the crown. Qualitative methods tend to rely on subjective clinical descriptions such as tooth wear indices. However there is no universally accepted quantitative, non-destructive, sensitive, reliable, quotable, and accurate diagnostic method that can detect tooth wear clinically (Holbrook et al., 2003; Bardsley, 2008; Koyano et al., 2008; Hall et al., 1997; Azzopardi et al., 2000; Hughes et al., 2009; Ghorayeb et al., 2008; Heintze, 2006). As tooth wear is a progressive problem, long-term monitoring is essential for assessing the progression of wear and the effectiveness of preventive treatments (Smith et al., 1997). The availability of such techniques in dental clinics can foster patients' awareness of the problem of tooth wear and may protect them from further irreversible damage (Koyano et al., 2008; Hall et al., 1997).

Considering the limitations of tooth wear measurement at an early stage, the hypothesis of the study was that a quantitative and non-destructive method can diagnose tooth wear at an early stage. Based on this hypothesis, the aim of this study was to evaluate the effectiveness of various methods for the diagnosis of dimensional changes in worn human incisors at different time periods. Therefore, the study was designed to evaluate the sensitivity and accuracy of the methods used to diagnose incisal tooth wear over different time periods.

Materials and Methods

In total, 100 extracted human incisors without caries, restorations, cracks, or developmental anomalies were collected randomly from maxillary or mandibulary arches. Differences in mineral content cause variation in the resistance to wear in enamel and dentin tissues (Zheng et al., 2003). Jagger and Harrison (1995a) suggested that enamel was more resistant to wear compared to dentin and Hooper et al. (2003) considered that enamel was more resistant to abrasion and erosion compared to dentin. In our study, the teeth collected were divided into two groups according to scores on the occlusal and incisal wear index; 50 teeth that were grade "0" (without wear on incisal edges) were termed the "Enamel Group," and 50 teeth that are grade "3" (with worn incisal edges) were termed the "Enamel–Dentin Group" (Oral, 2012). Each tooth was fixed in the middle of a cylindrical acrylic block (2.5 × 5 cm) with the enamel–cementum junction above the acrylic (Figure 1a, 1b). The base of each acrylic block was flattened, and all blocks were stored in 0.1% thymol solution before and after the abrasion cycles.

Figure 1a, 1b: The teeth were fixed in **the middle of cylindrical acrylic blocks.**

A number of wear-testing devices have been developed to simulate tooth wear in laboratory studies, most of which are used for two-body wear testing, in which the surfaces move against each other in direct contact during non-masticatory movement in the mouth (Lewis and Dwyer-Joyce, 2005; Lambrechts et al., 2006). Some simulation devices include abrasive slurries to replicate the role of food particles during mastication, allowing for three-body wear testing (Lambrechts et al., 2006; Zheng and Zhou, 2007). In our study, a mechanical tooth-grinding machine modified from an industrial-type two-body surface grinder was used to abrade extracted human teeth under dry conditions. The machine was similar to that used by Tillitson et al. (1971), termed a hydraulic surface grinder. However, our machine was intended for grinding the complete structure of the extracted human teeth, not single surfaces. The manner in which the teeth were abraded was not important, as the aim of this study was to evaluate the effectiveness of various diagnostic methods on detecting incisal tooth wear. Therefore, the machine we used allowed standardization of the mechanical abrasion on each sample after each cycle, which was a necessity for this study. A cylindrical part (5 × 15 cm) made of steel was created to fix the acrylic blocks and was soldered to the grinder (Figure 2a, 2b, 2c).

Figure 2a, 2b, 2c: Mechanical tooth-grinding machine and the cylindrical section.

Sandpapers of different roughness were used to abrade the teeth under dry conditions. The working length of the sandpapers was 17 cm in one direction, and samples of ~760 g (total weight of the cylindrical part and the tooth in acrylic block) were used as a constant load in each abrasion cycle. The total load used to abrade the teeth did not need to simulate the natural chewing of humans since the aim was to evaluate the diagnostic methods.

The teeth moved back and forward on the sandpaper at a constant frequency while being abraded. Accumulation of debris on grinding papers was an important problem according to some researchers (Tillitson et al., 1971; Elfick et al., 2000). Suzuki (2004) emphasized that water irrigation was a necessity for mechanical grinding of teeth in order to eliminate the debris accumulation. In the present study, instead of using water irrigation, the sandpaper was moved 0.5 cm to the right side after each back and forward movement to refresh the grinding surface and eliminate the abrasion debris.

The incisal edges of each tooth were flattened on the mechanical tooth-grinding machine using 600 grit sandpaper to create smooth edges and make them parallel to the grinding surface (Figure 3a, 3b).

