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Comparative Analysis of Traditional Vacuum Thermoforming and 3D Printing for Aligner Fabrication

Pauline Marie Mathilde Ursat

Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

—

Gandra, **maio de 2024**

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Trabalho realizado sob a Orientação de
Professora Doutora Primavera da Conceição Martins de Sousa Santos

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Eu, acima identificado, declaro ter atuado com absoluta integridade na elaboração deste trabalho, confirmo que em todo o trabalho conducente à sua elaboração não recorri a qualquer forma de falsificação de resultados ou à prática de plágio (ato pelo qual um indivíduo, mesmo por omissão, assume a autoria do trabalho intelectual pertencente a outrem, na sua totalidade ou em partes dele). Mais declaro que todas as frases que retirei de trabalhos anteriores pertencentes a outros autores foram referenciadas ou redigidas com novas palavras, tendo neste caso colocado a citação da fonte bibliografia

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ORAL COMMUNICATIONS

- Presentation of an oral communication entitled, "Avaliação do método tradicional de fabricação de alinhadores ortodônticos vs impressão direta com material Graphy" as part of the XXXII Conference "Medicina Dentária Digital – uma Nova Era"; April 9, 2024; Porto Palácio Hotel Congress Centre.

ACKNOLEGEMENTS

Em primeiro lugar, desejo expressar a minha sincera gratidão ao Instituto Universitário de Ciências da Saúde do Norte pela oportunidade de enriquecimento académico e profissional ao longo dos últimos cinco anos. Em especial, estendo meus mais sinceros agradecimentos à minha orientadora de dissertação - Professora Doutora Primavera Sousa-Santos. A sua disponibilidade inestimável, orientação perspicaz e compromisso foram fundamentais para a conclusão deste trabalho. Sem a sua orientação e apoio contínuo, este projeto não teria alcançado seu potencial máximo. Não posso deixar de expressar minha profunda apreciação à Doutora Ana Catarina Azeredo de Oliveira pela sua dedicação, amabilidade e contribuições valiosas para esta dissertação. As suas sugestões de melhoria foram extremamente enriquecedoras e contribuíram significativamente para a qualidade final deste trabalho.

"Papa", le premier mot doux que j'ai prononcé, symbole de l'amour et de l'admiration que je ressens pour toi. Au fil des années, tu me répétais tous les matins « Motivation, détermination, concentration, et après, mes félicitations". Chaque fois que je les entends, c'est comme si tu me disais je crois en toi, que tu me transmettais non seulement des conseils pour réussir dans la vie, mais aussi la passion et l'engagement nécessaire pour poursuivre mes rêves. Ces mots, résument à eux seuls toute ta philosophie de vie, ta manière d'aborder chaque défi avec courage et persévérance. Tu étais là, à chaque étape, à me soutenir, à me guider, à me pousser vers l'avant. Et pour ça, je ne pourrai jamais te remercier assez. Aujourd'hui, en finissant cette thèse et en me lançant dans ma carrière de dentiste, je suis pleine de gratitude envers toi, car c'est grâce à toi que j'ai découvert ma passion et ma vocation. Cette réussite est autant la tienne que la mienne. Alors, papa, cette thèse, c'est pour toi. Pour tout ce que tu as fait, pour tout ce que tu es. Je t'aime.

Maman, je ne pourrais jamais assez te remercier pour tous tes sacrifices. Je suis fière d'avoir une maman comme toi. Tu as mis de côté tes propres besoins et désirs pour être sûre que j'avais tout ce dont j'avais besoin. Chaque jour, tu as sacrifié ton temps, ton énergie et parfois même tes propres rêves pour moi, sans jamais rien attendre en retour. Alors merci maman, je t'aime.

Chère mamie, je suis également reconnaissante pour tout ton soutien et ton amour qui m'ont toujours appris à donner le meilleur de moi-même. Ta bienveillance m'a accompagnée tout au long de mes études, depuis les premiers pas à l'école jusqu'à la réalisation de cette thèse. Encore une fois merci pour tout ce que tu as fait et tout ce que tu fais encore.

À mes amis, Clara Charpentier et Davon Hassan, merci pour votre soutien, merci pour votre sincérité, merci pour votre confiance. Sans vous, je n'aurais jamais pu accomplir tout ce chemin. À Laura Touboul : "Un ami, c'est quelqu'un qui connaît la chanson qui est dans ton cœur et qui peut te la chanter quand tu en as oublié les paroles." - Ralph Waldo Emerson. Ta présence durant mes études au Portugal a transcendé les frontières de l'amitié pour devenir une véritable famille. Les défis que nous avons affrontés ensemble n'ont fait que renforcer nos liens, et nos conversations nocturnes ont souvent été le refuge où nos âmes pouvaient se confier sans crainte du jugement. À chaque instant de doute, de joie, ou de tristesse, Laura tu étais là, prête à m'écouter, à me soutenir et à m'encourager. Merci du fond du cœur.

Non potrei dimenticare di ringraziare il mio compagno di clinica, Mario Esposito, per il suo contagioso buon umore e la sua positività che hanno illuminato le mie giornate. La sua capacità di trasmettere il sorriso a tutti quelli che lo circondano è una qualità preziosa che, sono convinta, lo guiderà verso una brillante carriera in odontoiatria.

ABSTRACT

Introduction: Orthodontic aligners are manufactured using the traditional technique, which includes printing models followed by photographic molding. A new technique has been invented - 3D printing directly - without printing the dental models and using a special resin (TC-85DAC) with shape memory properties.

Objectives: Compare whether the innovative use of *Graphy Inc* material with shape-memory properties in 3D printing can surpass established norms in both the effectiveness of orthodontic aligners and their manufacturing process.

Material and Methods: Articles were searched in *PubMed*, *GoogleScholar* and *ScienceDirect* using specific inclusion and exclusion criteria. This systematic review adheres to PRISMA checklist and has been registered in the international prospective register of systematic reviews (PROSPERO) under the registration number CRD420245414.

Results: Of the 3718 articles obtained in a first search, 45 met the inclusion criteria after reading the title and abstract. After full reading, 28 were not relevant and 14 articles were included in this integrative systematic review.

Discussion: 3D printed aligners offer superior geometric and dimensional precision compared to thermoformed aligners, allow for customization of thickness and cleaning method. The TC-85DAC resin provides shape memory advantages for directly printed aligners.

Conclusion: While 3D printing shows promise, challenges remain. Benefits like consistent forces and improved strength are noted but concerns about biomechanics complexity and aligner thickness variations are raised. Advancements could lead to widespread adoption, pending further research to ensure reliability and effectiveness.

Keywords: "Orthodontic retainers"., "Printing"., "Three-Dimensional"., "Thermoforming, Orthodontics"., "Aligners".

RESUMO

Introdução: Os alinhadores ortodônticos são fabricados utilizando a técnica tradicional, que inclui a impressão de modelos seguida de moldagem fotográfica. Foi inventada uma nova técnica - a impressão 3D direta - sem imprimir os modelos dentários e utilizando uma resina especial (TC-85DAC) com propriedades de memória de forma.

Objectivos: Comparar se a utilização inovadora do material *Graphy Inc* com propriedades de memória de forma na impressão 3D pode superar as normas estabelecidas, tanto na eficácia dos alinhadores ortodônticos como no seu processo de fabrico.

