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Original Research

# Micro-computed tomography characterization of three-dimensionally printed denture base resins: an in vitro descriptive pilot study

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ABSTRACT

***Objectives:*** To characterize, by micro-computed tomography, internal defects, porosity, and radiopaque particle distribution in two three-dimensionally printed photopolymer denture base resins (NextDent Denture 3D Plus and NextDent Base) and to descriptively explore the influence of build orientation (0°, 45°, and 90°) for Denture 3D Plus.

***Methods:*** In this descriptive in vitro pilot study, standardized specimens (10×10×2 mm) were designed (Meshmixer) and printed by liquid crystal display technology. Denture 3D Plus was printed at 0°, 45°, and 90°, and Base at 90°. One specimen of three per group was randomly selected for micro-computed tomography scanning. Reconstructed volumes were segmented to assess internal defects, porosity, and radiopaque particle volume. Data were analyzed descriptively.

***Results:*** No microcracks, fractures, inclusions, contamination, or interlayer delamination were detected within the resolution limits of the scanning protocol. Porosity was below the detection threshold in NextDent Base at 90° and very low in Denture 3D Plus at 0° (0.001%), 45° (0.0001%), and 90° (0.0003%). Radiopaque particles were dispersed throughout the resin matrix. Because the analyzed regions of interest differed in volume, particle volume fractions were not directly comparable, and no orientation-related trend could be inferred.

***Conclusions:*** Within the limitations of this single-specimen-per-group pilot design, the scanned specimens showed no detectable internal defects and very low porosity. These findings should be interpreted as preliminary micro-computed tomography observations. Controlled studies with adequate sample sizes, standardized regions of interest, and validated segmentation protocols are required before material- or orientation-related conclusions can be drawn. (Rev Port Estomatol Med Dent Cir Maxilofac. 2026;67(x):1-8)



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## Introduction

The digital workflow has profoundly changed Prosthodontics, replacing error-prone analog steps with integrated acquisition and CAD/CAM (computer-aided design and computer-aided manufacturing), improving precision, reproducibility, and clinician–laboratory communication.[1,2] Within manufacturing, additive technologies (3D printing) offer lower material waste, greater geometric freedom, and a faster, more detailed production than subtractive milling.[3-7]

Vat-photopolymerization technologies include stereolithography (SLA), digital light processing (DLP), and liquid-crystal-display (LCD) printing. LCD selectively cures liquid resin layer-by-layer using a monochromatic LCD mask, enabling simultaneous exposure of an entire layer at micrometric resolution.[1,4,5,8]

Resins for 3D-printed removable denture bases are mostly methacrylate-based photopolymers derived from ethoxylated bisphenol A dimethacrylate (Bis-EMA), urethane dimethacrylate (UDMA), and 2-hydroxyethyl methacrylate (HEMA).[1,9] They provide good dimensional accuracy, an integrated digital workflow, and reproducible production, but their mechanical properties are generally still inferior to milled CAD-CAM and heat-cured PMMA, with marked sensitivity to printing parameters and post-processing.[10-13]

The internal microstructure largely determines clinical behavior, since defects, porosity, and filler distribution influence mechanical strength, dimensional stability, water sorption, and biofilm retention.[14,15] In turn, build orientation, layer thickness, exposure, and post-curing are recognized determinants of final quality.[14,16] Micro-computed tomography (micro-CT) is the reference non-destructive technique to assess porosity, interlayer irregularities, and particle distribution in three dimensions.[17-20]

Despite the growing clinical use of 3D printing materials, microstructural data on available denture base resins remain scarce, and the influence of build orientation on their structure is poorly characterized.[17,19] Thus, this descriptive in vitro pilot study aimed to explore the feasibility of using micro-CT to characterize internal defects, porosity, and radiopaque particle distribution in two LCD-printed denture base resins: NextDent Denture 3D Plus and NextDent Base. The effect of build orientation (0°, 45°, 90°) was explored descriptively only for Denture 3D Plus.

## Material and Methods

Two commercial NextDent resins (NextDent, Soesterberg, The Netherlands) were used: Denture 3D Plus and Base. Both are methacrylate-based photopolymers compatible with LCD 3D printing.

