Comparison of the Flexural Strength of Three Different Aged and Nonaged 3D-Printed Permanent Crown Resins

Yasemin Nur Korkmaz, DDS, MSD
Department of Orthodontics, Faculty of Dentistry, Bolu Abant Izzet Baysal University, Bolu, Türkiye.

S. Kutalmış Buyuk, DDS, PhD
Department of Orthodontics, Faculty of Dentistry, Ordu University, Ordu, Türkiye.

Huseyin Simsek, DDS, PhD
Department of Pediatric Dentistry, Faculty of Dentistry, Ordu University, Ordu, Türkiye

Feridun Abay, DDS
Department of Orthodontics, Faculty of Dentistry, Ordu University, Ordu, Türkiye.

Aim: The aim of this study was to evaluate the flexural strength properties of three different aged and nonaged 3D-printed resins built by different 3D printing systems used in dental applications. ***Materials and Methods:*** Bars (2 × 2 × 25 mm) were additively fabricated using a 3D printer and different dental crown resins (Saremco Crowntec, Senertek P-Crown V2, and Senertek P-Crown V3) per the manufacturers' recommendations. Each subgroup was divided into aged and nonaged subgroups (n = 10 bars per group). Thermocycling procedures (5° to 55°C; 5,000 cycles) were performed under favorable conditions for the aged subgroups from each material. Flexural strength (MPa) was measured in all samples using a universal test machine. ***Results:*** When both aged and nonaged resins are compared, significant differences were found in flexural strength measurements ($P < .001$). The highest flexural strength was observed in the Saremco Crowntec group, while the lowest flexural strength was observed in the Senertek P Crown V2 group. The flexural strength measurements of Saremco Crowntec and Senertek P Crown V3 displayed no significant difference between their aged and nonaged groups ($P > .05$), while Senertek P Crown V2 ($P = .039$) showed significant differences between its aged and nonaged groups. ***Conclusions:*** Saremco Crowntec showed the highest flexural strength both in aged and nonaged groups, while Senertek P Crown V2 had the lowest strength. The artificial aging process decreased flexural strength values in all 3D-printed resin groups.
Int J Prosthodont 2024;37(suppl):s203–s207. doi: 10.11607/ijp.8987

Technologic developments have been advancing at an incredible pace and are replacing many methods and materials that have been routinely used in dentistry for many years. Initially used in dentistry in 1985 to manufacture single crowns and bridges, CAD/CAM technology is now being used to manufacture various types of dental appliances.[1] Using CAD/CAM technology, dental appliances can be produced either by subtractive manufacturing, which is the milling of a block-shaped material, or by additive manufacturing (also known as 3D printing), which is the layering of printable polymers.[2] Additive 3D printing has a number of advantages compared to subtractive manufacturing, such as decreased material waste, the absence of burr wear, and the ability to manufacture more complex shapes.[3,4]

Correspondence to:
S. Kutalmış Buyuk,
skbuyuk@gmail.com

Submitted December 13, 2023;
accepted March 8, 2024.

In recent years, the use of 3D printing in dentistry has become quite common due to its easy-to-use technology and accuracy, which has improved greatly. Now, advanced 3D printing machines exist with increased types of printing materials, such as polymer resin, metal, plastic, and ceramic. 3D printers are now affordable and lighter. Moreover, multiple objects can be built simultaneously with a chairside design. The two main 3D printing methods used are stereolithography (SLA) and digital light projection (DLP). To build 3D structures, SLA polymerizes consecutive layers of photosensitive liquid polymer using a focused beam of ultraviolet (UV) light,[5] while DLP uses a digital projector screen that flashes light through the entire layer.[6] The DLP technique has the advantage of faster layer fabrication than SLA.[7]

3D printing is used in a variety of dental applications, such as manufacturing orthodontic appliances, clear aligners, orthodontic retainers, craniofacial osseous scaffolds, surgical guides, 3D-printed models, fixed prostheses, implant prostheses, complete dentures,[8] maxillofacial reconstruction,[9] implants,[10] occlusal splints,[11] removable partial dentures,[12] inlay and onlay restorations,[13] digital space maintainers, nasoalveolar molding appliances, and pediatric dental crowns.[14]