Material e Métodos: Os artigos foram pesquisados no *PubMed*, *GoogleScholar* e *ScienceDirect* usando critérios específicos de inclusão e exclusão. Esta revisão sistemática segue a lista de verificação PRISMA e foi registada no registo prospetivo internacional de revisões sistemáticas (PROSPERO) com o número de registo CRD420245414.

Resultados: Dos 3718 artigos obtidos numa primeira pesquisa, 45 cumpriam os critérios de inclusão após a leitura do título e do resumo. Após a leitura completa, 28 não eram relevantes e 14 artigos foram incluídos nesta revisão sistemática integrativa.

Discussão: Os alinhadores impressos em 3D oferecem uma precisão geométrica e dimensional superior em comparação com os alinhadores termoformados, permitem a personalização da espessura e melhor eficácia no método de limpeza. A resina TC-85DAC oferece vantagens de memória de forma para alinhadores impressos diretamente.

Conclusão: Embora a impressão 3D seja promissora, continuam a existir desafios. São registados benefícios como forças consistentes e maior resistência, mas são levantadas preocupações sobre a complexidade da biomecânica e as variações de espessura dos alinhadores. Os avanços podem levar a uma adoção generalizada, dependendo de mais investigação para garantir a fiabilidade e a eficácia.

Palavras-chave: "Orthodontic retainers"., "Printing"., "Three-Dimensional"., "Thermoforming, Orthodontics"., "Aligners".

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1. INTRODUCTION

Orthodontics is a dentistry specialty that treats dental malocclusions. Several therapeutic alternatives have been developed, such as ceramic brackets, lingual orthodontics, and, more recently, thermoformed clear aligners. The increasing popularity of clear aligner therapy is due, in part, to both adolescents and adults seeking an esthetic alternative to traditional braces and wires. (1) Clear aligners are a series of thin, clear, custom-made, removable, plastic aligners created to effectively move teeth into their desired position with various stages of aligner models over time. (2,3) The conventional method of fabricating clear thermoformed aligners involves multiple steps. First, the patient's mouth is scanned with a 3D scanner, and then the dental model is printed in resin in the laboratory. After 3D printing, using the conventional thermoforming process, a disposable one is made using a sheet of thermoplastic material. The model is then shaped, cut, refined and polished. (4,5) Using a 3D simulation software, the orthodontist composes a treatment plan on the computer screen and determines the required numbers and shapes of aligners over the duration of the treatment. (5) Once the first piece has been made, the practitioner places composite resin attachments on the teeth indicated in the treatment plan. The patient will then wear the set of aligners and the practitioner will follow up regularly to ensure the treatment progresses correctly. However, many factors can affect their effectiveness, including the thermoforming process's precision and the materials' quality. The manufacturing process can be time-consuming and costly, requiring several production steps before custom aligners are available. (1,3,6) The innovative technique of directly printing transparent aligners has piqued the curiosity of clinicians and researchers in the orthodontic community today. (7) When opposed to the thermoformed approach, the "directly printing clear aligners" technology allows practitioners to print aligners directly, removing the thermoforming process in aligner manufacture. (3) Direct aligner printing presents an opportunity to save time, workforce and expertise. (3)

A significant advancement was the introduction in 2019 of the first aligner resin for direct printing, TC-85DAC (*Graphy Inc*, Seoul, Korea), which has the unique property of having form memory. (8) The emergence of this direct 3D shape memory printing of aligners offers an alternative method of manufacturing that is more accurate, efficient, fast and economical. The aligner can be created through 3D printing without printing the model separately. It uses shape memory materials, like TC-85DAC, that deform at a specific temperature to adapt perfectly to the patient's dentition. Moreover, the practitioner will be able to print aligners directly in the dental clinic, which means that the entire series of aligners will not be manufactured at once and can adapt to the evolution of the patient's dentition. (9) Direct aligner printing might save time, labor and skill. (3)

However, before direct-printed aligners are adopted, they need to be compared to traditional thermoformed aligners. It is essential to know if these new direct shape-memory printing techniques offer significant advantages over thermoformed aligners currently used in orthodontics. For this purpose, several questions need to be studied, such as the improvement of the treatment accuracy, its advantages and disadvantages for the manufacturing and the treatment of the patient, its clinical effectiveness, its cost and accessibility. This study aims to compare the effectiveness of directly 3D printing dental aligners versus the traditional thermoforming method. Through an integrative systematic review, we will analyze the differences between these two approaches, explore the use of *Graphy Inc* material in direct printing and determine if this innovative technique is the way forward for orthodontics.

2. OBJECTIVES

The primary objective of this study is to compare the effectiveness of 3D printing with the innovative use of *Graphy, Inc* material (TC-85DAC), in contrast to the conventional thermoforming process, in the context of dental aligner design. At the same time, our approach is based on an exploration of the potential inherent in the shape-memory material *Graphy Inc* to produce dental aligners using 3D printing. This in-depth exploration aims to scrutinize the innovative capacity of this emerging material to revolutionize the established paradigms of traditional thermoforming in the design of dental aligners.

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3. MATERIALS AND METHODS

Considering the aim of this work an electronic bibliographical search of scientific articles was carried out.

This work is characterized as an integrative systematic review, based on a literature search in *PubMed*, *GoogleScholar* and *ScienceDirect* database.

The research expression used in each database were: (orthodontic retainers) AND (Printing, Three-Dimensional) and ((Three dimensional Printing[MeSH Terms]) AND (thermoforming)) AND (Orthodontics[MeSH Terms]) and the articles were also selected using the PICO criteria.

3.1 Eligibility criteria by PICO method (quantitative question)

The articles in this integrative systematic review were selected according to the PICO strategy. This systematic review has been registered in the international prospective register of systematic reviews (PROSPERO) under the registration number CRD42024541424.

Table 1: Questions of interest based on the population studied (P), intervention (I), comparison (C) and outcomes (O).

Population (P)	Orthodontic aligners
Intervention (I)	Manufacturing process of orthodontic aligners
Comparation (C)	Manufacture of traditional aligners vs. Manufacture of aligners with direct 3D printing.
Outcomes (O)	Effectiveness of treatment in the correction of dental malocclusion.

3.2 Inclusion criteria

The inclusion criteria involved are:

- Studies in English ;
- Studies published in the last ten years (between 2013 and 2023);
- Scientific articles dealing with aligner impression techniques;
- Research into the dimensional accuracy, mechanical strength, biocompatibility or other relevant criteria of the two methods;

3.2 Exclusion criteria

The exclusion criteria involved are:

- Studies that did not meet the defined inclusion criteria;
- Studies that are not written in English;
- Studies published with more than ten years;
- Scientific articles dealing with direct 3D impression and thermoforming impression in orthodontics other than retainers;
- Articles whose full text did not provide useful information;
- Articles whose abstracts do not fit the theme of this dissertation.

3.3 PRISMA Methodological Protocol

This integrative systematic review was conducted according to the PRISMA checklist ("The Preferred Reporting Items for Systematic Review and Meta- analysis") http://www.prisma-statement.org/documents/PRISMA-P-checklist.pdf.

