The Science Behind It

Research Publications using Graphy materials

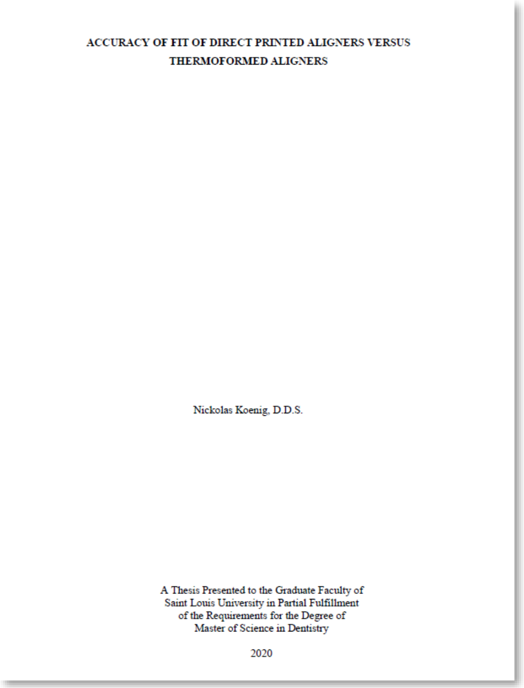
Jiho Lee, Jin Hong Min, Hoon Kim*

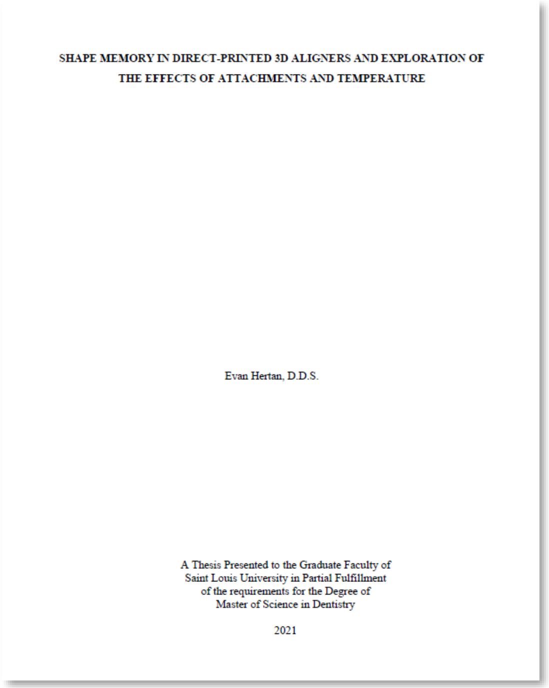
Graphy R&D Center
Graphy Inc.

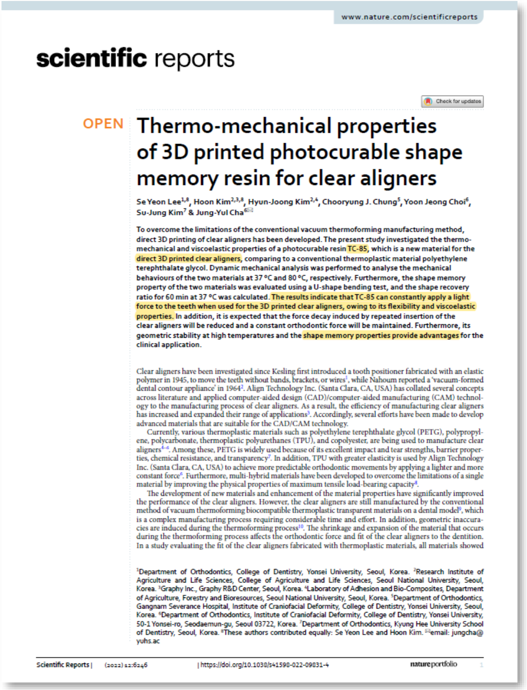
jiholee@itgraphy.com
hkim@itgraphy.com

Publications

Graphy







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

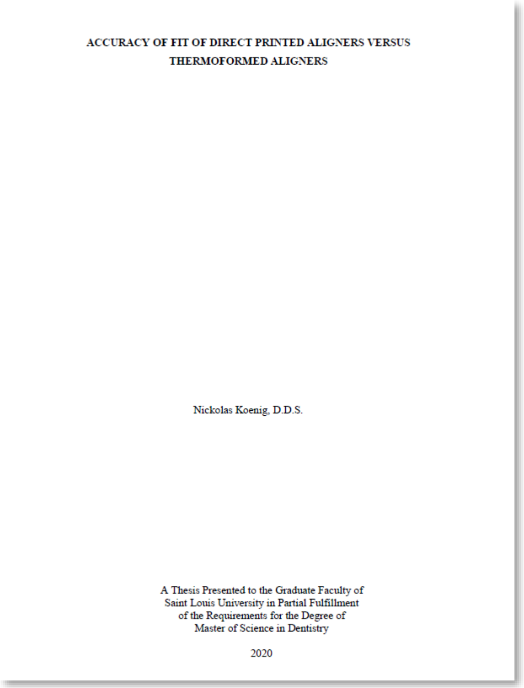
A4. 2022, Scientific Reports

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

Publications

Graphy

IF(2023) : 4.379
Citations : 22

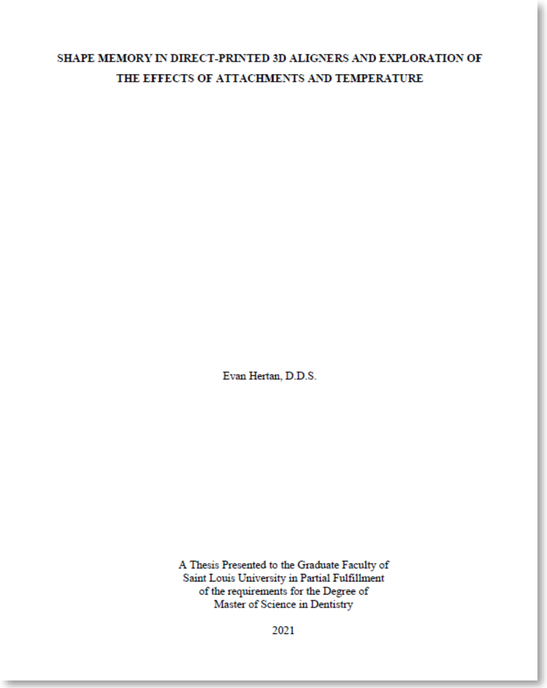


ACCURACY OF FIT OF DIRECT PRINTED ALIGNERS VERSUS THERMOFORMED ALIGNERS

Nickolas Koenig, D.D.S.

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

2020



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

Evan Hertan, D.D.S.

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

European Journal of Orthodontics, 2021, 1–5

Original article

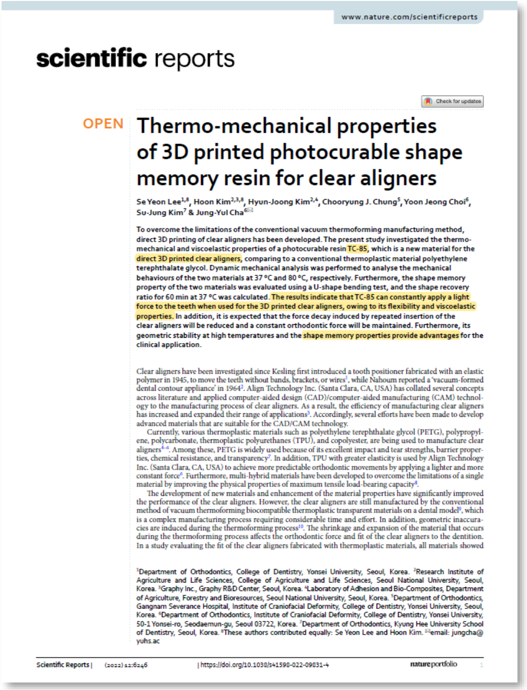
Original article

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

Esad Chan, Nearchos Panayi, Georgios Polychronis, Spyridon N. Papageorgiou, Spiros Zinelis, George Eliades and Theodore Eliades

Summary

Introduction



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scientific reports

OPEN

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

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

Publications

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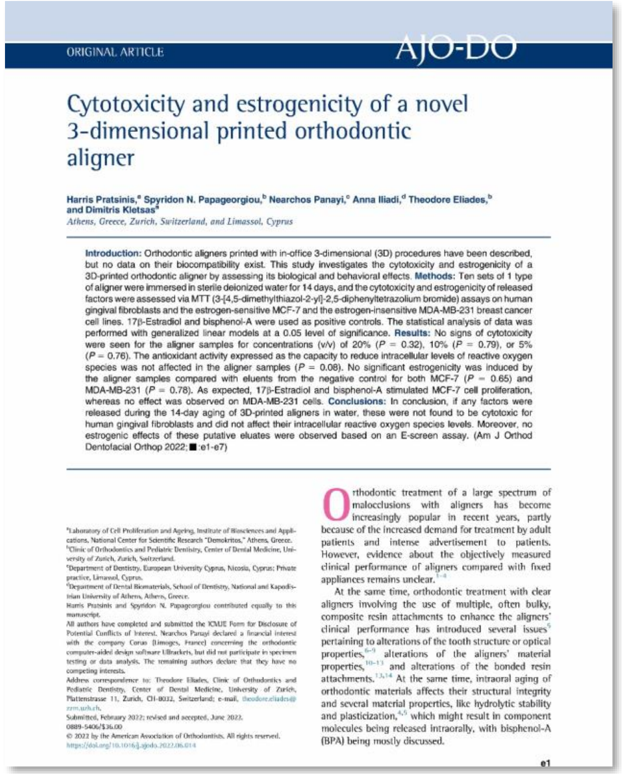
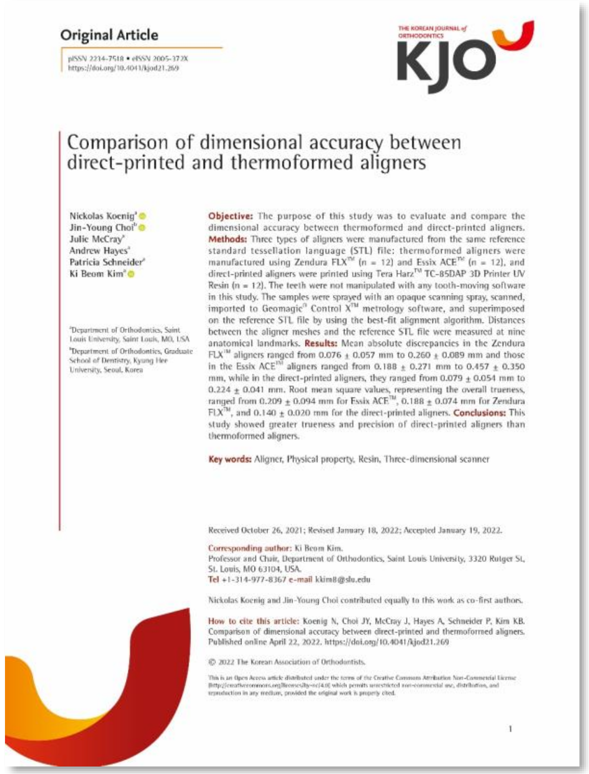