For the 3D printing of dental appliances, various materials can be used. These appliances must endure the changes in the intraoral environment, such as temperature changes, the forces that occur during mastication, and parafunctional habits such as bruxism. Physiologic values of occlusal forces during mastication vary between 10 and 120 N, and a dental appliance should resist these forces in the intraoral environment.[15] For dentists to choose the appropriate 3D-printing material, the mechanical properties of these materials and their behavior in intraoral conditions must be known. As well as the type of 3D printing technique, several additional factors affect the physical and mechanical behavior of the printed product, such as the material composition, printing orientation, postcuring time, layer thickness, and aging.[2,16] The main determining factor of a restorative material's mechanical behavior is its flexural strength and therefore must be analyzed.[17]

Even as extensive innovations occur in 3D-printing technology, the number of studies in the literature comparing the mechanical properties of different materials in different aging conditions remains limited. Therefore, this study aimed to compare the flexural strength properties of three different aged and nonaged 3D-printed resins built by different 3D-printing systems used in dental applications.

MATERIALS AND METHODS

The G*Power 3.1 program (alpha error probability = .05, power value 0.85, effect size 0.70) found that the total number of required samples was 52. The samples prepared for the present study were designed in a rectangular shape (2 × 2 × 25 mm) in accordance with ISO 4049 standards, using Tinkercad online design program. Designs were saved in .stl format. Samples were produced using three different materials: two different permanent crown resins with ceramic filler (P-crown Version 2 and P-crown Version 3, Senertek) and a flowable polymer based on methacrylic acid ester for production of permanent crowns (Crowntec, Saremco). Twenty samples were prepared for each material. During 3D printing, all samples were produced perpendicular to the table and with a 50-μm layer thickness, in accordance with the manufacturers' recommendations. Senertek P-crown V2 and P-crown V3 samples were produced on Anycubic Photon Mono X (LCD-based SLA printer; 405-nm light source, 3,840 × 2,400 XY resolution per 0.05 mm, 0.01-mm Z resolution, 192 × 120 × 245–mm build volume). Saremco Crowntec samples were produced in the NexDent 5100 LCD1 3D Printer as a closed system according to the manufacturer's recommendations.

Postcuring procedures were carried out according to the manufacturers' recommendations. While Senertek dental resins were washed (35 W) in ethanol alcohol for 3 minutes and cured in UV light for 20 minutes (36 W), Saremco Crowntec resins were wiped with ethanol and dried, and then cured in a curing machine (LC-3DPrint Box, NextDent) for 30 minutes.

After postcuring, the resin groups were each divided into aged and nonaged subgroups (n = 10 samples per group). Nonaged samples did not receive any additional treatment. For the aged samples, thermocycling (HaakeW15, Thermo Haake) was applied for 10,000 cycles between 5° and 55°C (± 2°), with a dwell time of 30 seconds and a transfer time of 5 seconds.

A total of 60 samples (six subgroups) were each loaded in the three-point test on a customized apparatus with two supports (20 mm apart) and fixed on a universal testing machine (Shimadzu, Instron) (Fig 1). Forces were applied to the center of the sample at a speed of 0.5 mm/minute. The following formula was used to calculate the flexural strength values in MPa:

Flexural strength = 3 × failure force at the fracture point (F) × (support span length/2) × width × (bar thickness)^2

Statistical Analysis

For statistical analysis, SPSS for Windows (version 26.0, IBM) was used. After normality test, the parametric tests one-way ANOVA (with post hoc Tukey HSD test) and independent *t* test were used. The significance level was set at $P < .05$.

Fig 1 Experimental setup of specimens to measure flexural strength.

Table 1 Comparison of the Flexural Strength of Nonaged 3D-Printed Resins

	Mean, MPa	SD , MPa	*P**
Senertek P Crown-V2	63.13^A	7.25	< .001
Senertek P Crown-V3	71.81^A	7.03	
Saremco Crowntec	92.06^B	9.08	

Groups with different uppercase letters are significantly different (Tukey HSD test, $P < .05$).
*One-way ANOVA.