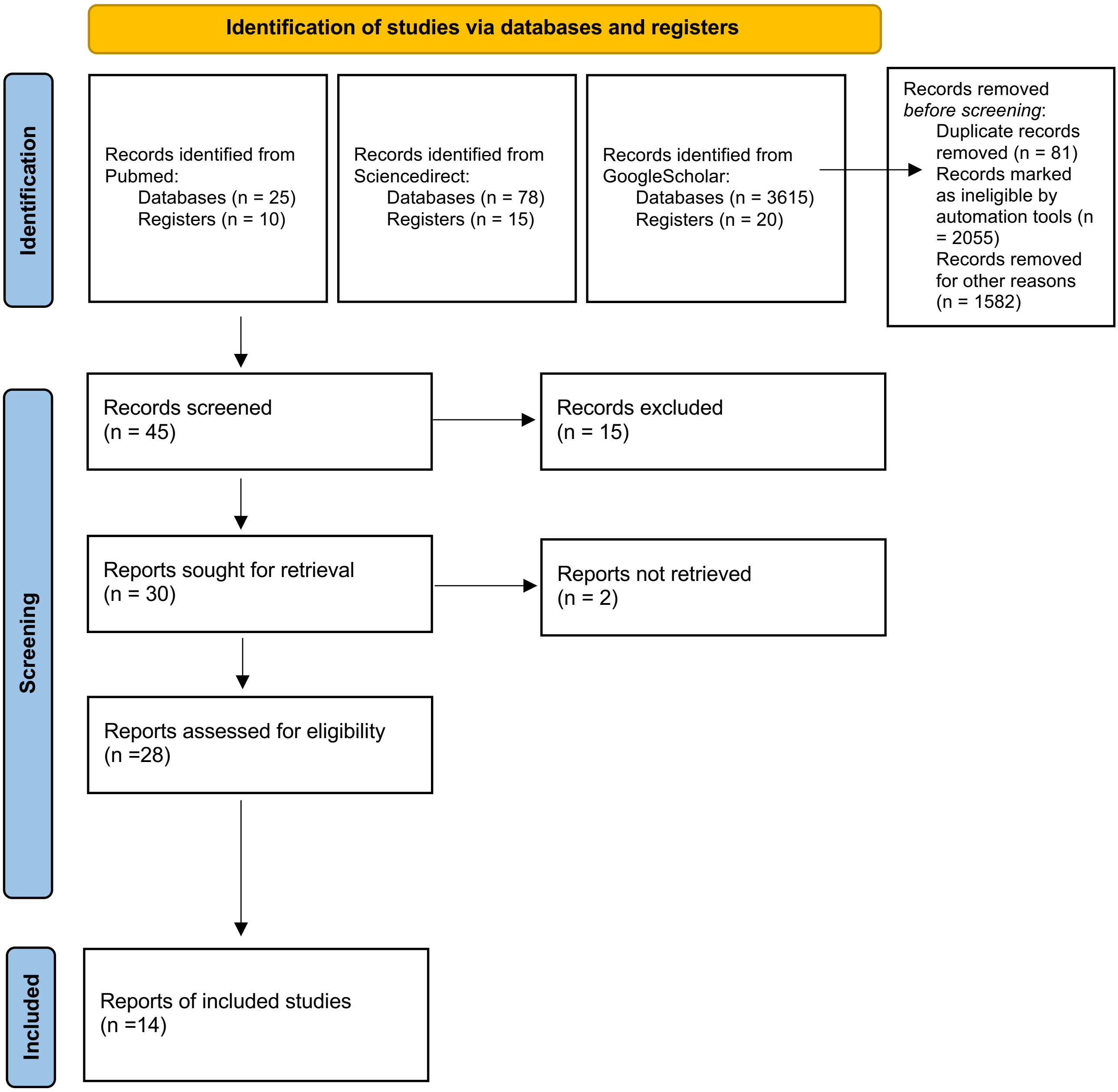

Figure 1 : Prisma 2020 Flow diagram for new systematic reviews which included searches of databases and registers only

4. RESULTS

The 14 selected articles obtained according to the flowchart for this study were read and individually evaluated regarding the objectives of this study. The RoB 2.0 tool was used to assess risk of bias for each of the included studies.

Table 2: The table displays for each included study the risk-of-bias judgment for each of six domains of bias, and for the overall risk of bias

Risk of bias domains

Study	D1	D2	D3	D4	D5	Overall
Nasef (2017)	?	-	+	-	?	-
Rajasekaran (2023)	?	-	+	-	-	-
Jindal (2022)	?	-	+	-	-	-
Hertan (2022)	?	-	?	-	?	-
Koenig (2022)	?	-	+	-	-	-
Jindal (2020)	?	-	+	-	-	-
Cole (2018)	?	-	?	-	?	-
Shirey (2023)	?	-	?	-	?	-
Edelmann (2020)	?	-	?	-	?	-
Park (2023)	?	-	?	-	?	-
Lee (2022)	?	-	+	-	?	-
Payani (2023)	?	-	+	-	-	-
McKay (2023)	?	+	+	+	+	+
Atta (2024)	?	-	+	-	-	-

Domains:
D1: Bias arising from the randomization process.
D2: Bias due to deviations from intended intervention.
D3: Bias due to missing outcome data.
D4: Bias in measurement of the outcome.
D5: Bias in selection of the reported result.

Judgement
- Some concerns
+ Low
? No information

These final articles are presented in the following tables, with general information such as title and authors, type of study, objectives, materials and methods, results and conclusion (Table 3-5).

Aligner's Manufacture

Table 3: Aligner's Manufacture results table

Title and Authors	Type of Study	Objectives	Materials and Methods	Results	Conclusion
Nasef et al., Accuracy of Orthodontic 3D Printed Retainers versus Thermoformed Retainers (2017)	Experimental, Transversal, Analytical, Retrospective	To assess the precision of 3D printed retainers in comparison to vacuum-formed retainers	-10 CBCT scans had alginate impressions taken and both 3D printed. Vacuum-formed retainers were created. -Linear measurements were taken and compared between the two types of retainers for various dimensions: inter-canine and inter-molar widths. -Reliability assessments were also conducted.	- High intra and inter-observer reliability was observed for both thermoformed and 3D printed retainers. -Comparison between thermoformed and 3D printed retainers showed high statistical agreement, except for the right canine-molar with no clinical significance (p=0.038, MD= 0.19).	The new method for fabricating a 3D printed retainer is accurate and reliable in comparison to the vacuum formed retainer (conventional method).
Rajasekaran et al., Integrated manufacturing of direct 3D-printed clear aligners (2023)	Observationnel, Descriptive, Prospective	Summarize the digital orthodontic process of manufacturing 3D-printed clear aligners and present the literary evidence in this regard	-Clear orthodontic aligners can be produced via thermoforming on 3D-printed models or direct 3D printing. -Thermoforming molds heated plastic sheets over 3D-printed dental models, while direct 3D printing uses clear resins without intermediaries. -Technologies like SLA, DLP, and LCD are used with resins such as Tera Harz TC-85DAC. Post-printing involves cleaning uncured resin, support removal and post-curing for resin enhancement.	- The various stages of the 3D-printed clear aligner manufacturing process, emphasizing the elimination of potential errors associated with traditional thermoforming, as well as precisely control the thickness, force and aesthetics of the aligners. -The use of direct 3D printing reduces production lead times and costs.	The field of orthodontic aligner manufacturing is continually evolving, with ongoing potential for improvement. The article encourages progress in the realm of 3D-printing clear aligners to enable more accessible, cost-effective, and environmentally friendly digital orthodontics.

