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Jiho Lee, Jin Hong Min, Hoon Kim*

**Graphy R&D Center
Graphy Inc.**

jiholee@itgraphy.com
hkim@itgraphy.com

ACCURACY OF FIT OF DIRECT PRINTED ALIGNERS VERSUS THERMOFORMED ALIGNERS

Nickolas Koenig, D.D.S.

2020

A Thesis Presented to the Graduate Faculty of Saint Louis University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dentistry

SHAPE MEMORY IN DIRECT-PRINTED 3D ALIGNERS AND EXPLORATION OF THE EFFECTS OF ATTACHMENTS AND TEMPERATURE

Evan Hertan, D.D.S.

2021

A Thesis Presented to the Graduate Faculty of Saint Louis University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dentistry

European Journal of Orthodontics, 2021, 1-9
doi:10.1093/ejo/cjaa022
Original article

OXFORD

Original article

In-house 3D-printed aligners: effect of *in vivo* ageing on mechanical properties

Esad Chan^{1,*}, Nearchos Panayi^{2,*}, Georgios Polychronis³, Spyridon N. Papageorgiou^{1,4}, Spiros Zinelis⁵, George Eliades³ and Theodore Eliades^{1,6}

¹Clinic of Orthodontics and Paediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland, ²Private Practice, Limassol, Cyprus, ³Department of Biomechanics, School of Dentistry, National and Kapodistrian University of Athens, Athens, Greece

*Equal contribution

Correspondence to: Theodore Eliades, Clinic of Orthodontics and Paediatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, Zurich 8032, Switzerland. E-mail: theodore.eliades@zsm.unizh.ch

Summary

Objective: To investigate alterations in the mechanical properties of in-house three-dimensional (3D) printed orthodontic aligners after intrasoral ageing.

Materials and methods: Sixteen 3D-printed aligners (TC-85QAC resin, Graphy, Seoul, Korea) were used for the purpose of the study, which were divided into 10 control (not used) aligners and 6 materials retrieved from 4 patients after 1-week service (retrieved group). Samples from the control group were analysed by attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy. Samples from control/retrieved groups were embedded resin and subjected to instrumented indentation testing (IT) to record force-indentation depth curves, calculating the following (as per ISO 14577-1, 2002 standard): Martens hardness (HM), indentation modulus (E_{it}), and elastic index (η_{it}), and the indentation relaxation index (R_{it}). Differences between control and retrieved 3D printed aligners were checked with Mann-Whitney tests at an alpha = 5%.

Results: ATR-FTIR analysis showed that aligners were made of a vinyl ester-urethane material. The results of the IT testing were: HM (control: median 915 N/mm², interquartile range [IQR] 88.0–93.0; as-retrieved: median 90.5 N/mm², IQR 89.0–93.0); E_{it} (control, mean 2616.3 MPa, standard deviation [SD] 107.0 MPa; as-retrieved, mean 2673.2 MPa, SD 143.4 MPa); η_{it} (control: median 28.8%, IQR 28.2–30.9%; as-retrieved: median 29.6%, IQR 28.7–29.2%); and R_{it} (control: median 45.5%, IQR 43.0–47.0%; as-retrieved: median 45.1%, IQR 45.0–45.3%). No differences between as-retrieved and control aligners were found for any of the mechanical properties tested ($P > 0.05$ in all instances).

Conclusion: The mechanical properties of the in-house 3D-printed aligners tested were not affected after 1 week in service period.

Introduction

Aligners present a highly aesthetic orthodontic treatment modality and assumes the first preference for many adult patients (1–3) regardless about their objective performance (4). Despite the high demand however for this modality, aligners are still a rather costly and complicated third-party controlled treatment option, due to the necessary involvement of aligner manufacturers or laboratories in the manufacturing process, which incurs fees and delays the appliance delivery. To overcome these obstacles, dental practitioners have adopted in-house three-dimensional (3D) printing technology as a cost-effective 'Do It Yourself' (5–7) workflow method. Such techniques are proposed to be able to offer same-day appliance

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scientific reports

OPEN

Thermo-mechanical properties of 3D printed photocurable shape memory resin for clear aligners

Se Yeon Lee^{1,2}, Hoon Kim^{3,4,5,6}, Hyun-Joong Kim^{3,4}, Chooryung J. Chung⁷, Yoon Jeong Choi⁸, Su-Jung Kim¹ & Jung-Yul Cha^{1,2}

To overcome the limitations of the conventional vacuum thermofforming manufacturing method, direct 3D printing of clear aligners has been developed. The present study investigated the thermo-mechanical and viscoelastic properties of a photocurable resin TC-85, which is a new material for the direct 3D printed clear aligners, comparing to a conventional thermoplastic material polyethylene terephthalate glycol. Dynamic mechanical analysis was performed to analyse the mechanical behaviours of the two materials at 37 °C and 80 °C, respectively. Furthermore, the shape memory property of the two materials was evaluated using a U-shape bending test, and the shape recovery ratio for 60 min at 37 °C was calculated. The results indicate that TC-85 can constantly apply a light force to the teeth when used for the 3D printed clear aligners, owing to its flexibility and viscoelastic properties. In addition, it is expected that the force decay induced by repeated insertion of the clear aligners will be reduced and a constant orthodontic force will be maintained. Furthermore, its geometric stability at high temperatures and the shape memory properties provide advantages for the clinical application.

Clear aligners have been investigated since Kolling first introduced a tooth positioner fabricated with a elastic polymer in 195, to move the teeth without bands, brackets, or wires¹, while Johnson reported a vacuum formed dental contour appliance in 1964². Align Technology Inc. (Santa Clara, CA, USA) has collated several concepts across literature and applied computer-aided design (CAD)/computer-aided manufacturing (CAM) technology to the manufacturing process of clear aligners. As a result, the efficiency of manufacturing clear aligners has increased and expanded their range of applications³. Accordingly several efforts have been made to develop advanced materials that are suitable for the CAD/CAM technology.

Currently various thermoplastic terephthalate glycol (PETG), polypropylene, polycarbonate, thermoplastic polyurethanes (TPU), and copolyester, are being used to manufacture clear aligners⁴. Among those, PETG is widely used because of its excellent impact and tear strength, better properties, chemical resistance, and transparency⁵. In addition, TPU with greater elasticity is used by Align Technology Inc. (Santa Clara, CA, USA) to achieve more predictable orthodontic movements by applying a lighter and more constant force. Furthermore, multi-layered materials have been developed to overcome the limitations of a single material by improving the physical properties of maximum tensile load-bearing capacity⁶.

The development of new materials and enhancement of the material properties have significantly improved the performance of the clear aligners. However, the clear aligners are still manufactured by the conventional method of vacuum thermofforming biocompatible thermoplastic transparent materials a dental model⁷, which is a complex manufacturing process requiring considerable time and effort. In addition, geometric inaccuracies are induced during the thermofforming process⁸, the shrinkage and expansion of the material that occurs during the thermofforming process affects the orthodontic force and fit of the clear aligners to the dentition. In a study evaluating the fit of the clear aligners fabricated with thermoplastic materials, all materials showed

Scientific Reports | (2021) 11:16146 | <https://doi.org/10.1038/s41598-021-09051-4> | www.nature.com/scientificreports/

A1. 2020

Accuracy of Fit of Direct Aligners versus Thermoformed Aligners

A2. 2021

Shape Memory in Direct-Printed 3D Aligners and Exploration of the Effects of Attachments and Temperature

A3. 2021, EJO

In-house 3D-printed aligners: effect of *in vivo* ageing on mechanical properties

A4. 2022, Scientific Reports

Thermo-Mechanical Properties of 3D Printed Photocurable Shape Memory Resin for Transparent Orthodontic Aligners

IF(2023) : 4.379
Citations : 22

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A2. 2021

Shape Memory in Direct-Printed 3D Aligners and Exploration of the Effects of Attachments and Temperature

Original article

In-house 3D-printed aligners: effect of *in vivo* ageing on mechanical properties

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A3. 2021, EJO

In-house 3D-printed aligners: effect of *in vivo* ageing on mechanical properties

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Thermo-mechanical properties of 3D printed photocurable shape memory resin for clear aligners

Se Yeon Lee^{1,2}, Hoon Kim^{3,4,5,6}, Hyun-Joong Kim^{3,4}, Chooryung J. Chung⁷, Yoon Jeong Cho⁸, Su-Jung Kim¹ & Jung-Yul Cha^{1,2}

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Currently various thermoplastic terephthalate glycol (PETG), polypropylene, polycarbonate, thermoplastic polyurethanes (TPU), and copolyester, are being used to manufacture clear aligners⁴. Among them, PETG is widely used because of its excellent impact and thermal barrier properties, chemical resistance, and transparency⁵. In addition, TPU with greater elasticity is used by Align Technology Inc. (Santa Clara, CA, USA) to achieve more predictable orthodontic movements by applying a lighter and more constant force. Furthermore, multi-layered materials have been developed to overcome the limitations of a single material by improving the physical properties of maximum tensile load-bearing capacity⁶.

The development of new materials and enhancement of the material properties have significantly improved the performance of the clear aligners. However, the clear aligners are still manufactured by the conventional method of vacuum thermofforming biocompatible thermoplastic transparent materials a dental model⁷, which is a complex manufacturing process requiring considerable time and effort. In addition, geometric inaccuracies are induced during the thermofforming process⁸. The shrinkage and expansion of the material that occurs during the thermofforming process affects the orthodontic force and fit of the clear aligners to the dentition. In a study evaluating the fit of the clear aligners fabricated with thermoplastic materials, all materials showed

Department of Orthodontics, College of Dentistry, Yonsei University, Seoul, Korea; ²Research Institute of Agriculture and Life Sciences, College of Agriculture and Life Sciences, Seoul National University, Seoul, Korea; ³Graphy Inc., Graphy R&D Center, Seoul, Korea; ⁴Laboratory of Adhesion and Bio-Composites, Department of Agriculture, Forestry and Bioresources, Seoul National University, Seoul, Korea; ⁵Department of Orthodontics, Gangneung Severance Hospital, Institute of Craniofacial and Maxillofacial, College of Dental Medicine, Yonsei University, Seoul, Korea; ⁶Department of Orthodontics, Institute of Craniofacial Deformity, College of Dentistry, Yonsei University, 53-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea; ⁷Department of Orthodontics, Yonsei University School of Dentistry, Seoul, Korea; ⁸These authors contributed equally: Se Yeon Lee and Hoon Kim. *email: jungyulcha@yonsei.ac.kr

Scientific Reports | (2021) 11:16146 | <https://doi.org/10.1038/s41598-021-09051-4> | nature portfolio

A4. 2022, Scientific Reports

Thermo-Mechanical Properties of 3D Printed Photocurable Shape Memory Resin for Transparent Orthodontic Aligners

ORIGINAL ARTICLE **AJO-DO**

Cytotoxicity and estrogenicity of a novel 3-dimensional printed orthodontic aligner

Harris Pratsinis,¹ Spyridon N. Pappagorgiou,² Nearchos Panayi,³ Anna Iliadi,⁴ Theodore Eliades,⁵ and Dimitris Klotzsch⁶

¹Athens, Greece, ²Zurich, Switzerland, and ³Limassol, Cyprus

Introduction: Orthodontic aligners printed with in-office 3-dimensional (3D) procedures have been described, but no data on their biocompatibility exist. This study investigates the cytotoxicity and estrogenicity of a 3D-printed orthodontic aligner by assessing its biological and behavioral effects. **Methods:** Ten sets of 1 type of aligner were immersed in sterile deionized water for 14 days, and the cytotoxicity and estrogenicity of released factors were assessed via MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) assays on human gingival fibroblasts and the estrogen-sensitive MCF-7 and the estrogen-insensitive MDA-MB-231 breast cancer cell lines. 17 β -Estradiol and bisphenol-A were used as positive controls. The statistical analysis of data was performed with generalized linear models at a 0.05 level of significance. **Results:** No signs of cytotoxicity were seen for the aligner samples for concentrations (w/v) of 20% ($P = 0.32$), 10% ($P = 0.79$), or 5% ($P = 0.78$). The antioxidant activity expressed as the capacity to reduce intracellular levels of reactive oxygen species was not affected in the aligner samples ($P = 0.08$). No significant estrogenicity was induced by the aligner samples compared with eluents from the negative control for both MCF-7 ($P = 0.65$) and MDA-MB-231 ($P = 0.78$). As expected, 17 β -Estradiol and bisphenol-A stimulated MCF-7 cell proliferation, whereas no effect was observed on MDA-MB-231 cells. **Conclusions:** In conclusion, if any factors were released during the 14-day aging of 3D-printed aligners in water, these were not found to be cytotoxic for human gingival fibroblasts and did not affect their intracellular reactive oxygen species levels. Moreover, no estrogenic effects of these putative eluates were observed based on an E-screen assay. (*Am J Orthod Dentofacial Orthop* 2022; ■ e1-e7)

Orthodontic treatment of a large spectrum of malocclusions with aligners has become increasingly popular in recent years, partly because of the increased demand for treatment by adult patients and internet advertisement to patients. However, evidence about the objectively measured clinical performance of aligners compared with fixed appliances remains unclear. At the same time, orthodontic treatment with clear aligners involving the use of multiple, often bulky, composite resin attachments to enhance the aligners' clinical performance has introduced several issues pertaining to alterations of the tooth structure or optical properties,¹⁻³ alterations of the aligners' material properties,⁴⁻⁷ and alterations of the bonded resin attachments.^{8,9} At the same time, intraoral aging of orthodontic materials affects their structural integrity and several material properties, like hydrolytic stability and plasticization,¹⁰ which might result in component molecules being released intraorally, with bisphenol-A (BPA) being mostly discussed.

*Laboratory of Orthodontics and Aging, Institute of Biomedical and Applications, National Center for Scientific Research "Demokritos," Athens, Greece. ²Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland. ³Department of Dentistry, European University Cyprus, Nicosia, Cyprus; Private practice, Limassol, Cyprus. ⁴Department of Dental Biomaterials, School of Dentistry, National and Kapodistrian University of Athens, Athens, Greece. ⁵Units Praxinos and Spyridon N. Pappagorgiou contributed equally to this manuscript. All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Nearchos Panayi declared a financial interest with the company Clear Aligners, having received the orthodontic computer-aided design software iBrackets, but did not participate in specimen testing or data analysis. The remaining authors declare that they have no competing interests. Address correspondence to: Theodore Eliades, Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, Zurich, CH-8002, Switzerland; e-mail: theodore@idm.kjp.unizh.ch. Submitted, February 2022; revised and accepted, June 2022. © 2022 by the American Association of Orthodontists. All rights reserved. https://doi.org/10.1016/j.ajodo.2022.06.014

A5. 2022, AJO-DO

Cytotoxicity and estrogenicity of a novel 3-dimensional printed orthodontic aligner

children **MDPI**

Review **Three-Dimensional-Printed Customized Orthodontic and Pedodontic Appliances: A Critical Review of a New Era for Treatment**

Ioannis A. Tsolakis ¹, Sotiria Giziari ¹, Apostolos I. Tsolakis ^{1,4} and Nearchos Panayi ^{1,4}

¹ Department of Orthodontics, School of Dentistry, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece; ² Department of Paediatric Dentistry, Dental School, National and Kapodistrian University of Athens, Athens 11527, Greece; ³notingtan@gmail.com; ⁴ Department of Orthodontics, National and Kapodistrian University of Athens, School of Dentistry, Athens 11527, Greece; ⁵apostoloi@uoi.gr; ⁶ Department of Orthodontics, C.W.F.E.L., Cleveland, OH 44115, USA; ⁷ Department of Orthodontics, European University of Cyprus, School of Dentistry, Egkoura 2404, Cyprus; ⁸ ipanayi@uoi.ac.cy; ⁹ School of Medicine, National and Kapodistrian University of Athens, Athens 11527, Greece; * Correspondence: iatsolakis@gmail.com

Abstract: Three-dimensional (3D) designing and manufacturing technology is a direct derivative of digital technology. Three-dimensional volume and surface acquisition, CAD software, and 3D manufacturing are major changes included in daily practice in many orthodontic and pedodontic offices. Customized appliances can be designed using dental CAD software or general-purpose CAD software in the office or a laboratory. Materials that can be used are resin, alloy, or titanium. **Methods:** The search strategy of this critical review included keywords in combination with MeSH terms in Medline, Scopus, and Cochrane Library up to June 2022 in the English language without any limit to the publication period. **Results:** According to our search, 12 articles were selected for our study. All the articles were in vitro prospective studies. **Conclusions:** The results suggested that almost all the known appliances can be designed and printed in a tailor-made fashion in contrast to the traditional one-size-fits-all approach. Customized appliances should be manufactured according to the patient's needs, and this is justified by the certainty that this approach will be beneficial for the patient's treatment. There is a need for more research on all direct 3D-printed appliances.

Keywords: 3D printing; CAD software; CoCr; resin; titanium; customized orthodontic appliances

1. Introduction

In the last century, significant advancements have been introduced into our daily lives. Engineering, computers, and software are some of the significant parts of this evolution. Unavoidably, this change has affected medicine and dentistry, mainly in the aspects of diagnosis and treatment. In the last few years, advancements in 3D technology have allowed the three-dimensional (3D) designing and printing of customized orthodontic appliances [1]. Traditionally, almost all orthodontic appliances were designed and manufactured in the environment of an orthodontic laboratory. Dental arch impressions were taken and sent to the lab, where dental casts were poured using plaster. Depending on the kind of appliances to be made, acrylic, orthodontic laboratory waxes, bands, soldering materials, premanufactured appliances parts, and wax were used. The appliances were in a way customized, meaning that they were made to fit the specific patient. Nevertheless, most appliance parts were bent and formed to match the particular patient's

children 2022, 9, 1107; https://doi.org/10.3390/children911107 www.mdpi.com/journal/children

A6. 2022, Children

Three-Dimensional-Printed Customized Orthodontic and Pedodontic Appliances: A Critical Review of a New Era for Treatment

Original Article **KJO**

ISSN 2234-7518 • ISSN 2005-173X
https://doi.org/10.4013/kjo.2021.1309

Comparison of dimensional accuracy between direct-printed and thermoformed aligners

Nickolas Koenig ¹, Jin-Young Choi ², Julie McCray ³, Andrew Hayes ⁴, Patricia Schneider ⁵, Ki Beom Kim ⁶

Objective: The purpose of this study was to evaluate and compare the dimensional accuracy between thermoformed and direct-printed aligners. **Methods:** Three types of aligners were manufactured from the same reference tessellation language (STL) file: thermoformed aligners were manufactured using Zentura FLX[®] (n = 12) and Essix ACE[™] (n = 12), and direct-printed aligners were printed using Tera Hand[™] TC-BSDAP 3D Printer IV Resin (n = 12). The teeth were not manipulated with any tooth-moving software in this study. The samples were sprayed with an opaque scanning spray, scanned, imported to Geomagic[®] Control X[™] metrology software, and superimposed on the reference STL file by using the best-fit alignment algorithm. Distances between the aligner meshes and the reference STL file were measured at nine anatomical landmarks. **Results:** Mean absolute discrepancies in the Zentura FLX[®] aligners ranged from 0.076 ± 0.057 mm to 0.250 ± 0.089 mm and those in the Essix ACE[™] aligners ranged from 0.188 ± 0.271 mm to 0.457 ± 0.350 mm, while in the direct-printed aligners, they ranged from 0.079 ± 0.054 mm to 0.224 ± 0.041 mm. Root mean square values, representing the overall trueness, ranged from 0.209 ± 0.094 mm for Essix ACE[™], 0.188 ± 0.074 mm for Zentura FLX[®], and 0.140 ± 0.020 mm for the direct-printed aligners. **Conclusions:** This study showed greater trueness and precision of direct-printed aligners than thermoformed aligners.

Key words: Aligner; Physical property; Resin; Three-dimensional scanner

Received October 26, 2021; Revised January 16, 2022; Accepted January 19, 2022.

Corresponding author: Ki Beom Kim, Professor and Chair, Department of Orthodontics, Saint Louis University, 3320 Ridge St, St. Louis, MO 63104, USA. Tel: +1-314-977-8367 • e-mail: kkim@slu.edu

Nickolas Koenig and Jin-Young Choi contributed equally to this work as co-first authors.