Figure 3a, 3b: Teeth with flattened incisal edges formed the "Enamel" and "Enamel–Dentin" groups.

We planned to abrade the incisal edges of the teeth gradually, using four cycles of the teeth-grinding machine. Before the abrasion cycles, the incisal edges of the teeth were slightly abraded to make the incisal edges parallel to the grinding surface of the machine.

The parameters of abrasion cycles were decided according to a pilot study. For the first abrasion cycle, teeth were abraded by five back and forward movements on 1200 grit sandpaper; for the second cycle, by 15 movements on 1200 grit sandpaper; for the third cycle, by three movements on 600 grit sandpaper; and for the final cycle, teeth were abraded by six back and forward movements on 600 grit sandpaper.

At the baseline and after each cycle, the teeth were evaluated by an ultrasonic system, FluoreCam, digital radiography, digital photography, and digital modeling. A digital micrometer was used as the control.

The ultrasonic system, the Novascope 4500 (Harisonic, Staveley NDT, Kennewick, WA, USA), is a non-destructive quantitative diagnostic tool used for detection of parts corrosion and thickness measurement in the aircraft industry. In recent years it has also been used in dentistry for periodontal and endodontic treatment in the clinic, detection of demineralized dental tissues, diagnosis of caries, and detection of tooth wear in *in vitro* studies (Ghorayeb et al. 2008; Yanıkoğlu et al., 1999; Yanıkoğlu et al., 2000; Barber et al., 1969; Huysmans and Thijssen, 2000; Fontana et al., 1999; Matalon et al., 2007). A delay-type transducer (Harisonic, Staveley NDT, Kennewick, WA, USA) at 11 MHz frequency with a 0.6-mm tip connected to an ultrasonic system was used to measure the thickness of the enamel in this study. The ultrasonic system is known to be more accurate and reproducible on single materials or tissues compared to mixed materials or tissues. Therefore many researchers have only used the ultrasonic system on enamel tissue in dental studies. This is probably because these researchers aimed to diagnose caries, lesions or tooth wear at the very beginning of the process (Hughes et al., 2009; Yanıkoğlu et al., 1999; Yanıkoğlu et al., 2000; Huysmans and Thijssen, 2000; Louwerse et al., 2004; Bozkurt et al., 2005; Hall and Girkin, 2004; Tagtekin et al., 2005; Tagtekin et al., 2008). Prior to measuring, the ultrasonic system was calibrated by using formerly created 0.17 mm and 2.86 mm enamel cross sections. The tip of the transducer was positioned vertically at the top of the abraded incisal enamel edges, and using glycerin as a conductor, the system calculated the distance between the edge and the enamel–dentin junction below.

The FluoreCam (Therametric Corp., Indianapolis, IN, USA) is a non-destructive quantitative diagnostic tool used for the detection of dental caries by fluorescence. The mechanism of the FluoreCam is very similar to that of the QLF tool, which is accepted worldwide (Shi et al., 2000; Angmar-Mansson and ten Bosch, 2001; Pretty et al., 2004a; Pretty et al., 2004b; Stookey, 2004). An intra-oral camera connected to the FluoreCam located at ~1 mm from the tooth was used to take pictures of incisal edges of the tooth. The pictures were taken in a dark room to obtain sharper images. The software system of the FluoreCam processed the images, and demineralized the areas on the incisal edges were selected automatically on the computer screen. Also, the quantitative data of each image were exported, and the intensity (alterations in mineral content) values were recorded. This is the first time that the FluoreCam device has been used for monitoring progressive tooth wear.

Phosphor plates and a scanner (Vista Scan Mini Plus, Dürr Dental, Bietigheim-Bissingen, Germany) were used for digital radiography. A film holder (Endo Bite Senso Anterior, Kerr Manufacturing Company, Detroit, MI, USA) was also used to standardize the digital radiography images for further comparison. Images were processed using a software program (Dürr Dental DBSWIN 5.3.1), and the distance between the apex and the abraded incisal edge was calculated and recorded for each image.

A digital DSLR 7.2 MP camera (T-50, Sony, Tokyo, Japan) and a ground-fixed tripod were used for digital photography. The samples were fixed on a table at the same position in every shot, allowing standardization. The images were saved in jpg format and processed using Adobe Photoshop CS2 software. The distance between the acrylic block base and the abraded incisal edge was calculated and recorded for each image.