Standardized specimens (10×10×2 mm) were designed in Meshmixer 3.5 (Autodesk, San Francisco, CA, USA) and exported as STL files. Specimens were printed by LCD technology (Phrozen Sonic Mini 8K S, Hsinchu, Taiwan). Denture 3D Plus was printed at three orientations: 0° (horizontal), 45° (oblique), and 90° (vertical). In turn, Base was printed at 90° to allow comparison in the same orientation. Printing parameters were established according to the resin requirements and preliminary calibration for the Phrozen printing system used in this study (Table 1).

Following printing, the specimens were cleaned in 96% isopropyl alcohol (IPA) using the washing unit of the Phrozen Wash & Cure Kit (Phrozen Technology, Hsinchu, Taiwan) for a single 5-minute washing cycle to remove uncured resin residues. After cleaning, the specimens were allowed to air-dry completely before post-curing. Post-curing was performed in the curing unit of the same Phrozen Wash & Cure Kit, equipped with 405-nm UV LEDs, a rotating platform that provided uniform 360° light exposure, and a maximum power output of 48 W. Base specimens were post-cured for 45 minutes, and Denture 3D Plus specimens for 30 minutes according to the selected protocol.

Four groups were prepared: Denture 3D Plus at 0°, 45°, and 90°; Base at 90°. Three specimens were produced per group, but only one per group was randomly selected for micro-CT scanning using a computer-generated random number sequence, thus defining a pilot single-specimen design.

Microstructural characterization was performed using a ZEISS Versa XRM 615 system (Carl Zeiss, Oberkochen, Germa-

**Table 1. Printing parameters and characteristics of the denture base resins used in the study. Printer settings were established during preliminary calibration for the Phrozen printing system used (Printer model: Phrozen Sonic Mini 8K S; software version: Chitubox V1.9.5).**

| Parameter | NextDent Base | NextDent Denture 3D Plus |
|---|---|---|
| Shade | Shade 05 | Classic Pink |
| Batch/Lot number | WT111N03 | WR294N01 |
| Layer thickness | 0.050 mm | 0.050 mm |
| Normal exposure time | 7.5 s | 5.0 s |
| Bottom-layer exposure time | 50.0 s | 35.0 s |
| Number of bottom layers | 6 | 6 |
| Lift speed (stage 1/stage 2) | 60 mm/min* | 40/120 mm/min† |
| Retract speed (stage 1/stage 2) | 150 mm/min* | 180/90 mm/min† |

* Single lift- and retract-speed values were used for NextDent Base.
† Two-stage lift and retract speeds were used for NextDent Denture 3D Plus, according to the printer settings.

ny) at a source voltage of 40 kV, an isotropic voxel size of 0.004 mm, exposure of 1.6 s, and a scanning time of approximately 90 min per specimen. Three-dimensional volumes were reconstructed from the projections and denoized with a machine-learning algorithm.

Reconstructed volumes were processed in Dragonfly (Comet/Object Research Systems). For each specimen, a region of interest (ROI) was defined by cropping. Thresholding segmentation (gray-level interval of 43864–57963) discriminated matrix, radiopaque particles, and pores, and the software quantified the number, volume, and percentage of voxels for the porosity and particle phases separately. The 0.004-mm voxel size constrained the minimum detectable defect size; therefore, defects smaller than the spatial resolution or affected by partial-volume effects may have been neglected. The segmentation threshold was selected manually after visual inspection of grayscale distributions and representative slices, and the same threshold interval was applied uniformly across specimens. Internal defects (microcracks, fractures, inclusions, contamination, and interlayer delamination) were inspected throughout the reconstructed volume.

Because ROI volumes differ between specimens, volume fractions are not directly comparable and are reported descriptively alongside absolute volumes. Given that there was a single specimen per group, no inferential statistical analysis was performed, and results are reported descriptively. Segmentation and defect inspection, as well as all other methodological procedures, were carried out by a single trained operator.

## Results

Specimen ROI dimensions and analyzed volumes are summarized in Table 2. ROI volumes ranged from 11.61 to 29.55 mm³ and differed markedly between specimens, reflecting the cropping applied to isolate internal regions.

Three-dimensional renderings confirmed global structural integrity in all specimens. No microcracks, fractures, inclusions, contamination, or interlayer delamination were detected in any group within the resolution limits of the micro-CT protocol (Figures 1 and 2).

Porosity values were very low across all groups (Table 3): not detectable in Base at 90°, and 0.001%, 0.0001%, and 0.0003% for Denture 3D Plus at 0°, 45°, and 90°, respectively. Isolated pores were identified in representative slices of Denture 3D Plus at 45° and 0° (Figures 3 and 4).