How to cite this article: Koenig N, Choi JY, McCray J, Hayes A, Schneider P, Kim KB. Comparison of dimensional accuracy between direct-printed and thermoformed aligners. Published online April 22, 2022. https://doi.org/10.4013/kjo.2021.1309

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A7. 2022, KJO

Comparison of dimensional accuracy between direct-printed and thermoformed aligners

children **MDPI**

Article **Novel 3D Printed Resin Crowns for Primary Molars: In Vitro Study of Fracture Resistance, Biaxial Flexural Strength, and Dynamic Mechanical Analysis**

Nayoung Kim ¹, Hoon Kim ², He-Hwan Kim ³, Jiho Lee ⁴, Ko Eun Lee ⁴, Hye-Seol Lee ⁴, Jee-Hwan Kim ⁴, Je Seon Song ^{1,4} and Yoonsook Shin ⁷

¹ Department of Pediatric Dentistry, College of Dentistry, Yonsei University, Seoul 03722, Korea; ² Research Institute of Agriculture and Life Sciences, College of Agriculture and Life Sciences, Seoul National University, Seoul 08050, Korea; ³ Department of Pediatric Dentistry, Yonsei University Dental Hospital, Seoul 03722, Korea; ⁴ Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Korea; ⁵ Department of Pediatric Dentistry, Kyung Hee University Dental Hospital, Seoul 03047, Korea; ⁶ Department of Prosthodontics, College of Dentistry, Yonsei University, Seoul 03722, Korea; ⁷ Department of Conservative Dentistry, College of Dentistry, Yonsei University, Seoul 03722, Korea; * Correspondence: songj@yda.ac.kr; Tel: +82-2-392-7420

Abstract: This study evaluated the fracture resistance, biaxial flexural strength (BFS), and dynamic mechanical analysis (DMA) of three-dimensional (3D) printing resins for the aesthetic restoration of primary molars. The 3D printing resins, Geomagic[®] GP and NextDent (NXT), and a prefabricated zirconia crown, NuSmile (NS), were tested. GP and NXT samples were 3D printed using the workflow recommended by each manufacturer. Data were analyzed and statistically analyzed. As a result of the fracture resistance test of 67-mm-thick 3D printed resin crowns with a thickness similar to that of the NS crown, there was no statistically significant difference among GP (1491.6 ± 394.6 N), NXT (1614.4 ± 293.9 N), and NS (1622.8 ± 323.9 N). The BFS of GP was higher for all thicknesses than that of NXT. Both resins showed high survival probabilities (more than 90%) when subjected to 50 and 150 MPa. Through DMA, the glass transition temperatures of GP and NXT were above 120 °C and the rheological behavior of GP and NXT according to temperature and frequency were analyzed. In conclusion, GP and NXT showed optimum strength to withstand bite forces in children, and 3D printed resin crowns could be an acceptable option for fixed prostheses of primary teeth.

Keywords: 3D printing; mechanical properties; fracture resistance; biaxial flexural strength; dynamic mechanical analysis; primary molar; 3D printed resin crown

1. Introduction

Esthetic dentistry has become an essential component of modern pediatric dentistry [1,2]. Parents' demands for cosmetic solutions when restoring their children's teeth are increasing these days [3,4]. In addition, children themselves want dentists to restore their decayed teeth to their original appearance [5,6].

The treatment of decayed primary teeth has always been challenging for clinicians. For children who present extensive, multi-surface lesions or high caries-risk, the American Academy of Pediatric Dentistry advocates for the use of full-coverage restorations. The most frequently used restoration has been a prefabricated stainless-steel crown (SSC). SSC is recommended due to its long-term durability, low recurrent caries, low cost, and ease of preparation and placement [7]. Despite these benefits, parents and patients are unsatisfied with the color of SSC owing to its metallic appearance [5,8]. Various attempts have been made to overcome this esthetic problem by introducing open-face SSC, pre-veneered SSC, and zirconia crowns. An open-faced SSC has a facial window cut, wherein the

children 2022, 9, 1445; https://doi.org/10.3390/children9111445 https://www.mdpi.com/journal/children

A8. 2022, Children (TC-80)

Novel 3D Printed Resin Crowns for Primary Molars - In Vitro Study of Fracture Resistance, Biaxial Flexural Strength, and Dynamic Mechanical Analysis

IF(2022) : 16.44
Citations : 12



Advances in orthodontic clear aligner materials
Yashodhan M. Bichu^a, Abdulraheem Alwaifi^{b,c}, Xiaomo Liu^d, James Andrews^e, Björn Ludwig^f, Aditi Y. Bichu^g, Bingzhuang Zou^h

ABSTRACT
Rapid technological improvements in biomaterials, computer-aided design (CAD) and manufacturing (CAM) have endeavored clear aligner therapy (CAT) as a mainstay of orthodontic treatment, and the materials employed for aligner fabrication play an all-important role in determining the clinical performance of clear aligners. This narrative review has attempted to comprehensively encompass the entire gamut of materials currently used for the fabrication of clear aligners and elucidate their characteristics that are crucial in determining their performance in an oral environment. Historical developments and current protocols in aligner fabrication, features of contemporary bioactive materials, and emerging trends related to CAT are discussed. Advances in aligner material chemistry and engineering possess the potential to bring about radical transformations in the therapeutic applications of CAT; in the absence of which, clear aligners would continue to underperform clinically, due to their inherent biomechanical constraints. Finally, while innovations in aligner materials such as shape memory polymers, direct three-dimensional (3D) printed clear aligners and bioactive materials combined with clear aligner materials are essential to further advance the applications of CAT, increased awareness of environmental responsibilities among aligner manufacturers, aligner prescribing clinicians and aligner users is essential for better alignment of our climate change goals towards a sustainable planet.

1. Introduction
With the rapid technological improvements in biomaterials, computer-aided design (CAD) and manufacturing (CAM), clear aligner therapy (CAT) has emerged as a promising alternative to conventional fixed appliances (TFA) in orthodontics. The demand for CAT has increased significantly over the last decade, presumably due to aggressive marketing strategies by commercial clear aligner companies that employ direct-to-consumer advertising as well as widespread utilization of various social media channels, thereby generating heightened public awareness for aesthetic orthodontic treatment alternatives, especially for the adult patients [1]. The global clear aligners market size was projected to increase from USD 3.1 billion in 2021 to USD 11.6 billion in 2027 with a compound annual growth rate (CAGR) of 13% [2]. A recent survey carried out across North America also indicated that more

Peer review under responsibility of KAI Communications Co., Ltd.
* Corresponding author. Department of Oral Health Science, Faculty of Dentistry, The University of British Columbia, Vancouver, V6T 1Z3, Canada.
E-mail address: drwaifi@dentistry.ubc.ca (B. Zou).
https://doi.org/10.1016/j.bioactmat.2022.10.006
Received 6 September 2022; Received in revised form 5 October 2022; Accepted 6 October 2022
Available online 20 October 2022
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IF(2022) : 5.43

Hertan et al. Progress in Orthodontics (2022) 23:49
https://doi.org/10.1186/s40510-022-00443-2

Progress in Orthodontics
SHORT REPORT Open Access

Force profile assessment of direct-printed aligners versus thermoformed aligners and the effects of non-engaged surface patterns

Eván Hertan, Julie McCray, Brent Bankhead and Ki Beom Kim^{*}

Abstract
Background: The purpose of the study was to measure the forces delivered by direct-printed aligners (DPA) in the vertical dimension and compare the force profile with traditional thermoformed aligners (TFA) and to investigate the impact of non-engaged surface patterns to the properties of DPA and TFA.
Methods: A force-measuring appliance was fabricated capable of displacing the aligner in 0.10 mm increments and measuring the resultant force. Polyethylene terephthalate glycol (ATMOS 0.030[®] American Orthodontics) and TC 85D4C resin (Graphy Inc) were used to create TFA and DPA, respectively. Aligners were temperature-controlled prior to and during testing to simulate the oral environment. The resultant forces from displacements ranging from 0.10 to 0.30 mm were measured.
Results: At intraoral temperatures, DPA demonstrated significantly less force than TFA. TFA demonstrated a substantial statistically significant increase in force with each 0.10 mm increase in vertical displacement. DPA demonstrated a much more consistent force profile across the range of displacements. The effects of surface patterns in both DPA and TFA were generally a decrease in force. Statistical significance of surface patterns was detected for TFA at displacements of 0.30 mm and greater and significant for DPA only at a displacement of 0.10 mm. Surface patterns in both DPA and the TFA did not show any statistical difference when assessing force properties.
Conclusions: Forces delivered by aligners in the vertical dimension by DPA are more consistent and of lower magnitude than those of TFA aligners. Surface patterns were not capable of altering the force properties of both DPA and TFA.

Background
New technological developments and market demands have rapidly increased the availability and affordability of intrascan scanners and 3D printers. These technological advancements combined with the market demand for aesthetic treatment options have driven a surge in the use of clear aligners for orthodontic tooth movement [1, 2]. Clear Aligner treatment utilizing 3D printing technology has been limited to printing 3D models with staged

*Correspondence: kiboomkim@health.ubc.ca
Department of Orthodontics, Saint Louis University, 3330 Rutger Street, Saint Louis, MO 63104, USA

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ARTICLE IN PRESS

3D printed aligners: Material science, workflow and clinical applications

Nearchos Panayi, Jung-Yeol Cha, and Ki Beom Kim

Clear aligner orthodontic treatment is not a new treatment modality. Treatment with the use of plastic invisible removable appliances counts more than 80 years when Kesling introduced the tooth positioner, Sheridan introduced the Essex aligner and Align technology its aligners. In-house designing and aligner fabrication has been around for more than 10 years. The last years a digital technological and material advancement has changed the process of aligner manufacturing from the plastic foil thermoforming procedure to a direct aligner printing one. Direct aligner printing poses advantages and some disadvantages compared to the traditional thermoforming procedure. The aligner designing and printing workflow entails steps that are sensitive to errors that must be carefully analyzed and studied through scientific research. Due to the versatile printed aligner designing capabilities, aligners can be designed to fulfill specific clinical needs. A few evidence based scientific studies have been published which help to understand and optimize the final printed outcome. Despite that, more studies are needed in order to overcome difficulties and create an appliance that will meet the demands of a successful orthodontic treatment. (Seminar Orthod 2023; 11:1-14) © 2023 Elsevier Inc. All rights reserved.

Introduction

Evolution of aligners

Aligner introduction into orthodontics is the consequence of a demand for esthetic and invisible orthodontic treatment. Kesling back in 1945 was the first to introduce an appliance called tooth positioner for teeth moving without the use of fixed appliances.¹ The tooth positioner was made of vulcanized rubber on a dental setup after orthodontic brackets were removed. Minor irregularities could be corrected using the tooth positioner which was worn full time pushing the teeth into the predetermined tooth setup.
Back in 1907 Zia Chishti and Kelsey Wirth combined the use of plastic foils (Essex) with the concept of tooth positioner creating Align Company that released the aligner system called Invisalign (Align Technology, Santa Clara, California). More companies followed like Orthocaps[®] (Hamm, Germany), Clear Aligner[®] (Berlino, Germany), Sure smile Aligners (Charlotte, North Carolina, USA), Spark (Ormco, Orange, California, USA) etc. The last years direct-to-consumers aligners were introduced. Initially, setups, were made on plaster models while later, and with the introduction of

¹ School of Dentistry, Fairleigh Dickinson University, Rutherford, NJ, USA; Clinic of Orthodontics & Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland; private office Linauskas, Cyprus; Director for Planning & Management Dental Hospital, Department of Orthodontics, Dental College, Yonsei University, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 120-752, Korea; Department of Orthodontics, Center for Advanced Dental Education, Saint Louis University, 3320 Rutger Street, Saint Louis, MO 63104, United States
*Corresponding author.
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1073-8746/12/1801-8X-00/0
https://doi.org/10.1016/j.smo.2022.12.007
Seminars in Orthodontics, Vol 11, No 1, 2023; pp 1-14

A9. 2022, Bioactive Materials

Advances in orthodontic clear aligner materials

A10. 2022, Progress in Orthodontics

Force profile assessment of direct-printed aligners versus thermoformed aligners and the effects of non-engaged surface patterns

A11. 2023, Seminars in Orthodontics

3D printed aligners: Material science, workflow and clinical applications



Review

Directly Printed Aligner: Aligning with the Future

Nearchos C. Panay^{1,2,3}

¹School of Dentistry, European University Cyprus, Nicosia, Cyprus
²Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland
³Private Clinic, Limassol, Cyprus

Cite this article as: Panay NC. Directly Printed Aligner: Aligning with the Future. *Turk J Orthod*. 2023; 36(1): 62-69

Main Points

- 3D technology enabled the inclusion of a digital lab in the orthodontic office.
- Thermofomed aligners is the main way to perform aligner orthodontic treatment.
- Novel aligner resin has been introduced for the direct aligner printing.
- Printed aligners present significant advantages and some disadvantages.
- Studies have been published concerning the properties of the aligners. More studies have to be conducted in order to investigate and optimize printed aligner orthodontic treatment and create a consistent 3D-designing and printing workflow.

ABSTRACT

Orthodontics stands on a junction where traditional analog appliance manufacturing slowly but steadily changes to a digital one with the use of 3D technology. The main cause of this shift was the invention and use of computers. The use of computers, computer-aided design (CAD) software, computerized machines, and newly invented materials allowed this change to occur in a relatively short time in dentistry and orthodontics. The trigger for this transformation is the ability to digitally scan the oral cavity. CAD software and 3D printers already existed. It took a few years to include this technology in orthodontics and continuously apply it in the orthodontic office. Orthodontic treatment is mainly based on the use of fixed appliances, while in the last years, thermofomed aligners have been introduced as an alternative whenever a more invisible treatment modality is preferred. Clear aligner treatment is performed using thermofomed aligner. A new aligner resin has been recently invented to allow direct aligner printing. Directly printed aligner possess many advantages compared to thermofomed one. Research has been initiated to investigate all the aspects of the workflow and aligner printing outcome. More studies must be performed to look into the various aspects of directly printed aligners.

Keywords: 3D technology, 3D printing, directly printed aligner, UV curing unit, nitrogen generator

INTRODUCTION

Orthodontics is the only specialty in dentistry and medicine that uses forces to move human body parts, and teeth. The biology of tooth movement is extensively investigated, and theories have been expressed regarding many aspects of this movement. The unique feature of the continuing movement of our teeth throughout our entire life is used to correct orthodontic problems. The main way to move teeth is fixed appliances, which passed a long way since Angle invented the edgewise appliance.

In 1945, a brilliant mind Dr. Kesling¹ introduced a plastic-made appliance called tooth positioner to move teeth without fixed appliances. The positioner was made of rubber on a dental setup and was used immediately after brackets debonding. Later Nahoum² evolved an appliance using a two-block appliance for the upper and lower dental arches, while Sheridan et al.³ in 1993 introduced an Essix appliance to correct minor orthodontic problems combined with the interproximal reduction first used by ML Ballard in 1944.^{4,5} The next big step was made four years later when Zia Christi and Kelsey Wirth founded an aligner system called Invisalign (Align Technology, Santa Clara, Calif, USA). Later, other companies followed that path, while in the last years direct-to-consumers aligner was introduced.

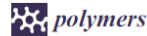
Corresponding author: Nearchos C. Panay, e-mail: dr.panay@cytcenter.com.cy
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Received: February 7, 2023
Accepted: February 28, 2023
Epub: March 09, 2023
Publication Date: March 21, 2023

A12. 2023, TJO

Directly Printed Aligner : Aligning with the Future

IF(2023) : 4.967



Article

Effect of Adhesion Conditions on the Shear Bond Strength of 3D Printing Resins after Thermocycling Used for Definitive Prosthesis

Yoo-Jung Kang^{1,*}, Ye Seul Park^{1,†}, Yoo Seok Shin^{2,†} and Jee-Hwan Kim^{1,4,*}

- ¹ Department of Prosthodontics, Oral Science Research Center, College of Dentistry, Yonsei University, Seoul 03722, Republic of Korea
- ² Department of Conservative Dentistry, Oral Science Research Center, College of Dentistry, Yonsei University, Seoul 03722, Republic of Korea
- * Correspondence: yooj@yuhs.ac; Tel.: +82-2-2228-3161; Fax: +82-2-312-3598
- † These authors contributed equally to this work.

Abstract: Three-dimensional (3D) printing polymers such as urethane dimethacrylate (UDMA) and ethoxylated bisphenol A dimethacrylate (Bis-EMA) are typically used in definitive prosthesis and require surface treatments before bonding. However, surface treatment and adhesion conditions often affect long-term use. Herein, polymers were divided into Groups 1 and 2 for the UDMA and Bis-EMA components, respectively. The shear bond strength (SBS) between two types of 3D printing resins and resin cements was measured using Rely X Ultimate Cement and Rely X U200, according to adhesion conditions such as single bond universal (SBU) and airborne-particle abrasion (APA) treatments. Thermocycling was performed to evaluate the long-term stability. Sample surface changes were observed using a scanning electron microscope and surface roughness measuring instrument. The effect of interaction between the resin material and adhesion conditions on the SBS was analyzed via a two-way analysis of variance. The optimal adhesion condition for Group 1 was achieved when U200 was used after ADA and SBU, whereas Group 2 was not significantly affected by the adhesion conditions. After thermocycling, the SBS significantly decreased in Group 1 without APA treatment and in the entire Group 2. Additionally, porosity, along with increased roughness, was observed on both material surfaces after APA.

Keywords: 3D printing resin; shear bond strength; surface roughness; adhesion conditions; surface treatment; thermocycling

1. Introduction

Several three-dimensional (3D) printing technologies and materials have been developed with advances in computer-aided design/computer-aided manufacturing (CAD/CAM) technology. To manufacture various restorations in the dental field, 3D printing or phototyping is typically used to fabricate 3D models by layering polymer materials [1–4]. Notably, 3D printing technology can easily and accurately manufacture detailed and complex prostheses. This approach significantly reduces the time and labor required in clinical and laboratory procedures compared to conventional methods [1,5–8]. Given these advantages, 3D printing resin materials for long-term definitive prostheses have been developed [9,10], and research on 3D printing materials is underway [2,11,12].

The primary component of 3D printing resins used for definitive prosthesis is either urethane dimethacrylate (UDMA) or ethoxylated bisphenol A dimethacrylate (Bis-EMA). When a new dental material is developed, various factors, such as the mechanical properties determined by the composition of the material, adhesion to existing dental cement, and processing method, must be considered. Among these, adhesion is a clinically essential factor in ensuring a successful restorative treatment. Certain previous studies have reported

Polymers 2023, 15, 1360. <https://doi.org/10.3390/polym15061360>

<https://www.mdpi.com/journal/polymers>

IF(2023) : 5.687



Effect of airborne particle abrasion treatment of two types of 3D-printing resin materials for permanent restoration materials on flexural strength*

Yoo-Jung Kang^{1,†}, Hoon Kim^{1,2,†}, Jiho Lee¹, Ye Seul Park¹, Jee-Hwan Kim^{1,4}

- ¹Department of Prosthodontics, Oral Science Research Center, College of Dentistry, Yonsei University, Seoul, the Republic of Korea
- ²Research Institute of Agriculture and Life Sciences, College of Agriculture & Life Sciences, Seoul National University, Seoul 05151, the Republic of Korea
- *Correspondence: yooj@yuhs.ac; Tel.: +82-2-2228-3161; Fax: +82-2-312-3598
- †These authors contributed equally to this work.

ARTICLE INFO

Keywords: 3D printing resin; flexural strength; surface treatment; Airborne-particle abrasion; Weibull analysis; Dynamic mechanical analysis; Nano-indentation

ABSTRACT

Objective: This study aimed to assess the effects of airborne-particle abrasion (APA) on the flexural strength of two types of 3D-printing resins for permanent restoration.
Methods: Two types of 3D printing resins (urethane dimethacrylate oligomer, UDMA, ethoxylated bisphenol-A dimethacrylate, BEMA) constituting different components were printed. The specimen surfaces were subjected to APA using 50 and 110 µm alumina particles under different pressures. The three-point flexural strength was measured for each surface treatment group, and a Weibull analysis was performed. Surface characteristics were analyzed via surface roughness measurements and scanning electron microscopy. Dynamic mechanical analysis and nano-indentation measurements were limited to the control group.
Results: The three-point flexural strength according to the surface treatment was significantly lower in the UDMA group for large particle sizes and at high pressures; the BEMA group demonstrated low flexural strength for large particle sizes regardless of the pressure. After thermocycling, the flexural strengths of UDMA and BEMA significantly decreased in the group subjected to surface treatments. The Weibull modulus and characteristic strength of UDMA were higher than those of BEMA under different APA and thermocycling conditions. As the abrasion pressure and particle size increased, a porous surface formed, and the surface roughness increased. Compared with BEMA, UDMA featured a lower strain, greater strain recovery, and a negligible increase in modulus according to strain.
Significance: Thus, surface roughness increased with the sandblasting particle size and pressure of the 3D-printing resin. Hence, a suitable surface treatment method to improve adhesion can be determined by considering physical property changes.

1. Introduction

Advances in the computer-aided design and manufacturing (CAD/CAM) technology have facilitated the production of inlays, crowns, and dentures using 3D printers and polymers. These developments have yielded distinct benefits for the dental community. Consequently, the digitalization of dental care has reduced working times and labor compared with conventional methods, facilitating easy and accurate reproductions of small and delicate teeth; moreover, the approach is economically competitive [1–4]. Notably, the 3D-printing resin materials currently used for temporary restorations in clinical practice

feature excellent mechanical properties and color stability, lower polymerization shrinkage compared with self-curing resins for existing temporary restorations, and better margin suitability than CAD/CAM milling-based materials. Moreover, the mechanical performance of these materials under various conditions, such as output and surface treatment, has been extensively studied [5–11]. Recently, resins for 3D printing that can be used as final prostheses are continuously being developed. These 3D-printing resins for permanent restorations comprise urethane dimethacrylate (UDMA), esterification products of 4, 4'-isopropylidenediphenol, ethoxylated, and 2-methylprop-2-enoic acid, and ethoxylated bisphenol-A dimethacrylate (Bis-EMA). Notably, using

- * Supported by the Korea Medical Device Development Fund (KMDFF) grant funded by the Korea government (MSIT) (Grant nos. KDD0026030000011 or RS-2020-KD000260).
- † Correspondence to: Department of Prosthodontics, Yonsei University College of Dentistry, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, the Republic of Korea. E-mail address: yooj@yuhs.ac (Y.-J. Kang).
- † These authors contributed equally to this work as first authors.

