journal of the mechanical behavior of biomedical materials 161 (2025) 106817

Contents lists available at ScienceDirect

Journal of the Mechanical Behavior of Biomedical Materials

journal homepage: www.elsevier.com/locate/jmbbm

Evaluation of flexural strength of additively manufactured resin materials compared to auto-polymerized provisional resin with and without hydrothermal aging

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ARTICLE INFO

Keywords:
3D Printing
Additive manufacturing
CAD/CAM
Dental materials
Prosthodontics
Provisional restorations

ABSTRACT

Purpose: Additive manufacturing (AM) technologies are used to fabricate 3D-printed provisional dental restorations. The purpose of this study was to investigate the flexural strength of 3D-printed resins and compare their mechanical performance with those of conventional resins indicated for provisional restorations.

Materials and methods: This study included six different 3D-printed resin materials, namely (Nextdent (ND); Temp PRINT (TP); Optiprint temp (OT); 3Delta Etemp (DE); Saremco print | CROWNTEC (SA); MED690 (ST)), and one conventional (Protemp (PT)) (Control) provisional resin material. Specimens (N = 168) were prepared (25x2x2 mm^3) following ISO 10477:2018 guidelines for temporary materials using a printer (Asiga MAX 3D). Post-processing was accomplished following each manufacturer's recommendation. While half of the specimens were tested after 24 H without aging, the other half was subjected to thermomechanical aging in a custom-made chewing simulator (1.200.000 cycles, 5 °C and 55 °C). Flexural strength of the specimens was determined using a Universal Testing Machine. Data were analyzed using two-way ANOVA followed by Tukey's post-hoc test ($\alpha = 0.05$). Weibull modulus for each group was calculated based on parametric distribution analysis of censored data for maximum fracture load.

Results: No significant difference was observed in mean flexural strength (MPa) when non-aged and aged conditions were compared in the OT and PT groups ($p>0.05$). Groups ND, SA, TP, DE, and ST presented significant differences ranging between 12.67 and 57.39 MPa ($p<0.05$). All groups presented lower shape and scale values in aged groups compared to their non-aged counterparts. While OT and PT maintained their flexural strength after aging, ND exhibited the highest decrease (30%), followed by DE (23.8%), SA (16.2%), TP (12%), and ST (8.6%) in descending order. Weibull modulus decreased as a function of aging except in group ST.

Conclusion: Significant effect of themomechanical aging especially on ND and DE materials should be considered with caution when such materials are indicated as interim or long-term interim provisional restorations. SA and TP exceeded the expectations from a provisional material compared to that of the conventional control material PT.

1. Introduction

Provisional fixed dental prostheses (FDP) are used to maintain the appearance and functionality of the patients while permanent tooth or implant-supported prostheses are being fabricated (Federick, 1975). Providing pulpal protection, maintaining occlusal and chewing function are essential in dental therapies until final reconstruction is provided to the patient (Rieder, 1989; Miller, 1983).

Provisional restorations can be produced either with the conventional techniques or using computer-aided design and computer-aided

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https://doi.org/10.1016/j.jmbbm.2024.106817
Received 23 October 2024; Accepted 15 November 2024
Available online 16 November 2024

manufacturing (CAD-CAM) technologies (Astudillo-Rubio et al., 2018). The most commonly used conventional resin materials include hand-mixed polymethyl methacrylate (PMMA), polyethyl or polybutyl methacrylate (PEMA), and auto-mixed dimethacrylates or bisacrylate resin composites (Fox, 1989; Bohnenkamp and Garcia, 2004; Köroglu et al., 2016). Prostheses can be produced using CAD-CAM technologies in two ways, namely by additive manufacturing (3D printing, AM) or subtractive manufacturing (Milling, SM) (Kattadiyil and AlHelal, 2017). While SM is more commonly used for manufacturing prosthesis, AM offers significant advantages with lower costs of production (Berman, 2012), allowing for reduced material loss during building the object and decreased maintenance costs, such as rotatory parts of the SM device (Abduo et al., 2014). Although the manufacturing accuracy of the SM depends on the number and size of the milling burs, the AM allows for repeatability in the production (Urrios et al., 2016).

The AM technologies most chosen for processing polymers in dentistry are based on vat polymerization and material jetting (Revilla-León and Özcan, 2019). There are a limited number of CE or FDA approved AM provisional dental polymer materials for intraoral use (Revilla-León et al., 2019). The chemical composition and bond strength of numerous AM polymers to dental tissues remain unknown (Revilla-León and Özcan, 2019).