A5. 2022, AJO-DO

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

A6. 2022, Children

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

A7. 2022, KJO

Comparison of dimensional accuracy between direct-printed and thermoformed aligners

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

P

Graphy

IF(2022) : 16.44
Citations : 12

IF(2022) : 5.43

Bioactive Materials 22 (2023) 384–403

Contents lists available at ScienceDirect

Bioactive Materials

journal homepage: www.keaipublishing.com/en/journals/bioactive-materials

Advances in orthodontic clear aligner materials

Yashodhan M. Bichu, Abdulraheem Alwafi, Xiaomo Liu, James Andrews, Björn Ludwig, Aditi Y. Bichu, Bingshuang Zou

Herțan 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

ARTICLE IN PRESS

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

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

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

Publications

Graphy

IF(2023) : 4.967

IF(2023) : 5.687

A12. 2023, TJO

Directly Printed Aligner : Aligning with the Future

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

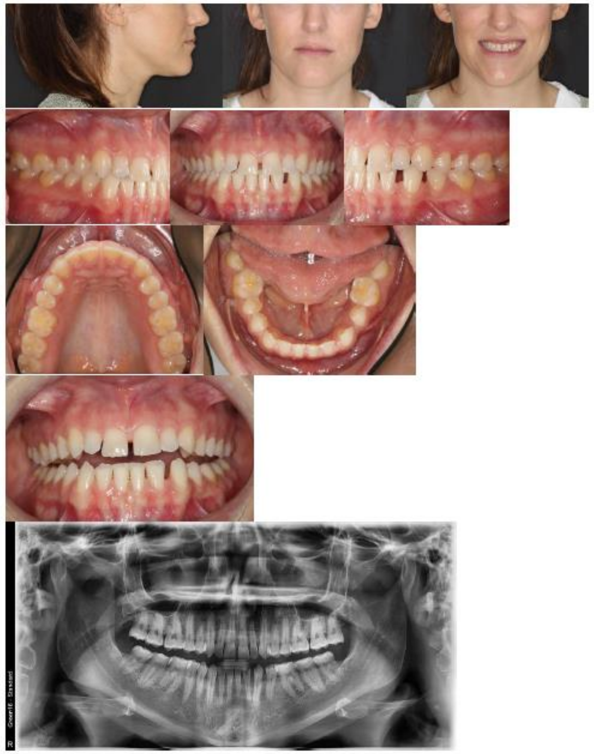


Fig 7a-j: Extra- and intraoral situation at the start of the in-office aligner treatment. The patient shows spaces in the maxillary and mandibular region with abrasions on several teeth and missing tooth 34. Closure of the space alone with orthodontics would not lead to an aesthetically pleasant result. 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.

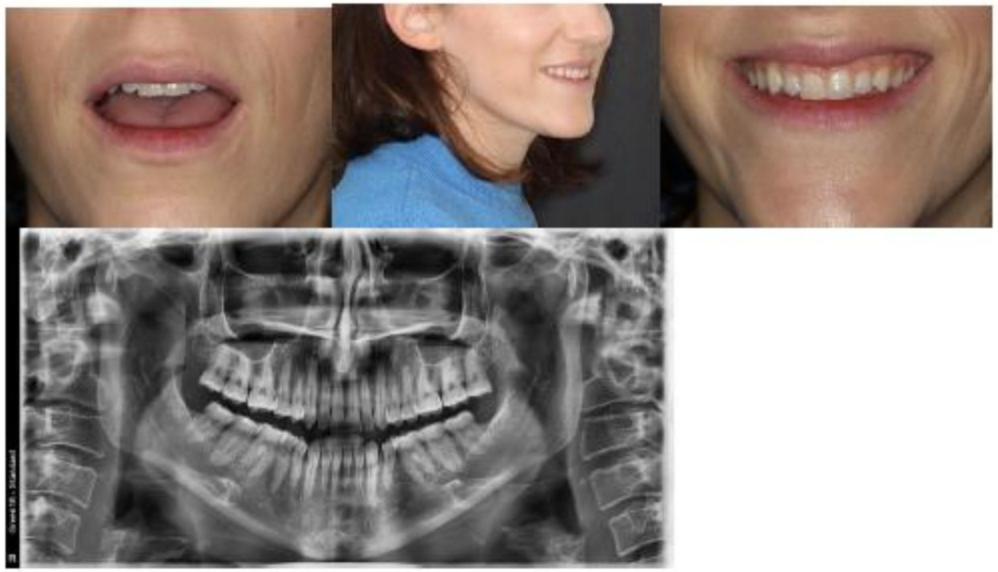


Fig 16a-r: Final extra- and intraoral situation after treatment with in-office direct Graphy aligners. The treatment was performed with longer straight aligner margins, but without any attachment on the teeth for additional anchorage. The final orthopantomogram shows no pathologies.

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

Shape Memory Aligner – A new dimension in Aligner Orthodontics

Publications

Graphy

IF(2023) : 3.748
Citations : 70

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

Publications

Graphy

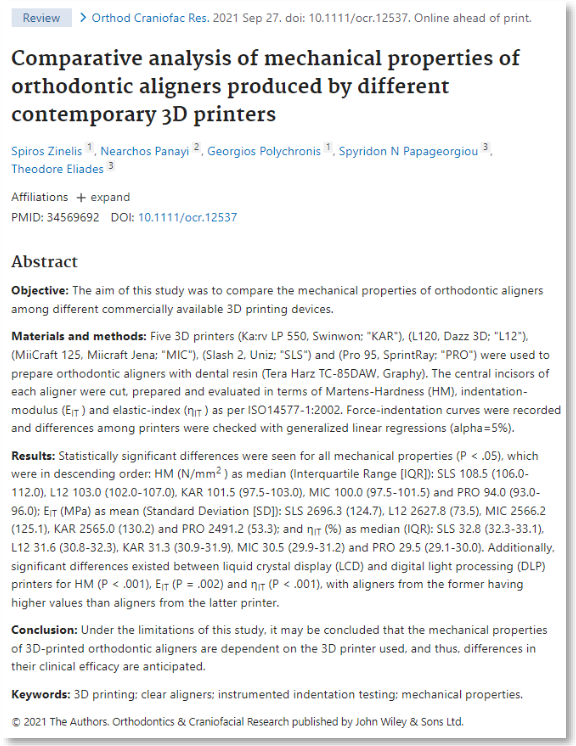

International Journal of Environmental Research and Public Health

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, Yong Kwon Chae, Chunui Lee, Sung Chul Choi and Ok Hyung Nam


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 (Ka:rv 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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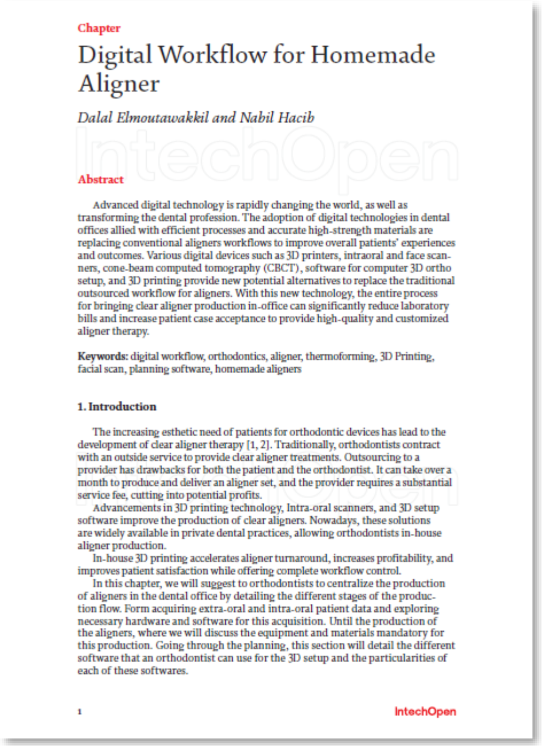

Chapter

Digital Workflow for Homemade Aligner

Dalal Elmoutawakkil and Nabil Hacib

Abstract

1. Introduction

IntechOpen


JTD

Original Article

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

정안나, 박유진, 최성민

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

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

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

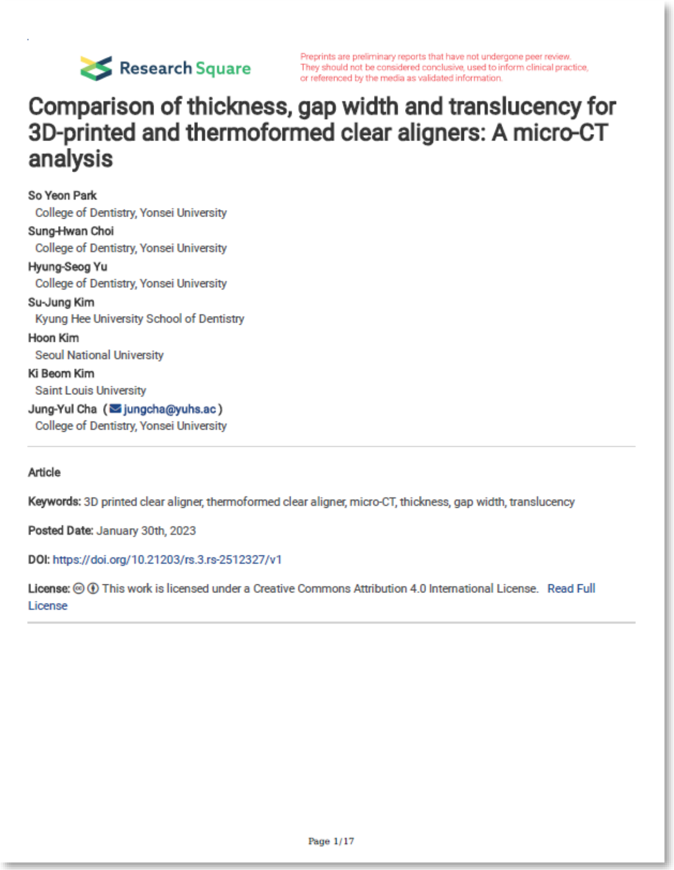
Publications


NARRATIVE LITERATURE REVIEW

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

Johan Hartshorne[a] and Mark Brian Wertheimer[b]
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 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 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)