<https://doi.org/10.1016/j.dental.2023.05.007>
Received 7 November 2022; Received in revised form 2 May 2023; Accepted 6 May 2023
0109-5641/© 2023 The Academy of Dental Materials. Published by Elsevier Inc. All rights reserved.

Please cite this article as: Y.-J. Kang, H. Kim, J. Lee et al., Effect of airborne particle abrasion treatment of two types of 3D-printing resin materials for permanent restoration materials on flexural strength, *Dental Materials*, <https://doi.org/10.1016/j.dental.2023.05.007>

A13. 2023, Polymers (TC-80)

Effect of Adhesion Conditions on the Shear Bond Strength of 3D Printing Resins after Thermocycling Used for Definitive Prosthesis

A14. 2023, Dental Materials (TC-80)

Effect of airborne particle abrasion treatment of two types of 3D-printing resin materials for permanent restoration materials on flexural strength

Publications

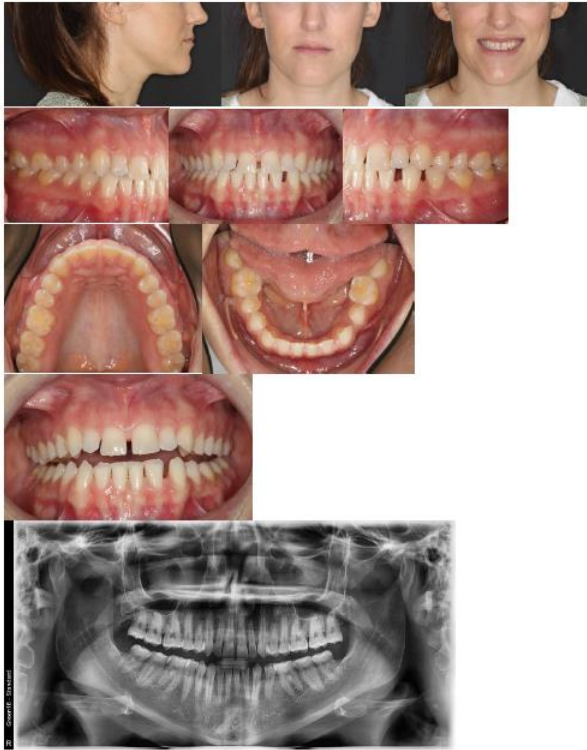


Fig 7a-j: Extra- and intraoral situation at the start of the in-office aligner treatment. The patient shows spaces in the maxillary and mandibular region with abrasions on several teeth and missing tooth 34. Closure of the space alone with orthodontics would not lead to an aesthetically pleasant result. The orthopantomogram revealed no pathologies, all wisdom teeth are in situ.



Fig 12a-d: Situation during treatment with aligner step number 4 (a, b) and with well-fitting Graphy direct aligners in situ (c, d).



Fig 18a-l: Comparison before (a-c) and after orthodontic treatment with in-office direct Graphy aligners (d-f). G-i) after restoratives with composite on maxillary and mandibular anteriors and one week after gingivectomy (Dr. W Boisserée, Cologne), j-l) smile before and after interdisciplinary therapy.

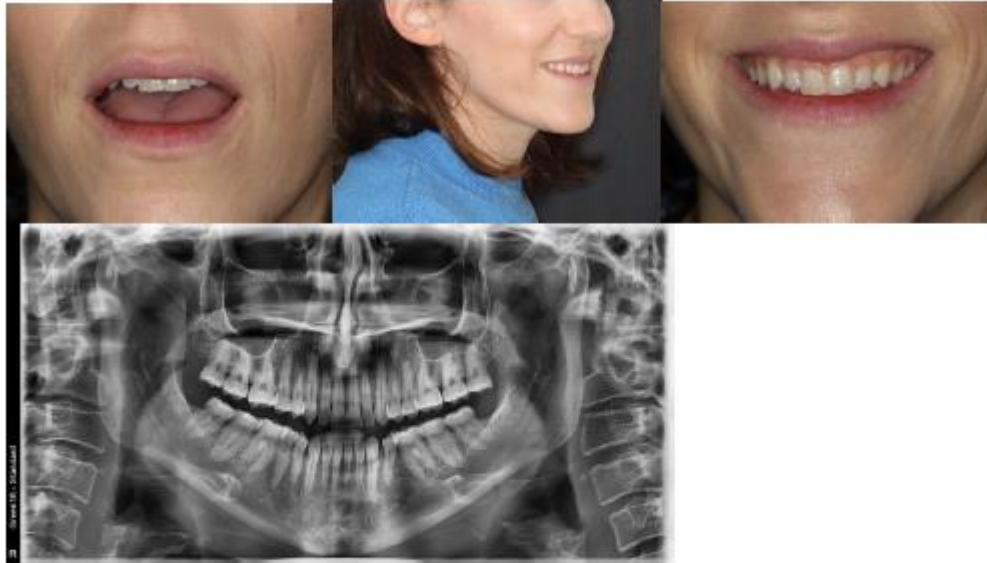


Fig 16a-r: Final extra- and intraoral situation after treatment with in-office direct Graphy aligners. The treatment was performed with longer straight aligner margins, but without any attachment on the teeth for additional anchorage. The final orthopantomogram shows no pathologies.

A15. 2023 (Dr. Werner Schupp's case report in process)

Shape Memory Aligner – A new dimension in Aligner Orthodontics

Publications

IF(2023) : 3.748
Citations : 70

DIGITAL ORTHODONTICS **AJO-DO**

Effect of print orientation and duration of ultraviolet curing on the dimensional accuracy of a 3-dimensionally printed orthodontic clear aligner design

Marian C. McCarty,* Stephen J. Chen,* Jeryl D. English,* and F. Kaspe*
Houston, Tex

Introduction: This study aimed to investigate the effect of print orientation and ultraviolet (UV) light curing duration on the dimensional accuracy of a clear aligner design fabricated directly using 3-dimensional (3D) printing. **Methods:** A master clear aligner design file was 3D printed on a stereolithography printer using 3 different build angles with respect to the build platform: parallel (Horizontal), perpendicular (Vertical), and 45° (45-Degree) (n = 10/group). The 45° orientation then was used to print aligners for 3 postprint processing treatment groups: 0 minutes of UV light and heat exposure (No Cure), 20 minutes of UV light exposure at 80°C (20 Minute), and 40 minutes of UV light exposure at 80°C (40 Minute) (n = 10/group). Each part was digitally scanned and superimposed with the input file for 3D design analysis. A generalized linear mixed model and post-hoc Tukey contrasts were applied for statistical analysis. **Results:** Difficulties were encountered in optical scanning of 3D-printed aligners, resulting in the exclusion of some samples and the No Cure group from the analysis. The average positive and negative deviations were not statistically significantly different among the print orientations, and postprint processing conditions were analyzed and fell within limits of clinical acceptability (0.250 mm). Color deviation maps illustrated localized areas of dimensional deviation that may affect the clinical utility of the printed aligner design. **Conclusions:** The print orientation and postprint curing duration have little effect on the overall accuracy of the 3D-printed aligner design under the conditions investigated. However, the potential effects of location-specific deviations on the clinical utility of 3D-printed aligners should be considered in future studies. (Am J Orthod Dentofacial Orthop 2020;158:889-97)

The influx of digital technology and computer-aided design and computer-aided manufacturing into the orthodontic space enables increased use of positioner-like appliances for major tooth movement. Applying computer-aided design and computer-aided manufacturing technology, the workflow for clear aligner therapy traditionally uses a single intraoral impression or digital scan to generate multiple digital setups. These setups are then 3-dimensionally (3D) printed as a series of dental models onto which clear, plastic aligners can be manufactured through thermoforming. Currently, the research has focused primarily on the accuracy of intraoral scanning, 3D-printed models, and fabrication of clear aligners on 3D-printed models using the traditional workflow. However, resins are emerging that may be suitable for direct fabrication of clear aligners through 3D printing, obviating the need for the 3D-printed intermediate models and thermoforming steps associated with the traditional workflow.¹ If accurate, these resins could dramatically improve the efficiency of the process, enabling more rapid delivery of aligners to the patients and generating a higher yield for the practice while reducing waste and cost. Although the accuracy of 3D-printed orthodontic models has been investigated in the literature,^{2,3} key differences exist in the geometry of models and aligners; specifically, the geometry of an aligner design file is more complex than a 3D-printed model. Each

*Department of Orthodontics, School of Dentistry, The University of Texas Health Science Center at Houston, Houston, Tex.
*Department of Orthodontics, School of Dentistry, and Graduate School of Biomedical Sciences, The University of Texas Health Science Center at Houston, Houston, Tex.
All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
Address correspondence to: F. Kaspe, Department of Orthodontics, School of Dentistry, The University of Texas Health Science Center at Houston, 3030 Campbell St, Box 1103, Houston, TX 77030 e-mail: Frank.D@uth.tmc.edu
Submitted September 2019; revised February 2020; accepted March 2020
0885-4426/21/158-889-09
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https://doi.org/10.1094/aaoe.2020.158.889

889

In Vitro Response of Anterior Teeth to Clear Aligners Programmed with Canine Rotation

Raanis Hirani, DDS

A Thesis Presented to the Graduate Faculty of Saint Louis University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dentistry

2021

materials **MDPI**

Direct 3D Printing of Clear Orthodontic Aligners: Current State and Future Possibilities

Gianluca M. Tartaglia ^{1,2}, Cinzia Maspero ^{1,2}, Tommaso Santaniello ³, Marco Serafini ^{1,2,*}, Marco Farronato ^{1,2} and Alberto Caprioglio ^{1,2}

Abstract: The recent introduction of three-dimensional (3D) printing is revolutionizing dentistry and is even being applied to orthodontic treatment of malocclusion. Clear, personalized, removable aligners are a suitable alternative to conventional orthodontic appliances, offering a more comfortable and efficient solution for patients, including improved oral hygiene and aesthetics during treatment. Contemporarily, clear aligners are produced by a thermoforming process using various types of thermoplastic materials. The thermoforming procedure alters the properties of the material, and the internal environment further modifies the properties of a clear aligner, affecting overall performance of the material. Direct 3D printing offers the creation of highly precise clear aligners with soft edges, digitally designed and identically reproduced for an entire set of treatment aligners, offering a better fit, higher efficacy, and reproducibility. Despite the known benefits of 3D printing and the popularity of the dental applications, very limited technical and clinical data are available in the literature about directly printed clear aligners. The present article discusses the advantages of 3D printed aligners in comparison to thermoformed ones, describes the current state of the art, including a discussion of the possible road blocks that exist such as a current lack of approved and marketed materials and limited evidence of aligner-specific software. The present review suggests the suitability of 3D direct printed aligners is superior to that of thermoformed manufactured aligners because of the prior's increased accuracy, load resistance, and lower deformation. It is an overall more stable way to produce an aligner where submillimeter movements can make a difference in treatment outcome. Direct 3D printing represents a complex method to control the thickness of the aligner and therefore has a better ability to control the force vectors that are used to produce tooth movement. There is currently no other approved material on the market that can do this. The conclusion of this article is that we encourage further in vitro and in vivo studies to test these new technologies and materials.

Keywords: 3D printing; clear aligners; dental printing resin; malocclusion; narrative review; orthodontics

1. Background
Brief History
Orthodontics is now approaching its fourth revolution since its inception as a specialty of dentistry in the early 1900s. In those days, malocclusion was treated with the application of metal rings cemented to teeth to support wires for applying moving forces. This initial treatment strategy for the correction of dental and skeletal malocclusion was often accompanied by a huge number of dental caries because it was almost impossible to maintain correct dental hygiene due to the limited offering of dental hygiene tools in the market at that time and to the mechanical encumbrance of the cemented rings and

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Materials 2021, 14, 1799. https://doi.org/10.3390/ma14071799 https://www.mdpi.com/journal/materials

JTD **Original Article**

https://doi.org/10.14337/jtd.2021.43.2.56
pISSN: 1228-3934 eISSN: 2288-5218
J Tech Dent 2021;43(2):56-61

치과용 자동바렐연마기의 연마시간에 따른 3종 레진의 표면거칠기 관찰

정안나, 고현정, 박유진
부산기공예대학교 보건과학대학 치기공학과

Observation of surface roughness on three types of resin based on grinding time of dental automatic barrel finishing

An-Na Jung, Hyeon-Jeong Ko, Yu-Jin Park
Department of Dental Laboratory Science, Catholic University of Pusan, Busan, Korea

Article Info
Received May 10, 2021
Revised May 26, 2021
Accepted June 6, 2021

Purpose: This study aimed to produce resin prosthetics using a dental automatic barrel finishing. Surface roughness and surface topography of resins were observed according to the grinding time of the dental automatic barrel finishing.
Methods: This study was performed with thermopolymer, autopolymer, and photopolymer resins. The dimensions of the specimens were 10×10×2 mm. Each specimen was polymerized according to the manufacturer's instructions. The polymerized resin was honed for 30 minutes at 5-min intervals in a dental automatic barrel finishing. The specimen was observed using a three-dimensional (3D) optical microscope, and the surface roughness was measured.
Results: After the polishing with the dental automatic barrel finishing, the heat-cured (HC) specimen showed the highest and lowest values of Ra after 10 and 20 minutes, respectively. The self-cured (SC) specimen showed the highest and lowest values of Ra after 10 and 25 minutes, respectively. Finally, the 3D specimen showed the highest and lowest values of Ra after 5 and 20 minutes, respectively.
Conclusion: After measuring the surface roughness of the three types of resins according to the grinding time of the dental automatic barrel finishing, the lowest Ra values for the HC, SC, and 3D specimens were measured after 15, 25, and 20 minutes, respectively. Therefore, we concluded that a limit on the grinding time of the resin using a dental automatic barrel finishing is needed.

Key Words: Barrel finishing, Grinding time, Ra, Resin, Surface roughness

Corresponding Author
Yu-Jin Park
Department of Dental Laboratory Science,
Catholic University of Pusan, 57 Oryunseon,
Geupyeong-gu, Busan 49252, Korea
E-mail: most@naver.com
https://orcid.org/0000-0001-8008-7416

B1. 2020, AJO-DO
Effect of print orientation and duration of ultraviolet curing on the dimensional accuracy of a 3-dimensionally printed orthodontic clear aligner design

B2. 2021
In Vitro Response of Anterior Teeth to Clear Aligners Programmed with Canine Rotation

B3. 2021, Materials
Direct 3D Printing of Clear Orthodontic Aligners Current State and Future Possibilities

B4. 2021, JTD
Observation of surface roughness on three types of resin based on grinding time of dental automatic barrel finishing

International Journal of Environmental Research and Public Health

MDPI

Case Report

A Digital Fabrication of Dental Prosthesis for Preventing Self-Injurious Behavior Related to Autism Spectrum Disorder: A Case Report

Seoung-Jin Hong ^{1,†}, Yong Kwon Chae ^{2,†}, Chunui Lee ³, Sung Chul Choi ^{2,†} and Ok Hyung Nam ^{2,*,†}

¹ Department of Prosthodontics, School of Dentistry, Kyung Hee University, Seoul 02447, Korea; mhob@hmail.net

² Department of Pediatric Dentistry, School of Dentistry, Kyung Hee University, Seoul 02447, Korea; pedoch@ghmail.com (Y.K.C.); pedoch@hku.ac.kr (S.C.C.)

³ Department of Oral and Maxillofacial Surgery, Wonju College of Medicine, Yonsei University, Wonju 26420, Korea; chunui@naver.com

* Correspondence: pedokhyung@gmail.com; Tel.: +82-2-940-8072; Fax: +82-2-940-9720

[†] Seoung-Jin Hong and Yong Kwon Chae equally contributed as first authors.

Abstract: This case report aimed to demonstrate the prosthetic solution of an autism patient with self-injurious behavior using digital dentistry. A 28-year-old male visited our clinic with chief complaints of severe gingival recession associated with self-injurious behavior. Bilateral food prosthesis with dentate flange were delivered using a digital workflow for the protection of the gingiva. The patient showed healed gingival tissue, behavioral modification, and acceptable oral hygiene during the follow-up period. Also, his caregivers reported no recurrence of the self-injurious behavior. Autism patients usually show self-injurious behavior, which can damage their oral tissue. With adoption of this prosthesis, behavior modification as well as healing of oral tissue was achieved.

Keywords: autism spectrum disorder; behavior guidance; digital dentistry; self-injurious behavior; special health care needs

1. Introduction

Patients with autism spectrum disorder (ASD) present with unique behavioral impairment, characterized by poor communication and social interactions, as well as stereotyped behaviors and responses [1]. These features can compromise dental care and oral hygiene [2]. In addition, repeated self-injurious behavior (SIB) that causes severe oral tissue damage has been reported in ASD patients [3].

ASD patients may develop self-induced injuries in the head and neck region [4]. Any oral tissues can be involved including gingiva, mucosa, teeth, and tooth-supporting tissues. A previous study reported that tongues and lips were the predominantly affected sites in oral self-injuries [5]. A previous study regarding Chinese children with ASD reported that these patients showed parafunctional habits, such as biting hard objects (41.9%), bruxism (16.2%), and lip biting (9.7%) [6]. However, ASD patients are less sensitive to painful stimuli and less likely to express their physical discomfort; caregivers and clinicians may misinterpret that the patient is not in pain [7,8]. Therefore, without appropriate intervention, self-injured lesions can cause chronic inflammation, leading to severe damage of tissue.

The SIB can be managed by a combination of behavior modification therapy and physical restraints [9]. Physical restrictive devices such as arm splints, gloves, or bandages were used to protect the body parts, and application of dental protective appliances for the protection of the lip or tongue has been reported. In case of gingival injury, behavior modification therapy has been used to reduce SIB but was found ineffective [10]. However,

Int. J. Environ. Res. Public Health 2021, 18, 9268. <https://doi.org/10.3390/ijerph1809268> <https://www.mdpi.com/journal/ijerph>

Review > Orthod Craniofac Res. 2021 Sep 27. doi: 10.1111/ocr.12537. Online ahead of print.

Comparative analysis of mechanical properties of orthodontic aligners produced by different contemporary 3D printers

Spiros Zinelis ¹, Nearchos Panayi ², Georgios Polychronis ¹, Spyridon N Papageorgiou ³, Theodore Eliades ³

Affiliations + expand

PMID: 34569692 DOI: 10.1111/ocr.12537

Abstract

Objective: The aim of this study was to compare the mechanical properties of orthodontic aligners among different commercially available 3D printing devices.

Materials and methods: Five 3D printers (Kavir LP 550, Swinwon: "KAR"), (L120, Dazz 3D: "L12"), (Miicraft 125, Miicraft Jena: "MIC"), (Slash 2, Uniz: "SLS") and (Pro 95, SprintRay: "PRO") were used to prepare orthodontic aligners with dental resin (Tera Harz TC-85DAW, Graphy). The central incisors of each aligner were cut, prepared and evaluated in terms of Martens-Hardness (HM), indentation-modulus (E_{IT}) and elastic-index (η_{IT}) as per ISO14577-1:2002. Force-indentation curves were recorded and differences among printers were checked with generalized linear regressions ($\alpha=5\%$).

Results: Statistically significant differences were seen for all mechanical properties ($P < .05$), which were in descending order: HM (N/mm^2) as median (Interquartile Range [IQR]): SLS 108.5 (106.0–112.0), L12 103.0 (102.0–107.0), KAR 101.5 (97.5–103.0), MIC 100.0 (97.5–101.5) and PRO 94.0 (93.0–96.0); E_{IT} (MPa) as mean (Standard Deviation [SD]): SLS 2696.3 (124.7), L12 2627.8 (73.5), MIC 2566.2 (125.1), KAR 2565.0 (130.2) and PRO 2491.2 (53.3); and η_{IT} (%) as median (IQR): SLS 32.8 (32.3–33.1), L12 31.6 (30.8–32.3), KAR 31.3 (30.9–31.9), MIC 30.5 (29.9–31.2) and PRO 29.5 (29.1–30.0). Additionally, significant differences existed between liquid crystal display (LCD) and digital light processing (DLP) printers for HM ($P < .001$), E_{IT} ($P = .002$) and η_{IT} ($P < .001$), with aligners from the former having higher values than aligners from the latter printer.

Conclusion: Under the limitations of this study, it may be concluded that the mechanical properties of 3D-printed orthodontic aligners are dependent on the 3D printer used, and thus, differences in their clinical efficacy are anticipated.

Keywords: 3D printing; clear aligners; instrumented indentation testing; mechanical properties.

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Chapter

Digital Workflow for Homemade Aligner

Dalal Elmoutawakkil and Nabil Hacib



Abstract

Advanced digital technology is rapidly changing the world, as well as transforming the dental profession. The adoption of digital technologies in dental offices allied with efficient processes and accurate high-strength materials are replacing conventional aligners workflows to improve overall patients' experiences and outcomes. Various digital devices such as 3D printers, intraoral and face scanners, cone-beam computed tomography (CBCT), software for computer 3D ortho setup, and 3D printing provide new potential alternatives to replace the traditional outsourced workflow for aligners. With this new technology, the entire process for bringing clear aligner production in-office can significantly reduce laboratory bills and increase patient case acceptance to provide high-quality and customized aligner therapy.

