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Effect Of Print Angulation On The Accuracy And Precision Of Direct Printed Shape Memory Aligners (Senertek Clear A Resin)

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Abstract:
Background:
The demand for clear aligners has risen due to advances in digital dentistry and patient preference for aesthetic orthodontic solutions. Direct 3D printing of aligners offers greater efficiency than conventional thermoforming methods. However, factors such as print angulation may influence their accuracy and precision. This study evaluates the effect of different print angulations on the dimensional accuracy of 3D-printed aligners using Senertek Clear A resin.
Materials and Methods:
Thirty-nine maxillary aligners were 3D-printed at three angulations (45°, 70°, and 90°) using a Sprintray 3D printer. Post-processing included curing and surface preparation with CAD/CAM spray for scanning. High-resolution scans were obtained using a SHINING 3D intraoral scanner and superimposed on original STL files in Geomagic Control X software to analyze dimensional deviations.
Results:
Print angulation significantly influenced the accuracy of the aligners, with variations observed at different levels of the teeth. Optimal accuracy was noted at specific angulations, while others exhibited minor deviations affecting fit.
Conclusion:
Optimizing print angulation enhances the dimensional accuracy of 3D-printed aligners, improving clinical outcomes. Future research should explore additional factors such as material properties and post-curing techniques to refine aligner fabrication protocols.
Key Word: *3D Printed aligner, CAD/CAM spray, Geomagic control X software, Superimposition.*

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I. Introduction

In recent years, the demand for adult orthodontics has increased significantly due to breakthroughs in dental technology as well as aesthetic preference[1].The simplicity and comfort of contemporary aligners, as well as the health advantages of having a bite that is properly aligned, are responsible for this. Patients are increasingly considering clear aligner therapy, according to the orthodontic industry, as more individuals place a higher value on oral health and appearance[2]. Computer-aided design (CAD) technology can now be used in modern orthodontic offices thanks to recent developments in digital dentistry[3].

Alginate and PVS (polyvinyl siloxane) are two traditional methods of obtaining impressions that have been somewhat marginalized by the innovation of digital impressions[4,5]Reduced patient pain, time savings, clinical process simplification, and the ability to record and save extremely accurate data are just a few of the many benefits that intraoral scanners can provide.By using intraoral scanners, practitioners may now easily manipulate three-dimensional (3D) digital models, which facilitates the essential measurements for precise diagnosis and treatment planning[4,6].Instead of using traditional manufacturing techniques that depend on machining, molding, and subtractive procedures, 3D printers are now used which allows for the layer-by-layer printing of parts.[7]

A technique called rapid prototyping (RP) uses digital data to recreate a three-dimensional (3D) structure. This incredibly flexible additive printing method uses a print head-deposited liquid to repeatedly deposit material "layer by layer" until the product is physically represented[8].

Directly 3D-printed aligners are made layer by layer from digital 3D models, as opposed to the indirect method, which involves thermoforming aligners over models. The majority of 3D printers polymerize resins in vertical, diagonal, or horizontal orientations using a light source. Because fewer layers and lines are required across the labial surfaces of the anterior teeth, horizontal orientation is typically the fastest per aligner. On the other hand, more appliances may be produced in a single print job thanks to vertical printing. Furthermore, the orientation chosen affects how printing supports are distributed. Printing in either a horizontal or vertical position has been shown to be accurate and typically satisfies patient expectations, regardless of the type of 3D printer[9].

Even though 3D-printed clear aligners are becoming more and more common in adult orthodontics, printing procedures are still not standardized. The accuracy, precision, and mechanical strength of the finished product can be greatly impacted by important variables such print angulation, printer type, and material qualities. Nevertheless, not much research has been done to systematically assess the influence of these factors, particularly when it comes to advanced materials like Senertek Clear A resin. It is essential to comprehend how these elements affect the quality of 3D-printed aligners in order to enhance treatment results, streamline manufacturing procedures, and guarantee dependable, consistent performance in various clinical contexts. In order to narrow this gap and offer data-driven insights for creating more efficient protocols in 3D-printed orthodontics, this study is essential.Thus the aim of the study is to compare the accuracy and precision of 3D-printed clear aligners at various angle setting.

