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YEDİTEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF ORTHODONTICS

EVALUATION of 3D PRINTERS ACCURACY in PRINTING ATTACHMETS of CLEAR ALIGNERS

MASTER THESIS

Dt. AMMAR QAWASMI

ISTANBUL - 2022

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APPROVAL

This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dated …………… numbered……………..

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Director of Institute of Health Science

DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

11.03.2022

Dt. Ammar Qawasmi

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LIST OF ABBREVIATIONS and SYMBOLS

3D	: Three-dimensional
CAD	: Computer-Aided Design
CAD/CAM	: Computer-aided design/computer-aided modeling
PVS	: Polyvinylsiloxane
PET-G	: Polyethylene terephthalate glycol
PVC	: Poly-vinyl chloride
CAT	: Clear aligner therapy
NITI	: Nickel Titanium
TADs	: Temporary anchorage devices
F/M	: Force/Moment value
IOS	: Intra-oral scanner
EOS	: Extra-oral scanner
2D	: Two-dimensional
LED	: Light emitting diode
POI	: Points of Interest
PT	: Passive triangulation
AT	: Active triangulation
STL	: Standard Tessellation Language

dpi	: dots per inch
µm	: micrometer
SLA	: Stereolithography Apparatus
DLP	: Digital Light Processing
FDM	: Fused Deposition Modelling
SLS	: Selective Laser Sintering
SLM	: Selective Laser Melting
MJ	: Material Jetting
MJM	: Multi-Jet Modelling
BJ	: Binder Jetting
AM	: Additive Manufacturing
UV	: Ultraviolet
ABO	: American Board of Orthodontists
G-CAD	: Generic-Computer Aided Design
D-CAD	: Dedicate-Computer Aided Design

ABSTRACT

Qawasmi, A. (2022). Evaluation of 3D Printers Accuracy in Printing Attachments of Clear Aligners. Yeditepe University Institute of Health Sciences, Department of Orthodontics, MSc Thesis, Istanbul. The aim of this study is to evaluate and compare the accuracy of different attachments' geometries printed by Stereolithography Apparatus (SLA) and Digital light processing (DLP) 3D printing techniques measuring volumetric changes using 3D superimposition analysis. Two Intraoral scans of patients treated at Yeditepe Dental Faculty and Hospital-Department of Orthodontics were selected randomly from the archive and were prepared using the Ortho Analyzer 3D software (3Shape A/S, Copenhagen, Denmark). Six attachments with different geometries were designed using Rhinoceros 3D Software version 7 (Robert McNeel & Associates, Seattle, USA), and were imported to the digital models to form the control group. The models were then printed using two different printers (SLA and DLP). Thereafter, the models were scanned with TRIOS intraoral scanner (3Shape, Copenhagen, Denmark) to result in two digital model sets (each upper and lower, total n=8) according to the printer's type. Each digital model set was divided into six subgroups (study groups) according to the shape of the attachments. The examined attachments were then superimposed to the control group using Geomagic Control X software (3D Systems, South Carolina, USA) to measure the volumetric changes by means of RMS mean. Statistically significant differences between printing techniques were present ($p<0.05$) with a significantly lesser RMS mean value for the SLA printer. Moreover, significant differences were shown between attachment groups ($p<0.05$) with the RMS mean of the Ellipsoid group being significantly lower than that of the Horizontal Rectangular and Optimized Rotation groups. SLA printers may be recommended for clear aligners' fabrication. The geometry of the attachments plays a role in the resultant printing accuracy. Along the same, the orientation of the attachments may be more influential. Nevertheless, the final orientation of the attachments in relationship to printing platform is unpredictable as it may be affected by the inclination, rotation and tipping of the teeth on that the attachments were placed, as well as the distance of the attachment to the long axis of the tooth along with the arch curvature.

Key Words: three-dimensional printing, clear aligners, clear aligners' attachments, three-dimensional analysis, printing accuracy.

ÖZET

Qawasmi, A. (2022). Üç Boyutlu Yazıcıların Şeffaf Plak Ataşmanlarını Baskı Doğruluğunun Değerlendirilmesi. Yeditepe Üniversitesi, Sağlık Bilimleri Enstitüsü, Ortodonti Anabilim Dalı, Master Tezi, İstanbul.

Bu çalışmanın amacı Stereolitografi (SLA) ve Dijital Işık İşleme (DLP) üç boyutlu (3B) yazıcı teknikleri ile oluşturulan farklı ataşman şekillerinin üç boyutlu üstüste çakıştırma analizi ile hacimsel değişim ölçümlerinin değerlendirilmesi ve karşılaştırılmasıdır.

Yeditepe Dişhekimliği Fakültesi Ortodonti Anabilim dalında tedavi gören hastaların ağıziçi dijital tarama arşivinden randomize olarak ikisi seçilmiş ve Ortho Analyzer 3D arayüz programı (3Shape A/S, Kopenhag, Danimarka). kullanılarak işlenmiştir. Rhinoceros 3B arayüz programı 7 versiyon (Robert McNeel & Associates, Seattle, ABD) ile altı farklı şekile sahip ataşman tasarlanmış ve dijital modele dönüştürülerek kontrol grubu oluşturulmuştur. Dijital modeler iki farklı yazıcı (SLA ve DLP) kullanılarak basılmıştır. Modeller TRIOS ağıziçi tarayıcı (3Shape A/S, Kopenhag, Danimarka) ile taranmış ve her yazıcı için 4 dijital model seti (üst ve alt olmak üzere, n=8) elde edilmiştir. Her dijital model seti ataşman şekline göre altı alt gruba (çalışma gruplarına) ayrılmıştır. Ortalama RMS ortalaması olarak hacimsel değişimlerin ölçülebilmesi için Geomagic Control X arayüz programı (3B Sistemler, Güney Karolina, ABD) kullanılarak incelenen ataşmanlar kontrol grubu üzerine üstüste çakıştırılmıştır. Yazıcı teknikleri arasında istatistiksel belirgin farklar tespit edilmiştir ($p<0.05$). SLA yazıcının RMS ortalama değerleri anlamlı düzeyde daha az olarak belirlenmiştir. Ataşman gruplarının karşılaştırılmasında da anlamlı farklar bulunmuştur ($p<0.05$). Elipsoid grubun RMS ortalamaları Yatay Dikdörtgen ve Optimal Rotasyon grubundan anlamlı düzeyde daha az olarak tespit edilmiştir. Şeffaf plaklarn üretiminde SLA yazıcılarının kullanımı önerilebilir. Boyutsal baskı doğruluğunu ataşman şekilleri etkilemektedir ancak ataşmanların oryantasyonu daha fazla önem arz etmektedir. Ataşmanların yazıcı platformuna göre son oryantasyonu ataşmanların konumlandırıldığı dişlerin inklinasyonuna, rotasyonuna ve devrilmesine, ataşmanın dişin uzun aksına olan mesafesine ve dişin ark içindeki konumuna bağlı olarak değişebileceği için öngörülebilir olamamaktadır.

Anahtar Kelimeler: üç boyutlu yazıcı, şeffaf plaklar, şeffaf plak ataşmanları, üç boyutlu analiz, boyutsal baskı doğruluğu

1. INTRODUCTION AND PURPOSE

An aesthetic smile is an integral part of an attractive face, hence, the demand for an aesthetic dental therapy has increased nowadays (1,2). Individuals are becoming increasingly conscious about how they look and the appearance of their teeth, and seek corrective and enhancement procedures even for minor aesthetic aberrations. This has fueled a sharp increase in aesthetic treatments in both developed and developing countries. Furthermore, patients are requesting minimally invasive rather than traditional and often protracted therapies.

Orthodontic therapy offers a minimally invasive approach for correcting a variety of aesthetic anomalies and malocclusions (3). However, traditional therapy with fixed brackets and wires has become objectionable due to its non-aesthetic appearance and its associated complications of compromising periodontal health and the development of white spot lesions (4), the thing that has limited the preference for other aesthetic alternatives orthodontic approaches such as ceramic brackets and lingual metal brackets that were introduced to address the aesthetic concern of the patients in the first place. In addition to their formerly mentioned drawbacks, these aesthetic alternative approaches were presented with other challenges from both the patient and the orthodontist perspective, to mention some but not limited to; alteration in speech and difficulty in swallowing as recalled by lingual brackets' patients (5–7), difficulty of removal with ceramic brackets (8), However, the advances in orthodontics haven't stop there, and further attempts to address many of these concerns have resulted in a revolution in orthodontics by getting advantage of some of the introduced digital technologies in dentistry.

From digital scanning that has replaced conventional impression taking and plaster dental models, to digital treatment planning and the ability to program tooth movements and design the final occlusion in a software program, orthodontics has led the scene to be among the first to incorporate digital technology in its daily workflow. Recently, merging these technologies with 3D printing technology and Computer-Aided Design (CAD) software, has led to the emergence of a new generation of digital orthodontics that gave rise to a more esthetic and customized orthodontic appliances capable of fulfilling the characteristics of an ideal orthodontic appliance of being esthetic, hygienic, and comfortable as well as its capability of correcting the malocclusion in the shortest time frame possible. And from this vision has emerged the philosophy of clear aligner therapy (9,10).

Clear aligner therapy sector constitutes the highest growing rate in the orthodontic market (11). Their preference among patients and orthodontics goes back to them being nearly invisible and removable rendering them more hygienic and thus reducing the risk of developing decalcifications and carious lesions often seen with conventional fixed orthodontic appliances (12–14).

To date, aligners have been consisted of three generations; the first generation solely relied on the aligners to achieve planned tooth movement, and no auxiliary feature was utilized. In the second generation, the manufacturers started to get help from the attachments by inserting composite buttons. Until this limit, clear aligners had failed to convince the orthodontic community of being able to replace the conventional fixed appliances. Finally, in the third generation, the designing and placement of attachments was programmed automatically by specialized software dictated by the type, magnitude and direction of the desired movement customized to move an individual tooth (15,16). This customization has brought about more predictability of teeth movements specially when complex movements such as root movements, extrusion and de-rotation are planned. Also, indentations pressure points and power ridges were inserted to improve root torque movement (17). This customization has led to better outcomes regarding the final orthodontic treatment results (16).

Such attachments are first bonded passively via a template and they are not fully engaged after insertion of the first aligner. During the treatment and by constant utilization of aligner by the patient, the attachments progress the tooth movement and finally fit the aligner slot (18).

Today, it is clearly understood that the process of aligner fabrication is a technique sensitive process. Similar to any other phase incorporated in the process of aligners fabrication, a precise construction of the attachments with the appropriate geometry, size and location is also mandatory (15). Attachments are first designed and programmed in the specialized software that simulates the exact size, shape and location of the attachments on a digital dental model through the whole period of treatment, to be then transferred into physical printed model using three-dimensional (3D) printing technology.

In the literature, attachments have been evaluated regarding size, shape, and location, and how does each of these factors serve in achieving the optimal use of aligners (17,19–22). But when it comes to the employment of 3D printing in orthodontics, only limited number of studies have addressed the different printing techniques with various printer's specifications (23–28). However, all of them have only approached the study models, and to the best of our knowledge, no study has examined the impact that different printing techniques may have on the accuracy of the printed attachments. Thus, the aim of this study is to compare the efficiency of two of the most commonly used 3D printing technologies used in dentistry to produce clear aligner's attachments that are accurately resembling their corresponding digital attachments in three dimensions.

2. LITERATURE REVIEW

2.1. Aesthetic Orthodontic Approaches

Aesthetics is one of the main concerns of individuals nowadays. The sense of attractiveness may be pleasurable, eliciting a favorable response, whereas less attractive features may inspire sentiments of sadness and sorrow (29). This perception has been enforced by cultural messages in media and billboards targeting different age groups. Children learn from cartoons that dump villains have less aesthetic faces and crooked teeth whereas good looking heroes have beautiful teeth. Television commercials suggest that good looks are associated with sociability, popularity and interpersonal ease whereas the opposite image stands for losers. Models with perfect faces and teeth on billboards also provoke the dissatisfaction with facial and dental appearance (30). Several studies have addressed the different impressions that can be made by different dental appearances. Sergl et al.(31) have monitored a substantial difference of social impressions among different dental conditions and malocclusions and the sensitivity of laypersons to variances in dental appearance by means of attractiveness score. Along the same, Shaw and his colleagues (31,32) took a similar approach and produced a widely cited research on the determinants of dentofacial appearance on the formation of social impressions by peers and adults. Children with normal occlusion were seen to be more attractive than those with other problems by their classmates, and they were thought to be more appealing as friends. From perspective of adults, the results of physical attractiveness were the same, as well as social acceptance, which will be reflected on the likability of getting a job (32). In a more recent investigation, faces with less noticeable dental disharmonies, such as median diastema, crowding, and protruding incisors, were presented to Finnish University students (33). The judgments according to 11 characteristics were analyzed and resulted in three dimensions such as beauty and success, personal virtue, and social capability. The results of the analysis of the assessments based on 11 qualities resulted in three dimensions: beauty and success, personal virtue, and social capacity. On the first factor, test faces with diastemas and crowding were rated less esthetic than those with typically looking teeth, although no differences in personal virtue and social capability were detected. These findings, too, are consistent with the findings of the previous meta-analysis on impression formation (34).

Seeking orthodontic treatment to match the cultural standards of an attractive smile was found to solve this cultural dilemma of beauty, but in the other hand, it was found to elicit another appearance-related conflict, were the patient had to live with a metallic smile for a considerable duration of treatment. Not so long ago, the demand for esthetic orthodontic treatment modalities especially among adult patients has been increased (1,2).

Aesthetic orthodontic approaches comprehend replacing conventional buccal metal bracket and wires with the use of ceramic brackets, lingual orthodontic techniques and clear aligner therapy. In a 2009 survey, the British Lingual Orthodontic Society reported that 72 percent of people had never heard of the phrase "invisible orthodontics."(35) When asked, 90% of respondents think aesthetic appliances are appealing and acceptable, but just 55% think stainless steel bracket systems are attractive and appropriate (36). Many people have sought orthodontic treatment since the advent of aesthetic ceramic brackets in 1986, knowing that the aesthetic braces are less noticeable and more socially acceptable. Even if the brackets are tooth-colored, the elastics that keep the archwire in place might discolor throughout treatment, even if they are replaced on a regular basis. At first, orthodontists may use tooth-colored archwires, which are also quite attractive, but in the latter phases of therapy, a metal archwire is frequently required. Furthermore, aesthetic brackets can achieve high bond strength, which can make debonding difficult, causing enamel damage (8).

On the other hand, the suggestion that orthodontic appliance can be placed behind the teeth was tempting to the patients from aesthetic perspective. However, patients do experience some discomfort with lingual appliances, such as distorted speech, tongue pain, difficulties maintaining oral hygiene, and food sticking between brackets (5). t has also been reported that it changes the morphology of the lingual surface and produces tongue limitations, resulting in difficulties speaking and chewing and biting (6,7). The onset of pain has been found to be earlier with lingual compared to labial appliances (37). However, modern lingual appliance systems that are custom designed to match an individual lingual tooth surface might integrate a lower bracket profile, which has been found to lessen this unpleasant feeling (38).

With the advent of the 20th century and the technological advancements it witnessed, this led to the emergence of a new revolutionary technology in orthodontics.

This technology gained its popularity due to the fact that it meets the aesthetic requirements of this era, and hence comes the name of clear aligners. In addition of being the most aesthetic among all other orthodontic treatment modalities; patients find clear aligners relatively comfortable for being removable and to bring about less pain, therefore, they have consistently endorsed them(39). In the original feasibility study, Vlaskalic and Boyd(40) reported that 100% of the patients would select clear aligner therapy over traditional fixed orthodontic therapy with braces. The fact that clear aligners are removable has facilitated the maintenance of good oral hygiene in clear aligners' users. Maintaining a good periodontal health and less white spot lesions became easier to obtain during the treatment as well(12–14,41). However, this approach has some challenges to obtain satisfactory treatment outcomes. Firstly, and due to the removability of the aligners, patient's motivation has created a challenge to the orthodontist, and a good case selection regarding patient compliance is mandatory(17,35,39). In addition to this, it was found to be challenging to achieve some tooth movements using this system, and hence, a good orthodontist experience working with this system together with a good knowledge and understanding to the mechanism of tooth movements and biomechanics is crucial (39). Also, the higher cost of treatment with clear aligners in comparison with conventional fixed appliances has put them in a position of trade-off by many patients (3).

2.2. **Development of Digital Dentistry and Clear Aligner Technology**

In 1970, Dr. Francois Duret and Dr. Christian Termoz established the first dental digital workflow for indirect prostheses utilizing computer-aided design/computer-aided modeling (CAD/CAM), marking the beginning of digital dentistry (42). Early versions of CAD/CAM systems, on the other hand, were so inconvenient and complicated that they were seen as a burden rather than an aid to practice workflow, and were largely used in labs. Fortunately, technological advancements in recent years have made CAD/CAM a more practical choice for dentists wishing to invest in-house restorations. The advent of intraoral scanners to the market is one reason why this technology has become considerably more accessible (43).

The introduction of intraoral scanners was followed by the invention of 3D printing technology, structuring a complete system of digital workflow to substitute the conventional high-laboratory workflow of a normal day in the clinic became possible.

Today nearly every dental discipline uses some form of digital workflow for providing patient care. Orthodontists are finding this concept to be perfect for orthodontic application as well, with orthodontics having taken the most advantage of digital dentistry among different dental branches. Several orthodontic therapies use a total digital workflow, starting with digital acquisition, virtual treatment planning, and 3D printing for customized appliances, retainers, and clear aligners' production (44).

There is a distinct difference between evolutionary change and revolutionary change. Evolutionary change comprises incremental changes that take place gradually over time. This can be explained by the evolution of fixed appliances represents variations and incremental improvements on a bracket and wire system that has taken place over the last 100 years. While revolutionary change, in contrast, is a dramatically transformational change. Revolutionary change challenges our conventional thinking and requires a radical paradigm shift in our mindset such as the development of clear aligners (45,46).

The history of clear aligners may be traced back to 1945, when Dr H. D. Kesling first proposed a clear, vacuum-formed tooth-positioning appliance for minor tooth movement (16,45). His idea was to replace brackets and wires with one-piece rubber appliance that is designed to resemble the ideal setup of the teeth in both arches. This technique was introduced to produce minor tooth alignment generally required to relapse after the main orthodontic therapy. Since the positioner was fabricated of a rubber material, it was capable of slipping and embracing the teeth that are not ideally settled according to the ideal dental arch setup. The patient was required to wear the appliance for at least 4 hours during daytime as well as during sleeping for 6-8 weeks in order to benefit the most from the appliance. This was estimated to reduce the time spent with brackets and wires by about 6 months for the patient and thus reducing the chair-side time for the orthodontist. It also saved the orthodontist the months bending effort to achieve the final settling of the teeth. On the other hand, the technically hard labor of taking an impression, pouring the model of the dental arch, dissecting the teeth, repositioning them and then fixing them using hot melted wax in accordance to the ideal setup were the limitations of the appliance/technique (47,48).

Henry I. Nahoum introduced approximately twenty year later in 1964 the "vacuum formed dental contour appliance” (49,50). He has acknowledged that his appliance can be used to correct minor discrepancies limited to only the 6 anterior teeth in both maxillary and mandibular arches. He described a similar method of fabricating the appliance similar to that described by Kesling(51) through dissecting the teeth in the model and repositioning them in wax, however, it was fabricated using a plastic sheet that was heated and vacuum formed over the adjusted teeth. Moreover, a major difference and advantage was that the maxillary and mandibular appliances were separated (50,52).

The development of the clear aligner technique never failed to continue when Sheridan(51) utilized the Essix material (Raintree Essix, New Orleans, LA) to fabricate a sequence of Essix-appliances as an alternative to Kesling's positioner for minor tooth movement(16,45,53). Unlike Kesling and Nahoum, his technique didn't include dissecting the teeth and repositioning them using wax, instead, the teeth in the plaster model were modified using block-out compound so that when the Essix material is vacuum formed over it the resulted aligner included a room space toward which the tooth will be moved. The thermoformed appliance can then be altered using thermoform adjusting pliers to place a divot or dimple to increase force delivery on the target tooth. Alternatively, a composite mound can be bonded to the patient's tooth to provide the force necessary to push the tooth into the space created by the block-out compound. As recommended by Sheridan, controlling the size and the location of the composite mound will help to gradually achieve the desired magnitude and direction of movement (54).

Another half-century went by until the first clear aligner laboratory was founded (Align Technology, Inc.) in 1997. Two graduate students at Stanford University have applied 3D computer imaging graphics to the field of orthodontics and created the world's first customized clear aligner system called Invisalign system. The workflow offered by the one of a kind at that time company was by taking an impression of the dental arches which can be taken by polyvinylsiloxane (PVS) or alternatively by digital scanning by the immergence of optical intraoral scanners later on. The impression is then sent to the company's laboratory to move the teeth using a 3D computer imaging software to the desired setup (45,55). The software also applies sequential movement of the teeth by dividing the overall movement into smaller steps each step planning for 0.25-0.33mm in crown movement in any direction per aligner, and 2º-3º of rotation correction per aligner (56–58). When the digital setups are finished each of these digital models are then transformed into a physical model using 3D printing technology and a clear aligner of different thickness is fabricated through thermoforming over each one of them for each stage (56).

Aligners are produced through thermoforming process of different polymers varying between polyethylene terephthalate glycol (PET-G), multi-layer aromatic thermoplastic polyurethane or poly-vinyl chloride (PVC) of about different thicknesses ranging between 0.02-inch, 0.025-inch or 0.03-inch.(17,56,59,60) The thickness of the aligner material can affect not only their optical properties(61), but also the forces and moments expressed by the device (62). According to some authors the use of gradually thickening aligners provides more control on tooth movement and reduces the pain caused by orthodontic forces (17). On the same context, Elkholy et al. (63) suggested the novel sequence 0.4, 0.5, and 0.75 mm for aligner systems based on sequentially increased material thickness. They found that this sequence combines sufficiently low initial aligner stiffness and steady load increases in single setup steps from one aligner to the next.

