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An In Vitro Assessment of a Ceramic-Pressed-to-Metal System as an Alternative to Conventional Metal Ceramic Systems

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Keywords
Ceramic pressed to metal; marginal gap; fracture resistance; microhardness; roughness.

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Abstract

Purpose: This article reviews a press-on metal (POM) ceramic versus a conventional veneering system regarding marginal gaps, fracture resistance, microhardness, and surface roughness. This was done to provide clinical recommendations for its use.
Materials and Methods: Forty crowns were constructed and divided into two main groups according to the metal coping design. *Group 1:* Twenty metal copings with metal margin extending to the axiogingival line angle. *Group 2:* Twenty metal copings with metal margin 1 mm occlusal to the axiogingival line angle. The specimens of each group were further subdivided into two subgroups (A and B) according to the veneering porcelain used. The vertical marginal gaps of the crowns were measured after veneering placement. For fracture resistance testing, the crowns were subjected to compressive load to failure. Representative samples of the two main groups were selected to measure surface roughness and microhardness.
Results: No statistically significant difference was evident regarding the vertical marginal gap distance in relation to the margin design of both tested groups ($p = 0.249$, $p = 0.815$); however, the POM veneer group with metal porcelain margin showed statistically lower marginal gaps than the conventional ceramic veneer group ($p = 0.043$). Fracture resistance values did not show statistically significant difference regarding the margin design ($p = 0.858$, $p = 0.659$) or type of the ceramic veneer material ($p = 0.592$, $p = 0.165$). Both groups showed no significant difference in their mean roughness values ($p = 0.235$). Conventional ceramics showed statistically significantly higher mean microhardness values than POM did ($p = 0.008$).
Conclusion: This study showed superior marginal adaptation, decreased microhardness, and similar load to failure and roughness values of the POM ceramic system. Moreover, considerable ease and speed of fabrication of this system were evident. The high variation in range values of some tested groups is among the limitations of this study, along with the lack of clinical trials to test the system in vivo.

Even with recent advances in all-ceramic systems, metal ceramic restorations still occupy and maintain an unthreatened position as permanent prosthetic restorations. They continue to be the gold standard and remain temporarily unrivaled as they fulfill both strength and moderate esthetic demands; however, with increasing demand in esthetics and advances in all-ceramic technology, their future has been less certain, necessitating additional qualities in terms of superior esthetics and ease of fabrication.

Optimum esthetics is inconsistent with conventional ceramometallic restorations, particularly in the labiogingival margins.[1] With the introduction of shoulder porcelains, the problem of cervical metal display has been resolved. All-porcelain margin design reportedly allows increased light transmission to the adjacent root structure and eliminates the need for metal in the cervical region.[2] However, a minor drawback remains—compared to the accuracy of cast metal restorations, shoulder porcelains do not provide the same marginal fidelity. Sintering shrinkage of porcelain during the firing process can compromise the accuracy of all-porcelain margins and lead to porcelain spheroiding.[3] Moreover, the labial margin, where the thickness of metal is limited by esthetics, is the part most subject to distortion during ceramic sintering.[4] Other authors disagree, stating that porcelain margins possess marginal openings that are as clinically acceptable as the metal margins.[5,6] Another problem with the use of porcelain margins is their effect on the strength of the restoration. During the conventional metal ceramic fabrication process, distortions of both the metal substructure and the porcelain can be introduced, resulting in altered accuracy of fit.[2,5,7]

Fracture resistance is a deciding factor determining the longevity of a restoration in the oral environment. Restorations possessing high fracture resistance have predictably high survival rates under masticatory forces. It appears easier to rationalize the minor esthetic deficiencies of porcelain-fused-to-metal restorations than to contend with fracture of all-ceramic crowns.[1]

Ceramic surface roughness contributes in many ways to the success of fixed restorations. Surface flaws initiate cracks in the ceramic, thus reducing its fracture resistance. Rough surfaces will enhance plaque accumulation and, consequently, periodontal disease. One of the main concerns over the use of porcelains is their abrasive potential or wear of the opposing tooth structure. Two major determinants of enamel wear are surface finish and microstructure.[8]