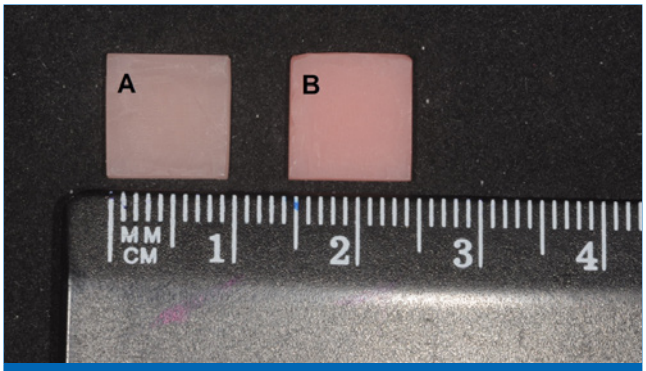


**Figure 1. Standardized specimens: (A) NextDent Base; (B) NextDent Denture 3D Plus.**

Dispersed radiopaque particles were observed in the resin matrix of all specimens, without visible agglomerates or evident heterogeneity (Table 4; Figures 5, 6, 7, and 8). Absolute particle volume was 0.17, 0.35, and 0.18 mm³ for Denture 3D Plus at 0°, 45°, and 90°, and 0.42 mm³ for Base at 90°. Because ROI volumes and dimensions differ between specimens, particle volume fractions (0.58%, 1.26%, 1.52%, and 1.65%, respectively) are reported only as descriptive within-specimen values and should not be interpreted as differences between resins or orientations.

## Discussion

This pilot study used micro-CT to characterize the internal microstructure of two 3D-printed denture base resins under different build orientations. All specimens showed good structural integrity, with no microcracks, fractures, inclusions, contamination, or interlayer delamination detected within the resolution limits of the micro-CT protocol, and very low porosity.

These findings contrast with reports of particle agglomeration and irregular filler distribution in some 3D-printed dental resins, which may translate into microstructural heterogeneity.[17] However, those materials differ from the resins studied here, precluding direct comparison. Denture 3D Plus has been described as offering mechanical performance comparable to conventional acrylics, although specific data on its internal microstructure are lacking.[9] Additionally, printing parameters and post-curing strongly influence internal defects in printed

**Table 2. ROI dimensions and analyzed volume per specimen (after cropping). Parameters processed using Dragonfly software.**

| Dimension | NextDent Denture 3D Plus 0° | NextDent Denture 3D Plus 45° | NextDent Denture 3D Plus 90° | NextDent Base 90° |
|---|---|---|---|---|
| **Width** | 669 px (2.70 mm) | 807 px (3.26 mm) | 503 px (2.03 mm) | 811 px (3.28 mm) |
| **Height** | 660 px (2.67 mm) | 515 px (2.08 mm) | 431 px (1.74 mm) | 465 px (1.88 mm) |
| **Depth** | 1013 px (4.10 mm) | 800 px (4.09 mm) | 810 px (3.28 mm) | 1013 px (4.10 mm) |
| **Total voxels** | 447 280 020 | 421 007 865 | 175 602 330 | 382 017 495 |
| **Volume** | 29.55 mm³ | 27.80 mm³ | 11.61 mm³ | 25.24 mm³ |

