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3D printing

international magazine of dental 3D-printing technology

opinion
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Dr George Freedman

Editor-in-chief

3D printing and artificial intelligence

3D printing, or additive manufacturing (AM), is reshaping the dental industry. It is one of the first technological approaches to mirror additive processes observed in nature, such as botanical growth and animal maturation and repair. Artificial intelligence (AI) can strategise and optimise AM methods from design to simulation and extend to real-time operational control for process management and detection of anomalies. Integrating AI within AM can enhance productivity, quality and innovation throughout the manufacturing process, all significant advantages. It is important to note, however, that a thorough understanding of both the AI parameters and the specific AM objectives is a prerequisite to merging these systems.

AI can functionally reorganise product design because it reduces manufacturing complexity and rationalises material usage while concurrently accelerating production. The earlier AI is incorporated into the process, the more successfully it can implement performance optimisation. Typical AM quality control is completely dependent on post-production inspection; AI quality control is predictive and proactive, resolving issues before production, thereby minimising waste and inefficiencies. It is also the role of AI to pre-analyse data and workflows to eliminate bottlenecks while increasing operational efficiency. AI can also plan production and post-production to boost efficiency and yield.

While the dental profession has been focused on the AM of laboratory products and, more recently, dental restorations, these are merely a drop in the bucket of near-future applications. After all, AM can utilise a wide variety of dental substrate materials. Resins and resin composites are well established. Ceramics and metals are somewhat more complicated, but they too are beginning to make their industrial mark. The utilisation of polymer–metal blends offers high-precision manufacturing, longevity and biocompatibility for implants, joints and other high-stress applications. The specific relationships involved (and the exacting AM steps required) are clearly within the scope of AI. The emerging field of biomaterials, involving hydrogels and bioinks for bioprinting tissue scaffolds and related medical products, is definitively an area where AM and AI must be utilised in tandem.

Since AM is a relatively new field, quality assurance in the absence of established clinical data is enormously important. AI computer vision automates defect detection and provides quality control during the active printing process. Similarly, reinforcement learning optimises complex workflows by the application of adaptive learning techniques. Most significantly, AI can reduce production time and material waste by analysing manufacturing data and suggesting procedural refinements prior to starting or in the midst of the process thereby enhancing quality assurance by preventing defects and ensuring consistency. Topology optimisation refines lattice structures for strength and weight efficiency. Finally (for now, at least), finite element analysis evaluates material properties and structural integrity under various conditions, accurately predicting the success and longevity of the restoration, thereby significantly reducing or eliminating the possibility of clinical failure.

Continued advancement in AM technology and materials will be driven by AI considerations and predictive assessments. In the same breath, AI will continue to advance collaboratively with AM to realise the profession's full potential in transforming production processes for the benefit of patients. It is essential that there is an open and comprehensive communication process among dentists, laboratory technicians, software and hardware developers, industry partners and the media in keeping every member of the community informed and up to date.

There will be a meeting of the International Academy for Dental 3D Printing (iad3dp.org) together with members of the Dental AI Association (www.dentalaia.org) at the 2025 International Dental Show in Cologne in Germany, to further this dialogue. It will take place on 26 March at 17:00 at the DTI Media Lounge (Booth D050–E051) in Hall 4.1.

Dr George Freedman
Editor-in-chief

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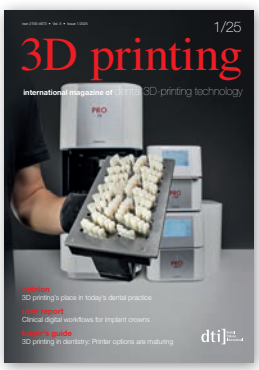

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3D-printed ceramics show promise for dental restorations

Dental Tribune International

Additive manufacturing is gaining traction as an alternative to milling for fabrication of ceramic restorations. However, experimental and clinical data on the mechanical properties and overall performance of 3D-printed ceramics remain limited. A recent systematic review has provided new insights into this issue and reported significant improvements in the mechanical properties of 3D-printed ceramics. However, the authors have cautioned that factors such as long-term reliability, the impact of printing layer orientation and overall clinical performance require further investigation.

© João Paulo Mendes Tribst

Co-author Dr João Paulo Mendes Tribst believes that 3D-printed ceramics could become a viable alternative to milling.

Milling has several limitations, including restricted ability to replicate intricate geometries, significant material wastage, potential formation of microcracks that weaken restorations and frequent wear of milling tools. Additionally, milling offers limited efficiency in mass production. 3D printing, however, offers the ability to produce complex geometries with greater efficiency while reducing material waste. Despite these advantages, the application of ceramic materials in 3D printing remains limited. A primary concern is the mechanical performance of 3D-printed ceramics, as their clinical success depends on factors such as initial strength and resistance to humidity, fatigue and occlusal wear in the oral environment.

"The rapid advancements in additive manufacturing for dental restorations, particularly ceramics, prompted my team to explore the topic further. With the growing interest in 3D-printing technologies, we aimed to evaluate whether 3D-printed ceramics could match or even exceed the mechanical properties of conventionally produced ceramics. Ultimately, our goal is to develop durable, long-lasting restorations for our patients," co-author Dr João Paulo Mendes Tribst, head of the section of restorative and reconstructive oral care at Academic Centre for Dentistry in Amsterdam, told Dental Tribune International.

