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Digital versus Conventional Methods of Wear Analysis Using Two Hybrid Ceramic Materials: In-Vitro Study

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ABSTRACT

Background: Hybrid ceramic materials have been introduced to resemble natural teeth appearance and behavior, allowing minimal reduction using modified preparation techniques. Their wear behavior against natural teeth is still under investigation. ***Aim of the study:*** This present study aims to compare wear analysis using both conventional and digital methods regarding two hybrid ceramic materials against natural tooth antagonists. ***Materials and methods:*** A total of 26 Samples fabricated from Vita Emanic and Cerasmart 270 (n=13 each) were cut into discs of 2mm thickness and 10mm diameter, then tested for wear using conventional and digital techniques. All samples were subjected to chewing simulation. Conventional wear testing was carried out by evaluating weight loss before and after chewing simulation. Digital wear testing was carried out by using Geomagic software from superimposing scan images before and after chewing simulation. Scans were first obtained through a Medit T710 desktop scanner. The generated data was collected and analyzed. ***Results:*** A positive correlation was found between conventional and digital measurements. There was a statistically significant difference between both materials in wear behavior. In both weight loss and digital superimposition methods, Vita Enamic displayed a significantly higher amount of wear than Cerasmart 270 ($p<0.001$); weight Vita Enamic and Cerasmart 270, respectively (22.12±3.41mg) (12.10±2.92mg), and RMS Vita Enamic and Cerasmart 270, respectively (0.82±0.24 µm) (0.52±0.15µm). ***Conclusion:*** Both conventional weight loss and digital volume loss can be used as reliable methods for assessing wear. Cerasmart 270 is more wear-resistant than Vita Enamic.

Keywords: Wear, Conventional wear analysis, Digital wear analysis, Hybrid ceramics.

INTRODUCTION

In modern dentistry, it is important to simultaneously conserve tooth structure while using materials that are esthetic and display physical properties close to those of

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the natural teeth.[1-4]

Ceramics have become the preferred dental restorative material due to their superior optical, mechanical, physical, and chemical properties, as well as biocompatibility.[2,4,5] The commonly used ceramic materials include feldspathic ceramic, leucite, lithium disilicate reinforced glass ceramic, and zirconia.[6] Various methods are used in ceramics fabrication, including powder condensation, the lost wax/heat press technique, slip casting, and computer-aided design/computer-aided manufacturing (CAD/CAM) techniques.[4] The introduction of CAD/CAM technology offered fewer visits, less fabrication time, and fewer errors.[7]

Despite the success of ceramics, the need for more biomimetic materials has led to the development of hybrid ceramic and nanoceramics to overcome shortcomings like reduced brittleness, rigidity, and hardness, while improving flexibility, fracture toughness, and machinability.[1,2,6] Hybrid ceramics combine inorganic ceramics and organic polymers, exhibiting properties such as a modulus of elasticity close to natural dentin and high modulus of resilience, allowing absorption of higher stresses without permanent deformation.[3] They are easily milled, aesthetically pleasing, do not require additional firing after milling, can be repaired intraorally, and are gentle on opposing natural teeth.[3,8] Examples of hybrid ceramics include Lava Ultimate, Shofu Block HC, Brilliant Crios, VITA Enamic, VITA Enamic multicolor, and Cerasmart.[3,9] Clinical applications range from inlays and onlays to veneers and single full coverage restorations.[7]

Wear, a natural and irreversible occurrence during oral function, affects both natural teeth and restorations. Accelerated wear may occur due to parafunctional habits like bruxism.[2,5,8,10] Assessing wear involves qualitative and quantitative methods, including tooth wear indices, weight loss, volume loss, and various microscopic techniques such as scanning electron microscopy (SEM). Laboratory studies using artificial masticatory simulators provide controlled testing environments, whereas clinical evaluations have limitations due to lack of control over the oral environment, time consumption, and high costs. [2,10-12]

Recent significant changes in dentistry involve the transition to a full digital workflow, utilizing advanced 2D and 3D image analysis methods, such as intraoral scanners, contact profilometers, non-contact white light micro/cone, CT scanners, laser scanners, and CAD/CAM systems.[12,13]

This study aims to compare wear analysis using both conventional and digital methods for two hybrid ceramic materials against natural tooth antagonists.