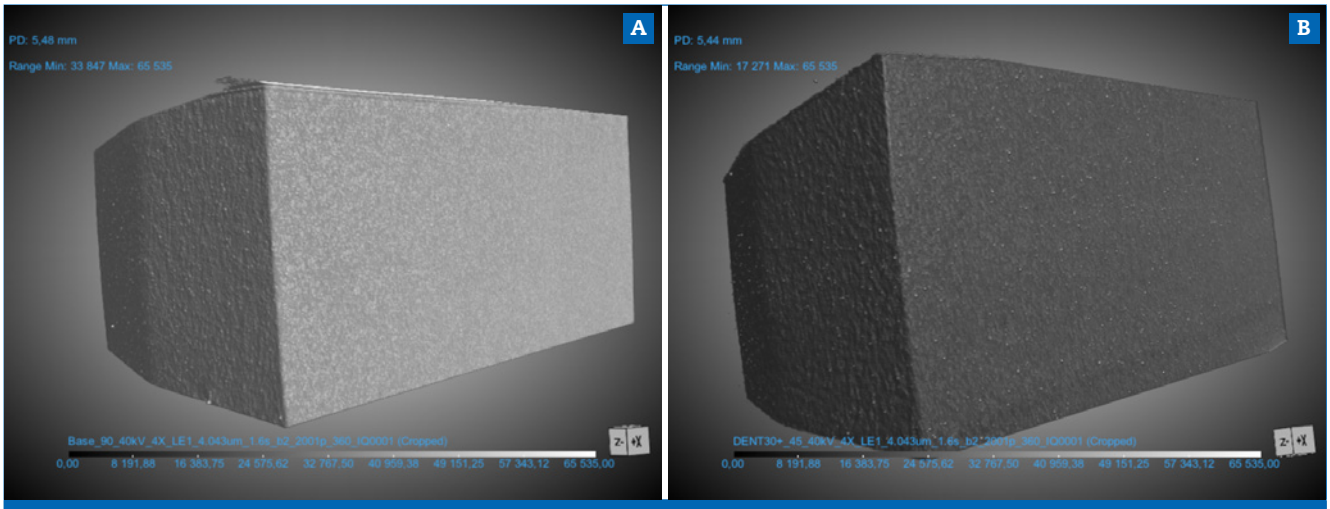


**Figure 2. Three-dimensional micro-CT renderings: (A) NextDent Base at 90°; (B) NextDent Denture 3D Plus at 45°.**

**Table 3. Pore voxels and porosity (volume %) per specimen. Results obtained after image segmentation and analysis.**

| | NextDent Base 90° | NextDent Denture 3D Plus 0° | NextDent Denture 3D Plus 45° | NextDent Denture 3D Plus 90° |
|---|---|---|---|---|
| **Voxels** | Not detected | 3622 | 236 | 497 |
| **Porosity** | Not detected | 0.001% | 0.0001% | 0.0003% |

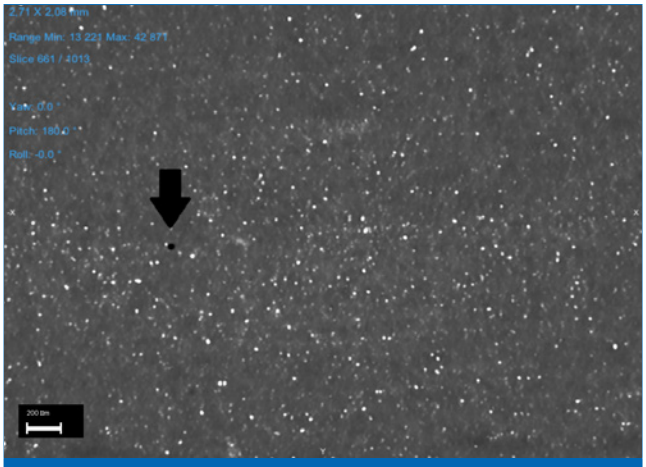

**Figure 3. Representative slice (NextDent Denture 3D Plus at 45°, slice 661/1013, 2.71 x 2.08 mm) showing pores in black (solid arrow) and radiopaque particles (white) within the matrix.**

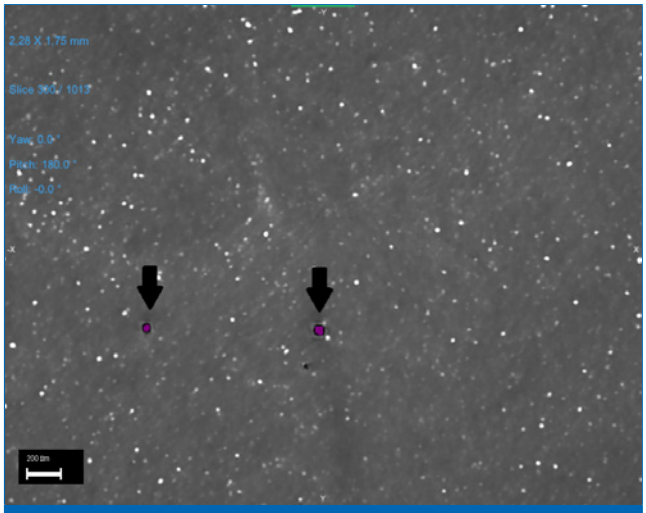

**Figure 4. Isolated pores in NextDent Denture 3D Plus at 0°, slice 300/1013, 2.28 x 1.75 mm (solid arrows).**

photopolymers.[9,14] Therefore, strict adherence to the manufacturer's protocols may partly explain the absence of detectable defects observed here.