Research Square

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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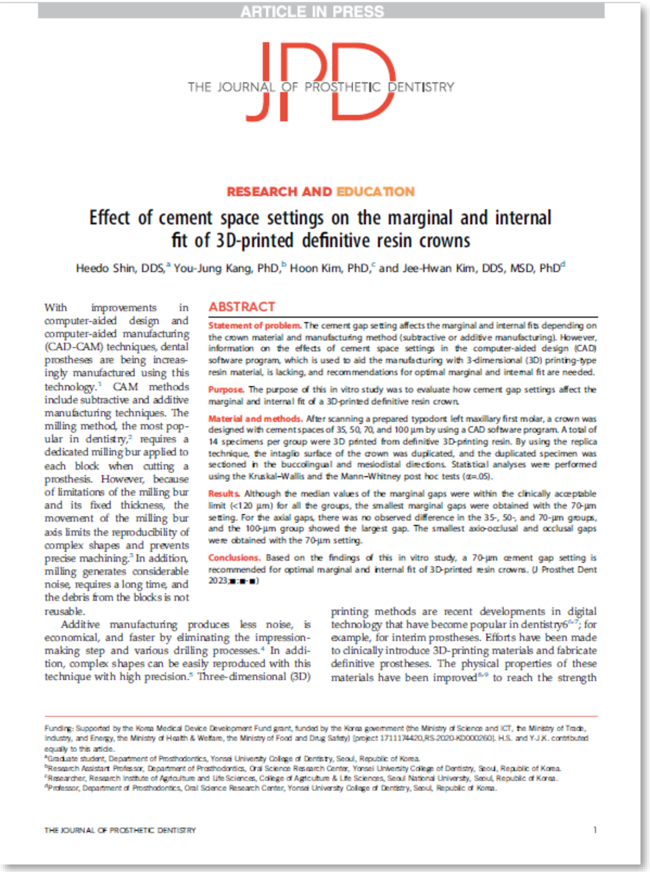

ARTICLE IN PRESS

THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

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

Heedo Shin, DDS,[a] You-Jung Kang, PhD,[b] Hoon Kim, PhD,[c] and Jee-Hwan Kim, DDS, MSD, PhD[d]

ABSTRACT

B9. 2022, AJO-DO Clinical Companion

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

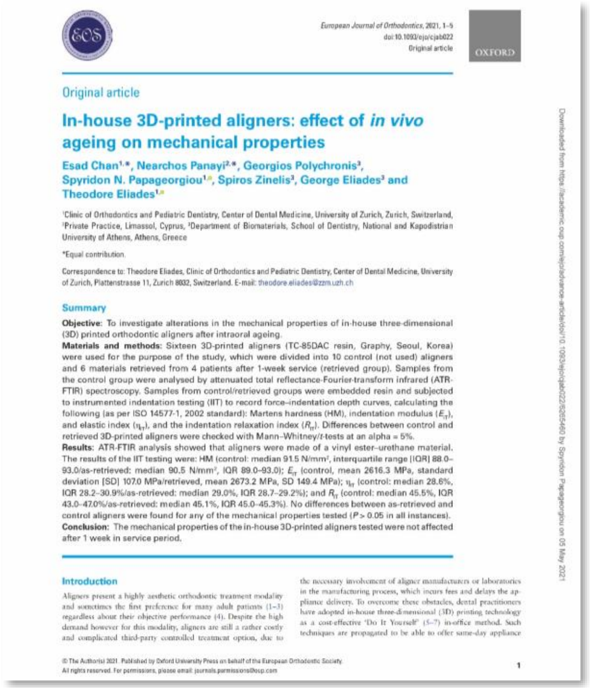
B10. 2023, Scientific Reports

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

Biocompatibility



European Journal of Orthodontics, 2021, 1–5
doi:10.1093/ejo/cjab022
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 Polychronis[3], Spyridon N. Papageorgiou[1], Spiros Zinelis[3], George Eliades[3] and Theodore Eliades[1]

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

*Equal contribution.

Correspondence to: Theodore Eliades, Clinic of Orthodontics and Pediatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, Zurich 8032, Switzerland. E-mail: theodore.eliades@zzm.uzh.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 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 (IIT) 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/*t*-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 91.5 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/retrieved, mean 2673.2 MPa, SD 149.4 MPa); η_{IT} (control: median 28.6%, IQR 28.2–30.9%/as-retrieved: median 29.0%, 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.

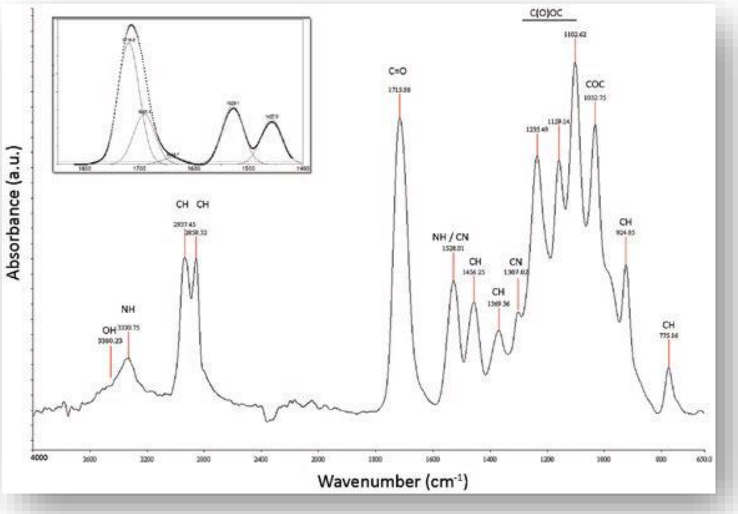
Introduction

Aligners present a highly aesthetic orthodontic treatment modality and 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 propagated to be able to offer same-day appliance

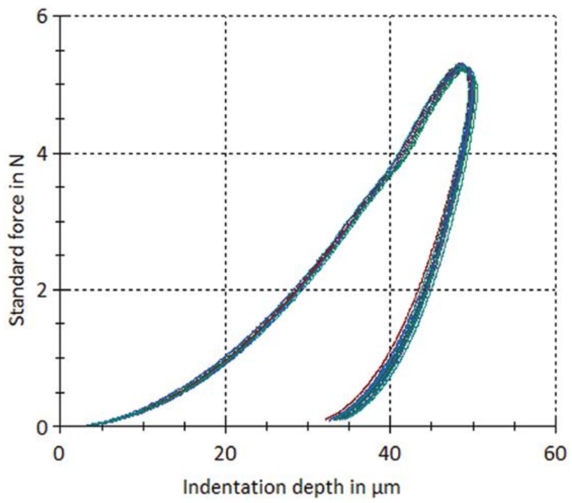
1

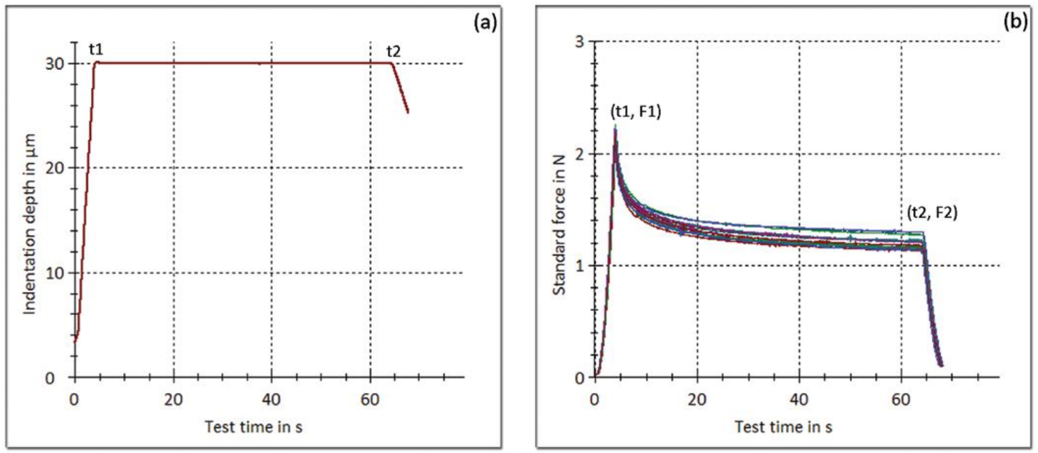
A3. 2021, EJO

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

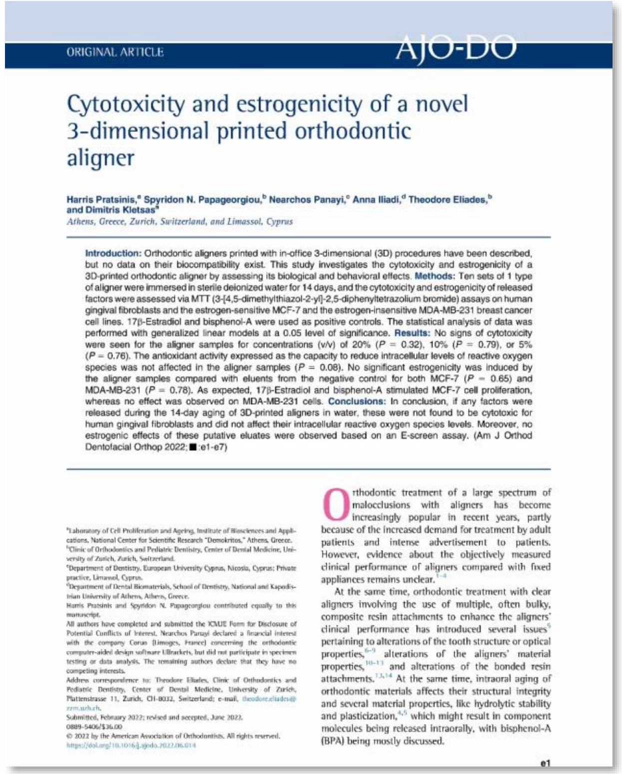


"One week of intraoral service does not seem to significantly change the mechanical properties of an in-house 3D-printed orthodontic aligner."





