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Original Article

Effect of polishing on hybrid CAD/CAM ceramics after gastric acid

Efeito do polimento em cerâmicas híbridas CAD/CAM após erosão ácida

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Resumo

Objetivo: Avaliar a influência de diferentes sistemas de polimento e do desafio erosivo por ácido gástrico simulado sobre a rugosidade superficial e a microdureza Vickers de cerâmicas híbridas CAD/CAM. **Material e método:** Quarenta espécimes (n=10/grupo) de uma cerâmica infiltrada por polímero (VITA Enamic) e de uma resina nanocerâmica (Cerasmart) foram distribuídos em quatro grupos, conforme o material e o sistema de polimento: sistema convencional para cerâmica (CPS) ou sistema específico para materiais híbridos (HSP). A rugosidade superficial (Ra) e a microdureza Vickers (VHN) foram avaliadas após 24 horas e após imersão cumulativa em ácido clorídrico a 5% (pH 2,0) por 91, 182 e 455 horas, períodos cumulativos simulados de exposição ao ácido gástrico. Os dados foram analisados por ANOVA de três fatores com medidas repetidas e teste de Tukey ($\alpha=0,05$). **Resultado:** Houve interação significativa entre material, sistema de polimento e período de avaliação para ambas as variáveis ($p<0,05$). O HSP reduziu significativamente a rugosidade da VITA Enamic em todos os períodos avaliados ($p<0,001$), enquanto não houve benefício consistente para a Cerasmart. Independentemente do protocolo de polimento, a VITA Enamic apresentou maior microdureza que a Cerasmart ($p<0,001$). O desafio erosivo reduziu a microdureza de ambos os materiais ao longo do tempo. **Conclusão:** O sistema de polimento específico para materiais híbridos proporcionou menor rugosidade superficial comparado à cerâmica infiltrada por polímero, enquanto não foi observado benefício consistente para a resina nanocerâmica. A exposição ao

ácido gástrico simulado foi associada a reduções na microdureza em períodos específicos de avaliação em ambos os materiais. Esses achados estão limitados às propriedades superficiais avaliadas nas condições experimentais do estudo.

Descritores: CAD-CAM; cerâmicas; polimento dentário; rugosidade superficial; dureza; erosão dentária.

Abstract

Objective: To evaluate the effects of polishing systems and simulated gastric acid on the surface roughness and Vickers microhardness of hybrid CAD/CAM ceramics. **Material and method:** Forty specimens (n=10/group) were prepared from a polymer-infiltrated ceramic network (VITA Enamic) and a resin nanoceramic (Cerasmart). Specimens were polished with either a conventional ceramic polishing system (CPS) or a hybrid-specific polishing system (HSP). Surface roughness (Ra) and Vickers microhardness (VHN) were measured after 24 h and after cumulative immersion in 5% hydrochloric acid (pH 2.0) for 91, 182, and 455 h, cumulative simulated gastric acid exposure periods. Data were analyzed by three-way mixed-design ANOVA with repeated measures and Tukey's post hoc test ($\alpha=0.05$). **Result:** Significant interactions among material, polishing system, and evaluation period were found for both outcomes ($p<0.05$). HSP reduced the roughness of VITA Enamic compared with CPS at all periods, whereas no consistent improvement was observed for Cerasmart. VITA Enamic showed higher microhardness than Cerasmart regardless of the polishing method. Simulated gastric acid reduced microhardness over time in both materials, while roughness depended on the interaction between material and polishing protocol. **Conclusion:** The hybrid-specific polishing system resulted in lower surface roughness for the polymer-infiltrated ceramic network, whereas no consistent benefit was observed for the resin nanoceramic. Simulated gastric acid exposure was associated with reductions in microhardness at specific evaluation periods in both materials. These findings are limited to the surface properties evaluated under the experimental conditions.

Descriptors: CAD-CAM; dental polishing; surface roughness; hardness; dental erosion.