High mechanical strength is expected from provisional FDP materials particularly when they are applied for a longer period of time, in long-span reconstructions with several pontics, when patient suffers from bruxism and vertical dimension increase is necessary. One important indicator for assessing the mechanical strength, stiffness, and rigidity of the provisional material is flexural strength (Akova et al., 2006; Balkenhol et al., 2009; Thompson and Luo, 2014). Provisional materials with a high flexural strength were reported less likely to fail in clinical applications (Hamza et al., 2024). Although the FS of conventional provisional materials has been widely studied, information about on the flexural strength of different AM polymers is scarce (Alp et al., 2019; Revilla-León et al., 2020a,b).

The objective of this study therefore was to compare flexural strength of conventionally and additively fabricated provisional resin materials in the presence and absence of thermomechanical aging. The null hypothesis tested was that there would be no significant difference in flexural strength among all tested resin-based materials in both non-aged and aged conditions.

2. Material and methods

2.1. Specimen preparation

A digital bar design (25x2x2 mm^3) was obtained by using an open-

Table 1
Group abbreviations, manufacturers, brands, chemical composition, filler type, printer type, wavelength for polymerization.

Group abbreviations	Manufacturer	Brand	Chemical Composition	Filler Type	3D PRINTER	Wavelength (nm)
ND	Nextdent, Vertex Dental, Soesterberg, The Netherlands	C&B MFH	Methacrylic oligomers, methacrylate monomer, inorganic Urethane methacrylate oligomer, acrylate monomer, filler, phosphine oxides, pigments, methacrylate monomer, phosphine oxide, cerium Class IIa CE certified FDA-approved	Microfillers	ASIGA MAX UV, D20II Rapid Shape, Rapid Shape D30	Blue UV-A (315–400) + UV-blue (400–550)
TP	GC Europe N.V., Leuven Belgium	Temp PRINT	Urethane dimethacrylate 50 -<75%, 2,2'-ethylenedioxydiethyl dimethacrylate 10 < 25% Class IIa CE-certified FDA-approved	Quartz (10 –< 25 wt%)	ASIGA MAX UV, D20II Rapid Shape	LED 380-510
OT	Dentona, Dortmund, Germany	Optiprint temp	bisphenol A-ethoxylate (2 EO/Phenol) Dimethacrylat Aliphatic difuctional methacrylate< 50 2,2'-ethylenedioxydiethyl dimethacrylate <40 Aliphatic urethane acrylate <20 Phosphine oxide <2,5% Class IIa CE-certified Not FDA-approved		ASIGA MAX UV	385
DE	Deltamed, Friedberg, Germany	3Delta Etemp	Methacrylates, UDMA, TMPTA, TPO Not FDA-approved	Siliciumdioxid, dental glass (50 wt %)	D20II Rapid Shape	385
SA	Saremco Dental AG, Rebstein, Switzerland	Saremco print | CROWNTEC	bis-EMA, trimethylbenzonyldiphenylphosphine oxide Class IIa for permanent crown FDA-approved		ASIGA MAX UV	320–500
ST	Stratasys, Rehovot, Israel	MED690	Acrylic monomer, 2-Propenoic acid, 1,7,7-trimethylbicyclo[2.2.1]hept-2-yl ester, exo-, acrylic oligomer, photo Initiator, titanium dioxide, acrylic acid ester, carbon black, xylenes (o, m-, p- isomers), n-Butyl acetate, ethylbenzene, propylene glycol monomethyl ether acetate, phosphoric acid (Class II) light-curable resin FDA-approved		ASIGA MAX UV	385
PT	3M, St. Paul, USA	Protemp	bis-acryl composite FDA-approved	Ethanol, 2,2'-[(1-Methylidene)bis (4,1-Phenyleneoxy)] bis-, Diacetate, Benzly-Phenly-Barbituric acid, silane treated silica, (1-methylethylidene)bis (4,1-phenyleneoxy-2,1-ethanediyl) (1-phenylenoxy-2,2'ethoxyethanediyl)bisacetate, Tert-butyl peroxy −3,5,5-Trimethylhexanoate		Not applicable

source computer-aided design (CAD) software program (3Shape software program/EXOCAD, Zurich, Switzerland). The specimen size followed the dimensions recommended by the International Organization for Standardization (ISO) 10477-2018. Two groups were generated depending on the manufacturing method: additive manufacturing (AM group) or conventional methods (CN group). The brand, manufacturer, material type, and chemical compositions of the investigated materials are summarized in Table 1. All the manufacturing procedures were performed by one calibrated prosthodontist.

