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Influence Of Print Angulation On The Accuracy And Precision Of Direct-Printed Shape Memory Aligners (Graphy Inc, Seoul)

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Abstract:
Background*:*
Three-dimensional (3D) printing has revolutionized orthodontics by enabling the direct fabrication of clear aligners, offering a more efficient and customizable alternative to traditional thermoformed aligners. To ensure the clinical effectiveness of 3D-printed aligners, it is essential to evaluate their accuracy in relation to different print angulations. Superimposing printed aligners onto a reference digital model using 3D analysis software allows for precise measurement of deviations. This study aims to assess the effect of print angulation on the dimensional accuracy of direct-printed maxillary aligners by utilizing an intraoral scanner and Geomagic Control X software for detailed analysis.
Materials and Methods*: Using a stereolithography (SLA) 3D printer and a clear resin (Graphy Inc., Seoul). A total of 39 aligners will be printed at three different angulations (45°, 60°, and 90°) with a resolution of 100 µm. Post-processing will be carried out following the manufacturer's instructions. The internal surfaces of the aligners will be sprayed with CAD/CAM spray and scanned using a SHINING 3D intraoral scanner. The scans will be processed and converted into STL files. For accuracy assessment, the STL file of the maxillary dental arch will be imported into Geomagic Control X software, where three bilateral landmarks—at the incisal/occlusal portion, mid-crown level, and gingival margin—will be used for superimposition.*
Conclusion: *Our study confirms that print angulation impacts the dimensional accuracy of direct-printed aligners. Among the tested angles, 70° demonstrated the highest precision with minimal deviation, making it the optimal choice for accurate and well-fitting orthodontic aligners.*
Key Word: *3D printing, stereolithography (SLA), orthodontic aligners, print angulation, dimensional accuracy, clear aligners, Geomagic Control X, intraoral scanning, CAD/CAM,*

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I. Introduction

Three-dimensional (3D) printing is transforming dentistry, and it is even being used to correct malocclusion. Clear, individualized, removable aligners are a viable alternative to traditional orthodontic gear, providing a more comfortable and effective solution for patients. Including better dental hygiene and attractiveness during therapy. Fabrication of orthodontic aligners directly via 3-dimensional (3D) printing has the potential to increase aligner production efficiency compared to traditional workflows; however, tunable aspects of the 3D-printing process may affect the dimensional fidelity of the fabricated appliances[1].

The foundation for 3D systems were laid by Charles Hull in 1986, when he launched a Stereolithographic 3D printer[2].

Stereolithography (SLA), FDM, digital light processing (DLP), polyjet photopolymer (PPP), and selective laser sintering (SLS) are the most widely utilized 3D printer types in orthodontics[3]. The first kind of 3D printer to be developed was SLA[4]. An ultraviolet laser beam is first applied to the liquid photo-curable resin to start the production process.

Three-dimensional models will transfer to the printer while defining their surface geometry using triangles. Its uniform format, open-source code, and ease of use make it compatible with nearly all CAD and 3D printers[5].

This study aimed to evaluate the differences in the effect of print angulationon the precision and accuracy of direct printed shape memory aligners{Graphy inc,Seoul}.

II. Material And Methods

This prospective crosssectional study was carried out on patients of Department of general Medicine at Department of orthodontics, at Tagore dental college and Hospital, vandalur , chennai fromJULY 2024 TO NOVEMBER 2024. A total 13 adult subjects were for in this study.

Study Design: cross sectional study

Study Location: This was the study done in Department of orthodontics, at Tagore dental college and Hospital, vandalur, chennai.

Study Duration: November 2014 to November 2015.

Sample size: 13 patients.

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

This study was carried out in the Department of Orthodontics at Tagore Dental College. STANDARD TESSELLATION LANGUAGE (STL) files from previously treated patients were collected for this investigation. A total of 39 maxillary aligners were manufactured using a stereolithography (SLA) 3D printer (Form 2; Formlabs, Somerville, MA) and a clear resin (Graphy inc, Seoul) at three print angulations (n=13)[6]. There is no recommended angulation when constructing aligners.

We printed with a resolution of 100 µm and centrifuged for 5-6 minutes at 500-600 rpm[7]. The entire uncured resins are removed using centrifugation. Aligner had form memory qualities, and it was yellow, sticky, and extremely soft. After that, we stored aligners for UV curing polymerization, and the outer shell of the aligner was cured in the nitrogen chamber. After curing, all of the potential properties of aligners were active. We employed the Tera Herz curing unit [7,8].

Figure 1: Nitrogen chamber

Figure 2: Uniz NBEE Resin-Based High Speed LCD 3D Printer

After printing, the aligners inside surfaces were sprayed with CAD/CAM spray. A SHINING 3D intraoral scanner was used to capture the intaglio of the direct printed aligners. Scanning program processes the scans and converts them to STL format.