INTRODUCTION

In recent years, hybrid CAD/CAM ceramics have emerged as alternatives to conventional glass-ceramics for indirect restorations¹⁻³. There are two classes of CAD/CAM composites: the first consists of composites with dispersed fillers - resin nanoceramic (e.g., Cerasmart, GC), and the second is polymer-infiltrated ceramic network (PICN), similar to direct resins but polymerized to a high degree (e.g., Vita Enamic, VITA Zahnfabrik H. Rauter GmbH & Co. KG)⁴. These materials combine favorable mechanical, esthetic, and functional properties of ceramics with the enhanced elasticity, machinability, reparability, and ease of polishing associated with resin-based materials⁵.

To reduce the surface roughness of these restorations, various materials have been developed for chairside finishing and polishing^{6,7}. Multi-step finishing and polishing systems typically involve three to four different discs or instruments, each featuring a different abrasive grit size⁸. With this approach, ceramic surfaces can be mechanically polished using rubber polishing points or cups, with or without polishing pastes^{9,10}. A polishing system incorporating diamond polishing paste was recently introduced specifically for hybrid CAD/CAM materials. Furthermore, these polishing methods allow for intraoral repolishing of restorations after cementation, occlusal adjustment, or during periodic follow-up appointments, potentially contributing to their long-term maintenance¹¹.

Dental erosion is associated with tooth damage, which can range from superficial enamel loss to complete exposure of the dentin¹². The source of the erosive acid can be intrinsic (diseases and eating disorders) or extrinsic (acidic diet)¹². Gastroesophageal reflux disease (GERD), anorexia, and bulimia nervosa are among the primary conditions that cause oral changes, such as dental erosion^{12,13}. The low pH of gastric acid (≤ 2.0) erodes tooth structure.¹²

Restorative materials in the oral cavity can also be affected by acid^{14,15}, including the resin-matrix ceramics evaluated in this study. Recent studies^{16,17} have suggested that resin-matrix ceramics may be a viable alternative for patients susceptible to erosion. However, evidence regarding the long-term performance of these restorations remains limited, particularly concerning the potential influence of polishing procedures. Thus, this study aimed to evaluate the effects of different polishing systems on the surface roughness (Ra) and Vickers microhardness (VHN) of two hybrid CAD/CAM ceramics, a polymer-infiltrated ceramic network (PICN) and a resin nanoceramic (RNC), after cumulative simulated gastric acid

exposure periods. The null hypothesis was that material type, polishing system, and exposure period would not significantly affect surface roughness or Vickers microhardness.

MATERIAL AND METHOD

Sample size calculation

The sample size was determined a priori using G*Power software, version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany), considering each specimen as the experimental unit, regardless of the number of measurements performed on its surface. The effect size was estimated based on the results reported by Yıldırım-Işık, Büyükgöze-Dindar⁴ (2025), who evaluated the Vickers microhardness of VITA Enamic and Cerasmart before and after exposure to simulated gastric acid. Based on the means and standard deviations reported for the interaction between material and acidic exposure, an effect size of $f=0.238$ was estimated.

An F test for repeated-measures analysis of variance, considering the interaction between within- and between-subject factors, was selected. A significance level of 5%, statistical power of 80%, four experimental groups, four evaluation periods, a correlation of 0.50 among repeated measurements, and a nonsphericity correction of 1.00 were adopted. The calculation indicated a minimum requirement of 38 specimens. To allow equal allocation among the four experimental groups, the sample size was increased to 40 specimens, corresponding to 10 specimens per group.

Experimental design

The experimental design is shown in Figure 1. A total of 40 specimens were prepared, comprising 20 specimens from each resin-matrix CAD/CAM material. The specimens were allocated to four experimental groups according to the combination of material and polishing system ($n=10$): RNC-CPS, Cerasmart subjected to the conventional polishing system; RNC-HSP, Cerasmart subjected to the hybrid-specific polishing system; PICN-CPS, VITA Enamic subjected to the conventional polishing system; and PICN-HSP, VITA Enamic subjected to the hybrid-specific polishing system.

The same specimens were evaluated repeatedly at four time points: after 24 h of storage in distilled water, corresponding to baseline (T0), and after cumulative exposure to simulated

gastric acid for 91 h (T1), 182 h (T2), and 455 h (T3). Surface roughness and Vickers microhardness were considered the response variables.