For the fabrication of the conventional temporary resin, silicone moulds were prepared (Zetaplus, Zhermack, Badia Polesine, Italy). Then, the material chosen for the conventional method (Protemp A2, 3M ESPE, St. Paul, USA), was mixed with an automix syringe and filled in the mould. The material was applied from the base of the silicone mould to the surface in layers to prevent the formation of air bubbles. After the polymerization, the specimens were removed from the silicone mould.

In the AM group, the specimens were fabricated using vat-polymerization 3D printing (ASIGA MAX UV, ASIGA, Henry Schein, Ontario, CA) using one of the following provisional 3D printed dental resins (Nextdent (C&B MFH, ND); Temp PRINT (GC, TP); Optiprint temp (Dentona, OT); 3Delta Etemp (Deltamed, DE); Saremco print | CROWNTEC (Saremco, SA); MED690 (Stratasys, ST)) at a constant room temperature of 23 °C.

The printer was calibrated according to the manufacturer's recommendations. All specimens were fabricated at the same time, and the specimens were oriented on the build platform so that the layer was perpendicular to the load to be applied in the fracture resistance test. Specimens (N = 168, n = 24 per group) were removed from the build platform with the removal tool provided by the manufacturer and fully submerged in an ultrasonic bath for rinsing purposes (Table 2). After removing the specimens from the bath, they were placed on a paper towel to dry in ambient air for 30 min and then placed in a UV polymerization machine (Otoflash G171, NK-Optik GmH, Paris, France) according to each manufacturer's recommendations (Table 3).

The support material of all specimens was removed with a removal tool provided by the manufacturer. Then, another polymerization cycle of 20 min at 60 °C was accomplished with the same polymerization unit and the specimens were stored in an opaque container until the measurements were performed.

Half of the specimens in each material group was randomly assigned to 2 subgroups of aging (N = 84, n = 12 per group). Specimen size was established based on a previous investigation (Scherer et al., 2022). While half of the specimens in each group were tested without aging, the other half was subjected to hydrothermal aging.

2.2. Thermomechanical aging

In the aging group, the specimens were subjected to cyclic loading (1.200.000 cycles, 50 N, 1.67 Hz, 5–55 °C, distilled water) in a custom-made chewing simulator (University of Zurich) where the load was applied to the occlusal surface of the pontic with a steel sphere (diameter: 3 mm). The applied force was perpendicular to the middle of the rectangular specimen.

Table 2
Detailed rinsing procedures for the 3D printed materials tested. For abbreviations, see Table 1.

Groups	Rinsing procedures
ND	1st: Ultrasonic bath 96% IPA 3 min 2nd: Ultrasonic bath 96% IPA 2 min
TP	1st: Ultrasonic bath 96% IPA 3 min 2nd: Ultrasonic bath 96% IPA 2 min
OT	1st: Ultrasonic bath 99% IPA 3 min, 2nd: Ultrasonic bath 99% IPA 3 min
DE	Centrifugal force for 3 min at 1.800 rounds per minute (Allegra X-15R)
SA	Remove excessive material with an alcohol-soaked (96%) cloth or brush, until the surface is slightly matt
ST	1st: Ultrasonic bath 99% IPA 3 min 2nd: Ultrasonic bath 99% IPA 3 min

Table 3
Details of post-polymerization procedures for the 3D printed materials tested. For abbreviations, see Table 1.

Groups	Post- polymerization procedures
ND	30 min in an UV- polymerization device (Nexdent LC- 3D Print Box; 3D Systems)
TP	6 min in Labolight DUO OPTIGLAZE color 6 min in an UV- polymerization device (Otoflash G171; NK- Optik GmH)
OT	10 min in an UV- polymerization device (Otoflash G171)
DE	10 min in an UV- polymerization device (Otoflash G171)
SA	6 min in an UV- polymerization device (Otoflash G171)
ST	6 min in an UV- polymerization device (Otoflash G171)