Porosity is a key indicator of microstructural quality: a sound denture base should show few micropores and minimal air incorporation.[15,17] Clinically, porosity is associated with reduced mechanical strength, stress concentration, higher fracture risk, and impaired dimensional stability. Biologically, porosity favors biofilm and Candida albicans retention, increasing the risk of denture stomatitis.[10,13-15,19,21] Greater porosity also increases water sorption, promoting hydrolytic degradation and plasticization, and impairs color stability and surface gloss.[15,22] The very low porosity observed is a favorable feature. However, the present study did not evaluate mechanical strength, water sorption, aging behavior, surface roughness, microbial adhesion, or clinical

Table 4. Particle voxels and particle volume per specimen. Volume fractions are computed over each specimen's ROI; because ROI volumes differ (Table 2), fractions are not directly comparable across specimens.

| | NextDent Base 90° | NextDent Denture 3D Plus 0° | NextDent Denture 3D Plus 45° | NextDent Denture 3D Plus 90° |
|---|---|---|---|---|
| **Voxels** | 6 305 405 | 2 597 575 | 5 310 326 | 2 671 383 |
| **Volume** | 0.42 mm³ (1.65%) | 0.17 mm³ (0.58%) | 0.35 mm³ (1.26%) | 0.18 mm³ (1.52%) |

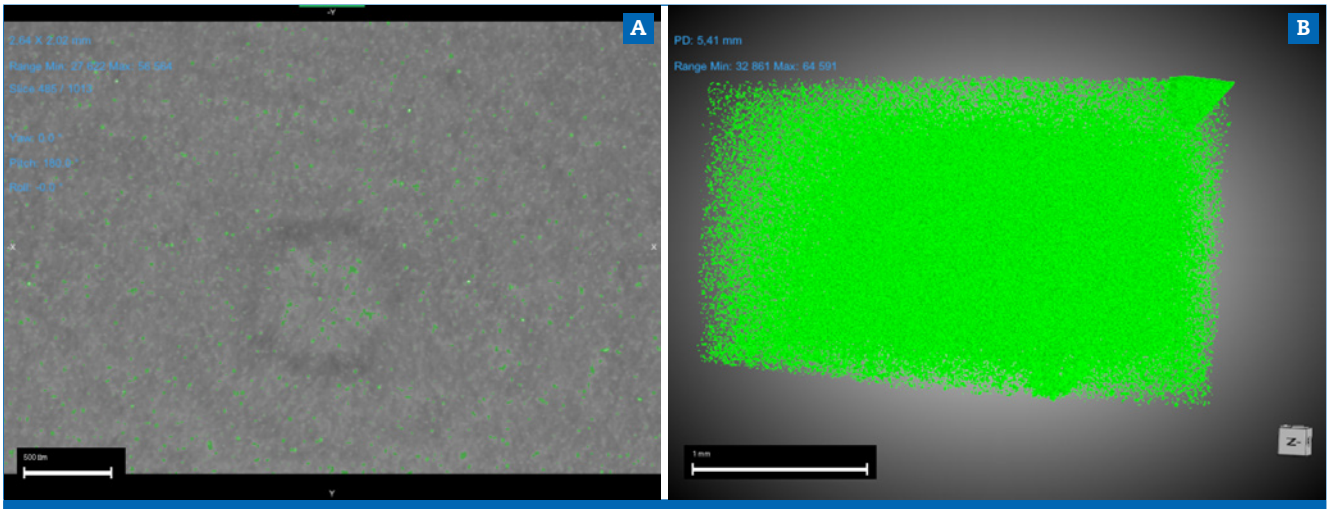


**Figure 5. Particle distribution in NextDent Base at 90°: (A) Representative 2D cross section, slice 485/1013, 2.64 x 2.02 mm; (B) 3D view. Particles are highlighted in green.**