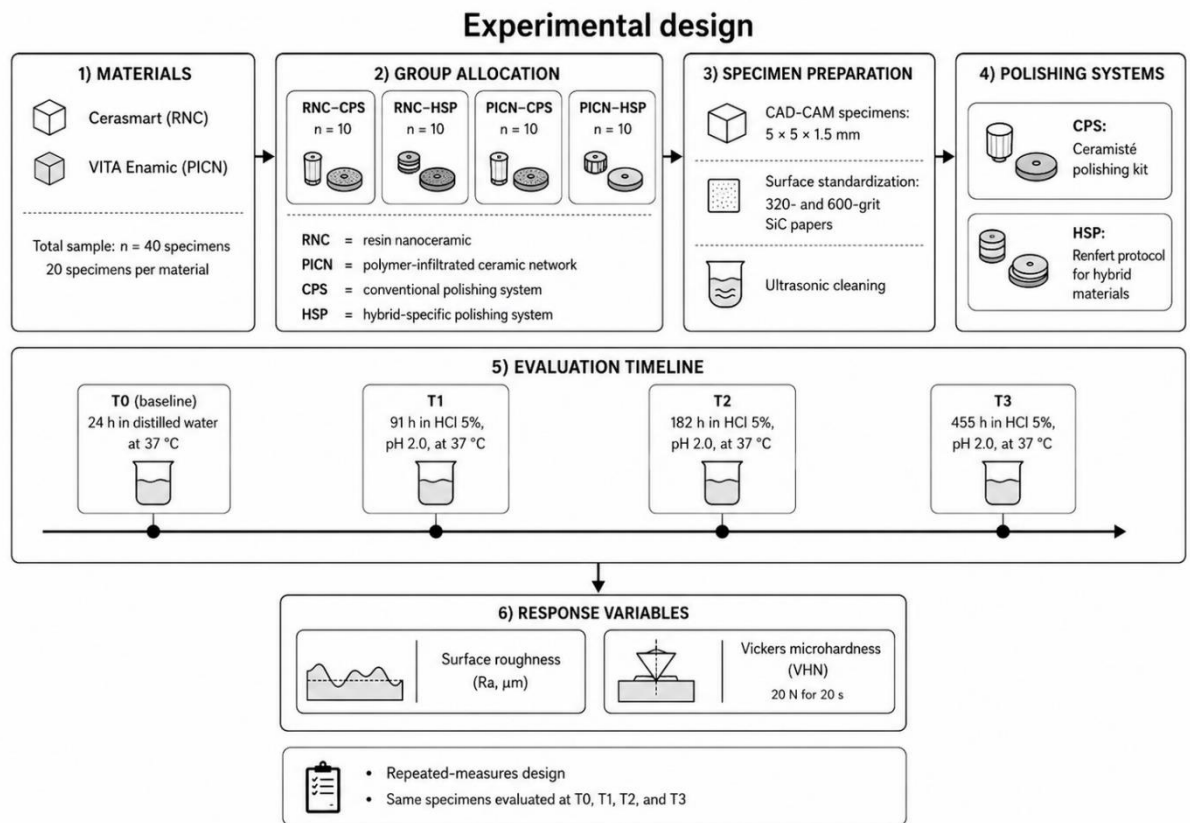


Figure 1. Experimental design.

Materials

Two resin-matrix CAD/CAM ceramics with different microstructural compositions were evaluated: Cerasmart, classified as a resin nanoceramic, and VITA Enamic, classified as a polymer-infiltrated ceramic network. The materials, manufacturers, and compositions are presented in Table 1.

Table 1. Resin-matrix CAD/CAM materials evaluated in the study

Classification	Material	Manufacturer	Composition
Resin nanoceramic	Cerasmart	GC Corporation, Tokyo, Japan	Bis-MEPP-, UDMA-, and DMA-based resin matrix containing approximately 71 wt% silica (20 nm) and barium-glass (300 nm) fillers.
Polymer-infiltrated ceramic network	VITA Enamic	VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany	86 wt% feldspathic ceramic network infiltrated with a 14 wt% polymer phase composed mainly of UDMA and TEGDMA.