The first null hypothesis was that there would be no statistically significant difference between digital and conventional wear analysis using hybrid ceramic materials, and the second null hypothesis was that there would be no statistically significant difference in the wear resistance between Vita Enamic and Cerasmart 270.

MATERIALS AND METHODS

A total of twenty-six discs were prepared and used in this study. The discs were divided into two groups for conventional and digital wear test groups (n=13) each. The samples were polished and tested for conventional and digital wear behavior before and after their exposure to thermodynamic two-body wear testing machine; for the conventional test, the samples were weighed, and for the digital test, the samples were scanned. The two-body wear test was carried out by mounting the samples into the ROBOTA chewing simulator, a thermodynamic two-body wear testing machine, opposed by natural teeth. Wear outcomes were obtained from calculating the difference in weight for the conventional method, and by superimposing before and after digital scans for the digital method.

Sample preparation

Vita Enamic and Cerasmart 270 CAD/CAM block size 14 (12x14x18mm) were milled into cylinders using the Mc X5 (DENTSPLY Sirona InLab). Z Brush software was used to design the cylinders. The design was exported as STL files to Dentsply Sirona Inlab CAM software 18.1., and then milled using the Mc X5 milling machine. The dimension was verified using a digital caliper. The cylinders (18mm height and 10mm diameter) of each material were sectioned into disc samples 2mm thick using a precision cutting machine (Isomet, Buehler 4000, USA), the thickness was selected based on the manufacturer's recommendations.

A total of twenty-six disc samples were cut: Vita Enamic and Cerasmart 270 hybrid ceramics, each (n=13) respectively. The dimensions (2mm thickness x 10mm diameter$\pm$0.01) were validated using a digital caliper. The sample underwent the same polishing protocol using the EVE extra-oral polishing kit; a 3-step polishing system was done manually by the operator, containing coarse, medium, and fine polishing tips successively; each polishing tip was used for one minute.

In addition, a total of twenty-six maxillary first premolars were used as the wear antagonist for in-vitro wear testing against the experimental materials in this study, a premolar for each respective sample used only once. The premolars were recently extracted for orthodontic demands; they were collected from the outpatient clinic of the Misr International University, Cairo, Egypt (IRB# 00010118). Teeth with worn-out, sharp, or fractured cusps were excluded. They were cleaned with detergent and water using a very soft tooth brush, after immersion in a 0.5% chloramine solution (Chloramine-T; Sigma Aldrich Laborchemikalien, Seelze, Germany) at room temperature for a period of one week after extraction, and then they were washed and stored in distilled water at 5˚C till the testing started. For testing purposes and to be mounted into the upper member of the ROBOTA, each premolar was embedded in a plastic cylinder in self-cured acrylic resin; acrylic resin was then left to set in cold water to account for the heat generated during its setting.

The two-body wear testing involved the use of programmable logic-controlled equipment, the ROBOTA chewing simulator; it has four stations/chambers, operates on a thermo-cyclic protocol with a servo-motor, designed to simulate both vertical and horizontal movements simultaneously in a thermodynamic atmosphere. The station/chamber has an upper and lower member; to ensure stability of the test material, the upper is a Jacob's chuck for holding the antagonist, and a lower member is a holder designed to retain test samples.

For the reason of standardization, each disc sample and its corresponding premolar were given the same number. The testing assembly for the two-body wear test comprised placing the disc samples in the lower member of the station/chamber opposed by the extracted premolars. Since the ROBOTA chewing simulator is designed to accommodate four samples per run, a total of seven runs were carried out to expose all the study samples (Vita Enamic and Cerasmart 270) to a simulated chewing cycle. The run was set to operate at 10 kg weight, equivalent to 100 N of chewing force, at 1.6 Hz for 60,000 cycles, simulating six months of intraoral use.[14]

To evaluate both conventional and digital wear behaviors, respectively, all samples (n=26) underwent weighing and scanning before and after the chewing simulation test.