Recently a new generation of ceramics has been introduced for veneering metallic and non-metallic cores. It was developed following the idea of pressable all-ceramic systems. First, a metal substructure is waxed and cast. After the casting has been opaqued, a complete contour wax pattern is fabricated, and the ceramic is heat-pressed onto the undercasting.[10-12] Pressable ceramics are known to possess many desirable properties, but little data are available in the literature regarding ceramics pressed to metal (press-on metal, POM) versus conventional veneering techniques. The purpose of this study was to compare the effect of two marginal designs (metal/porcelain margins and circumferential porcelain margins) on the vertical marginal gap distance and fracture resistance values of ceramic pressed to metal and conventional metal ceramic restorations. Moreover, this study sought to investigate such clinically relevant properties as the microhardness and surface roughness of veneering porcelain of both ceramic pressed to metal and conventional metal ceramic systems.

A hypothesis was set suggesting superiority of the POM system over a conventional metal ceramic system regarding marginal gap distance, fracture resistance, microhardness, and surface roughness. In addition, the null hypothesis suggested vertical marginal gap distance and fracture resistance superiority of metal porcelain margin compared to circumferential porcelain margin of both tested systems.

Materials and methods

To compare the two metal ceramic veneering systems [IPS In-Line (conventional feldspathic) and IPS InLine POM (Ivoclar Vivadent, AG, Schaan, Liechtenstein)], the following procedure was done. A stainless steel metal die simulating a prepared mandibular first molar following the general rules for metal ceramic restorations was fabricated. The die was 8 mm high with an 8° axial wall taper, 5 mm occlusal diameter, and 1.2 mm shoulder finish line. The metal die was duplicated using rubber base impression material to produce 40 stone dies (Dental stone, extra-hard, type IV, Bego, Bremen, Germany). The dies were prepared with one layer of die spacer 1 mm short of the margin. According to the metal coping design the specimens were classified into two main groups (Fig 1):

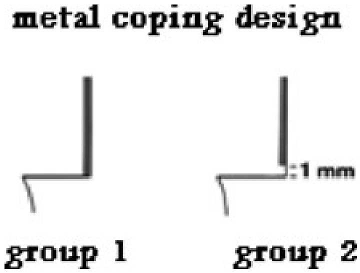

Figure 1 Metal coping design of the two tested groups. Group 1: metal coping extending to axiogingival line angle. Group 2: metal coping 1 mm occlusal to axiogingival line angle.

Group 1: Twenty metal copings with metal margin extending to the axiogingival line angle.

Group 2: Twenty metal copings with metal margin 1 mm occlusal to the axiogingival line angle.

Using a split steel mold, 0.3 mm wax patterns were constructed over the stone die and cast using the conventional lost-wax technique in a nickel chromium alloy (IPS d.SIGN 15, Ivoclar Vivadent). The wax copings of group 2 were shortened 1 mm before investing and casting. All metal copings were subjected to oxidation firing cycle, and two layers of opaque (IPS InLine/IPS POM Opaquer) in paste form were applied and fired according to the manufacturer's instructions. The specimens of each group were further subdivided into two subgroups according to the veneering porcelain used.

Subgroup A: Ten metal copings veneered with IPS Inline conventional metal ceramics.

Subgroup B: Ten metal copings veneered with IPS InLine POM press on metal ceramics.

Specimen veneering

Group 1 subgroup A specimens were veneered using IPS in-line conventional metal ceramics. The first and second dentin firing were done according to the manufacturer's recommendations (Dentin shade A2). Veneering was done by the layering technique with the help of the split steel template. Body porcelain was vibrated and condensed onto the copings. Firing was done using a Programat furnace (Ivoclar Vivadent) with firing parameters recommended by the manufacturer. Three points were determined on every wall to standardize the thickness of veneering on all specimens by means of a caliper, and additional correctional firing was done whenever necessary to compensate for shrinkage. Finally all specimens were finished and glazed as usual.

The same veneering process was made for group 2 subgroup A, but an additional step was performed to fabricate a ceramic shoulder using IPS margin shade A2. First the stone die was sealed with IPS Margin Sealer and then, after drying, with IPS Ceramic Separating Liquid. IPS InLine Margin Material was then applied to the cervical area. The specimens were fired as recommended by the manufacturer. The accuracy of fit was further optimized by means of a second margin firing.