Bis-MEPP, bisphenol A ethoxylated dimethacrylate; DMA, dimethacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

Specimen preparation

Twenty specimens were prepared for each CAD-CAM material, yielding a total of 40 specimens. The CAD-CAM blocks were sectioned into rectangular specimens measuring 5×5×1.5 mm (±0.05 mm) using a low-speed precision cutting machine (IsoMet 1000 Precision Saw, Buehler, Lake Bluff, IL, USA) equipped with a diamond blade (Buehler, Lake Bluff, IL, USA). Sectioning was performed at 300 rpm under continuous water irrigation and a load of 300 gf.

The dimensions of each specimen were verified using a digital caliper (Mitutoyo Sul Americana Ltda., Santo Amaro, SP, Brazil). The specimen surfaces were standardized using 320-grit silicon carbide abrasive paper, followed by 600-grit silicon carbide abrasive paper (Carbimet Paper Discs, Buehler, Lake Bluff, IL, USA) on a polishing machine (Arotec Indústria e Comércio Ltda., São Paulo, SP, Brazil) under continuous water cooling to obtain flat and standardized surfaces. After surface standardization, the specimens were ultrasonically cleaned (Unique USC 2850, São Paulo, Brazil) in distilled water for 10 min and dried using an air stream.

Polishing procedures

The specimens from each material were allocated to two polishing protocols, resulting in 10 specimens per material and polishing system. The polishing systems, manufacturers, components, and application protocols are presented in Table 2.

The same trained operator performed all polishing procedures according to the manufacturers' instructions, and the applied force was standardized at 1 N using a digital scale¹⁸. After polishing, the specimens were ultrasonically cleaned in distilled water for 10 min to remove polishing residues and were subsequently dried using an air stream.

Table 2. Polishing systems and application protocols evaluated in the study

Polishing system	Components	Manufacturer	Application protocol
Conventional polishing system (CPS)	Ceramisté Standard, Ceramisté Ultra, and Ceramisté Ultra II	Shofu Inc., Kyoto, Japan	Each instrument was applied for 15 s in one direction and for an additional 15 s in a perpendicular direction using a low-speed contra-angle handpiece at 8000 rpm.
Hybrid-specific polishing system (HSP)	Silicone polisher, Bison polishing brush, cotton buff, and diamond polishing paste specifically indicated for hybrid materials	Renfert GmbH, Hilzingen, Germany	Each polishing step was performed for 15 s in one direction and for an additional 15 s in a perpendicular direction using a low-speed contra-angle handpiece at 8000 rpm, according to the manufacturer's instructions.

Simulated gastric acid challenge

After polishing, all specimens were stored in distilled water at 37 °C for 24 h. Surface roughness and Vickers microhardness were then measured to obtain the baseline values (T0).

Following baseline measurements, the same specimens were immersed in a 5% hydrochloric acid solution adjusted to pH 2.0 and maintained at 37 °C. The specimens were evaluated after cumulative immersion periods of 91 h (T1), 182 h (T2), and 455 h (T3). The exposure durations were selected based on cumulative acid-contact protocols reported in previous studies^{14,19,20}, particularly the protocol described by Harryparsad et al.²⁰ In that protocol, an assumed gastric acid contact time of approximately 15 min/day yields approximately 91 h of cumulative exposure over 365 days. Accordingly, cumulative exposure periods of 91, 182, and 455 h were adopted. These experimental durations should not be interpreted as direct equivalents of clinical service time.

Surface roughness

Surface roughness was measured using a contact surface profilometer (SJ-411, Mitutoyo Sul Americana Ltda., Santo Amaro, SP, Brazil). Three parallel measurements were performed on each specimen: one at the center of the evaluated surface and two additional measurements positioned to the right and left of the central measurement.

The arithmetic mean surface roughness value (Ra) was calculated from the three measurements and considered the representative value for each specimen. Measurements were performed using a scanning length of 300 µm and a measurement time of 12 s. Surface roughness values were expressed in micrometers (µm).

Vickers microhardness

Vickers microhardness was assessed using a microhardness tester (HMV-2000, Shimadzu Corporation, Kyoto, Japan). A 20-N load was applied for 20 seconds. Three indentations were made in the central region of each specimen, arranged linearly and spaced 100 µm apart from center to center. The mean of the three measurements was calculated and reported as the Vickers hardness number (VHN) for each specimen.