2.3. Flexural strength test

The specimens that survived the artificial aging were then tested for flexural strength in a universal testing machine (Z010, ZwickRoell GmbH & Co, Ulm, Germany). Flexural strength measurements (MPa) were made for all the specimens according to ISO 10477-2018. All specimens were then tested in a three-point bending fixture where the specimens were mounted flat on two support rollers with a center-to-center distance of 10 mm (same specimen placement design as in the thermomechanical loading machine) and loaded to fracture. For every specimen, breaking load [N] and exact dimensions (mm) were noted. Three-point flexural strength values (MPa) were calculated by the formula described in ISO standard No: 6872:2008 (https://www.iso.org/standard/59936) (E) as follows:

$$\sigma = \frac{3pl}{2wb^2}$$

Where P is the breaking load (N), l is the test-span (mm) (center-to-center distance between support rollers), w is the width of the specimen (mm) (the dimension of the side at right angles to the direction of the applied load) and b is the thickness of the specimen (mm) (the dimension of the side parallel to the direction of the applied load.

2.4. Statistical analysis

Data were analyzed using a statistical software package (SPSS Software V.20, Chicago, IL, USA). Normal distribution of the data was tested using Shapiro-Wilks test which presented a normal distribution ($p<0.05$). Therefore, two-way ANOVA test was utilized to analyze the variance and post-hoc Tukey test was employed for pairwise comparisons ($\alpha = 0.05$). In addition, maximum likelihood estimation without a correction factor was used for the 2-parameter Weibull distribution. The Weibull distribution, including the Weibull modulus, scale (m), and shape (0), was performed to interpret the predictability and reliability of flexural strength measurements (Minitab Software V.16, State College, PA, USA). $P<0.05$ was considered to be statistically significant in all tests.

Weibull distribution maximum likelihood estimation without a correction factor was used, including the Weibull modulus, scale (m), and shape (0), to interpret the predictability and reliability of the flexural strength tests (Minitab Software V. 16; Minitab) (Scherer et al., 2022).

3. Results

Mean flexural strength results were significantly affected by the material type ($p<0.05$) and aging (0.05). Interaction terms were also significant ($p<0.05$) (Table 4).

Table 4
Mean flexural strength, standard deviations, decrease in flexural strength in percentage for the 3D printed materials tested in non-aged and aged conditions. Different superscript letters show significant differences within the columns, and different superscript numbers within the rows. For abbreviations, see Table 1.

Groups (n = 24)	Non-aged (mean ± SD) (MPa) (n = 12)	Aged (mean ± SD) (MPa) (n = 12)	Decrease in flexural strength (%)	*p*
ND	191.22 ± 4.99^{b,1}	133.83 ± 27.16^{a,2}	30.01	0.002*
TP	223.07 ± 8.93^{dc,1}	196.34 ± 22.20^{cb,2}	11.98	0.006*
OT	141.22 ± 46.74^{a,1}	116.48 ± 38.56^{a,1}	12.58	0.061
DE	145.41 ± 22.77^{a,1}	110.87 ± 37.31^{a,2}	23.75	0.021*
SA	244.16 ± 19.17^{c,1}	204.50 ± 44.34^{b,2}	16.25	0.012*
ST	146.52 ± 13.08^{a,1}	133.84 ± 2.38^{a,2}	8.65	0.008*
PT	137.79 ± 27.24^{a,1}	112.64 ± 21.91^{a,1}	18.25	0.067

No significant difference was observed between the flexural strengths of non-aged and aged specimens for 2 of the 7 materials included in the study, namely OT and PT (Fig. 1). These two materials retained their flexural strength after the termomechanical aging. Conversely, in the case of five materials, a significant difference in flexural strengths were observed before and after aging. ND exhibited the highest mechanical decrease, with a reduction of 57.39 MPa, followed by SA (39.67), TP (26.73), DE (34.54) and ST (12.67). In terms of percentage, ND showed the highest percentage decrease with 30% followed by DE (23.8%), SA (16.2%), TP (12%) and ST (8.6%) (Table 4).

When compared to control material PT, only ND, SA and TP showed significantly higher mean flexural strength results ($p<0.05$), while the others were not significant ($p>0.05$).

In non-aged conditions, mean flexural strength of ND (191.23 MPa) was 38.8% higher than PT (137.79 MPa). Furthermore, non-aged mean flexural strength of SA (244.17) was 77.2% higher than PT (137.79 MPa) while TP's mean flexural strength (223.07 MPa) was 61.9% higher than PT (137.79 MPa).

