

MECHANICAL PROPERTIES OF 3D PRINTED AND MILLED SPACE MAINTAINERS USED IN PREVENTIVE ORTHODONTICS

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ABSTRACT

Aim of the study: This study aimed to evaluate the mechanical strength, when subjected to compressive forces, of aesthetic space maintainers manufactured through various digitally-assisted methods specifically, additive techniques (LCD and SLA) and subtractive milling. **Materials and methods:** Space maintainer designs were digitally modelled in Exocad and then produced by LCD printing using TC100 resin and plant-based Anycubic resin, by stereolithography (SLA) printing using Next Dent and Harz Labs resins, and by a subtractive technique using Tempo Block PMMA milling discs (Sid Dental). All samples underwent compression testing using the Zwick/Roell Z 005 machine. **Results:** A one-way ANOVA statistical test revealed significant differences in the compression breaking force among the four groups with milled samples showing a significantly higher strength than all 3D printed samples (LCD, SLA_Harz, and SLA_Next). Tukey post hoc tests confirmed these differences ($p < 0.001$), while no significant differences were found among the 3D printed groups. The soy-based Anycubic resin samples exhibited high elasticity, leading to deformation without fracture, and were excluded from the study due to their inability to properly maintain the mesiodistal space. **Conclusions:** Beyond the aesthetic benefit, the milled space maintainers proved to offer a substantial advantage in terms of mechanical strength over those fabricated with additive printing techniques (LCD and SLA), making the subtractive manufacturing technique more suitable for clinical applications that involve higher mechanical stress.

Key words: preventive orthodontics, space maintainers, milled, 3D printed, metal-free, mechanical strength

INTRODUCTION

Space maintainers play a vital role in preventive orthodontics by holding the space for permanent teeth after the premature loss of primary molars [1,2]. The advancement of digital technology has led to the development of both 3D printing and milling techniques to enhance the mechanical properties, biocompatibility, and patients' acceptance of these devices [3].

Traditionally, space maintainers are comprised of soldered metal components such

as stainless-steel bands and wires, following the most common band-and-loop design. This method requires dental impressions and the involvement of a dental lab technician [4]. However, digital dentistry uses CAD/CAM (computer-aided design and manufacturing) to create precise, custom-fit devices from advanced materials like resin and zirconia [5].

3D printed space maintainers, made from materials such as biocompatible resins and PEEK (polyether ether ketone), exhibit high mechanical strength, dimensional stability,

and biocompatibility, making them suitable for children [6,7]. Studies show that 3D printed materials like E-Guard have adequate flexural strength and elasticity, though their retention strength is lower than traditional stainless-steel bands [8].

Milled space maintainers, especially those fabricated from zirconia, offer notable mechanical benefits. A fully digital workflow can produce zirconia devices with high mechanical performance, as well as improved aesthetics and biocompatibility [9]. CAD/CAM technology further ensures an accurate fit, minimizing human error during production [9].

Nevertheless, for 3D printed space maintainers, enhancing retention strength and ensuring long-term durability remain areas for future research [5]. For milled devices, refining digital workflows and reducing production costs are important goals [9]. Further clinical studies are needed to validate the effectiveness and success rates of these modern technologies.

Overall, space maintainers help prevent malocclusion by preserving arch length and preventing tooth migration, potentially reducing the need for extensive orthodontic treatment [10]. They may also offer a cost-effective approach by lowering future orthodontic expenses [11,12]. Technological advancements in digital space maintainers improve device precision and comfort, boosting patient compliance and reducing chairside time [13,14,15].

However, space maintainers have some drawbacks, such as an increased risk of plaque buildup, cavities, gum inflammation, and soft tissue irritation [16]. These devices can interfere with the eruption of adjacent teeth and may break or dislodge, requiring frequent adjustments or replacements [16]. Additionally, there is limited scientific evidence on their overall clinical effectiveness, cost-efficiency, and patient satisfaction.

Traditional designs, like the band-and-loop design, can lead to enamel demineralization of adjacent teeth and can present a risk of metal allergies [17]. In aesthetic applications, particularly in the anterior teeth, fixed space maintainers can face medium- to long-term complications, such as resin tooth fractures, welding fractures, and gingivitis, especially in younger patients [18].