MD: Mean diference; SLA: Stereolithography; DLP: digital light processing; LCD: liquid crystal display

Physical Properties

Table 4: Physical Properties results table

Article and Authors	Type of study	Objectives	Materials and Methods	Results	Conclusion
Jindal et al., Mechanical and geometric properties of thermoformed and 3D printed clear dental aligners (2022)	Experimental, Transversal, Analytical	Compare the mechanical compression properties and geometric inaccuracies between conventionally manufactured Duran® thermoformed transparent dental aligners and 3D-printed Dental Long Term (LT) resin-based transparent aligners using 3D modeling and printing techniques.	-Patient dental scan impressions, used 3D modeling to create 3D-printed dental models. -Two types of transparent dental aligners produced: one via thermoforming Duran® thermoplastic sheets and the other by 3D printing with *Dental LT* resin. -Geometric deviations were assessed through tooth height measurements by five observers and the aligners' response to a 1000 N compressive load was analyzed.	- 3D-printed aligners: more precise (2.55% vs. 4.41% height difference), low standard deviations (0.03-0.09 mm). 3D aligners withstand 662 N for 2.93 mm displacement; Thermoformed aligners manage 105 N. -3D-printed aligners show reversible elastic deformation for smaller displacements; Thermoformed aligners deform irreversibly for larger displacements.	3D-printed transparent Dental LT resin aligners, if properly polymerized, are deemed more suitable for patients due to their superior geometric accuracy. This can save treatment time while ensuring aligners are mechanically more durable and elastic than conventionally thermoformed transparent thermoplastic aligners.
Hertan et al., Force profile assessment of direct-printed aligners versus thermoformed aligners and the effects of non-engaged surface patterns (2022)	Experimental, Analytical	Measure the forces exerted by directly printed aligners in the vertical dimension, compare the force profile with traditional thermoformed aligners, and investigate the impact of non-engaged surface patterns on the properties of DPA (Directly Printed Aligners) and TFA (Thermoformed Aligners)	-A force-measuring device, moving the aligner by 0.10 mm increments, was used. -Two materials: polyethylene terephthalate glycol (TFA for thermoformed aligners) and TC-85DAC resin (DPA for directly printed aligners). -Aligners were temperature-controlled to mimic oral conditions. Forces from 0.10 to 0.30 mm movements were measured.	-At oral temperatures, TC-85DAC had lower force than TFA. TFA exhibited increasing force with 0.10 mm displacement, while DPA maintained consistent force profiles. -Surface patterns in both materials reduced force, significant for TFA at 0.30 mm displacement and beyond, and for DPA at 0.10 mm displacement. -No statistical difference was found in force properties between DPA and TFA surface patterns.	The forces exerted by DPA aligners in the vertical dimension 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.

Koenig et al., Comparison of dimensional accuracy between direct-printed and thermoformed aligners (2022)	Experimental, Analytical	Evaluate and compare dimensional accuracy between thermoformed and directly printed aligners	-Three types of aligners were created: thermoformed aligners using Zendura FLXTM (n = 12), Essix ACETM (n = 12) and direct-printed aligners with Tera HarzTM TC-85DAC 3D Printer UV Resin (n = 12). -Samples were scanned and imported into *Geomagic® Control XTM* software. Distances between aligner meshes and the reference STL file were measured at nine anatomical landmarks.	-The direct-printed aligners exhibited the least mean absolute discrepancies and the smallest root mean square values, signifying the highest precision and accuracy among the aligner types. -In contrast, the thermoformed aligners showed larger discrepancies. -These findings highlight the potential advantages of direct-printed aligners in orthodontic treatment in terms of dimensional accuracy.	Greater accuracy and precision were observed in directly printed aligners compared to thermoformed aligners.
Jindal et al., Mechanical behaviour of 3D printed vs thermoformed clear dental aligner materials under non-linear compressive loading using FEM (2020)	Observational, Analytical	To compare the geometric precision and mechanical resistance to human bite forces of dental aligners manufactured through thermoforming (DuranSoft® and Duran®) and 3D direct printing (Dental TD).	-Three materials (Dental LT Clear Resin, Duran ®, DuraSoft®). -Geometric precision assessed by comparing aligner design with STL model, measuring dental crown height differences. -Mechanical resistance evaluated with FEA, measuring von Mises stress distribution under compression forces like human bites.	-Dental LT Clear aligners showed better geometric precision than traditional thermoplastic ones, with mean dental crown height differences of 1.94% versus 4.52%. -Regarding mechanical resistance, Dental LT Clear had stresses comparable to thermoplastics. Both types withstood up to 600N compression loads with stresses ranging from 0.2% to 7.7% compared to thermoplastic aligners.	Aligners made with Dental LT Clear resin offer geometric precision advantages over traditional thermoplastic aligners. 3D-printed aligners demonstrate comparable mechanical performance, making them suitable for withstanding human bite forces. The biocompatibility of Dental LT Clear resin further enhances its suitability for use in dental applications.

Cole et al., Evaluation of fit for 3D-printed retainers compared with thermoform retainers (2018) .	Comparative Study, Experimental, Analytical .	Assess the accuracy of 3D-printed retainers compared to conventionally vacuum-formed commercial retainers.	-Three reference models (1, 2, and 3) used to create vacuum-formed retainers conventionally (TVF), commercially available (CVF) and 3D-printed. -Each model made retainers using all three methods, totaling 27 retainers. Accuracy assessed by measuring distance between each retainer and its digital model at reference points using engineering software. -Measurements compared to those of conventionally vacuum-formed retainers.	-CVF and 3D-printed retainers had ranges of 0.10 to 0.30 mm and 0.10 to 0.40 mm, respectively. TVF retainers showed the least deviation from reference models. CVF retainers had low variance at incisors and cusp tip points but higher variance on smooth tooth surfaces. -3D-printed retainers had less deviation at incisors and cusp tip points but more significant differences on smooth tooth surfaces.	TVF retainers showed minimal deviation from reference models, while 3D-printed retainers had more discrepancies. Further clinical trials are needed to assess 3D-printed retainer performance and ongoing material improvements are required for accurate clinical fitting. All three methods yielded measurements within the clinically acceptable range of 0.5 mm deviation from reference models.
Shirey et al., Comparison of mechanical properties of 3-dimensional printed and thermoformed orthodontic aligners (2023)	Experimental, Longitudinal, Analytical	Mechanical properties (elastic modulus, ultimate tensile strength, and stress relaxation) of thermoformed thermoplastic aligner materials and direct 3D-printed materials, under both dry and wet conditions	Aligner samples from four different materials were mechanically tested for elastic modulus, ultimate tensile strength (UTS) and stress relaxation in both dry and wet conditions, with statistical material comparisons.	-In dry conditions, thermoformed aligners were less elastic than 3D-printed ones, but humidity affected their elasticity inversely. -Thermoformed aligners had higher UTS in dry conditions, but all materials experienced decreased in humid environments. -3D-printed aligners exhibited more stress relaxation, potentially impacting clinical efficacy, highlighting the need for adjustments to optimize performance.	Significant impact of humidity on these materials, potentially affecting their clinical efficacy. To make 3D-printed aligners a viable alternative to thermoformed ones, additional research and development efforts are essential to ensure these materials meet clinical performance requirements.