Table 2 Comparison of the Flexural Strength of Aged 3D-Printed Resins

	Mean, MPa	SD, MPa	*P**
Senertek P Crown V2	57.08^A	4.60	< .001
Senertek P Crown V3	65.88^B	5.52	
Saremco Crowntec	88.04^C	9.14	

Groups with different uppercase letters are significantly different (Tukey HSD test, $P < .05$).
*One-way ANOVA.

Table 3 Comparison of the Flexural Strength of Aged and Nonaged 3D-Printed Resins

		Mean, MPa	SD, MPa	*P**
Senertek P Crown V2	Nonaged	63.13	7.25	.039
	Aged	57.08	4.60	
Senertek P Crown V3	Nonaged	71.81	7.03	.050
	Aged	65.88	5.52	
Saremco Crowntec	Nonaged	92.06	9.08	.337
	Aged	88.04	9.14	

*Independent *t* test.

RESULTS

Table 1 shows the flexural strength comparisons between different nonaged 3D-printed resins. The flexural strength was found to be significantly different between different nonaged resin groups ($P < .001$). Pairwise comparisons showed that there were significant differences between each group, except for the Senertek P Crown V2 and Senertek P Crown V3 groups. Saremco Crowntec resin had the highest flexural strength, while Senertek P Crown V2 had the lowest strength.

Table 2 shows the flexural strength comparison between different aged 3D-printed resins. A significant difference was found between the aged resins ($P < .001$), and pairwise comparisons showed significant differences between each group. Saremco Crowntec had the highest flexural strength, while Senertek P Crown V2 had the lowest strength.

Table 3 shows the flexural strength comparison between different aged and nonaged 3D-printed resins. While Senertek P Crown V2 showed significant differences ($P = .039$) between its nonaged and aged groups, Senertek P Crown V3 and Saremco Crowntec had no significant difference between their aged and nonaged groups.

DISCUSSION

Dentistry has seen an increased interest in 3D printing techniques, as digitalization has also increased in every aspect of life, including dental applications. Accordingly, new 3D-printing materials are constantly being produced for dental use. It is therefore essential to comprehend the mechanical behavior of various 3D-printing materials used to manufacture different dental appliances in order to select the correct printing material. Flexural strength values could be used as an indicator of the clinical performance of the materials. Therefore, the present study evaluated the flexural strength of three different aged and nonaged 3D-printed resins manufactured by different 3D-printing systems. To the present authors' knowledge, this study is the first to compare the flexural strength properties of these specific materials.

The production conditions of resins produced by rapid prototyping technology greatly affect their physical and mechanical characteristics. Alharbi et al[5] previously showed that improved mechanical properties were detected when the specimens were vertically printed with layers oriented perpendicular to the load direction. Accordingly, the specimens in the present study were produced perpendicular to the table. The fabrication method and printing layer thickness also affect the properties of a 3D-printed specimen.[7,18,19] The present samples were fabricated according to the manufacturer's recommendations, and with a layer thickness of 50 μm. According to the manufacturers, a postcuring procedure (15 to 30 minutes) must be implemented for 3D-printed resins via a UV lightbox to decrease the amount of residual monomer.[2] As the postcuring time increases, the flexural strength also increases.[2,19] The present specimens were subjected to UV light for 20 and 30 minutes, according to the manufacturer's recommendations. The three-point test is a common method of determining the flexural strength of 3D printed resins and has been used in previous studies,[20–23] and thus this method was used herein.

The type of 3D printing material significantly affected the flexural strength in the present study. The results showed that there was a significant difference between the flexural strength of the three nonaged resins. Senertek P Crown-V2 and Senertek P Crown-V3 resins showed significantly worse flexural strength compared to Saremco Crowntec. The mean flexural strength ranged from 63.13 to 92.06 MPa in the nonaged 3D-printed resins. All tested materials showed flexural strengths > 50 MPa, which is accepted as the minimum requirement for polymer-based crowns.[24] Differences in flexural strength may be due to the different chemical compositions of the materials, different printing methods with different polymerization patterns, and postcuring time.