Statistical analysis

The normality of the residuals was assessed using the Shapiro–Wilk test. Surface roughness and Vickers microhardness data were analyzed separately using a three-way mixed-design analysis of variance with repeated measures. Material and polishing system were considered between-subject factors, whereas evaluation time was considered the within-subject repeated factor. The Geisser–Greenhouse correction was applied to account for potential violations of the sphericity assumption. When significant main effects or interactions were

detected, multiple comparisons were performed using Tukey's test. The significance level was set at 5% ($\alpha = 0.05$). Statistical analyses were performed using GraphPad Prism, version 10 (GraphPad Software, Boston, MA, USA).

Statement on the use of artificial intelligence

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to assist in the creation of the experimental design figure. After using this tool, the authors carefully reviewed and edited the final image and take full responsibility for the content of the publication.

RESULT

Surface Roughness (Ra)

The roughness results are presented in Figure 2. The three-way ANOVA revealed a statistically significant interaction among material, polishing method, and evaluation period ($F=3.994$; $p=0.01$). Regarding the polishing method, the PICN-HSP significantly reduced the roughness values compared to the PICN-CPS at all evaluation time periods ($p<0.001$). For the RNC, HSP resulted in higher roughness values than CPS after 182 h ($p=0.048$), but showed lower values after 455 h ($p=0.001$).

Regarding the material type, PICN exhibited higher roughness values than Resin Nanoceramic when subjected to the ceramic polishing system at all evaluation periods ($p<0.001$). The hybrid-specific polishing system showed no statistical difference between the materials at the initial times (24 h and 91 h); however, after 182 h and 455 h, PICN showed lower ($p=0.001$) and higher ($p=0.040$) roughness values.

Regarding the evaluation period, no statistically significant differences were observed among time points for PICN-CPS ($p>0.05$) or PICN-HSP ($p>0.05$). For RNC-CPS, roughness values remained unchanged up to 182 h and increased significantly only after 455 h compared with the initial 24-h evaluation ($p = 0.037$). In contrast, RNC-HSP exhibited significantly higher roughness values at 182 h than at all other evaluation periods ($p < 0.01$).

