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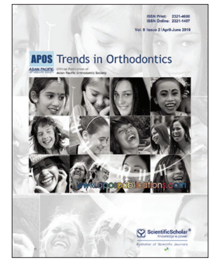

Original Article

In vitro examination of fracture resistance of 3D-printed resin blocks in different diameters

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ABSTRACT

Objectives: The intraoral use of commercial printable polymers in dental patients is still a challenge due to the unknown physical properties of the materials. The present study aimed to comparably evaluate the maximum load and deflection values of three-dimensional-printed resin blocks in different diameters that can be used intraorally in dental patients.

Material and Methods: Forty-five cylindrical resin blocks in diameters of 2 mm (Group 1, n = 15), 3 mm (Group 2, n = 15), and 4 mm (Group 3, n = 15) and lengths of 20 mm were designed and printed. The samples were placed in the universal testing device to conduct the 3-point bending test. According to the Shapiro–Wilk normality test results, Kruskal–Wallis and Mann–Whitney U tests were performed for the statistical analysis. The level of statistical significance was accepted as $P < 0.05$.

Results: The values for the maximum load (N) and deflection (mm) in the study groups were 218.4 ± 31.9, 2.96 ± 0.86 in Group 3; 77.05 ± 61.5, 3.91 ± 0.92 in Group 2; and 19.67 ± 2.63, 4.06 ± 1.02 in Group 1, respectively. The mean values of maximum load for Group 3 were superior to Group 2 (P = 0.020) and Group 1 (P = 0.00). Group 2 revealed higher maximum load results than Group 1 (P = 0.003). The mean values of maximum deflection in Group 3 were lower compared to Group 2 (P = 0.014) and Group 1 (P = 005).

Conclusion: The results of this *in vitro* study encourage the use of resin-printed intraoral appliances in place of conventional treatment modalities.

Keywords: Digital dentistry, 3-point bending test, Fracture resistance, Three-Dimensional printing, Printable resin

INTRODUCTION

In the past few years, digital dentistry has been popular among clinicians and has taken the place of the time-lasting and complicated conventional procedures in which dental laboratories are also involved. Recently, three-dimensional (3D) printing as a part of the digital dentistry workflow has been used widely in various areas of dentistry, including prosthodontics, surgical treatments, and orthodontics.[1,2] 3D printing term is used to describe the manufacturing process of one layer added at a time to form a complete object. This process can be described as additive manufacturing that aims at rapid prototyping.[3] This process is completed by transferring the saved data to the interface of the 3D printer software, and then, adding manufacturing of 3D printing can be started at this point.[4-6]

3D printing could be used in pediatric dentistry and orthodontics for various treatment modalities. These choices include designing-producing orthodontic appliances, bite plates, orthodontic retainers, and space maintainers.[7-9] Although the clinical success of these new treatment options depends on several factors, maintaining the physical integrity under intraoral forces is the pre-condition of a biocompatible material to be used within the mouth.[10] Bite forces vary over a wide range among individuals. While physiological values of occlusal forces differ between 10 and 120 Newton (N), maximum bite forces range between 190 and 290 N in the anterior region and 200–360 N in the molar region.[11] Accordingly, a material planned to be used intraorally should have a force resistance among 10–120 N, at least.[12]

Metal-based materials can be used to produce 3D-printed intraoral treatment modalities. The endurance of metallic alloy-based fabricated and printable space maintainers under occlusal forces has been proven by various clinical applications and studies.[4,13,14] Polyetheretherketone (PEEK) is another printable rigid substance that can be used as an alternative to metallic alloys.[15-17] Metal alloys may lead to allergic reactions, and the unesthetic results may cause displeasure even in pediatric patients.[18] However, PEEK may also lead to the same displeasure regarding esthetic aspects with its high opacity and thickness.[19] Biocompatible printable resins may also be used in this area. The esthetic appearance due to transparency makes these resin materials a strong candidate for an alternative to metal alloys and PEEK in 3D-printed intraoral treatment modalities.