Publications


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 Iliadi,[d] Theodore Eliades,[b] and Dimitris Kletsas[a]
Athens, Greece, Zurich, Switzerland, and Limassol, 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. 17β-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, 17β-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

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 ± standard deviation

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

NA, no addition.

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

	Aligner vs				*Negative control vs*		
Absorbance (% of untreated)	*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

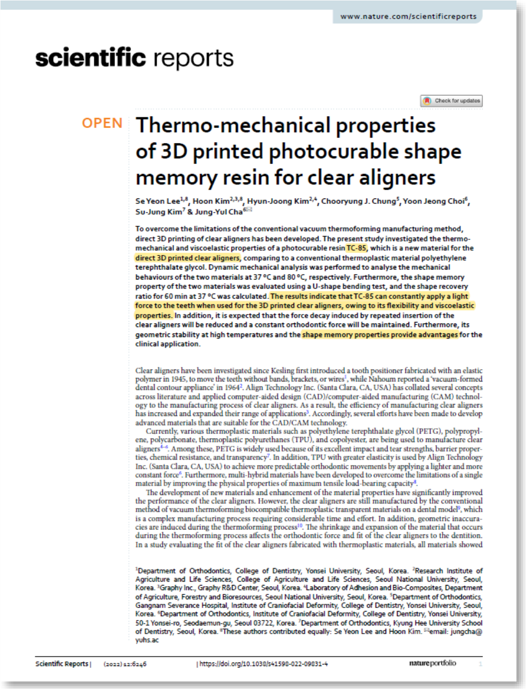
"…these were not found to be cytotoxic for for human gingival fibroblasts and did not affect their intracellular ROS levels. Moreover, no estrogenic effects of these putative eluates were observed on the basis of an E-screen assay."

Shape Memory

(Force Delivery)

Publications

Graphy


www.nature.com/scientificreports

scientific reports

OPEN

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

Se Yeon Lee[1,8], Hoon Kim[2,3,8], Hyun-Joong Kim[2,4], Chooryung J. Chung[5], Yoon Jeong Choi[6], Su-Jung Kim[7] & Jung-Yul Cha[6]

To overcome the limitations of the conventional vacuum thermoforming 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 Kesling first introduced a tooth positioner fabricated with an elastic polymer in 1945, to move the teeth without bands, brackets, or wires[1], while Nahoum reported a 'vacuum-formed dental contour appliance' in 1964[2]. 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 applications[3]. Accordingly, several efforts have been made to develop advanced materials that are suitable for the CAD/CAM technology.

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

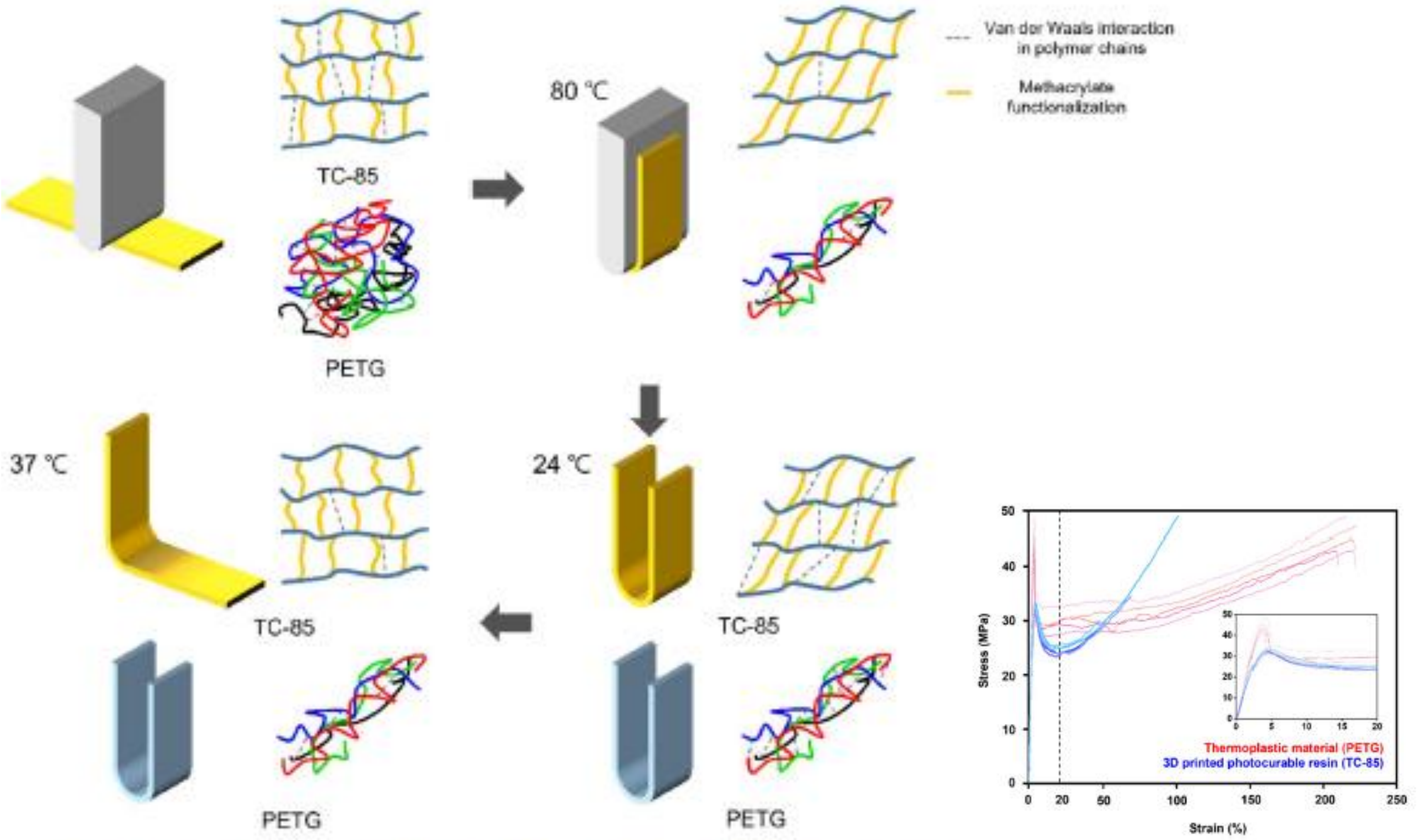

Figure 5. Shape memory property test procedure and shape memory mechanism; Yellow and blue specimens indicate TC-85 and PETG, respectively.

Publications


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Advances in orthodontic clear aligner materials

Yashodhan M. Bichu [a], Abdulraheem Alwafi [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 Abdulaziz 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 Homburg, Saar, Germany

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ABSTRACT

Rapid technological improvements in biomaterials, computer-aided design (CAD) and manufacturing (CAM) have endorsed 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 (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 esthetic 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 [5–9], 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,

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* Corresponding author. Department of Oral Health Science, Faculty of Dentistry, The University of British Columbia, Vancouver, V6T 1Z3, Canada.
E-mail address: drzou@dentistry.ubc.ca (B. Zou).

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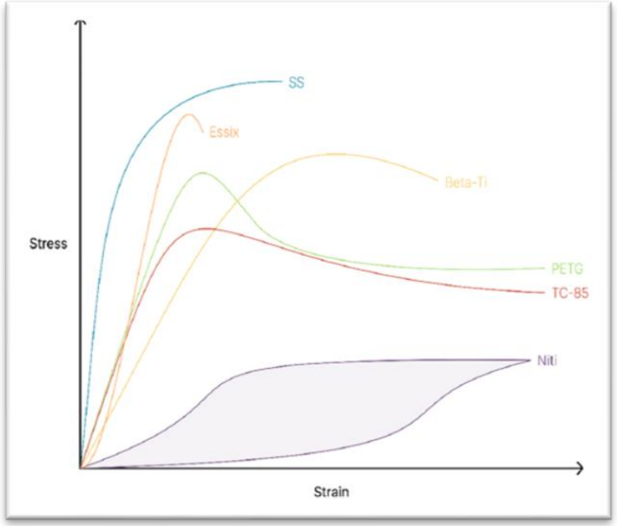
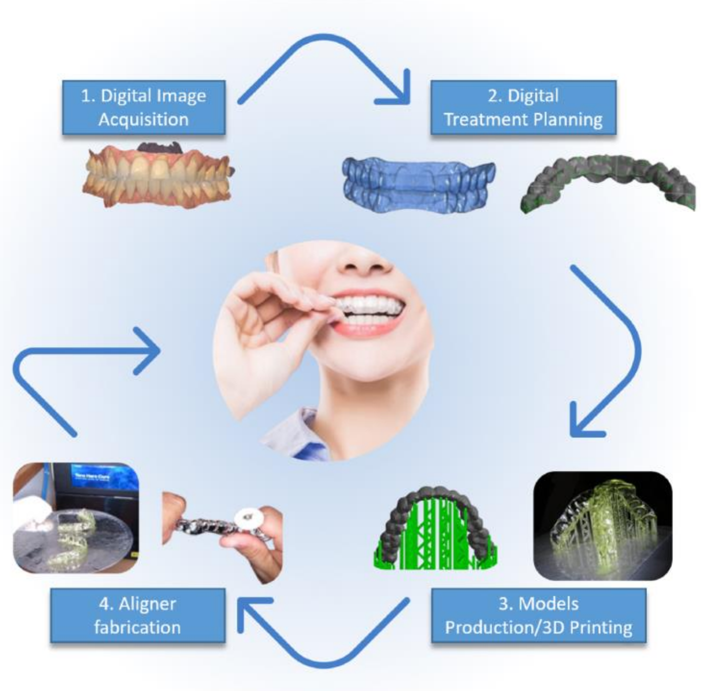
Advances in orthodontic clear aligner materials



stress-strain curves of different orthodontic materials (relative comparison)