Clear aligners are not a product it is an orthodontic treatment technique similar to labial and lingual fixed ones. Several clear aligner systems are being developed all over the world.(64) Many other products such as ClearCorrect™ (ClearCorrect, LLC, Round Rock, TX), SureSmileR Aligners (Dentsply Sirona, York, PA) and 3M™ Clarity™ Aligners (The 3M Company, Maplewood, MN) have entered the marketplace. With advances in (CAD/CAM) technology and workflow, some specialists are even producing in-office clear aligners (64). It is clear that clear aligner therapy (CAT) has become a milestone in orthodontics and has the potential to increase in popularity. All these systems use a similar concept of 3D graphic imaging and Computer-Aided Design technologies to fabricate a series of aligners according to sophisticated computer algorithms developed in the software program in order to achieve desired tooth movements (39,45,56,65,66).

Clear aligner therapy is a true representation of the future vision of an ideal orthodontic therapy of all time by utilizing digital technology for diagnosis, treatment planning, and designing the final occlusal outcome. To a certain degree, it is possible to customize the biomechanics by staging tooth movements in a specific sequence in the software program (45). The rate of tooth movement may also be adjusted according to the individual's bone physiology by altering the scheduled number of days for aligner changes, depending on the individual's response to tooth movement.

2.3. **Comparison of Conventional Bracket Systems with Clear Aligners**

Clear aligner technology was introduced to represent a revolutionary, transformational change in orthodontics that challenges the conventional thinking of how orthodontists move teeth. However, the advent of clear aligner technology does not mean that 150 years of orthodontic principles are no longer valid. The time-tested principles and concept of bone biology, biomechanics, anchorage, and occlusion still apply. However, in this 21st century of digital technology, the clinician must now learn to apply those principles of orthodontics to the field of clear aligner technique (67).

In contrast to bracket and wire system which moves the teeth by exerting pulling force depending on the elasticity of flexible deflectable Nickel Titanium (NITI) wires during leveling phase or by using elastomeric chains or NITI coils to close spaces, clear aligners move teeth by exerting a pushing force. When an aligner is inserted over teeth, there are minor differences between the positions of the teeth intraorally and the positions of the teeth in the aligner, so the aligner deforms over the teeth, and the elasticity in the aligner material pushes the teeth into the new position (67).

In fixed appliances where the tooth movement in a three planes is produced by a wire engaging the bracket and ligated to it, and by moving sequentially from thin flexible wires to thick rigid ones, more of the tip, torque, and in-and-outs that are built into the bracket slot or base will be expressed, this is opposed in the clear aligners by having the aligner material being wrapped around the teeth for tooth-appliance engagement i.e. the more aligner material wrapped around a tooth, the better the engagement and hence more forces being expressed and the more accurate the desired movement is. In other words, in teeth with long clinical crowns and larger surface area, there is better engagement and therefore better expression of tooth movement. Conversely, in teeth with short clinical crowns and less surface area, there is less engagement and less expression of tooth movement (67).

In the early days of clear aligners, most clinicians understood them to be an orthodontic appliance that was suitable only for the treatment of Class I cases with minor crowding, which can be resolved with the help of a minor interproximal reduction (45). Nowadays, the clear aligner system is a comprehensive orthodontic appliance that is capable of treating a wide range of malocclusions including complex ones (35,45). Djeu et al. (39) has compared the treatment outcomes of patient treated with clear aligner with these of conventional fixed braces using the American Board of Orthodontic grading systems. They concluded that both systems are effective however they emphasized the use of attachments to improve the accuracy of teeth movement in aligner therapy. Boyd

(56,68,69) has suggested that clear aligners are capable of achieving good outcomes when treating deepbite, crossbite and extraction cases. For more challenging cases such as these require absolute anchorage, molars intrusion in brachycephalic patients, full premolars retraction, openbite cases, or distalization of mandibular molars, temporary anchorage devices (TADs) can be incorporated with clear aligners to aid in more challenging teeth movements (70–72). Moreover, the combination of orthognathic surgery and clear-aligner therapy (e.g., Invisalign) is a novel idea, but with limited evidence so far. To date, knowledge of clear aligners with orthognathic surgery is minimal, with most being case reports (73–78). Pagani et al. (74) presented a case report where he successfully managed to implement the Invisalign system to treat a Class III malocclusion with lateral deviation of the mandible surgically. He also emphasized the stability of the treatment after 6 years follow up. Kankam et al. (75,76) has pushed the Invisalign system further and used it to treat surgical cases that require a complex double or triple-jaw surgeries and compared the results with the ones of the same surgical procedure performed with conventional fixed appliance. He found that neither the perioperative outcomes nor the postoperative edema were significantly affected when implementing Invisalign system as an alternative to the conventional fixed appliance. Nowadays, few conservative attempts to combine Invisalign with Surgery-First concept has been successfully presented in case reports (79,80).

However, when clear aligners first emerged, they were not as efficient as brackets and wires system and the type of tooth movement played an important role in the realistic of clear aligner therapy. One of the major challenging tooth movements of clear aligner therapy is the correction of rotated conical teeth, especially canines and premolars (81). According to Boyd et al. (56) rotation of lower premolars and extrusion of teeth are two of the most challenging movements to accomplish with clear aligners. Likewise, Simon et al. (58,82) provided that premolar de-rotation and upper incisors torque had the lowest accuracy among all other movements of only 40% and 42%, respectively. He also stated that bodily tooth movements such as molar distalization, incisor torque, as well as premolar de-rotation can be accomplished with the aid of attachments. Kravitz et al. (83) conducted a study to evaluate the efficacy of clear aligner therapy using Invisalign. He found that the overall accuracy of tooth movement to be 41% with the most accurate tooth movement to be lingual constriction (47.1%). The least accurate tooth movement was extrusion (29.6%), followed rotation of maxillary laterals and canines, with the mandibular canines being the most difficult teeth to control. The accuracy of canine rotation was found to be reduced to 32.2% if rotation more than 15 degrees had to be done. This is due to the fact that conical teeth lack interproximal undercuts, and as a result the aligner tends to slip as de-rotation is attempted. No difference in accuracy between maxillary and mandibular teeth of the same type for any tooth movement have been found.

Moreover, Bollen et al. (84) conducted that all patients who completed their first set of aligners required refinement or transition to fixed appliances to achieve the original pretreatment goals. This came in accordance to Sheridan's (85) conclusions, that Orthodontists report that 70-80% of cases do not achieve pre-treatment goals and require further treatment, with one of the most common reasons for refinement or converting to fixed appliances is uncorrected rotations.

As regard to the treatment duration, Djeu et al. (39) found a significant difference between the treatment duration using Invisalign (1.4 years) and the conventional edge-wise brackets with (1.7 years). However, he pointed that the final outcomes by Invisalign weren't ideal due to the absence of finishing stage, which may have contributed to the shorter period of treatment time. Buschang et al. (86) investigated the differences between Invisalign system and conventional fixed appliances as well. The Invisalign patients spent 50% less time in the chair than Edge-wise patients per session, which enables more patients to be seen by the orthodontist during the day. Moreover, the total chair time for Invisalign patients was also less due to fewer adjustment appointments and absence of finishing stage. This will be directly reflected to the total number of visits required during the treatment, which happened to be less in Invisalign group by 67% than Edge-wise group. He also noted that emergency visits are not common with clear aligners' treatment because there are few auxiliary parts that are likely to break unlike the conventional fixed appliances.

Through literature and until today, we have seen some orthodontists struggling with simple cases treated with clear aligners and others achieving near ideal treatment outcomes with more complex cases similar to these achieved by conventional fixed appliances. Therefore, no conclusion could have been made regarding the limitations of the Invisalign system, especially after the massive evolution that clear aligners have witnessed since their emersion which gave solutions to manage a lot of complex cases which were considered to be challenging to treat with clear aligners in the past, and neither of the mentioned indications or contraindications are supported with a strong scientific evidence (86–88). Moreover, the use of this system is strongly dependent on the experience of the orthodontist and the opinion of experts, the presented limited evidence and most importantly the understanding the concepts of teeth movement and biomechanics (86,88,89).

Although clear aligners have already evolved since they were released to the market in 1999, however, due to these early data available evaluating the efficiency of clear aligners' therapy, a state of insecurity has been raised among the orthodontists rendering them hesitating to shift into this technique, and until this day there is a common misconception that clear aligners are a "compromise" orthodontic appliances that are only capable of minor tooth movement.

To accommodate for these drawbacks reported in the early literatures, authors have imported many modifications into the clear aligners over the years to increase the engagement of the aligner onto the teeth, starting from the aligner's margin design, extension, material thickness and the incorporation of different shapes and sizes of a small morphologies called attachments to increase the surface area onto which the aligner will be engaging (19,90,91).

2.4. **Attachments**

The success of aligner therapy is inextricably bound with the use of the appropriate attachments. Attachments is a term used to describe specifically shaped composite resin protrusions that are "attached" and bonded to strategic locations on specified tooth surfaces and increasing the tooth surface that will be engaged by the clear aligner material (64,92). Predetermined attachment forms are provided within various orthodontic CAD software, but they can also be designed individually in other 3D software like Meshmixer, Rhino or Blender and imported into the CAD software.

Considering the small size and customization of optimized attachments, molding and bonding them using a template with their exact size, shape and location is crucial, as errors any error in their bonding may cause an unplanned impede the planned movement or result in an unplanned one.(93) Composite resin is produced in three viscosities; low, medium and high viscosity. Few studies have compared the efficacy of different composite viscosities to conclude about the preferable type of composite resin to be used for attachments molding. D’Antò et al. (94) has examined three types of composite resin based on their viscosity; low-viscous flowable composite, medium-viscous orthodontic composite and high-viscous dental restorative composite. It was concluded that different composites do not affect the volume and shape of attachments and all of them are applicable for the fabrication of attachments. Wechmann et al. (93) examined both low and high viscosities and provided that the use of low-viscous composite with non-perforated template or the high-viscous composite in two-phase protocol are the most price techniques to bond attachments. That is to be said that high or low viscous composite can be used to pack the attachments template. Also, Feinberg et al. (95) compared the translucency, hardness, and stain resistance of restorative and orthodontic composites for attachment production. They observed that both of them would undergo staining over time. Also, orthodontic composite showed greater or similar hardness in comparison with the restorative composite. Thus, generally orthodontic adhesives as well as other composites can be utilized for attachment fabrication.

2.4.1. Efficacy of Attachments

Simon et al. (58) investigated the efficacy of orthodontic treatment using the Invisalign system regarding incisor torque, premolar de-rotation and molar distalization with and without attachments. He found out that incisor torque as well as molar distalization can be performed using Invisalign aligners, regardless the use of attachments, providing that the study didn’t investigate the root position in case of molar distalization, while the exertion of incisor torque was managed by power ridge instead. Gomez et al. (96) has confirmed that the absence of composite attachments produces an uncontrolled tooth tipping during simulation of canine distalization, and that the presence of attachments if effective in achieving bodily movement. Elkholy et al. (21) investigated the effect of three different shapes of attachments;’geometries (quarter-sphere, vertical-ellipsoid, and pyramidal) on the 3D force and moment (F/M) values exerted during de-rotation of a mandibular canine and compared it to the values of control group of no attachments being used. By all measures, all attachment group managed to de-rotate the canine, but the quarter-sphere geometry had the best overall mechanical properties because it induced relatively high rotational moment together with counteracting the unwanted intrusive forces during de-rotation, unlike other attachments where some intrusion occurs in coincidence with de-rotation movements. Comba et al. (97) indicated that canine distalization without attachment or with rectangular attachment would cause intrusion and distal crown tipping; while, insertion of optimized attachments would cause bodily translation although with some intrusion, which can be prevented by application of Class II elastics directly to the attachment. Yokoi et al. (98) clarified the effect of attachment on closing midline diastema by moving the two central incisors bodily. In his study he used a pair of hemi-ellipsoid attachment. He demonstrated that the incisors tipped and rotated after placement of the aligner irrespective to the presence of the attachment, however, after a sufficient time of using the aligner the centrals up-righted and moved bodily in the aligner with the attachment while they remained tipped in the aligner without attachment. Zhouyan et al. (99) compared the efficacy of using rectangular attachments in comparison with no attachments being used for correcting the rotation of maxillary canine teeth. The results showed a greater stress value of periodontal ligament with the use of rectangular attachments and this greater tooth movement than the ones without attachments. Savignano et al. (100) has compared the performance of clear aligners in exerting extrusion movement to central incisor using three designs of attachments differs in shape and location (rectangular palatal, a rectangular buccal, and an ellipsoid buccal attachment) with the one using no attachments. He confirmed that extrusion of central incisor cannot be achieved without attachments, and emphasized that the use of rectangular palatal attachment's configuration was the best to exert incisor extrusion.

2.4.2. Classification of Attachments According to Their Function

The utilization of attachments in clear aligners therapy can be classified as serving three main purposes:

- introduce higher generated moments
- increase retention
- increase the anchorage.

2.4.2.1. Retention

The most basic clinical situation they are used for is providing retention to the aligner. In order to fully express prescribed movements, the aligners have to be fully seated. Aligners have a flexibility that needs to be compensated when seated onto arches that require movement. These serve the purpose of locking the teeth in the plastic while couples of forces are applied to their crowns (eg, rotation, torque, angulation) (19,91). They therefore prevent any loss of tracking that could be caused due to consequential intrusive forces "watermelon seed effect" (64,67). In addition, retention attachments are often placed on molars to ensure that the distal end of the aligner is locked in place over the crowns (92), on which slits are added to the aligners for elastic use. The vertical component of the elastic force has a dislodging effect on the aligner, necessitating the placement of a retention attachment to prevent this occurrence (64).

For this purpose, retention attachments are always passive and their only aim is to increase the engagement of the aligner onto the tooth (91,101). In other words, they act as handles for the aligners to move teeth. The Invisalign System provides two conventional attachment's geometries for that purpose; the first conventional attachment is the Ellipsoid attachment (Figure 2.4.2.1.A.); they are the original attachments from the early days of clear aligners, and still being used at times, especially when the tooth surface area is limited, for example the labial surface of maxillary lateral incisors or the lingual surface of a lingually inclined mandibular second molar. The second conventional attachment is Rectangular attachment (Figure 2.4.2.1.B. and 2.4.2.1.C.), these attachments if designed passively in aligner retention and may be vertical or horizontal. Vertical rectangular attachment may also be useful for root control and may be used instead of optimized root control attachments when the software is unable to place them due to conflicts in the software program, or in lower incisor extraction cases if there is significant root tip to correct root inclinations on the mandibular incisors. Horizontal rectangular attachment, may be used where a short clinical crown or occlusal interference does not allow placement of a vertical rectangular attachment. They may also be used for root control, particularly in the buccolingual dimension to effect buccal root torque on molars. Increasing the retention of aligner after addition of attachments coincides with the results of Dasy et al. (19) has evaluated the effect that adding attachments does have on retention when added to clear aligner. In their study they compared two different attachments (ellipsoid and beveled) with a control group having no attachments at all. They demonstrated that the use of attachments increases the retention significantly compared with no use of attachments. They also added that the beveled attachments were significantly superior to ellipsoid attachments. These finding came in coincidence with the results founded by Al Noor et al. (91) who determined that adding beveled attachments lead to the significant increase in the retention.

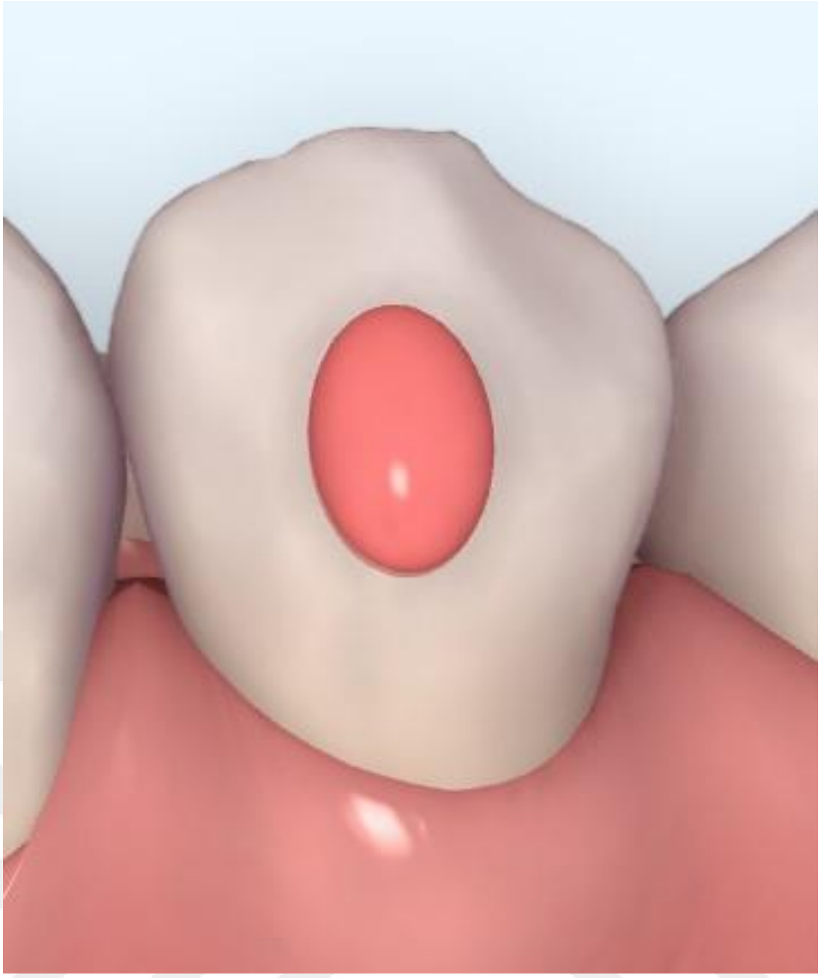

Figure 2.4.2.1.A. Ellipsoid attachment configurations.

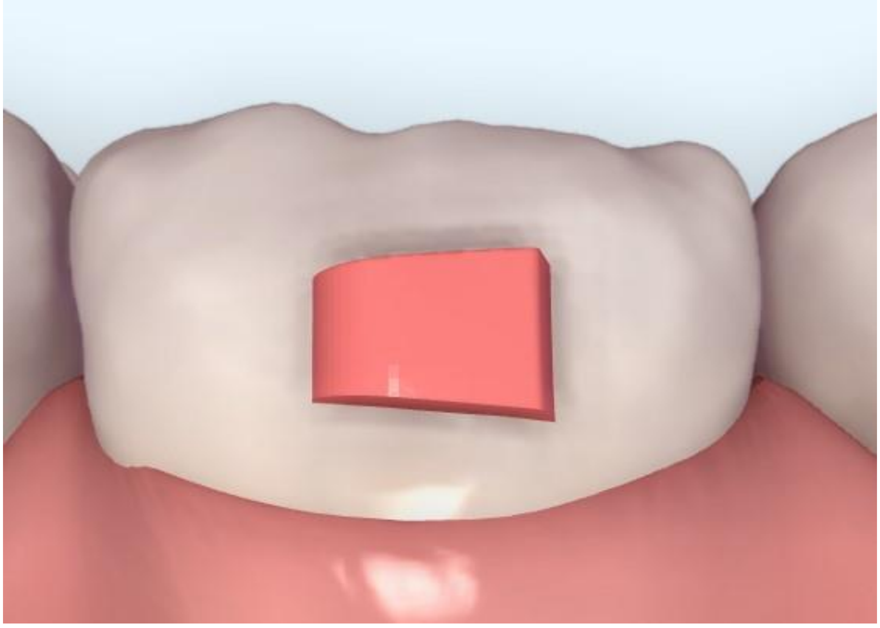

Figure 2.4.2.1.B. Horizontal Rectangular attachment configurations.

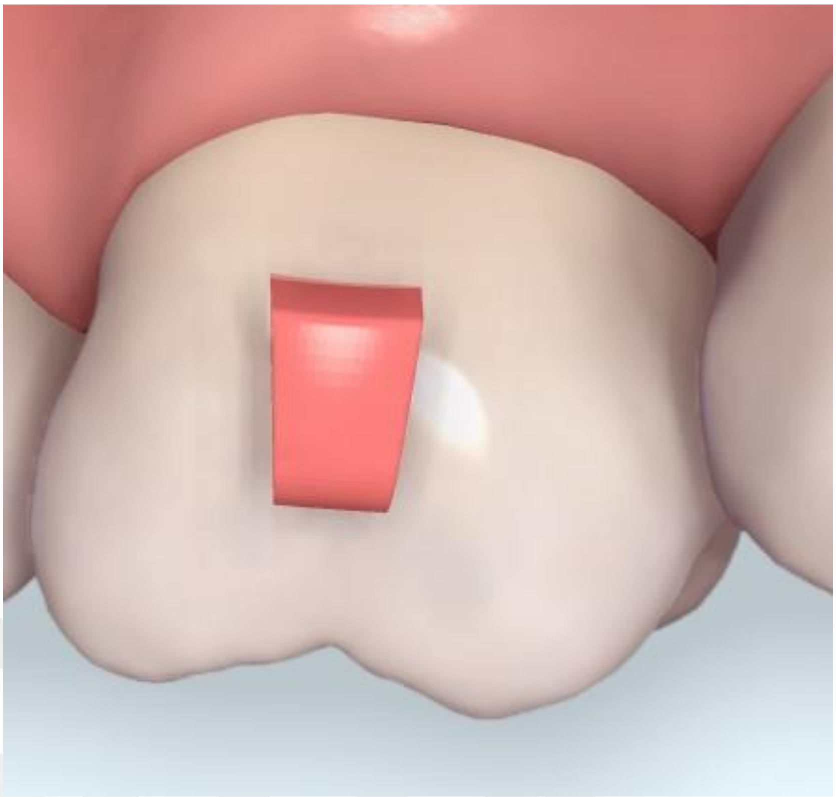

Figure 2.4.2.1.C. Vertical Rectangular attachment.