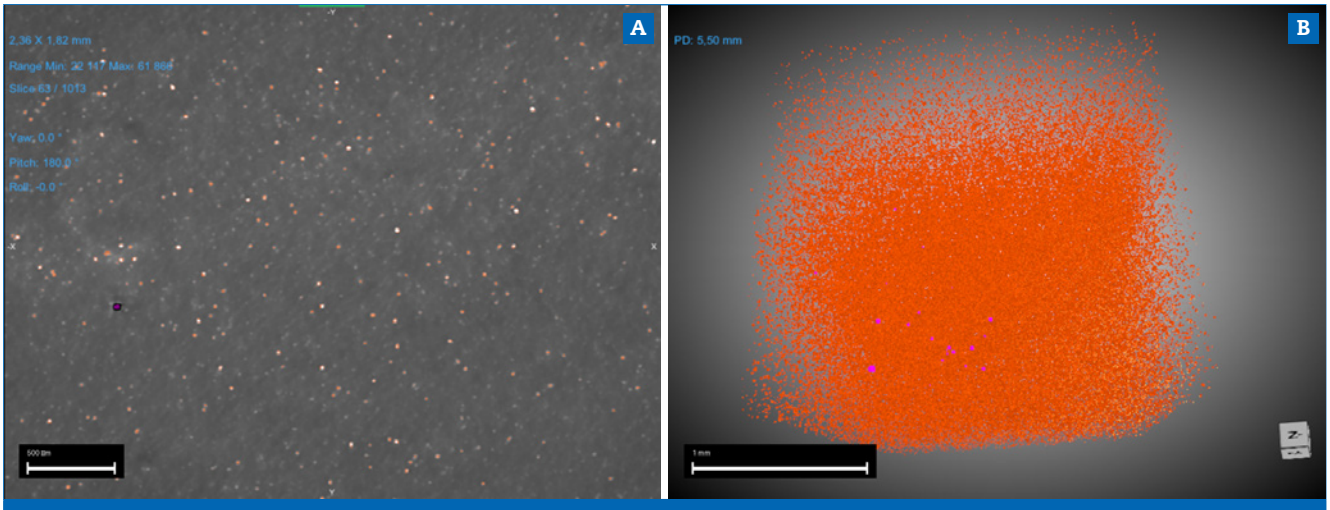


**Figure 6. Particle distribution in NextDent Denture 3D Plus at 0°: (A) Representative 2D cross section, slice 63/1013, 2.36 x 1.82 mm; (B) 3D view. Particles are highlighted in orange.**

performance. Therefore, the findings should not be interpreted as evidence of clinical superiority or long-term durability.

Micro-CT visualizes density, porosity, inclusions, and particle distribution, but it cannot identify chemical composition; complementary techniques such as SEM, FTIR, or Raman spectroscopy would be required for that purpose.[17,23] In this study, radiopaque particles, presumed to correspond to inorganic filler or opacifying components, were observed; however, their chemical composition could not be confirmed by micro-CT. No orientation-related heterogeneity was apparent, contrary to the interlayer defects and anisotropy frequently reported for printed resins.[14,16] A plausible explanation may lie in the material composition: both resins are rich in Bis-EMA — which