Keywords: digital workflow, orthodontics, aligner, thermoforming, 3D Printing, facial scan, planning software, homemade aligners

1. Introduction

The increasing esthetic need of patients for orthodontic devices has led to the development of clear aligner therapy [1, 2]. Traditionally, orthodontists contract with an outside service to provide clear aligner treatments. Outsourcing to a provider has drawbacks for both the patient and the orthodontist. It can take over a month to produce and deliver an aligner set, and the provider requires a substantial service fee, cutting into potential profits.

Advancements in 3D printing technology, intra-oral scanners, and 3D setup software improve the production of clear aligners. Nowadays, these solutions are widely available in private dental practices, allowing orthodontists in-house aligner production.

In-house 3D printing accelerates aligner turnaround, increases profitability, and improves patient satisfaction while offering complete workflow control.

In this chapter, we will suggest to orthodontists to centralize the production of aligners in the dental office by detailing the different stages of the production flow. Form acquiring extra-oral and intra-oral patient data and exploring necessary hardware and software for this acquisition. Until the production of the aligners, where we will discuss the equipment and materials mandatory for this production. Going through the planning, this section will detail the different software that an orthodontist can use for the 3D setup and the particularities of each of these softwares.

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IntechnOpen

JTD
https://doi.org/10.14347/jtd.2021.43.4.145
pISSN: 1229-3954 eISSN: 2288-5218
JTD创刊 2021.1.24(4):145-152

Original Article

치과용 레진 연마를 위한 바렐 연마재의 성분 분석 및 표면 잔류물 관찰

정이나, 박유진, 최성민
부산기공대학대학교 치기공학과

Component and surface residue observation of barrel finishing media for grinding dental resins

An-Na Jung, Yu-Jin Park, Sung-Min Choi

Department of Dental Laboratory Science, Catholic University of Pusan, Busan, Korea

Article Info
Received August 18, 2021
Revised September 5, 2021
Accepted October 22, 2021

Purpose: This study aimed to produce resin prosthetics using a dental barrel finishing machine. For dental resin grinding, the ingredients of the barrel finishing media were analyzed, and surface residues of the resin were observed.

Methods: Two types of barrel finishing media for dental resin grinding were tested. Specimens were made from thermal polymerized, auto polymerized, and photopolymerized resins. Finishing media were analyzed through energy-dispersive X-ray spectroscopy (EDS) component analysis and inductively coupled plasma-optical emission spectrometry (ICP-OES) component analysis. Then, the prepared specimen was barrel finished for 25 minutes using two types of barrel finishing media, and scanning electron microscope was photographed to observe the surface residues.

Results: As a result of EDS component analysis, both types of finishing media were analyzed for the components of C, O, Zr and Al elements, and industry media (IM) was further analyzed for the components of Si and Mg elements. In the ICP-OES component analysis, Cd and As, which are harmful elements, were detected in IM, and no harmful elements were detected in manufacturing media (MM). Because of observation of surface residues, no residues were observed in the three types of resin specimens that were barrel finished with two types of finishing media.

Conclusion: Surface residue wasn't observed on the specimens polished using two types of finishing media. However, in IM, Cd and As, which are harmful elements, were detected, making it inappropriate for clinical use. In MM, harmful elements were not detected, therefore, clinical use will be possible.

Corresponding Author
SungMin Choi
Department of Dental Laboratory Science,
Catholic University of Pusan, 37 Guyuk-dong,
Geungjeong-gu, Busan 46252, Korea
Email: smchoi@cup.ac.kr
<https://orcid.org/0000-0001-0005-7732>

Key Words: Barrel finishing, Energy-dispersive X-ray spectroscopy, inductively coupled plasma-optical emission spectrometry, Media, Resin, Scanning electron microscope

B5. 2021, Int. J. Environ. Res. Public Health

A digital fabrication of dental prosthesis for preventing self-injurious behavior related to autism spectrum disorder: a case report

B6. 2021, Orthod Craniofac Res.

Comparative analysis of mechanical properties of orthodontic aligners

B7. 2021

Digital Workflow for Homemade Aligner

B8. 2021, JTD

Component and surface residue observation of barrel finishing media for grinding dental resins

Publications

NARRATIVE LITERATURE REVIEW

Emerging insights and new developments in clear aligner therapy: A review of the literature

Johan Hartshorne* and Mark Brian Wertheimer[†]
 Bellville and Johannesburg, South Africa

Aggressive promotion by stakeholders and increased public awareness for alternative esthetic orthodontic treatment options have popularized the demand for clear aligner therapy (CAT). Patient demand is driven by appearance, comfort, convenience, and less complicated oral hygiene control. CAT is an important treatment alternative to conventional fixed appliances and a viable alternative for mild-to-moderate malocclusions in non-extraction, nongrowing patients. CAT is less effective and predictable than conventional fixed appliances for complex orthodontic tooth movements and malocclusions. However, the introduction of improved software, aligner materials, and auxiliary devices has enhanced the scope of malocclusions that may be treated. Managing complex tooth movements during CAT requires auxiliaries, overcorrections, and refinements to improve the predictability, effectiveness, and stability of treatment outcomes. The main predictors of treatment outcome are proper patient selection, patient complexity, treatment planning, compliance, clinician experience, and regular monitoring. Currently, there are no evidence-based clinical guidelines for CAT. Aligner technology and therapy are continuously evolving and improving. This literature review aimed to assess and summarize current scientific knowledge and evidence relating to CAT. (Am J Orthod Dentofacial Orthop Clin Companion 2022;XX:XX-XX)

Clear aligner treatment (CAT) is a rapidly developing modality of orthodontic treatment, that has received increased attention as an alternative to conventional braces, especially among adult patients wishing to improve smile esthetics.¹⁻⁶ Easier oral hygiene maintenance,⁷ less pain and discomfort,⁸ shorter treatment time,⁹ less inconvenience¹⁰ and better quality of life,^{10,11} are claimed advantages compared with conventional fixed appliances. Demand for CAT is further increased because of aggressive promotion by stakeholders through direct-to-consumer advertising and social media, generating increased public awareness for alternative esthetic orthodontic treatment options.¹² In contrast, orthodontists have often cited treatment outcomes and clinical performance as the

most important factors when considering using aligners instead of fixed appliances.¹³ It is imperative that both patient and clinician expectations are addressed when selecting the appliance for treatment.¹⁴

The demand and use of CAT have subsequently motivated people of all ages, including older adults, to seek orthodontic treatment.¹⁵ However, concerns have been raised regarding the effectiveness and predictability of CAT. Bowenian¹⁶ argued that "a series of aligners alone can not solve most malocclusion issues, no matter the quality of the software design, modeling, nor type of plastic used." However, with improved software design, modeling, and 3-dimensional (3D) printing technology and biomaterials, together with the input of innovative clinicians, the evolution of CAT is being steered in the right direction. Initially, the indications for CAT were limited to the correction of alignment in mild-to-moderate malocclusions with minor crowding. Nowadays, moderate to extremely complex treatment is embarked upon with some degree of success.¹⁷ The top six companies driving the clear aligner industry are summarized in the Table.

This literature review aimed to assess and summarize current scientific knowledge and evidence related to CAT.

*Intercare Medical and Dental Centre, Bellville, South Africa.
[†]Private practice, Johannesburg, South Africa.
 All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
 Address correspondence to: Mark Brian Wertheimer, Private practice, Suite 1107, The Leonardo, 75 Maude St, Sandton 2196, Johannesburg, South Africa; e-mail: mwerth@onet.co.za



Preprints are preliminary reports that have not undergone peer review. They should not be considered conclusive, used to inform clinical practice, or referenced by the media as validated information.

Comparison of thickness, gap width and translucency for 3D-printed and thermoformed clear aligners: A micro-CT analysis

So Yeon Park
 College of Dentistry, Yonsei University
 Sung-Hwan Choi
 College of Dentistry, Yonsei University
 Hyung-Seog Yu
 College of Dentistry, Yonsei University
 Su-Jung Kim
 Kyung Hee University School of Dentistry
 Hoon Kim
 Seoul National University
 Ki Beom Kim
 Saint Louis University
 Jung-Yul Cha (✉ jungcha@yuhs.ac)
 College of Dentistry, Yonsei University

Article

Keywords: 3D printed clear aligner, thermoformed clear aligner, micro-CT, thickness, gap width, translucency

Posted Date: January 30th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2512327/v1>

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ARTICLE IN PRESS



RESEARCH AND EDUCATION

Effect of cement space settings on the marginal and internal fit of 3D-printed definitive resin crowns

Heedo Shin, DDS,¹ You-Jung Kang, PhD,² Hoon Kim, PhD,³ and Jee-Hwan Kim, DDS, MSD, PhD⁴

With improvements in computer-aided design and computer-aided manufacturing (CAD-CAM) techniques, dental prostheses are being increasingly manufactured using this technology.¹ CAM methods include subtractive and additive manufacturing techniques. The milling method, the most popular in dentistry,² requires a dedicated milling bur applied to each block when cutting a prosthesis. However, because of limitations of the milling bur and its fixed thickness, the movement of the milling bur axis limits the reproducibility of complex shapes and prevents precise machining.³ In addition, milling generates considerable noise, requires a long time, and the debris from the blocks is not reusable.

Additive manufacturing produces less noise, is economical, and faster by eliminating the impression-making step and various drilling processes.⁴ In addition, complex shapes can be easily reproduced with this technique with high precision.⁵ Three-dimensional (3D)

ABSTRACT

Statement of problem. The cement gap setting affects the marginal and internal fit depending on the crown material and manufacturing method (subtractive or additive manufacturing). However, information on the effects of cement space settings in the computer-aided design (CAD) software program, which is used to aid the manufacturing with 3-dimensional (3D) printing-type resin material, is lacking, and recommendations for optimal marginal and internal fit are needed.

Purpose. The purpose of this in vitro study was to evaluate how cement gap settings affect the marginal and internal fit of a 3D-printed definitive resin crown.

Material and methods. After scanning a prepared typodont left maxillary first molar, a crown was designed with cement spaces of 35, 50, 70, and 100 µm by using a CAD software program. A total of 14 specimens per group were 3D printed from definitive 3D-printing resin. By using the replica technique, the intaglio surface of the crown was duplicated, and the duplicated specimen was sectioned in the buccolingual and mesiodistal directions. Statistical analyses were performed using the Kruskal-Wallis and the Mann-Whitney post hoc tests (α=0.05).

Results. Although the median values of the marginal gaps were within the clinically acceptable limit (<120 µm) for all the groups, the smallest marginal gaps were obtained with the 70-µm setting. For the axial gaps, there was no observed difference in the 35-, 50-, and 70-µm groups, and the 100-µm group showed the largest gap. The smallest axio-occlusal and occlusal gaps were obtained with the 70-µm setting.

Conclusions. Based on the findings of this in vitro study, a 70-µm cement gap setting is recommended for optimal marginal and internal fit of 3D-printed resin crowns. (J Prosthet Dent 2023; ■■■)

printing methods are recent developments in digital technology that have become popular in dentistry⁶⁻⁸; for example, for interim prostheses. Efforts have been made to clinically introduce 3D-printing materials and fabricate definitive prostheses. The physical properties of these materials have been improved⁹⁻¹⁰ to reach the strength

Funding: Supported by the Korea Medical Device Development Fund grant, funded by the Korea government (the Ministry of Science and ICT, the Ministry of Trade, Industry, and Energy, the Ministry of Health & Welfare, the Ministry of Food and Drug Safety) (project 171118420,RS-2020-0000000). H.S. and Y.J.K. contributed equally to the article.
¹Graduate student, Department of Prosthodontics, Yonsei University College of Dentistry, Seoul, Republic of Korea.
²Research Assistant Professor, Department of Prosthodontics, Oral Science Research Center, Yonsei University College of Dentistry, Seoul, Republic of Korea.
³Researcher, Research Institute of Agriculture and Life Sciences, College of Agriculture & Life Sciences, Seoul National University, Seoul, Republic of Korea.
⁴Professor, Department of Prosthodontics, Oral Science Research Center, Yonsei University College of Dentistry, Seoul, Republic of Korea.

B9. 2022, AJO-DO Clinical Companion

Emerging insights and new developments in clear aligner therapy (CAT): A review of the literature

B10. 2023, Scientific Reports

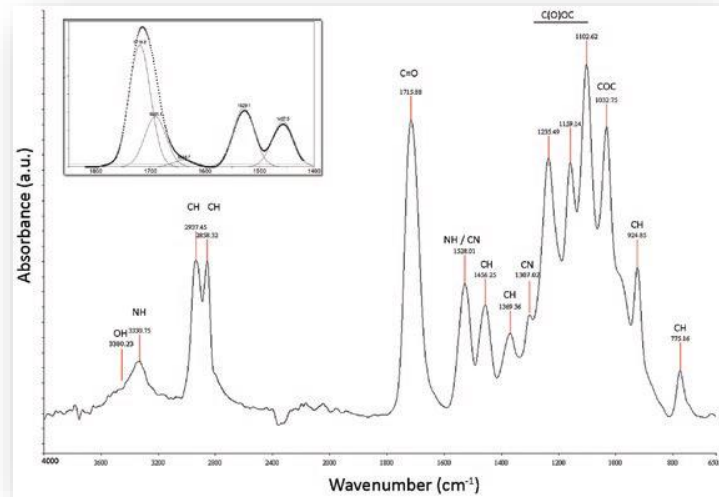
Comparison of thickness, gap width and translucency for 3D-printed and thermoformed clear aligners - A micro-CT analysis

B11. 2023, JPD (TC-80)

Effect of cement space setting on the marginal and internal fit of 3D-printed definitive resin crowns

The background features a dynamic, abstract composition. On the left, a thick, flowing stream of golden liquid curves across the frame. This stream transitions into a more complex, multi-layered structure on the right, composed of overlapping, semi-transparent golden and orange geometric shapes, including triangles and polygons, which create a sense of depth and movement. The overall color palette is warm, dominated by shades of gold, orange, and yellow, set against a clean white background.

Biocompatibility



“One week of intraoral service does not seem to significantly change the mechanical properties of an in-house 3D-printed orthodontic aligner.”

Original article
In-house 3D-printed aligners: effect of *in vivo* ageing on mechanical properties
 Esad Chan^{1*}, Nearchos Panayi^{2*}, Georgios Polychronis³, Spyridon N. Papageorgiou^{1*}, Spiros Zinelis³, George Eliades^{2*} and Theodore Eliades^{1*}

*Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland, ²Private Practice, Limassol, Cyprus, ³Department of Biomaterials, School of Dentistry, National and Kapodistrian University of Athens, Athens, Greece

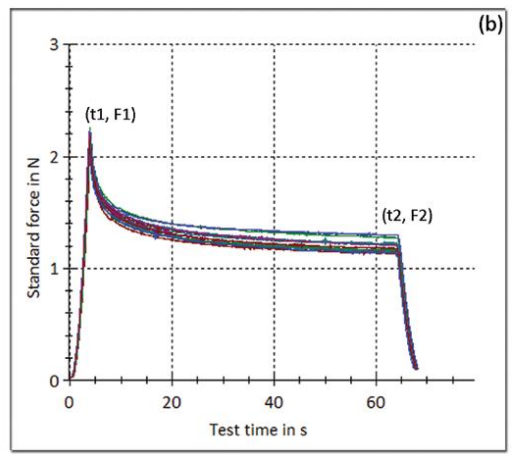
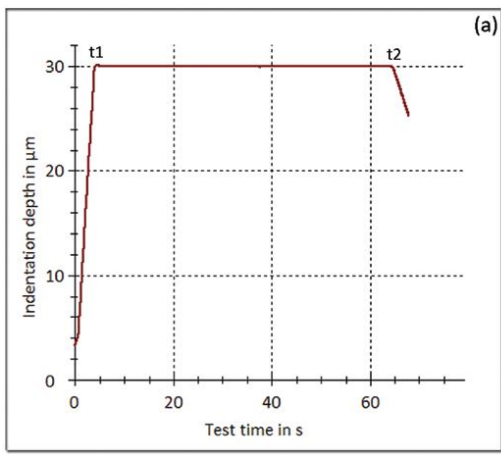
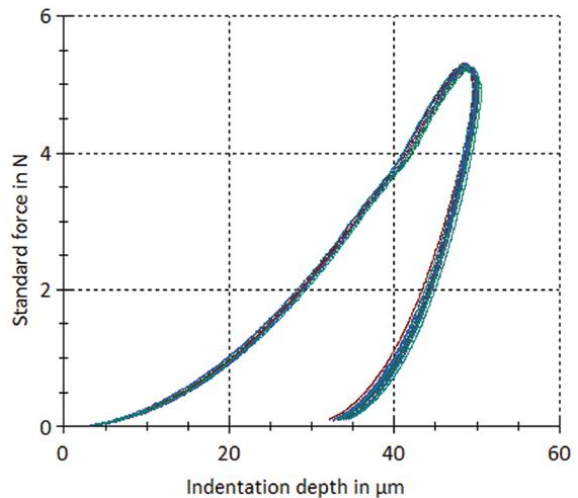
Correspondence to: Theodore Eliades, Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, Zurich 8002, Switzerland. E-mail: theodore.eliaades@zkm.unizh.ch

Summary
Objective: To investigate alterations in the mechanical properties of in-house three-dimensional (3D) printed orthodontic aligners after intraoral ageing.
Materials and methods: Sixteen 3D printed aligners (TC-85DAC resin, Graphy, Seoul, Korea) were used for the purpose of the study, which were divided into 10 control (not used) aligners and 6 materials retrieved from 4 patients after 1-week service (retrieved group). Samples from the control group were analyzed by attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy. Samples from control/retrieved groups were embedded resin and subjected to instrumented indentation testing (IIT) to record force-indentation depth curves, calculating the following (as per ISO 14877-1, 2002 standard): Martens hardness (HM), indentation modulus (E_p), and elastic index (η_p), and the indentation relaxation index (R_p). Differences between control and retrieved 3D printed aligners were checked with Mann-Whitney U-tests at an alpha = 5%.
Results: ATR-FTIR analysis showed that aligners were made of a vinyl ester-urethane material. The results of the IIT testing were: HM (control: median 93.5 N/mm², interquartile range [IQR] 88.0–93.0; as-retrieved: median 90.5 N/mm², IQR 89.0–93.0); E_p (control: mean 2616.3 MPa, standard deviation [SD] 1070 MPa; retrieved: mean 2673.2 MPa, SD 149.4 MPa); η_p (control: median 28.8%, IQR 28.2–30.0%; as-retrieved: median 29.0%, IQR 28.7–29.2%); and R_p (control: median 43.5%, IQR 43.0–47.0%; as-retrieved: median 45.1%, IQR 45.0–45.2%). No differences between as-retrieved and control aligners were found for any of the mechanical properties tested ($P > 0.05$ in all instances).
Conclusion: The mechanical properties of the in-house 3D-printed aligners tested were not affected after 1 week in service period.

Introduction
 Aligners present a highly aesthetic orthodontic treatment modality and sometimes the first preference for many adult patients (1–3) regardless about their objective performance (4). Despite the high demand however for this modality, aligners are still a rather costly and complicated third-party controlled treatment option, due to the necessary involvement of aligner manufacturers or laboratories in the manufacturing process, which incurs fees and delays the appliance delivery. To overcome these obstacles, dental practitioners have adopted in-house three-dimensional (3D) printing technology as a cost-effective “Do It Yourself” (5–7) in-office method. Such techniques are pre-empted to be able to offer secondary appliances.

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A3. 2021, EJO
 In-house 3D-printed aligners: effect of *in vivo* ageing on mechanical properties



ORIGINAL ARTICLE **AJO-DO**

Cytotoxicity and estrogenicity of a novel 3-dimensional printed orthodontic aligner

Harris Pratsinis,^a Spyridon N. Papageorgiou,^b Nearchos Panayi,^c Anna Iladi,^d Theodore Eliades,^e and Dimitris Kletas^f

^aAthens, Greece, ^bZurich, Switzerland, and ^cLimassol, Cyprus

Introduction: Orthodontic aligners printed with in-office 3-dimensional (3D) procedures have been described, but no data on their biocompatibility exist. This study investigates the cytotoxicity and estrogenicity of a 3D-printed orthodontic aligner by assessing its biological and behavioral effects. **Methods:** Ten sets of 1 type of aligner were immersed in sterile deionized water for 14 days, and the cytotoxicity and estrogenicity of released factors were assessed via MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) assays on human gingival fibroblasts and the estrogen-sensitive MCF-7 and the estrogen-insensitive MDA-MB-231 breast cancer cell lines. 17 β -Estradiol and bisphenol-A were used as positive controls. The statistical analysis of data was performed with generalized linear models at a 0.05 level of significance. **Results:** No signs of cytotoxicity were seen for the aligner samples for concentrations (v/v) of 20% ($P = 0.32$), 10% ($P = 0.79$), or 5% ($P = 0.76$). The antioxidant activity expressed as the capacity to reduce intracellular levels of reactive oxygen species was not affected in the aligner samples ($P = 0.08$). No significant estrogenicity was induced by the aligner samples compared with eluents from the negative control for both MCF-7 ($P = 0.65$) and MDA-MB-231 ($P = 0.78$). As expected, 17 β -Estradiol and bisphenol-A stimulated MCF-7 cell proliferation, whereas no effect was observed on MDA-MB-231 cells. **Conclusions:** In conclusion, if any factors were released during the 14-day aging of 3D-printed aligners in water, these were not found to be cytotoxic to human gingival fibroblasts and did not affect their intracellular reactive oxygen species levels. Moreover, no estrogenic effects of these putative eluates were observed based on an E-screen assay. (Am J Orthod Dentofacial Orthop 2022; ■: e1-e7)

O orthodontic treatment of a large spectrum of malocclusions with aligners has become increasingly popular in recent years, partly because of the increased demand for treatment by adult patients and intense advertisement to patients. However, evidence about the objectively measured clinical performance of aligners compared with fixed appliances remains unclear.¹⁻³ At the same time, orthodontic treatment with clear aligners involving the use of multiple, often bulky, composite resin attachments to enhance the aligners' clinical performance has introduced several issues⁴ pertaining to alterations of the tooth structure or optical properties,⁵⁻⁷ alterations of the aligners' material properties,⁸⁻¹¹ and alterations of the bonded resin attachments.^{12,13} At the same time, intraoral aging of orthodontic materials affects their structural integrity and several material properties, like hydrolytic stability and plasticization,¹⁴ which might result in component molecules being released intraorally, with bisphenol-A (BPA) being mostly discussed.