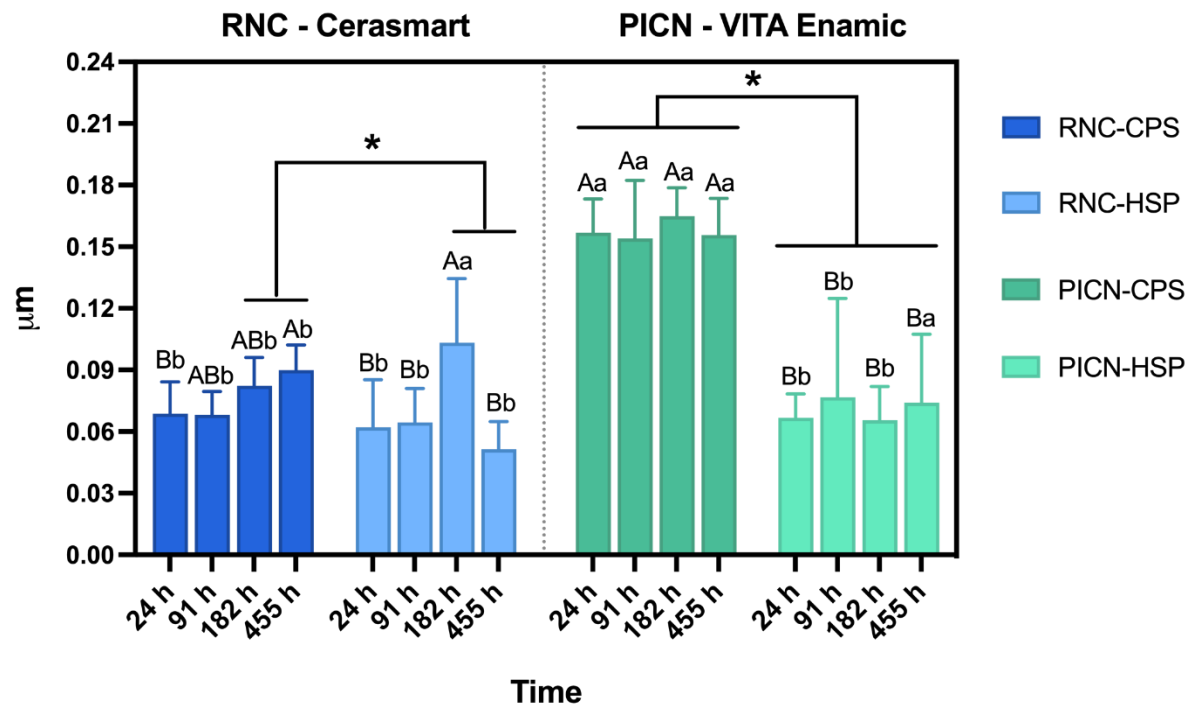


Figure 2. Mean and standard deviation of surface roughness values according to material type (Resin nanoceramic and PICN), polishing method (ceramic polishing system and hybrid-specific polishing system), and evaluation periods (24 h, 91 h, 182 h, and 455 h). Bars marked with an asterisk (*) indicate a statistically significant difference between polishing methods within each material type and evaluation time ($p < 0.05$). Different uppercase letters indicate a significant difference between time points within each material type and polishing method ($p < 0.05$). Different lowercase letters indicate a significant difference between materials within each polishing method and evaluation period ($p < 0.05$).

Vickers Microhardness (VH)

The Vickers microhardness results are presented in Figure 3. Three-way ANOVA revealed a statistically significant interaction among material, polishing method, and evaluation period ($F = 5.440$; $p = 0.002$).

Regarding the polishing method, at the initial 24h evaluation, the hybrid-specific polishing system resulted in lower PICN microhardness values than the ceramic polishing system ($p < 0.001$). However, after 182 h ($p = 0.009$) and 455 h ($p = 0.031$), PICN specimens polished with the hybrid-specific polishing system exhibited significantly higher microhardness values than those polished with the ceramic polishing system. For the Resin Nanoceramic material, no statistical difference was observed between the polishing methods ($p > 0.05$).

Regarding the material type, PICN exhibited higher microhardness values than Resin Nanoceramic for both polishing methods across all evaluation periods ($p<0.001$).

Regarding the evaluation period, all groups showed higher numerical microhardness values at the initial 24-hour mark compared to the other time periods. Statistically, the PICN-CPS showed higher microhardness values at the initial 24-hour period compared to the other time points ($p<0.001$). For PICN-HSP, higher microhardness values were also observed at the initial 24-hour period, with a statistically significant difference compared to the 91 h ($p<0.001$) and 455 h ($p=0.002$) time periods. Similarly, RNC-CPS specimens showed higher microhardness values at the initial 24-hour period compared to the 91 h ($p=0.009$) and 455 h ($p=0.049$) time periods. The RNC-HSP group presented higher microhardness values at the 24h evaluation, with a statistically significant difference only compared with 91 h ($p=0.017$).