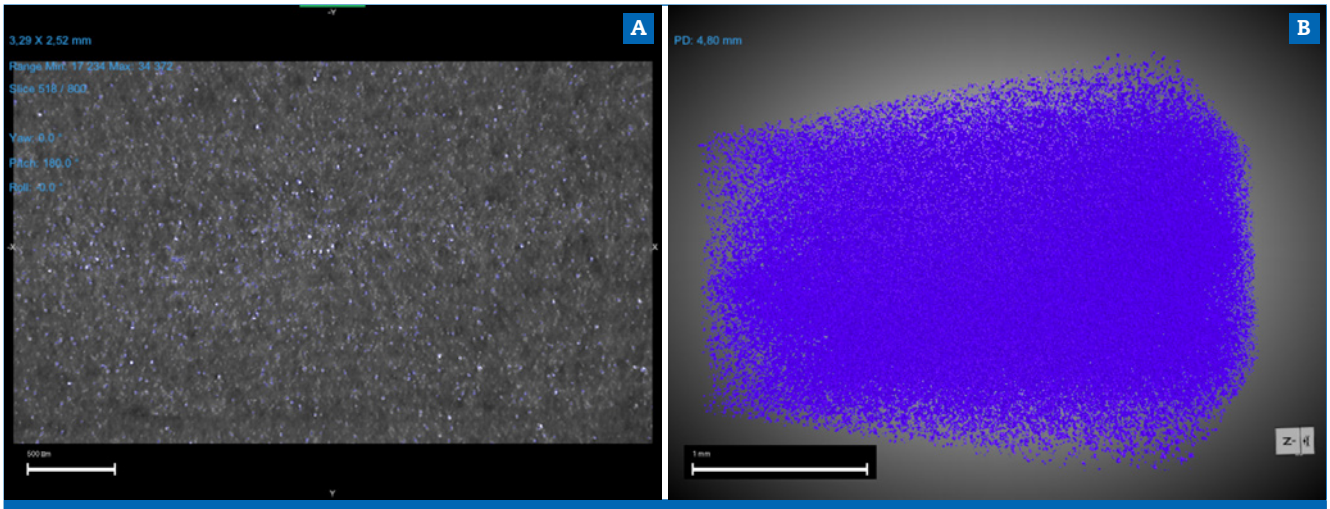


**Figure 7. Particle distribution in NextDent Denture 3D Plus at 45°: (A) Representative 2D cross section, slice 518/800, 3.29 x 2.52 mm; (B) 3D view. Particles are highlighted in blue.**

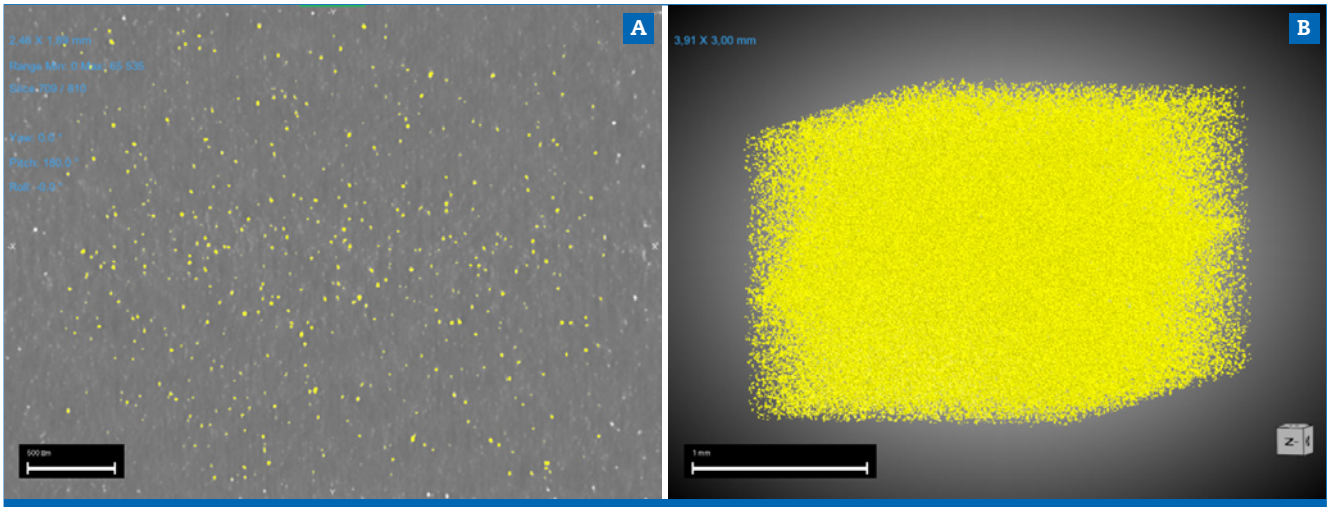


**Figure 8. Particle distribution in NextDent Denture 3D Plus at 90°: (A) Representative 2D cross section, slice 709/810, 2.46 x 1.89 mm; (B) 3D view. Particles are highlighted in yellow.**

reduces polymerization shrinkage and confers rigidity — and contain UDMA derivatives that increase crosslinking, together limiting voids and interlayer stresses.[9,24] In the Base specimen, the limited contrast between matrix and potential voids may have hampered pore detection; therefore, very small or low-contrast pores cannot be excluded.

The single-specimen-per-group design precludes any statistical inference and limits generalisability, and the differing, non-standardized ROI volumes make particle volume fractions non-comparable. This design is a limitation of the study because within-group variability could not be assessed. Moreover, only one commercial brand was studied, with Denture 3D Plus being a more recent evolution of Base, which may explain their similarity. Another limitation of this study is the use of a single LCD printer and the manufacturer's parameters, so the results should not be extrapolated to other technologies or settings. Build orientation was explored only for Denture 3D Plus, and Base was evaluated only at 90°; thus, orientation-related observations apply solely to Denture 3D Plus and cannot be generalized to both materials. Finally, thresholding segmentation is operator- and parameter-dependent. A limitation of the present study is that segmentation robustness was not assessed through repeated analyses using slightly varied threshold values or by independent verification by a second trained examiner; future investigations should consider these approaches.