The specimens of subgroup B in both groups were veneered using IPS POM ceramic. A wax-up was built on the opaqued metal frameworks using ash-free wax (XP Dent Corp., Miami, FL). Wax thickness (0.8 mm cervically to 1.2 mm occlusally) was controlled by means of a counter die to standardize the wax-ups of the pressed veneers. The wax-ups were sprued and invested (IPS PressVEST Speed Investment, Ivoclar Vivadent), and the recommended burnout cycle was performed (1 hour at 850°C) (Burnout Furnace: Vulcaan TM 3–130; Degussa-Ney, Yucaipa, CA). Ingots (color A2 Xs) were chosen and inserted by means of a tong in the hot investment ring. The powder-coated IPS e-max Alox plunger was subsequently placed into the hot investment ring. Finally the hot and completed investment ring was placed at the center of the hot press furnace (EP600 Combi, Ivoclar Vivadent) using the investment tongs. At the end of the press program, the hot investment ring was removed from the furnace and left to cool to room temperature. One hour later the specimens were divested, finished, and glazed. The specimens were then ready for testing.

Vertical marginal gap measurement

The vertical marginal gaps of the crowns were measured after veneering placement. Each group of crowns was placed individually on the stainless steel die and examined using a stereomicroscope (SZ 40, Olympus, Tokyo, Japan). A specially designed metal device was used to ensure correct seating of the crowns during microscopic measurements. Photos of different crowns were captured by a digital camera (P10, Olympus) linked to the microscope with original magnification 30x. Image analysis software (Image J 1.31, NIH, Washginton, DC) was used to measure the gap between the crown margin and the finishing line, by drawing a line from the cervical margin of the crown and the outer end of the finishing line at four points on the same surface of the crown. Sixteen readings were taken for each crown circumferentially, four readings at each quarter turn. The readings were given in microns. The mean vertical marginal gap was calculated for each group of specimens and subjected to statistical analysis.

Fracture resistance test

The stainless steel die was duplicated 40 times in epoxy (Polypoxy, 700 Polymer, C.I.C., Cairo, Egypt) for fracture testing, over which the crowns were cemented using glass ionomer cement (Vivaglass CEM, Ivoclar Vivadent). Crowns with their epoxy base were vertically mounted on a computer-controlled testing machine (Model LRX-plus; Lloyd Instruments Ltd., Fareham, UK) with a 5 kN load cell. Data were recorded using computer software (Nexygen-MT; Lloyd Instruments). The epoxy dies were secured to the lower fixed compartment of the machine by tightening screws so the long axis of each specimen was parallel to the force, and the occlusal surface of the specimen was aligned perpendicular to it. Load was applied with a custom-made load applicator (steel rod with half sphere tip placed at the center of the occlusal surface of crown specimens, 3.8 mm in diameter) attached to the upper movable compartment of the machine. A layer of rubber sheet was placed between the loading tip and the occlusal surface of crown specimens to achieve an even stress distribution. Specimens were loaded to fracture at a 1 mm/min crosshead speed, and the values were recorded in Newtons (N).

Roughness testing

Roughness was measured using roughness software (Image J, 1.31 b). The software uses an image captured by a CCD (charge-coupled device) zoom digital camera (DP 10, Olympus) stereomicroscope at 20x magnification. The specimen was mounted on a standardized site on the mechanical stage with the light source at 90°. This angle was standardized by the use of a cool ring light mounted around the objective lens. A photo of the tested surface was recorded. The software interprets the roughness as shadows of the peaks and valleys, with the lower values indicating higher roughness contrary to the Profilometer. In the case of rough surfaces, the Ra value indicates a low measure of gray scale from a central baseline (i.e., toward the 0 value, as 0 value indicates black, while 255 value indicates white).

Microhardness testing

Microhardness was tested using a computerized microhardness tester (MicroHardness Tester, Shimadzu, Kyoto, Japan). Testing consisted of making a dent in the crown specimens with a 5 N load (500 g) in 20 seconds. The Vicker indenter is a square-based, pyramid-shaped diamond, which leaves a square-shaped indentation on the surface of the material being tested. Hardness was determined by measuring the diagonals of the square (d1 and d2) and calculating the average of the dimensions. Three readings were calculated for five selected random crown specimens (before fracture testing), representing the two main groups, ensuring that the surfaces of the tested veneering materials were represented (n = 15 for each tested ceramic group). Microhardness was measured as Vickers hardness numbers (VHN).