Edelmann et al., Analysis of the thickness of 3-dimensional-printed orthodontic aligners (2020)	Experimental, Transversal, Analytical	Investigate the effect of digitally designed aligner thickness on the thickness of the corresponding 3D-printed aligner.	-Digitally designed aligners of 3 different thicknesses were 3D printed in 2 resins-Dental LT via stereolithography. -The Dental LT aligners were coated and scanned with an optical scanner. Grey V4 aligners were scanned pre- and post-spray. -Aligner scans were superimposed onto digital design files. Average wall thickness per aligner was measured with metrology software.	-The printed aligners were consistently thicker than the design files. Superimpositions showed that 3D-printed aligners were thicker overall than the corresponding design file. -The Dental LT aligners had the largest thickness deviation, whereas the Grey V4 without spray had the smallest. -The results indicate that the excess thickness in the Dental LT groups could not be attributed to spray alone.	Fabrication of clear aligners directly by 3D printing with the workflow applied resulted in an increased thickness that may deleteriously affect the clinical utility of the aligners.
Park et al., Comparaison of translucency, thickness, and gap width of thermoformed and 3D-printed clear aligners using micro-CT and spectrophotometer. (2023)	Experimental *in vitro*, Transversal	Compare the translucency, thickness and gap width of clear aligners (CAs) made via thermoforming and 3D printing	-Four groups of clear aligners (CAs): thermoforming with polyethylene terephthalate glycol (TS), thermoforming with a copolyester-elastomer combination (TM) and 3D printing with two cleaning methods: cleaned with alcohol (PA) and cleaned with centrifuge (PC). -Researchers employed micro-CT and spectrophotometry for a detailed evaluation of CA properties, including translucency, thickness and gap width. -The focus was on understanding how manufacturing and cleaning procedures impact these properties, contributing valuable insights to the orthodontic field.	-Translucency: PC was more translucent than PA, while TS and TM were like PA. Cleaning impacted 3D-printed CA's translucency. -Thermoformed CAs decreased thickness, while 3D-printed CAs increased. Variations depended on tooth type and location, emphasizing manufacturing and post-processing importance. -Thermoforming resulted in thinner buccal and gingival areas, while 3D-printed CAs had thicker incisal/occlusal areas. Different cleaning methods affected 3D-printed CAs, with centrifuge method improving outcomes.	This comparison revealed significant variations in translucency, thickness, and gap width between CAs manufactured through thermoforming and 3D printing. Manufacturing and cleaning methods significantly impact CA properties. The findings contribute to improved orthodontic treatments, emphasizing the importance of careful fabrication and post-processing procedures.

STL: Standard Tessellation Language; FEA: Finite Analysis

Shape Memory

Table 5: Shape Memory results table

Article and Authors	Type of study	Objectives	Materials and Methods	Results	Conclusion
Lee et al., Thermo-mechanical properties of 3D printed photocurable shape memory resin for clear aligners (2022)	Experimental, transversal, analytical, prospective	Evaluate the thermo-mechanical and viscoelastic properties of a newly developed photopolymerizable resin, TC-85DAC, used for 3D printing of transparent aligners. The goal was to compare TC-85DAC to the conventional thermoplastic material, polyethylene terephthalate glycol (PETG), widely used for transparent aligners.	-To evaluate the properties of the two materials, dynamic mechanical analysis and U-shaped bending tests were performed. -Tensile strength tests, dynamic mechanical analysis (DMA) and shape memory property tests were conducted on TC-85DAC and PETG samples. -Static mechanical properties, stress relaxation and creep behavior, as well as shape memory properties were evaluated.	-TC-85DAC exhibits flexibility and viscoelastic properties that allow it to consistently apply a gentle force on the teeth when used for transparent aligners. -TC-85DAC also showed high-temperature geometric stability and shape memory properties. -On the other hand, PETG exhibited higher tensile strength and modulus of elasticity, but less flexibility and shape recovery capability compared to TC-85DAC.	TC-85DAC exhibits favorable mechanical and viscoelastic properties, shape memory properties, which can maintain a constant orthodontic force and reduce force decay. Further research is needed to evaluate the long-term clinical performance.
Panayi et al., 3D printed aligners: Material science, Workflow and Clinical applications (2023)	Observational, descriptive, analytical	Evaluate the entire process of designing and manufacturing 3D-printed dental aligners, with a specific focus on manufacturing variables and clinical outcomes.	- TC-85DAC is cleaned by centrifugation and supports are removed before or after UV polymerization. -Aligners are virtually positioned on a 3D printing platform. Printing utilizes VAT (stereolithography) technology, affecting quality due to oxygen presence. - UV curing is ideally performed with nitrogen to create an oxygen-free environment.	- Results show potential for customizing aligner thickness for specific movements with recommendations on optimal thickness. -A 50 µm printing resolution yields smoother surfaces, though doubling printing time. - 3D-printed aligner effectiveness in orthodontic cases, particularly controlled tooth movements.	3D printing offers advantages but needs precise manufacturing management. Clinical results show effectiveness, but specific guidelines are required for optimal printing outcomes. Despite technological advancements, human intervention remains crucial in orthodontic treatment. Integration of AI will play a prominent role in digital orthodontic practice transition.

McKay et al., Forces and moments generated during extrusion of a maxillary central incisor with clear aligners: an in vitro study (2023)	Experimental, analytical, *in vitro*	Assess the extrusion potential of a maxillary central incisor using buccal and lingual pressure columns without attachments, and to evaluate the forces and moments experienced by teeth with thermoformed and 3D-printed clear aligners.	-A force and moment sensor measured forces during UL1 extrusion and forces on UR1 with thermoformed aligners (ATMOS® and Zendura FLX®) and 3D-printed aligners (TC-85 clear photocurable resin). -Each material underwent three conditions: Group 1 - No attachment or pressure columns (control), Group 2 - Attachment only and Group 3 - Pressure columns only, for 0.5 mm of UL1 extrusion.	-All force readings differed significantly among materials and groups ($P < 0.001$). -In Group 1, TC-85DAC exerted lower forces and moments on UL1 than ATMOS® and Zendura FLX®. In Group 2, TC-85DAC showed distinct UR1 forces compared to thermoformed groups. In Group 3, only TC-85DAC 3D-printed aligners applied extrusive force. -Thermoformed aligners had higher forces and moments than 3D-printed aligners, with unintended forces present in all groups.	Force levels from TC-85DAC 3D-printed aligners are significantly lower during extrusion compared to thermoformed aligners. Attachments consistently produce extrusive forces, aiding in incisor extrusion. Extrusion without attachments is feasible with pressure columns in TC-85DAC 3D-printed aligners.
Atta et al., Physiochemical and mechanical characterisation of orthodontic 3D printed aligner material made of shape memory polymers (4D aligner material) (2024)	Experimental, transversal, analytical	Comparing the physico-chemical and mechanical properties of 3D printed shape memory polymer orthodontic aligners (4D aligners) to thermoformed aligners. Four materials were studied: CA Pro, Zendura A, Zendura FLX (thermoformed), and Tera Harz TC-85DAC (3D printed).	The analyses included differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), shape recovery tests, three-point bending test, and surface microhardness.	-TC-85DAC exhibits exceptional shape memory at oral temperature, substantial shape recovery capability, and microhardness like thermoformed sheets.	3D-printed 4D aligners offer mechanical properties better suited for orthodontic treatment than thermoformed materials, with improved adaptation and less force loss.