For weighing, a highly precise electronic analytical balance (Sartorius, Biopharmaceutical and Laboratories, Germany) with an accuracy of 0.0001 grams was used. This device is a sensitive electronic balance, equipped with fully automated calibration technology and a micro weighing scale, ensuring accurate weighing of samples. To ensure precision, the balance was placed on a stable, level table away from vibrations. The samples were weighed with the balance's glass doors closed to minimize the effect of air drafts. Additionally, the disc samples were cleaned and dried with tissue paper before weighing. Each disc sample underwent three weighing sessions, with three readings recorded for each disc sample. The statistician then calculated the mean reading for each disc sample. Samples' wear described in weight loss was determined by subtracting the initial weight (before chewing simulation) from the final weight (after chewing simulation).

Concerning digital method, the disc samples (n=26) were scanned before and after the chewing simulation test using the Medit T710 extraoral desktop scanner (Medit, South Korea). Before and after chewing simulation test scans were then converted into STL files and exported for further analysis. The scanner underwent regular calibration before scanning each group, following the manufacturer's recommendations. To ensure sample positioning standardization as well as maintaining proper sample orientation and scan consistency, markings were made on the undersurface of the samples. These markings were aligned with the corresponding mark on the rubber mold of the scanner to enhance the reliability of the results by minimizing variability in sample positioning.

Both the scans made before and after the chewing simulation were trimmed using metrology software to remove excess data points from the outer edges of the discs. Samples' wear was described digitally, utilizing Geomagic Control X, reverse engineering software, to measure the volume loss by superimposing the obtained scans, before and after, employing the best fit alignment.

This alignment method employs an iterative closest point algorithm, a standard technique for aligning digital 3D files. In the alignment process, the CAD reference model (CRM) and CAD test models (CTMs) are initially aligned, and a 3D comparison is performed. The optimal alignment algorithm utilizes the iterative closest point (ICP) algorithm to minimize the difference between point clouds.

The root mean square (RMS) formula was used to calculate the absolute mean distance between corresponding points in the CRM and CTMs:

RMS = 1 √ n · s n ∑ i=1 Di 2

Where Di represents the gap distance of point i between CRM and CTM, and n is the total number of points evaluated. A color difference map, set in a range of ±1.0 mm, was used, where the red region (positive error: +10 µm~+100 µm) indicates the CTM is above the CRM, and the blue region (negative error: −10 µm~−100 µm) indicates the CTM is below the CRM.

Once aligned, the 3D compare function isolated areas of interest for deviation calculation. Color-coded images of the disc samples were created, illustrating the magnitude and pattern of deviation, with darker blue highlights indicating a negative or inward deviation, and darker red highlights indicating a positive or outward deviation of the test model.

All the generated data was collected and analyzed.

Statistical analysis

Numerical data were presented as mean and standard deviation values. They were analyzed for normality using Shapiro-Wilk's test, were found to be normally distributed and were analyzed using independent t-test. Correlation analysis was done using Spearman's rank order correlation coefficient (Rs), for this analysis it was 0.521, with a 95% confidence interval. The significance level was set at P-value 0.006 ($P<0.05$) within all tests. Statistical analysis was performed with R statistical analysis software version 4.3.2 for Windows[1].

RESULTS

The primary outcome revealed a strong positive and statistically significant correlation between conventional wear analysis (weight loss) and digital wear analysis (volume loss by superimposition software) (rs=0.521, p=0.006). The linear and monotone correlations observed imply that both methods are reliable for assessing wear and provide results in the same direction whether increasing or decreasing readings denote material gain or material loss, respectively. **(Figure 1)**