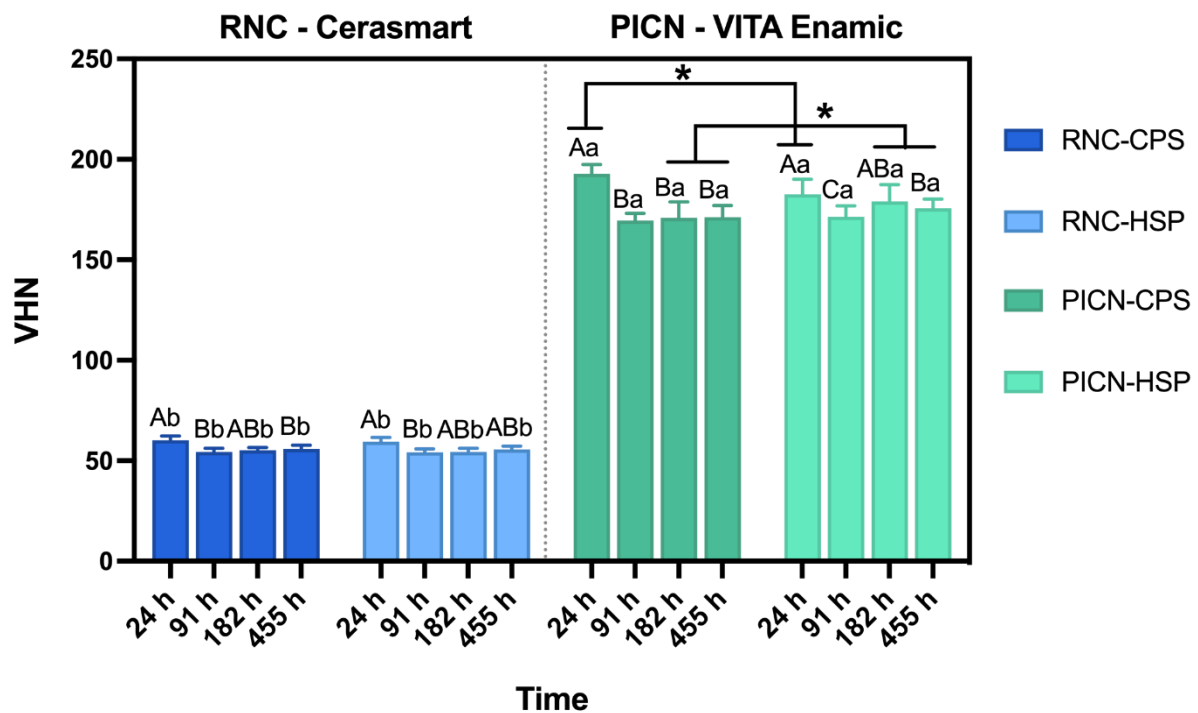


Figure 3. Mean and standard deviation of Vickers microhardness values according to material type (PICN and RNC), polishing method (ceramic polishing system or hybrid-specific polishing system), and evaluation time (24 h, 91 h, 182 h, and 455 h). Bars marked with an asterisk (*) indicate a statistically significant difference between polishing methods within each material type and evaluation time ($p<0.05$). Different uppercase letters indicate a significant difference between time points within each material type and polishing method ($p<0.05$). Different lowercase letters indicate a significant difference between materials within each polishing method and evaluation period ($p<0.05$).

DISCUSSION

The null hypothesis was rejected because material type, polishing system, and erosive challenge period significantly influenced surface roughness (Ra) and Vickers microhardness (VHN). An erosive challenge (EC) is a method used to evaluate the effects of HCl on material surfaces, simulating exposure to gastric acid ($\text{pH} \leq 2.0$) in patients with GERD or eating disorders such as bulimia and anorexia^{19,20}. In the present study, immersion times were established to represent cumulative simulated gastric acid exposure periods for hybrid CAD/CAM ceramics, based on a previously published protocol^{20,21}. Previous studies²¹⁻²³ have demonstrated that erosive challenges can alter the characteristics of these materials.

Regarding surface roughness, ceramic restorations should have smooth, polished surfaces, not only for patient comfort and esthetic reasons but also to minimize wear and biofilm accumulation, which may contribute to gingivitis and secondary caries. The results showed that PICN specimens polished with HSP exhibited significantly lower surface roughness values than those polished with CPS at all evaluation periods. For RNC, differences between the polishing systems varied across the evaluation periods. Thus, the hybrid-specific polishing system appears to yield promising results regarding surface roughness reduction, which is consistent with previous studies reporting that polishing protocols specifically designed for hybrid materials can improve surface roughness^{24,25}.

Although PICN contains 86 wt% feldspathic ceramic, previous studies have suggested that its polymer-infiltrated structure may contribute to reducing acid-induced surface degradation.²⁶ Consistent with these findings, PICN exhibited no statistically significant changes in surface roughness across the simulated gastric acid exposure periods, regardless of the polishing protocol. However, the potential protective role of the polymer network was not directly investigated in the present study. Regarding the evaluation period, RNC-CPS showed a difference only after 455 hours, with values increasing compared to the initial (24 hours). In contrast, RNC-HSP specimens exhibited higher roughness values at the 182-hour mark compared to the other time points. These differences in surface roughness may be associated with material-dependent responses to acidic exposure and the polishing protocols employed, although the underlying mechanisms remain uncertain. Previous studies have demonstrated that erosive challenges, alone or combined with mechanical abrasion, can alter the surface topography and mechanical properties of CAD/CAM restorative materials, with the extent of these changes depending on material composition.²⁷ From a physicochemical perspective,

water sorption within polymer networks may induce swelling and plasticization, while prolonged exposure to aqueous environments may promote hydrolytic degradation of susceptible chemical bonds.²⁸ These processes could potentially weaken the polymer matrix and the filler–matrix interface, favoring localized filler exposure or detachment and the formation of surface irregularities that may contribute to increased surface roughness.²⁸ However, water sorption, hydrolysis, filler release, and interfacial degradation were not directly investigated in the present study. Therefore, these mechanisms should be regarded as possible explanations for the observed surface changes rather than experimentally established findings.