UV: ultraviolet; AI: artificial intelligence; UL1: upper left central incisor; UR1: upper right central incisor

5. DISCUSSION

5.1 Aligner's Manufacture

Orthodontic clear aligners can be manufactured by thermoforming on the 3D-printed models or directly 3D printing aligners. (7)

5.1.1 Manufacture of aligners by thermoforming: traditional method

The conventional method of manufacturing transparent aligners can be categorized into four distinct stages: acquiring the original dental anatomy, manipulating the teeth, three-dimensional printing, and thermoforming. (9) Dental aligner manufacturing via thermoforming starts with negative impressions of the dental arches using the patient's alginate or PVS silicone. These impressions are 3D scanned to generate a virtual model of the patient's teeth. (3) Digital scanners are used in traditional and direct fabrication to obtain data on the patient. The resulting scanned data, formatted as an STL (Standard Tessellation Language) file, is exported to the treatment planning software. This model is integrated into Computer Aided Design (CAD) software to plan the desired dental movements and virtually design the aligners. Dental models are 3D printed from the virtual designs to produce the physical aligners. These models serve as molds for the thermoforming process. (7) Thermoforming involves heating a sheet of transparent thermoplastic material, usually Duran®, to a specified temperature. This sheet is then molded onto the 3D-printed dental models to obtain the shape of the aligners. The thermoformed sheet is cut and finished to ensure a precise shape with no sharp edges. Patients then receive their personalized aligners and detailed instructions on how to wear and care for them.(3,7,8) Clear aligners produced using Duran® and Durasoft® involve more steps including impressions, scanning, 3D modelling of stages, 3D printing of dental models for each stage and final vacuum thermoforming of the clear sheet to form the clear aligner. (10)

5.1.2 Manufacture of aligners using 3D printing: Direct 3D printing

In contrast, manufacturing aligners using direct 3D printing bypasses the thermoforming process. Firstly, as with the traditional printing technique for thermoformed aligners, an impression of the patient's arches is made (physical impression or digital with the 3D photo process with scanner). The dental scans in STL format are imported into orthodontic software with a specific workflow, including model orientation, base design, and root alignment like the traditional method. (8) The software intended for computer-aided designing of clear aligners allow the segmentation of individual teeth to reset them in the desired configuration in an incremental manner. (7) The thickness of the aligners can be customized, ranging from 0.25mm to 1.2mm, typically 0.75mm. The design also allows the cutting height of the aligners to be customized, particularly for specific movements. (11) Once virtually designed, the aligners are exported on the 3D printer's virtual platform. Aligners can be oriented horizontally, vertically, or diagonally to optimize platform space. Support structures are necessary for successful printing and are generated using pre-processing software. These structures must touch and penetrate the aligner shells. (11) Several 3D printing technologies, such as stereolithography (SLA), photopolymerization, digital light processing (DLP) and liquid crystal display (LCD), are used for this process. (7) The technique used in Panayi N. et al.'s article for 3D printing is carried out using VAT (stereolithography) technology. (11) The aligners are printed in layers of resin and the process is carried out in the presence of oxygen, a well-known polymerization inhibitor. After printing, aligners are cleaned to remove residual unpolymerized resin, typically by centrifuging for about 6 minutes. Ultraviolet curing hardens the aligners, preferably in a unit with nitrogen generation for an oxygen-free environment, enhancing quality. Subsequently, a polishing process with rotating brushes can smooth surfaces, optionally followed by resin application for further refinement. (11)

5.1.3 Advantages and disadvantages of the techniques:

Discussion of the advantages and disadvantages of the techniques used to manufacture orthodontic aligners reveals a persistent predominance of the thermoforming technique, particularly among major players such as Invisalign Inc., K-line® and ClearCorrect®. However, technological developments, such as advanced 3D printing technology, have introduced alternatives. Panayi N. et al. 's article uses stereolithography with VAT technology, offering notable results regarding smooth surfaces and less visible layer lines. Compared with conventional thermoforming, this approach guarantees superior quality, reinforcing its appeal in the manufacture of orthodontic aligners. A notable aspect of 3D technology is its flexibility in aligner design regarding thickness, enabling customized treatments to meet unique needs that may be challenging with traditional thermoforming. Additionally, integrating nitrogen into the printing process enhances aligner mechanical and optical quality by removing oxygen. In addition, cleaning process, including centrifugation, ensures the effective removal of support residues without compromising the shape of the aligners, thus contributing to the overall quality of the final product. Despite its promise, widespread acceptance of this new approach may be limited by factors such as associated costs and established industry preferences. (11)

5.2. Comparison of the two techniques on their physical properties

5.2.1 Geometric and dimensional accuracy

When manufacturing aligners, various criteria must be considered, and errors can arise at different stages from digital design to tray fitting. Numerous articles address accuracy and precision, including dimensional accuracy, which refers to how closely printed objects match the specified and geometric dimension, which pertains to the fidelity of shapes and details. Jindal et al. conducted a study to evaluate the dimensional accuracy of aligners. It found that 3D-printed aligners were significantly more accurate and closer to the digital model than thermoformed aligners. Direct 3D printing would be able to maintain dimensions closer to the digital file than thermoformed aligners, which is essential for obtaining accurate orthodontic results. (10) These results are supported by Koenig et al. The 3D-printed aligners showed higher dimensional accuracy than the thermoformed aligners. Significant differences were observed at several anatomical landmarks, indicating that the 3D-printed aligners were more accurate at these locations. The use of high-precision scanners to measure the distances between the aligners and the maxillary models reinforces the reliability of the results. However, the study also has significant limitations, as adding a scanning spray can introduce a significant error in aligner dimensions. (9) Unlike others for Nasef et al., there were no differences of clinical significance between the two types of aligners, confirming that 3D-printed aligners can maintain accuracy. (12) However, Cole et al. compared the dimensional accuracy of thermoformed retainers versus direct-printed retainers and found that direct-printed retainers had more significant discrepancies. Nevertheless, all methods yielded measurements within 0.5 mm, which was previously accepted as clinically sufficient. (13) The dimensional accuracy of 3D aligners impacts their clinical effectiveness, with conflicting findings among authors. While Koenig et al. noted potential inaccuracies due to scanning spray use, Cole et al. found discrepancies between thermoformed and direct printed aligners within acceptable limits. (13) Despite varied results, most authors agree on the comparable or superior accuracy of 3D printed aligners. However, their evaluation should be individualized, considering manufacturing methods, scanner specifications, and patient characteristics.

5.2.2 Mechanical strength and forces exerted

Mechanical strength is an essential feature of aligners, crucial for resisting masticatory and orthodontic forces. The research of Jindal et al. reveals the exceptional strength of 3D printed aligners, capable of withstanding loads of up to 600N, whereas thermoformed aligners can only tolerate 105N. (10)The human bite force, estimated at around 600N, underscores 3D-printed aligners' capability to endure forces nearly six times greater than thermoformed aligners. Additionally, stress analysis (Von Mises) reveals minimal stress reduction in Dental LT™ resin compared to conventional materials, suggesting its significant mechanical resistance to masticatory stress. Furthermore, 3D-printed aligners demonstrate exceptional resilience to non-linear cyclic compressive forces, underscoring their durability in real-world conditions. This quality sets apart 3D-printed aligners using Dental LT™ resin, showcasing their adaptability and reliability in challenging orthodontic scenarios. In conclusion, this research suggests that 3D-printed aligners are excellent in withstanding high loads while maintaining exceptional mechanical properties. (10) To further support the above findings, Hertan et al. highlight that the 3D-printed aligners offer more constant forces over the entire displacement range, unlike the thermoformed aligners, which show significant force variations. The control of dental movements may be improved by the stability of forces exerted by 3D aligners, which can positively impact clinical effectiveness. (14) From these findings, it is apparent that aligners produced by 3D printing, particularly those made of Dental LT resin® that Prashant et al. previously examined, offer significant mechanical strength and force stability benefits. (10)