Statistical analysis

Data were presented as means and standard deviations (SD). Student's *t*-test was used for comparison between the two margins and the two ceramic types. The significance level was set at $p \leq 0.05$. Statistical analysis was performed with SPSS 16.0® (SPSS Inc., Chicago, IL) for Windows.

Table 1 Statistical analyses of the mean marginal gap distance values (μm) of conventional IPS inline and press-on metal ceramics with two different margins

	Metal porcelain margin	All-porcelain margin	
	Mean ± SD	Mean ± SD	*p*-value
Conventional ceramics	121.6 ± 35.6	110.8 ± 29.7	0.249
Press-on metal ceramics	102.7 ± 29	104.8 ± 22.3	0.815
p-value	0.043*	0.502	

*: Significant at $p \leq 0.05$

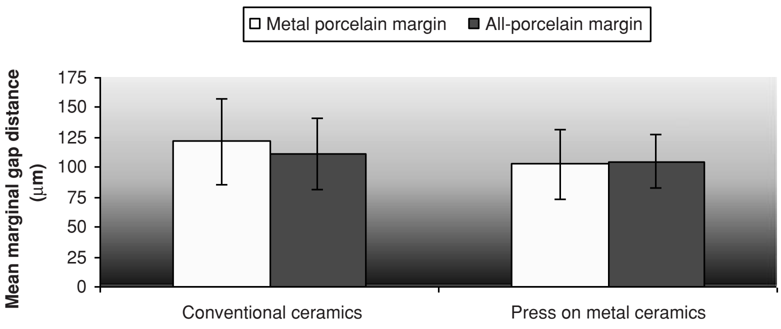

Figure 2 Mean marginal gap values of the tested groups.

Table 2 Statistical analyses of the mean fracture resistance values (N) of conventional IPS inline and press-on metal ceramics with two different margins

	Metal porcelain margin	All-porcelain margin	*p*-value
Conventional ceramics	1810.3 ± 417.9	1751.9 ± 326.5	0.858
Press-on metal ceramics	2025.6 ± 486.4	2181.4 ± 293.1	0.659
p-value	0.592	0.165	

Table 3 Statistical analysis of the mean roughness values of conventional IPS inline and press-on metal ceramics

	Conventional ceramics	Press-on metal ceramics
Mean ± SD	129.4 ± 1.4	131.7 ± 2.5
p-value	0.235	

Results

The results of the statistical analysis of the mean marginal gap distance of the tested groups are represented in Table 1 and Figure 2. These showed no statistically significant difference between mean marginal gap distance with metal porcelain margin and all-porcelain margin using conventional ceramics and POM ceramics at p-Values of 0.249 and 0.815, respectively.

With the metal porcelain margin (Table 1), there was a statistically significant difference between mean marginal gap distance of conventional ceramics and press-on ceramics ($p = 0.043$). With the all-porcelain margin, there was no statistically significant difference between mean marginal gap distance of conventional ceramics and press-on ceramics ($p = 0.502$).

Regarding the fracture resistance (Table 2, Fig 3), there was no statistically significant difference between mean fracture resistance with metal porcelain and all-porcelain margins using conventional ceramics. The mean marginal gap distance of the POM ceramics also showed no significant difference between the two coping designs. There was no statistically significant difference between mean fracture resistance of conventional ceramics and POM ceramics ($p = 0.592$ and $p = 0.165$, respectively).

There was no statistically significant difference between mean roughness of conventional ceramics and POM ceramics ($p = 0.235$, Table 3, Fig 4). There was a statistically significant difference between mean hardness of conventional ceramics and POM ceramics ($p = 0.008$). Conventional ceramics showed statistically significantly higher mean hardness than press-on ceramics (Table 4, Fig 5).