2.4.2.2. **Facilitating Teeth Movements**

The second purpose of using the attachments is to facilitate tooth movement by changing the shape of the tooth to provide an active surface for pushing which in turn will increase the generated moments in order to express the wanted tooth movement (102). The surface geometry of the attachments used for this purpose has been modified to provide an active, flat surface that is oriented against which the aligner will push to deliver the desired forces while simultaneously extruding, rotating or providing root control. Therefore, the Invisalign System has proposed conventional beveled rectangular attachments. Both the vertical and horizontal attachments may be beveled (Figure 2.4.2.2.A. and 2.4.2.2.B.).

The beveled surface of the attachment is the active surface. The bevel provides a flat surface for the aligner to push against to affect the desired tooth movement. For extrusive tooth movements, a horizontal attachment that is beveled gingivally will be effective. Likewise, for molar intrusion, the use of a horizontal attachment beveled occlusally is recommended.

In order to control the point of force application, the direction of the force and the amount of force applied, the Invisalign System has presented optimized attachments, which are customized for each individual tooth. All optimized attachments have an active surface that varies in geometry based on the unique morphology of each tooth.

Hemi-ellipsoid attachments (Figure 2.4.2.2.C.) are used either solely for de-rotations, or in pairs where root movements are attempted, by which they allow for the production of a moment of couple to upright the roots of canine or premolars during distalization (16).

In the literature, all the studies carried to evaluate the efficiency of aligners in moving teeth have supported the use of attachments to improve tooth movements accuracy and treatment predictability. Rossini et al. (102) conducted a systematic review about the efficiency of clear aligners to control different orthodontic tooth movements. He concluded that when clear aligners are used alone without attachments they effective in controlling anterior intrusion but not anterior extrusion, they are effective in controlling posterior buccolingual inclination but not anterior buccolingual inclination, they are effective in controlling upper molar bodily movements of about 1.5 mm, and they are not effective in controlling rotation of rounded teeth in particular. He also emphasized that the use of clear aligner therapy requires altering teeth geometry by using attachments to improve the predictability of orthodontic movements. In their retrospective study, Simon et al. (58,82), investigated the efficacy of orthodontic treatment using the Invisalign system regarding incisor torque, premolar de-rotation and molar distalization and studied the force system generated by aligners regarding the same movements in a separate study. He emphasized that the forces and moments generated by aligners of the Invisalign system are within the range of orthodontic forces. He also commented that incisor torque as well as molar distalization can be performed using Invisalign aligners, regardless the use of attachments, providing that the study didn’t investigate the root position in case of molar distalization, while the exertion of incisor torque was managed by power ridge instead. However, he recommended that premolar de-rotation should be supported with an attachment, especially if these teeth have short crowns and few undercuts.

Ravera et al. (103) and Garino et al. (104) have demonstrated the importance of using vertical rectangular attachments on posterior teeth to improve the root control during molars distalization in class II treatments. He also exhibited its role in controlling molar extrusion, reducing distal crown tipping and anterior anchorage loss. Gomez et al. (96) has confirmed that the absence of composite attachments produces an uncontrolled tooth tipping during simulation of canine distalization, and that the presence of attachments if effective in achieving bodily movement. Elkholy et al. (21) investigated the effect of three different shapes of aligner attachment geometry (quarter-sphere, vertical-ellipsoid, and pyramidal) on the 3D force and moment (F/M) values exerted during de-rotation of a mandibular canine. The quarter-sphere geometry had the best overall mechanical properties because it induced relatively high rotational moment together with counteracting the unwanted intrusive forces during de-rotation. Comba et al. (97) indicated that canine distalization without attachment or with rectangular attachment would cause intrusion and distal crown tipping; while, insertion of optimized attachments would cause bodily translation although with some intrusion, which can be prevented by application of class II elastics directly to the attachment. Costa et al. (22) performed a 3D evaluated of the force generated during extrusion of upper central incisors by three geometrically different attachments modified from ellipsoid, rectangular and beveled attachments by modifying the active surface of each attachment. They concluded that shape of attachment can affect the intensity and direction of force. Yokoi et al. (98) clarified the effect of attachment on closing midline diastema by moving the two central incisors bodily. In his study he used a pair of hemi-ellipsoid attachment. He demonstrated that the incisors tipped and rotated after placement of the aligner irrespective to the presence of the attachment, however, after a sufficient time of using the aligner the centrals up-righted and moved bodily in the aligner with the attachment while they remained tipped in the aligner without attachment.

An attempt to establish a good understanding of the variant aspects regarding attachments that may influence the tooth movement has led the researches to investigate the relationship between the planned movement and the attachment size or thickness as well as the location of the attachment. Goto et al. (105) analyzed the possible effect of changing attachments shape, size and location on the predictability of canines distalization during closing an extraction space. He noted no influence of changing the attachment shape, size or location on the tipping of the canine during space closure. However, the study only investigated placing the attachments on the buccal surface of the canine. He also assumed that the effect of the attachment might be more dependent on the morphology of the crown. In contrast, Chen Zhouyan et al. (99) compared the effect of changing the thicknesses and locations of rectangular attachments for correcting the rotation of maxillary canine teeth. The results showed that increasing the attachment thickness has a direct relationship with stress value of periodontal ligaments and thus canine displacement. Moreover, he confirmed that changing the location of the attachment vertically had a significant influence on controlling canine rotation, with occlusal placed attachment providing better control that apically placed ones, while changes in mesial and distal directions were irregular. However, the two previous studies didn't address the lingual surface or the tooth and only limited the investigation to examine the attachments on different locations of the buccal surface. In contrast, Kim et al. (106) examined the optimal shape and position of attachments to be placed on lower canine during extrusion, intrusion, rotation and torque movements on both buccal and lingual surfaces. He suggested that the placement of attachments on the lingual surface of the tooth provides optimal torque control and effective tooth movement rather than the buccal surface. He also added that the use of cylindrical attachment sums for a better contact angle between the attachment and the aligner and thus a better stress distribution. Savignano et al. (100) has compared the performance of clear aligners in exerting extrusion movement to central incisor using three designs of attachments differs in shape and location (rectangular palatal, a rectangular buccal, and an ellipsoid buccal attachment) with the one using no attachments. He confirmed that extrusion of central incisor cannot be achieved without attachments, and emphasized that the use of rectangular palatal attachment's configuration was the best to exert incisor extrusion with the attachment position showing a stronger influence on the outcome compared to its shape due to its effect on the active surface of the attachment. This elicitation came to support the conclusions given previously by Cai et al. (89) who analyzed the force system given by attachments, and showed that the attachment could be optimized to help the tooth move effectively. He also added that the most important factor affecting the attachment's efficiency was found to be the active surface direction, which can be optimized by the moment-to-force ratio needed by the movement.

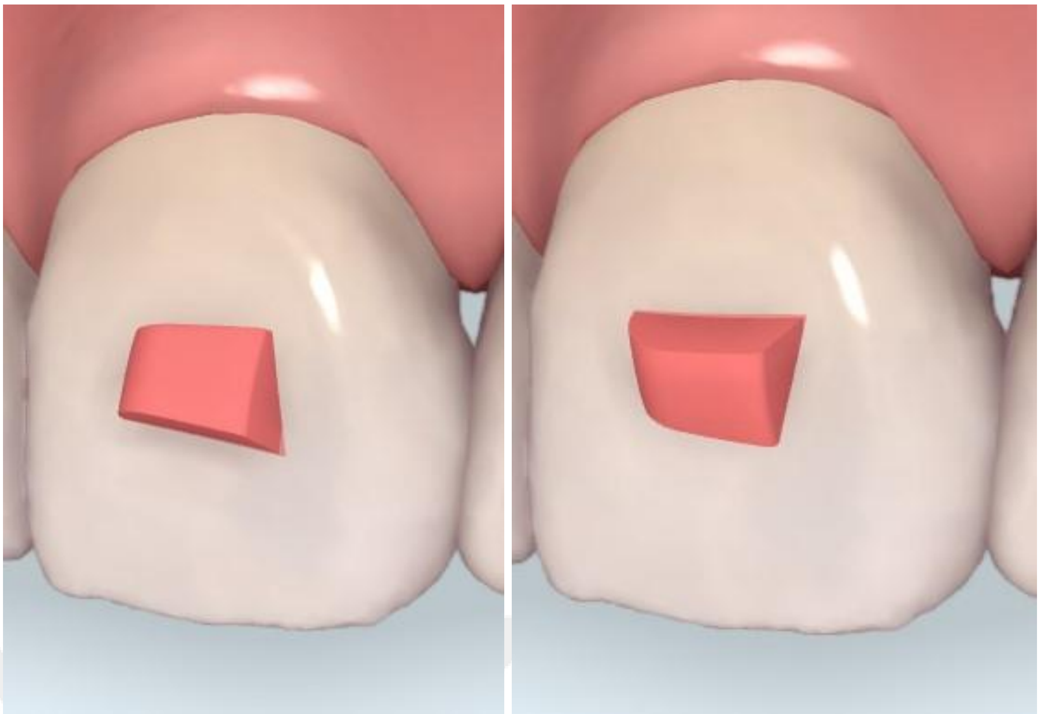

Figure 2.4.2.2.A. (left): Horizontal Rectangular attachments with gingivally beveled active surface. (right): Horizontal Rectangular attachments with incisally beveled active surface.

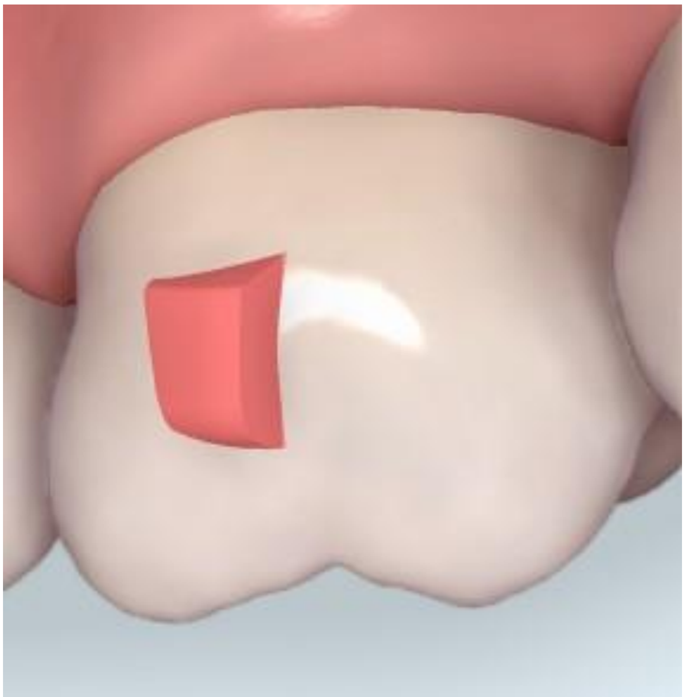

Figure 2.4.2.2.B. Vertical Rectangular attachment with mesial beveled active surface.

Figure 2.4.2.2.C. A pair of Hemi-ellipsoid attachment.

2.4.2.3. **Anchorage:**

The third clinical situation where attachments are being used is providing anchorage to prevent some movements and allow other movement like anterior teeth intrusion to take place without dislodging of the aligner. As stated by Higley (107), anchorage indicates the resistance necessary to prevent tooth movement when not desired while permitting movement where it is desired. Anchorage control refers to the prevention of undesirable tooth movement in the three dimensions of space: sagittal, vertical, and transversal, beginning in the early stages of therapy (108). Attachments are effective features for controlling orthodontic tooth movement and managing anchoring units, for this reason they are placed in "anchor units," on which the intended biomechanics will have expressed the equilibrium forces generated on the non-anchorage unit while counteracting the reciprocal forces exerted on the anchorage unit, whether during retraction of anterior segment when closing spaces, sequential distalization of posterior teeth (103,104) or during leveling the curve of spee where the digital plan might only include intrusion of the mandibular incisors (64,67).

Although they have an active surface, though they don't cause the tooth to move as the force they exert is just a compensatory counteractive force. Rectangular attachments can also be added to the anchor unit to enhance posterior anchorage during anterior retraction (103,104). Only one study derived by Mantovani et al. (109) has analyzed the aligner fitting on anchorage attachment. They showed that fitting of every investigated aligner on anchorage attachments is excellent despite differences in aligners' thermoplastic material composition.

2.5. Aligners Fabrication

Clear aligner therapy is a critical and a technique sensitive treatment approach in terms of planning and fabrication, which follows a specific protocol for achieving the desired corrections through a sequence of teeth movements. From the sensitiveness of the technique comes the necessity of fabricating accurately fitting aligners. The stages of aligners fabrication pass through the following phases:

- Digital Acquisition
- Computer-Aided Designing using CAD software
- Printing of Models using 3D printers
- Fabrication of Clear Aligners

2.5.1. Digital Acquisition

The initial stage of aligner fabrication is digital acquisition of dental arches. Therefore, either an intra-oral optical scanner (IOS) can be used or a conventional impression that will be later scanned by an extra-oral scanner (EOS) to invert the physical impression into a digital model. From the above, digital data acquisition may be classified as intra-oral or extra-oral scanners. (43,110).

2.5.1.1. Extra-Oral Scanners (EOS)

An EOS consists of a light emitter and a camera(s) or a sensor. The optical scanning of an object's 3D geometry takes place in three steps. Both IOS and EOS operate on the same basic premise. The first stage involves projecting light onto the surface and analyzing the reflected light's deformations to generate two-dimensional (2D) pictures in the x and y coordinates. For capturing a picture, this phase may be separated into two types: passive and active. The difference between the two is the type of lighting utilized to gather data. An active capture employs a coherent structured light source, commonly a laser or light emitting diode (LED), to project stationary or oscillating (time-varying or pulse) patterns known as codes, whereas a passive capture uses non-coherent (ambient) light. The codes can be a single point (dot), multiple points (multiple dots), lines (stripes), meshes, or grids that are projected onto the object's surface to speed up the acquisition process (111).

The second stage is recording the third z coordinate in order to create a 3D rendition. Unlike hand-held IOS, which are moved across the surface of a stationary object, this is accomplished in EOS by moving the object via turntable that rotates the object in different directions for capturing its surface from various angles (112). The sensor or camera can either record successive still images (single-shot) or be used for continuous video (multi-shot) capture.

The next step is to use distance measurement technologies such as triangulation to calculate the distance between points of interest (POI) on the surface. Triangulation is a technique for determining the distance between two things without having to physically touch them. Depending on the light source utilized, triangulation can be passive or active. As previously stated, passive triangulation (PT) employs an ambient, non-coherent light source, whereas active triangulation (AT) employs a structured light source, such as a laser or LED, which is projected onto the object. The emitter(s), object, and sensor(s) are arranged in a triangle, thus the word triangulation (113). Surface reconstruction software employs point cloud data to recreate the surface's shape, textural changes, and topography. A point cloud is a volumetric dataset that represents an object's 3D surface in x, y, and z dimensions. A point cloud's digital data is incredibly exact, but it must be transformed into a mesh or surface model before it can be used in CAD software. This is accomplished by transforming the point cloud to triangular or quad meshes that are conducive for CAD models. However, because the created meshes have a high density, they require a lot of computer processing power, which slows down the design process. To save processing times, high-density meshes are reduced to low-density meshes, but with edge preservation detail to ensure that quality is not compromised (114).

2.5.1.2. **Intra-Oral Scanners (IOS):**

The first intra-oral scanner was introduced in the late 80s by Drs. Werner Mormann and Marco Brandestini and commercialized as CEREC 1, opening the door for the digital orthodontics to move from lab to chair-side (115).

The patenting of digital scanning technology has allowed the technicians to work with digital models instead of conventional cast models. The advantages of working on digital models were reduction of treatment session time, time serving due to not fabricating the plaster model, no need to store models and overcoming the shortcomings of analogue impressions such as tears, distortions, air blows, etc. (44,116,117). In addition, the distortions associated with delayed model poring or delayed stone cast expansion are also overcome. In beside of being a good marketing tool, digital impression obtained from intra-oral scanners can improve patient comfort especially for those with gag reflex, truisms, or mobile teeth. This environmentally friendly solution also ensures that patients' models are not damaged, lost or mixed-up over time. The concept of virtually representing dental tissues by optical scanning has opened up the arena for its application in variable disciplines. For instance, creating digital models have further improved doctors' diagnostic capabilities by implementing them to orthodontic-specific design software that can take basic distance measurements for case diagnosis. Overall digital models can be easily shared with the other disciplines such as the technicians via internet to produce orthodontic appliances or other doctors in multidisciplinary teams of patients with craniofacial syndromes (28,118,119).

2.5.1.3. **Intra-Oral VS Extra-Oral Scanners**

Both extra-oral (EOS) and intra-oral (IOS) scanners are available in the market, with the former being the first type of scanners available. As a general rule EOS yield greater accuracy when compared to IOS, as the scan is performed in a controlled environment without contamination with oral fluid, and eliminating the necessity for patient compliance or a skilled operator (110).

Many studies have concluded that EOS provides higher accuracy than IOS, with an average of 5-25 µm and 50 µm, respectively (120). An in-vivo study has evaluated the precision of intra-oral digitization using iTero IOS and compared it to the precision of extra-oral digitization using iTero IOS and a D250 desktop model scanner. It was reported that scanning with the iTero both intra and extra orally were less accurate than scanning with the D250 scanner. Additionally, intra-oral scanning with the iTero was found to be less accurate than model scanning with the iTero, suggesting that the intra-oral conditions (saliva, limited spacing), patient cooperation, and the experience of the operator contribute to the inaccuracy of a scan (120). However, they suggested that if the conditions would be the same (no saliva etc.) IOS may be capable of providing accuracy that is comparable to that provided by EOS (121,122). An in-vitro study has compared the measurements on a dry mandible between one EOS and two IOS. The researchers have reported that the differences between them were clinically acceptable (123). As a result, more accurate, reliable, faster and more user-friendly IOS are being introduced to the market nowadays, allowing for a complete digital workflow, unlike EOS that require a conventional impression and/or the subsequent cast model to yield the digital model adding one more step to the workflow and by this increasing the risk for errors along the working chain. Therefore, if the impression or the poured model has any inaccuracies of distortions, this will compromise the EOS scan.

2.5.2. Computer-Aided Design (CAD) Software

A digital scan imported directly from the scanner is not ready to be printed and require some modifications to be transferred into a solid model before it is suitable for sending it to be printer (Figure 2.5.2.1.). Therefore, the scanned data is transferred to a CAD software program, where they are edited by removing any defects or imperfections from the mesh such as: holes, creases and cracks. In addition, the extraneous polygons are trimmed from the model (Figure 2.5.2.2.). The editing and trimming process of a digital model is done automatically or manual by the software program of the IOS. Afterwards comes the process of adding a base to the model and converting it from a hollow surface to a solid one (Figure 2.5.2.3.). The last process is reducing the density of the scan's mesh or the polygon's count in order to speed up the processing times if the scan's file is too large for the printer to handle, or to facilitate its transmission via internet to a dental laboratory (114).

Figure 2.5.2.1. A hollow scan as imported directly from the scanner Showing holes and excess margins.

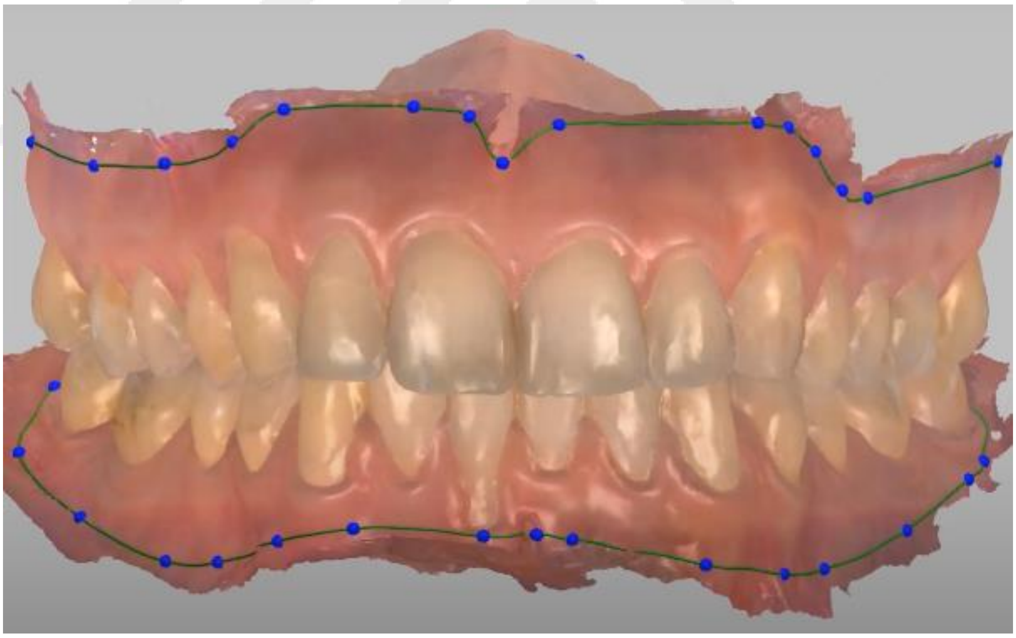

Figure 2.5.2.2. Editing the model by trimming extraneous polygons

Figure 2.5.2.3. Solidifying the model and adding a base

This workflow creates a major advantage for clear aligner therapy as the clinician no longer has to dissect teeth from a stone model and reset them in wax for each stage of movement. Instead tooth movement stages can now be planned digitally using the CAD software that offers teeth segmentation and then moving the teeth to the desired setup in a sequential movement. For each setup a 3D model has to be constructed using 3D printing technology for subsequent aligner fabrication (45,55) (Figure 2.5.2.4.). It also favors the clear aligner technology by allowing the technician or the practitioner to add attachments to the refined model. The shape, size and the location of the attachments that are to be used should be chosen according to the orthodontist preference and knowledge and dictated by the kind of movement or function for these attachments to fulfill (Figure 2.5.2.5.). Now as the refined and designed model is ready to be printed, what follows is exporting the CAD file to a 3D file format, usually the Standard Tessellation Language (stl.) file, prior to outputting the model to the printer.