II. Material And Methods

This prospective comparative study was carried out on patients of Department of Tagore dental college and hospital,Vandalur,Chennai from July 2024 to October 2024. A total 13 STL files from previously treated patients were used.

Study Design: Prospective open label observational study
Study Location: This study done in Department of Tagore dental college and hospital, Vandalur, Chennai.
Study Duration: July 2024 to October 2024.
Sample size: 13
Sample size calculation: The sample size was calculated using G Power software to ensure adequate statistical power. A priori power analysis was conducted for a one-tailed t-test, targeting an effect size (dz) of 0.5, with an alpha (α) level of 0.05 and desired power of 0.49. This analysis determined a noncentrality parameter (δ) of 1.80 and a critical t-value of 1.78, with 12 degrees of freedom. The total sample size needed was calculated to be 13, achieving an actual power of 0.52.

Procedure methodology

In the study, 3D-printed maxillary aligners were created using STL files from patients who had previously received treatment. Using CHITUBOX software, these STL files were processed and made ready for printing. The aligners were set up at three distinct print angulations: 45°, 70°, and 90°. Senertek Clear A resin was used for printing utilizing the Phrozen ks 3D printer[[10](Fig 1).

Fig 1: Senertek Clear A Resin And Phrozen Ks 3D Printer[
Fig 2: Printed Shape Memory Aligners At 90,° 70°, 45° Respectively

To guarantee uniform surface detailing and quality, the printing process was carried out with a layer resolution of 100 µm. Each angulation group was given 13 of the 39 maxillary aligners that were printed(Fig 2).

After printing, the supports in the aligners are removed and the aligners were centrifuged and post-processed, which included curing in glycerin to improve their dimensional stability and mechanical qualities(Fig 3).

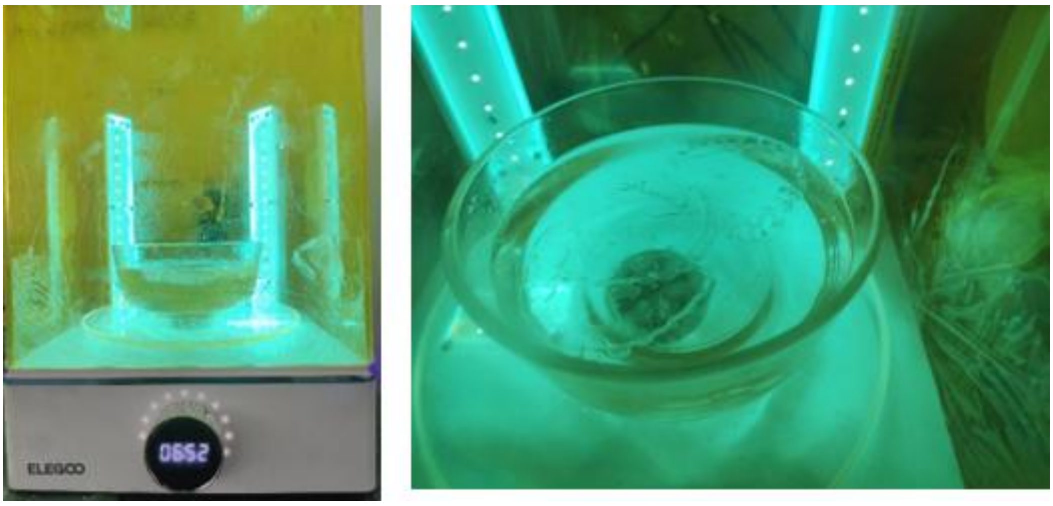

Fig 3: Processing and Curing

After curing, the internal surfaces of the aligners were uniformly sprayed with a CAD/CAM spray to improve scan quality by reducing reflection and boosting surface recognition during the scanning process[10].

The internal surfaces of the printed aligners were then scanned using the SHINING 3D intraoral scanner, capturing high-resolution digital impressions. These scans were converted to STL file format for additional investigation. Three bilateral landmarks located at the incisal/occlusal portions of teeth, the mid-crown level, at the gingival margins are used for superimposition. The generated STL files, as well as the original maxillary STL files from the patients, were loaded into Geomagic Control X software for superimposition and analysis[10].

