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COMPARATIVE EVALUATION OF COMPRESSIVE STRENGTH OF 3D-PRINTED RESIN AND POLYLACTIC ACID: AN IN-VITRO STUDY

Dr Aswathi R[1*], Dr Vishnu Rekha Chamarthi[2], Dr Santham Krishnamoorthy[3], Dr Dhanraj Kalaivanan[4], Dr Sumaiyya Saleem[5], Dr Santhosh Priya A K R[6], Dr Selvapriya Subbaraj[7]

[1*]Postgraduate student; Department of Pediatric and Preventive Dentistry, Sathyabama Dental College and Hospital, Chennai, Tamil Nadu, India. Email ID: aswathiaravind2018@gmail.com
[2]MDS; Professor and Head; Department of Pediatric and Preventive Dentistry, Sathyabama Dental College and Hospital, Chennai, Tamil Nadu, India. Email ID: drvishnurekha@yahoo.com
[3]MDS; Associate Professor; Department of Pediatric and Preventive Dentistry, Sathyabama Dental College and Hospital, Chennai, Tamil Nadu, India. Email ID: shanthamdent@gmail.com
[4]MDS; Associate Professor; Department of Pediatric and Preventive Dentistry, Sathyabama Dental College and Hospital, Chennai, Tamil Nadu, India. Email ID: dhanrajkalaivanan@gmail.com
[5]MDS; Professor (Assistant); Department of Pediatric and Preventive Dentistry, Sathyabama Dental College and Hospital, Chennai, Tamil Nadu, India. Email ID: sumaiyya.sms@gmail.com
[6]MDS; Professor (Assistant); Department of Pediatric and Preventive Dentistry, Sathyabama Dental College and Hospital, Chennai, Tamil Nadu, India. Email ID: santhosh.appiya@gmail.com
[7]MDS; Professor (Assistant); Department of Pediatric and Preventive Dentistry, Sathyabama Dental College and Hospital, Chennai, Tamil Nadu, India. Email ID: selvapriyasubbaraj1995@gmail.com
***Corresponding Author:** Email: aswathiaravind2018@gmail.com

ABSTRACT
Background: Three-dimensional (3D) printing has gained significant importance in dentistry for the fabrication of provisional restorations, study models, and auxiliary appliances. Among the commonly used materials, 3D printed resin and polylactic acid (PLA) are widely utilized. To ascertain their clinical applicability in dentistry, their mechanical characteristics, especially compressive strength, must be assessed. The study aimed to evaluate and compare the compressive strength of 3D printed resin and polylactic acid polymer materials. Materials and methods: 20 Cylindrical samples were made with 3D printed resin and polylactic acid and compressive strength was evaluated using universal testing machine. Shapiro–Wilk test was done for normality and intergroup comparison was done with independent sample t test. Results: The mean compressive strength of the 3D-printed resin group was higher than that of polylactic acid group. The difference between the two groups was statistically significant. Conclusion: The compressive strength of FDM-printed PLA was 28.90 ± 2.28. With material modifications and optimized printing parameters, its properties can be improved, making it a promising, customizable, and cost-effective option for pediatric dental applications.

KEYWORDS: 3D printing, Resin, Polylactic acid, compressive strength, Biodegradable polymer