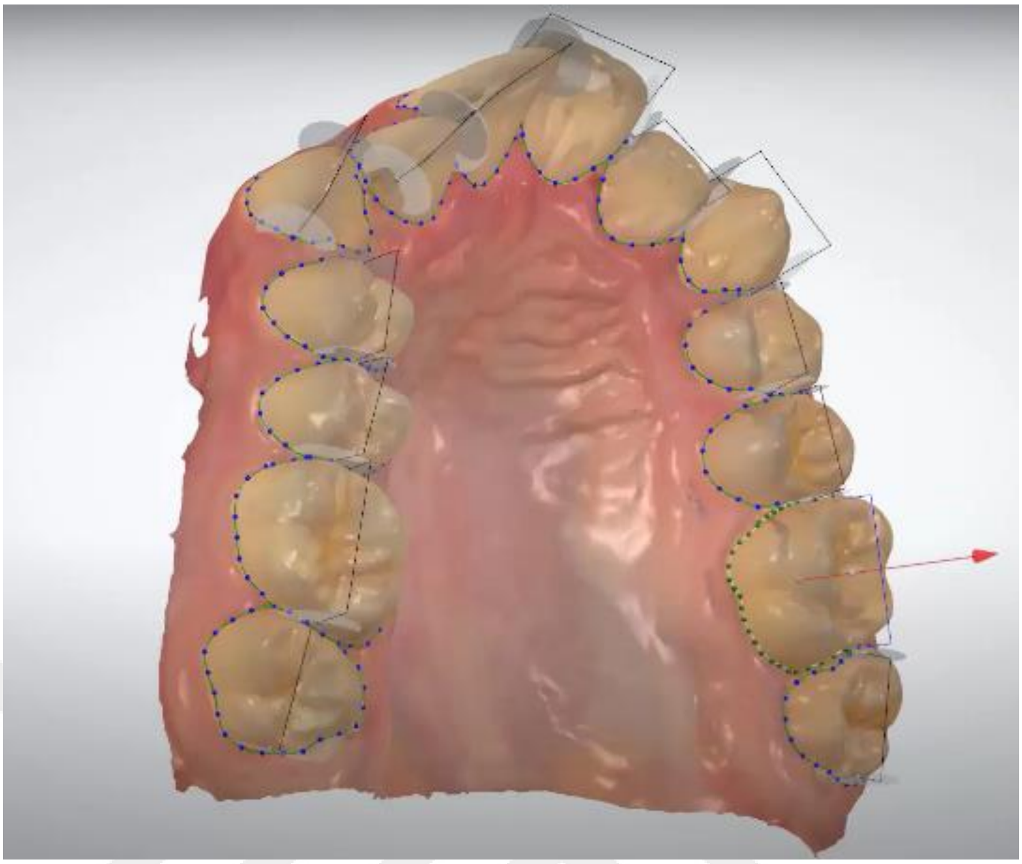

Figure 2.5.2.4. Automated tooth segmentation performed using 3D CAD Software

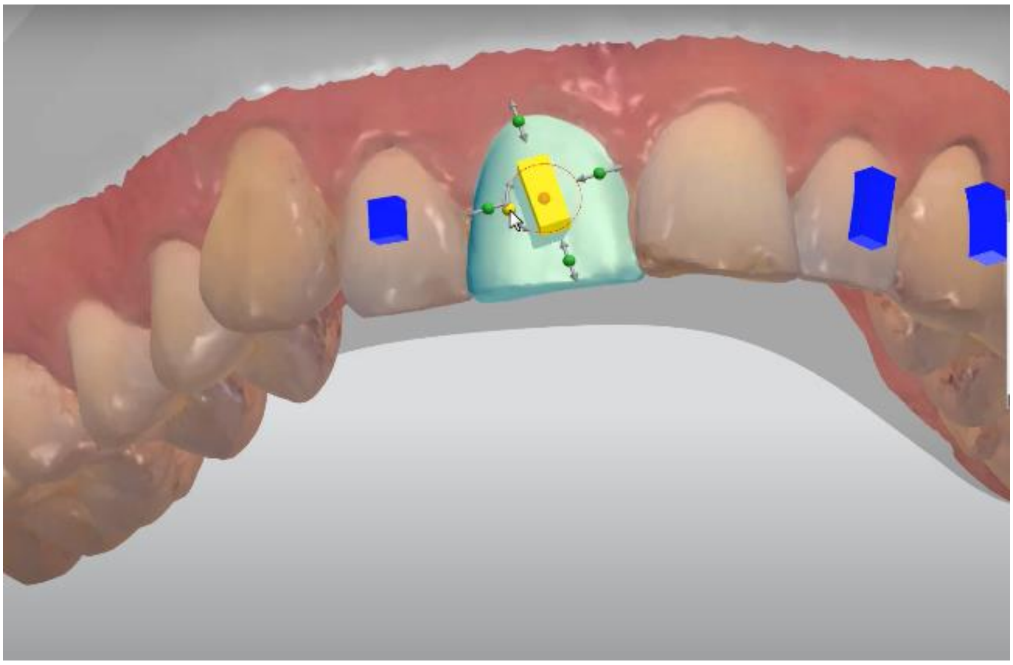

Figure 2.5.2.5. Adding attachments and changing its size, shape and location

2.5.3. 3D Printing of Models

The history of 3D printing can be traced back to 1984 when Charles Hull invented the first 3D stereolithography, a printing method that uses UV light to create a 3D object by building up layer after layer.(124) Afterwards he founded the 3D Systems in 1986 to develop his new technology further and to make it more commercial. The first stereolithography apparatus was sold in 1988 (125). At that time, this technology was still nascent and was used to produce initial designs for primary researches and studies before engaging it into the expensive production process. The late 90s was the beginning of implementing this technology in medicine when the scientists created a 3D printed scaffold covered by the patient cells for augmenting urinary bladder surgery, thus avoiding the complications of transplant rejection. By the 21th century, the technology of 3D printing has developed a lot and became capable of delivering precision to within few microns, paving the way for this century to witness a huge employment of the 3D printing technology in the medical field, varying from printing artificial human organs to artificial blood vessels and human prosthesis (126–128). It didn’t take too long until this technology started gaining popularity in the dental health science where accuracy is of paramount concern. And by the scrambling of different dental companies to synchronize with the acceleration in technological development, they found in the 3D printing technology a chance to replace several labor-intensive workflows by entirely digital workflow (117,119).

The main advantage offered by 3D printing is customization. Customized appliances and modifications according to specific requirements can be obtained. Furthermore, the nature of this technology allows reduction of the amount of material waste and hence the reduction of the production cost compared to material subtracting techniques. Compared to the traditional laboratory production, the use of 3D printing technology has improved the accuracy and reduced the production time and the need for human resources. Models made with 3D printing technology have several advantages over plaster models, including reduced weight, lower damage likelihood, better durability and higher wear resistance. However, the need for post processing phase for some 3D printing techniques can jeopardize the production time, not to mention the high cost of the printing materials as well as extra cost added for maintenance requirements. It’s also important to be noted that one of the main 3D printing limitations regarding techniques, materials, and applications is that there is no single solution for all applications. From the user's point of view, the major aspects to take into considerations in choosing a 3D printer are time, cost, and functionality that allows the user need to be fulfilled with easiest running and operating manner. None of the processes is perfect in all respects. Each process has its own particular characteristics and restrictions imposed by price, material, geometry, size, and accuracy (129–131).

Nowadays the market is providing a variety of different 3D printers that uses different orienting techniques. The choice of printers is impressive and confusing. Furthermore, the industry is currently unregulated, especially in the dental and medical fields. Most professional regulatory bodies have not implemented any guidelines or standards for 3D printing technologies or materials. However, as this process of manufacturing becomes more widely adopted, committees will undoubtedly be set up for introducing and monitoring a code of practice, as well as to address health and safety issues (132).

The printed objects are subject to deviations according to the accuracy of the 3D printer. There are two components of “accuracy”: trueness and precision. “Trueness” is the closeness of a mean of a set of measurements to the actual value, and “precision” is the closeness of agreement of the measurements among each other within a set (133). Therefore, at present, choosing a 3D printer or a particular 3D technology for dental use should be based on the practice and the intended use of the printer, so as the purchased printer should be capable of efficiently producing a physical 3D object that accurately resemble the corresponding pre-designed digital one with an acceptable given margin of deviation based on the clinical application. There are four criteria, which if considered may be useful for making the upmost decision that fulfills this purpose. First, the accuracy of the scanning method (whether IOS or EOS) that has been discussed previously considering the advantages and drawbacks of each method. The second factor is the resolution of the 3D printer. Different 3D-printing technologies can offer different resolutions. A 3D printer resolution stated by the manufacturer refers to the vertical resolution that is also the layer thickness and is measured by dots per inch (dpi) which also corresponds to a certain value in microns (µm). A higher resolution or by other words; a greater (dpi) or a smaller value by µm indicates greater accuracy (134). Next comes the complexity of the CAD design, which may be also referred to the nature of the laboratory work being carried out in the practice, for example, an orthodontist is mainly concerned about printing dental models and maybe some appliances as palatal expansion appliances. This may be important to consider since the geometrical complexity of a design or an object can also affect the printing accuracy, as for better cloning of a complex geometrical design; a printer of higher resolution and a smaller layer thickness by height is required. However, in certain circumstances, a higher resolution doesn’t always necessitate the production of better quality of print, as the complexity of the object's geometry plays a major role here. For example, for simple geometry, a finer resolution may not result in a better-quality print and will only slow down the printing speed, nevertheless, it will result in a rougher surface, while in contrast, a fine detailed object will benefit better from a high-resolution printer (135).

The last item to consider is the printing technique and the type of the printing material used and its properties. The main technologies that dominate the dental market are Stereolithography Apparatus (SLA), digital light processing (DLP), fused deposition modelling (FDM), selective laser sintering (SLS), selective laser melting (SLM), material jetting (MJ)/ PolyJet/multi-jet modelling (MJM) and binder jetting (BJ).

As the number of dental applications of 3D printing increases, new materials are being introduces to cater for these needs. Each 3D printing technology can process different materials in different ways. The available materials vary, with polymers and plastics being the most common, but metals, ceramics, and various other composites are also emerging. The produced parts can also have a wide range of physical properties depending on the additive manufacturing (AM) process, parameters, and application (136–146). The most common printing technology that can be deemed for orthodontic practice is the resin-based printing technology or the so called material polymerization printing technology, which utilizes a photosensitive polymer in a tank or a vat that is to be cured by a light source. The commonly used printing techniques that embrace the resin-based printing technology are the Stereolithographic Apparatus (SLA) and the Digital Light Processing (DLP) (Figure 2.5.3.1. and 2.5.3.2.). (134,147,148)

Vat polymerization utilizes ultraviolet (UV) light to selectively cure liquid photopolymer in a vat. SLA is the first and original 3D printing technique initially commercialized by 3D Systems. In this process, a UV light source (laser) is directed in the x-y axis by mirrors (called galvanometers) to cure photosensitive liquid resin. The laser beam draw or trace the pattern of the object design layer by layer by hitting the resin, which is cured, and a thin layer of solid material is produced. After each layer is completed, the platform moves by a small amount corresponding to the predetermined printing layer thickness, thus exposing another thin layer of resin that can also be cured. In this way a solid model slowly builds up. There are two ways to shift the platform in SLA technology. The first is the top-down movement of the platform. The building platform, which is immersed in the resin reservoir, is covered in a coating of resin. The building platform glides down after the laser scans the first layer, and a wheel next to it adds a fresh layer of resin. The build cycle is repeated until the object is created. The other approach is the bottom-up movement of the platform. In this approach, the platform is submerged at the bottom of the resin reservoir, and the gap between the platform and bottom can shift only a single layer of resin. The resin layer would be scanned with the laser, which would be installed at the bottom of the reservoir. After curing, the platform shifts upward by one layer, and the resin material can completely fill the gap between the platform and the bottom of the vat. Nowadays, most SLA printers introduce the later approach as it is advantageous over the former one due to the following reasons; in top-down approach the resin is in direct contact with oxygen as it undergoes polymerization, whereas in the bottom-up approach the light-curing occurs at the bottom to avoid oxygen interference. Moreover, in the bottom-up approach, the laser is located at the bottom, which reduces the potential for injury to the operators. To prevent collapse of the structure, most of the time supports must be provided for the resin layers. Once complete, the model is carefully removed from the bath, cleaned of excess resin by immersing it in an alcoholic solution, and then placed in a UV oven for further curing and to achieve its final material properties. Any support structures must then be removed from the model, and the object can be further smoothed. The DLP technology consists of a rectangular arrangement of mirrors, called a digital micro-mirrors device. Each mirror represents one pixel, and the resolution of the projected image depends on the number of mirrors. Instead of curing one point at time, DLP uses a digital light projector to "flash" an image of the cross-sectional layer and cure a whole layer at once. The utilized source of light is a light-emitting diode (LED) or UV light lamp. As mentioned, the digital projector is comprised of pixels, so that when the light emitted by the light source is refracted by the micro-mirrors and then projected onto the surface, the material curing is done in the form of voxels. Unlike the SLA technique where the printed object is being traced by a laser beam for each layer, the DLP technique allows the entire layer to be exposed to the light source and cured at a time, and thus, the printing time can be reduced (129,134,149,150).

few studies have examined the use of SLA and DLP printers in dentistry from the dimensional accuracy aspect. Brown et al. (23) assessed the accuracy of DLP printed models by comparing them to stone models. DLP technique produced clinically acceptable models with high accuracy that may allow it to serve as a replacement for stone models and to be considered viable options for clinical applications. The mean difference between crown height measurements for the DLP and stone models was statistically significant in this study, but it was within a clinically acceptable range. Camardella et al. (24) found that the accuracy of SLA models may differ according to the model base shape. Choi et al. (151) compared both SLA and DLP printed models with a reference typodont model consisting of inlay preparation, single crown unit preparation and 3-unit bridge preparation. Stone models showed better accuracy than the printed models for the full arch segment. Both the reference and the test models were scanned and turned into digital models then the test (SLA and DLP) models were superimposed with reference model for accuracy evaluation. 3D printed models showed reduced trueness of the three-unit preparation segment compared to the inlay and single crown preparations, which is consistent with previous studies that show that the accuracy of 3D printed models is inferior as the span increases (152). On the other hand, for the prepared units, SLA showed better trueness than DLP for all prepared teeth except inlay preparation, which is inconsistent with the study results of Kim et al. (153), who found a significant differences in precision of all measurements and in trueness of tooth and arch measurements among the SLA and DLP printing techniques compared to the digital control models, with the DLP technique being more precise than the SLA technique. He also recommended that 3D-printing techniques should be selected on the basis of required clinical application. Hazeveld et al. (25) investigated the accuracy and reproducibility of physical dental models reconstructed from 3D printer uses DLP technique. DLP technique indicated high reproducibility. When replicas reconstructed by DLP technique were compared to plaster models it showed low mean systematic differences, considering DLP replicas to be clinically acceptable in terms of accuracy and reproducibility and might be appropriate for selected applications in orthodontics. Cuperus et al. (154) determined the validity and reproducibility of measurements on SLA models replicated from human skulls. They concluded that distances measurements of dentition made on the SLA models were valid and reproducible. Rebong et al. (26) assessed the dimensional accuracy of SLA produced models by comparing them to traditional plaster casts. SLA models showed a tendency toward expansion for intra- and interarch measurements and a tendency toward shrinkage in the vertical plane. Hassan et al. (27) compared agreement and accuracy of measurements made with SLA-printed models and stone models for different degrees of crowding. SLA-models were not clinically comparable with conventional stone models regardless of the degree of crowding. They also added that 3D printed models may not be an acceptable replacement for conventional stone models. Keating et al. (28) determined the accuracy of physical model replicas constructed from SLA printer by comparing it to the same measurements made on the original plaster model. Their results led to the accuracy of physical models reconstructed from digital data using the SLA technique, may not be sufficient for certain applications.

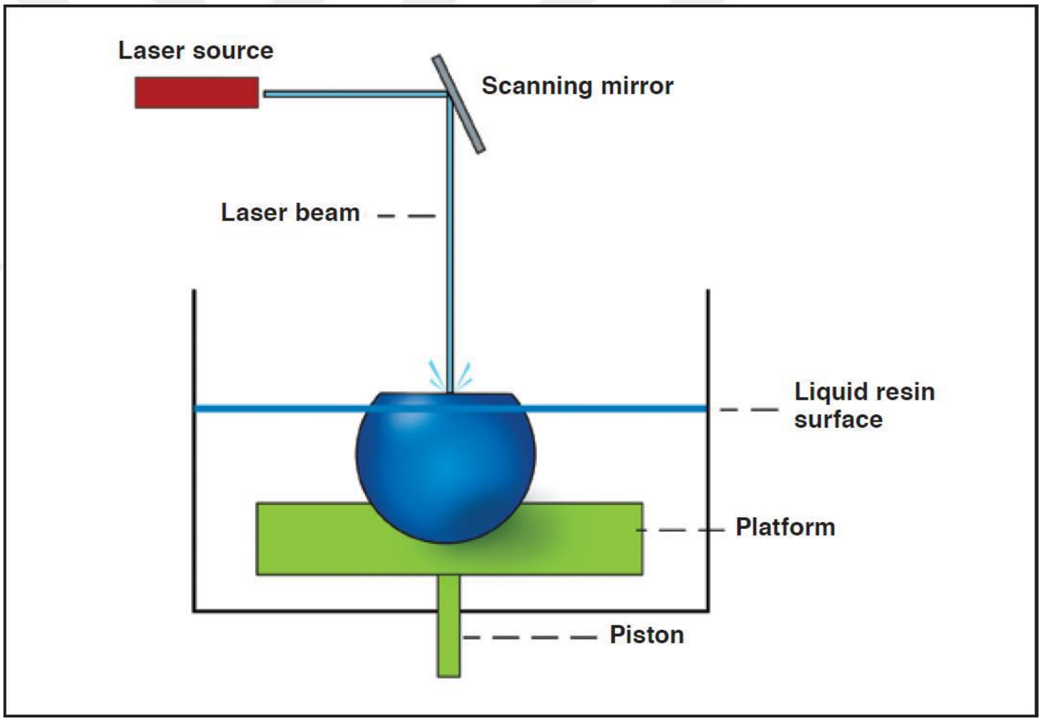

Figure 2.5.1.3. Stereolithographic Apparatus (SLA) 3D Printing Technique.

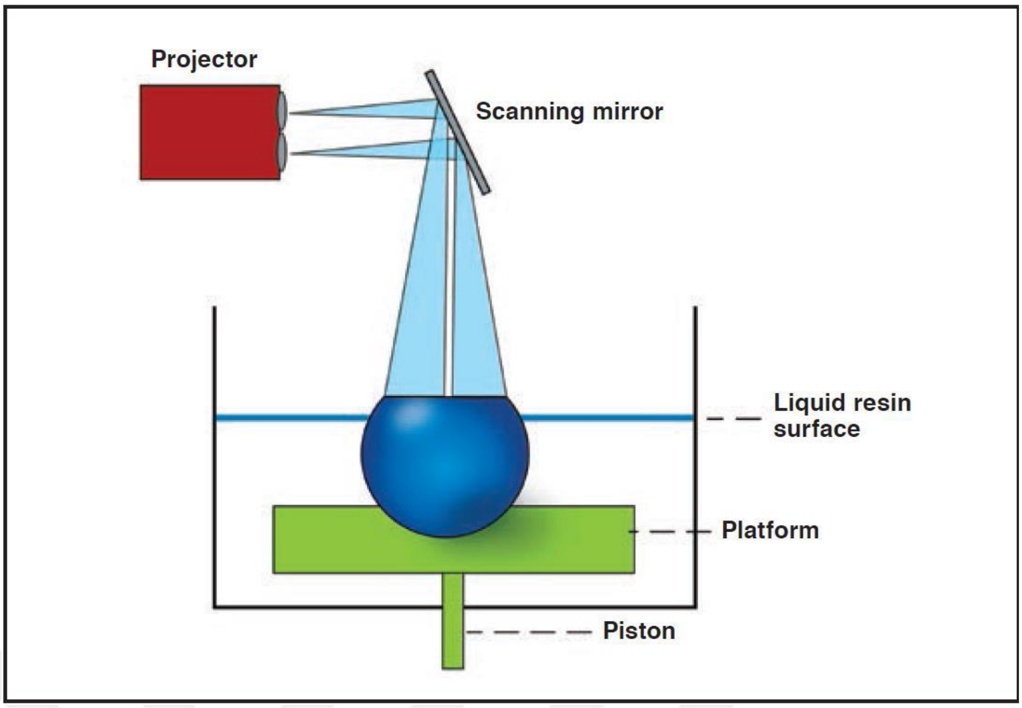

Figure 2.5.1.3. Digital Light Processing 3D Printing Technique

3. SUBJECTS and METHODS

This study was approved by Yeditepe University Ethical Board for Non-Interventional Clinical Research, application number (202110099). The selected individual showed no objection against using his scanned dental arch in the present study and has signed the Informed Consent Form after receiving information about the study.

3.1. Subjects:

This study was carried out on two groups; digital data obtained by scanning of printed attachments using SLA technique and DLP technique. Each of these two groups was divided into 6 sub-groups according to the shape of the attachments being used in this study. As controls, the original digital data of the same attachments before printing were used.

The subjects were selected from the previously scanned patients at Yeditepe Dental Faculty and Hospital-Department of Orthodontics. All patients were scanned with TRIOS intraoral scanner (3Shape, Copenhagen, Denmark) according to the manufacturer's instructions.