^aLaboratory of Oral Prosthodontics and Aging, Institute of Biomechanics and Applications, National Center for Scientific Research "Demokritos," Athens, Greece.
^bClinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland.
^cDepartment of Dentistry, European University Cyprus, Nicosia, Cyprus; Private practice, Limassol, Cyprus.
^dDepartment of Dental Biomaterials, School of Dentistry, National and Kapodistrian University of Athens, Athens, Greece.
^eHarris Pratsinis and Spyridon N. Papageorgiou contributed equally to this manuscript.
 All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Nearchos Panayi declared a financial interest with the company Clear Aligners, related to reviewing the orthodontic computer-aided design software iBrackets, but did not participate in specimen testing or data analysis. The remaining authors declare that they have no competing interests.
 Address correspondence to: Theodore Eliades, Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, Zurich, CH-8032, Switzerland; e-mail: theodore@iada.uzh.ch
 Submitted, February 2022; revised and accepted, June 2022.
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<https://doi.org/10.1016/j.ajodo.2022.06.014>

A5. 2022, AJO-DO

Cytotoxicity and estrogenicity of a novel 3-dimensional printed orthodontic aligner

Table I. Results of the cytotoxicity and estrogenicity assays, given as means \pm standard deviation

Absorbance (% of untreated)	Aligners	Negative control	NA	Trolox	E2	BPA
Cell viability (MTT): 20% v/v	92.0 \pm 13.0	100.0 \pm 15.2	-	-	-	-
Cell viability (MTT): 10% v/v	98.3 \pm 15.9	100.0 \pm 11.0	-	-	-	-
Cell viability (MTT): 5% v/v	97.6 \pm 14.6	100.0 \pm 15.2	-	-	-	-
DCFH-DA assay	103.6 \pm 4.4	99.9 \pm 4.0	100.0 \pm 4.2	63.4 \pm 1.5	-	-
MCF-7 cells	70.6 \pm 12.2	73.5 \pm 26.1	100.0 \pm 17.1	-	165.4 \pm 24.1	140.0 \pm 10.2
MDA-MB-231 cells	83.2 \pm 9.8	85.4 \pm 19.4	100.0 \pm 7.9	-	100.6 \pm 5.7	89.2 \pm 6.4

NA, no addition.

Table II. Statistical testing for the cytotoxicity and estrogenicity assays, given as P values from general linear models

Absorbance (% of untreated)	Aligner vs				Negative control vs		
	Negative control	Trolox	β -estradiol	BPA	Trolox	β -estradiol	BPA
Cell viability (MTT): 20% v/v	0.32	-	-	-	-	-	-
Cell viability (MTT): 10% v/v	0.79	-	-	-	-	-	-
Cell viability (MTT): 5% v/v	0.76	-	-	-	-	-	-
DCFH-DA assay	0.08	<0.001	-	-	<0.001	-	-
MCF-7 cells	0.65	-	<0.001	<0.001	-	<0.001	<0.001
MDA-MB-231 cells	0.78	-	<0.001	<0.001	-	0.07	0.66

"...these were **not found to be cytotoxic** for for human gingival fibroblasts and did not affect their intracellular ROS levels. Moreover, **no estrogenic effects** of these putative eluates were observed on the basis of an E-screen assay."



Shape Memory

(Force Delivery)

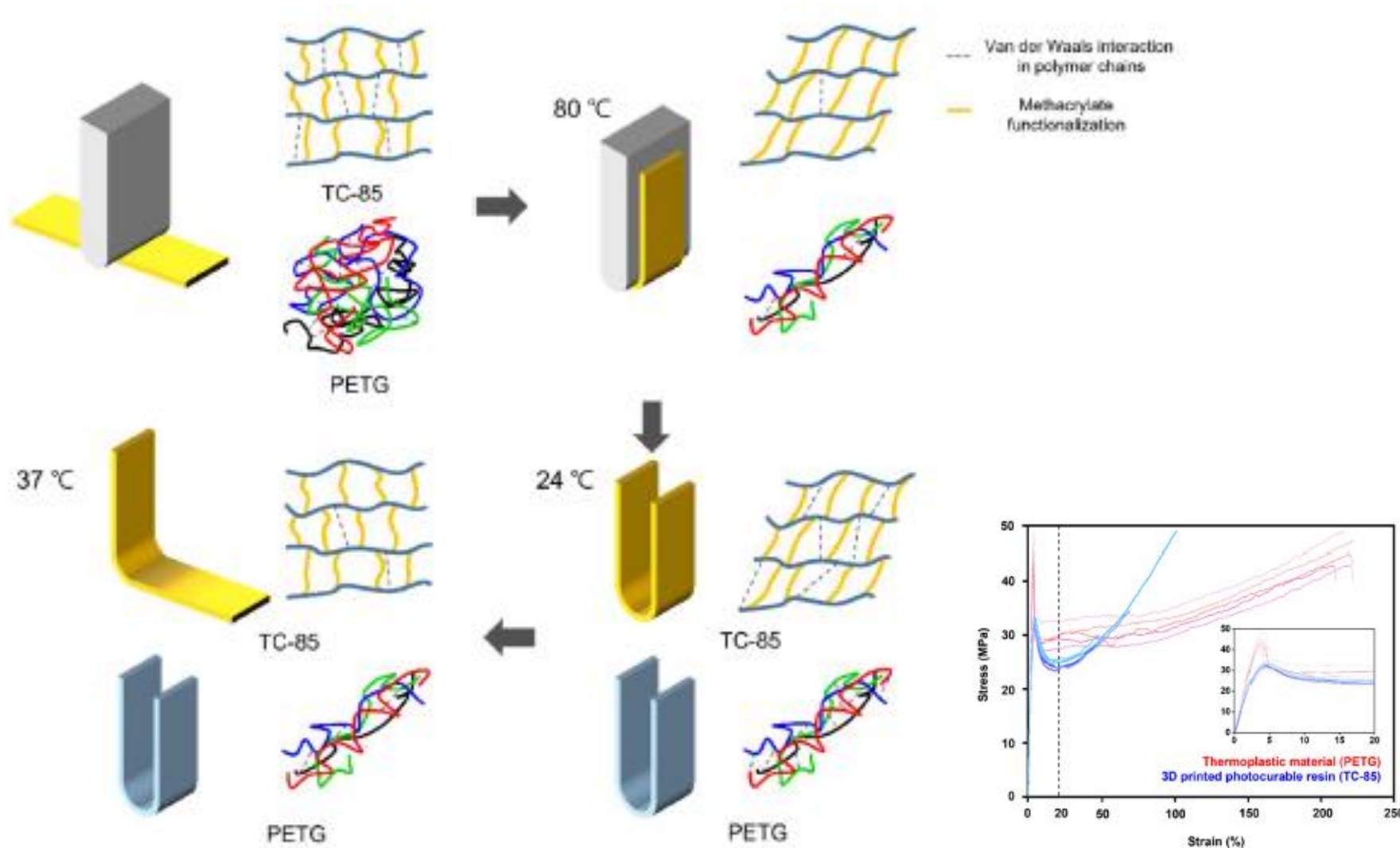
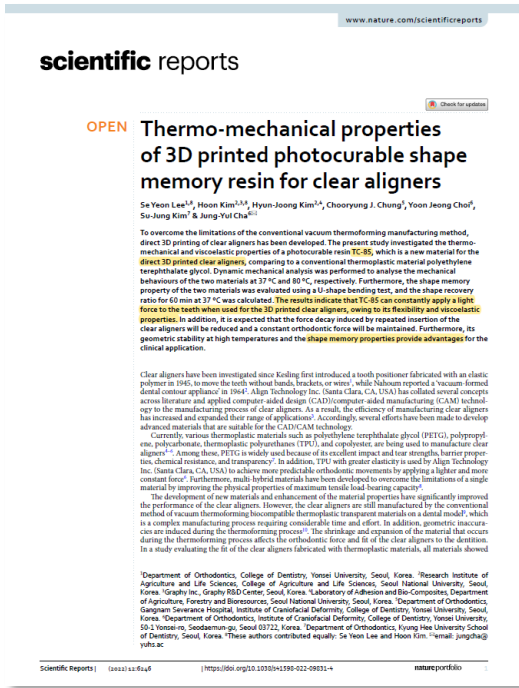


Figure 5. Shape memory property test procedure and shape memory mechanism; Yellow and blue specimens indicate TC-85 and PETG, respectively.

A4. 2022, Scientific Reports

Thermo-Mechanical Properties of 3D Printed Photocurable Shape Memory Resin for Transparent Orthodontic Aligners

Publications



Advances in orthodontic clear aligner materials

Yashodhan M. Bichu^a, Abdulraheem Alwaifi^{b,c}, Xiaomo Liu^d, James Andrews^e, Björn Ludwig^f, Aditi Y. Bichu^a, Bingshuang Zou^{b,*}

^a Private Practice, Abu Dhabi, United Arab Emirates
^b Department of Oral Health Science, Faculty of Dentistry, University of British Columbia, Vancouver, Canada
^c Faculty of Dentistry, Department of Dental Public Health, King Fahad University, Jeddah, Saudi Arabia
^d Department of Orthodontics, Peking University School and Hospital of Stomatology, Beijing, China
^e Private Practice, Perth, Australia
^f Department of Orthodontics, University of Hamburg, Saar, Germany

ARTICLE INFO

Keywords:
 Clear aligners
 Bioactive materials
 Shape memory polymers
 Direct 3D printing
 Reinforcement
 Review

ABSTRACT

Rapid technological improvements in biomaterials, computer-aided design (CAD) and manufacturing (CAM) have endeavored clear aligner therapy (CAT) as a mainstay of orthodontic treatment, and the materials employed for aligner fabrication play an all-important role in determining the clinical performance of clear aligners. This narrative review has attempted to comprehensively encompass the entire gamut of materials currently used for the fabrication of clear aligners and elucidate their characteristics that are crucial in determining their performance in an oral environment. Historical developments and current protocols in aligner fabrication, features of contemporary bioactive materials, and emerging trends related to CAT are discussed. Advances in aligner material chemistry and engineering possess the potential to bring about radical transformations in the therapeutic applications of CAT; in the absence of which, clear aligners would continue to underperform clinically, due to their inherent biomechanical constraints. Finally, with innovations in aligner materials such as shape memory polymers, direct three-dimensional (3D) printed clear aligners and bioactive materials combined with clear aligner materials are essential to further advance the applications of CAT; increased awareness of environmental responsibilities among aligner manufacturers, aligner prescribing clinicians and aligner users is essential for better alignment of our climate change goals towards a sustainable planet.

1. Introduction

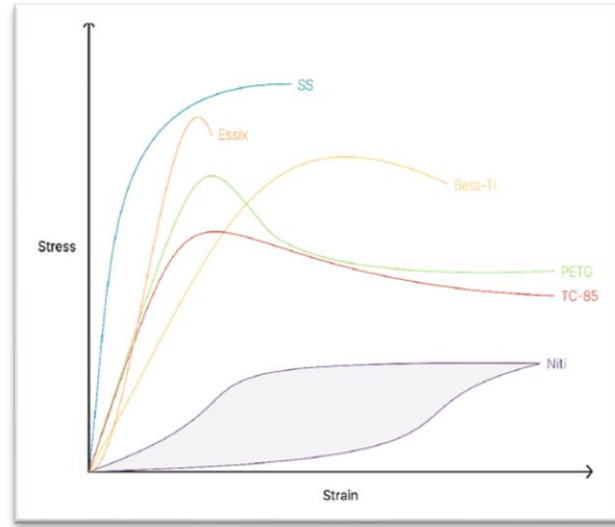
With the rapid technological improvements in biomaterials, computer-aided design (CAD) and manufacturing (CAM), clear aligner therapy (CAT) has emerged as a promising alternative to conventional fixed appliances (FAs) in orthodontics. The demand for CAT has increased significantly over the last decade, presumably due to aggressive marketing strategies by commercial clear aligner companies that employ direct-to-consumer advertising as well as widespread utilization of various social media channels, thereby generating heightened public awareness for aesthetic orthodontic treatment alternatives, especially for the adult patients [1]. The global clear aligners market size was projected to increase from USD 3.1 billion in 2021 to USD 11.6 billion in 2027 with a compound annual growth rate (CAGR) of 13% [2]. A recent survey carried out across North America also indicated that more

orthodontists in the younger generations believe that clear aligners will be the main technique to treat malocclusions [3].

CAT typically comprises a series of clear plastic trays covering the dentition with a snug fit, that is to be used by the patient at all times except eating and brushing and generally changed sequentially every one to two weeks to accomplish planned orthodontic tooth movements. Although multiple commercial clear aligner systems are available today globally, the use of clear thermoformed plastic materials for clear aligner fabrication remains a common feature [4].

Although the clinical efficacy of clear aligners can be affected by a multitude of factors [5-8], the properties of materials used for their fabrication remain one of the most essential aspects in determining their mechanical and clinical features [10]. This review endeavours to comprehensively cover the advances in biomaterials used for clear aligner fabrication. Historical developments, current protocols, properties, and clinical performances of various clear aligner materials,

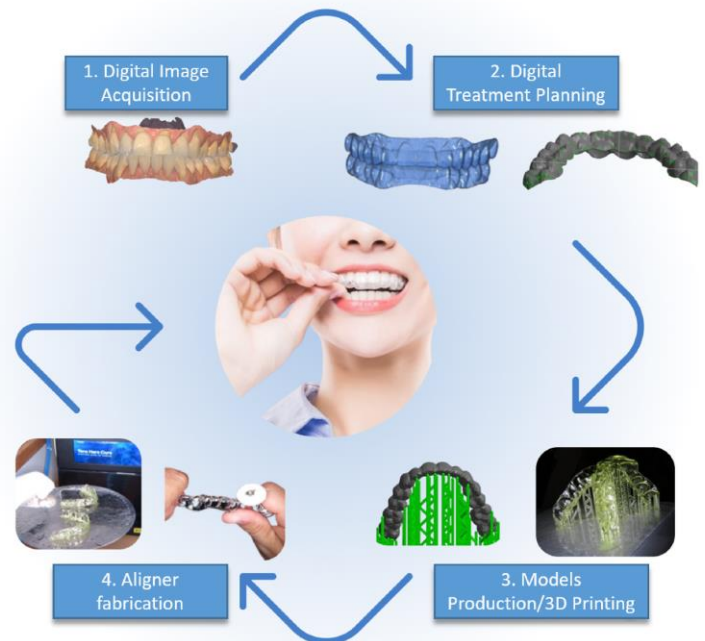
Peer review under responsibility of KeAi Communications Co., Ltd.
 * Corresponding author. Department of Oral Health Science, Faculty of Dentistry, The University of British Columbia, Vancouver, V6T 1Z3, Canada.
 E-mail address: dzou@dentistry.ubc.ca (B. Zou).
<https://doi.org/10.1016/j.bioactmat.2022.10.006>
 Received 6 September 2022; Received in revised form 5 October 2022; Accepted 6 October 2022
 Available online 20 October 2022
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stress-strain curves of different orthodontic materials (relative comparison)

- SS, stainless steel.
- Beta-Ti, Beta titanium
- Niti, Nickel titanium
- Essix, clear retainer material
- PETG, polyethylene terephthalate glycol (thermoplastic aligner material)
- TC-85, photocurable resin (3D-printed aligner material)

“there is **no other 3D printable material** currently available commercially that meets the standard of **biocompatibility, translucency, and appropriate mechanical properties**”



A9. 2023, Bioactive Materials

Advances in orthodontic clear aligner materials

The background features a dynamic, abstract composition. On the left, a thick, flowing stream of golden liquid curves across the frame. To the right, a more complex, crystalline structure of golden liquid is shown, composed of numerous overlapping, semi-transparent triangular facets. Scattered around these liquid forms are several small, light-colored geometric shapes, including triangles and squares, some of which appear to be floating or falling. The overall aesthetic is clean, modern, and high-tech.

Accuracy Fit

Original Article

ISSN 2234-7518 • eISSN 2005-121X
<https://doi.org/10.4041/kjoa1.1269>

KJO

Comparison of dimensional accuracy between direct-printed and thermoformed aligners

Nickolas Koenig¹, Jin-Young Choi², Julie McCray³, Andrew Hayes⁴, Patricia Schneider⁵, Ki Beom Kim⁶

Objective: The purpose of this study was to evaluate and compare the dimensional accuracy between thermoformed and direct-printed aligners. **Methods:** Three types of aligners were manufactured from the same reference standard tessellation language (STL) file; thermoformed aligners were manufactured using Zendura FLX™ (n = 12) and Essix ACE™ (n = 12), and direct-printed aligners were printed using Tera Harz™ TC-85DAP 3D Printer LV Resin (n = 12). The teeth were not manipulated with any tooth-moving software in this study. The samples were sprayed with an opaque scanning spray, scanned, imported to Geomagic® Control X™ metrology software, and superimposed on the reference STL file by using the best-fit alignment algorithm. Distances between the aligner meshes and the reference STL file were measured at nine anatomical landmarks. **Results:** Mean absolute discrepancies in the Zendura FLX™ aligners ranged from 0.076 ± 0.057 mm to 0.260 ± 0.089 mm and those in the Essix ACE™ aligners ranged from 0.188 ± 0.271 mm to 0.457 ± 0.350 mm, while in the direct-printed aligners, they ranged from 0.079 ± 0.054 mm to 0.224 ± 0.041 mm. Root mean square values, representing the overall trueness, ranged from 0.209 ± 0.094 mm for Essix ACE™, 0.188 ± 0.074 mm for Zendura FLX™, and 0.140 ± 0.030 mm for the direct-printed aligners. **Conclusions:** This study showed greater trueness and precision of direct-printed aligners than thermoformed aligners.

Key words: Aligner, Physical property, Resin, Three-dimensional scanner

Received October 26, 2021; Revised January 18, 2022; Accepted January 19, 2022.

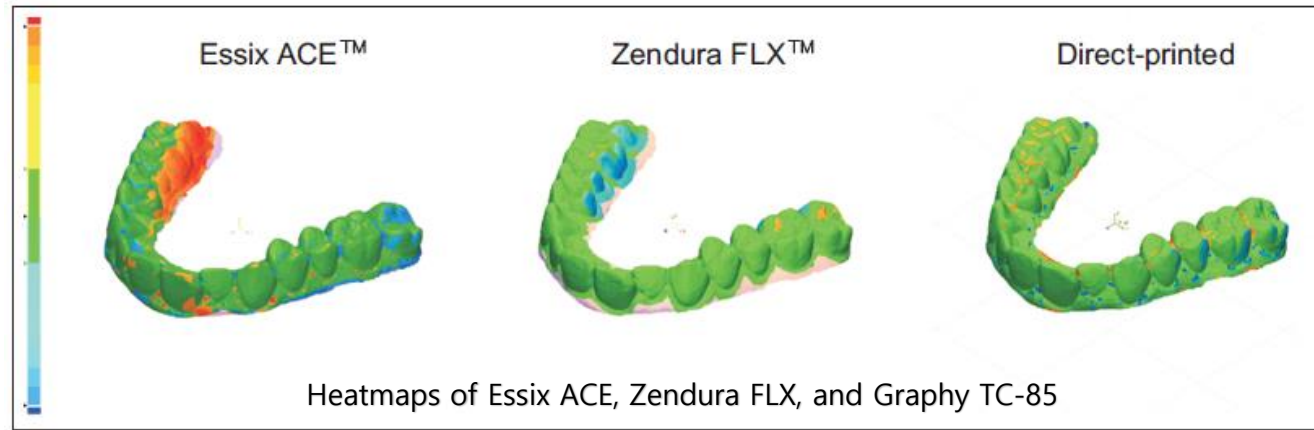
Corresponding author: Ki Beom Kim, Professor and Chair, Department of Orthodontics, Saint Louis University, 3320 Roger St, St. Louis, MO 63104, USA. Tel +1-314-977-8367 e-mail kkimk@slu.edu

Nickolas Koenig and Jin-Young Choi contributed equally to this work as co-first authors.