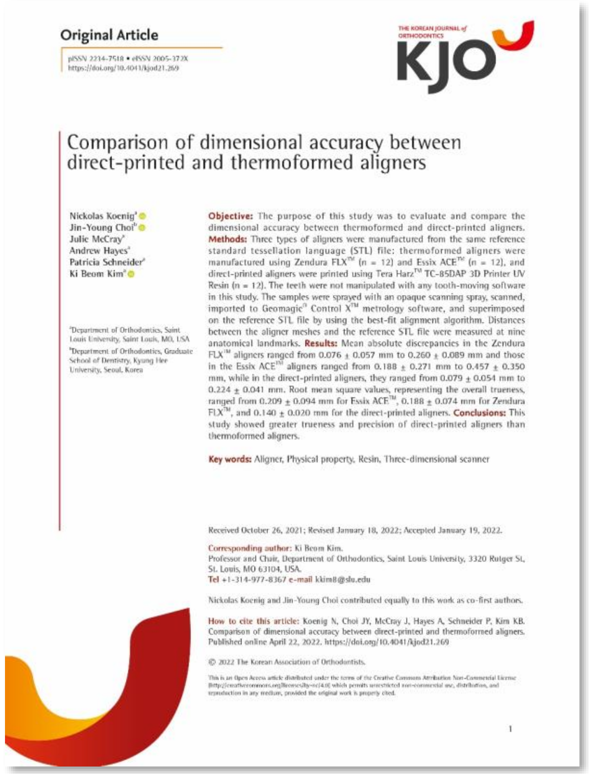
- SS, stainless steel.
- Beta-Ti, Beta titanuim
- Niti, Nickel titanium
- Essix, clear retainer material
- PETG, polyethylene terephthalate glycol (thermoplastic aligner material)
- TC-85, photocurable resin (3D-printed aligner material)

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



Accuracy Fit

Publications


Original Article

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KJO

Comparison of dimensional accuracy between direct-printed and thermoformed aligners

Nickolas Koenig[a]
Jin-Young Choi[b]
Julie McCray[a]
Andrew Hayes[a]
Patricia Schneider[a]
Ki Beom Kim[a]

[a]Department of Orthodontics, Saint Louis University, Saint Louis, MO, USA
[b]Department of Orthodontics, Graduate School of Dentistry, Kyung Hee University, Seoul, Korea

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 UV 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 ± 0.020 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

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Corresponding author: Ki Beom Kim.
Professor and Chair, Department of Orthodontics, Saint Louis University, 3320 Rutger St, St. Louis, MO 63104, USA.
Tel +1-314-977-8367 e-mail kkim8@slu.edu

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

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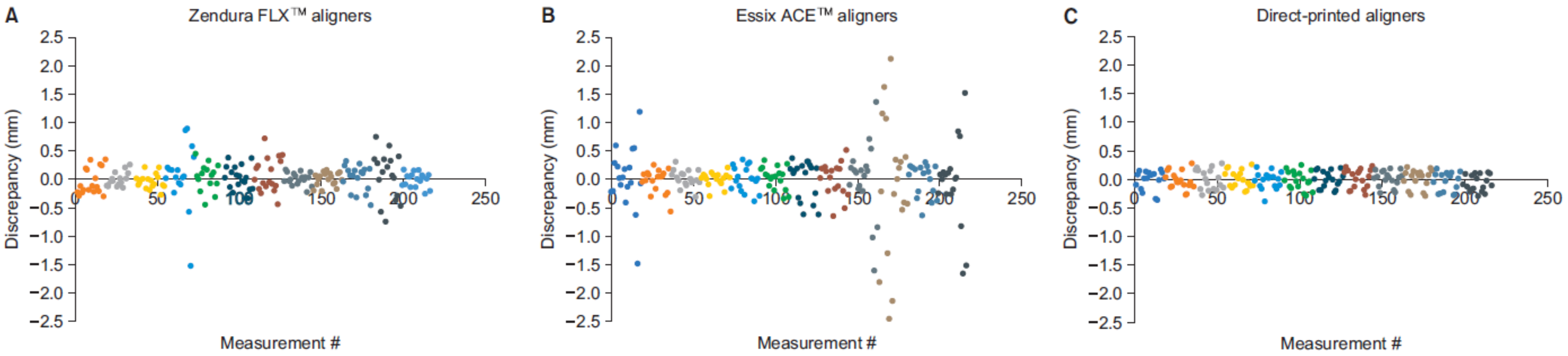
A7. 2022, KJO

Comparison of dimensional accuracy between direct-printed and thermoformed aligners

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)

“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 proprieties.

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 printing 3D 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.slu.edu
Department of Orthodontics, Saint Louis University, 3320 Rutger Street, Saint Louis, MO 63104, USA

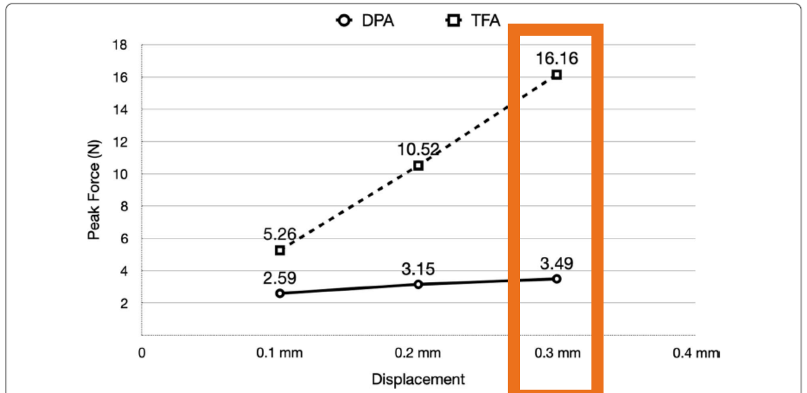


Fig. 4 Comparison of Peak Forces of TFA versus DPA

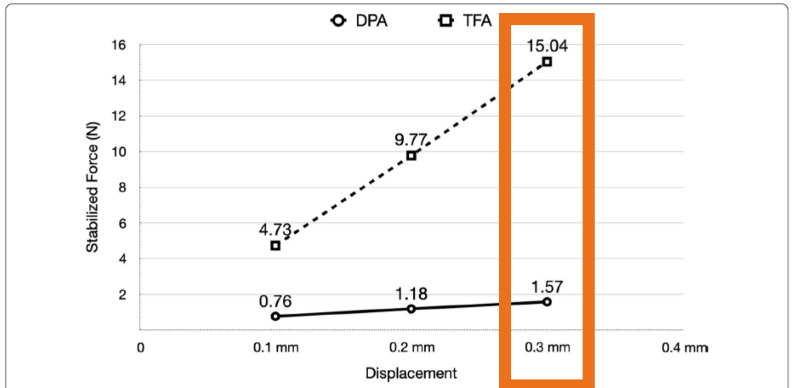


Fig. 5 Comparison of Stabilized Forces of TFA versus DPA

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

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… ”

Workflow

(Processing Advantages)

Publications

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 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; apostso@otenet.gr
4 Department of Orthodontics, C.W.R.U., Cleveland, OH 44106, USA
5 Department of Orthodontics, European University of Cyprus, School of Dentistry, Egkomi 2404, Cyprus; dr.panayi@cytanet.com.cy
6 School of Medicine, National and Kapodistrian University of Athens, Athens 15772, Greece
* Correspondence: tsolakisioannis@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 man-

Figure 8. Direct-printed aligners.

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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 unerupted molar eruption Nance hybrid guiding appliance. The appliance was inserted prior to molar 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.

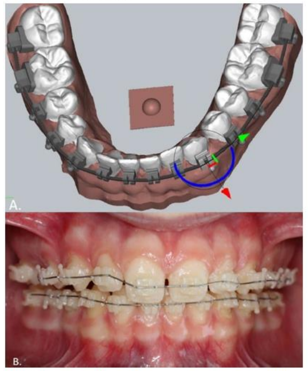


Figure 7. (**A**) Setup and automatic positioning of customized brackets in Ubrackets software. Setup is the first step in the customization process, followed by the automatic placement of the 0.018 × 0.025 inches slot brackets on a flat 0.018 × 0.025 inches archwire. (**B**) Customized brackets designed in Ubrackets software and printed in permanent crown resin by Bego (Bremen, Germany) bonded. The wire is a 0.012-inch Nitinol customized archwire bend on the exported pdf file archwire drawing.

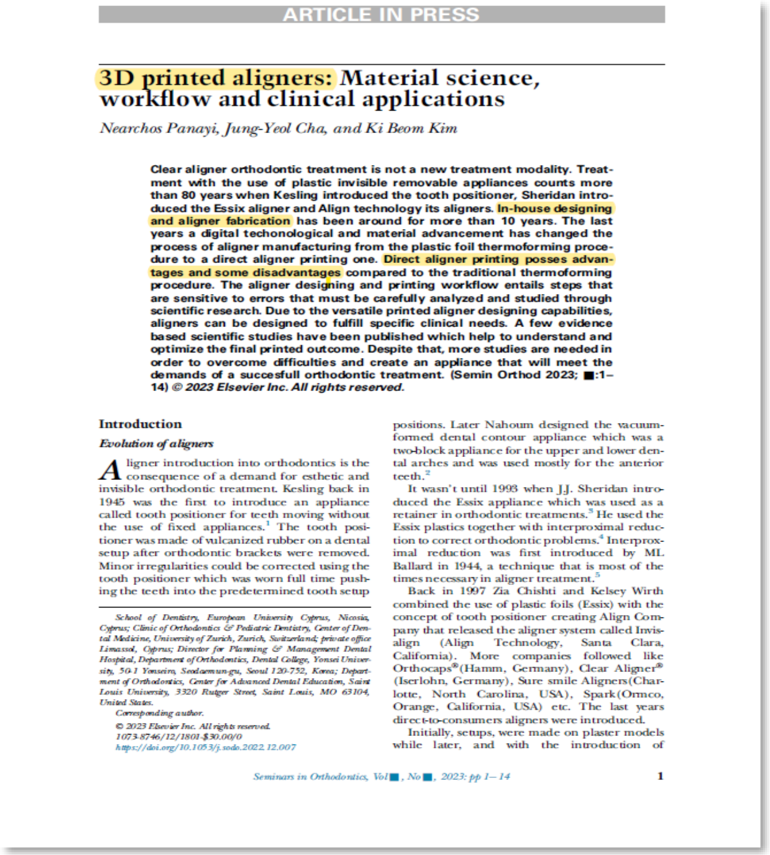
"TC-85 (Graphy, Seoul, Korea), which can constantly apply a light force to the teeth when used for the 3D printed clear aligners, owing to its flexibility and viscoelastic properties.