The STL file of the maxillary dental arch was imported into Geomagic® Control XTM metrology software and superimposed on the STL files of the maxillary dental arch by using the best-fit alignment algorithm, which superimposes both meshes with the shortest distance between every data point[8].

The midpoint on the central groove of the second premolars (PG), the mesio-lingual cusp points of the first molars (ML), and the mid-incisal edge point of the lateral incisors (MI) are three bilateral landmarks found at the incisal/occlusal parts of teeth. The zenith point of the central incisors (GZ), the highest point on the palate-gingival margin of the first premolars (HP), and the central point on the gingival margin of the first molars (MC) are the three bilateral landmarks at the gingival margins. Three bilateral landmarks at the mid-crown level, specifically the buccal pits of the second molars (BP), the midpoint on the palatal surfaces of the first premolars, and the functional axis of clinical crown points of the central incisors (FACC) these points were used forsuperimposition[8].

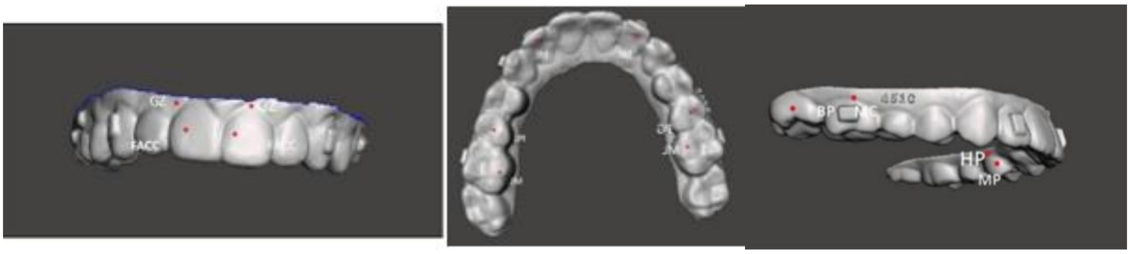

Figure 3: anatomical landmarks of reference model

III. Result

We fabricated direct-printed orthodontic aligners using three different print angulations: 45°, 70°, and 90°. The objective was to assess how print orientation influences the dimensional accuracy of the aligners, as variations in angulation can lead to inconsistencies that may affect the fit and effectiveness of the final appliance.

Upon evaluation, we observed distinct differences in dimensional accuracy based on the chosen angulation. Aligners printed at a 45° angulation exhibited minor inconsistencies, primarily in the molar and premolar regions. These deviations, although present, were relatively small and did not significantly compromise the overall fit of the aligners. This suggests that a 45° angulation is a viable option, though slight variations may occur in posterior teeth.

Aligners printed at a 70° angulation demonstrated a slight discrepancy in the incisor region, while the overall fit remained more consistent in other areas, including the premolars and molars. The minimal deviation observed at this angulation indicates that 70° offers a balanced and stable orientation for achieving a precise fit. This could be attributed to improved support structures during the printing process, reducing material distortion and maintaining the integrity of the aligner's shape.

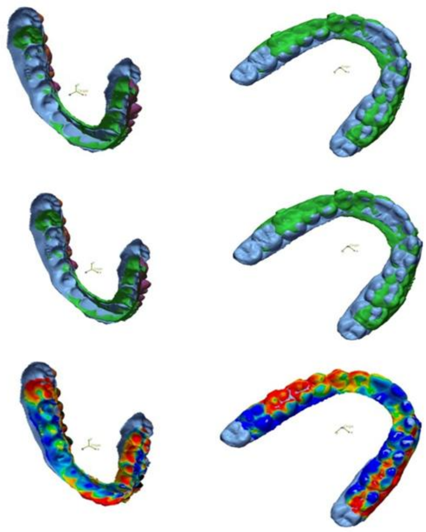

Figure 4: colour mapping using Geomagic Control X software.

In contrast, aligners printed at a 90° angulation exhibited the most significant dimensional variations, with substantial discrepancies observed in multiple regions, including the incisors, premolars, and molars. The increased deviation at this angulation suggests that a more vertical print orientation may negatively impact dimensional accuracy, likely due to increased gravitational effects, material shrinkage, or distortions occurring during post-processing. These findings indicate that 90° angulation may not be the most suitable choice for fabricating accurate and well-fitting aligners.

When comparing the overall dimensional accuracy of aligners across these three angulations, our findings suggest that the 70° angulation produces the most precise and reliable aligners. This angulation resulted in minimal deviation, making it the optimal choice for direct 3D-printed orthodontic aligners in terms of accuracy, fit, and clinical effectiveness. By selecting the appropriate print angulation, clinicians and dental technicians can enhance the performance of direct-printed aligners, ensuring a better fit and improved treatment outcomes for patients. Future studies should explore additional factors, such as resin composition, layer thickness, and post-processing methods, to further refine the dimensional accuracy of 3D-printed orthodontic appliances.

