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Evaluation of Thermoplastic 3D Printing for Zirconia-Based Dental Applications

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Objectives Threedimensional printing is transforming manufacturing of prosthetic restorations by allowing for precise creation of custom-tailored zirconia ceramics with minimal waste. While vat photopolymerization (VPP) stands out for its precision, thermoplastic material extrusion (MEX) introduces possibility of multi-material fabrication, though it faces challenges in achieving necessary dimensional accuracy. This study aims to assess potential of MEX in production of clinically viable zirconia dental structures, comparing its dimensional accuracy and mechanical properties with those achieved through VPP and traditional CAD-CAM milling.

Methods Zirconia dental bars (approx. 15×4×8 mm) were manufactured using MEX (Prusa i3 MK3S, Prusa, Czech Republic), VPP (CeraFab 7500, Lithoz, Austria), and CAD-CAM milling as a control (n=10/group). Bars were scanned by nano-computed tomography (Xradia Versa 620, Zeiss, Germany). 3D deviation was analyzed using root mean square values (RMS). Additionally, disk-shaped specimens (n=30/group) were fabricated to assess surface roughness (Sa), density, porosity, grain size analysis (SEM), and biaxial flexural strength. Statistical analysis was conducted using ANOVA with Tukey's HSD post hoc and Weibull analysis coupled with fractography for mechanical properties ($P<0.05$).

Results CAD-CAM milling and VPP showed superior dimensional accuracy over MEX, with RMS values within clinically acceptable margins (below 150 µm). MEX exhibited the highest surface roughness (Sa=0.83±0.02 µm) and porosity, while Sa values of VPP (0.33±0.01 µm) and CAD-CAM milling (0.34±0.08 µm) were comparable. Mechanical testing revealed that while CAD-CAM milling exhibited the highest characteristic strength (1240 MPa) and reliability, followed by VPP (1120 MPa) and MEX (960 MPa), all groups reached clinically acceptable strength levels. Critical flaws observed in VPP and MEX specimens were predominantly process-related.

Conclusions Despite its current challenges in dimensional accuracy and mechanical strength relative to traditional CAD-CAM milling and VPP, MEX's capability to fabricate multi-material dental prostheses remains promising. The findings suggest further optimization of MEX parameters to enhance its application in the dental field.