The systematic review included 40 studies examining ceramic materials such as zirconia, alumina, alumina–zirconia composites, lithium disilicate, porcelain and fluorapatite glass-ceramic. Researchers evaluated the mechanical properties of 3D-printed ceramics based on material type and processing technique, focusing on key factors such as density, flexural strength, fracture toughness, Young's modulus, hardness and overall performance. Additionally, the studies examined common processing defects, including porosity, agglomerates, cracks and surface roughness.

Mechanical properties show improvement but reliability issues persist

The findings indicate a general improvement in the mechanical properties of 3D-printed ceramics, bringing them closer to the performance of milled ceramics. However, the authors of the review noted that 3D-printed ceramics still exhibit less reliability compared with milled ceramics. The mechanical properties of the ceramics also varied greatly depending on the specific 3D-printing technique, composition of the material and post-processing treatments used. Among the materials studied, 3Y-TZP emerged as the most developed and studied 3D-printed ceramic.

"We observed an upward trend in mechanical strength across various ceramic materials, including zirconia, alumina, lithium disilicate and glass-ceramics. However, we identified significant defects in 3D-printed restorations not present in milled ones, such as porosity, cracks and layer orientation issues, which affect fatigue performance. Therefore, it is important to consider how the restoration will be produced based on its intended use in the mouth," Dr Tribst explained. "Our findings suggest that 3D-printed ceramics hold great potential for dental restorations, particularly for customised prostheses. With further improvements in processing techniques, they could become a viable alternative to milling, offering greater design flexibility while reducing material waste," Dr Tribst said.

The study concluded that, while additive manufacturing presents exciting opportunities for advancing dental restoration techniques, further research and development are essential to address current limitations and fully integrate 3D-printed ceramics into clinical practice.

Editorial note: The study, titled "Additive-manufactured ceramics for dental restorations: A systematic review on mechanical perspective", was published online on 10 February 2025 in Frontiers in Dental Medicine.

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Systematic review compares flexural strength of 3D-printed prostheses

Dental Tribune International

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Researchers have found that stereolithography and selective laser sintering provide the greatest flexural strength in 3D-printed provisional fixed dental prostheses.

As the use of 3D printers in dental clinics and laboratories increases, dental teams must navigate the various additive manufacturing technologies and decide which is best for their work. A recent systematic review and network meta-analysis by researchers at Recep Tayyip Erdoğan University in Rize has compared the flexural strength of provisional fixed dental prostheses made using different 3D-printing technologies. The results provide useful insights for dental professionals regarding which is most suitable for producing durable restorations.

The researchers selected 11 *in vitro* studies, nine of them further contributing to the network meta-analysis. All the studies provided detailed and comparable 3D-printing parameters, such as layer thickness, printing angle and post-polymerisation protocols. The 3D-printing technologies used in the selected studies were stereolithography (SLA), liquid crystal display (LCD), selective laser sintering (SLS), digital light synthesis (DLS), fused deposition modelling (FDM) and digital light processing (DLP).

The ranking of these 3D-printing technologies according to flexural strength showed that SLS performed the best, followed by SLA. DLS and FDM offered moderate strength, and LCD and DLP, the weakest. These results indicate that SLS and SLA are the preferred choices for the fabrication of stronger and more durable provisional restorations and that restorations manufactured using LCD and DLP may be more prone to fracture under stress.

The various 3D-printing technologies have advantages and limitations that can influence their suitability for specific clinical applications. SLA and SLS offer superior flexural strength owing to their ability to produce dense, homogeneous structures with minimal microstructural defects, enhancing mechanical durability and fracture resistance. Although SLA achieves high precision and surface quality, it requires thorough post-polymerisation, whereas SLS provides the highest flexural strength but has high costs and complex powder handling requirements. In contrast, DLP and LCD offer faster printing speeds and affordability, but their prints may have microvoids, weaker interlayer bonding and lower durability. The most economical option, FDM produces prints with lower surface quality and flexural strength, making it less suitable for demanding clinical applications.

In discussing the results, the authors commented that a comparison between additive and subtractive methods of manufacturing provisional fixed dental prostheses provides context to the results of the study. They highlighted a 2023 study that emphasised that PMMA resins for milling exhibited better mechanical properties than 3D-printing resins did. A systematic review from the same year found that, compared with subtractive techniques, 3D-printing technologies produced prostheses with lower resistance to mechanical pressure, the authors pointed out. They emphasised that "the versatility and cost-effectiveness of 3D printing, however, make it an attractive option for cases requiring rapid fabrication or unique geometries".

The authors noted that their findings corroborate the evidence supporting the use of SLA and SLS systems. However, they also cautioned that "further studies are necessary to validate these findings under standardised and clinically relevant conditions, ensuring that each technology is evaluated using consistent parameters and materials".

Editorial note: The study, titled "Effect of different 3D-printing systems on the flexural strength of provisional fixed dental prostheses: A systematic review and network meta-analysis of in vitro studies", was published online on 16 January 2025 in BMC Oral Health.

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