In the oral environment, thermal changes occur quite frequently. Considering that temperature changes can affect the properties of a 3D-printed material, these properties must be analyzed in environments that mimic the intraoral environment. Thermocycling is an artificial aging method that is used to mimic the temperature changes that biomaterials are exposed to during their intraoral usage, affecting the properties of the printed resin. Thermocycling increases the water sorption and solubility of 3D-printed materials while decreasing the translucency.[25,26] The aged specimens in the present study were thermocycled for 10,000 cycles, simulating 2 years of intraoral use.[15]

Gad et al[27] investigated the strength properties of 3D-printed denture base resin and indicated that thermocycling significantly lowered the flexural strength. In accordance with their study, the present results showed that thermocycling caused poorer flexural strength in all three tested resin groups when compared to the nonthermocycled samples. This decrease in flexural strength may be associated with increased water absorption of the resin.[27] The mean flexural strength ranged from 57.08 to 88.04 MPa in the aged 3D-printed resins. Just like in nonaged resins, the highest flexural strength value in the aged group was detected in Saremco Crowntec, while the lowest value was seen in Senertek P Crown-V2, which should be considered. Although flexural strength decreased in all groups after aging, all tested materials still showed flexural strengths > 50 MPa.

Nevertheless, the flexural strength values of aged and nonaged groups were significantly different only in the Senertek P Crown V2 group, while the decrement of flexural strength in the aged groups of the Senertek P Crown V3 and Saremco Crowntec groups did not result in significant differences between the aged and nonaged groups. This revealed that Senertek P Crown V3 and Saremco Crowntec were more durable to temperature changes in terms of flexural strength, while Senertek P Crown V2 was more susceptible. This difference could also be attributed to the differences in the chemical compositions of the materials, different printing methods with different polymerization patterns, and the postcuring procedures.

Although thermocycling was included in the present study, some limitations still exist in terms of mimicking the oral environment, such as lack of mastication forces, saliva, and more anatomically relevant specimens. Further studies that include these conditions should be conducted. Additionally, the present results need to be further expanded by carrying out different production conditions and by investigating other mechanical and physical properties of the materials.

CONCLUSIONS

Saremco Crowntec showed the highest flexural strength both in aged and nonaged specimens, while Senertek P Crown V2 had the lowest flexural strength. Thermocycling resulted in decreased flexural strength values in all three materials. However, the only significant difference between aged and nonaged resin groups was detected in the Senertek P Crown V2 group. Because these materials are newly developed, further studies are needed to evaluate their different properties.

ACKNOWLEDGMENTS

The authors declare no conflicts of interest.