3.1.1. Subject Selection Criteria:

One subject was chosen based on the following criteria:

- Mild crowding from ≥ 0 to ≤1 mm according to the Discrepancy Index of the American Board of Orthodontists (ABO).(155)
- Fully erupted and complete permanent dentition, from second molar to second molar for both maxillary and mandibular arches.
- None of the teeth having any dental anomalies in size or shape.
- No significant dental crown defects due to abrasions, attritions or erosions.
- No carious lesions or restorations extending to the labial or the buccal surface.
- None of the teeth covered with fixed crowns or bridges.

64 dental scans (32 maxillary and 32 mandibular) were first examined and the

inclusion criteria were applied except for the crowding criterion. 22 scans (12 maxillary and 10 mandibular) were selected and then subjected to crowding examination. Crowding was assessed by applying the Discrepancy Index of the American Board of Orthodontists (ABO)(155). The 22 scans were transformed into digital models and digital measurements were carried out on these models using (Ortho Analyzer 3D software, 3Shape A/S, Copenhagen, Denmark). Each arch was considered for examination separately and was given a score from 1-7 points accordingly. If crowding is 1-3 mm, 1 point is scored; from 3.1-5 mm, 2 points are scored; from 5.1-7mm, 4 points are scored, and if greater than 7 mm, 7 points are scored. Only arches that scored 1 point (1-3 mm crowding) were considered. All scans were excluded except for 8 (4 maxillary and 4 mandibular) scans that were found to fall within the mild crowding group. Two models (1 maxillary and 1 mandibular) of which was chosen randomly to collaborate in the study. Each of these two models will be duplicated an equal number of times by 3D printing to obtain 4 models of each (2 maxillary-SLA, 2 maxillary-DLP, 2 mandibular-SLA and 2 mandibular-DLP). The decision of choosing two models and duplicating them instead of choosing 8 different models can be justified by the urge to standardize the position, location, angulation, tilting and size of each attachment individually which is dictated by rotation, tilting, angulation and different sizes of the teeth, the thing that will lead to more reliable measurements when superimposing the attachments on the same corresponding teeth.

3.2. **Methods:**

The present study was carried on over four phases:

- First phase: The attachments with the desired shapes and dimensions were designed using Rhinoceros 3D Software version 7 (Robert McNeel & Associates, Seattle, USA)
- Second phase: Preparing the models to receive the attachments using Ortho Analyzer 3D software (3Shape A/S, Copenhagen, Denmark)
- Third phase: Printing and scanning the models
- Fourth phase: Superimposition and 3D comparison using Geomagic Control X software (3D Systems, South Carolina, USA).

3.2.1. Designing the Attachments:

Attachments can be provided within various orthodontic CAD software. There are two options for dental computer-aided designing: either to purchase a dedicated dental CAD software like Ortho Analyzer 3D software (3Shape A/S, Copenhagen, Denmark) which provides the user with a ready-made attachments' configurations, or a generic 3D manipulation software (generic CAD or G-CAD) like Meshmixer, Blender and Rhino, which can be used to design customized attachments following the user preference. The decision was to design customized attachments for this study and not to rely on the ones provided by a (D-CAD) software, as their attachments library, most of the time, need to be updated by the company itself in a way that meets the needs of the user to manage different clinical cases. Furthermore, trying to adapt a pre-designed attachments manually on each tooth will result in different dimensions of the same attachment on each tooth specially in their height, as there is no way to guarantee a uniform height for all attachments due to their flat basal surface in contrast to the convexity buccal/labial surfaces of all the teeth, and thus, the need to push the attachment perpendicular to the labial/buccal surface to make sure to close all the margins circumferentially. In addition to this, none of the commercially available clear aligner companies in the market agreed to provide us with the stl. format of their attachments, therefore, all attachments' configurations used in this study were designed built and from scratch by the author himself using Rhinoceros 3D Software version 7 (Robert McNeel & Associates, Seattle, USA).

3.2.1.1. **Shapes of the used Attachments:**

Six types of attachments were designed according to their applied function:

- Beveled Horizontal Rectangular Attachment (Figure 3.2.1.1.A.).
- Two different shapes of root control attachments (vertical rectangular and Optimized Root Control Attachments) (Figure 3.2.1.1.B. and 3.2.1.1.C.).
- Optimized Rotation Attachment (Figure 3.2.1.1.D.).
- Two different shapes of retention attachments (Horizontal Rectangular and Ellipsoid Attachments) (Figure 3.2.1.1.E. and 3.2.1.1.F.).

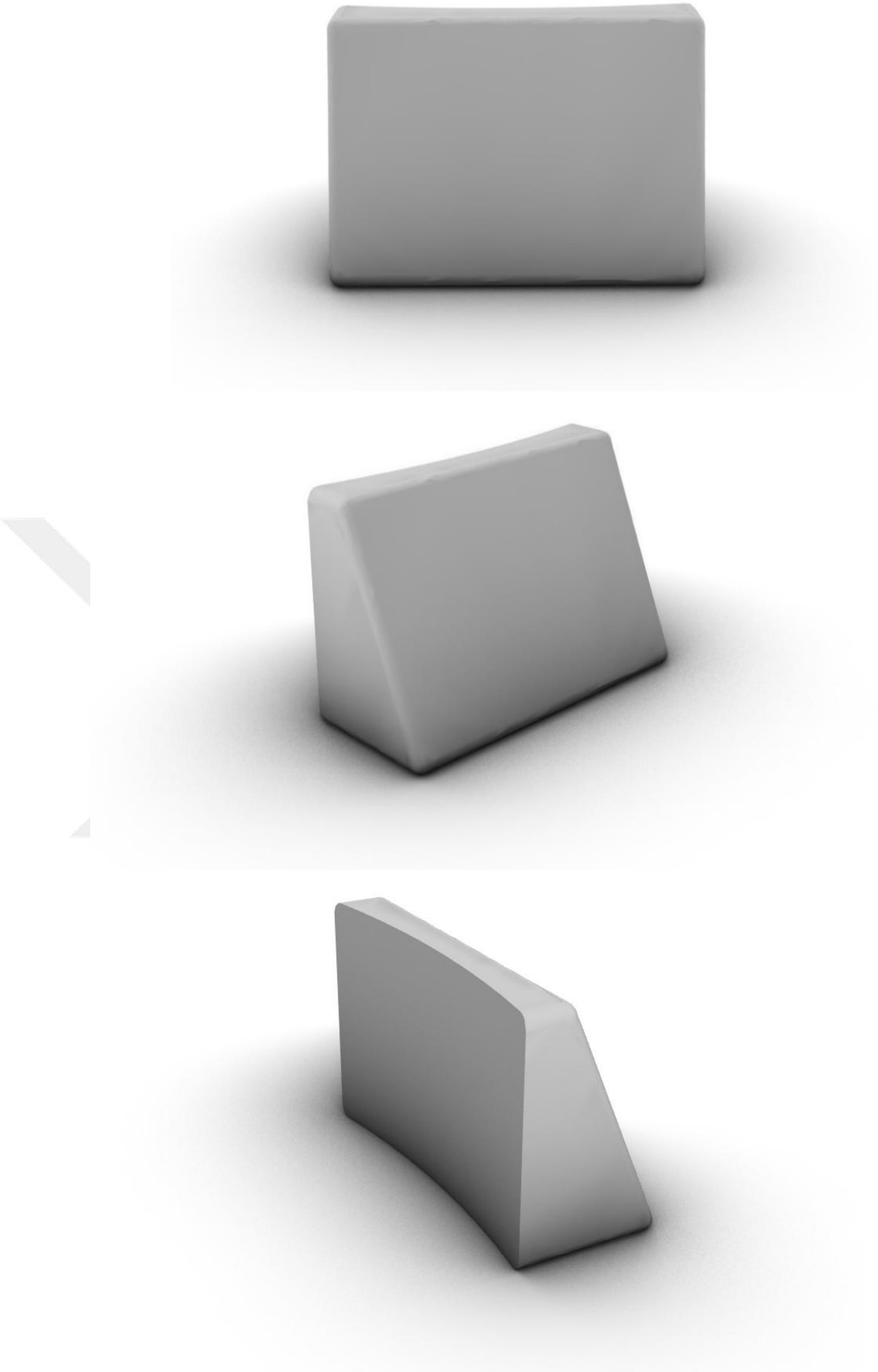

Figure 3.2.1.1.A. Beveled Horizontal Rectangular Attachment

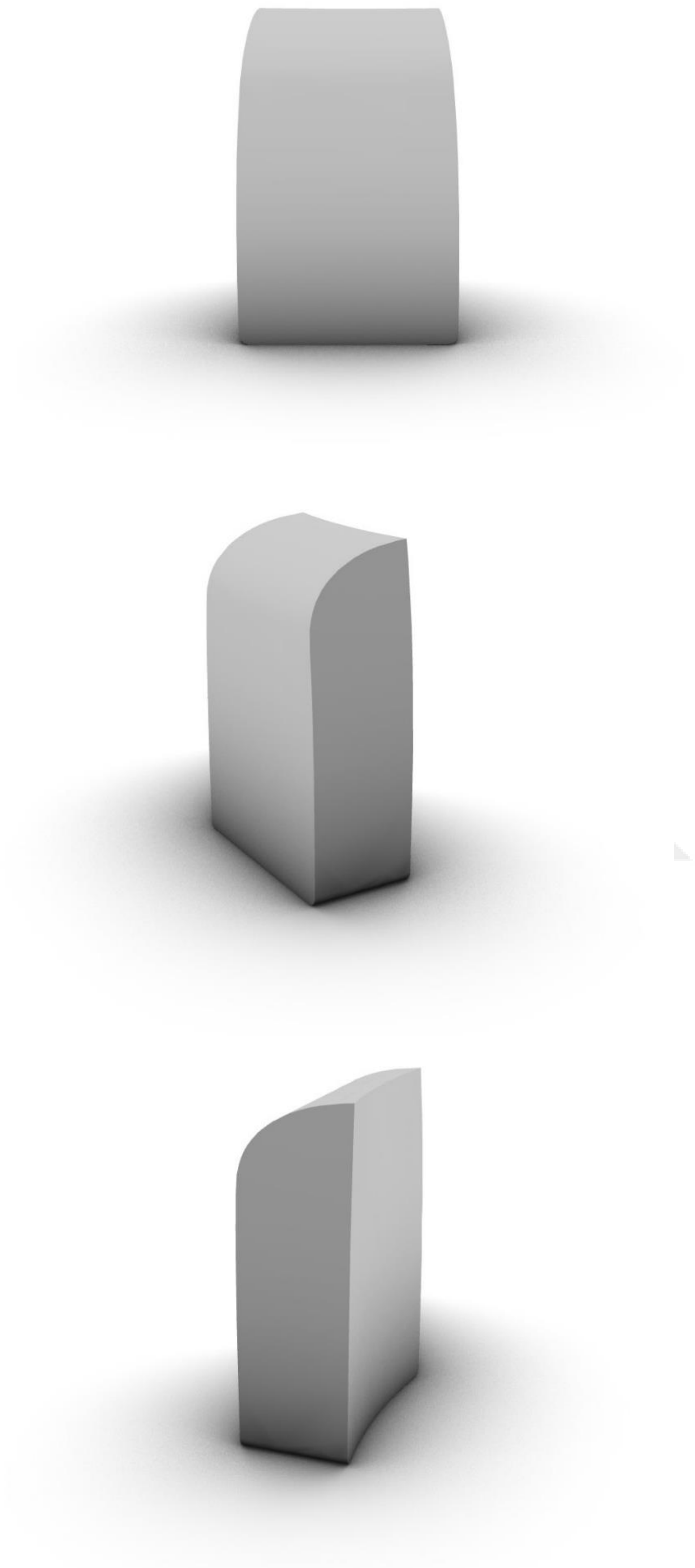

Figure 3.2.1.1.B. Vertical Rectangular Attachment

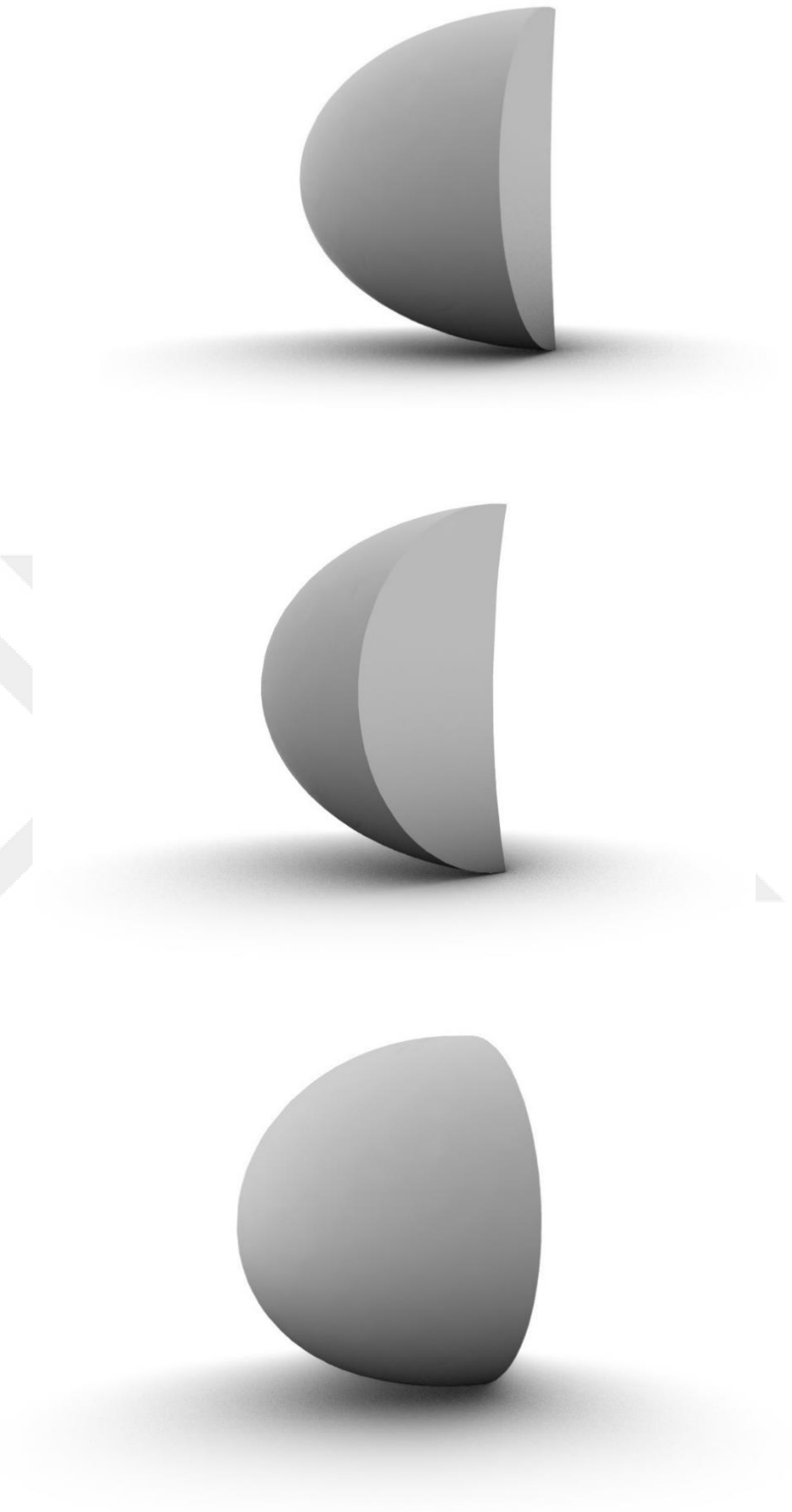

Figure 3.2.1.1.C. Optimized Root Control Attachment.
Note that in normal clinical application of this attachment, it is used as a pair in order to control root movement.