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). "

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 techonological 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 posses 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 succesfull 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 positions. Later Nahoum designed the vacuum-formed dental contour appliance which was a two-block appliance for the upper and lower dental arches and was used mostly for the anterior teeth.[2]

It wasn't until 1993 when J.J. Sheridan introduced the Essix appliance which was used as a retainer in orthodontic treatments.[3] He used the Essix plastics together with interproximal reduction to correct orthodontic problems.[4] Interproximal reduction was first introduced by ML Ballard in 1944, a technique that is most of the times necessary in aligner treatment.[5]

Back in 1997 Zia Chishti and Kelsey Wirth combined the use of plastic foils (Essix) 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® (Iserlohn, 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

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 Yonseiro, 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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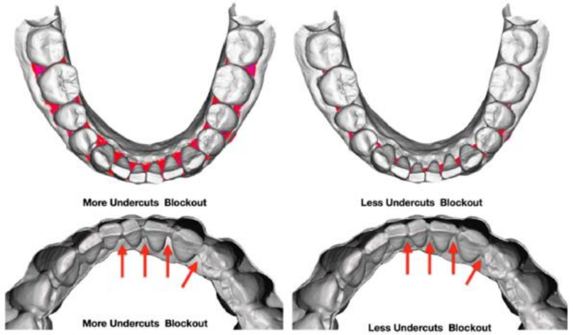

Fig. 2. Generalized spaces or black triangles and undercuts should be blocked out properly in order to avoid problems like space opening between teeth or problematic interdental aligner fitting.

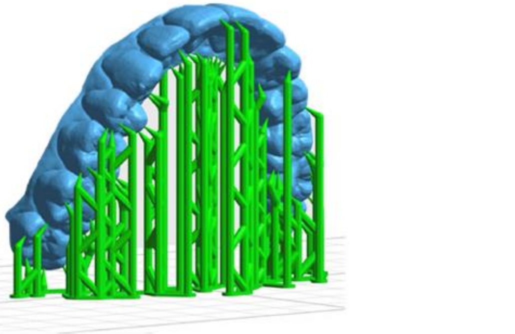

Fig. 5. Support structures can be created by special freeware, CAD orthodontic software or printer software.

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.

A11. 2023, Seminars in Orthodontics

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

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

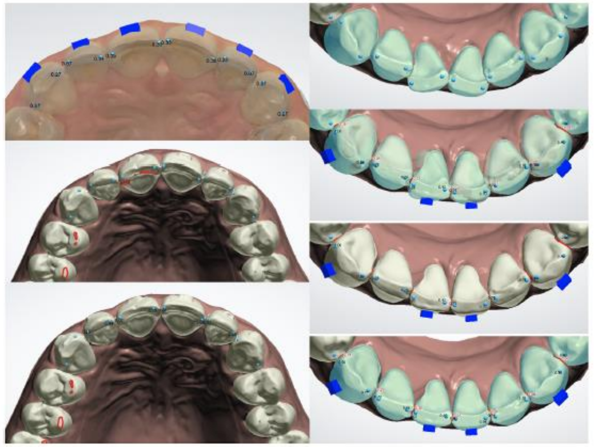

Fig. 10. Design of attachment and the process of sequencial teeth movement for Aligner designing.

Publications

Graphy

TURKISH JOURNAL of ORTHODONTICS

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Review

Directly Printed Aligner: Aligning with the Future

Nearchos C. Panayi[1,2,3]

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

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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. 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, 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. Kesling[1] 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 Nahoum[2] 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. Panayi, e-mail: dr.panayi@cytanet.com.cy

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in the needed areas (it is done automatically). The aligner can be positioned horizontally or vertically on the virtual printer

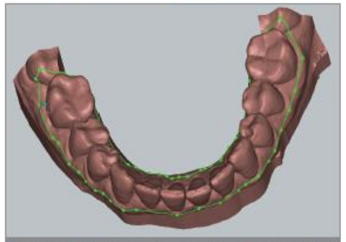

Figure 1. Directly printed aligner virtual design in Brackets software. Thickness can also be adjusted in the printed aligner module

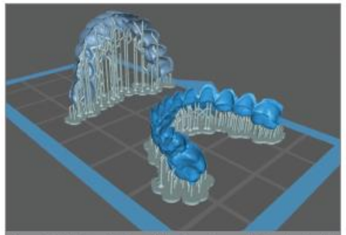

Figure 3. Virtual positioning of the aligner in a vertical and horizontal orientation. Horizontal positioning has the advantage of faster printing, but fewer aligner can be printed each time and more supports are needed. Vertically positioned aligner have the disadvantage of slower printing, but more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

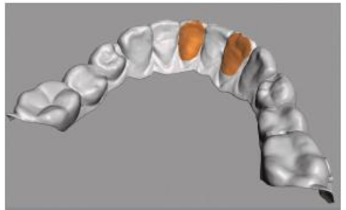

Figure 2. Brackets software enables the clinician to increase the aligner thickness in specific areas where teeth movement occurs. The software detects the areas where movement occurs and adds the extra predetermined material. Note the increased thickness of the aligner at the lingual side of 42 and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

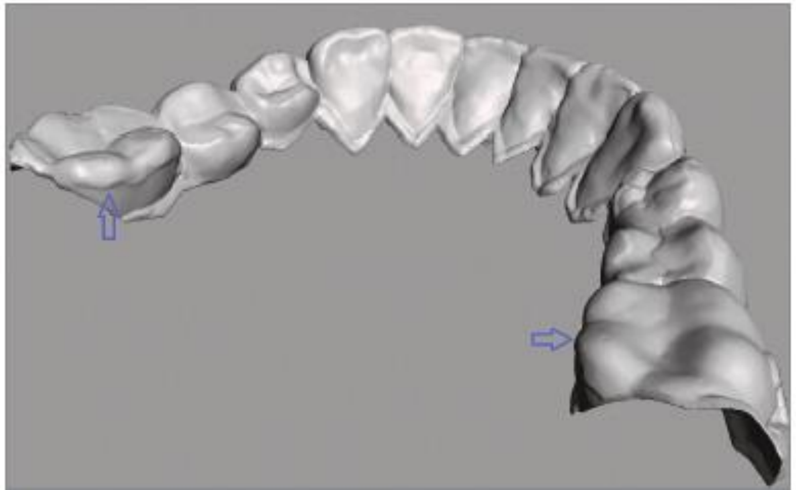

Figure 6. In cases of open bite, the orthodontist can choose to increase the thickness of the aligner at the molars to facilitate bite closure

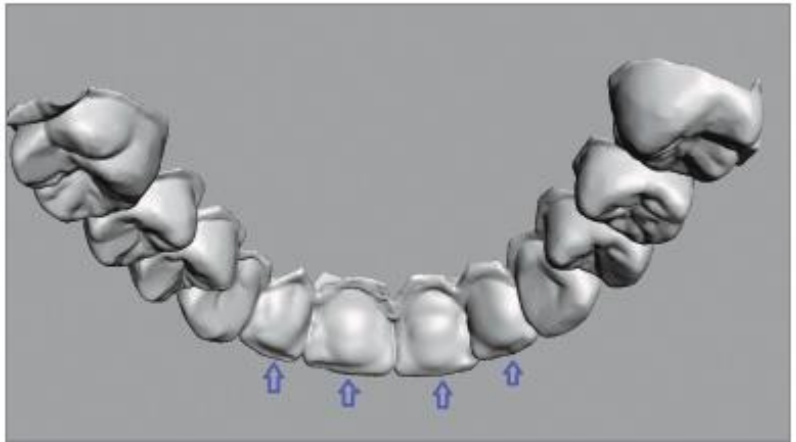

Figure 7. In cases of deep bite, the orthodontist can increase the thickness of the palatal side of the upper incisors to correct the deep bite.

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,[a] Stephen J. Chen,[a] Jeryl D. English,[a] and F. Kasper[b]
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)

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,[2-7] 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

[a]Department of Orthodontics, School of Dentistry, The University of Texas Health Science Center at Houston, Houston, Tex.
[b]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. Kurtis Kasper, Department of Orthodontics, School of Dentistry, The University of Texas Health Science Center at Houston, 7500 Cambridge St, Ste 5130, Houston, TX 77054; e-mail, Fred.K.Kasper@uth.tmc.edu.
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Effect of print orientation and duration of ultraviolet curing on the dimensional accuracy of a 3-dimensionally printed orthodontic clear aligner design

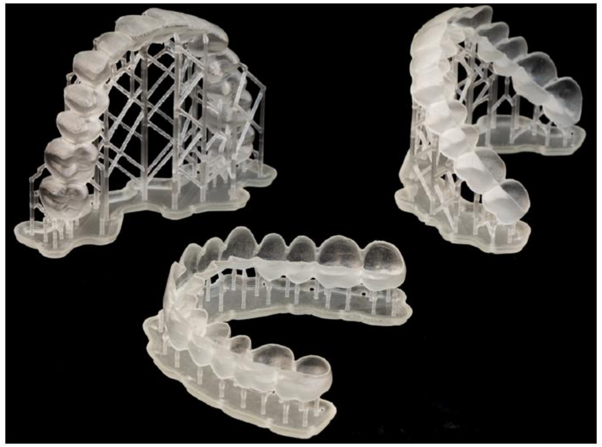


Fig 2. Representative aligners of each of the 3 orientations (horizontal, 45°, and vertical) investigated in part 1 were shown before removing supports.

"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."