REFERENCES

1. Cattaneo PM, Cornelis MA. Digital Workflows in Orthodontic Postgraduate Training Seminars in Orthodontics. Elsevier; 2023:4–10.
2. Al-Dulaijan YA, Alsulaimi L, Alotaibi R, et al. Effect of printing orientation and postcuring time on the flexural strength of 3D-printed resins. J Prosthodont 2023;32:45–52.
3. Barazanchi A, Li KC, Al-Amleh B, Lyons K, Waddell JN. Additive technology: Update on current materials and applications in dentistry. J Prosthodont 2017;26:156–163.
4. Berman B. 3-D printing: The new industrial revolution. Business horizons 2012;55:155–162.
5. Alharbi N, Osman R, Wismeijer D. Effects of build direction on the mechanical properties of 3D-printed complete coverage interim dental restorations. J Prosthet Dent 2016;115:760–767.
6. Scotti CK, Velo MMdAC, Rizzante FAP, de Lima Nascimento TR, Mondelli RFL, Bombonatti JFS. Physical and surface properties of a 3D-printed composite resin for a digital workflow. J Prosthet Dent 2020;124:614.e611–e615.
7. Alshamrani AA, Raju R, Ellakwa A. Effect of printing layer thickness and postprinting conditions on the flexural strength and hardness of a 3D-printed resin. BioMed Res Int 2022;2022.
8. Sehrawat S, Kumar A, Prabhakar M, Nindra J. The expanding domains of 3D printing pertaining to the speciality of orthodontics. Materials Today: Proceedings 2022;50:1611–1618.
9. Fernandes N, Van den Heever J, Hoogendijk C, Botha S, Booysen G, Els J. Reconstruction of an extensive midfacial defect using additive manufacturing techniques. J Prosthodont 2016;25:589–594.
10. Tunchel S, Blay A, Kolerman R, Mijiritsky E, Shibli JA. 3D printing/additive manufacturing single titanium dental implants: A prospective multicenter study with 3 years of follow-up. Int J Dent 2016;2016.
11. Venezia P, Muzio LL, De Furia C, Torsello F. Digital manufacturing of occlusal splint: From intraoral scanning to 3D printing. J Osseointegration 2019;11:535–539.
12. Guo F, Huang S, Liu N, Hu M, Shi C, Li D et al. Evaluation of the mechanical properties and fit of 3D-printed polyetheretherketone removable partial dentures. Dent Mater J 2022;41:816–823.
13. Ahlholm P, Sipilä K, Vallittu P, Kotiranta U, Lappalainen R. Accuracy of inlay and onlay restorations based on 3D printing or milling technique-a pilot study. Eur J Prosthodont Restor Dent 2019;27:56–64.
14. Shaheen SR, Sridevi E, Sankar AS, Krishna V, Sridhar M, Sankar KS. Contemporary era of Three-dimensional printing in pediatric dentistry: An overview. J Oral Res Review 2023;15:72–79.
15. Topsakal KG, Aksoy M, Duran GS. The effect of aging on the mechanical properties of 3-dimensional printed biocompatible resin materials used in dental applications: An in vitro study. Am J Orthod Dentofac Orthop 2023;164:441–449.
16. Tian Y, Chen C, Xu X, Wang J, Hou X, Li K et al. A review of 3D printing in dentistry: Technologies, affecting factors, and applications. Scanning 2021;2021:9950131.
17. Derban P, Negrea R, Rominu M, Marsavina L. Influence of the printing angle and load direction on flexure strength in 3D printed materials for provisional dental restorations. Materials 2021;14:3376.
18. Farkas AZ, Galatanu S-V, Nagib R. The Influence of printing layer thickness and orientation on the mechanical properties of DLP 3D-printed dental resin. Polymers 2023;15:1113.
19. Gad MM, Fouda SM. Factors affecting flexural strength of 3D-printed resins: A systematic review. J Prosthodont 2023;32:96–110.
20. Prpić V, Schauperl Z, Ćatić A, Dulčić N, Čimić S. Comparison of mechanical properties of 3D-printed, CAD/CAM, and conventional denture base materials. J Prosthodont 2020;29:524–528.
21. Simoneti DM, Pereira-Cenci T, Dos Santos MBF. Comparison of material properties and biofilm formation in interim single crowns obtained by 3D printing and conventional methods. J Prosthet Dent 2022;127:168–172.
22. Soto-Montero J, de Castro EF, Romano BdC, Nima G, Shimokawa CA, Giannini M. Color alterations, flexural strength, and microhardness of 3D printed resins for fixed provisional restoration using different post-curing times. Dent Mater 2022;38:1271–1282.
23. Saini RS, Gurumurthy V, Quadri SA, et al. The flexural strength of 3D-printed provisional restorations fabricated with different resins: A systematic review and meta-analysis. BMC Oral Health 2024;24:66.
24. Atria PJ, Bordin D, Marti F, et al. 3D-printed resins for provisional dental restorations: Comparison of mechanical and biological properties. J Esthet Restor Dent 2022;34:804–815.
25. Gad MM, Alshehri SZ, Alhamid SA, et al. Water sorption, solubility, and translucency of 3D-printed denture base resins. Dent J 2022;10:42.
26. Greil V, Mayinger F, Reymus M, Stawarczyk B. Water sorption, water solubility, degree of conversion, elastic indentation modulus, edge chipping resistance and flexural strength of 3D-printed denture base resins. J Mech Behav Biomed Mater 2023;137:105565.
27. Gad MM, Fouda SM, Abualsaud R, et al. Strength and surface properties of a 3D-printed denture base polymer. J Prosthodont 2022;31:412–418.