[1]R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

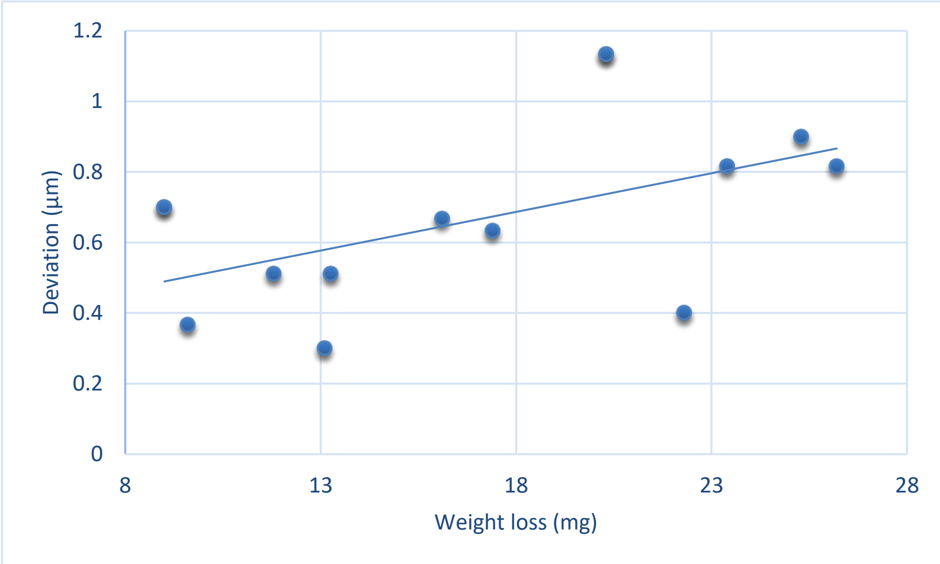

Figure (1): Scatter plot showing the correlation between conventional and digital wear measurements.

For the secondary outcome, the results showed that Vita Enamic samples displayed significantly higher weight loss (22.12±3.41mg) (i.e., more wear) than Cerasmart 270 (12.10±2.92mg) ($p<0.001$). **(Figure 2).**

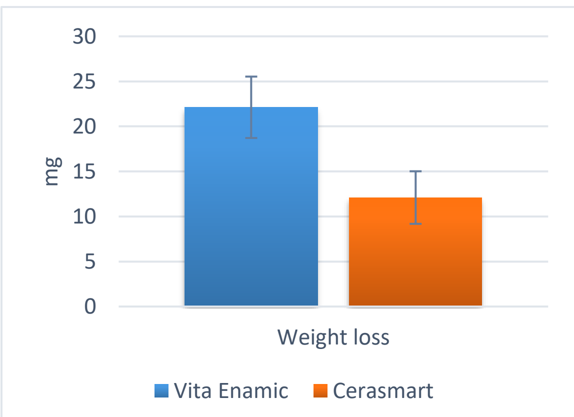

Figure (2): Bar chart showing mean and standard deviation values of weight loss (mg) for different materials.

The digital volume loss wear analysis method results showed the Vita Enamic samples displayed a significantly higher deviation (0.82±0.24 µm) (i.e., more wear) than Cerasmart 270 (0.52±0.15µm) ($p<0.001$). **(Figure 3)**

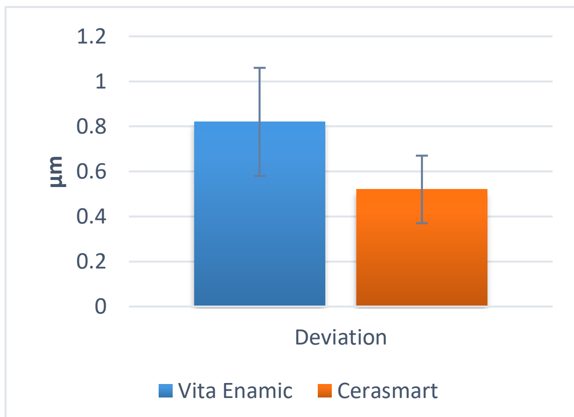

Figure (3): Bar chart showing mean and standard deviation values of deviation (µm) for different materials.