Future studies should include adequate sample sizes, multiple brands and technologies, artificial aging and thermal cycling, and should combine micro-CT with SEM, FTIR, and Raman spectroscopy, correlating microstructure with mechanical properties and, ultimately, with in vivo clinical performance.

## Conclusions

Within the limitations of this single-specimen-per-group pilot design, the scanned specimens showed no detectable internal defects and very low porosity. These findings should be interpreted as preliminary micro-CT observations rather than evidence of equivalence between resins or build orientations. Controlled studies with an adequate sample size, standardized ROIs, and validated segmentation protocols are required to draw material- or orientation-related conclusions.

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## Conflict of interest

The authors have no conflicts of interest to declare.

## Ethical disclosures

**Protection of human and animal subjects.** The authors declare that no experiments were performed on humans or animals for this study.

**Confidentiality of data.** The authors declare that no patient data appear in this article.

**Right to privacy and informed consent.** The authors declare that no patient data appear in this article.

## CRediT authorship contribution statement

**Pedro Norton:** Conceptualization; Formal analysis; Investigation; Methodology; Writing – original draft; Writing – review & editing. **Maria Helena Figueiral:** Formal analysis; Investigation; Project administration; Resources; Supervision; Validation; Visualization; Writing – review & editing. **Manuel António Sampaio-Fernandes:** Data curation; Formal analysis; Methodology; Project administration; Validation; Writing – review & editing.

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## Caracterização por microtomografia de resinas para bases protéticas impressas tridimensionalmente: estudo piloto descritivo *in vitro*

RESUMO

***Objetivos:*** Caracterizar, por microtomografia computorizada, os defeitos internos, a porosidade e a distribuição de partículas radiopacas em duas resinas fotopolimerizáveis para bases protéticas impressas tridimensionalmente (NextDent Denture 3D Plus e NextDent Base) e explorar descritivamente a influência da orientação de impressão (0°, 45° e 90°) na resina Denture 3D Plus.
***Métodos:*** Neste estudo piloto descritivo *in vitro*, foram concebidos provetes padronizados (10×10×2 mm) no programa Meshmixer e impressos por tecnologia de ecrã de cristais líquidos (LCD). A resina Denture 3D Plus foi impressa a 0°, 45° e 90°, e a NextDent Base a 90°. Um de cada três provetes por grupo foi selecionado aleatoriamente para análise por microtomografia computorizada. Os volumes reconstruídos foram segmentados para avaliar defeitos internos, porosidade e volume de partículas radiopacas. Os dados foram analisados descritivamente.
***Resultados:*** Não foram detetadas microfissuras, fraturas, inclusões, contaminação ou delaminação entre camadas, dentro dos limites de resolução do protocolo de aquisição. A porosidade foi inferior ao limiar de deteção na resina NextDent Base a 90° e muito baixa na resina Denture 3D Plus a 0° (0,001%), 45° (0,0001%) e 90° (0,0003%). As partículas radiopacas encontravam-se dispersas na matriz da resina. Como as regiões de interesse analisadas apresentavam volumes diferentes, as frações volumétricas das partículas não eram diretamente comparáveis, não sendo possível inferir qualquer tendência relacionada com a orientação de impressão.
***Conclusões:*** Considerando as limitações deste estudo piloto com um único provete por grupo, os provetes analisados não apresentaram defeitos internos detetáveis e revelaram porosidade muito baixa. Estes resultados devem ser interpretados como observações preliminares de microtomografia computorizada. São necessários estudos controlados, com tamanhos amostrais adequados, regiões de interesse padronizadas e protocolos de segmentação validados, antes de se poderem estabelecer conclusões relacionadas com o material ou com a orientação de impressão. (Rev Port Estomatol Med Dent Cir Maxilofac. 2026;67(x):xxx-xxx)



***Palavras-chave:***
Materiais dentários
Bases de prótese
Técnicas *in vitro*
Porosidade
Impressão tridimensional
Microtomografia por raio-X