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ASSESSMENT OF THE MILLING TRUENESS AND RELIABILITY OF TWO DIFFERENT IMPLANT SUPPORTED BAR MATERIALS BY 3D OPTICAL SCANNING.

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ABSTRACT

OBJECTIVE: Milling trueness is a critical factor in digital dentistry, influencing the precision and fit of milled restorations. This paper reviews the concept of milling trueness, factors affecting its accuracy, and its clinical implications. Studies indicate that material properties, milling strategies, tool wear, and machine calibration significantly impact the final restoration's dimensional accuracy. Advances in CAD/CAM technology and improved milling protocols contribute to enhanced trueness, ensuring better clinical outcomes.
METHODS: The milling trueness was measured by the 3D optical scan and superimposition method. A deviation assessment was made between the intraoral scan's STL files and the reference virtual design STL file to assess the milling trueness, all STL files were imported into a surface-matching software program (Medit Design v3.0.6 Build 286; Medit Corp) where RMS (root mean square) deviations in (μm) were calculated.
RESULTS: Titanium bar was significantly more true when compared to the PEEK bar. However, there was no significant difference in the precision of both groups.
Conclusion: Milling trueness is a fundamental aspect of digital dentistry, directly influencing restoration accuracy and clinical performance. The titanium bar exhibited significantly greater trueness compared to the PEEK bar, due to its rigidity and reduced milling distortions indicating superior accuracy in milling. PEEK, being a polymer-based material, may exhibit increased deviations due to its lower stiffness and the potential for minor elastic deformation under milling forces. However, both materials demonstrated comparable precision.
RUNNING TITLE: Milling Trueness and precision of Titanium vs. PEEK in Implant-Supported Bars
KEYWORDS: Titanium bar, PEEK bar, milling trueness, Deviation.

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INTRODUCTION

Milling trueness is a crucial factor in digital dentistry, influencing the precision and fit of milled prosthetic restorations. This study examines the milling trueness of two implant-supported bar materials, exploring the factors affecting accuracy and their clinical significance. Research indicates that material properties, milling strategies, tool wear, and machine calibration significantly impact the dimensional accuracy of the final restoration.(1)
Advancements in CAD/CAM technology and milling protocols have improved trueness, contributing to enhanced clinical outcomes. The integration of computer-aided design and computer-aided manufacturing (CAD/CAM) has revolutionized prosthetic fabrication. Milling trueness, defined as the deviation between a milled restoration and its original digital design, is a key determinant of prosthetic success. High accuracy in milling reduces the need for manual adjustments, minimizes marginal gaps, prevents secondary caries, and enhances restoration longevity.(1, 2) Milling trueness refers to the degree of accuracy with which a CAD/CAM-milled

restoration replicates its digital counterpart. It is distinct from precision, which describes the reproducibility of milling results over multiple iterations. High trueness is essential for achieving optimal prosthesis fit, reducing adjustment time, and improving long-term clinical performance.(1, 3) Several factors influence milling trueness, including the material properties, the composition and hardness of the material (e.g., zirconia, lithium disilicate, resin composites, PEEK (poly-ether-ether-ketone), Titanium), which affect milling efficiency and accuracy. There are different milling Strategies like Toolpath algorithms, milling bur diameter, and step-over strategies that determine the detail retention and surface smoothness of restorations. Five-axis milling machines have been shown to produce better marginal fit and more accurate restorations than four-axis milling machines.