Microhardness testing is also considered an important investigation regarding the mechanical behavior of restorative dental ceramic materials. Surface hardness reflects a material's resistance to indentation and can be measured using standardized testing equipment.²⁹ The microhardness of Resin Nanoceramic was not affected by the different polishing methods (CPS or HSP). According to the manufacturer, this hybrid ceramic material features a flexible nanoceramic matrix structure. However, few laboratory studies are available for comparison with the microhardness values observed in the present study^{19,21}. PICN exhibited higher microhardness values; this may be attributed to its composition, as previously mentioned. The microhardness values obtained for PICN are consistent with those reported in previous studies^{1,21}.

Although PICN specimens polished with HSP exhibited higher Vickers microhardness values than those polished with CPS after 182 and 455 h of simulated gastric acid exposure, these differences reflect only the measured surface resistance to indentation and do not establish greater overall material stability or resistance to degradation. A previous study²⁹ reported that different storage media significantly affected the microhardness of resin-matrix ceramics without significantly affecting their wear resistance. Another study showed that, when hybrid ceramics were compared, volumetric loss during impact-sliding wear was not directly related to microhardness, indicating that wear behavior is strongly dependent on material microstructure and damage mechanisms rather than hardness alone.³⁰ Therefore, the reductions in VHN observed after simulated gastric acid exposure should be interpreted as changes in localized surface resistance to indentation under the experimental conditions. Although some of these changes were statistically significant, their clinical relevance remains uncertain. Vickers microhardness alone cannot establish whether the observed changes would result in clinically meaningful deterioration, increased wear, or reduced restoration longevity, as these outcomes were not directly evaluated in the present study.

As this was an *in vitro* study conducted under controlled conditions, the use of standardized flat specimens was necessary to ensure reproducibility and minimize experimental variability. However, these conditions differ from the clinical environment, where surface curvature, accessibility, bur-induced defects, polishing pressure, and instrument angulation may influence the effectiveness of intraoral repolishing of CAD/CAM restorations. In addition, the continuous acid immersion protocol does not reproduce the episodic nature of gastric acid exposure *in vivo*, and relevant intraoral factors such as salivary clearance and buffering, acquired pellicle formation, neutralization periods, thermal variations, mechanical fatigue, and toothbrushing-induced abrasion were not simulated. Therefore, the cumulative immersion periods evaluated in this study should not be directly translated into years of clinical function. These findings should be interpreted as material- and surface-specific *in vitro* responses and should not be directly extrapolated to long-term clinical performance or restoration longevity.

CONCLUSION

Under the experimental conditions of this *in vitro* study, the hybrid-specific polishing system resulted in lower surface roughness for the polymer-infiltrated ceramic network compared with the conventional polishing system at all evaluation periods, whereas no consistent benefit was observed for the resin nanoceramic. Simulated gastric acid exposure was associated with reductions in Vickers microhardness at specific evaluation periods in both materials, with responses varying according to the material, polishing protocol, and exposure period. These findings are limited to the surface properties evaluated and should not be extrapolated to overall material stability or clinical performance.

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AUTHORS' CONTRIBUTIONS

João Pedro Justino de Oliveira Limírio: Methodology, Data curation, Writing - Original Draft, Investigation

Tielly Nogueira FETTI: Methodology, Investigation

Gabriel Nunes SAMPAIO: Methodology, Investigation

Bruna Egumi NAGAY: Writing - Review & Editing, Validation

Jessica Marcela de Luna GOMES: Investigation, Formal analysis

Aldieris Alves PESQUEIRA: Data curation

Eduardo Piza Pellizzer (tutor): Conceptualization, Project administration, Resources

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CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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