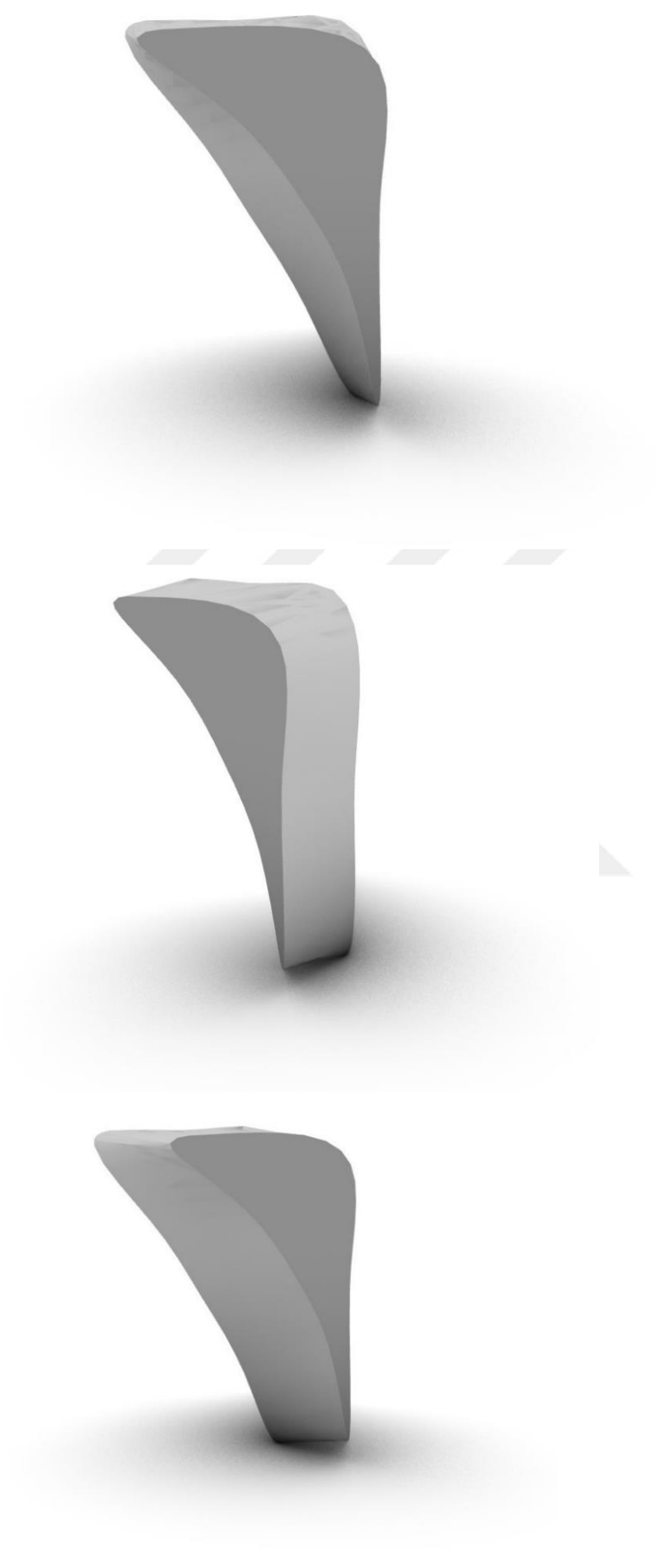

Figure 3.2.1.1.D. Optimized Rotation Attachment

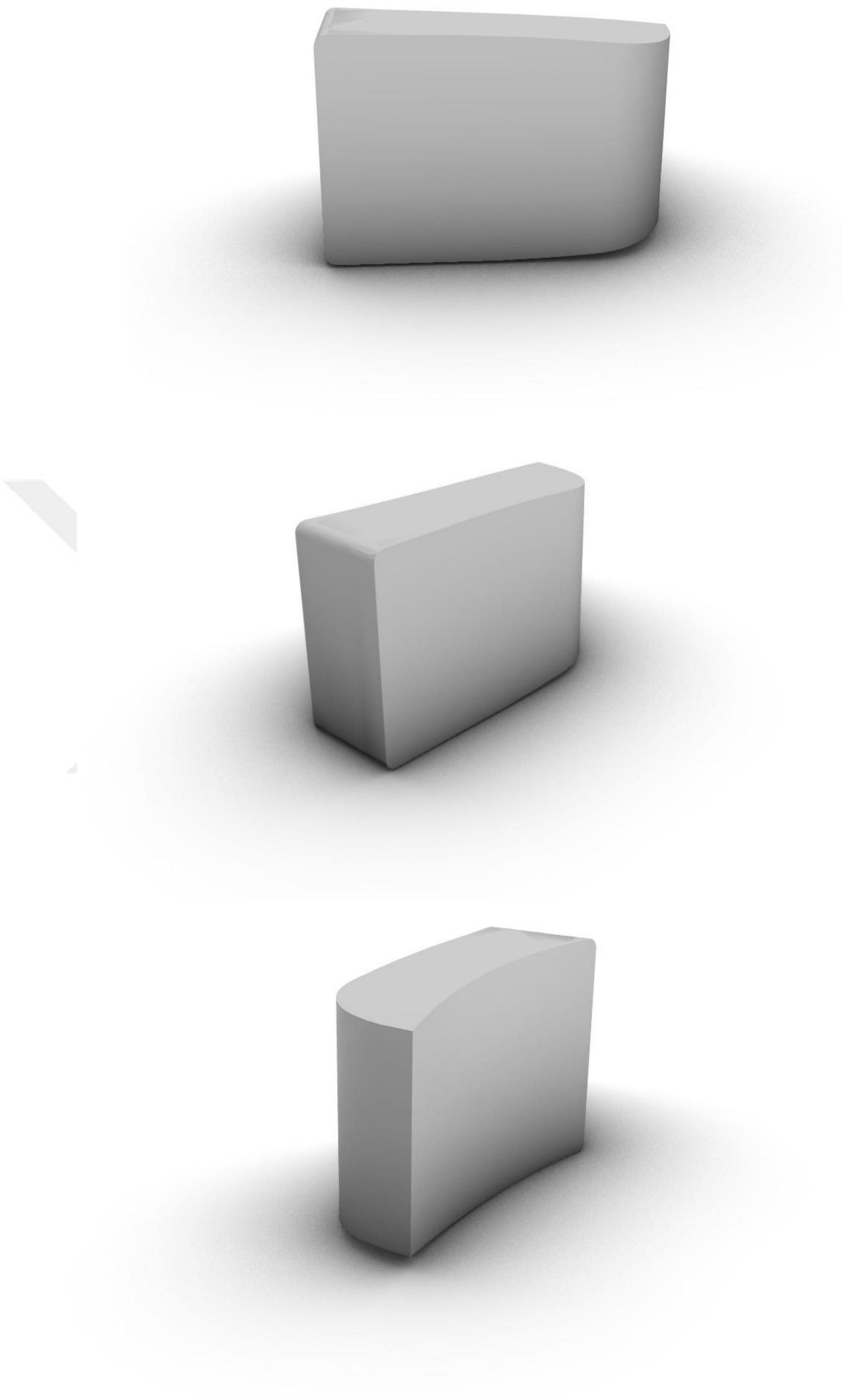

Figure 3.2.1.1.E. Horizontal Rectangular Attachments

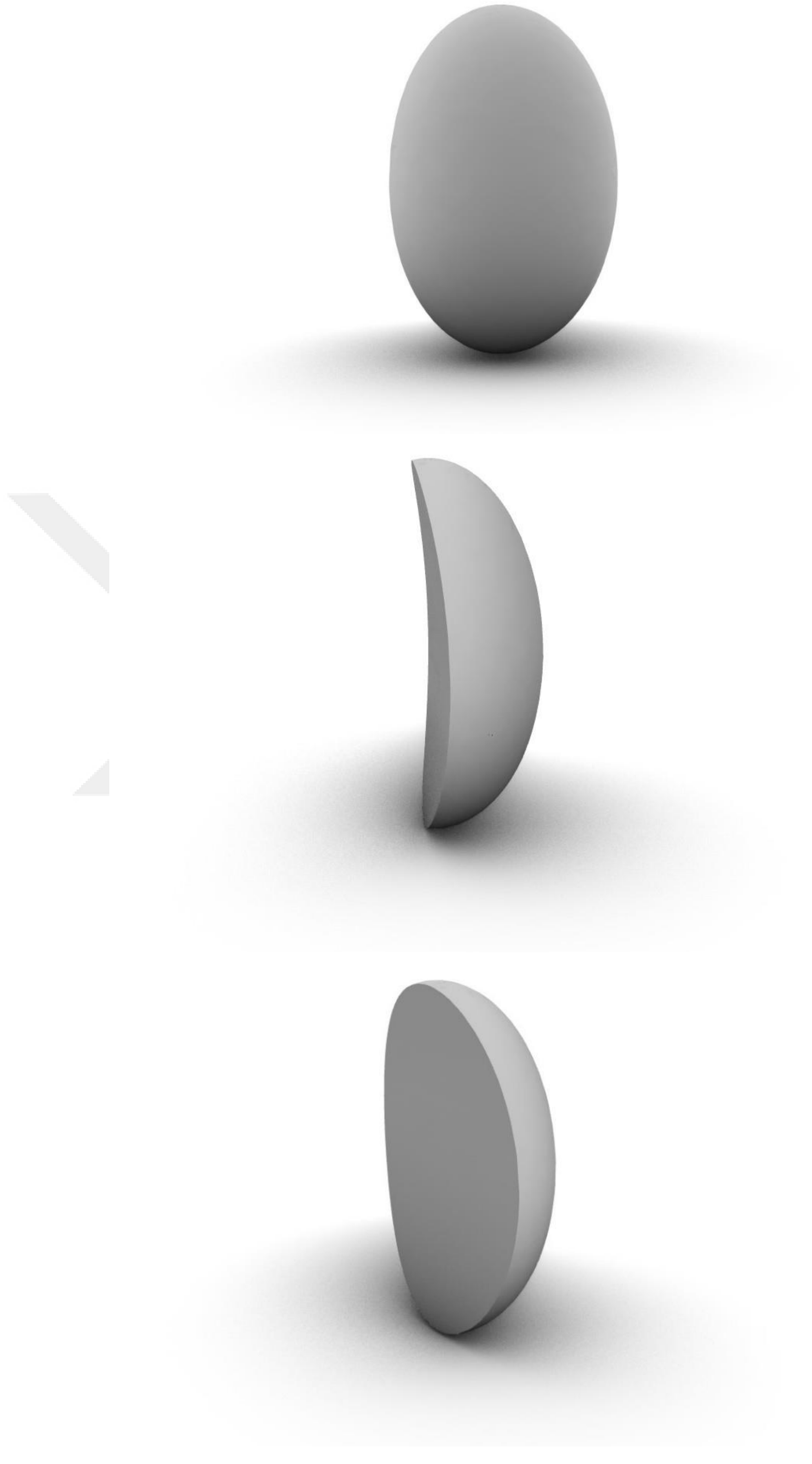

Figure 3.2.1.1.F. Ellipsoid Attachment

By these designs we intended to cover all the attachments that are common between different clear aligner companies, and by which most of the time are being referred to as conventional attachments, except for rotation attachment. No intrusion attachment was used in the study as intrusion is achieved by either using the same geometry as extrusion attachment in an inverted position with the beveled surface directed incisally or by using retention attachments on the posterior teeth while intrusion forces are being exerted by the aligner itself.

3.2.1.2. **Dimensions of The Attachments:**

The attachments' dimensions were designed as default sizes for conventional attachments by referring to Invisalign conventional attachments as follow:

- Ellipsoid attachment: 3 mm height, 2mm width, 1 mm prominence (Figure 3.2.1.2.A.).
- Vertical Rectangular attachment: 3 mm height, 2 mm width, 1mm prominence (Figure 3.2.1.2.B.).
- Horizontal Rectangular attachment: 3 mm height, 2 mm width, 1mm prominence (Figure 3.2.1.2.C.).
- Beveled Horizontal Rectangular Attachment: 3 mm height, 2 mm width, 0.5-1.25 mm prominence (Figure 3.2.1.2.D.).
- Optimized Root-Control attachment: 2 mm height, 1.5 mm width, 1 mm prominence (Figure 3.2.1.2.E.).
- Optimized Rotation attachment: 3 mm height, 2 mm width, 1 mm prominence (Figure 3.2.1.2.F.).

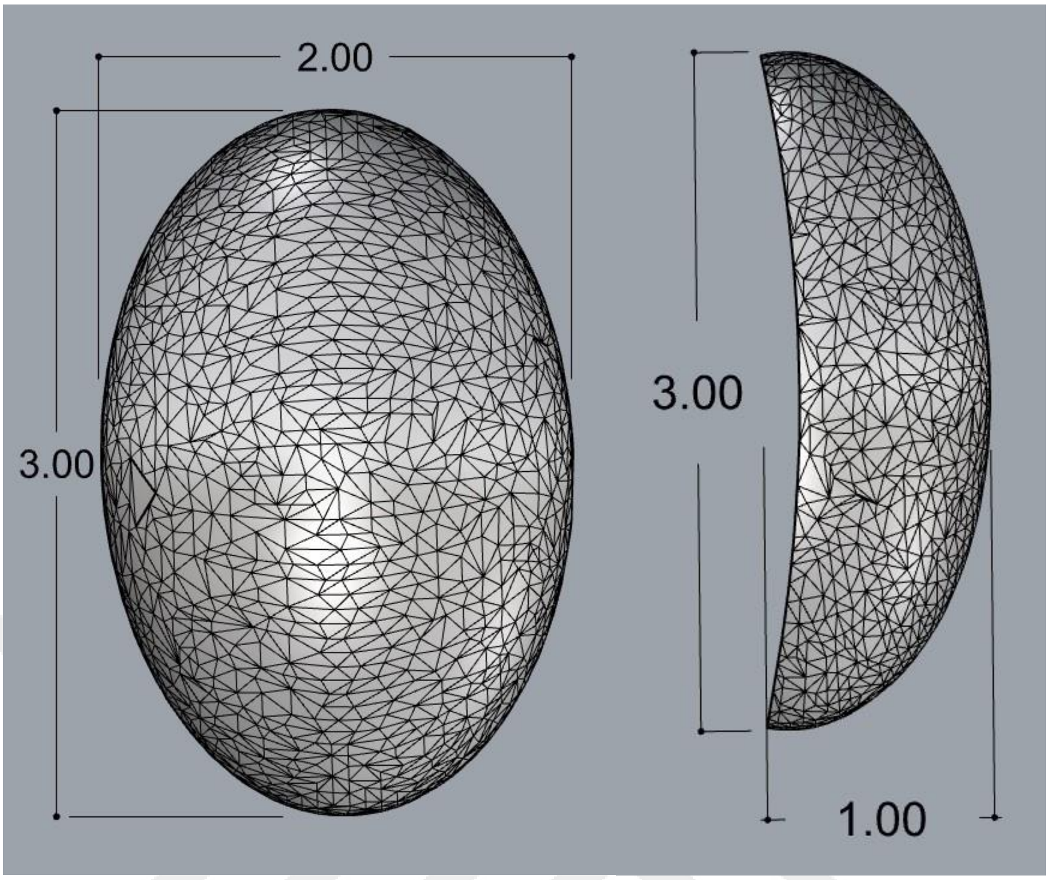

Figure 3.2.1.2.A. Dimensions of Ellipsoid attachment.

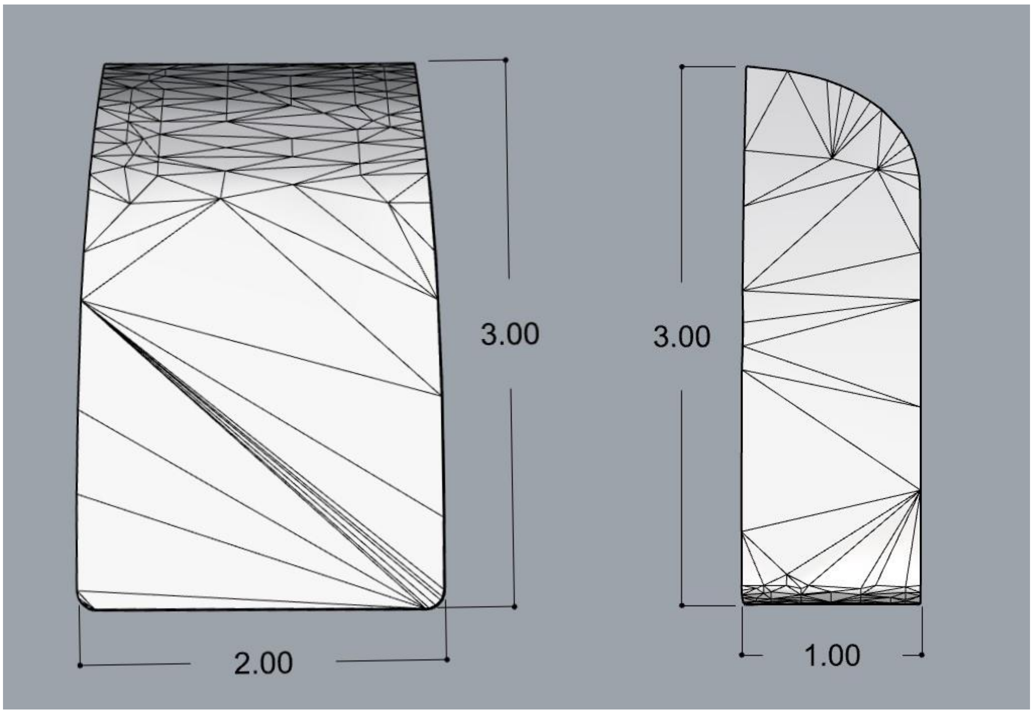

Figure 3.2.1.2.B. Dimensions of Vertical Rectangular attachment.

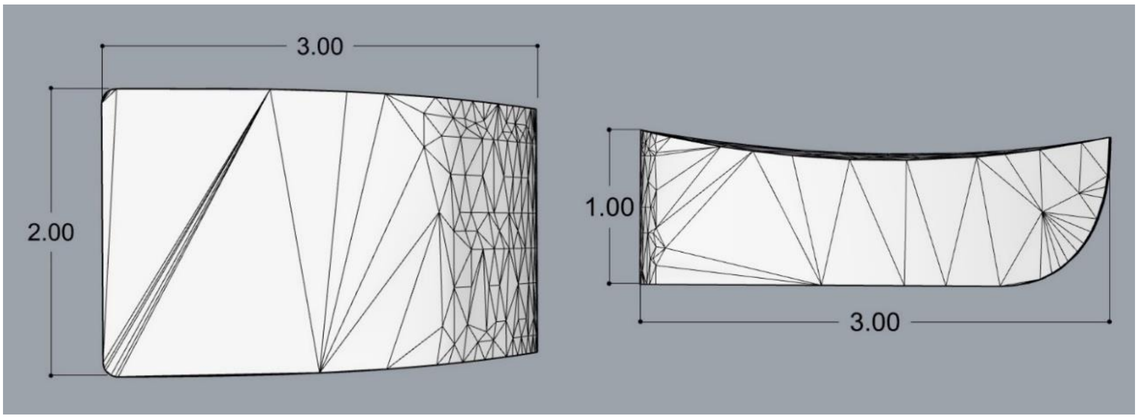

Figure 3.2.1.2.C. Dimensions of Horizontal Rectangular attachment.

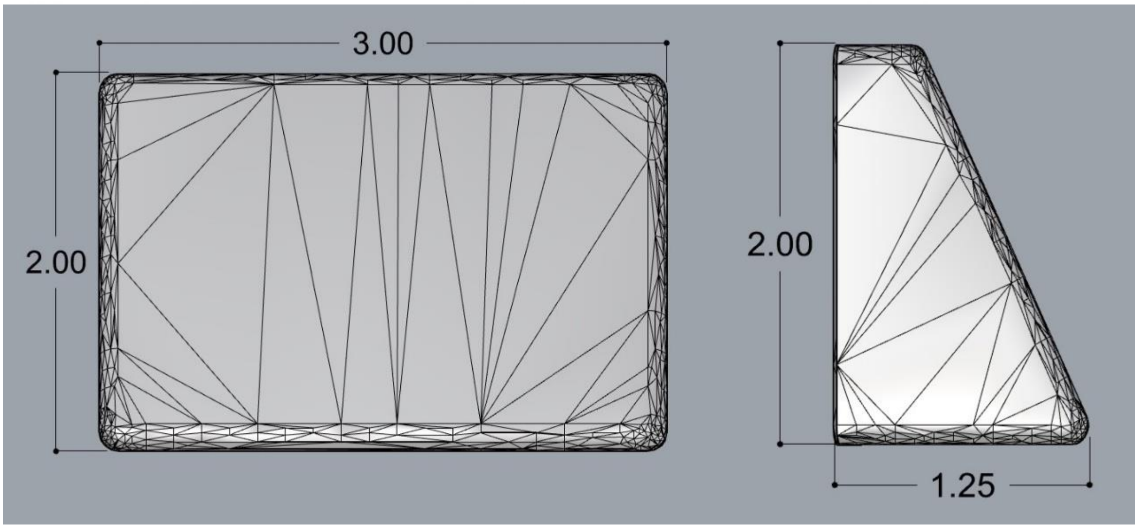

Figure 3.2.1.2.D. Dimensions of Beveled Horizontal Rectangular Attachment.

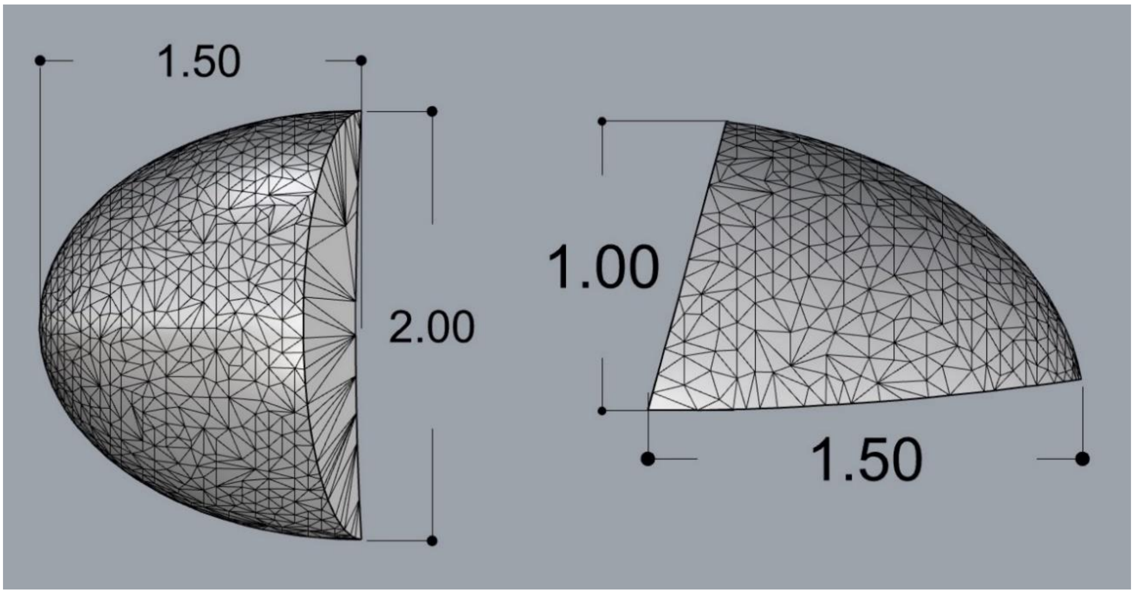

Figure 3.2.1.2.E. Dimensions of Optimized Root-Control attachment.

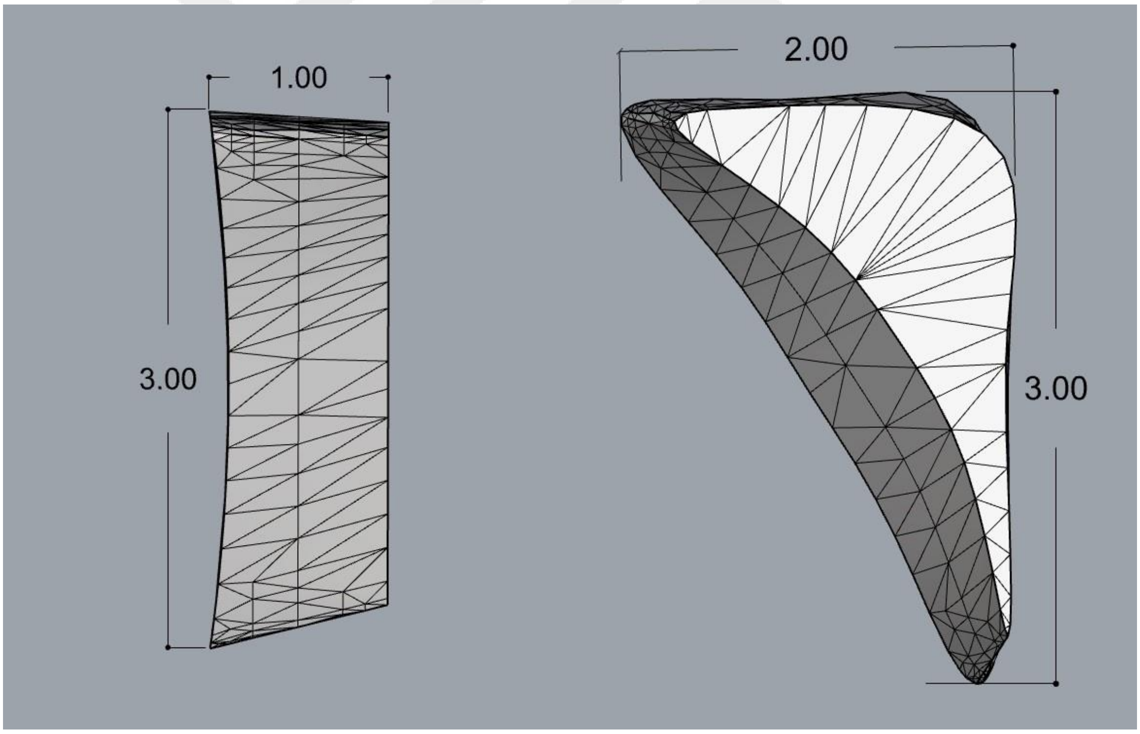

Figure 3.2.1.2.F. Dimensions of Optimized Rotation attachment.

3.2.2. Second Phase; Preparing the Models:

The scans of both arches when exported directly from the TRIOS scanner are not suitable for printing and are incompatible with the printing software. The incompatibility result in models being not “water-tight” which in CAD/CAM terms refers to a 3D model that is not solid with voids or holes in in its body (Figure 3.2.2.1.A.). To overcome this problem, the images have to undergo an additional step of processing using a mesh repair CAD software.

3.2.2.1. Cleaning the Scans and Transforming them to 3D Models:

Various software products are available to custom- design appliances digitally. Each orthodontist and/or laboratory should choose a dental analysis and appliance design software according to their preferences in terms of user-friendliness of the design procedures, time involved in the preparation of the digital design, and pricing. However, the most popular (D-CAD) software for orthodontics is the Ortho analyzer software (Copenhagen, Denmark) from 3Shape Ortho System. Purchasing a (D-CAD) software package has the advantage of being user friendly with familiar dental terminologies and a bunch of customized steps implemented in order that guides the user through the determined procedure which make is easier to prepare the models and adding the attachments, unlike the (G-CAD) software which require a lot of knowledge and user experience to configure them for dental use.

The images were imported to the Ortho analyzer software to transform them into two digital models of the maxillary and mandibular arched separately. On the digital models any defects and unnecessary margins were erased, any holes were filled and base for both models was added (Figure 3.2.2.1.B. and 3.2.2.1.C.).

Figure 3.2.2.1.A. The STL unsolid scan images imported directly from the intraoral scanner. Notice the voids and holes in the body of the scan.