After themomechanical aging, mean flexural strength SA (204.50 MPa) was 81.6% higher than PT (112.64 MPa). This was followed by TP (196.34 MPa) being 74.3% higher than PT (112.64 MPa).

Weibull distribution presented lower shape and scale values for aged groups compared to their non-aged counterparts for flexural strength, except for ST (Fig. 2a and b).

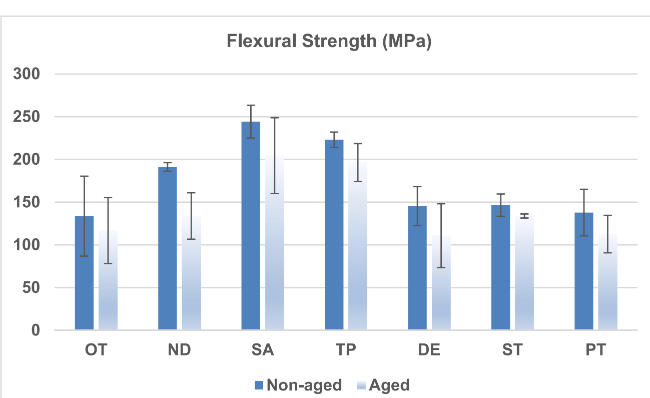

Fig. 1. Flexural strengths of non-aged and aged materials in (MPa).

4. Discussion

The results of this research showed significant difference in the mean flexural strength of the 3D-printed resin materials fabricated using the vat-polymerization DLP method when compared to conventionally fabricated auto-polymerized resin material. Artificial aging caused in most materials a significant reduction in the mean flexural strength of the tested materials. Therefore, the null hypothesis was rejected as there were significant differences in the flexural strength of the specimens.

Some of the AM material presented higher flexural strength than the control group. These findings suggest that 3D printed resin materials hold potential for clinical applications (Yao et al., 2014; Rayyan et al., 2015; Akiba et al., 2019; Coelho et al., 2021; Alshamrani et al., 2022; Ellakany et al., 2022; Taşın and Ismatullaev, 2022).

According to the study of Kessler et al. (2021), flexural strength values in non-aged and aged materials were in descending order as follows: Freeprint temp < ND < DE. In our study, however, ND and DE did not show the highest results among the tested materials after aging conditions. Additionally, the results of a previous study (Park et al., 2020) showed SLA groups presenting significantly higher flexural strength results compared to the conventional group ($p<0.001$). No significant difference was observed in flexural strength between DLP and SLA groups where the FDM group showed only dents but no fracture. The study also highlighted that provisional restorations fabricated by DLP and SLA technologies provide adequate flexural strength for dental use. In this study, the materials that made a significant difference compared to the control material (PT) were ND, SA and TP ($p<0.05$). No significant difference was observed with other materials ($p>0.05$) in line with the previous study (Park et al., 2020). Al-Qahtani et al. (2021) found in their study that CAD-CAM and 3D printed technologies yielded comparable strength values while conventionally produced specimens showed significantly lower strength. In this study, resin materials processed with subtractive methods were non included as the focus was more on the economic options, namely the additive manufactured ones.

It is crucial to recognize that masticatory processes and bite force are influenced by numerous factors, such as the number of the existing teeth, dental and periodontal status, the number and stability of occlusal contacts, jaw muscle activity, age, the presence of dental prostheses (fixed or removable; supported on implants or natural teeth), and temporomandibular disorders. As an example, a previous study indicated that the maximum voluntary bite force is dependent on age and sex where the average value of maximum voluntary bite force for females was 33–51 kgf and for males 42–63 kgf, and a stronger bite was recorded for younger subjects than for older ones. In this in vitro study, a dynamic loading of 50 N was applied during thermomechanical aging (Manzon et al., 2021). The mean flexural strength values for the ND (133 MPa) after aging, was higher when compared to the value provided by the manufacturer (>50 MPa). TP on the other hand exhibited values of 196 MPa, which was also higher compared to the values provided by the manufacturer (>90 MPa). Likewise, mean value for SA (204 MPa) was also higher when compared to the value provided by the manufacturer (>130 MPa). The reasons for this could be attributed to the post processing procedures. Since no information was provided by the manufacturers of OT, DE, and ST, such a comparison could not be made. Additionally, the mean flexural strength for the conventional resin, PT corresponded to the values provided by the manufacturers as well as previous studies (Manzon et al., 2021; Poli et al., 2021; Pantea et al., 2022).