A previous study investigated the idea of a 3D-manufactured removable space maintainer and evaluated this appliance's tissue adaptation.[15] Khanna *et al*.[4] have also reported manufacturing a metal-based band loop space maintainer and successful follow-up appointments over 6 months. PEEK has also preferred to produce 3D-printed intraoral appliances, and the study results revealed successful findings.[16,17] However, using different commercial polymers to fabricate space maintainers have not been well defined, and the durability of the 3D-printed commercial resin materials under the occlusal forces is questionable. In light of this data, the present study aimed to assess the fracture resistance of different diameters of 3D-printed cylindrical resin blocks under occlusal forces, *in vitro*. According to the study results, a proper diameter and thickness for this printable polymer resisting occlusal forces will also be determined. Furthermore, the convenience of using commercial resin-printed treatment modalities in the pediatric population will also be studied. The null hypothesis was that the maximum load and maximum deflection values of the study groups were similar.

MATERIAL AND METHODS

Ethical considerations

The study protocol did not need ethical approval as it was not performed on humans or the materials taken from them.

Sample size determination

Power analyses were performed, and the sample size was determined following the study in which the fracture resistance of pediatric zirconia crown was assessed.[20] G*Power Software detected the study population based on an effect size of 0.25, and an alpha significance level of 5% (0.05), to achieve an 82% power. The values for each group were determined as 15. Thus, a total of 45 samples were planned to be used for the study. Three additional samples were also planned to be printed considering the possible problems regarding the process of manufacturing and experiments.

Study groups

Group 1

The cylindric samples with a diameter of 2.00 ± 0.25 mm and length of 20.00 ± 0.25 mm were printed using a commercially printed resin (DentaClear, Asiga, Sydney, Australia) in MAX UV Direct Light Processing (DLP) printer (Asiga, Sydney, Australia).

Group 2

The cylindric samples with a diameter of 3.00 ± 0.25 mm and length of 20.00 ± 0.25 mm were printed using a commercially printed resin (DentaClear, Asiga, Sydney, Australia) in MAX UV DLP printer (Asiga, Sydney, Australia).

Group 3

The cylindric samples with a diameter of 4.00 ± 0.25 mm and length of 20.00 ± 0.25 mm were printed using a commercially printed resin (DentaClear, Asiga, Sydney, Australia) in MAX UV DLP printer (Asiga, Sydney, Australia).

3D Printing process

Sample design and manufacturing

The samples (n = 45) were designed by Meshmixer software (Autodesk Meshmixer, v3.5.35; Autodesk, Inc.) [Figure 1], and the data were saved in standard tessellation language (STL) format. The STL data were exported to 3D printer interface software (Composer; Asiga, Sydney, Australia). The printing process was carried out by MAX UV (Asiga, Sydney, Australia) DLP printer, using a commercially printed resin (DentaClear, Asiga, Sydney, Australia). The printed