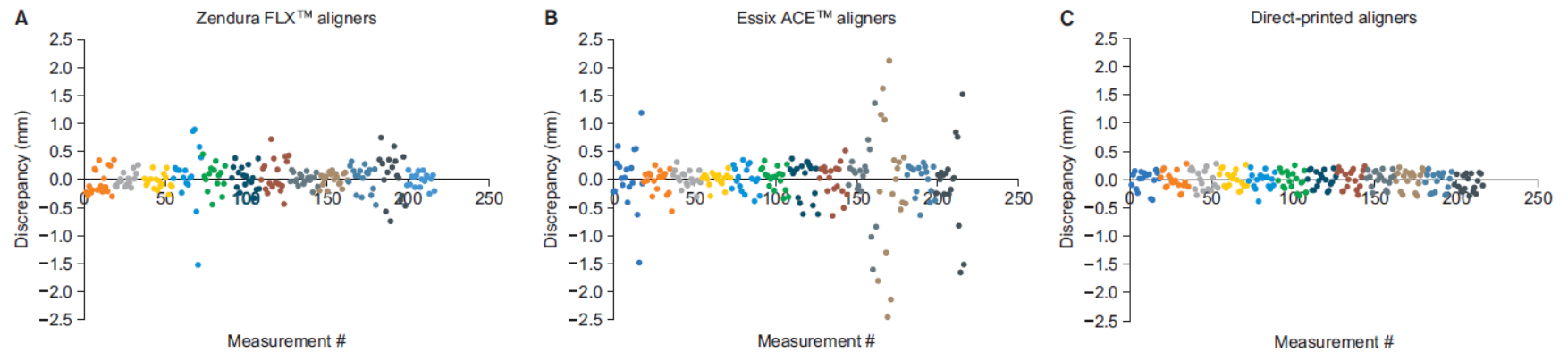
How to cite this article: Koenig N, Choi JY, McCray J, Hayes A, Schneider P, Kim KB. Comparison of dimensional accuracy between direct-printed and thermoformed aligners. Published online April 22, 2022. <https://doi.org/10.4041/kjoa1.1269>

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Heatmaps of Essix ACE, Zendura FLX, and Graphy TC-85



Modified Bland-Altman plots of landmark measurements for all samples (Zendura FLX, Esix ACE, Graphy TC-85)

A7. 2022, KJO

Comparison of dimensional accuracy between direct-printed and thermoformed aligners

“This study showed **greater trueness and precision** of direct-printed aligners than thermoformed aligners.”

Publications

Hertan et al. Progress in Orthodontics (2022) 23:49
<https://doi.org/10.1186/s40510-022-00443-2>

Progress in Orthodontics

SHORT REPORT Open Access

Force profile assessment of direct-printed aligners versus thermoformed aligners and the effects of non-engaged surface patterns

Evan Hertan, Julie McCray, Brent Bankhead and Ki Beom Kim

Abstract
Background: The purpose of the study was to measure the forces delivered by direct-printed aligners (DPA) in the vertical dimension and compare the force profile with traditional thermoformed aligners (TFA) and to investigate the impact of non-engaged surface patterns to the properties of DPA and TFA.
Methods: A force-measuring appliance was fabricated capable of displacing the aligner in 0.10 mm increments and measuring the resultant force. Polyethylene terephthalate glycol (ATMOS 0.030° American Orthodontics) and TC-85DAC resin (Graphy Inc) were used to create TFA and DPA, respectively. Aligners were temperature-controlled prior to and during testing to simulate the oral environment. The resultant forces from displacements ranging from 0.10 to 0.30 mm were measured.
Results: At intraoral temperatures, DPA demonstrated significantly less force than TFA. TFA demonstrated a substantial statistically significant increase in force with each 0.10 mm increase in vertical displacement. DPA demonstrated a much more consistent force profile across the range of displacements. The effects of surface patterns in both DPA and TFA were generally a decrease in force. Statistical significance of surface patterns was detected for TFA at displacements of 0.30 mm and greater and significant for DPA only at a displacement of 0.10 mm. Surface patterns in both DPA and the TFA did not show any statistical difference when assessing force properties.
Conclusions: Forces delivered by aligners in the vertical dimension by DPA are more consistent and of lower magnitude than those of TFA aligners. Surface patterns were not capable of altering the force properties of both DPA and TFA.

Background
 New technological developments and market demands have rapidly increased the availability and affordability of intraoral scanners and 3D printers. These technological advancements combined with the market demand for aesthetic treatment options have driven a surge in the use of clear aligners for orthodontic tooth movement [1, 2]. Clear Aligner treatment utilizing 3D printing technology has been limited to tooth models with staged tooth movements and subsequently thermoforming plastic sheets to create the desired aligners. The prospect of direct 3D printing of aligners themselves offers to usher in an era of innovation. Specifically, the direct 3D printing of aligners offers the opportunity to control material dimensions, structure, and properties more directly [3, 4]. Furthermore, direct 3D printing of aligners offers the promise of reduced waste [5], improved turnaround time, and an era of on-demand clear aligner treatment [4, 6, 7]. Direct-printed aligners (DPA) in contrast to traditional thermoformed aligners (TFA) offer to usher in a new world of opportunities and possibilities to control tooth movements through novel techniques. Specifically, the creation of different thicknesses throughout the

*Correspondence: kibeom.kim@health.usu.edu
 Department of Orthodontics, Saint Louis University, 3120 Rutgers Street, Saint Louis, MO 63104, USA



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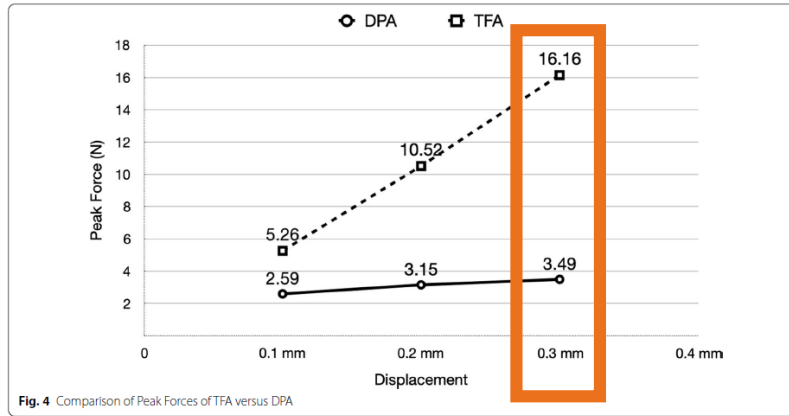


Fig. 4 Comparison of Peak Forces of TFA versus DPA

Table 1 Comparing TFA-NA (no attachments) and TFA-YA (with attachments)

Displacement	Unit (N)	TFA-NA		TFA-YA		p value
		Mean ± SD	Median	Mean ± SD	Median	
0.10 mm	Peak force	5.26 ± 0.51	5.11	5.13 ± 0.89	5.34	0.94
	Stabilized force	4.73 ± 0.50	4.60	4.6 ± 0.84	4.74	0.97
0.20 mm	Peak force	10.52 ± 0.69	10.52	10.37 ± 1.21	10.39	0.82
	Stabilized force	9.77 ± 0.76	9.68	9.60 ± 1.18	9.75	0.94
0.30 mm	Peak force	16.16 ± 0.71	16.10	15.85 ± 1.36	16.26	0.94
	Stabilized force	15.04 ± 0.8	14.89	14.84 ± 1.48	15.30	0.55

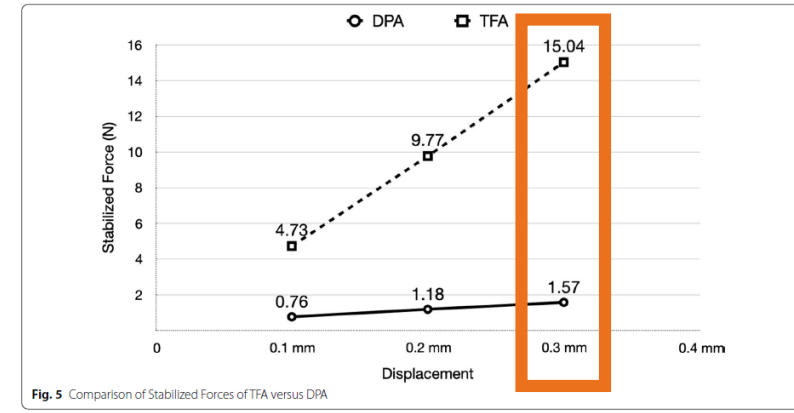


Fig. 5 Comparison of Stabilized Forces of TFA versus DPA

Table 2 Comparing DPA-NA (no attachments) and DPA-YA (with attachments)

Displacement	Unit (N)	DPA-NA		DPA-YA		p value
		Mean ± SD	Median	Mean ± SD	Median	
0.10 mm	Peak force	2.59 ± 0.62	2.44	2.77 ± 0.60	2.65	0.45
	Stabilized force	0.76 ± 0.18	0.73	0.81 ± 0.21	0.79	0.65
0.20 mm	Peak force	3.15 ± 0.65	3.18	3.58 ± 0.51	3.52	0.14
	Stabilized force	1.18 ± 0.27	1.19	1.33 ± 0.23	1.26	0.15
0.30 mm	Peak force	3.49 ± 0.71	3.48	4.04 ± 0.67	3.87	0.08
	Stabilized force	1.57 ± 0.37	1.52	1.78 ± 0.39	1.69	0.24

A10. 2022, Progress in Orthodontics

Force profile assessment of direct-printed aligners versus thermoformed aligners and the effects of non-engaged surface patterns

“Direct-printed aligners can deliver biologically compatible forces for orthodontic tooth movement...”

The background features a dynamic, flowing golden liquid that curves across the frame. The liquid has a glossy, reflective surface with highlights and shadows, giving it a three-dimensional appearance. In the lower right quadrant, there are several semi-transparent, golden geometric shapes, including triangles and polygons, some of which are slightly offset from the main flow, creating a sense of movement and depth. The overall color palette is warm, dominated by shades of gold, orange, and yellow against a plain white background.

Workflow

(Processing Advantages)

Publications

“TC-85 (Graphy, Seoul, Korea), which can **constantly apply a light force** to the teeth when used for the 3D printed clear aligners, owing to its **flexibility** and **viscoelastic** properties.

In addition, the expected **force decay** induced by repeated insertion of the clear aligners is reduced and a **constant orthodontic force** can be maintained.

Furthermore, its **geometric stability** at high temperatures and its **shape memory properties** provide advantages for clinical application [13–15]. (Figure 8). ”



Review
Three-Dimensional-Printed Customized Orthodontic and Pedodontic Appliances: A Critical Review of a New Era for Treatment

Ioannis A. Tsolakis ^{1*}, Sotiria Gizani ², Apostolos I. Tsolakis ^{3,4} and Nearchos Panayi ^{5,6}

- ¹ Department of Orthodontics, School of Dentistry, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece
- ² Department of Paediatric Dentistry, Dental School, National and Kapodistrian University of Athens, Athens 11527, Greece; sotiriagizani@gmail.com
- ³ Department of Orthodontics, National and Kapodistrian University of Athens, School of Dentistry, Athens 11527, Greece; apostoltsolakis@gmail.com
- ⁴ Department of Orthodontics, C.W.R.U., Cleveland, OH 44106, USA
- ⁵ Department of Orthodontics, European University of Cyprus, School of Dentistry, Egleous 2404, Cyprus; n.panayi@euc.ac.cy
- ⁶ School of Medicine, National and Kapodistrian University of Athens, Athens 11577, Greece; ioa.papadimitriou@med.uoi.gr
- * Correspondence: tsolakisioannis@gmail.com

Abstract: Three-dimensional (3D) designing and manufacturing technology is a direct derivative of dental technology. Three-dimensional volume and surface acquisition, CAD software, and 3D man-



Figure 8. Direct-printed aligners.

Children 2022, 9, 1107; <https://doi.org/10.3390/children9081107> www.mdpi.com/journal/children

A6. 2022, Children

Three-Dimensional-Printed Customized Orthodontic and Pedodontic Appliances: A Critical Review of a New Era for Treatment



Figure 4. A lingual arch designed in Meshmixer and printed using CoCr alloy in SLS printer.



Figure 5. An uncorrected maxillary eruption. Space hybrid guiding appliance. The appliance was used prior to maxillary eruption in order to guide its eruption.



Figure 6. An RPE designed in Meshmixer and printed in CoCr. The screw is soldered to the customized bands on a printed dental model.

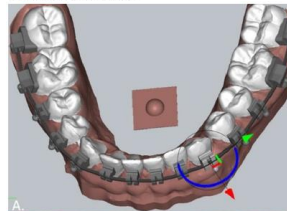


Figure 7. (A) Setup and automatic positioning of customized brackets in Utracklets software. Setup is the first step in the customization process, followed by the automatic placement of the 0.012 × 0.022 inches slot brackets on a full 0.012 × 0.022 inches archwire. (B) Customized brackets designed in Utracklets software and printed in permanent crown resin by Bego (Bremen, Germany) bonded. The wire is a 0.012-inch Nitinol customized active bend on the reported full file archwire drawing.



Table 1. Three-dimensional printing materials used in Orthodontic and pedodontic appliances.

Materials	Characteristics	Use
Dental model resin	rigid, hard, high fracture toughness, temperature resistant	thermoforming procedure
Occlusal splint resin	transparent, medium fracture toughness	occlusal splints
IDB tray resin	transparent, soft	IDB tray
CoCr alloy	rigid, non-flexible, printed in SLS printers	metallic orthodontic appliances
Ti alloy	rigid, non-flexible, printed in SLS printers	metallic orthodontic appliances
Stainless steel alloy	rigid, non-flexible, printed in SLS printers	metallic orthodontic appliances
Permanent crown resin	low hardness, high fracture toughness	crowns, brackets (tested)
Zirconia slurry	high hardness, low fracture toughness, printed in zirconia printers	crowns, bridges, brackets, bands
Aligner resin	high elastic index, transparent, stable mechanical properties	printed aligners

ARTICLE IN PRESS

3D printed aligners: Material science, workflow and clinical applications

Nearchos Panayi, Jung-Yeol Cha, and Ki Beom Kim

Clear aligner orthodontic treatment is not a new treatment modality. Treatment with the use of plastic invisible removable appliances counts more than 80 years when Kesling introduced the tooth positioner. Sheridan introduced the Essix aligner and Align technology its aligners. In-house designing and aligner fabrication has been around for more than 10 years. The last years a digital technological and material advancement has changed the process of aligner manufacturing from the plastic foil thermoforming procedure to a direct aligner printing one. Direct aligner printing poses advantages and some disadvantages compared to the traditional thermoforming procedure. The aligner designing and printing workflow entails steps that are sensitive to errors that must be carefully analyzed and studied through scientific research. Due to the versatile printed aligner designing capabilities, aligners can be designed to fulfill specific clinical needs. A few evidence based scientific studies have been published which help to understand and optimize the final printed outcome. Despite that, more studies are needed in order to overcome difficulties and create an appliance that will meet the demands of a successful orthodontic treatment. (Semin Orthod 2023; ■:1-14) © 2023 Elsevier Inc. All rights reserved.

Introduction

Evolution of aligners

Aligner introduction into orthodontics is the consequence of a demand for esthetic and invisible orthodontic treatment. Kesling back in 1945 was the first to introduce an appliance called tooth positioner for teeth moving without the use of fixed appliances.¹ The tooth positioner was made of vulcanized rubber on a dental setup after orthodontic brackets were removed. Minor irregularities could be corrected using the tooth positioner which was worn full time pushing the teeth into the predetermined tooth setup

School of Dentistry, European University Cyprus, Nicosia, Cyprus; Clinic of Orthodontics & Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland; private office Limassol, Cyprus; Director for Planning & Management Dental Hospital, Department of Orthodontics, Dental College, Yonsei University, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 120-752, Korea; Department of Orthodontics, Center for Advanced Dental Education, Saint Louis University, 3320 Rutger Street, Saint Louis, MO 63104, United States.

Corresponding author:

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1073-5746/12/18101-14\$30.00/0
<https://doi.org/10.1053/j.smo.2022.12.007>

Seminars in Orthodontics, Vol ■, No ■, 2023; pp 1-14

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A11. 2023, Seminars in Orthodontics

3D printed aligners: Material science, workflow and clinical applications

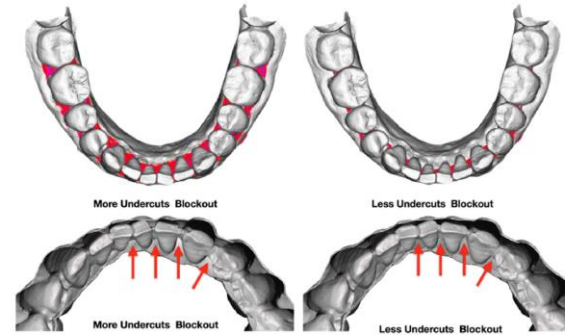


Fig. 2. Generalized spaces or black triangles and undercuts should be blocked out properly in order to avoid problems like space opening between teeth or problematic interdental aligner fitting.

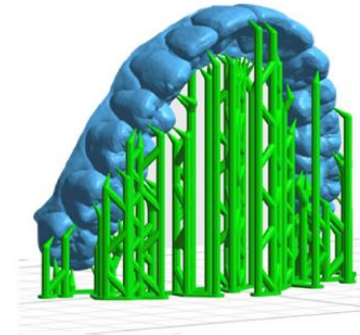


Fig. 5. Support structures can be created by special freeware, CAD orthodontic software or printer software.



Fig. 7. Tera Harz Cure Machine with a nitrogen generator.

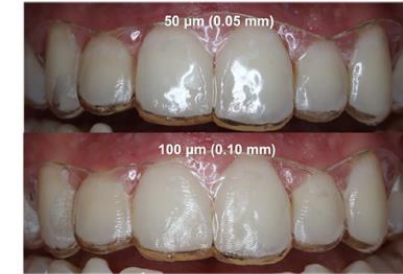


Fig. 4. Comparison between 50 µm and 100 µm z axis layer printing. Note the difference in transparency.



Fig. 8. Progress of a case using direct printed aligners.

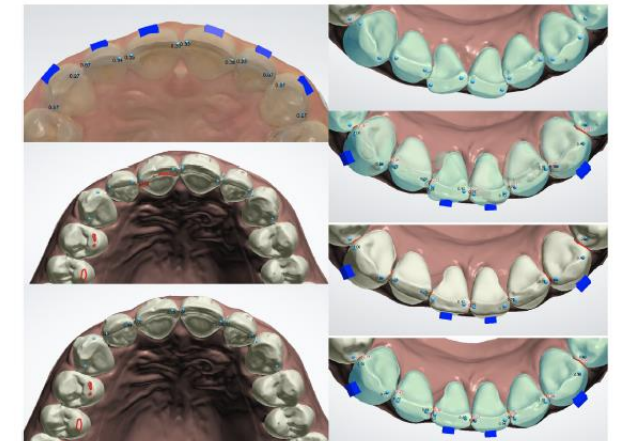


Fig. 10. Design of attachment and the process of sequential teeth movement for Aligner designing.



TURKISH JOURNAL OF
ORTHODONTICS

DOI: 10.4274/TurkOrthod.2023.2023.20



Review

Directly Printed Aligner: Aligning with the Future

Neachos C. Panayi^{1,2,3}

¹School of Dentistry, European University Cyprus, Nicosia, Cyprus
²Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland
³Private Clinic, Limassol, Cyprus

Cite this article as: Panayi NC. Directly Printed Aligner: Aligning with the Future. Turk J Orthod. 2023; 36(1): 62-69

Main Points

- 3D technology enabled the inclusion of a digital lab in the orthodontic office.
- Thermoformed aligners is the main way to perform aligner orthodontic treatment.
- Novel aligner resin has been introduced for the direct aligner printing.
- Printed aligners present significant advantages and some disadvantages.
- Studies have been published concerning the properties of the aligners. More studies have to be conducted in order to investigate and optimize printed aligner orthodontic treatment and create a consistent 3D-designing and printing workflow.

ABSTRACT

Orthodontics stands on a junction where traditional analog appliance manufacturing slowly but steadily changes to a digital one with the use of 3D technology. The main cause of this shift was the invention and use of computers, computer-aided design (CAD) software, computerized machines, and newly invented materials allowed this change to occur in a relatively short time in dentistry and orthodontics. The trigger for this transformation is the ability to digitally scan the oral cavity. CAD software and 3D printers already existed. It took a few years to include this technology in orthodontics and continuously apply it in the orthodontic office. Orthodontic treatment is mainly based on the use of fixed appliances, while in the last years, thermoformed aligners have been introduced as an alternative whenever a more invisible treatment modality is preferred. Clear aligner treatment is performed using thermoformed aligner. A new aligner resin has been recently invented to allow direct aligner printing. Directly printed aligner possess many advantages compared to thermoformed one. Research has been initiated to investigate all the aspects of the workflow and aligner printing outcome. More studies must be performed to look into the various aspects of directly printed aligners.

Keywords: 3D technology, 3D printing, directly printed aligner, UV curing unit, nitrogen generator

INTRODUCTION

Orthodontics is the only specialty in dentistry and medicine that uses forces to move human body parts, and teeth. The biology of tooth movement is extensively investigated, and theories have been expressed regarding many aspects of this movement. The unique feature of the continuing movement of our teeth throughout our entire life is used to correct orthodontic problems. The main way to move teeth is fixed appliances, which passed a long way since Angle invented the edgewise appliance.