Progressive tool wear of milling burs leads to dimensional inaccuracies, requiring periodic tool replacement. Worn tools can result in poor marginal fit and internal adaptation of restorations.(4, 5) Machine calibration and maintenance, regular calibration of milling machines ensures consistent performance and reduces geometric deviations. (1) CAD/CAM software and post-processing settings, compensation algorithms, and post-milling sintering or polishing influence the final fit of restorations. The choice of milling protocols can affect margin chipping, topographic characteristics, and fracture load of dental restorations. (5, 6)

There are several methods to evaluate milling trueness. It is commonly assessed by using 3D Optical Scanning, this is done via superimposing scanned images of the milled restoration with the digital design to measure deviations. This method allows for precise evaluation of the restoration's accuracy. (1) Coordinate Measuring Machines (CMM) are also used to provide precise measurements of milled structures. CMMs are used to assess the dimensional accuracy of restorations. (7)Micro-CT analysis offers high-resolution assessment of internal and external discrepancies. This technique is useful for evaluating the internal fit of restorations.(8, 9) This study has clinical implications because Inaccurate milling may lead to poor prosthesis fit, compromised occlusion, and patient discomfort. Enhancing milling trueness minimizes chairside adjustments, reduces laboratory remakes, and improves restoration longevity. Emerging technologies, including AI-driven milling optimization and adaptive toolpath strategies, aim to further refine milling trueness.

The objective of this study is to evaluate the milling trueness of two different bar materials, polyether ether ketone (PEEK) and titanium, by analyzing 3D optically scanned bars. The null hypothesis was that no significant difference would be found in the milling trueness of the two study groups.

MATERIALS AND METHODS

Ethical Approval

All procedures performed in the study involving human participants were following the ethical standards of the institutional research committee (Medical Research Ethics Committee of Faculty of Dentistry Alexandria University, Egypt) and with the 2008 Helsinki declaration and its later amendments or comparable ethical standards.

Statement of Informed Consent: An informed written consent was obtained from the patient before inclusion in the study.

A maxillary edentulous patient with integrated implants was selected for this study. Multiunit abutments (MUA, Vitronex Elite) were chosen, properly positioned, tightened, and torqued according to the manufacturer's specifications. Scan bodies (MUA Scan Body, Vitronex Elite) were attached to the abutments, and a digital impression of the maxillary arch was obtained using an intraoral scanner (Medit i700; Medit Corp).

A full-arch screw-retained framework was designed using CAD software (Blender for Dental v3.6, Blender Foundation, B4D iBar™ module) (fig 1.) A fully anatomic try-in was 3D printed (MAMMOTH 3D Printer 6.6, V-Ceram Shop) from a temporary resin material (Pro Shape Temp Resin, Turkey). The CAD design was then segmented into a bar substructure and a suprastructure, considering the alveolar ridge, implant locations, and prosthetic contours.

The inter-arch space and arch width allowed for a bar height of 5.1–6.6 mm occluso-cervically and a width of 5–6 mm bucco-lingually. Buccal and lingual finish lines were created with a width of 1 mm. Two framework groups were established based on material type: PEEK (breCAM BioHPP Disk, Bredent GmbH & Co. KG, Senden, Germany (fig.2), and titanium (Dentatec, GmbH, Germany). The virtual framework's STL file was exported, and both materials were milled using a milling machine (Roland DWX-52D Plus, Roland DGA Corporation).

To enhance surface roughness, both bars underwent airborne-particle abrasion with 50 µm Al_2O_3 (Eisenbacher Dentalwaren; ED GmbH) at 0.2 MPa pressure from a 10 mm distance for 1 minute. The bars were evaluated for passivity on the printed model and then tested intraorally, the one-screw test was conducted to confirm passivity.(10)

The milling trueness was measured by the 3D optical scan and superimposition method (1). A deviation assessment was made between the intraoral scan's

STL files and the reference virtual design STL file to assess the milling trueness. All STL files were imported into a surface-matching software program (Medit Design v3.0.6 Build 286; Medit Corp), where RMS (root mean square) deviations in (µm) were calculated.(11) (fig 3,4).