Aim of the study

The purpose of the study was to compare the mechanical strength under compression forces of aesthetic space maintainers obtained through digital fabrication techniques, using additive stereolithography (SLA) and LCD techniques, as well as subtractive methods.

MATERIALS AND METHODS

For this study, we selected the clinical case of an 8-year-old patient who prematurely lost 7.5 and 8.4 because of extensive carious processes with periapical pathology. After the digital scanning of the dental casts, the design of the space maintainers was digitally modelled in Exocad. Based on the exported .stl files, 28 space maintainers were printed with two additive techniques (seven space maintainers in each group): the LCD technique, using Phrozen Sonic Mini 4K printer, and two types of resins (TC100 Temporary Crown & Bridge Resin and the plant-based Anycubic UV resin), and the stereolithography (SLA) technique, using the Formlabs Form 2 printer and two types of resins (Next Dent C&B Micro Filled Hybrid resin and Harz Labs Dental Bleach colour resin). Using the subtractive technique, seven space maintainers were milled from Tempo Block PMMA discs in D3 colour with a 5-axis milling machine PrograMill PM7.

After printing, all samples were placed in an isopropyl alcohol bath to clean off the excess resin and any remaining residue, then placed in a UV oven for curing. Seven samples

from each category, were subjected to compression forces shortly after fabrication.

The dental space maintainers were placed on a 3D printed mandibular study model created using Fused Deposition Modelling (FDM) from thermoplastic polymer (Fig. 1).

To evaluate the mechanical strength, the Zwick/Roell Z 005 machine was used, which applied a constant force through a plastic spatula on the arms of the space maintainers (Fig. 2), until the devices fractured (Fig. 3).

Following the mechanical tests, it was observed that the samples made from soy-based Anycubic resin exhibit an increased modulus of elasticity, which lead to sample deformation without causing fracture. The testing was stopped by the operator when the horizontal arms of the device came into contact with the support base (Fig. 4). The compression test did not result in the fracture of the devices, demonstrating their inability to properly maintain the mesiodistal space. Therefore, we considered them not suitable for

clinical applications, and they were excluded from the study.

Statistical analysis

For the statistical analysis, the data was analysed using IBM SPSS Statistics for Windows software (Version 25.0. Armonk, NY: IBM Corp).

There were no outliers in the data, as assessed by inspection of a boxplot. The data was normally distributed, as assessed by Shapiro-Wilk's test ($p > 0.05$). There was homogeneity of variances, as assessed by Levene's test for equality of variances ($p > 0.05$).

One-way ANOVA was used to determine if the compression breaking force was different between the four groups. In order to determine which specific groups differed from each other, a Tukey post hoc analysis was conducted. The level of significance was set at $p < 0.05$.



Figure 1. 3D printed space maintainers placed on the dental cast.



Figure 2. Compression load testing using the Zwick/Roell Z 005 machine.



Figure 3. Fractured space maintainer after compression load testing.

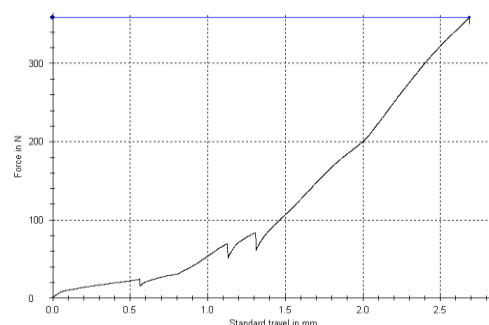


Figure 4. Displacement diagram for the compression test of Anycubic resin.

RESULTS AND DISCUSSIONS

A boxplot diagram showing the distribution of compression breaking force values (N) across the four groups is shown in Fig. 5. The descriptive statistics for the data are presented in Table 1.