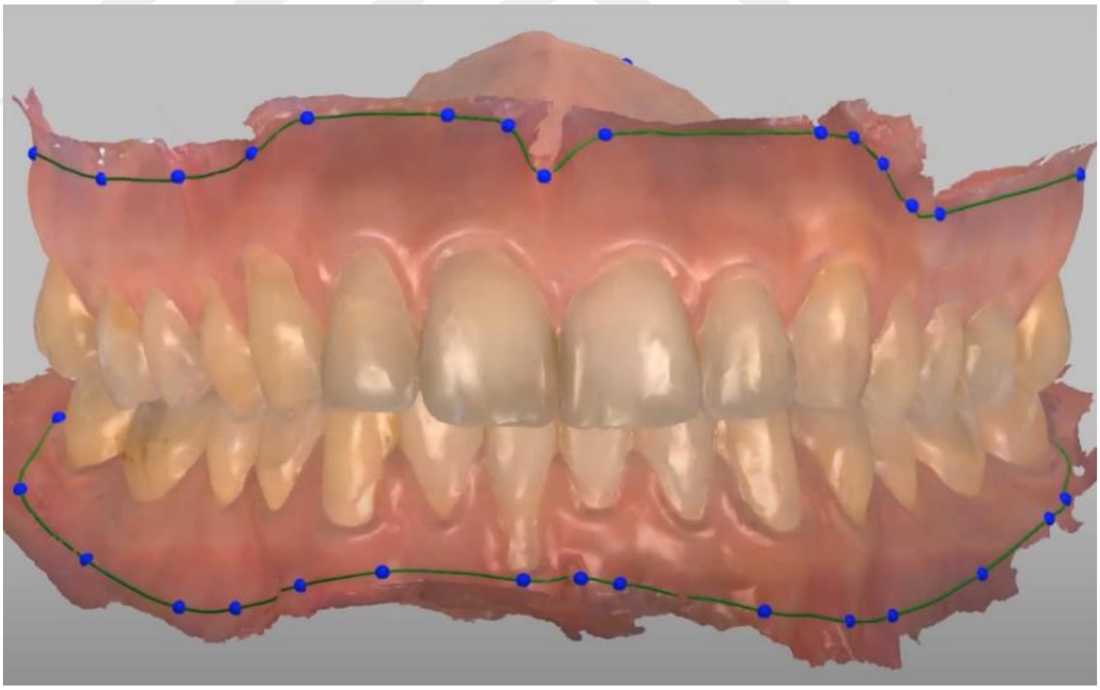

Figure 3.2.2.1.B. Cleaning the scan from any defects, cutting unnecessary extended margins and closing any holes in the model scan body.

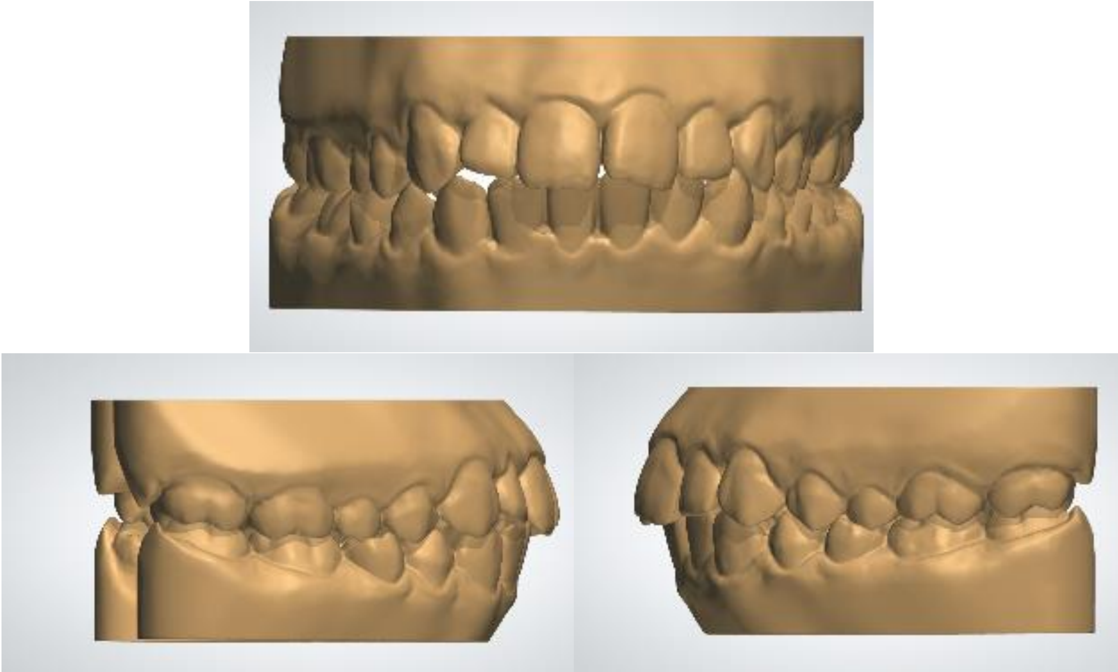

Figure 3.2.2.1.C. Solid model with closed base.

3.2.2.2. **Importing the Attachments to Ortho Analyzer Software:**

The attachments were imported to the Ortho Analyzer software (3Shape A/S, Copenhagen, Denmark) to be received over the teeth labial/buccal surface in the following order (Figure 3.2.2.2.A. and Figure 3.2.2.2.B.). The distribution of attachments over the teeth is explained in (Table 3.2.2.2.A.):

Table 3.2.2.2.A. The distribution of attachments over the teeth.

Teeth group	**Attachment design**
Upper central and lateral incisors	Beveled Horizontal Rectangular Attachment
Upper and lower canines	Optimized Root Control Attachment
Upper first and second premolars	Optimized Rotation Attachment
Upper first and second molars	Vertical Rectangular Attachment
Lower first and second premolars	Ellipsoid Attachment
Lower first and second molars	Horizontal Rectangular Attachment

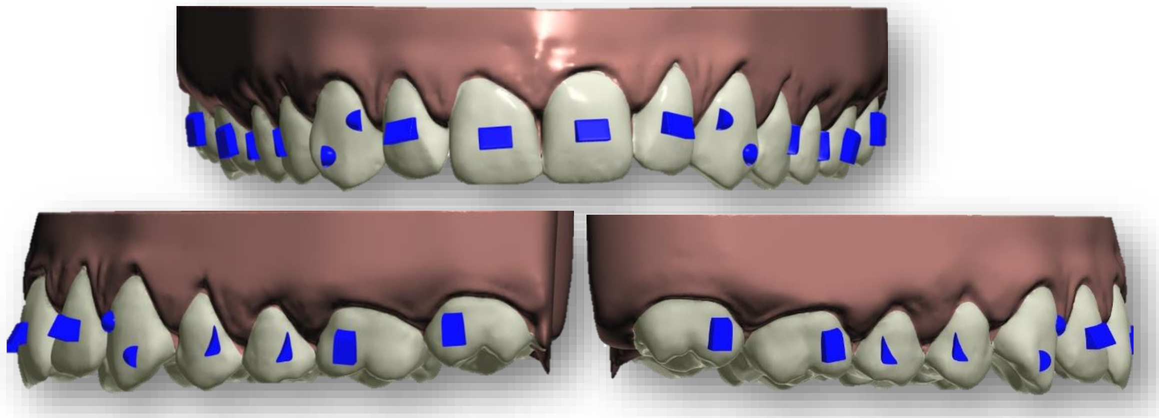

Figure 3.2.2.2.A. The distribution of the attachment over the labial/buccal surface of each tooth in the upper arch.

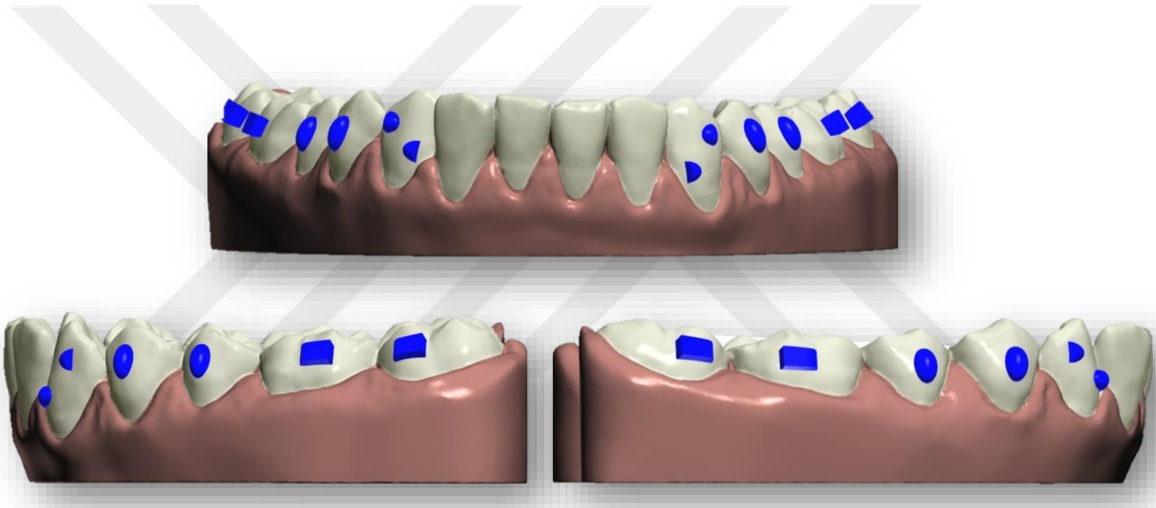

Figure 3.2.2.2.B. The distribution of the attachment over the labial/buccal surface of each tooth in the lower arch.

3.2.2.3. **Attachments Location:**

The adopted methodology in determining the area of labial/buccal tooth surface over which the attachments will be placed was by dividing each tooth surface virtually both vertically and horizontally into thirds.

The position of the attachments on each tooth is explained in (Table 3.2.2.3.A.) and demonstrated in (Figures 3.2.2.3.A. - 3.2.2.3.A.-F.):

Table 3.2.2.3.A. position of the attachments on each tooth.

Teeth group	Description of the attachment Position
Central and lateral incisors	The flattest or less convex surface of the middle vertical third (Figure 3.2.2.3.A.)
Upper and lower canines	The flattest surface of the mesial-cervical and distal-incisal thirds respectively (Figure 3.2.2.3.B.)
Upper premolars	The flattest surface of the mesial-cervical and mesial-middle thirds (Figure 3.2.2.3.C.)
Upper molars	The flattest surface of the mesial vertical third (Figure 3.2.2.3.D.)
Lower premolars	The flattest surface of the middle-middle third (Figure 3.2.2.3.E.)
Lower molars	The flattest surface of the middle horizontal third (Figure 3.2.2.3.F.)

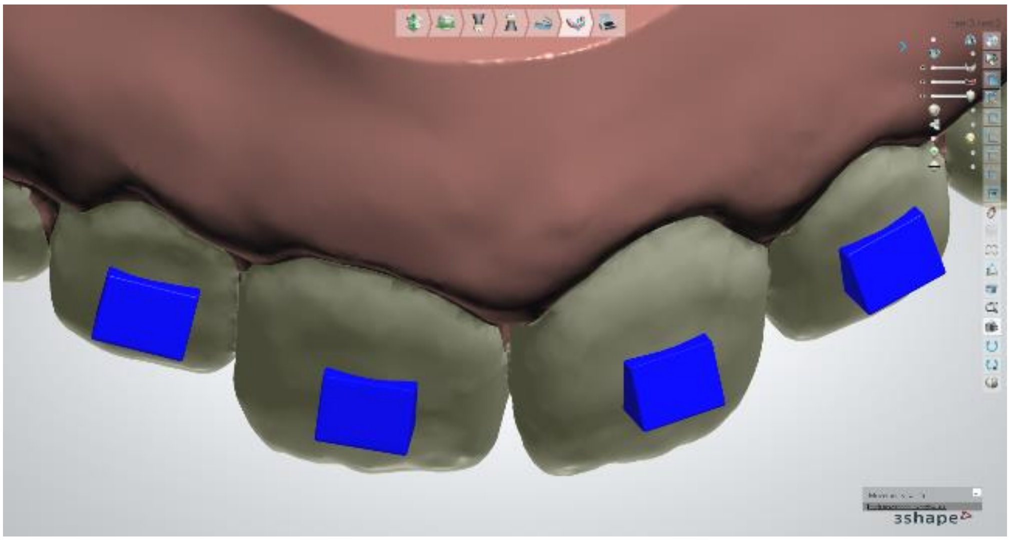

Figure 3.2.2.3.A. The position of the attachment on the flattest surface of the middle vertical third of the central and lateral incisors labial surface.

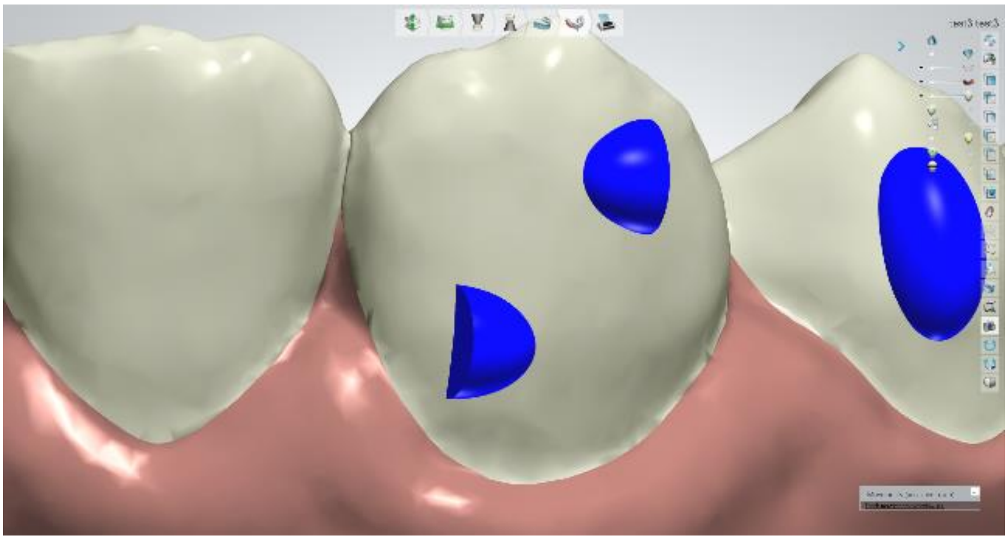

Figure 3.2.2.3.B. The position of the attachment on the flattest surface of the mesial cervical and distal-incisal thirds respectively of the canine labial surface.

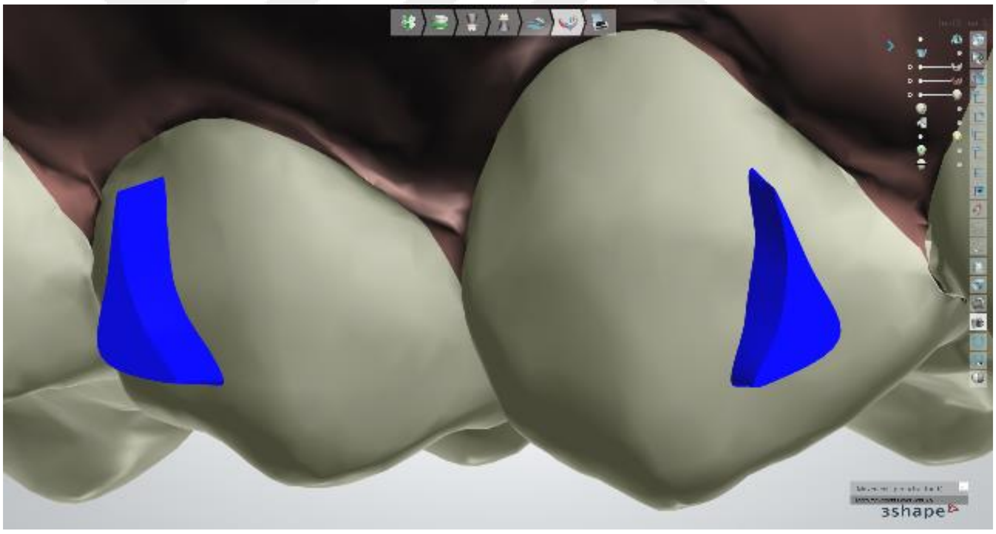

Figure 3.2.2.3.C. The position of the attachment on the flattest surface of the mesial-cervical and mesial-middle thirds of upper premolar buccal surface.

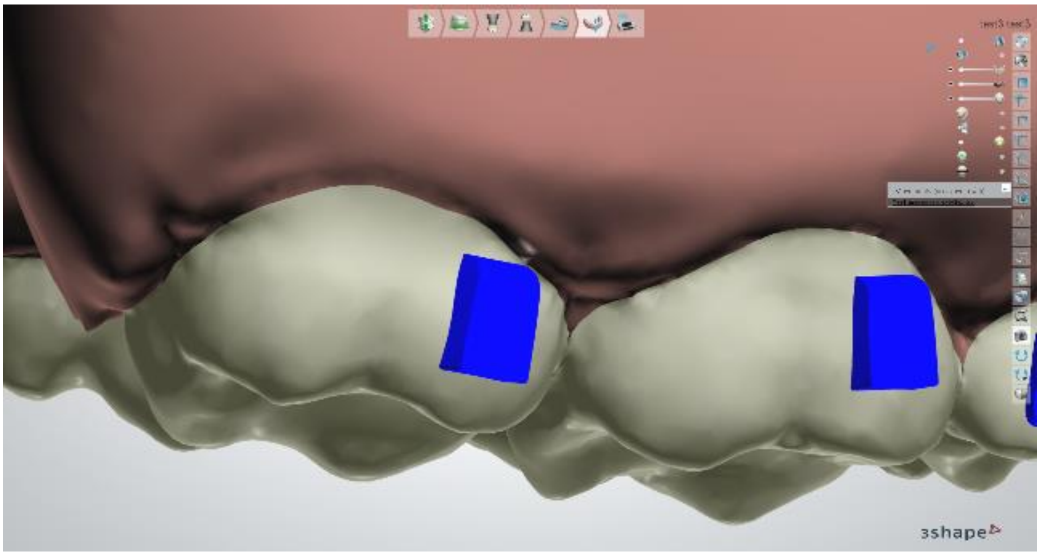

Figure 3.2.2.3.D. The position of the attachments on the flattest surface of the mesial vertical third of upper molars buccal surface.

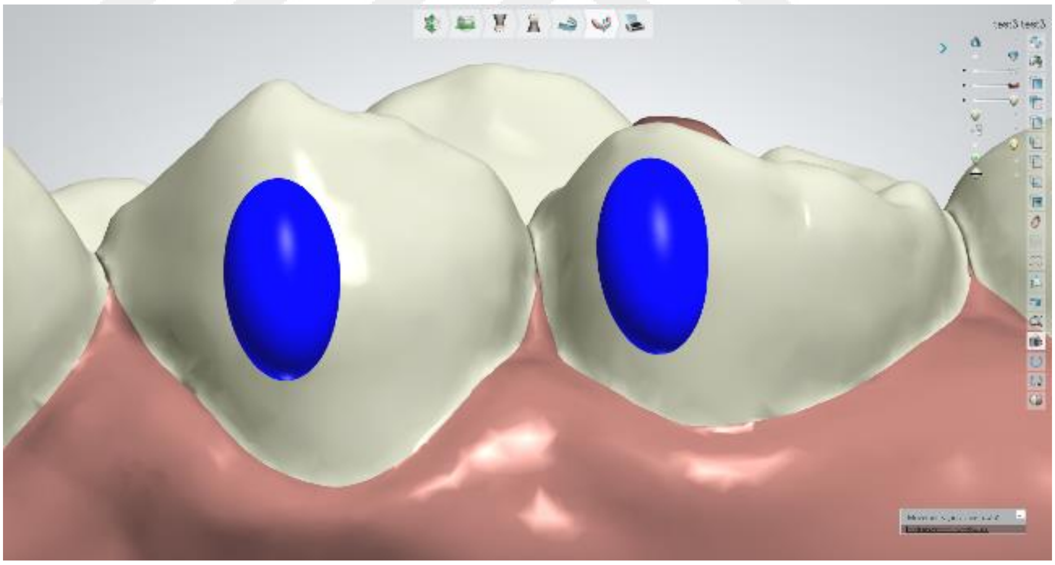

Figure 3.2.2.3.E. The position of the attachment on the flattest surface of the middle-middle third of lower premolars buccal surface.

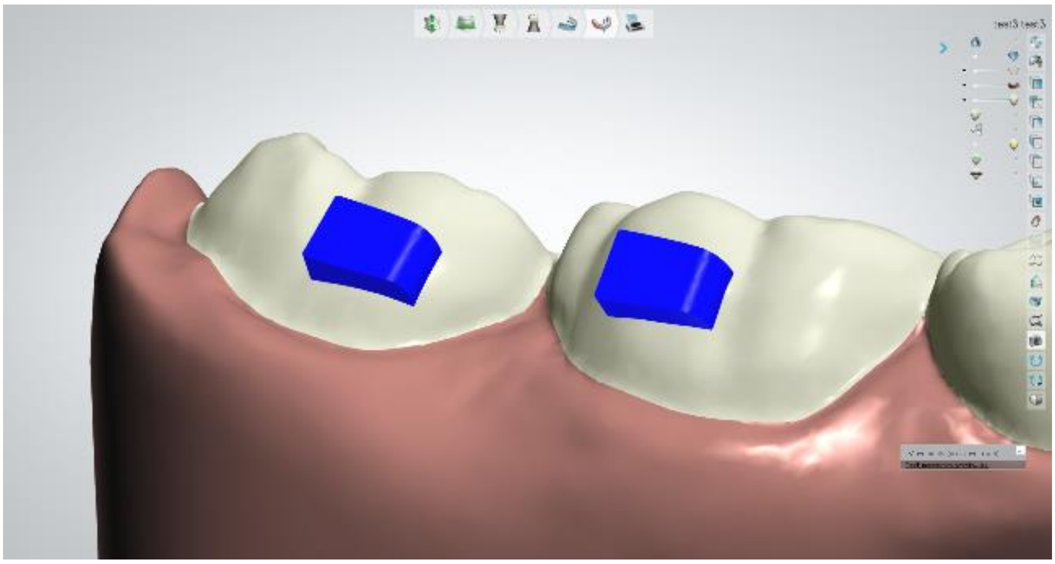

Figure 3.2.2.3.F. Notice the position of the attachment on flattest surface of the middle horizontal third of lower molars.