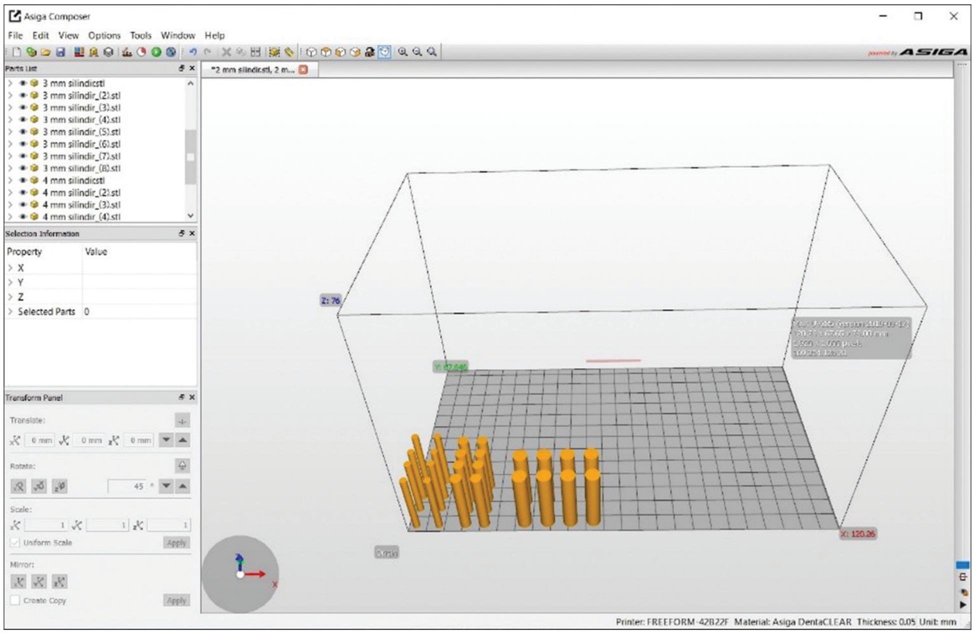

Figure 1: The appearance of the exported data in 3D printer interface software (Composer Asiga, Sydney, Australia).

samples were immersed in isopropyl alcohol for 10 min in an ultrasonic cleaner (Sonorex Super, Bandelin Electronic, Berlin, Germany) to eliminate the polymerization residues. This process was repeated 2 times for each group (n = 15), and the alcohol was refreshed for each set. Ultraviolet in 2000 flash was applied to each side of the samples following the ultrasonic cleaning process for the final polymerization of the samples in a dental polymerization device (Asiga Flash, Asiga). The accuracy of the length and diameter of the printed samples was confirmed by a digital calibrator (Marcal 16 ER).

Fracture load test

The cylindrical samples were placed in a universal testing machine (Lloyd LRX Instruments, UK). The distance between the support points was 17.45 mm. The cross-sectional tip of 1.74 mm diameter was placed perpendicular to the centrum of the samples (10 mm from each edge) [Figure 2]; the measurement was conducted at a crosshead speed of 1 mm/min. The fracture load test was stopped as soon as the fracture was observed. A computer linked to the universal testing machine recorded the maximum force for the breakage in N and the maximum deflection in mm [Figure 3].

Statistical analysis

All statistical analyses were performed using the SPSS software (Statistical Package for the Social Sciences for Windows 13.0, IBM Inc., Chicago, IL, USA). According to the Shapiro–Wilk normality test results, the data did not show a normal distribution. Kruskal–Wallis test was used to compare maximum load and maximum deflection values. The Mann–Whitney U-test was used as a *post hoc* test for multiple comparisons. The level of statistical significance was accepted as $P < 0.05$.

RESULTS

The present study results revealed that the mean values of maximum force for the fracture were 218.4 ± 31.9 in Group 3, 77.05 ± 61.5 in Group 2, and 19.67 ± 2.63 in Group 1. The mean values for maximum deflection were 2.96 ± 0.86, 3.91 ± 0.92, and 4.06 ± 1.02 for Group 3, Group 2, and Group 1, respectively [Tables 1 and 2].

The maximum load was recorded in Group 3 (280.29 N) and the maximum deflection was determined as 5.7 mm in Group 2. The minimum load was recorded in Group 1 (11.15 N) and the minimum deflection was determined as 1.84 mm in Group 3.

According to the Mann–Whitney U tests, there was a significant difference in the maximum load values among all the groups compared (P = 0.00). The mean values of maximum load for Group 3 were superior to Group 2 (P = 0.020) and Group 1 (P = 0.00). Group 2 revealed higher maximum load results than Group 1 (P = 0.003) [Table 3].

The analyses have also revealed that the mean values of maximum deflection in Group 3 were higher compared to the values of Group 2 (P = 0.014) and Group 1 (P = 005). No statistical difference was detected between the values of Group 2 and Group 1 ($P > 0.05$) [Table 3].