DISCUSSION

Ideally, fixed dental restorations should be durable and minimize wear on opposing teeth. Materials like high-performance polymers, ceramics, and composite resins used in fixed prosthodontics have different wear characteristics. Directly assessing wear in the mouth is complex, so wear simulation techniques are used to study the wear performance of these dental restorative materials.[15]

Aesthetic restorations should ideally wear at a similar rate to the enamel they replace, typically ranging from about 20 to 40 micrometers per year. This aligns with the average rate of occlusal wear in the molar region, which is approximately 30 to 40 micrometers per year. Ceramics are recognized for inducing wear on natural opposing teeth, whereas hybrid ceramics exhibit wear behavior that is favorable to the antagonist, making novel materials promising alternatives for use in fixed dental restorations within the oral cavity. These innovative materials include Vita Enamic and Cerasmart 270.[1,3,8,10]

As literature is scarce in comparing the wear behavior of both materials, the purpose of this study was to compare the conventional and digital wear assessment methods, while the second purpose was to evaluate the wear behavior of two hybrid ceramic materials (Vita Enamic and Cerasmart 270) when opposed by natural human enamel.

The current study utilized hybrid ceramic samples of Vita Enamic and Cerasmart 270, shaped uniformly into flat discs measuring 10mm in diameter and 2mm in thickness. Flat samples were chosen to facilitate easier integration with volume loss calculation software, offering a more efficient method for analysis. The thickness of 2mm was selected based on the manufacturer's recommendations to thickness of the restoration occlusally.[2,16]

In this study, wear was assessed conventionally using the weight loss method to determine the amount of wear, by calculating the pre- and post-testing weight difference of Hybrid ceramic discs (Vita Enamic and Cerasmart 270). This method aligns with previous studies conducted by Abo El Fadl et al.,[2] Elhomiamy et al.,[10] Mandour,[17] and Salem[18] in which the same measuring method was employed.

Also, in the present study, digital wear assessment was conducted by superimposing pre-testing and post-testing samples scanned with an extraoral desktop scanner, Medit T710, to generate three-dimensional images. These images were analyzed using

Geomagic Control X software. The software's accuracy has been validated within a margin of 0.5 micrometers, and a deviation of up to 20 micrometers between pre- and post-testing images was deemed acceptable. This innovative measuring method has been utilized by various authors, including Kumar et al.,[13] Bekhiet et al.,[16] Chong et al.,[19] Turker and Kursoglu,[20] and Beleidy and Ziada.[21]

The Medit T710 extraoral desktop scanner from Medit, South Korea, was employed in the current study to digitize the tested samples both before and after wear simulation. It's reported high accuracy of 13-16 micrometers for trueness and 3-4 micrometers for precision, as validated by Borbola et al.[22] that can be used as a reference scanner for studying intraoral scanners' accuracy.

This study focuses on two-body wear, occurring when teeth come into direct contact without abrasive substances, such as during dynamic occlusion movements. To simulate this, a dual-axis ROBOTA chewing simulator was used, subjecting samples to 60,000 cycles with a 100N load, 3mm horizontal movement per direction, 1mm vertical movement per direction, and a cycle frequency of 1.6 Hz. Loading involved a three-step sequence: first, a 1mm descending movement until contact was established between the steatite ball and the buccal cusp; then, a 3mm horizontal movement towards the occlusal sulcus; finally, a 3-minute ultrasonic cleaning in distilled water was performed on the specimens.[17,18,21]

Selecting the right number of chewing cycles was pivotal for obtaining meaningful results and gaining insight into the wear behavior of hybrid ceramics. Previous studies have employed a wide range of chewing simulation cycles, from around 5,000 to 1,200,000 cycles, reflecting the variability in experimental approach-es.[2,5,16,18,21]

Based on older literature, to mimic roughly one year of normal chewing in the mouth, it's suggested to conduct at least 240,000 to 250,000 loading cycles. For a simulation resembling about six months of real-world use, approximately 120,000 to 130,000 chewing cycles are recommended.[11,23]

In the current study, the test was conducted for 60,000 cycles to replicate six months of real-life chewing conditions. A weight equivalent to 100 N of chewing force (comparable to 10 kg) was applied. This methodology was inspired by Nawafleh et al.'s study,[14] which demonstrated that doubling the load while halving the number of cycles can simulate the same duration of real-life chewing conditions, a concept known as "Accelerated wear". Thus, instead of testing for 120,000 cycles with a load of 50 N, the load was doubled to 100 N, and the number of cycles was decreased to half, which was 60,000 cycles.