One-way ANOVA demonstrated that the compression breaking force was statistically significantly different between the four manufacturing processes, $F(3,24) = 82.57$, $p < 0.001$. The compression breaking force increased from the LCD (68.54 ± 14.15), to SLA_Harz (81.78 ± 9.50), to SLA_Next

(95.52 ± 13.22), to Milled (199.94 ± 27.71) manufacturing process groups, in that order. Tukey post hoc analysis (Table 2) revealed that the increase in compression breaking force was statistically significant from the LCD to the Milled group (131.40 , $p < 0.001$), from the SLA_Harz to the Milled group (118.16 , $p < 0.001$), as well as from the SLA_Next to the Milled group (107.42 , $p < 0.001$). No statistically significant differences were observed between the 3D printed groups (LCD, SLA_Next and SLA_Hartz).

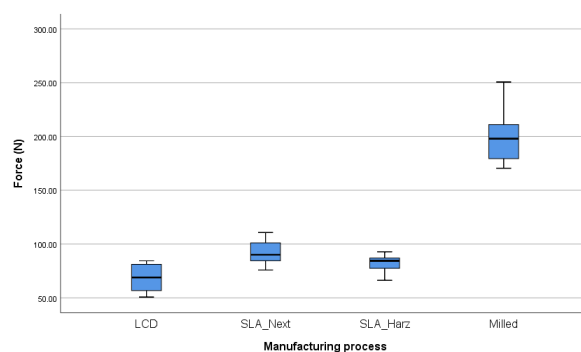


Figure 5. Boxplot diagram showing the distribution of compression breaking force values (N) across the four groups.

Table 1. Descriptive statistics for the compression breaking force (Newton).

Type of manufacturing process	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
LCD	7	68.54	14.15	5.35	55.46	81.62	50.73	84.40
SLA_Next	7	92.52	13.22	5.00	80.30	104.75	75.82	110.69
SLA_Harz	7	81.78	9.50	3.59	72.99	90.57	66.30	92.73
Milled	7	199.94	27.71	10.47	174.31	225.57	170.42	250.53

Table 2. Tukey post hoc analysis.

Multiple Comparisons							
Dependent Variable: Force (N)							
Tukey HSD	(I) Manufacturing process	(J) Manufacturing process	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
	SLA_Next	LCD	23.98	9.39	0.076	-1.91	49.87
		SLA_Harz	13.24	9.39	0.505	-12.65	39.13
	Milled	SLA_Next	-10.74	9.39	0.666	-36.63	15.15
		LCD	131.40	9.39	0.000*	105.51	157.29
		SLA_Next	107.42	9.39	0.000*	81.53	133.31
		SLA_Harz	118.16	9.39	0.000*	92.27	144.05

* $p < 0.001$.

In preventive orthodontics, space maintainers are critical for preserving dental arch length following early tooth loss [19]. This study highlights the development and comparative effectiveness of advanced digital manufacturing techniques for space maintainers, particularly 3D printing and milling techniques.

With the development of 3D printing technology, studies were carried out on printed dental space maintainers, which offer notable advantages in terms of customization, production efficiency, and patient comfort [20,21]. The custom fit achieved through digital techniques enhances clinical outcomes and reduces chairside time, contributing to patient satisfaction [5]. However, challenges remain in optimizing retention strength in 3D printed devices, which is generally lower than the retention provided by traditional metal space maintainers [8]. Additionally, milled zirconia maintainers offer exceptional mechanical durability and aesthetic benefits, positioning them as a strong alternative to metal maintainers [3]. Nevertheless, digital methods require improvements to streamline workflows and to further reduce costs.

A study by Rodrigues et al. [22] aligns with this research regarding the procedure for fabricating space maintainers using milling technology. The authors presented a fully digital workflow protocol for creating these devices, involving intraoral scanning before extracting the primary tooth, designing the device digitally, and fabricating it with a 5-axis milling machine (CAM PM7; Ivoclar AG). The space maintainer was milled from polymethyl methacrylate (PMMA), allowing for the immediate post-extraction cementation [22].