To assess the dimensional accuracy and overall precision of the aligners, a detailed superimposition process was performed. This involved aligning the STL files based on three bilateral landmarks at predefined levels: the incisal/occlusal portions of the teeth, the mid-crown level, and the gingival margins. The superimposition allowed for a comparative analysis of the printed aligners against the original digital designs.

III. Result

Superimposition analysis was performed in Geomagic Control X software by comparing the patient's original STL files with aligners printed at 45°, 70°, and 90°(Fig 4a).The analysis revealed varying degrees of discrepancies across different regions of the aligners(Fig 4b).

Aligners printed at 45° exhibited noticeable discrepancies in the premolar and molar regions, indicating deviations from the original STL file in these areas. Aligners printed at 70° exhibited discrepancies primarily in the incisor region, while those printed at 90° demonstrated discrepancies in the incisor, premolar, and molar regions.

Among the three tested angulations, the aligners printed at 70° showed the highest level of dimensional accuracy, showing minimal deviation from the original STL files. Aligners printed at 45° showed slightly more discrepancies than those printed at 70°, but they still maintained a good level of accuracy. While some deviations were noticeable, especially in the premolar and molar regions, the overall fit remained fairly reliable, making 45° the second-best option.

In contrast, aligners printed at 90° had the most significant variations, with discrepancies appearing across various regions, including the incisors, premolars, and molars. This suggests that printing aligners at 90° leads to the greatest deviations from the original STL file, which could affect fitness of the aligners

These findings indicate that a 70° print angulation offers the best accuracy and fit, minimizing discrepancies in key areas. The 45° angulation is a next alternative, with slightly higher but still manageable deviations. However, the 90° angulation results in the most inaccuracies, making it the least suitable option for producing well-fitting shape memory aligners.

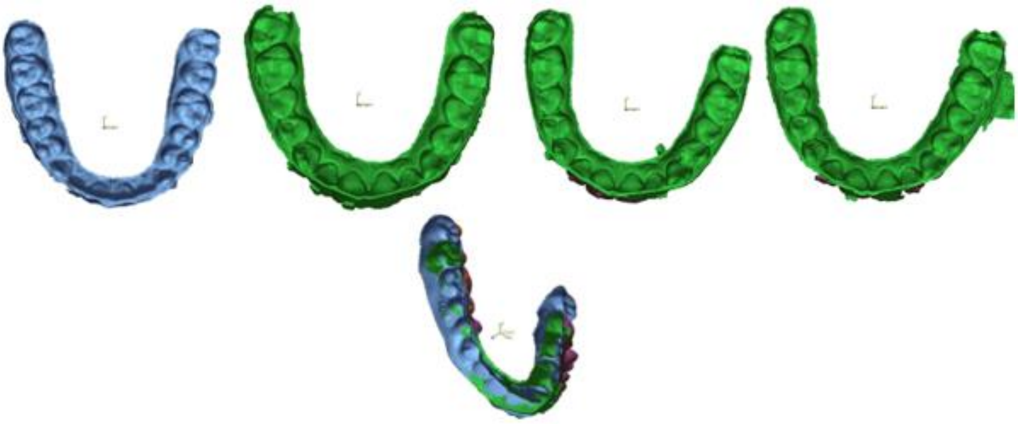

Fig 4: 4a.STL files of patient and aligners printed at three different angulations 45°, 70°, and 90°; 4b. Original superimposed colour mapping using Geomagic Control X software.

IV. Discussion

A common oral health issue that affects both orofacial function and long-term psychosocial well-being is malocclusion. The goal of orthodontic treatment is to improve mastication and attractiveness while correcting malocclusion and craniofacial skeletal abnormalities.[11]

However, the impact of orthodontic appliances on the oral microbiota and periodontal tissues must be recognized. Inserting orthodontic appliances modifies the structure of plaque biofilm, which has a substantial impact on dental and periodontal health[12].

Removable appliances provide a solution by making patients' dental hygiene practices easier. Adult patients seeking orthodontic treatment have increased recently, and they are expecting more comfortable and visually acceptable options than standard fixed equipment[13].