INTRODUCTION
Three-dimensional printing (3DP), also referred to as additive manufacturing, has emerged as a leading technology in modern digital dentistry, enabling the precise and efficient fabrication of dental appliances and prostheses. The inception of this technology dates back to 1983, when Charles Hull created the first three-dimensional object using a 3D printer.1 Various materials have been introduced for 3D printing in dental application. Application of 3D printed resins in dentistry have been widely documented. Polylactic acid is a relatively new material introduced in 3D printing. Polylactic acid (PLA) is a highly crystalline, high–molecular weight polymer derived from renewable sources such as corn starch, sugarcane, potato starch, and tapioca starch.2 In the 1970s, PLA-based products were approved by the U.S. Food and Drug Administration (FDA) for direct contact with biological fluids.3 Because of biocompatibility, biodegradability, ease of fabrication, low cost, high transparency, flexibility, stiffness, thermoplastic behavior and excellent moldability resistance to acids and alkalis, and low energy demand for manufacturing make PLA popular. 2,3,4 Inside the human body, PLA degrades into lactic acid, which is metabolized into pyruvate and eventually excreted as carbon dioxide and water via the tricarboxylic acid cycle and the process takes between 12 and 30 months and upto 3 years in vitro and in vivo respectively.2 Since then, polylactic acid (PLA) has been widely utilized in diverse medical applications, including tissue engineering scaffolds for bone and cartilage regeneration, controlled drug delivery systems, and craniofacial implants.3 along with medical application PLA has been proposed for various dental applications such as dental prosthesis, temporary dental crowns, tooth extraction healing agent, orthodontic appliance, 3D printed membranes, guided tissue regeneration/ guided bone regeneration, Intracanal post. Its biodegradable property makes it a reliable restorative solution in pediatric dentistry until physiological root resorption of the tooth. Along with this, adequate compressive strength ensures resistance to fracture, enhances longevity, and maintains structural integrity making it a key factor in evaluating the clinical suitability

of dental materials. This study aims to comparatively evaluate the compressive strength of commercially available polylactic acid (Stratasys) and resin (Prestocraft) materials

METHODS

Cylindrical specimen of 25.4 mm length and 12.7 mm diameter based on ASTM D 695 Standard was designed in thinkercad app and that stl file (Figure1a) was used to print the samples.5 Sample size was estimated in G power software and decided to be 20 PLA samples (Figure 1b) and 20 resin samples (Figure 1c) in group 1 and group 2 respectively. Stratasys polylactic acid samples were printed in fused deposition printer Stratasys F 370 printer (Figure 2a) with printing parameters infill density 50%, nozzle diameter 0.6mm, infill pattern triangle. PrestoCraft resin samples were printed using digital light processing Elegoo printer (Figure 2b) at 45 degree6 orientation. All samples were tested for compressive strength using universal testing machine M 50 – UTM (Hitech Equipment India Pvt)(Figure 3). Compressive load was applied at a crosshead speed of 0.75 mm/min, and the values were recorded at the point of failure.7

Statistical analysis was carried out using IBM SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Test values were tabulated and Shapiro–Wilk test was done for normality and intergroup comparison was done with independent sample t test.

RESULT

Mean compressive strength of PLA and resin samples were 28.90 ± 2.28 and 498.31 ± 1.37 respectively (Table 1). An independent samples t-test was conducted to compare PLA values between the Resin and PLA groups. The resin group (Mean = 498.31, SD = 1.37, n = 20) demonstrated significantly higher values compared to the PLA group (Mean = 28.90, SD = 2.28, n = 20). The difference between groups was statistically significant, $t(38) = –790.04$, $p < 0.001$. The mean difference was –469.41 (95% CI: –470.62 to –468.21), indicating a substantial difference between the two materials.