CAD/CAM devices have been used to compare the accuracy and reproducibility of conventional impressions and for digital modeling aimed at producing restorations in dentistry (Erdinç et al., 2008; Dinçel et al., 2013; Leifert et al., 2009; Sousa et al., 2012; Bell et al., 2003; Perry et al., 2000). The Cerec 4 CAD/CAM system with the Omnicam camera (Sirona, Beinsheim, Germany) was used as a digital modeling method in this study; this was the first time that a CAD/CAM system with its own software was used to measure incisal tooth wear. Each sample was scanned using the Cerec 4 Omnicam at baseline and after each abrasion cycle. Using the Cerec 4 software, digital models were processed and sagittal cross sections created. In the sectional images, using the Cerec 4 software measuring distance tool, the distance between the abraded incisal edge and the formerly created cervical reference point were calculated for each digital model.

A screw-type digital micrometer (BMI 770150, Germany) was used as a control method in this study, similar to many previous studies (Bozkurt et al., 2005; Dinçel et al., 2013; Leifert et al., 2009; Sousa et al., 2012; Bell et al., 2003; Redlich et al., 2008; Alcan et al., 2009; Imbery et al., 2010; Nassar et al 2012). However, in our study, a digital micrometer was used not on dental models but directly on real extracted human teeth. The acrylic block bases were marked to achieve standardization in each measurement. The distance between the acrylic block base and the abraded incisal edge was calculated for each sample and recorded.

Statistics
IBM SPSS Statistics 22 (IBM SPSS, Turkey) software was used for the statistical analysis. The parameters were evaluated for normality of distribution using the Shapiro–Wilks test. Comparisons between normally distributed groups were assessed by the Student's t-test, and comparisons between non-normally distributed groups were made using the Mann–Whitney U-test. Comparisons between pairs of variables were assessed by the paired-sample t-test. Associations between groups were assessed using the intraclass correlation coefficient (ICC). In all cases, statistical significance was indicated by p-values <0.01 and <0.05.

Results and Discussion
The results showed no statistically significant differences between the two groups (Table 1). Therefore, the two groups can be defined as homogeneous, and we could conclude that the degree of wear depended on the wear resistance of only the enamel surface contacting the grinding surface, not the dentin. This result is different from the findings of Zheng et al. (2003) and Hooper et al. (2003), who examined enamel and dentin tissues separately using cross sections. This inconsistency may derive from the fact that our assessments were based on intact teeth rather than cross sections, as well as from differences in the abrasion method.

Table 1: The Assessment of Micrometer Measurements

Micrometer (mm)	Enamel	Enamel-Dentin	[1]p
	Avr±SD	Avr±SD	
Baseline	45,793±2,060	45,223±1,794	0,143
1st abrasion cycle	45,765±2,059	45,195±1,795	0,143
2nd abrasion cycle	45,582±2,063	45,017±1,797	0,147
3rd abrasion cycle	45,233±2,059	44,658±1,794	0,140
4th abrasion cycle	44,708±2,060	44,132±1,792	0,139
Baseline-1st abrasion cycle [2]p	0,001**	0,001**	
Baseline-2nd abrasion cycle [2]p	0,001**	0,001**	
Baseline-3rd abrasion cycle [2]p	0,001**	0,001**	
Baseline-4th abrasion cycle [2]p	0,001**	0,001**	

[1]Student t Test [2]Paired Samples Test
** p<0.01

The ultrasonic system and the control method were well matched in detecting progressive incisal wear quantitatively, and the results were consistent with those of Yanikoğlu et al. (1999, 2000), Tağtekin et al. (2005) and Bozkurt et al. (2005). After each abrasion cycle, the measurements for the enamel group had decreased significantly compared to baseline. The results also shows that the ultrasonic system provided reproducible measurements, consistent with Tağtekin et al. (2008). Moreover, the ultrasonic system successfully detected dimensional changes of less than 50 µm on the incisal edges of the teeth abraded, with a standard error of only 10 µm, comparable to the results for the control method (Table 2). Louwerse et al. (2004) reported that the ultrasonic system could not detect enamel thicknesses of more than 0.33 mm, and Hall and Girkin (2004) reported that 0.4 mm was the maximum. Huysmans and Thijssen (2000) also showed that the ultrasonic system could detect the incisal enamel thickness to a limit of

0.5 mm, and they attributed this limitation to the inadequate thickness of the aluminum blocks they used for calibrating the ultrasonic device. Our study contradicts these findings, probably because we used 0.17-mm and 2.86-mm enamel cross sections for calibration.