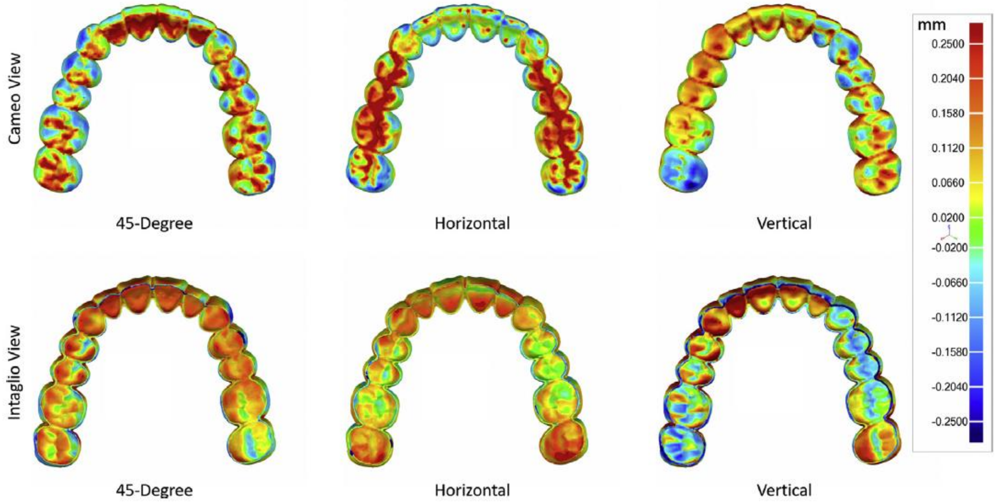


Fig 3. Representative views of superimpositions of aligners from each of the 3 orientations (horizontal, 45°, and vertical) investigated in part 1 showing areas of dimensional deviation as compared with the input file used for printing. *Cool colors* indicate negative deviations, and *warm colors* indicate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

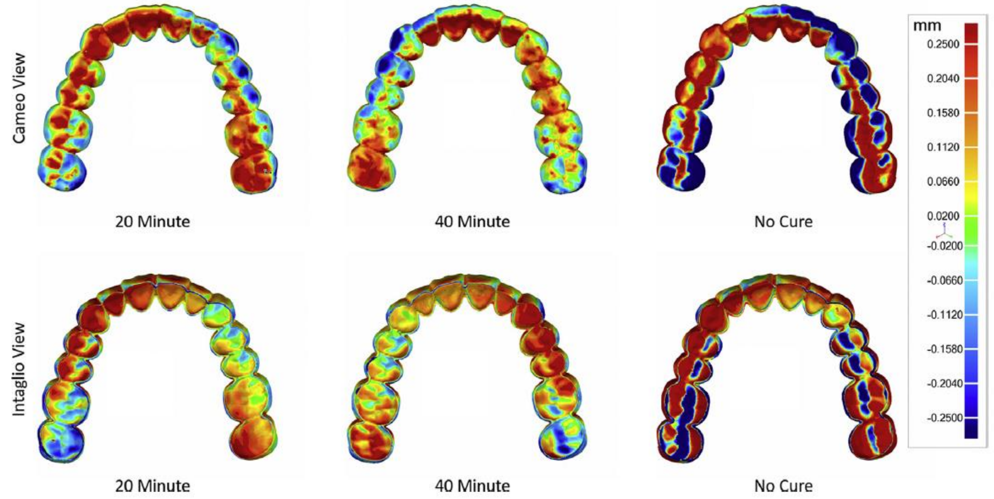
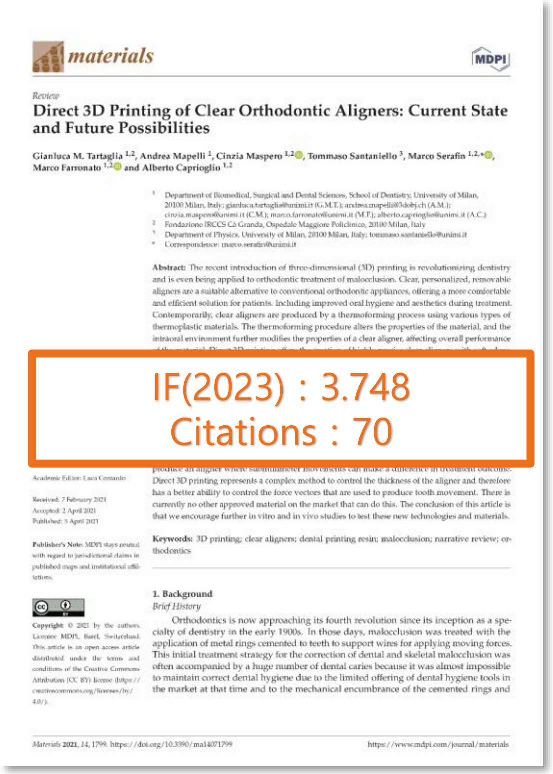


Fig 4. Representative views of superimpositions of aligners from each of the 3 postprint processing treatments (20-minute, 40-minute, and No Cure) investigated in part 2 showing areas of dimensional deviation as compared with the input file used for printing. *Cool colors* indicate negative deviations,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

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], Tommaso Santaniello [3], Marco Serafin [1,2,*], Marco Farronato [1,2] 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@3dobj.ch (A.M.); cinzia.maspero@unimi.it (C.M.); marco.farronato@unimi.it (M.F.); alberto.caprioglio@unimi.it (A.C.)
2 Fondazione IRCCS Cà Granda, Ospedale Maggiore Policlinico, 20100 Milan, Italy
3 Department of Physics, University of Milan, 20100 Milan, Italy; tommaso.santaniello@unimi.it
* 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 intraoral environment further modifies the properties of a clear aligner, affecting overall performance ... 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.

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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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Citations : 70

B3. 2021, Materials

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

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).

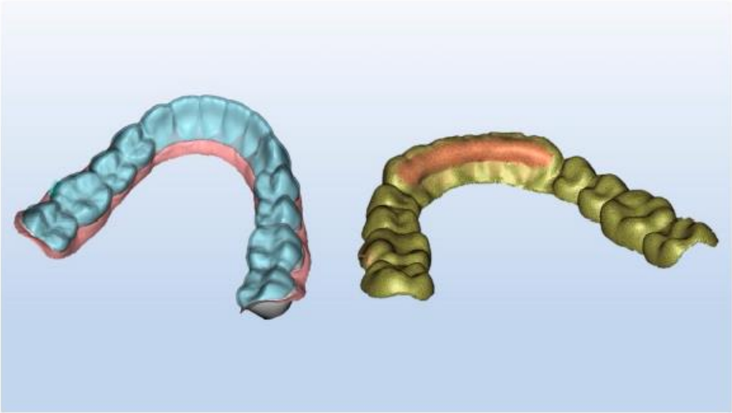
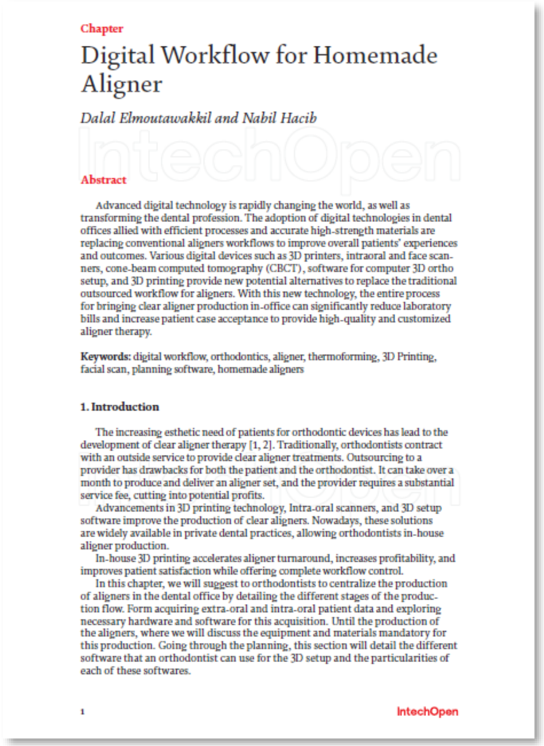


Figure 4. Customization of design and thickness of directly printed aligners.

Publications



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 lead 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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Digital Workflow for Homemade Aligner

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

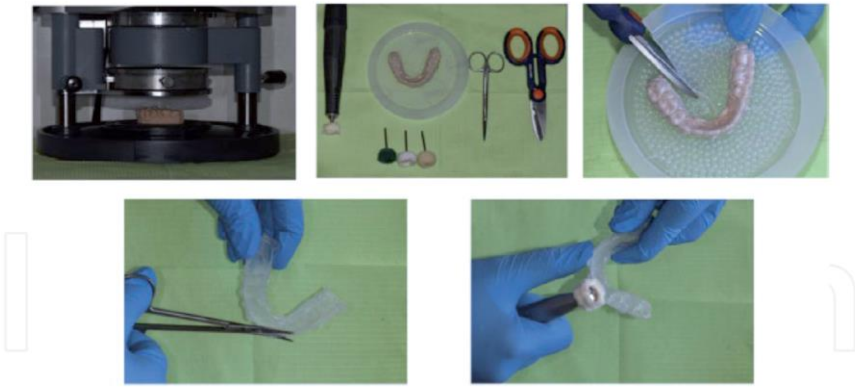

Figure 10.
In-office trimming of aligners.

"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."

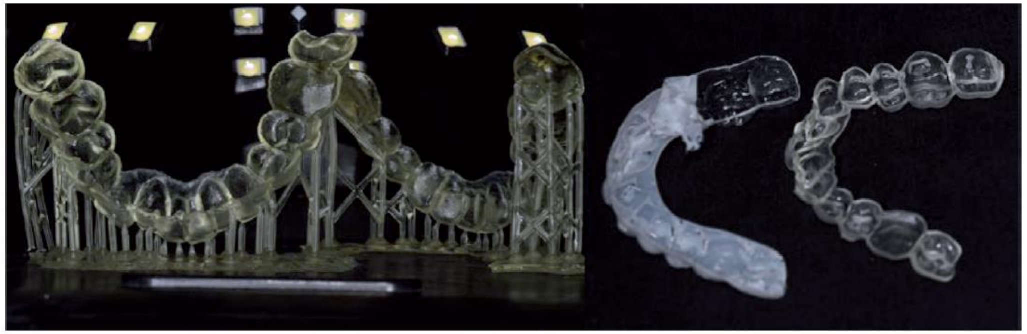

Figure 8.
Directly printed aligners with Tera Harz TC-85 resin (TC-85DAC) put, after post-treatment side by side with thermoformed aligner (Biolon 0,75 mm).

Publications

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]
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 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 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 inconvenience[10] 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.[10] 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. Bowman[16] argued that "a series of aligners alone cannot solve most malocclusion issues, no matter the quality of the software design, modelling, 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.

[a]Intercare Medical and Dental Centre, Bellville, South Africa.
[b]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, werty@gonet.co.za

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."