While both conventional and AM manufacturing technology are recommended for both dental and implant-supported intermediate FDPs, it is essential to conduct further investigations into new temporary 3D printed dental materials as they are indicated for clinical use even though clinical trials are lacking. Thus, future studies should focus on accuracy, repeatability, mechanical properties, and long-term behaviour. Dentistry is constantly evolving by adopting the use of the latest technologies and additive manufacturing is an emerging methodology

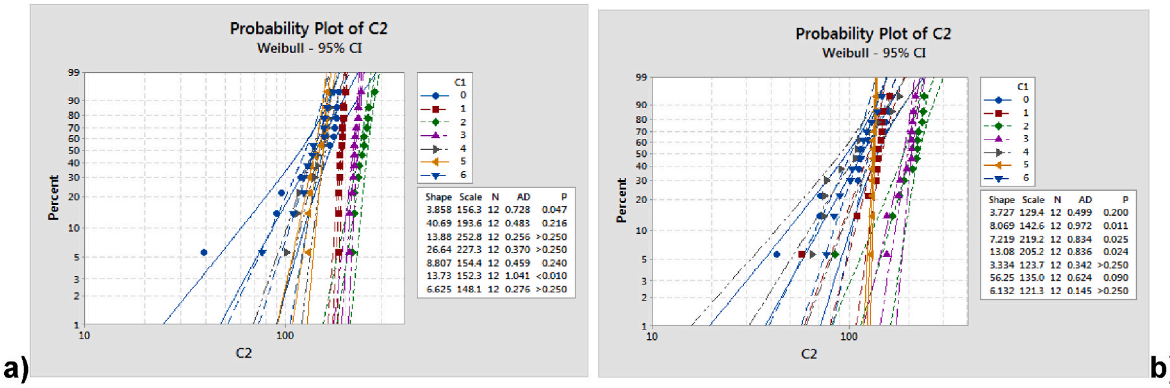

Fig. 2a–b. Weibull parameters (shape and scale) of the 3D printed resin materials tested (0: OP, 1: ND, 2: SA, 3: TP, 4: DM, 5: ST, 6: PT) under a) aged and b) non-aged conditions.

that provides a cost-effective solution, although the rapid growth in this field still lack data on different mechanical properties of 3D-printed provisional prosthetic materials. In fact, AM offers a much higher customization potential and complex geometries compared to conventional manufacturing (Revilla-León et al., 2020a,b; Salmi, 2021; Reyes et al., 2022).

Regarding the results obtained in this study for the provisional conventional acrylic resins tested (auto-polymerized and pressure/heat-polymerized acrylic resin), it can be stated that appropriate mechanical behaviour of fixed temporary prostheses is critical for preserving oral structures, ensuring adequate function, maintaining aesthetics (Patras et al., 2012; Murakami et al., 2013). Interim treatment should meet criteria for strength, marginal compliance, and longevity (Patras et al., 2012) where material selection plays an important role in the performance of temporary FDPs (Lee et al., 2020). While conventional resins have been the most common choice for these applications, issues such as failure in intermediate restorations are frequently encountered, particularly in traditional custom-made provisional restorations. The most common materials used to fabricate temporary fixed dentures have traditionally been conventional resins, materials based on mono-methacrylates or acrylic resins and dimethacrylates or bis-acryl/composite resins (Rosenstiel et al., 2006; Firlej et al., 2021). However, scientific evidence indicates that failure of intermediate restorations and other shortcomings are encountered daily by clinicians, mostly in traditional, custom-made intermediate restorations (Lee et al., 2020; Reyes et al., 2022). In this context, Peñate et al. (2015) showed that the fracture resistance of directly (conventional) fabricated temporary FDPs is lower than those produced via CAD/CAM technology (Firlej et al., 2021). Conversely, Digholkar et al. (2016) noted that conventional thermosetting PMMA and milled PMMA have higher bending strengths (95.58 MPa and 104.20 MPa, respectively) than 3D printed resins (79.54 MPa) (Digholkar et al., 2016). Regarding the mechanical behaviour of conventional intermediate resins, a previous study noted that polycarbonate crowns showed the highest fracture resistance values (585 ± 42.78 N) compared to crowns manufactured using bis-acryl composite (380 N), auto-polymerizing PMMA resin (448.3 N), and heat-polymerized PMMA resin (253.3 N) (Yilmaz and Baydas, 2007). It is also worth noting that in one former studies, heat polymerized resin showed significantly lower strength value than autopolymerized acrylic resin (Lee et al., 2020). The authors suggested that one of the possible reasons for this result might be the strong plasticizing effect of the residual monomer in the autopolymerizing acrylic resin. For this reason, fractures may occur after the load is applied to the heat polymerized acrylic resins, which form a rigid structure.