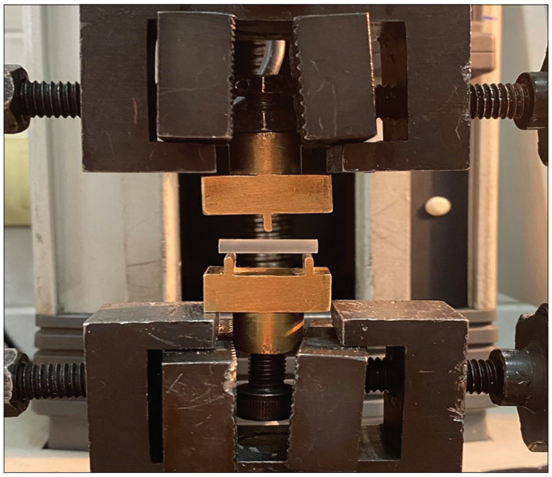

Figure 2: The cylindric sample in Universal Test Device before 3-point bending fracture load test.

DISCUSSION

The fracture resistance of different diameter resin (DentaClear-Asiga) cylindrical blocks was assessed in the present study, and the primary outcome revealed that all the diameters have the strength to resist the values resembling physiological occlusal bite forces.

Computer-aided designing and production have recently had an essential effect on dentistry. 3D design and manufacturing have lessened the time-lasting process of manufacturing prosthetic restorations, removable and fixed orthodontic devices, space maintainers, dental crowns, and surgical guides.[21-25] This design also has the advantage of personal customizing following the needs of individuals. The single-unit manufacturing of the appliance removes the risk of solder breakage and eliminates the laboratory process, lessening the chairside time by simplifying the complex workflows. The high precision of the produced appliances and materials is also one of the many advantages of 3D printing systems.[4] Considering metal-based printed materials and PEEK have been widely studied previously,[26] a commercial resin polymer was subjected in the current study. A dental material should have various features to be suitable for intraoral use, and maintaining physical integrity under several conditions is one of them.[10] Accordingly, the load-bearing of the commercial printable resin material suitable to be used for intraoral pediatric and early orthodontic dental applications was determined to be assessed in the present study.

According to the recent study results, the maximum load and deflection in the study groups were as follows: 218.4 ± 31.9, 2.96 ± 0.86 in Group 3, 77.05 ± 61.5, and 3.91 ± 0.92 in Group, 2, 19.67 ± 2.63 and 4.06 ± 1.02 in Group 1. Regarding the values of maximum load, Group 3 was superior to Groups 1 and 2, while the values of Group 2 were higher than Group 1.

Table 1: The descriptive variables of maximum load values before fracture.

Max load	*n*	Mean±SD	25% quartile values	75% quartile values	Median
Group 1	15	19.67±2.63	20.31	147.8	20.01
Group 2	15	77.05±61.5	52.75	57.34	54.41
Group 3	15	218.4±31.9	192.52	236.63	223.02

Descriptive statistical analysis was performed. Group 1: 2 mm samples, Group 2: 3 mm samples, Group 3: 4 mm samples. Max load: Maximum load (N), SD: Standard deviation

Table 2: The descriptive variables of maximum deflection values before fracture.

Max Def.	*n*	Mean±SD	25% quartile values	75% quartile values
Group 1	15	4.06±1.02	3.28	5.18
Group 2	15	3.91±0.92	3.27	4.76
Group 3	15	2.96±0.86	2.44	3.33

Descriptive statistical analysis was performed. Group 1: 2 mm samples, Group 2: 3 mm samples, Group 3: 4 mm samples. Max load: Maximum load (N), SD: Standard deviation.

Table 3: The mean values of maximum load and maximum deflection for each group.