Discussion

Marginal adaptation is a fundamental element for the long-term clinical success of restorations. Poor marginal adaptation increases the potential for microleakage and plaque retention, raising the risk of recurrent caries and periodontal disease.[13-15]

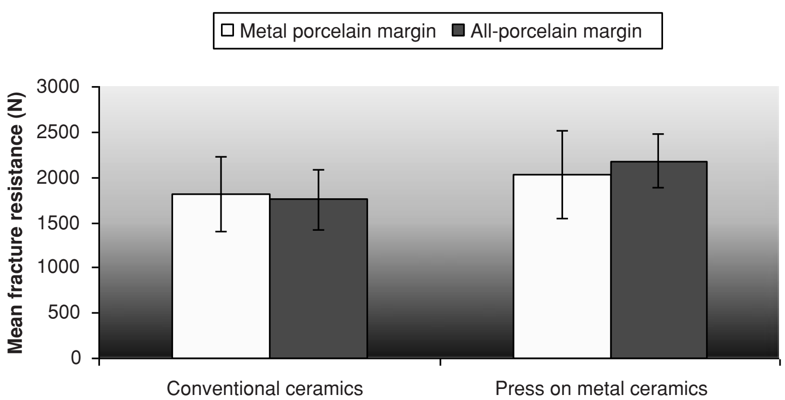

Figure 3 Mean fracture resistance values of the tested groups.

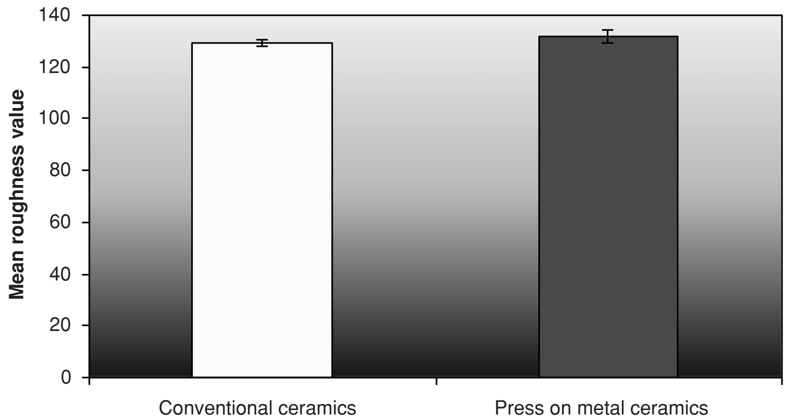

Figure 4 Mean roughness values (VHN) of conventional IPS inline and press-on metal ceramics.

Table 4 Statistical analysis of the microhardness mean values (VHN) of conventional IPS inline and press-on metal ceramics

	Conventional ceramics	Press-on metal ceramics
Mean ± SD	620.8 ± 58.7	502.4 ± 46.3
p-value	0.008*	

*: Significant at $p \leq 0.05$

Press-on metal ceramic resulted in better marginal adaptation than conventional ceramic. This finding agrees with the findings of Goldin et al,[10] who reported that pressed restorations with or without metal possessed equal or better marginal adaptation than traditional metal ceramic restorations. They attributed this to better fit and less variation than metal ceramic restorations with feldspathic margins. This has been confirmed by the results in the current study.

No statistically significant difference was evident between the all-porcelain margins of both groups; however, pressed crowns were not corrected during fabrication, while the crowns with the shoulder porcelain were corrected with a second firing. Many authors claim that porcelain margins possess marginal openings that are as clinically acceptable as the metal margins.[3,5,6] The pressed-to-metal restorations with all-ceramic margins offer a great advantage when compared to shoulder porcelain application, which requires advanced technical skill and multiple corrections.

Ceramic failure is related to cracks within the ceramic caused by condensation, sintering process, and thermal coefficient differences.[16] The four tested groups showed no statistical difference regarding their failure loads. Early failure manifested by delamination is induced by low bond strength of the veneering materials to their cores.[17] Schweitzer et al[11] found no difference in the debonding/crack initiation strength of a low-fusing pressable leucite-based glass ceramic fused to metal and feldspathic porcelain fused to metal (Ni Cr alloy). This finding was also confirmed by Venkatachalam et al,[12] regarding cobalt chrome alloys. In addition, O'Boyle et al[2] reported no change in fracture strength with up to 1 mm of framework reduction. It is also possible that the type of margin had little influence on failure loads, as failure evidently initiated at the point of load application, which was on the occlusal surface distant from the margin.