Recent advancements in digital dentistry have significantly transformed orthodontic practices, particularly with the integration of 3D printing technologies. The ability to directly fabricate orthodontic appliances, such as aligners, using 3D printing offers enhanced efficiency and customization compared to traditional methods. However, the accuracy of these 3D-printed appliances is influenced by various factors, including print orientation. For instance, a study by McCarty et al. demonstrated that print orientation and ultraviolet curing duration significantly affect the dimensional accuracy of 3D-printed orthodontic clear aligner designs[14]. Their findings suggest that optimizing these parameters is crucial for producing clinically effective aligners.

In retainers, Cole et al. evaluated the fit of 3D-printed retainers compared to thermoformed retainers and found that while thermoformed retainers had slightly better accuracy, 3D-printed retainers still fell within clinically acceptable limits. Their study highlighted that deviations in 3D-printed retainers were slightly higher but did not significantly impact clinical function.Applying this concept to aligners, our study assesses how print angulation affects the accuracy of 3D-printed aligners[15].The findings highlight the influence of print angulation on the dimensional accuracy and surface detail of the aligners. The use of a high-resolution 3D printing system with a 100 µm layer thickness ensured a reliable baseline for assessing these parameters.

The incorporation of three distinct angulations (45°, 70°, and 90°) allowed for a comprehensive comparison, demonstrating the effect of orientation on the final printed outcome. Print angulation directly impacts layer adhesion, structural integrity, and post-curing deformation, which are critical factors in achieving clinically acceptable aligners. The use of a CAD/CAM spray and SHINING 3D intraoral scanner ensured precise digital scans of the internal surfaces, enabling accurate superimposition in Geomagic Control X software.

The superimposition methodology, utilizing bilateral landmarks at the incisal/occlusal, mid-crown, and gingival levels, provided a robust framework for evaluating deviations between the original STL designs and the printed aligners. This approach ensures a detailed assessment of both accuracy (how closely the printed aligners match the digital design) and precision (reproducibility across multiple aligners).

The study underscores the importance of optimizing print orientation to minimize discrepancies and improve the overall fit of aligners. Such improvements in accuracy are critical for clinical applications where the aligners' fit impacts the effectiveness of orthodontic treatments.Future studies should investigate additional aspects such as resin characteristics, curing methods, and alternative printing technologies to further optimize the reliability of 3D-printed aligners. Previous studies have highlighted similar outcomes. For example, Williams et al. explored the effect of print angulation on the accuracy of 3D-printed retainers and found that accuracy at cusp tips and incisal edges remained clinically acceptable across all tested angulations, while smooth surfaces exhibited deviations that occasionally surpassed acceptable thresholds[16]. Their work underscores the importance of optimizing print angulation to balance time efficiency and material usage with accuracy.

Additionally, research by Camenisch et al. investigated the influence of printing orientation on the mechanical properties of 3D-printed aligners[9]. Their results indicated no substantial differences in mechanical strength across various print orientations. This suggests that while angulation may not heavily impact the durability of aligners, it plays a significant role in achieving accurate fit and surface quality.

The findings of this study are consistent with the conclusions drawn by Williams et al. and Camenisch et al., highlighting that while mechanical properties may remain stable, print angulation directly affects the dimensional accuracy and clinical fit of 3D-printed appliances. This reinforces the need for careful selection of print orientations to improve clinical outcomes.

Future research could focus on evaluating additional parameters, such as the influence of different resin types, post-curing conditions, and patient-specific aligner designs, to further refine the 3D printing process for orthodontic applications. Optimizing these variables will enhance both the accuracy and practicality of 3D-printed orthodontic devices, ensuring better patient outcomes in clinical practice.

V. Conclusion

Superimposing the STL files of aligners printed at 3 different angulation showed that printing angulation affects the accuracy of the aligner.

The aligners printed at 70° showed least discrepancies.This is followed by aligners printed at 45°.The aligners printed at 90° showed maximum discrepancies.

This limitation of the study is that the sample size of the study is small and it did not evaluate the functional performances of aligners.

Future research could focus on additional factors such as functional performance in clinical setting.

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