In 1945, a brilliant mind Dr. Kesling¹ introduced a plastic-made appliance called tooth positioner to move teeth without fixed appliances. The positioner was made of rubber on a dental setup and was used immediately after brackets debonding. Later Nahoum² evolved an appliance using a two-block appliance for the upper and lower dental arches, while Sheridan et al.³ in 1993 introduced an Essix appliance to correct minor orthodontic problems combined with the interproximal reduction first used by ML Ballard in 1944.^{4,5} The next big step was made four years later when Zia Chitlani and Kelsey Wirth founded an aligner system called Invisalign (Align Technology, Santa Clara, Calif, USA). Later, other companies followed that path, while in the last years direct-to-consumers aligner was introduced.

Corresponding author: Neachos C. Panayi, e-mail: dp.panayi@cyprusnet.com.cy
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Received: February 7, 2023
Accepted: February 26, 2023
Epub: March 09, 2023
Publication Date: March 21, 2023

IN THE PERSPECTIVE OF (IT IS MORE FLEXIBILITY), THE SPLITTER CAN be positioned horizontally or vertically on the virtual printer

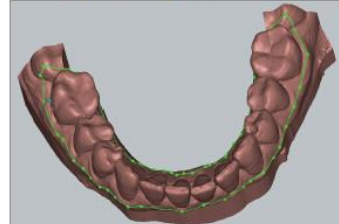


Figure 1. Directly printed aligner virtual design in Brackets software. Thickness can also be adjusted in the printed aligner module

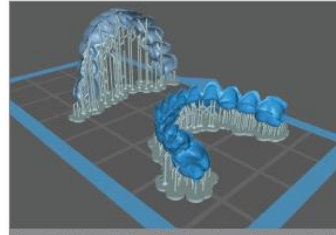


Figure 3. Virtual positioning of the aligner in a vertical and horizontal orientation. Horizontal positioning has the advantage of faster printing, but fewer aligner can be printed each time and more supports are needed. Vertically positioned aligner have the disadvantage of slower printing, but more aligner can be printed each time with the need of fewer supports

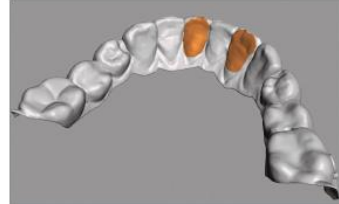


Figure 2. Brackets software enables the clinician to increase the aligner thickness in specific areas where teeth movement occurs. The software detects the areas where movement occurs and adds the extra predetermined material. Note the increased thickness of the aligner at the lingual side of 42 and 31 which is planned to be moved labially



Figure 4. Vertically printed aligner with their supports. Note the yellow color which turns transparent after UV curing



Figure 5. Tera Harz UV curing with a nitrogen generator that allows an oxygen-free polymerization

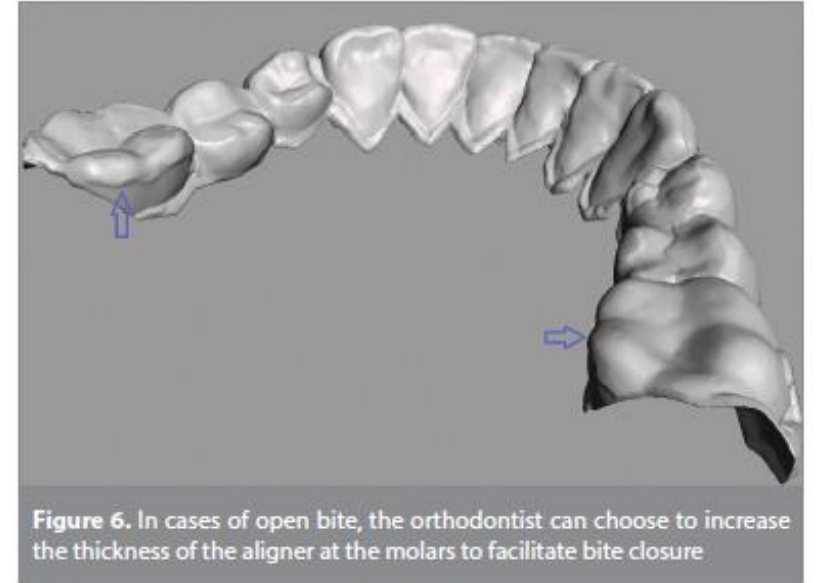


Figure 6. In cases of open bite, the orthodontist can choose to increase the thickness of the aligner at the molars to facilitate bite closure

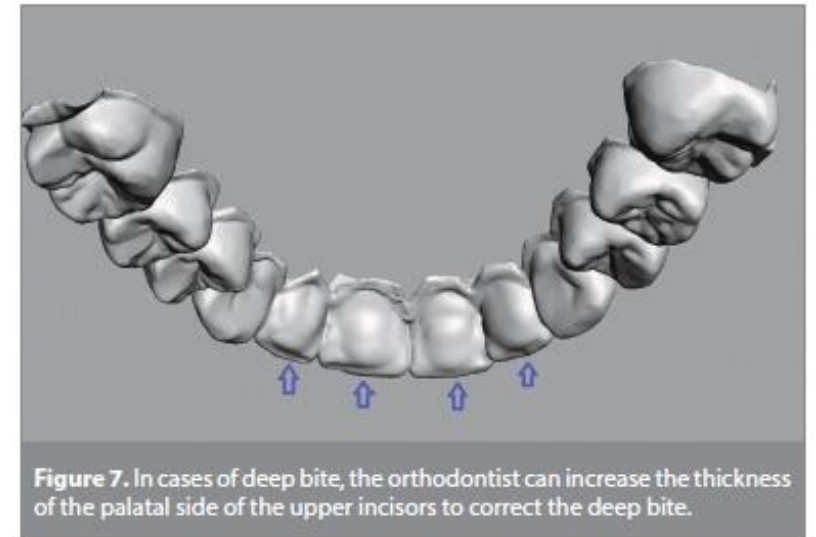


Figure 7. In cases of deep bite, the orthodontist can increase the thickness of the palatal side of the upper incisors to correct the deep bite.

A12. 2023, TJO

Directly Printed Aligner : Aligning with the Future

Publications

DIGITAL ORTHODONTICS **AJO-DO**

Effect of print orientation and duration of ultraviolet curing on the dimensional accuracy of a 3-dimensionally printed orthodontic clear aligner design

Marian C. McCarty,* Stephen J. Chen,* Jeryl D. English,* and F. Kaspe†
Houston, Tex

Introduction: This study aimed to investigate the effect of print orientation and ultraviolet (UV) light curing duration on the dimensional accuracy of a clear aligner design fabricated directly using 3-dimensional (3D) printing.

Methods: A master clear aligner design file was 3D printed on a stereolithography printer using 3 different build angles with respect to the build platform: parallel (Horizontal), perpendicular (Vertical), and 45° (45-Degree) (n = 10/group). The 45° orientation then was used to print aligners for 3 postprint processing treatment groups: 0 minutes of UV light and heat exposure (No Cure); 20 minutes of UV light exposure at 80°C (20 Minute); and 40 minutes of UV light exposure at 80°C (40 Minute) (n = 10/group). Each part was digitally scanned and superimposed with the input file for 3D deviation analysis. A generalized linear mixed model and post-hoc Tukey contrasts were applied for statistical analysis. **Results:** Difficulties were encountered in optical scanning of 3D-printed aligners, resulting in the exclusion of some samples and the No Cure group from the analysis. The average positive and negative deviations were not statistically significantly different among the print orientations, and postprint processing conditions were analyzed and fell within limits of clinical acceptability (0.250 mm). Color deviation maps illustrated localized areas of dimensional deviation that may affect the clinical utility of the printed aligner design. **Conclusions:** The print orientation and postprint curing duration have little effect on the overall accuracy of the 3D-printed aligner design under the conditions investigated. However, the potential effects of location-specific deviations on the clinical utility of 3D-printed aligners should be considered in future studies. (Am J Orthod Dentofacial Orthop 2020;158:889-97)

Abstract: The influx of digital technology and computer-aided design and computer-aided manufacturing into the orthodontic space enable increased use of positioner-like appliances for major tooth movement. Applying computer-aided design and computer-aided manufacturing technology, the workflow for clear aligner therapy traditionally uses a single, bilateral impression or digital scan to generate multiple digital setups. These setups are then 3-dimensionally (3D) printed as a series of dental models onto which clear, plastic aligners can be manufactured through thermoforming. Currently, the research has focused primarily on the accuracy of intraoral scanning, 3D-printed models, and fabrication of clear aligners on 3D-printed models using the traditional workflow. However, resins are emerging that may be suitable for direct fabrication of clear aligners through 3D printing, obviating the need for the 3D-printed intermediate models and thermoforming steps associated with the traditional workflow. If accurate, these resins could dramatically improve the efficiency of the process, enabling more rapid delivery of aligners to the patients and generating a higher yield for the practice while reducing waste and cost. Although the accuracy of 3D-printed orthodontic models has been investigated in the literature,¹⁻⁷ key differences exist in the geometry of models and aligners; specifically, the geometry of an aligner design file is more complex than a 3D-printed model. Each

*Department of Orthodontics, School of Dentistry, The University of Texas Health Science Center at Houston, Houston, Tex.
†Department of Orthodontics, School of Dentistry, and Graduate School of Biomedical Sciences, The University of Texas Health Science Center at Houston, Houston, Tex.
All authors have completed and certified the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were stated.
Address correspondence to: F. Kaspe, Department of Orthodontics, School of Dentistry, The University of Texas Health Science Center at Houston, 77030 Cambridge St, Ste 5110, Houston, TX 77054; e-mail: Fred.Kaspe@uth.tmc.edu.
Submitted September 2019; revised February 2020; accepted March 2020.
0889-4428/20/158-889-09
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https://doi.org/10.1097/eao.0000000000000102

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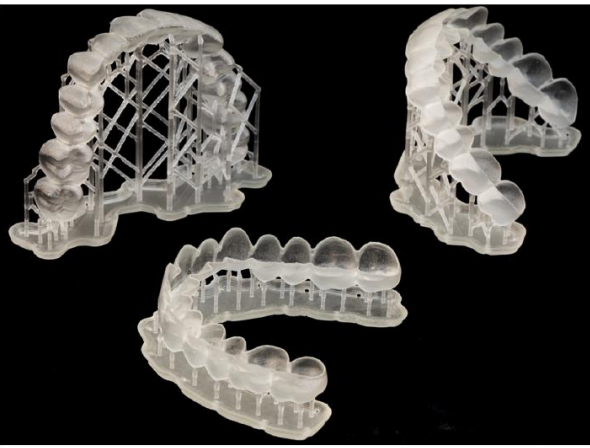


Fig 2. Representative aligners of each of the 3 orientations (horizontal, 45°, and vertical) investigated in part 1 were shown before removing supports.

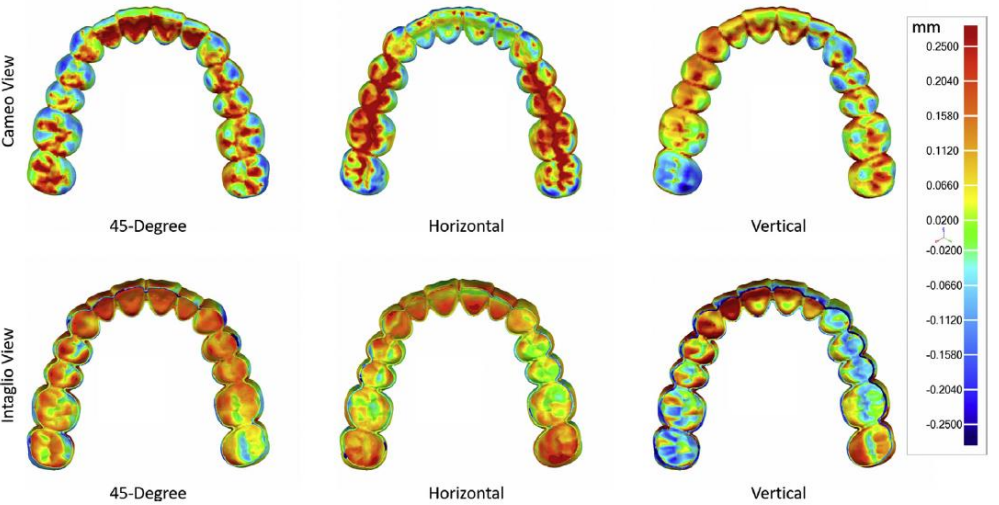


Fig 3. Representative views of superimpositions of aligners from each of the 3 orientations (horizontal, 45°, and vertical) investigated in part 1 showing areas of dimensional deviation as compared with the input file used for printing. Cool colors indicate negative deviations, and warm colors indicate positive deviations.

“The overall dimensional accuracy of the 3D-printed aligners at the 3 orientations investigated fell within the clinical tolerances.

...
Increased curing duration did not have a statistically significant effect on the dimensional accuracy of the 3D-printed aligners.”

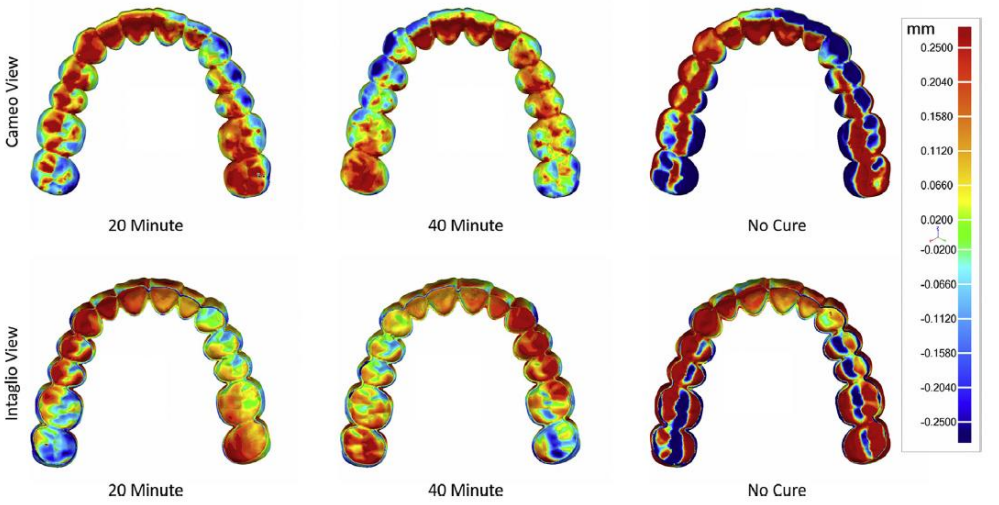


Fig 4. Representative views of superimpositions of aligners from each of the 3 postprint processing treatments (20-minute, 40-minute, and No Cure) investigated in part 2 showing areas of dimensional deviation as compared with the input file used for printing. Cool colors indicate negative deviations, and warm colors indicate positive deviations.

B1. 2020, AJO-DO

Effect of print orientation and duration of ultraviolet curing on the dimensional accuracy of a 3-dimensionally printed orthodontic clear aligner design

Publications

materials MDPI

Review
Direct 3D Printing of Clear Orthodontic Aligners: Current State and Future Possibilities

Gianluca M. Tartaglia ^{1,2}, Andrea Mapelli ¹, Cinzia Maspero ^{1,2,3}, Tommaso Santaniello ³, Marco Serafin ^{1,2,4}, Marco Farronato ^{1,2,4} and Alberto Caprioglio ^{1,2}

¹ Department of Biomedical, Surgical and Dental Sciences, School of Dentistry, University of Milan, 20100 Milan, Italy; gianluca.tartaglia@unimi.it (G.M.T.); andrea.mapelli@unimi.it (A.M.); cinzia.maspero@unimi.it (C.M.); marco.farronato@unimi.it (M.F.); alberto.caprioglio@unimi.it (A.C.)
² Fondazione IRCCS Ca' Granda, Ospedale Maggiore Policlinico, 20100 Milan, Italy
³ Department of Physics, University of Milan, 20100 Milan, Italy; tommaso.santaniello@unimi.it
⁴ Correspondence: marco.serafin@unimi.it

Abstract: The recent introduction of three-dimensional (3D) printing is revolutionizing dentistry and is even being applied to orthodontic treatment of malocclusion. Clear, personalized, removable aligners are a suitable alternative to conventional orthodontic appliances, offering a more comfortable and efficient solution for patients, including improved oral hygiene and aesthetics during treatment. Contemporarily, clear aligners are produced by a thermoforming process using various types of thermoplastic materials. The thermoforming procedure alters the properties of the material, and the thermal environment further modifies the properties of a clear aligner, affecting overall performance.

Keywords: 3D printing; clear aligners; dental printing; resin; malocclusion; narrative review; orthodontics

1. Background
Brief History
 Orthodontics is now approaching its fourth revolution since its inception as a specialty of dentistry in the early 1900s. In those days, malocclusion was treated with the application of metal rings cemented to teeth to support wires for applying moving forces. This initial treatment strategy for the correction of dental and skeletal malocclusion was often accompanied by a huge number of dental caries because it was almost impossible to maintain correct dental hygiene due to the limited offering of dental hygiene tools in the market at that time and to the mechanical encumbrance of the cemented rings and

IF(2023) : 3.748
Citations : 70

Academic Editor: Luca Costantini
 Received: 7 February 2023
 Accepted: 2 April 2023
 Published: 3 April 2023

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Materials 2023, 14, 1799. <https://doi.org/10.3390/ma14071799> <https://www.mdpi.com/journal/materials>



Figure 1. Conventional orthodontic treatment (a) and thermoformed clear aligner with its 3D printed mold (b).



Figure 2. Direct 3D printed clear aligner.



Figure 3. Final step of an orthodontic treatment with 3D direct printed clear aligners (experimental trial on a voluntary patient).

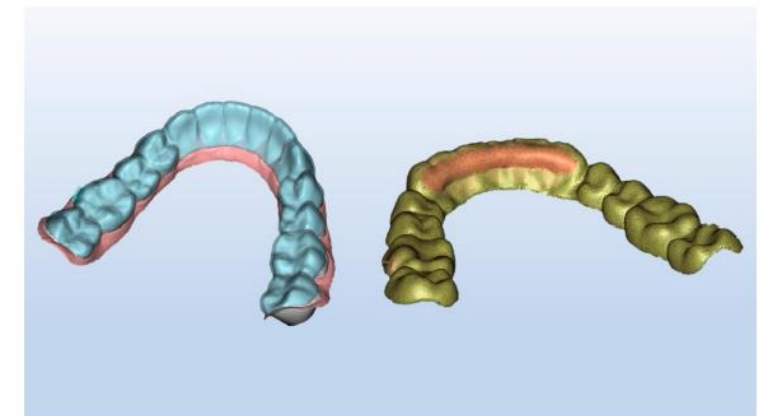


Figure 4. Customization of design and thickness of directly printed aligners.

B3. 2021, Materials

Direct 3D Printing of Clear Orthodontic Aligners Current State and Future Possibilities

Chapter
Digital Workflow for Homemade Aligner

Dalal Elmoutawakkil and Nabil Hacıb



Abstract

Advanced digital technology is rapidly changing the world, as well as transforming the dental profession. The adoption of digital technologies in dental offices allied with efficient processes and accurate high-strength materials are replacing conventional aligners workflows to improve overall patients' experiences and outcomes. Various digital devices such as 3D printers, intraoral and face scanners, cone-beam computed tomography (CBCT), software for computer 3D ortho setup, and 3D printing provide new potential alternatives to replace the traditional outsourced workflow for aligners. With this new technology, the entire process for bringing clear aligner production in-office can significantly reduce laboratory bills and increase patient case acceptance to provide high-quality and customized aligner therapy.

Keywords: digital workflow, orthodontics, aligner, thermoforming, 3D Printing, facial scan, planning software, homemade aligners

1. Introduction

The increasing esthetic need of patients for orthodontic devices has led to the development of clear aligner therapy [1, 2]. Traditionally, orthodontists contract with an outside service to provide clear aligner treatments. Outsourcing to a provider has drawbacks for both the patient and the orthodontist. It can take over a month to produce and deliver an aligner set, and the provider requires a substantial service fee, cutting into potential profits.

Advancements in 3D printing technology, intra-oral scanners, and 3D setup software improve the production of clear aligners. Nowadays, these solutions are widely available in private dental practices, allowing orthodontists in-house aligner production.

In-house 3D printing accelerates aligner turnaround, increases profitability, and improves patient satisfaction while offering complete workflow control.

In this chapter, we will suggest to orthodontists to centralize the production of aligners in the dental office by detailing the different stages of the production flow. From acquiring extra-oral and intra-oral patient data and exploring necessary hardware and software for this acquisition. Until the production of the aligners, where we will discuss the equipment and materials mandatory for this production. Going through the planning, this section will detail the different software that an orthodontist can use for the 3D setup and the particularities of each of these softwares.



Figure 9.
 Pressure forming machines for aligner's fabrication.



Figure 10.
 In-office trimming of aligners.

“Graphy’s Tera Harz has obtained CE, FDA, and KFDA medical device certification...The clear Tera Harz resin is **fully transparent** and has **high durability** agreed with **orthodontic treatment** device purposes.”