IV. Discussion

The first orthodontic aligners debuted around the close of the 20th century and early in the twenty-first century. This breakthrough invention was primarily motivated by patient demand for more comfortable and less intrusive orthodontic procedures for their teeth. Indeed, since their inception as a treatment option in orthodontics, aligners have grown in popularity, with an increasing number of patients having orthodontic treatment with them. The use of aligners in orthodontics has caused a paradigm change in dentistry, encouraging patients of all ages, including older adults, to seek treatment for their malocclusion[9].

Transparent aligners used in series, or a set of tooth positioners made using exact impressions or digital scans of the patient's teeth, have become more and more popular due to the drawbacks of traditional treatment and patients' growing desire for alternative "invisible" treatments. Each aligner produces a different force to gradually achieve the desired dental alignment[10].

The principal benefits are the clear translucent appearance of the devices and the possibility to remove them when eating and keeping oral hygiene, coupled with improved comfort and simplicity of usage[11]. Compared to traditional fixed braces and archwires, clear aligner therapy is shorter and requires less chair-side time[12].

In their 2023 study, Grassia et al. evaluated the accuracy—specifically trueness and precision—of 3D-printed orthodontic models derived from both crowded and spaced dentition, intended for clear aligner production. They utilized four different 3D printers employing various technologies and market segments. The study found that models produced using SLA printers demonstrated lower trueness errors compared to those created with DLP/LCD technologies. Additionally, the entry-level printer exhibited the highest trueness error. These findings underscore the influence of 3D printer technology and the anatomical characteristics of dental arches on the accuracy of orthodontic models[13].

The Tera Harz TC-85DAP 3D Printer UV Resin was used to create the direct-printed aligners used in this investigation utilizing SprintRay Pro. The SprintRay Pro is a DLP printer with a high resolution structure, sharp edges, and a faster speed than laser exposure formats[14]. A comparative study of orthodontic aligners made by several 3D printers revealed that the kind of 3D printer used to generate the aligners affected their mechanical characteristics[15]. The device would be less brittle but more prone to wear because SprintRay Pro had the lowest Martens hardness, indentation modulus, and elastic index. Furthermore, compared to aligners made with liquid crystal display printers, those made with DLP printers exhibited inferior mechanical qualities. Different 3D printers may create the output with varying degrees of precision, even if the impact of mechanical qualities on clinical efficacy has not been studied[16].

When comparing the fit of 3D-printed and thermoformed retainers, Cole et al. discovered that although the former had marginally higher precision, the latter still fell within clinically acceptable bounds. Their research showed that while 3D-printed retainer abnormalities were somewhat more common, they had no discernible effect on clinical function. Our work evaluates the impact of print angulation on the precision of 3D-printed aligners by applying this idea to aligners[17]. The results demonstrate how print angulation affects the aligners' surface detail and dimensional accuracy. A trustworthy baseline for evaluating these characteristics was guaranteed by the use of a high-resolution 3D printing machine with a layer thickness of 100 µm.

Three different angulations (45°, 70°, and 90°) were included to enable a thorough comparison and show how orientation affects the printed result. Print angulation has a direct effect on post-curing deformation, layer adhesion, and structural integrity—all of which are essential for producing aligners that are clinically acceptable. Accurate superimposition in Geomagic Control X software was made possible by the exact digital scans of the inside surfaces obtained using a CAD/CAM spray and a SHINING 3D intraoral scanner.

A strong foundation for assessing differences between the original STL designs and the printed aligners was offered by the superimposition technique, which made use of bilateral landmarks at the incisal/occlusal, mid-crown, and gingival levels. This method guarantees a thorough evaluation of precision (reproducibility over numerous aligners) and correctness (how closely the printed aligners match the digital design)[18].

The study emphasizes how crucial it is to maximize print orientation in order to reduce inconsistencies and enhance aligner fit overall. For clinical applications where the fit of the aligners affects the efficacy of orthodontic treatments, such accuracy gains are essential. To further maximize the dependability of 3D-printed aligners, future research should look into other factors like resin properties, curing techniques, and other printing technologies. Similar results have been noted in earlier research.

Similar to this study Koeing et al showed that compared to the thermoformed aligners examined in this study, direct printed aligners were more accurate and truer[8].

V. Conclusion

Our study found that print angulation significantly affects the dimensional accuracy of direct-printed aligners. While the 45° and 90° angulations exhibited varying degrees of discrepancies, the 70° angulation proved to be the most precise, with minimal deviation. Therefore, 70° is the optimal print angulation for achieving accurate and well-fitting orthodontic aligners

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