A similar study by N. Aktaş et al. [23] assessed the fracture resistance of space maintainers printed from PEEK, resin and metal. The highest maximum load was

observed in the 3D printed metal group, reaching 145.43 N, with significantly higher fracture resistance compared to the other groups ($p < 0.05$). In contrast, the lowest fracture resistance was recorded in the 3D printed resin group, with a value of 84.41 N. The maximum load capacities for the 3D printed PEEK, conventional, and 3D printed resin groups were 41.50 N, 63.40 N, and 84.41 N, respectively, with no statistically significant differences among these three groups. In comparison, our study found fracture resistance values for resin-printed maintainers ranging between 68.54 N (LCD) and 92.52 N (SLA_Next), without any statistically significant differences between the printed groups ($p < 0.001$).

Soni et al. [24] developed a ceramic space maintainer (BruxZir) that appears to be a viable alternative to the traditional band-and-loop space maintainers. BruxZir, a CAD/CAM-manufactured device, offers high strength due to its monolithic design. In contrast, we manufactured the milled space maintainers using Tempo Block PMMA discs, which achieved a fracture resistance of 199.94 N. Statistically significant differences were observed when comparing these results with those from the 3D printed groups. We observed an increase in compressive breaking force between the LCD and Milled group (131.40 N), between the SLA_Harz and Milled group (118.16 N), and between the SLA_Next and Milled group (107.42 N).

Compared to conventionally manufactured PMMA space maintainers, CAD-CAM PMMA space maintainers showed higher durability and mechanical resistance [25,26]. 3D printed space maintainers have the advantage of higher production rates and at lower production costs [27]. However, 5-axis milling machines proved to be more precise in the manufacturing process of resin devices [28], these findings being consistent with the

present study.

Regarding the fabrication of removable space maintainers (RSMs), Hui Guo et al. [29] conducted a study using the same technology – a 5-axis numerical-control milling machine (Organical Multi, R + K GmbH, Germany) – to produce RSMs from polyetheretherketone (PEEK). They concluded that digital design and manufacturing streamlined the production process, minimized deformation and errors, and enhanced the overall quality of the RSMs.

Other authors such as Pawar [20] and Khanna [30] used SLS technology to manufacture band-and-loop space maintainers from titanium-based powdered materials. Similarly, Tokuc [31] assessed the band fit of metal space maintainers made with SLS 3D printing, finding no significant differences in the fit between conventional and 3D printed metal band-and-loop maintainers. While space maintainers made from 3D printable metals like CoCr and titanium alloys appear clinically suitable, these materials are often described as rigid and lacking in aesthetics (Tsolakis et al. [32] Zarean et al. [5]).

Bite force can be influenced by several factors such as gender, age, periodontal status, temporomandibular or muscular disorders, and parafunctions, like bruxism. Among children, bite forces ranged from 12.61 N to 353.64 N, with an average value of 196.60 N [33].

Braun et al. [34] reported that the maximum bite force was 78 N between 6 to 8 years of age. On the contrary, Karunakaran et al. [35] reported significantly higher maximum bite forces of 351.5 N, in the control group, recorded on the posterior teeth, bite forces of

281.7 N in the group that had cavities on the posterior teeth, 181.1 N in the crossbite group, and 250.2 N in children with bruxism. In typical conditions, both 3D printing and milling techniques can be used to create aesthetic dental space maintainers, if the bite forces range from 70 to 176 N, as reported by Gale [36]. However, under higher forces or during the accidental interposition of harder objects between the dental arches, the fracture of the space maintainers may occur.

The literature suggests that the main cause of the failure of 3D printed materials is the fracture caused by cyclic loading and aging. After artificial aging (equivalent to 1 year), fracture resistance in resin 3D printed materials tends to decline, which may limit their long-term clinical use [37]. Properties like rigidity and mechanical strength influence the fracture strength of these materials [26].

Despite the advances made in digital fabrication technologies, there may still be some limitations. In clinical practice, there is a need for comprehensive studies to assess the long-term durability and retention strength of 3D printed space maintainers.

CONCLUSIONS

Beyond the aesthetic benefit, the milled space maintainers proved to offer a substantial advantage in terms of mechanical strength over those fabricated with additive printing techniques (LCD and SLA), making the subtractive manufacturing technique more suitable for clinical applications that involve higher mechanical stress.

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