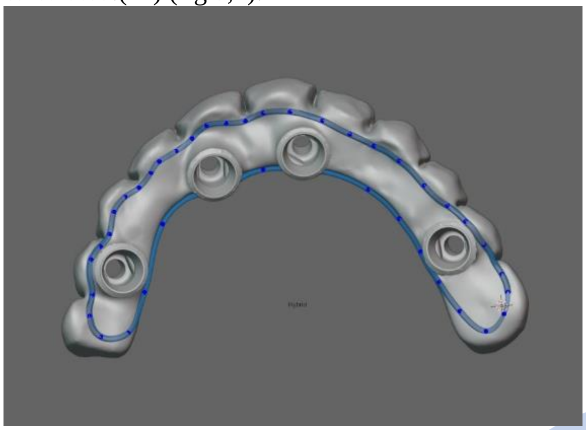


Fig. (1): Prosthesis split on Blender for dental to supra and substructures.

Fig. (2): Milling of PEEK bar.

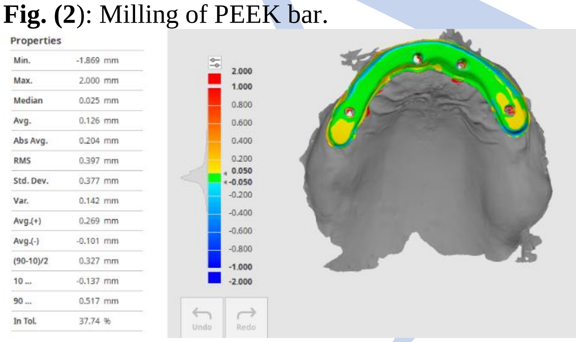


Fig. (3): representative color-coded map showing milling trueness of the titanium bar through measuring the discrepancy between 2 meshes (reference and test scans).

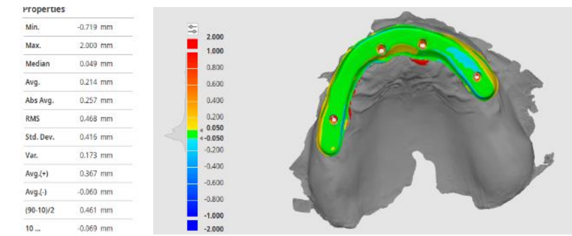


Fig. (4): representative color-coded map showing milling trueness of the PEEK bar through measuring the discrepancy between 2 meshes (reference and test scans).

Statistical Analysis

To allow statistical comparison, according to the methods of Flügge et al,(12) and Emam et al, (13) ten digital scans will be performed for each framework, producing a total of 20 scan files, Total sample= Number of scans x Number of groups = 10 x 2 = 20 scans.

Normality of the study variable was tested using descriptive statistics, Q-Q plots, histograms, box plots, and Shapiro Wilk normality test. Normal distribution was confirmed, so means and standard deviation (SD) were calculated, and parametric tests were used. Comparison of trueness between the two study groups was performed using independent samples t-test, while precision comparison was performed using Levene's test (Homogeneity of Variances). Mean difference and 95% confidence interval (CI) was calculated. Significance was set at p-value <0.05. Data were analyzed using IBM SPSS for Windows (Version 26.0)

RESULTS

The titanium bar demonstrated significantly higher trueness compared to the PEEK bar (*P*< 0.001). By using T-test the mean trueness values were 396.90 ± 12.73 µm for titanium and 465.10 ± 38.93 µm for PEEK, with a mean difference of -68.20 µm (95% CI: -95.41, -40.99).

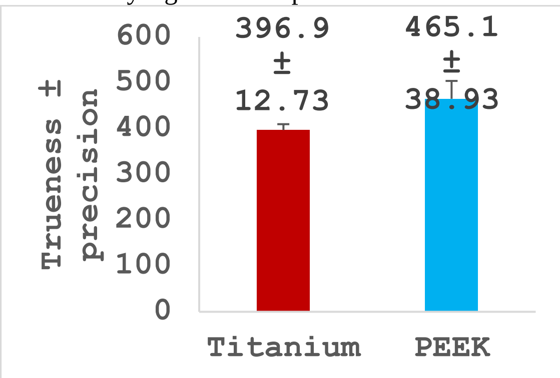
There was no statistically significant difference in precision between the two groups, as indicated by Levene's test for homogeneity of variances (*P*= 0.10). This suggests that while trueness varied significantly between the materials, both demonstrated comparable precision, which is displayed in Table 1, Graph 1.