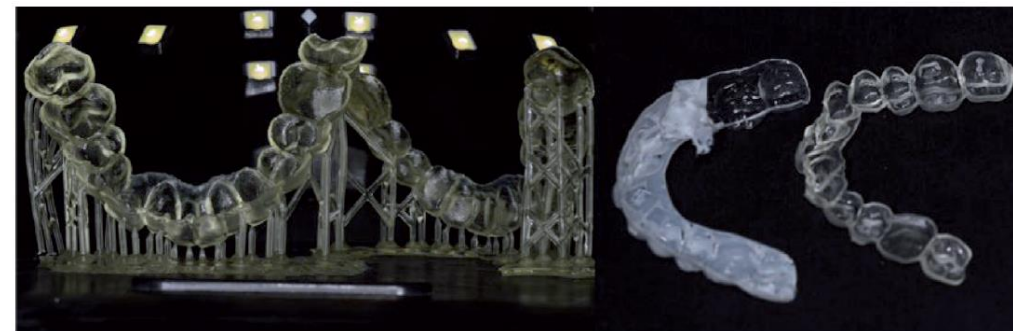


Figure 8.
 Directly printed aligners with Tera Harz TC-85 resin (TC-85DAC) put, after post-treatment side by side with thermoformed aligner (Biolon 0,75 mm).

B7. 2021

Digital Workflow for Homemade Aligner

NARRATIVE LITERATURE REVIEW

Emerging insights and new developments in clear aligner therapy: A review of the literature

Johan Hartshorne^a and Mark Brian Wertheimer^b
 Belville and Johannesburg, South Africa

Aggressive promotion by stakeholders and increased public awareness for alternative esthetic orthodontic treatment options have popularized the demand for clear aligner therapy (CAT). Patient demand is driven by appearance, comfort, convenience, and less complicated oral hygiene control. CAT is an important treatment alternative to conventional fixed appliances and a viable alternative for mild-to-moderate malocclusions in nonextraction, nongrowing patients. CAT is less effective and predictable than conventional fixed appliances for complex orthodontic tooth movements and malocclusions. However, the introduction of improved software, aligner materials, and auxiliary devices has enhanced the scope of malocclusions that may be treated. Managing complex tooth movements during CAT requires auxiliaries, overcorrections, and refinements to improve the predictability, effectiveness, and stability of treatment outcomes. The main predictors of treatment outcome are proper patient selection, patient compliance, treatment planning, compliance, clinician experience, and regular monitoring. Currently, there are no evidence-based clinical guidelines for CAT. Aligner technology and therapy are continuously evolving and improving. This literature review aimed to assess and summarize current scientific knowledge and evidence relating to CAT. (Am J Orthod Dentofacial Orthop Clin Companion 2022;XX:XX-XXX)

Clear aligner treatment (CAT) is a rapidly developing modality of orthodontic treatment, that has received increased attention as an alternative to conventional braces, especially among adult patients wishing to improve smile esthetics.¹⁻⁶ Easier oral hygiene maintenance,⁷ less pain and discomfort,⁸ shorter treatment time,⁹ less inconvenience¹⁰ and better quality of life,^{11,12} are claimed advantages compared with conventional fixed appliances. Demand for CAT is further increased because of aggressive promotion by stakeholders through direct-to-consumer advertising and social media, generating increased public awareness for alternative esthetic orthodontic treatment options.¹³ In contrast, orthodontists have often cited treatment outcomes and clinical performance as the

most important factors when considering using aligners instead of fixed appliances.¹⁴ It is imperative that both patient and clinician expectations are addressed when selecting the appliance for treatment.¹⁴

The demand and use of CAT have subsequently motivated people of all ages, including older adults, to seek orthodontic treatment.¹⁵ However, concerns have been raised regarding the effectiveness and predictability of CAT. Bowman¹⁶ argued that "a series of aligners alone cannot solve most malocclusion issues, no matter the quality of the software design, modeling, nor type of plastic used." However, with improved software design, modeling, and 3-dimensional (3D) printing technology and biomaterials, together with the input of innovative clinicians, the evolution of CAT is being steered in the right direction. Initially, the indications for CAT were limited to the correction of alignment in mild-to-moderate malocclusions with minor crowding. Nowadays, moderate to extremely complex treatment is embarked upon with some degree of success.¹⁷ The top six comparisons driving the clear aligner industry are summarized in the Table.

This literature review aimed to assess and summarize current scientific knowledge and evidence related to CAT.

^aIntercare Medical and Dental Centre, Belville, South Africa.

^bPrivate practice, Johannesburg, South Africa.

All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.

Address correspondence to: Mark Brian Wertheimer, Private practice, Suite 1107, The Leonardo, 75 Maude St, Sandton 2196, Johannesburg, South Africa.; e-mail: mwerth@onet.co.za

Month 2022, Vol 00, Issue 00

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B9. 2022, AJO-DO Clinical Companion

Emerging insights and new developments in clear aligner therapy (CAT): A review of the literature

"Future directions of 3D printing"

"Korean photopolymer company Graphy Inc has recently developed a **biocompatible** aligner material, Tera Harz TC-85, for direct 3D printing of aligners.

... has enhanced **strength, elasticity, and shape memory** properties.

... is positioned to be the world's first commercially available integrated solution for printing aligners with **enhanced accuracy and surface quality**, and to overcome the current limitations of thermoformed aligners.

....Direct 3D printing of aligners will considerable increase the **efficiency of the production process** and decrease the **environmental impact** of clear aligner production.

Additional advantages may include manufacturing with **smooth edges**, **negating the need for trimming or polishing**, and **digital elimination of undercuts**.

Higher precision improves fit and effectiveness and provides for **customizable intra-aligner thickness**."

The background features a dynamic, flowing golden liquid that curves across the frame. The liquid has a glossy, reflective surface with highlights and shadows, giving it a three-dimensional appearance. In the lower right quadrant, there are several semi-transparent, geometric shapes, including triangles and polygons, some of which are outlined in a light orange color. The overall color palette is warm, dominated by shades of gold, orange, and yellow against a white background.

Comparative Analysis

(Crown & Bridge Materials)



Article
Novel 3D Printed Resin Crowns for Primary Molars: In Vitro Study of Fracture Resistance, Biaxial Flexural Strength, and Dynamic Mechanical Analysis

Nayoung Kim¹, Hoon Kim², Ik-Hwan Kim³, Jiho Lee⁴, Ko Eun Lee⁵, Hyo-Seol Lee⁶, Jee-Hwan Kim⁴, Je Seon Song^{1,4} and Yoosok Shim⁷ *

- ¹ Department of Pediatric Dentistry, College of Dentistry, Yonsei University, Seoul 03722, Korea
- ² Research Institute of Agriculture and Life Sciences, College of Agriculture and Life Sciences, Seoul National University, Seoul 0826, Korea
- ³ Department of Pediatric Dentistry, Yonsei University Dental Hospital, Seoul 03722, Korea
- ⁴ Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Korea
- ⁵ Department of Pediatric Dentistry, Kyung Hee University Dental Hospital, Seoul 02447, Korea
- ⁶ Department of Prosthodontics, College of Dentistry, Yonsei University, Seoul 03722, Korea
- ⁷ Department of Conservative Dentistry, College of Dentistry, Yonsei University, Seoul 03722, Korea

Abstract: This study evaluated the fracture resistance, biaxial flexural strength (BFS), and dynamic mechanical analysis (DMA) of three-dimensional (3D) printing resins for the esthetic restoration of primary molars. Two 3D printing resins, Graphy (GP) and NextDent (NXT), and a prefabricated zirconia crown, NuSmile (NS), were tested. GP and NXT samples were 3D printed using the workflow recommended by each manufacturer. Data were collected and statistically analyzed. As a result of the fracture resistance test of 0.7-mm-thick 3D printed resin crowns with a thickness similar to that of the NS crown, there was no statistically significant difference among GP (1491.6 ± 394.6 N), NXT (1634.4 ± 289.3 N), and NS (1622.8 ± 323.9 N). The BFS of GP was higher for all thicknesses than that of NXT. Both resins showed high survival probabilities (more than 90%) when subjected to 80 and 150 MPa. Through DMA, the glass transition temperatures of GP and NXT were above 120 °C and the rheological behavior of GP and NXT according to temperature and frequency were analyzed. In conclusion, GP and NXT showed optimum strength to withstand bite forces in children, and 3D printed resin crowns could be an acceptable option for fixed prostheses of primary teeth.

Keywords: 3D printing; mechanical properties; fracture resistance; biaxial flexural strength; dynamic mechanical analysis; primary molar; 3D printed resin crown

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 Cheon Kim, N., Kim, H., Kim, I.-H., Lee, J., Lee, K.S., Lee, H.-S., Kim, J.-H., Song, J.S., Shim, Y., Novel 3D Printed Resin Crowns for Primary Molars: In Vitro Study of Fracture Resistance, Biaxial Flexural Strength, and Dynamic Mechanical Analysis. *Children* 2022, 9, 1445. <https://doi.org/10.3390/children9101445>

Academic Editor: Ziad D. Bughdadi
 Received: 26 August 2022
 Accepted: 19 September 2022
 Published: 22 September 2022

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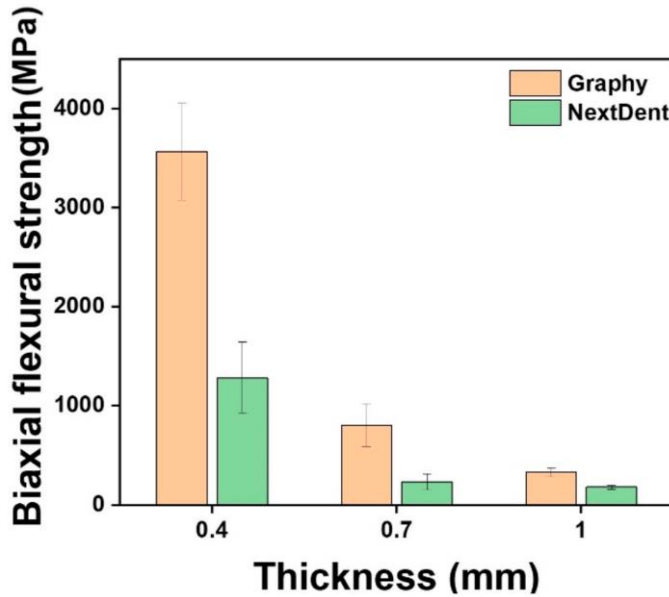


Figure 4. Mean biaxial flexural strength (MPa) of the various experimental groups.

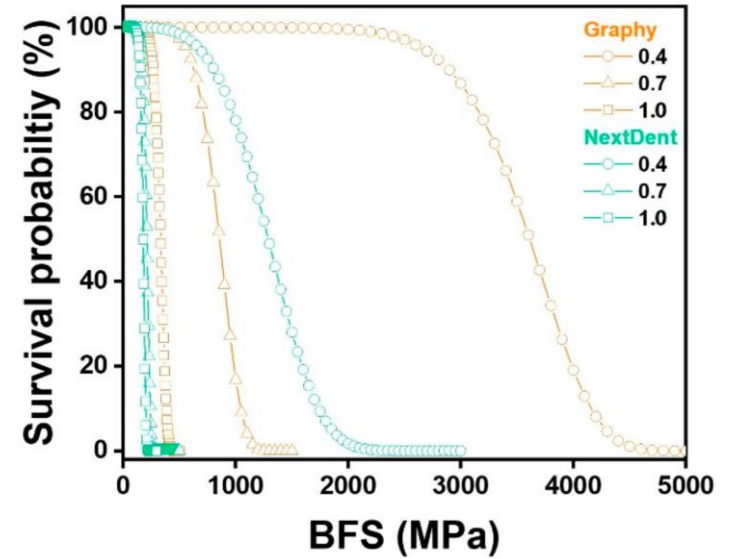
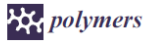


Figure 6. Weibull survival probability based on biaxial flexural strength (BFS) for thicknesses 0.4, 0.7, and 1.0 mm for Graphy and NextDent materials.

A8. 2022, Children (TC-80)

Novel 3D Printed Resin Crowns for Primary Molars - In Vitro Study of Fracture Resistance, Biaxial Flexural Strength, and Dynamic Mechanical Analysis

“3D printed resin crowns could be a new alternative to restoring primary molars while satisfying the need for esthetics.”



Article
Effect of Adhesion Conditions on the Shear Bond Strength of 3D Printing Resins after Thermocycling Used for Definitive Prosthesis

You-Jung Kang ^{1,†}, Yesul Park ^{1,†}, Yoosook Shin ² and Jee-Hwan Kim ^{1,*}

¹ Department of Prosthodontics, Oral Science Research Center, College of Dentistry, Yonsei University, Seoul 03722, Republic of Korea
² Department of Conservative Dentistry, Oral Science Research Center, College of Dentistry, Yonsei University, Seoul 03722, Republic of Korea
 * Correspondence: jee917@yuhs.ac; Tel.: +82-2-2228-3161; Fax: +82-2-312-3598
 † These authors contributed equally to this work.

Abstract: Three-dimensional (3D) printing polymers such as urethane dimethacrylate (UDMA) and ethoxylated bisphenol A dimethacrylate (Bio-EMA) are typically used in definitive prosthesis and require surface treatments before bonding. However, surface treatment and adhesion conditions often affect long-term use. Herein, polymers were divided into Groups 1 and 2 for the UDMA and Bio-EMA components, respectively. The shear bond strength (SBS) between two types of 3D printing resins and resin cements was measured using Rely X Ultimate Cement and Rely X U200, according to adhesion conditions such as single bond universal (SBU) and airborne-particle abrasion (APA) treatments. Thermocycling was performed to evaluate the long-term stability. Sample surface changes were observed using a scanning electron microscope and surface roughness measuring instrument. The effect of interaction between the resin material and adhesion conditions on the SBS was analyzed via a two-way analysis of variance. The optimal adhesion condition for Group 1 was achieved when U200 was used after APA and SBU, whereas Group 2 was not significantly affected by the adhesion conditions. After thermocycling, the SBS significantly decreased in Group 1 without APA treatment and in the entire Group 2. Additionally, porosity, along with increased roughness, was observed on both material surfaces after APA.

Keywords: 3D printing resin; shear bond strength; surface roughness; adhesion conditions; surface treatment; thermocycling

1. Introduction

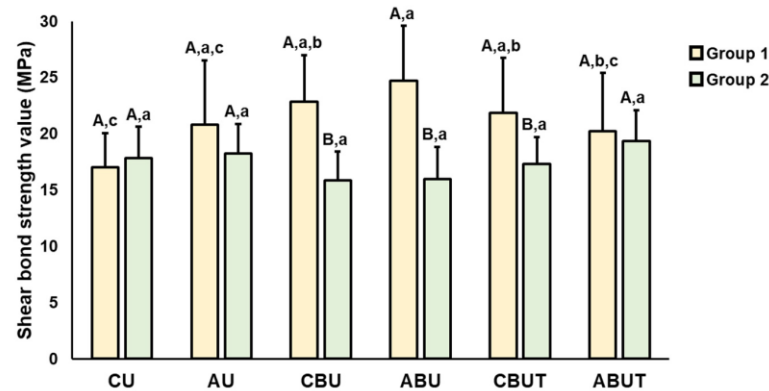
Several three-dimensional (3D) printing technologies and materials have been developed with advances in computer-aided design/ computer-aided manufacturing (CAD/CAM) technology. To manufacture various restorations in the dental field, 3D printing or prototyping is typically used to fabricate 3D models by layering polymer materials [1–4]. Notably, 3D printing technology can easily and accurately manufacture detailed and complex prostheses. This approach significantly reduces the time and labor required in clinical and laboratory procedures compared to conventional methods [1,5–8]. Given these advantages, 3D printing resin materials for long-term definitive prostheses have been developed [9,10], and research on 3D printing materials is underway [2,11,12].

The primary component of 3D printing resins used for definitive prosthesis is either urethane dimethacrylate (UDMA) or ethoxylated bisphenol A dimethacrylate (Bio-EMA). When a new dental material is developed, various factors, such as the mechanical properties determined by the composition of the material, adhesion to existing dental cement, and processing method, must be considered. Among these, adhesion is a clinically essential factor in ensuring a successful restorative treatment. Certain previous studies have reported

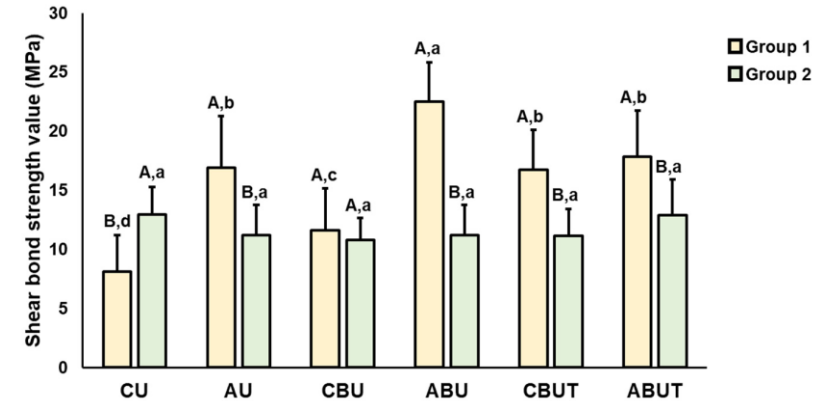
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 You-Jung Kang, Yesul Park, Yoosook Shin, Jee-Hwan Kim, J.H. Effect of Adhesion Conditions on the Shear Bond Strength of 3D Printing Resins after Thermocycling Used for Definitive Prosthesis. Polymers 2023, 15, 1360. <https://doi.org/10.3390/polym15061360>
 Academic Editors: Mark Fisher, Edina Lempert and Zsófia Tóth
 Received: 10 February 2023
 Revised: 8 March 2023
 Accepted: 9 March 2023
 Published: 10 March 2023

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SBS before thermocycling



SBS after thermocycling

“Graphy resin showed high adhesive stability after thermocycling, whereas Formlabs resin showed a considerable decrease in shear bond strength after thermocycling.”

A13. 2023, Polymers (TC-80)

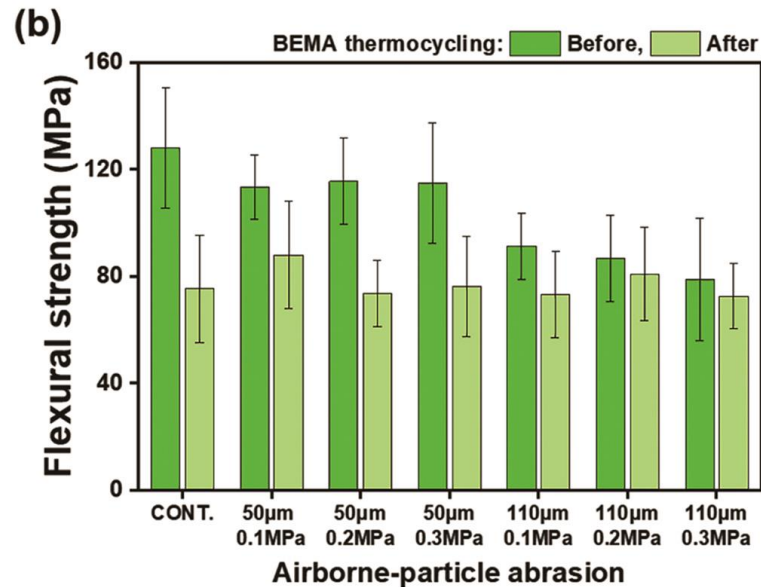
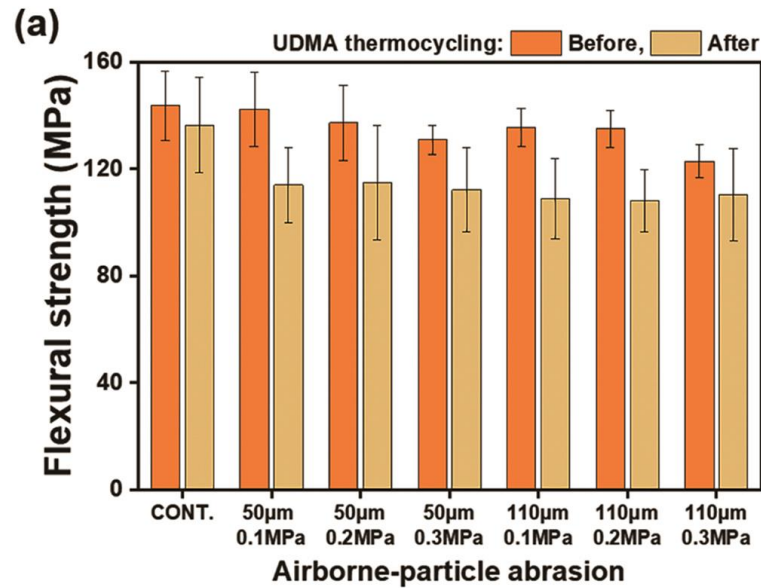
Effect of Adhesion Conditions on the Shear Bond Strength of 3D Printing Resins after Thermocycling Used for Definitive Prosthesis

Publications



A14. 2023, Dental Materials (TC-80)

Effect of airborne particle abrasion treatment of two types of 3D-printing resin materials for permanent restoration materials on flexural strength



Graphy TC-80 shows flexural strength of **145MPa** and maintains flexural strength higher than **120MPa** even after airborne particle surface abrasion treatment and accelerated aging.

Formlab Permanent Crown A2 shows flexural strength of **134MPa** immediately after printing, then decreases to **70MPa** after surface treatment and thermocycling.