Table 2: The Assessment of Ultrasound Measurements

Ultrasound (mm)	Enamel
	Avr±SD
Baseline	2,287±0,302
1st abrasion cycle	2,261±0,301
2nd abrasion cycle	2,077±0,301
3rd abrasion cycle	1,724±0,297
4th abrasion cycle	1,199±0,298
Baseline-1st abrasion cycle ²p	0,001**
Baseline-2nd abrasion cycle ²p	0,001**
Baseline-3rd abrasion cycle ²p	0,001**
Baseline-4th abrasion cycle ²p	0,001**

Paired Samples Test ** p<0.01

Digital radiography, digital photography, and digital modeling methods detected dimensional reductions on the incisal edges; hence, the homogeneity of the groups was confirmed by the control and the ultrasonic system. For all three methods, the reductions in both groups after the second, third, and fourth abrasion cycles were statistically significant; however, there was no statistically significant decrease compared with baseline after the first cycle (Table 3). The sensitivity of the computer software we used for measuring the distances for digital radiography, digital photography, and digital modeling methods were approximately the same, i.e., 100 μm. The failure of these methods in measuring dimensional changes less than 100 μm is probably due to limitations of the software used.

Table 3: The Assessment of Digital Radiography, Digital Photography and Digital Modeling Measurements

	Enamel	Enamel-Dentin	p
	Avr±SD	Avr±SD	
²Digital Radiography (Δ)			
Baseline-1st abrasion cycle	0±0 (0)	-0,002±0,014 (0)	0,317
Baseline-2nd abrasion cycle	-0,166±0,048 (-0,2)	-0,158±0,054 (-0,2)	0,380
Baseline-3rd abrasion cycle	-0,522±0,055 (-0,5)	-0,516±0,055 (-0,5)	0,455
Baseline-4th abrasion cycle	-1,050±0,071 (-1)	-1,050±0,058 (-1,05)	0,860
²Digital Photography (Δ)			
Baseline-1st abrasion cycle	0±0 (0)	0±0 (0)	1,000
Baseline-2nd abrasion cycle	-0,176±0,052 (-0,2)	-0,152±0,05 (-0,2)	0,026*
Baseline-3rd abrasion cycle	-0,534±0,072 (-0,5)	-0,510±0,058 (-0,5)	0,065
Baseline-4th abrasion cycle	-1,054±0,086 (-1)	-1,038±0,06 (-1)	0,479
²Digital Modelling (Δ)			
Baseline-1st abrasion cycle	0±0 (0)	0±0 (0)	1,000
Baseline-2nd abrasion cycle	-0,172±0,05 (-0,2)	-0,152±0,05 (-0,2)	0,049*
Baseline-3rd abrasion cycle	-0,528±0,067 (-0,5)	-0,520±0,073 (-0,5)	0,312
Baseline-4th abrasion cycle	-1,050±0,084 (-1)	-1,046±0,081 (-1)	0,957

¹Student t Test ²Mann Whitney U test
* p<0.05 ** p<0.01

The FluoreCam intensity findings revealed statistically significant reductions after each cycle for the enamel group. This can be interpreted as decreasing mineral content in the enamel during progressive incisal tooth wear, reflecting the fact that the inorganic mineral content decreases from enamel to dentin (Elliott, 1997; Shahmorardi et al., 2014; Roberson et al, 2011). For the enamel–dentin group, the reduction after only the first abrasion cycle was found to be statistically significant, however, there was no statistically significant decrease after the second, third, and fourth cycles compared with the baseline data. The FluoreCam images were based on the assumption of 87% inorganic content in the enamel tissue. The greater consistency of the device in measuring enamel than dentin is likely for this reason (Table 4).

Tablo 4: The Assessment of FluoreCam Measurements

FluoreCam	Intensity		
	Enamel	Enamel-Dentin	¹p
	Avr±SD	Avr±SD	
Baseline	-8,96±2,04	-12,13±3,92	0,001**
1st abrasion cycle	-14,11±5,29	-16,61±6,19	0,032*
2nd abrasion cycle	-13,59±4,08	-12,73±3,65	0,267
3rd abrasion cycle	-13,42±3,69	-13,32±3,26	0,895
4th abrasion cycle	-12,15±3,59	-13,15±4,24	0,203

¹Student t Test ²Paired Samples Test
** p<0.01

Conclusions

According to the statistical data, all the methods used were found to be accurate, reliable, and reproducible. The ultrasonic system could detect progressive incisal tooth wear quantitatively even if that wear was less than 50 μm; it was found to be the most sensitive method under the conditions studied. This research verified that the ultrasonic system has the potential to fill the space in monitoring progressive tooth wear at early stages and necessitates further *in vivo* studies. Digital radiography and digital photography methods were found to be effective quantitative diagnostic methods for monitoring progressive incisal tooth wear only if it was greater than 100 μm. The Cerec 4 CAD/CAM device, using its own software, was used for monitoring progressive incisal tooth wear for the first time in this study and was found to be a promising diagnostic tool with 100-μm sensitivity. The sensitivity of the distance measurement tool of the software needs to be improved for further studies. The FluoreCam device was also used for monitoring progressive tooth wear for the first time and was found to be effective in detecting mineral content differences at different layers of the teeth.

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