5.2.3 Impact of humidity

According to Park et al. humidity can influence the ability of aligners to generate and maintain appropriate force levels for tooth movement, highlighting the importance of studying this factor. (15) Prashant et al.'s research highlights the impact of force relaxation on the effectiveness of aligners, but moisture-induced variations present an additional dimension to consider. It emphasized the need for optimal force relaxation to ensure consistent application of force to the teeth, thereby promoting efficient tooth movement. (10) Shirey et al.'s results suggest that moisture-induced changes can influence this force relaxation, potentially compromising the ability of aligners to generate and maintain adequate force levels. (16) This significant variation could influence the rigidity of the aligners, with direct implications for their insertion and removal. These mechanical changes underline a concern already addressed by Jindal et al., highlighting the importance of mechanical properties to the handleability of orthodontic aligners. A significant decrease in ultimate tensile strength was observed in humid conditions, raising concerns about its ability to effectively resist stresses during dental movement. (10) These observations support earlier concerns expressed by Jindal et al., underlining the crucial importance of considering the actual environmental conditions in which aligners are used clinically. The changes observed under the effect of humidity raise questions about its mechanical stability in realistic oral environments. In addition, simulation of the oral environment with immersion in a humid environment for a specific period may not faithfully reproduce the real conditions of aligners worn by patients daily.

5.2.4 Aesthetics, translucency and thickness

Edelmann et al.'s study examines the manufacture of orthodontic aligners by 3D printing and its implications for their clinical utility. The results showed that the 3D-printed aligners were systematically thicker than the corresponding design files, with a mean thickness deviation of around 0.2 mm. The study highlights that scanning pulverization affected measured thickness but didn't account for all deviations. 3D surface deflection maps identified potential overbuild areas, affecting aligner fit and force application. It emphasizes the complexity of direct aligner manufacturing, with thickness deviations of clinical concern. Uncontrolled thickness may require adjustments and lead to unpredictable tooth movements. (1) Following Edelmann et al´s research into the thickness of 3D-printed orthodontic aligners, Park et al.'s study offers a complementary perspective by looking at the translucency, thickness and width of the space between transparent thermoformed and 3D-printed aligners. (15) The study finds that 3D-printed aligners are more translucent than thermoformed ones, with variations in space thickness and width depending on tooth type and location. Cleaning methods also impact aligner properties. Manufacturing protocols and cleaning techniques significantly influence aligner properties, with acknowledged limitations in sample selection and experimental conditions. The study emphasizes considering variations in thickness and width when activating aligners for different malocclusions and optimizing parameters like post-curing process, build angle settings, and layer thickness to enhance accuracy. Post-curing under nitrogen prevents oxygen-inhibiting layer formation, crucial for aligner surface polymerization, while injecting inert nitrogen gas aids in achieving optimal mechanical properties and surface smoothness. Optimizing parameters is crucial for enhancing 3D-printed aligner accuracy and clinical performance. (15)

5.3. 3D printing material and the shape memory

McKay et al. point out that, traditionally, the manufacture of transparent aligners has involved using the thermoforming technique with various thermoplastic materials. However, he highlights the drawbacks of this process, including alterations to the physical properties of the material, geometric inaccuracies, dimensional instability, reduced strength, and lower wear resistance. (17) The last three years have seen a significant breakthrough in orthodontics with the emergence of a new aligner technology. *Graphy Inc* (Seoul, Korea) has been leading in the development of the TC-85DAC. This revolutionary light-curing resin allows clinicians to directly 3D print aligners without needing dental models, as mentioned by Panayi et al. (11)This resin would offer unique flexibility and viscoelastic properties, allowing constant force to be applied to the teeth. In addition, it would offer advantages such as geometric stability at elevated temperatures and shape memory properties, providing significant benefits for its clinical application, as highlighted in the work of Jindal, Koenig, and Lee. What makes this resin special is its unique shape memory property. (6,9,10) In addition, according to the manufacturer's website, the TC-85DAC biocompatible material is a photopolymer with worldwide certifications for medical devices, ensuring its safety and suitability for orthodontic use. It is actively used in the Korean and international markets, demonstrating superior results compared to conventional methods.

5.3.1 Orthodontic efficiency: Enhanced Orthodontic Force through Shape Memory Function

According to Lee et al., the advantage of shape memory in transparent aligners lies in their ability to maintain a constant orthodontic force on the teeth, even after deformation when the aligners are worn. Hot water, recommended by the manufacturer, makes the aligners more flexible before insertion, thanks to the shape memory effect, which ensures that they return to their original shape at the normal body temperature of 37°C. (6) Atta et al. describe shape memory polymers like TC-85DAC as dynamic materials capable of altering their macroscopic configuration under specific stimuli. They maintain a temporary shape until exposed to the right stimulus, swiftly returning to their original form. This mechanism involves a stable polymer network determining the material's initial shape and a reversible polymer network enabling temporary transformation. These polymers can endure higher stress levels and adopt various temporary shapes due to multiple phases with different shape recovery temperatures. (18) In this study by Lee et al., the thermomechanical and viscoelastic properties of TC-85DAC photocurable resin were examined. The shape memory test confirms the findings of the Atta et al. study, demonstrating that TC-85DAC has a 96% shape recovery rate after 60 minutes at 37°C. This significantly underlines its ability to recover its original shape after deformation. (6) In addition, McKay et al's paper highlights the crucial effect of temperature on TC-85DAC aligners, offering a significant advance in improving patient comfort. (17) One innovative practice involves immersing the aligners in warm water before insertion into the patient's mouth, making the aligners more flexible for easier initial adaptation, as the manufacturer recommends. Once in the mouth, thanks to the shape memory property, the aligners quickly return to their original shape, ensuring a precise and comfortable fit. The direct aligner's shape memory function will reduce the discomfort associated with wearing and removal. Softening in warm water reduces discomfort during insertion and removal. Also, according to *Graphy Inc*'s manufacturing site, in the event of a reduction in orthodontic strength and elasticity, the direct aligner can be immersed in hot water to recover its original shape. This simple process allows the orthodontic force to be restored to its original shape, maintaining optimal treatment efficacy.

5.3.2 Viscoelastic properties and dynamic mechanical analysis

Park et al's study, indicate that TC-85DAC exhibits favorable thermo-mechanical and viscoelastic properties, with an ability to maintain a constant orthodontic force, reduce force decay, and recover its original shape. These characteristics make TC-85DAC a promising candidate for clinical applications in orthodontics, particularly in 3D-printed transparent aligners. Although the results are promising, the study acknowledges certain limitations, such as the sample size and the lack of blind testing. Further research is needed to assess the clinical performance and long-term durability of TC-85DAC under real conditions of use. (15)