	Group 1	Group 2	Group 3	*P**
	Mean±SD	Mean±SD	Mean±SD	
Max load	19.67±2.63[a]	77.05±61.5[b]	218.4±31.9[c]	0.00*
Max def	4.06±1.02[d]	3.91±0.92[d]	2.96±0.86[e]	0.03*

Kruskal–Wallis and Mann–Whitney U tests were performed. Group 1: 2 mm samples, Group 2: 3 mm samples, Group 3: 4 mm samples. Max load: Maximum load (N), Max def: Maximum deflection (mm), SD: Standard deviation. *There is a statistically significant difference at $P<0.05$. Groups with different letters are significantly different from each other

Since the thickness of the cylindrical blocks was enhanced, the maximum load values before the occurrence of fracture were increased. Therefore, the thickness of the material was found to be correlated with fracture resistance.

Although the values of max deflection were higher in Group 1, there was no significant difference between the values of Groups 1 and 2. The deflection of the samples in Group 3 was found to be less than the other groups, statistically. Even though the increase in diameter was the same (1 mm) in all groups, the statistical difference was not detected between all the groups compared, and the difference in the volume change of the cylindrical blocks may cause these results.

A 3-point bending test assessed the fracture resistance of different dental materials and treatment appliances in a

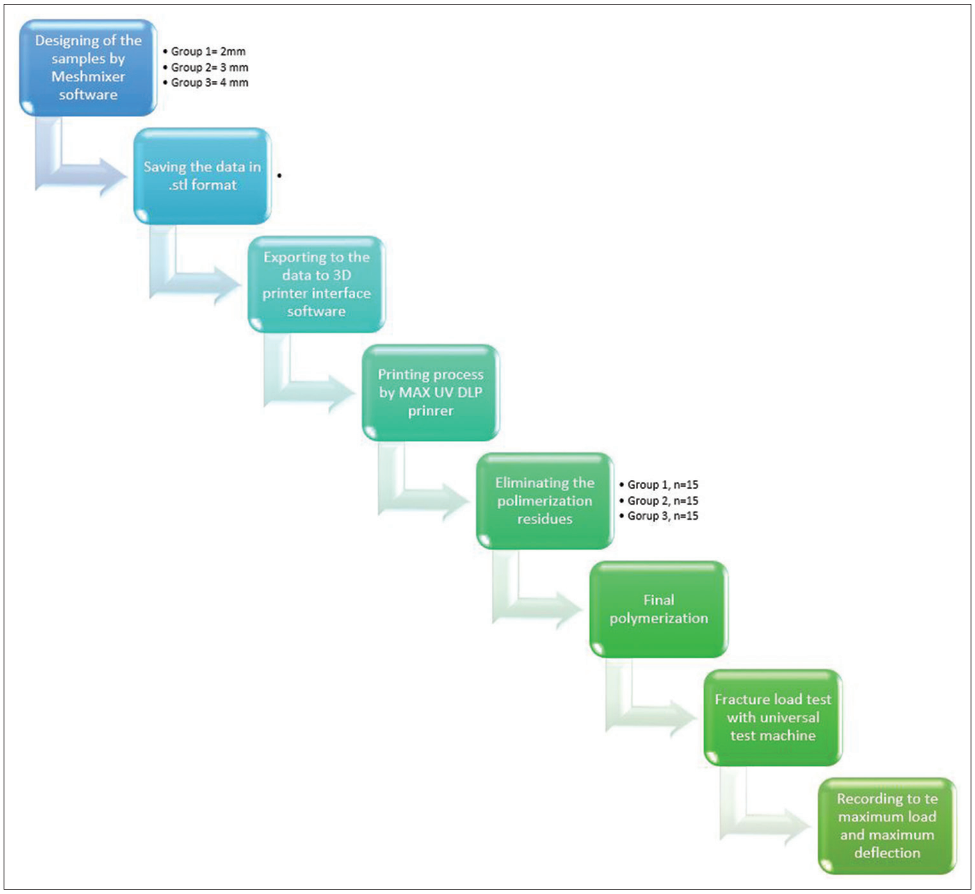

Figure 3: The flowchart of the study.

universal testing machine in previous studies.[9,27] In a study held by Çiftçi *et al.*,[27] the maximum load before fracture of various commercial fiber posts were comparably evaluated by a 3-point bending test. In another study, the fracture resistance of different pediatric zirconia crowns was aimed to be assessed by the same tests.[28] This technique is a well-accepted method for assessing the mechanical properties of materials regarding strength, and accordingly, in the recent study, the 3-point bending test was preferred.