In the case of auto-polymerizing acrylic resins, plastic deformation may occur first, followed by failure in the form of breakage. Another possible reason mentioned by the authors for the higher values of fracture resistance in auto-polymerized acrylic resin compared to heat polymerized PMMA resin may be the addition of glycol dimethacrylate to the autopolymerizing material that provides molecular crosslinking (Lee et al., 2020). Another study concluded that co-polymerizing bis-acrylic composite resin contributes to higher stiffness and strength than auto-polymerized bis-acrylic composite resin, providing higher structural strength (Patras et al., 2012).

Over the years, different attempts have been made to improve the mechanical properties of conventional acrylic resins one of which was the polymerization methods and its effect on the number and size of pores formed in resin materials. Typically, the highest number of pores occurred in unfilled heat-polymerized acrylic resin and photo-polymerized resin, while the lowest numbers of pores were found in heat-polymerized micro-filled acrylic resin (Berge and Hegdahl, 1987). Polymerization under 500 MPa high pressure through isostatic pressure for 24 h at 70 °C increased the durability of an experimental PMMA resin (toughness was defined as the amount of elastic and plastic deformation energy required to break acrylic resin samples) (Murakami et al., 2013). However, a recent study (Bauer et al. (2021) provided encouraging results showing that intermediate materials such as milled PMMA and di-methacrylate resins are sufficiently resistant to fracture for the fabrication of temporary implant-supported anterior FDPs as they are expected to survive 6 months to 2 years before failure. In this study, the conventional resin tested was a di-methacrylate resin. Conventional manufacturing and its reproducibility may be strongly dependent on the skills of the dental technician and therefore, inhomogeneous specimens may adversely affect the mechanical behaviour of such materials (Lange and Radford, 1971; Chung and Greener, 1990).

Weibull modulus for maximum flexural strength indicated the lowest reliability of strength for OP (3.8) and PT (control) (6.6) in non-aged conditions. Degradation under simultaneous thermal and mechanical challenge in water was also reflected in the decreased Weibull modulus in all groups with the exception of ST.

Knowledge on the mechanical properties of printable biomaterials is a prerequisite for optimal performance in any clinical situation when using 3D printing technologies in dentistry, including the design and manufacturing parameters for oral devices (Revilla-León et al., 2020a,b; Reyes et al., 2022). The present study validates the data found in the dental literature and can contribute to guiding dentists to optimized selection of the designated materials for temporary FDPs. Specimens tested for flexural strength are geometric in shape and thus do not imitate the anatomic features of a prosthetic appliance which is a limitation. Future studies should compare the same materials considering the design parameters which play a role on survival of FDPs.

5. Conclusions

From this study, the following could be concluded:

1. Mean flexural strengths of OT and PT showed no significant difference in non-aged and aged conditions with the descending order of PT < OP < ST < DE < TP < SA < ND.
2. In non-aged conditions among the tested 3D-printed resins SA demonstrated the higher results than that of conventional resin PT with the descending order of SA > TP > ND > ST > DE > OP > PT.
3. After thermomechanical aging the majority of the 3D printed resin materials tested outperformed conventional auto-polymerized resin (PT) (SA > TP > ST > ND > OP > PT > DE).
4. Weibull distribution presented lower shape and scale values for aged groups compared to their non-aged counterparts, meaning resin materials showed degradation under simultaneous thermal and mechanical challenge in water, with the exception of ST.

CRediT authorship contribution statement

Kübra Aycan Tavuz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft. **Nadin Al-Haj Husain:** Validation, Writing – original draft, Writing – review & editing. **Kiren Jan Mätzener:** Investigation, Methodology, Validation. **Mehmet Muzaffer Ateş:** Conceptualization, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft. **Tan Fırat Eyüboğlu:** Validation, Writing – original draft, Writing – review & editing. **Mutlu Özcan:** Methodology, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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