DISCUSSION

With increasing concerns regarding material consumption and environmental pollution, subtractive manufacturing is being progressively replaced by additive manufacturing techniques for the fabrication of restorations using various 3D printing technologies. Compared to subtractive methods, additive manufacturing reduces material and energy consumption as well as tool wear.4 In FDM, products are fabricated via the extrusion of liquefied filaments or granules through a moving nozzle to layer materials on a scaffold. PLA samples were fabricated in FDM printer. A DLP printing system, which selectively polymerizes a photosensitive liquid resin layer by layer using a UV light projector, was used to create resin samples.8 Compared to DLP, FDM printer is more economical. In our study, we kept printing parameters infill density 50%, nozzle diameter 0.6mm, infill pattern triangle and mean compressive strength obtained was 28.90 ± 2.28 Mpa. In a study done my Mostafa Adel Hamed et al, with the same printing parameters, the compressive strength was 28.876 Mpa and highest compressive strength was found with 75% infill, concentric pattern, 0.6 mm nozzle diameter and 0.3 mm layer thickness.9 Girish K B et al obtained compressive strength of 35.91 MPa for PLA- calcium composite with the same printing parameters as ours and they found highest compressive strength at 80% infill density with triangular pattern.10 When Crenn et al. compared the mechanical properties including Young's modulus, flexural strength, microhardness, and fracture surface characteristics of PLA and interim resins such as Unifast®, Integrity®, and Temporary CB®, PLA exhibited lower mechanical properties than 3D printed SLA polymers but showed values comparable to auto polymerized acrylic resins and nanoparticle filled bisacrylic resins used for interim prostheses.11 Won Il Cho et al. evaluated and compared the mechanical properties of PLA and PMMA produced by subtractive manufacturing (PLA Mill and PMMA Mill) with PLA fabricated using fused deposition modeling and Bisphenol resin produced through stereolithography as additive manufacturing techniques.12 It was concluded that Bisphenol SLA was the most durable among the tested CAD CAM polymers, and FDM printed PLA displayed mechanical properties that fall within clinically acceptable limits. Re-Mee Doh et al assessed mechanical properties of PLA interim crowns with those of polymethylmethacrylate (PMMA) and bisphenol crowns after thermocycling.4 In their study PLA interim crowns demonstrated mechanical properties comparable to those of conventional PMMA and bisphenol crowns after thermocycling. These studies are contradictory to our study result where PLA samples had significantly lower compressive strength than Resin samples. Mizutani et al did an in vitro study to evaluate and compare the biodegradable polymers such as polyglycolic acid (PGA) and poly-L-lactic acid (PLLA) as post materials and results showed PGA and PLLA have bending strength and bending elastic modulus, similar to composite resins used for core build-up. Although both showed adequate hydrolysis, the hydrolysis rate of PGA was higher than that of PLLA and they suggested PGA and PLLA as a suitable biodegradable screw posts for primary teeth.13

Literature shows limited number of studies evaluating the clinical application of PLA. Hua Xu et al. compared the clinical performance of glass fibre and resorbable polylactic acid intracanal posts for the restoration of carious primary incisors in young patients. No statistically significant differences were observed between the groups in terms of colour matching, anatomical form, marginal adaptation, marginal pigmentation, surface roughness, occlusal contact, and secondary caries.14 Dr. Jaya et al states that PLA posts are promising alternative to exisiting posts in Pediatric dentistry.2 Ahmed M. Abdelrhman et al investigated the mechanical properties of Polylactic Acid (PLA) in 3D-printed medical implants, focusing on dental applications and concluded that it is biocompatible and easy to fabricate but its mechanical strength is insufficient for permanent dental implants.15 Eun Kyong Kim et al. fabricated three dimensional printed temporary crowns using polylactic acid with a fused deposition modeling printer and evaluated them for discomfort, fracture, and dislodgement. The crowns remained intact without fracture, dislodgement, or patient discomfort until placement of the permanent prosthesis. The authors also reported that polylactic acid is prone to thermal degradation, which makes high speed polishing challenging; therefore, methods to reduce surface roughness of these crowns are essential.16

Studies have focused on enhancing the mechanical properties of polylactic acid. Niha Naveed et al. modified polylactic acid by incorporating cooking grade sesame oil to improve its precision, dimensional stability, density, hardness, and load bearing capacity for use in orthodontic appliance fabrication17 Ricardo Donate et al. coated polylactic acid scaffolds with calcium carbonate particles to enhance their mechanical properties.18 Girish K B et al evaluated the mechanical property of Polylactic Acid (PLA)-Calcium composite with different infill parameters. their results indicate that a 50% triangular infill optimizes tensile strength and elongation, suitable for simulating dentin's elasticity. An 80% octo-gram infill maximizes impact toughness, mimicking enamel's resistance to fracture. Compressive strength peaks at 80% triangular infill, aligning with dentin's compressive strength (100–150 MPa). They confirmed that infill density has a statistically significant effect on all mechanical properties, with pattern influencing impact toughness more than tensile or compressive strength.10 Mostafa Adel Hamed et al states that infill density dominates compressive strength (70%) and nozzle diameter has little influence (5%) on compression.9 Ahmed M. Abdelrhman et al states that increasing nozzle temperature, reducing layer height, and increasing infill density leads to an increase in compressive strength and modulus.15

In this study, the compressive strength of PLA was found to be inferior to that of conventional resin. Therefore, it may be more suitable for use in low stress-bearing areas, particularly where its biodegradable and biocompatible properties can be advantageous, such as in intracanal posts for primary teeth. By optimizing printing parameters and appropriate incorporation of additives mechanical property of PLA can be improved. Future investigations should emphasize improving the mechanical performance of polylactic acid through material blending and surface modification strategies to enhance its strength and biocompatibility. In addition, long term in vivo studies are required to comprehensively evaluate its durability and degradation behavior over time.