In a previous case report presented by Pawar,[29] a fixed titanium-based space maintainer was designed and printed. In 3 months of follow-up appointments, the space maintainer was found intact. In another case report,[4] a 3D-printed space maintainer's clinical survival was compared to a conventional band-loop space maintainer for 6 months. Accordingly, while no plaque accumulation was observed in the 3D-printed space maintainer's surface, a mild inflammation was examined in the neighborhood gingiva of the conventional band-loop space maintainer with deformations in the buccal aspect of the material.[4] These case reports revealed that, according to clinical examinations, the 3D space maintainers were found to be superior to conventional appliances and could be a successful alternative to conventional analogs. Although metal-based printable materials were tried and polymers were not preferred to be used, these papers support the idea of printable and customized early orthodontic treatment appliances in children.

The physiological occlusal forces and the maximum bite forces differ in several conditions. The results detected in the previous studies vary in an extensive range between 10 N and 433 N in children with mixed dentition. Although the present study findings were compatible with physiological bite forces, the maximum load may differ in various regions and conditions such as bruxism, malocclusions, and muscular tonus alterations. The values of the present study seem to be inadequate to withstand the exceed occlusal forces.[11,12] Therefore, the intraoral use of the studied resin material for permanent applications should also be examined in future clinical studies.

However, this study was planned as the first stage of the following projects, and determining the correct diameter of the studied polymer was the main aim and the only parameter. A single type (DLP) of a 3D printer with one resin sample was used in the present study. Since the values of occlusal forces are well documented, a control group resembling conventional materials was not performed in the recent study. In future approaches, adding different comparing factors such as the type of the 3D printer, content type of the polymer used, and the effect of time-heat-mechanical factors related to the oral conditions might affect the results. Different aging procedures such as thermal cycles and chewing simulations may be added to the study protocol of a future study to simulate the oral conditions. The biocompatibility tests, the color changes in the printed resin related to individuals' nutrition habits, and the dental plaque accumulation on the resin material may also be examined in the following studies.

In future approaches, the design of programmable and four-dimensional dentistry applications can take the place of conventional procedures. Being familiar with the current treatment modalities of 3D systems seems like the pre-condition for keeping up with future medical advances. The present study may expand the clinics' digital dentistry scope and encourage pediatric dentistry practitioners to choose digital alternatives to conventional dentistry procedures.

According to the present study results, the designed samples in all diameters revealed the resistance toward the values resembling the physiological occlusal forces. Group 3 showed better results in force resistance, while Group 1 had higher deflection values. These findings had importance in 3D dentistry applications, especially in pediatric dentistry and early orthodontic treatment practices. The obtained values may be used in future studies in which printable resin materials will be examined in detail. Furthermore, this study can be approved as the first stage of future projects examining the various mechanical, biological, and chemical features of the resin-printed oral appliances planned to be used in the oral cavity of pediatric patients.

CONCLUSION

- Digital approaches have started to take the place of conventional dental treatment modalities in all fields of dentistry. Although different substitutes have been tried for the 3D manufacturing process, there have been questions about the intraoral use of commercial resin materials regarding the strength of the printable resins.
- According to the study results, the resin-printed cylindrical samples in all diameters have the strength to resist the values resembling the physiological occlusal bite forces. Since these resin materials were planned to be used to produce space maintainers, orthodontic appliances, occlusal splints, and other similar treatment modalities, these results may encourage pediatric dentists to prefer 3D technologies in their daily clinic routines instead of conventional methods and expand the pediatric dentists' scope in digital dentistry.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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