In this study, the restorative hybrid ceramic materials (Vita Enamic and Cerasmart 270) were exclusively polished, as hybrid ceramics do not require glazing after milling. Polishing alone saves time and is easy to maintain over extended periods. Recent advancements suggest that polished ceramic samples result in less wear on opposing enamel and other restorative materials. Therefore, the decision was made to solely polish the samples.[19,24]

Polishing is essential for eliminating surface defects and achieving a high gloss and low roughness, crucial for patient comfort and aesthetic appearance. Gloss retention, indicative of wear resistance, is an important aspect for longevity and quality of dental materials, particularly for direct resin composites. However, it is worth noting that the thin glazed layer, which varies in thickness from 10 to 40 microns according to various authors, is the first to wear off, creating a third medium between testing specimens.[19,24]

The first null hypothesis, stating no significant difference between digital and conventional wear analysis using hybrid ceramic materials, was rejected. Also, the second null hypothesis stating no significant difference in wear resistance between Vita Enamic and Cerasmart 270 was rejected as well.

The results of this study regarding the first outcome revealed a statistically significant, strong positive correlation between the two methods of wear analysis behavior. Linear and monotone correlations were observed, suggesting that both methods are reliable for assessing wear and provide consistent results in the same direction. While the units of measurement differ between the two methods (grams/milligrams for conventional and micrometers for digital), they were found to be statistically correlated, indicating a correlation between them.

On the other hand, the results of the current study concerning the second outcome indicated that Vita Enamic exhibited significantly higher weight loss and deviation (indicating more wear) compared to Cerasmart 270. This difference was observed in both conventional weight loss and digital volume loss wear analysis methods, with p-values <0.001.

This study's results are consistent with Lauvahutanon et al.[25] who revealed that Vita Enamic showed significantly higher wear, experiencing substantial surface fracturing and volume loss due to attrition wear. In contrast, Cerasmart, which undergoes high-pressure and high-temperature polymerization, demonstrated better wear resistance with compression and delamination occurring mainly in the terminal third of wear traces. Despite some delamination from micro-cracks, Cerasmart ability to absorb forces makes it suitable for demanding occlusal conditions. Overall, Cerasmart performed better in terms of wear resistance compared to Vita Enamic and other composite resin blocks.

Moreover, similar results were reported by Lawson et al.[1] where the amount of material wear exhibited by Cerasmart was significantly lower than the Vita Enamic. This was attributed to the differences in the microstructure properties between the two materials as well.

However, contradictory results were found by Aladag et al.,[5] Izim Turker and Pinar Kursoglu,[20] and Stawarczyk et al.[26] where they all observed increased wear in Cerasmart compared to Vita Enamic.

Within the limitations of this study, Cerasmart 270 emerged as more wear-resistant and hence more durable for single-unit final restorations. However, extending the number of chewing simulation cycles could yield different outcomes due to material properties and wear bi-product formation, potentially transitioning from two-body to three-body wear testing. Further research is needed to explore the effect of hybrid ceramics on the wear of natural teeth, the use of different number of chewing simulation cycles to mimic more in-vitro functional time, more investigations concerning material selection, inter-material wear comparisons, surface finish and roughness, and clinical applications of such hybrid ceramic materials.

CONCLUSION

Within the limitations of this study, the following could be concluded:

1- Both conventional weight loss and digital volume loss using superimposition software methods are reliable methods for assessing wear analysis.

2- Cerasmart 270 is more wear resistant than Vita Enamic, since they showed less amount of wear using both conventional and digital wear analysis methods.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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