5.3.3 Force and stress relaxation

McKay et al's highlight the crucial importance of the aligner material, particularly TC-85DAC, in modulating the forces generated and the complexity of the associated biomechanics. The force levels generated during extrusion with 3D aligners printed from TC-85DAC were significantly lower, highlighting the potential effectiveness of this material in reducing the forces applied during dental movements. The study also suggests extrusion can be achieved without attachments by incorporating pressure columns into 3D aligners printed from TC-85DAC. (17) Comparing force levels, the study highlights that thermoformed aligner can exhibit excessively high force levels, far exceeding the recommended physiological range. Conversely, 3D aligners printed with TC-85DAC material showed greater force levels than biology, although some groups still exceeded the recommended ranges. McKay et al.'s study emphasizes the significance of maintaining ideal force levels, typically between 0.5N and 1.0N, for tooth movement. Thermoformed aligners in the study exhibited force levels exceeding this range, while 3D aligners printed with TC-85DAC demonstrated lower, more biologically aligned levels. The high force levels observed may be attributed to the extent of planned tooth movement, notably the extrusion of the upper left central incisor. The article underscores the complexity and unpredictability of clear aligner biomechanics, noting significant variability in unplanned forces and moments on intended teeth and adjacent ones. Aligner material and tooth movement strategies play pivotal roles in influencing these factors, emphasizing the necessity of meticulous and personalized treatment planning with clear aligners. The study acknowledges potential thickness variations in TC-85DAC aligners, highlighting their impact on adaptation. In addition, although the force levels generated by TC-85DAC aligners are more consistent, their occasional exceeding of recommended physiological ranges necessitates a careful approach to orthodontic treatment planning. In addition, a significant concern with conventional aligners is their susceptibility to stress relaxation during wear, leading to decreased applied force. This usually occurs within the first few hours after insertion of the aligner into the patient's mouth. To overcome these problems, continuous progress is being made to improve the effectiveness of orthodontic aligners and the patient experience, notably through shape memory polymers. Stress relaxation and creep behavior are important properties to evaluate for transparent aligners. (17) The article by Lee et al., indicates that TC-85DAC showed lower stress relaxation, higher static residual force and higher stress recovery after relaxation. (6) This suggests that TC-85DAC can maintain a more constant orthodontic force and reduce permanent deformation caused by repeated insertion of aligners.

5.3.4 Surface microhardness

According to Atta et al., surface microhardness analysis evaluates material hardness at a microscopic level, crucial for orthodontic aligners due to its impact on stress resistance, color stability, and susceptibility to crack formation. TC-85DAC demonstrates intermediate microhardness compared to other materials, striking a balance between flexibility for precise adaptation to teeth and surface hardness for structural stability. This suggests TC-85DAC offers a compromise option. Additionally, TC-85DAC is praised for its compatibility with clinically recommended orthodontic forces, despite lower flexural strength compared to other materials, indicating its effectiveness in orthodontic adjustments while maintaining flexibility. (18) In summary, Tera Harz TC-85DAC is positioned as a compromise between rigidity and flexibility, offering a microhardness that allows precise adaptation while maintaining the necessary stability. These characteristics could translate into improved clinical performance, providing an optimal balance between the desired tooth movement and the stability of the aligner. However, it is important to note that the choice of material also depends on the specific needs of the orthodontic treatment and the preferences of the practitioner.

5.3.5 Material characteristics: Perfect Transparency, Resistance to Discoloration and Ease of Transparency Recovery

Edelmann et al.'s study highlights the absence of any other 3D printable material currently commercially available that meets the standards of biocompatibility, translucency, and appropriate mechanical properties, highlighting the exceptional nature of TC-85DAC in these specific areas. (1) However, according to Lee et al., despite the significant advantages, TC-85DAC is not without its limitations. In-depth analysis revealed that the material had a thickness of 0.56mm, 12% greater than the expected 0.5mm after manufacture. This increase is attributed to excessive polymerization of the material during 3D printing, as well as residual polymerization during the post-cure process. These thickness variations highlight the need for careful management of the manufacturing process to ensure optimal fit of the aligners in clinical use. (6) The *Graphy Inc* website highlights achieving perfect material transparency for their aligners, claiming near invisibility when worn and resistance to discoloration, with easy restoration of transparency by brushing with toothpaste. Despite TC-85DAC's advantages, post-fabrication thickness requires attention, manageable through careful manufacturing. Emphasis on transparency by *Graphy Inc* underscores aesthetics' importance in aligner material development. Thus, while acknowledging TC-85DAC's benefits, a balanced approach considering mechanical, biocompatible, and aesthetic factors is crucial for 3D aligner material selection.

5.3.6 Comfort and convenience: Minimized Inconvenience of Wearing, Removing and Convenience of Storage

Aligners made from Tera Harz TC-85DAC could allow more significant tooth movement per step, reducing the number of aligners needed for treatment. The TC-85DAC material maintains its structural stability at elevated temperatures, a feature that can be attributed to its cross-linked structure. This behavior contrasts with that observed in other thermoformed materials, which undergo phase changes at higher temperatures. This could offer clinical advantages by allowing disinfection or even precise sterilization of the aligner before and during use. However, further research is needed to ensure that sterilization at elevated temperatures will not negatively impact the aligner's performance. This research highlights thermal disinfection benefits of direct aligners sourced from the *Graphy Inc* manufacturer's website. Unlike thermoformed materials, direct aligners remain stable in hot water, allowing thermal disinfection below 100 °C. This process preserves aligner shape and mechanical properties despite prolonged use and exposure to debris. Shape memory function and thermal disinfection remove the need for a separate storage case, simplifying patient usage, especially during activities like eating. Furthermore, Tera Harz TC-85DAC resin enables single-day orthodontic treatments, reducing manufacturing time and increasing dental laboratory productivity with minimal equipment investment for economic profitability. *Graphy Inc* gives absolute priority to achieving total material transparency. The perfect transparency of the direct aligner makes it virtually imperceptible when worn. Unlike existing materials prone to discoloration, the direct aligner remains resistant to discoloration and easily regains its transparency simply by brushing with toothpaste.

5.5. Limitations and criticism of the discussion

Although this study has made significant contributions, it is essential to acknowledge its limitations and the criticisms that might be raised. Firstly, a crucial limitation of this study stems from the intrinsic novelty of the subject. As an emerging field, research may still be at a preliminary stage, limiting the availability of in-depth data and comprehensive studies. The newness of the subject may result in a lack of existing literature, in-depth analyses and the hindsight required to fully assess the extent of the phenomena studied. This limitation could potentially influence the conclusions and suggests the need for future research to address this shortcoming. It is important to recognize that direct method 3D printing of aligners is an evolving field, and therefore further developments may add new perspectives or correct some of the shortcomings identified in this research. A notable limitation of this study is that although information was collected from manufacturers, the lack of references to specific research articles presents a challenge. The data provided by manufacturers may be subject to potential bias, as it is directly linked to the promotion of their products. The absence of independent and verifiable scientific publications on the specific aspects studied limits the ability to confirm the validity and reliability of the information provided. This limitation highlights the need for caution in interpreting data based solely on information provided by commercial sources, underlining the relevance of independent validation to reinforce the scientific rigor of the study.

5. CONCLUSIONS

The study's conclusion on manufacturing orthodontic aligners by 3D printing highlights promising results while acknowledging some limitations:

-Advantages of 3D Printed Aligners: More consistent forces across the displacement range, improvement in mechanical strength and stability of forces, superior geometric and dimensional precision.

-TC-85DAC and Shape Memory: Transparency. Immersing the aligners in hot water makes them more flexible before insertion, thanks to the shape memory effect, ensuring that they regain their original shape at the normal body temperature of 37°C.

-Challenges with 3D Printing: Thickness deviations and unpredictability in dental movements.

-Obstacles: High cost of TC-85DAC resin, thickness problems, and laboratory flow issues hinder the adoption of this new technique.

In summary, although advances in the manufacture of orthodontic aligners using 3D printing offer promising prospects, further research is needed to overcome the challenges identified and ensure the reliability and clinical effectiveness of these new technologies.

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