Table (1): Comparison of milling trueness and reliability of titanium and PEEK bar frameworks.

	Titanium	**PEEK**	**Mean difference (95% CI)**	**P value 1**	**P value 2**
Trueness Precision	396.90 ± 12.73	465.10 ± 38.93	-68.20 (-95.41, -40.99)	<0.001*	0.10

P value 1: Comparison of trueness using independent samples t-test

P value 2: Comparison of precision using Levene's test (Homogeneity of Variances)
*Statistically significant at p-value <0.05



Graph. (1): Comparison of milling trueness and precision of titanium and PEEK bar frameworks.

DISCUSSION

The findings of this study highlight the significant influence of material choice on milling trueness, as evidenced by the superior accuracy of titanium bars compared to PEEK bars. The lower RMS deviation in titanium suggests that it maintains a higher level of dimensional fidelity to the digital design. This outcome aligns with previous research indicating that metallic materials often exhibit greater milling trueness due to their structural stability and reduced susceptibility to tool deflection during the milling process.(14)

Titanium's higher milling trueness may be attributed to its rigidity and resistance to wear, which minimizes deformation during milling. Studies have shown that metals, particularly titanium, demonstrate minimal discrepancies in CAD/CAM milling due to their homogeneous composition and predictable material behavior. In contrast, PEEK, being a polymer-based material, may exhibit increased deviations due to its lower stiffness and the potential for minor elastic deformation under milling forces.(14-16)

Furthermore, polymer materials may be more prone to localized heating during milling, potentially affecting their dimensional stability. However, some studies challenge the superiority of titanium in milling trueness, suggesting that advanced polymer-based materials can achieve comparable accuracy with optimized milling protocols. Research has demonstrated that high-performance polymer restorations, when milled with extra-fine strategies and reduced step-over distances, can exhibit trueness levels like metal-based restorations. Moreover, newer composite materials and advanced milling algorithms have significantly improved the precision of non-metal restorations.(17)

On the other hand, a study by Yilmaz et al. found that PEEK frameworks exhibited higher trueness compared to titanium frameworks. These results suggest that the accuracy of scanned data can vary depending on the material of the framework and the scanner used.(18)

Another factor influencing milling trueness is tool wear. Over time, milling burs experience progressive degradation, affecting the accuracy of the milled structure. Studies indicate that milling burs used for titanium wear at a different rate than those used for polymer materials, potentially influencing outcomes. Ensuring proper tool maintenance and periodic replacement is critical to maintaining milling accuracy.

In addition to material properties, machine calibration and maintenance play a crucial role in milling accuracy. Regular calibration has been shown to reduce geometric deviations and enhance the consistency of milling results. The CAD/CAM software settings and post-processing protocols, including surface finishing and sintering, also impact the final fit of the restorations.(14)

While titanium outperformed PEEK in this study, the choice of material should also consider clinical factors beyond milling trueness. PEEK offers advantages such as reduced weight, biocompatibility, and shock absorption, making it a viable alternative for specific prosthetic applications. Future research should explore the impact of different milling strategies and optimization techniques to enhance the milling trueness of polymer-based materials.(19)

Overall, these findings emphasize the importance of material selection and milling protocols in achieving optimal prosthesis fit. Further investigations using larger sample sizes and different CAD/CAM systems are necessary to validate these results and refine clinical recommendations.

CONCLUSION

Titanium demonstrated superior milling trueness compared to PEEK, likely due to its rigidity and reduced milling distortions. However, advancements in polymer-based materials and milling strategies may improve the accuracy of non-metal restorations. Continuous optimization of CAD/CAM technology, milling protocols, and tool maintenance is essential for enhancing prosthetic outcomes. Further research with larger sample sizes and different CAD/CAM systems is needed to validate these findings.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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