By examining the fractures using a magnifying lens, most of the observed failures in the pressed group were adhesive/cohesive in nature. About one third of the metal coping surface area was evident; however, most of the delaminations observed were cohesive within the pressed ceramic itself. This suggests that the opaquer-pressed ceramic bond was stronger

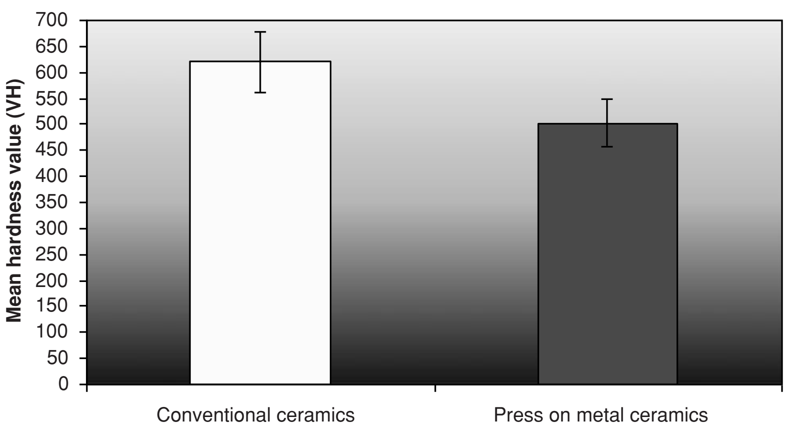

Figure 5 Mean microhardness values (VHN) of conventional IPS inline and press-on metal ceramics.

than the cohesive strength of the pressed ceramic. On the other hand, within the conventional ceramic group, the pattern of failure was mostly adhesive in nature, with large areas of the metal coping left denuded. This different pattern of failure would need further investigation, since intraoral repair of these restorations could vary depending on the limited amount of exposed metal coping.

The roughness of intraoral hard surfaces enhances the retention of plaque.[18] It may also abrade opposing teeth or restorative materials.[19,20] No difference in roughness was evident between both ceramic types. The Ra values obtained are the arithmetic mean of all the registered peak and valley readings within the specimens of the same group. The presence of porosity is a problem in the laboratory fabrication of conventional ceramic restorations. It is caused by air trapped during sintering, which leads to undesirable roughness and pits, especially during grinding, affecting the strength and optic properties of porcelain.[21] Ceramic press technology on the other hand, allows the production of defect-free structures associated with the lost-wax technique.

The pressed-to-metal groups showed significantly lower microhardness values than the traditional ceramics. This new technology promises less wear and abrasion to opposing enamel. Hardness is one of the most frequently measured properties of a ceramic. Its value helps to characterize resistance to deformation, densification, and fracture.[22] Two major determinants of enamel wear are surface finish and microstructure. At a microstructural level, previous generation veneering materials had crystalline phases with leucite crystals possessing an average size greater than 30 μm. These large particles left microscopically rough surfaces that abraded opposing enamel, thus increasing wear rate.[9]

Feldspathic porcelain has been around for decades and is at present the traditional choice for porcelain-fused-to-metal restorations. Ceramic-pressed-to-metal restorations are a promising addition to the traditional metal ceramic systems, complementing their position among the new ceramic systems due to several factors: ease of fabrication (conventional lost-wax technique), occlusal accuracy, better marginal integrity, translucency, good mechanical properties (crystal reinforcing systems), net-shape forming by pressing, and decreased porosity.[23,24]

The null hypothesis suggesting superiority of the POM system over the conventional metal ceramic system was accepted regarding microhardness and marginal gap distance only for the group with porcelain metal margins; however, marginal gap of the groups with all-porcelain margins showed no significant superiority of POM system over the conventional metal ceramic system. Regarding fracture resistance and surface roughness, the null hypothesis was rejected due to similarity in the values between two tested systems. This in vitro study has several limitations that must be addressed in future studies; these include the small number of the specimens, using static instead of cyclic loading, and the lack of thermal fatigue testing.

Conclusions

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. No difference was evident regarding the vertical marginal gap distance in relation to the margin design of both tested groups; however, the POM group with metal porcelain margin showed better marginal adaptation to conventional metal ceramics.
2. Fracture resistance values showed no difference regarding the margin design or type of the ceramic veneer material.
3. POM and conventional metal ceramics showed similar roughness values.
4. POM ceramics showed statistically lower microhardness values than conventional metal ceramics.

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