Comparative Analysis

(Crown & Bridge Materials)

Publications

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], Ik-Hwan Kim [3], Jiho Lee [4], Ko Eun Lee [5], Hyo-Seol Lee [5], Jee-Hwan Kim [6], Je Seon Song [1,*] and Yooseok 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 08826, 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
* Correspondence: songjs@yuhs.ac; Tel.: +82-2-2228-3170; Fax: +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 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 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

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Citation: Kim, N.; Kim, H.; Kim, I.-H.; Lee, J.; Lee, K.E.; Lee, H.-S.; Kim, J.-H.; Song, J.S.; Shin, 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

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1. Introduction

Esthetic dentistry has become an essential component of modern pediatric dentistry [1,2]. Parents' demands for esthetic 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 appearances [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 preformed stainless-steel crown (SSC). SSC is recommended due to its long-term durability, less 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-faced 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/children9101445 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

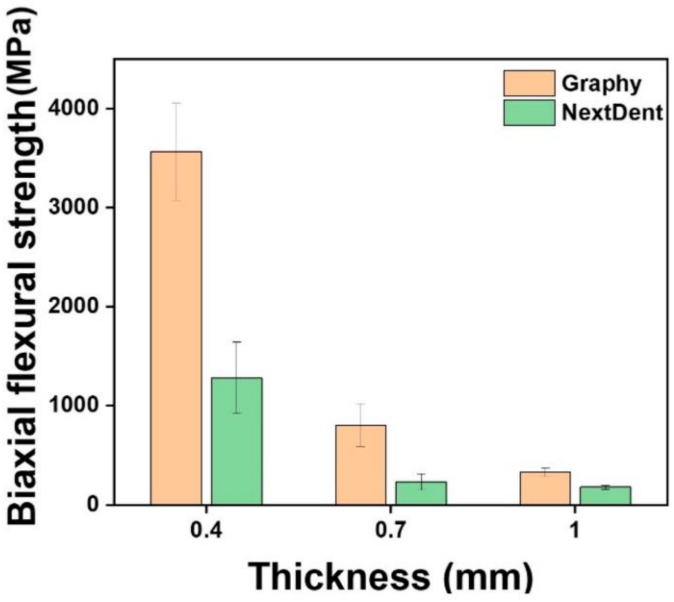

Figure 4. Mean biaxial flexural strength (MPa) of the various experimental groups.

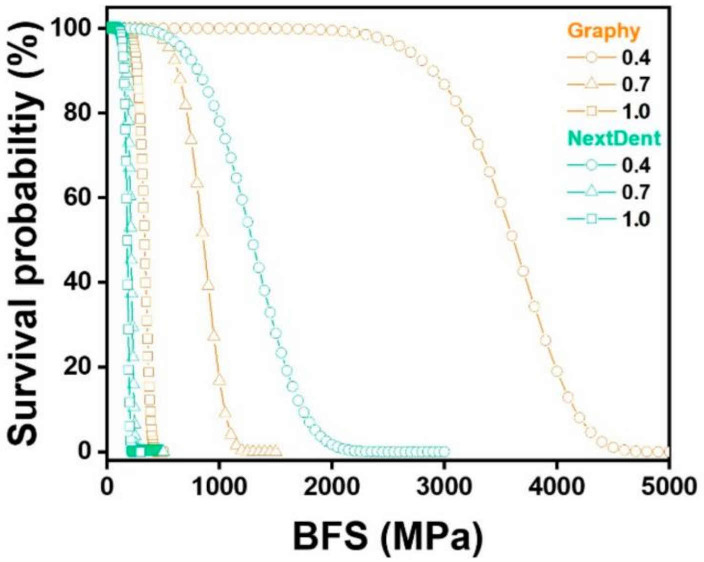

Figure 6. Weibull survival probability based on biaxial flexural strength (BFS) for thicknesses 0.4, 0.7, and 1.0 mm for Graphy and NextDent materials.

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

Publications

polymers

MDPI

Article

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

You-Jung Kang [1,†], Yeseul Park [1,†], Yooseok 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 (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 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

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Citation: Kang, Y.-J.; Park, Y.; Shin, Y.; 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*, 1390. https://doi.org/10.3390/polym15061390

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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 (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

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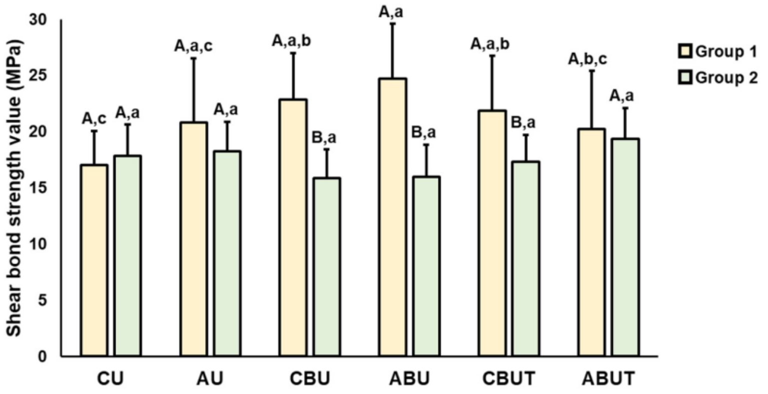
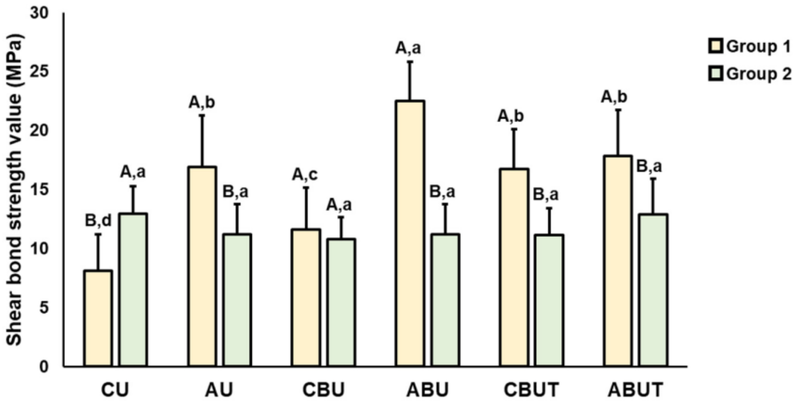
Effect of Adhesion Conditions on the Shear Bond Strength of 3D Printing Resins after Thermocycling Used for Definitive Prosthesis



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."

Publications

Graphy

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

You-Jung Kang[a,1], Hoon Kim[b,c,1], Jiho Lee[c], Yeseul Park[a], Jee-Hwan Kim[a,*]

[a] Department of Prosthodontics, Oral Science Research Center, College of Dentistry, Yonsei University, Seoul, the Republic of Korea
[b] Research Institute of Agriculture and Life Sciences, College of Agriculture & Life Sciences, Seoul National University, Seoul 08826, the Republic of Korea
[c] Graphy, Inc. 6th Fl, Ace GasanFORHU, 225 Gasan digital 1-ro, Geumcheon-gu, Seoul 08501, the Republic of Korea

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ABSTRACT

Objectives: 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 treatment. 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

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* 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: jee917@yuhs.ac (J.-H. Kim).
[1] These authors contributed equally to this work as first authors.

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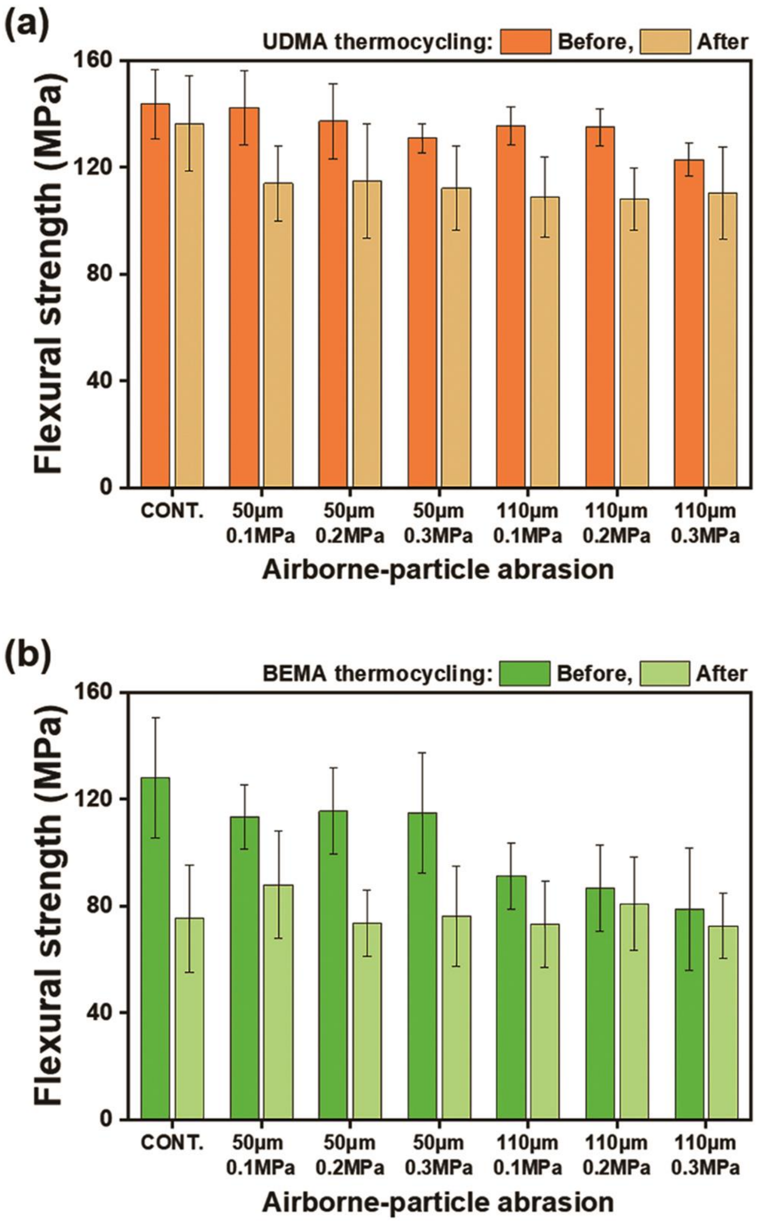
Effect of airborne particle abrasion treatment of two types of 3D-printing resin materials for permanent restoration materials on flexural strength



Graphy TC-80 shows flexural strength of 145MPa and maintains flexural strength higher than 120MPa even after airbone particle surface abrasiton 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.