CONCLUSION

Compressive strength of FDM printed polylactic acid was 28.90 ± 2.28. Through appropriate material modifications and optimization of printing parameters, the mechanical and functional properties of PLA can be effectively enhanced. Therefore, modified FDM-printed PLA can serve as a promising, customizable, and cost-effective material for various applications in pediatric dentistry.

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Table 1: Mean ± SD of compressive strength, mean difference (95% CI), t(df), and p value for comparison between the study groups

Variable	Group	n	Mean ± SD	Mean Difference (95% CI)	t (df)	p-value
Material	PLA	20	28.90 ± 2.28	-469.41 (-470.62 to -468.21)	-790.04 (38)	<0.001
	Resin	20	498.31 ± 1.37			

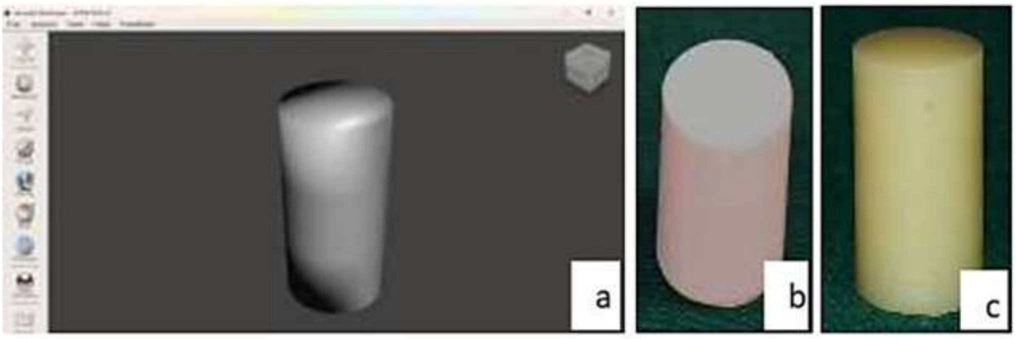

Figure 1(a) stl file of cylindrical specimen (b) Stratasys polylactic acid sample (c) Pristocraft resin sample

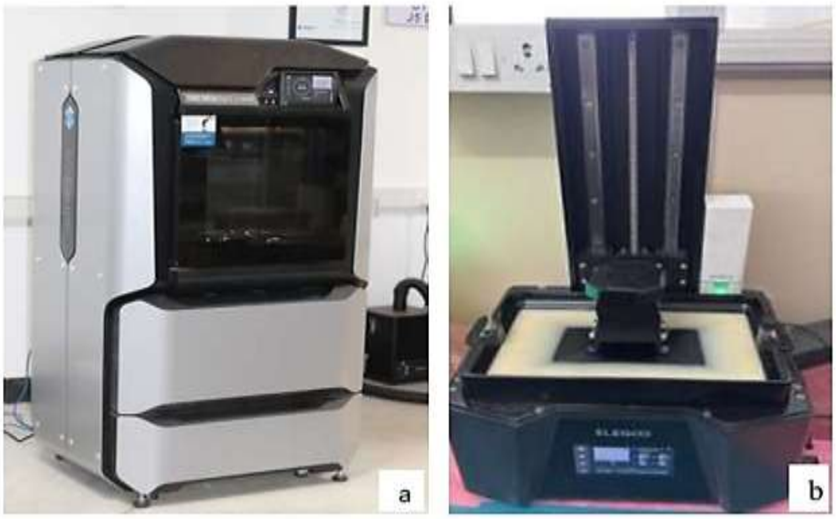

Figure 2 (a)Stratasys F 370 FDM printer (b)Elegoo DLP printer

Figure 3: Sample placed in Universal testing machine M 50 – UTM (Hitech Equipment India Pvt)