After importing the attachments to the Ortho Analyzer software, it was recognized that the attachments over the labial/buccal surface of teeth do not adapted completely leaving an open margin between the attachment-tooth surface interface. The labial/buccal surfaces of teeth vary in convexity while the basal surface of the attachments was flat. Complete adaptation of the attachment over the teeth surfaces was not possible without pressing the attachment into the labial or buccal surface of the tooth to seal the interface between the attachment and the tooth surface and that on the other hand caused some loss in the attachment prominences. In respect to this fact, all attachments have been modified from the basal surface to facilitate their adaptation over the convex labial/buccal surface of each tooth by slightly concaving the basal surface of each attachment. So complete fitting of the attachment over the tooth surface with no open margins between the attachment and the tooth surface interface was achieved. Moreover, the attachments were not compressed toward inside of the labial/buccal surface of the tooth. Overall the predetermined prominence of each attachment which is important keep standardized along with all other attachments' dimensions for scientific quality purposes was maintained (Figure 3.2.2.3.G. - 3.2.2.3.L.).

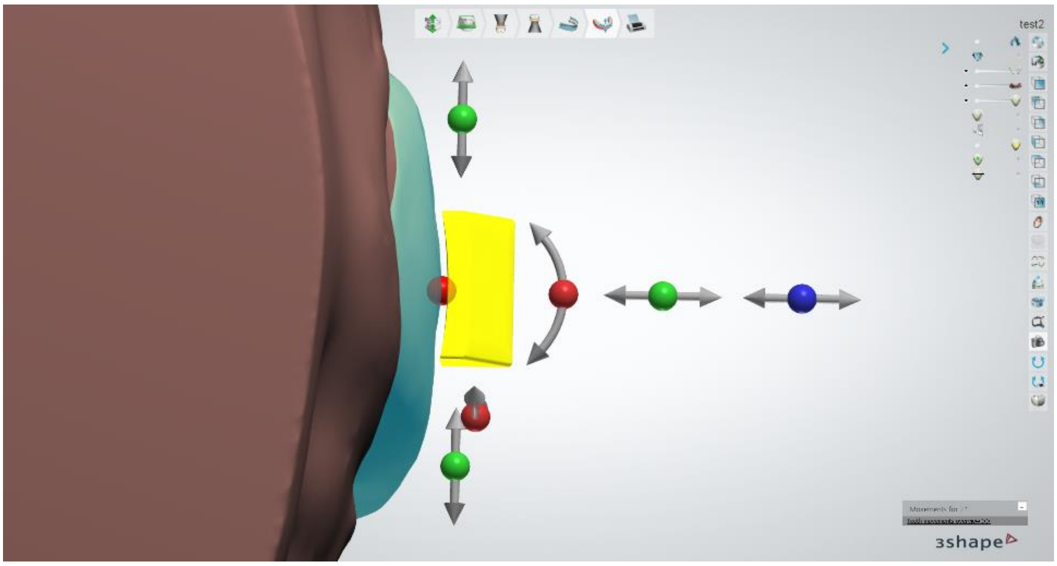

Figure 3.2.2.3.G. The concave base of the beveled rectangular attachment to accommodate the convexity of the labial surface of the incisors.

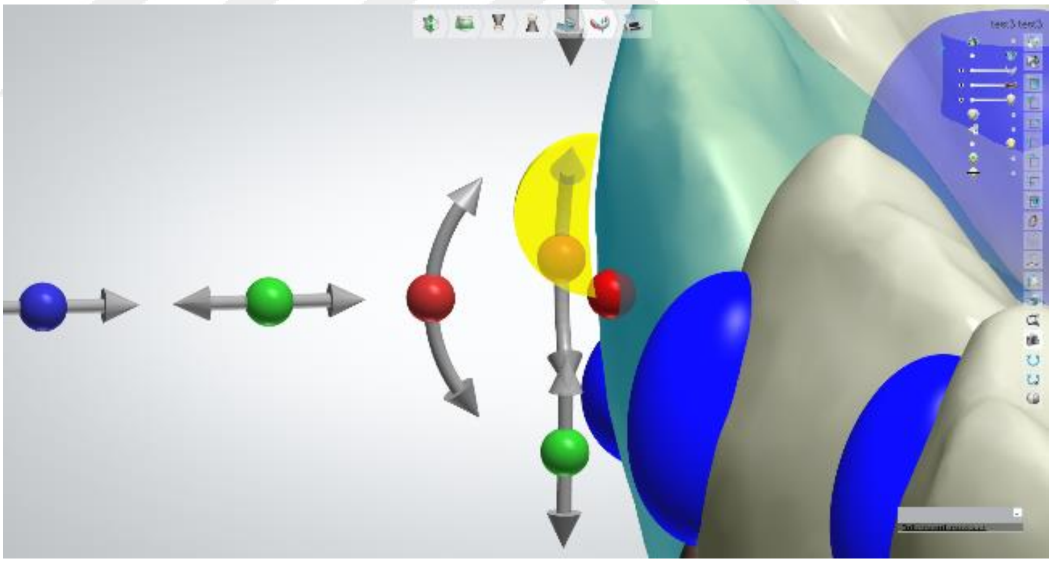

Figure 3.2.2.3.H. The concave base of the hemi-ellipsoid attachment to accommodate the convexity of the labial surface of the canines.

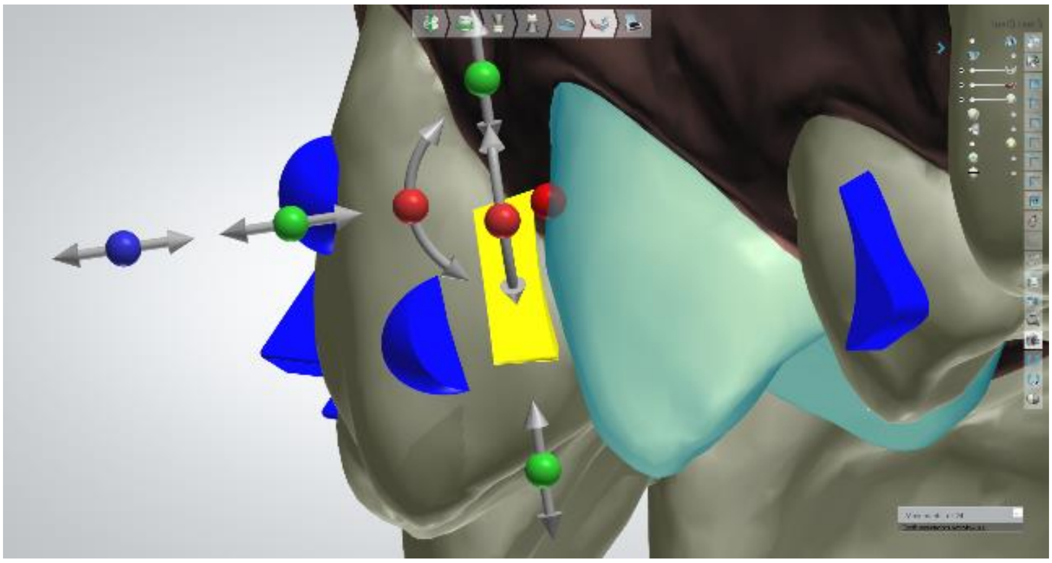

Figure 3.2.2.3.I. The concave base of the rotational attachment to accommodate the convexity of the buccal surface of the upper premolars.

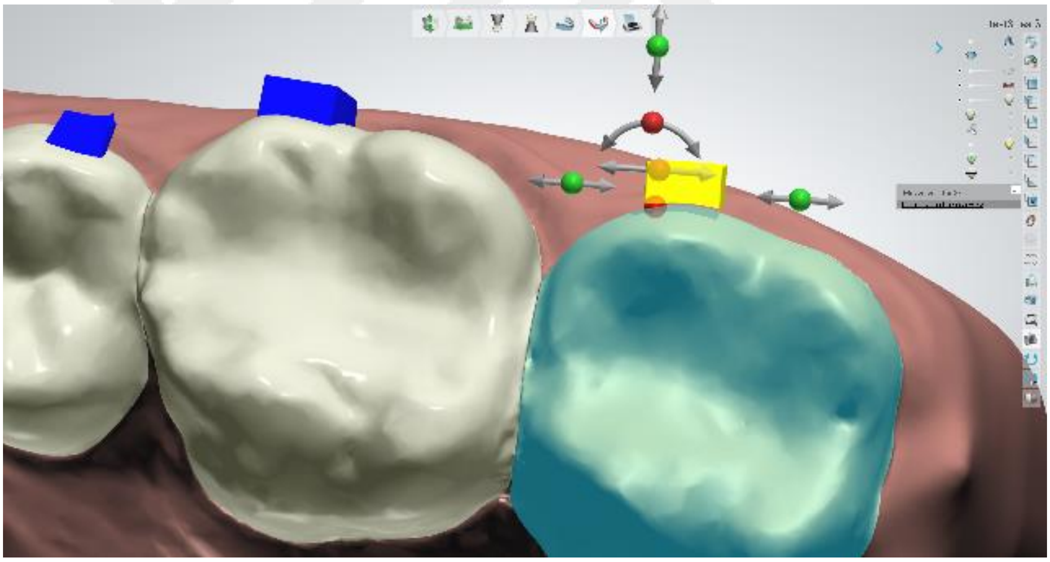

Figure 3.2.2.3.J. The concave base of the vertical rectangular attachment to accommodate the convexity of the buccal surface of the upper molar.

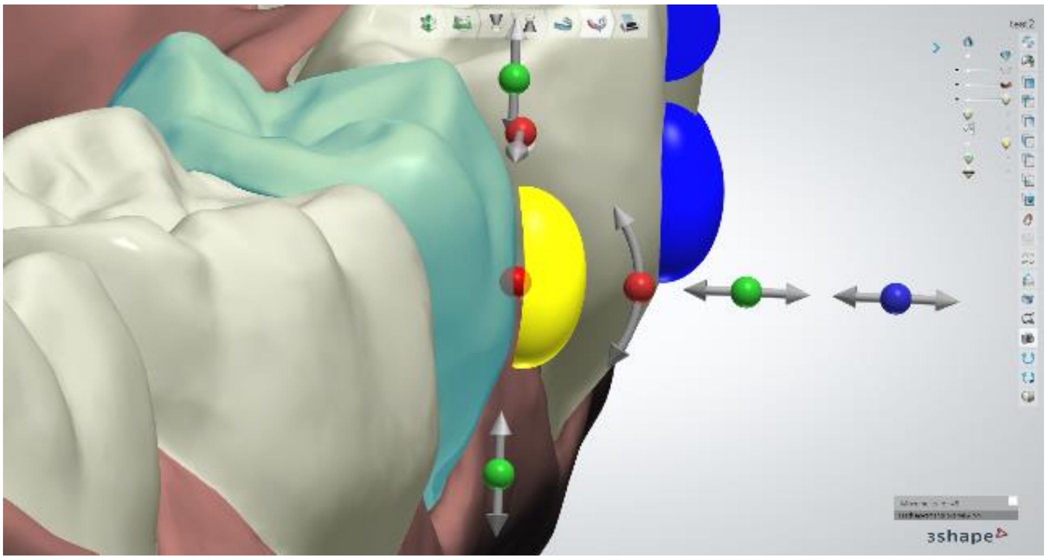

Figure 3.2.2.3.K. The concave base of the ellipsoid attachment to accommodate the convexity of the buccal surface of the lower premolars.

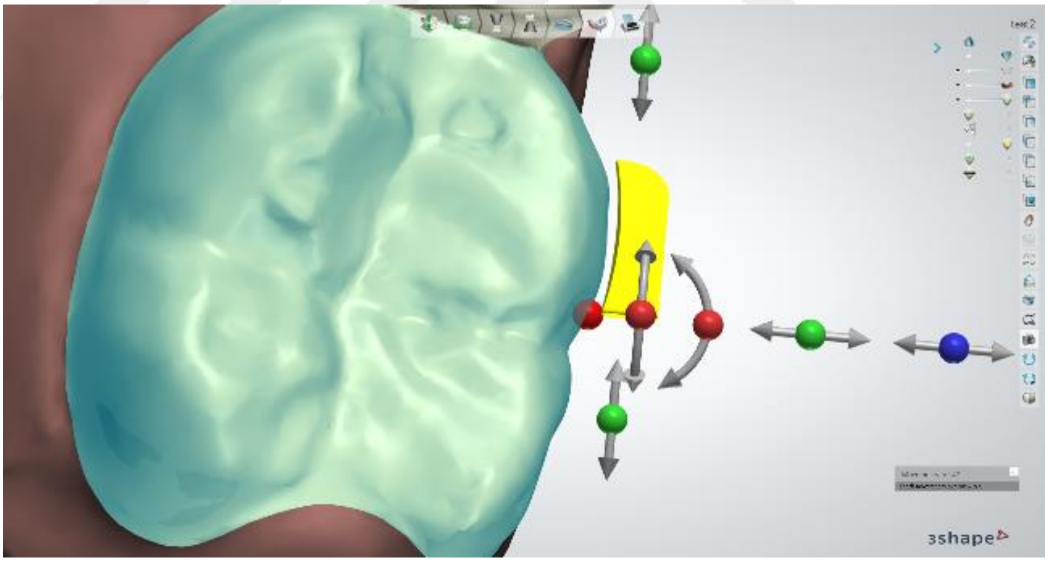

Figure 3.2.2.3.L. The concave base of the horizontal rectangular attachment to accommodate the convexity of the buccal surface of the lower molar.

The models with attachments were defined as the reference models and these attachments were categorized according to their shape configuration into 6 control groups.

3.2.3. Third Phase; Printing Methods and Post-Printing Processing:

3.2.3.1. Printing Methods:

The reference models were printed twice using both of each printer (Figure 3.2.3.1.A.):

1. XFAB 2500PD from DWS company that utilizes SLA technique to produce 4 models (2 maxillary and 2 mandibular) replica of the reference digital models. Invicta 907 resin material from the same company was used as the printing material.
2. AccuFab-D1 from Shining 3D company that utilizes DLP technique to produce another 4 models (2 maxillary and 2 mandibular) replica of the reference digital models. KeyModel Ultra resin material from Keystone Industries company was used as the printing material with this printer.

Figure 3.2.3.1.A. Left: XFAB 2500PD from DWS company. Right: AccuFab-D1 from Shining 3D company.

The reference model was printed in a horizontal orientation with the occlusal plane parallel to the build platform and the teeth cusps away from it to reduce the printing errors (Figure 3.2.3.1.B.). The resultant printed models are 4 SLA models (2 maxillary and 2 mandibular) and 4 DLP models (2 maxillary and 2 mandibular).

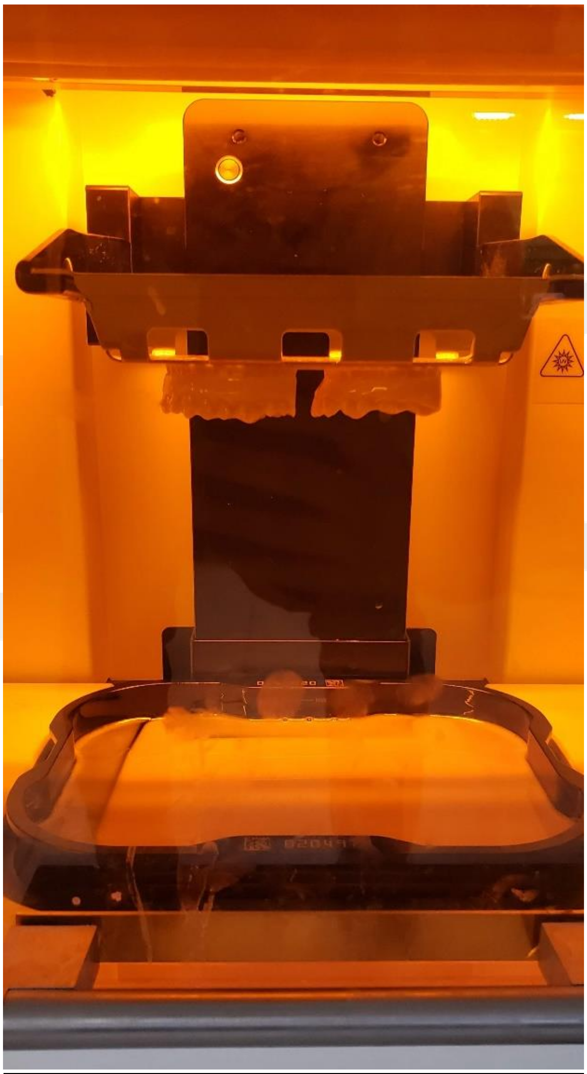

Figure 3.2.3.1.B. horizontal orientation of the printed models on the printing platform.

3.2.3.2. **Post-Printing Processing:**

Following printing with DLP and SLA printer, a post-printing procedure must be performed. This requires the use of two other machines. First, the printed models must be immersed in 91% isopropyl alcohol for 5 minutes according to the resin manufacturer's guidelines; this cleans the models and eliminates uncured resin from the printed its surface (Figure 3.2.3.2.A. and 3.2.3.2.B.). The models were then undergone post-curing phase using a special machine that expose them to ultraviolet light to facilitate continued polymerization of the resin, which may be necessary to achieve optimal physical properties of the model (Figure 3.2.3.2.C. and 3.2.3.2.D.).

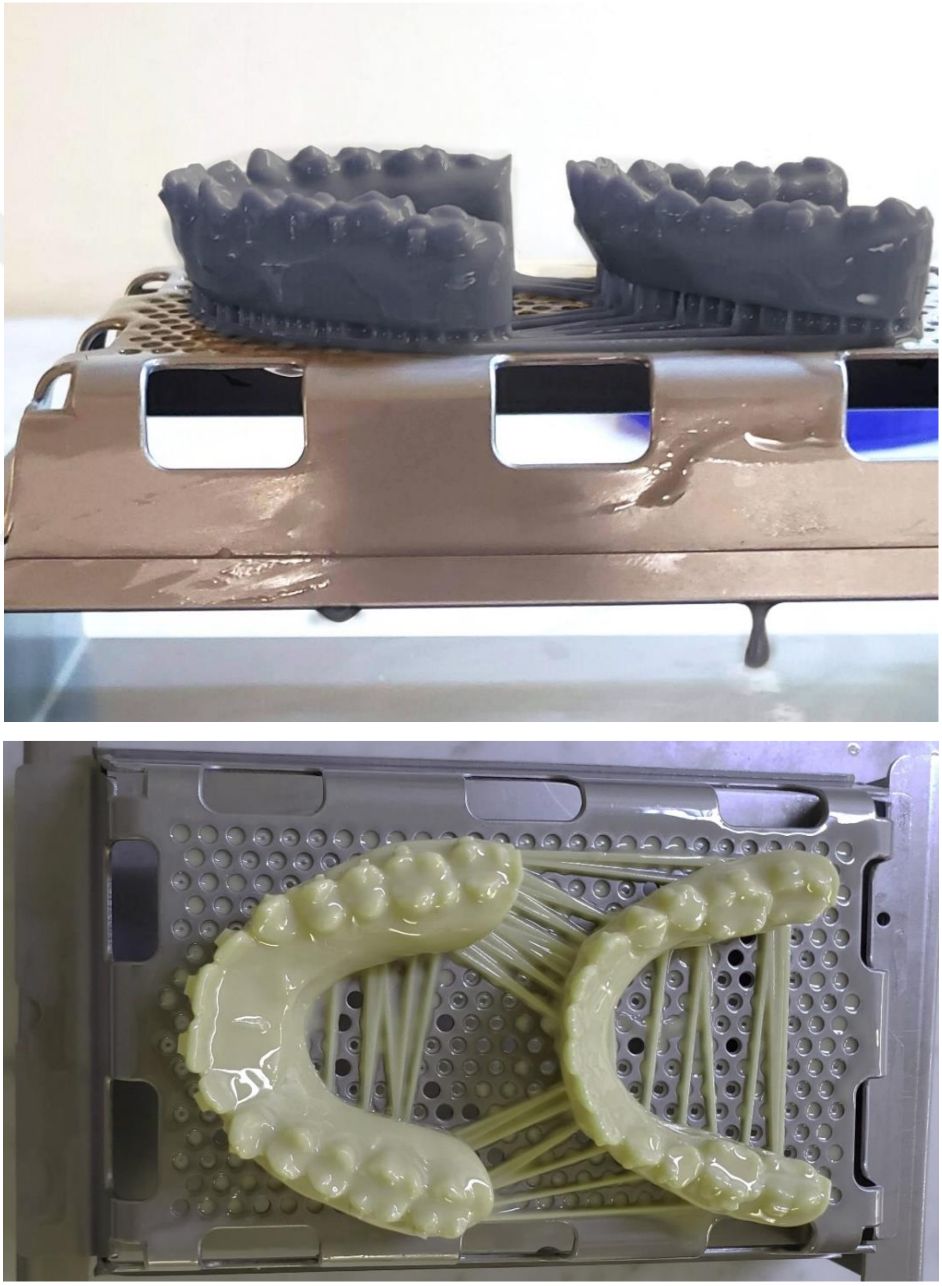

Figure 3.2.3.2.A. uncured resin covering the printed models immediately after leaving the printer.

Figure 3.2.3.2.B. Washing Container contain 91% isopropyl alcohol

Figure 3.2.3.2.C. Ultraviolet light curing machine.

Figure 3.2.3.2.D. Models after post-printing process.

The printed models were then scanned again using the same intraoral scanner used to obtain the initial scan (TRIOS from 3Shape) and the resultant digital models were defined as test models (Figure 3.2.3.2.E.).

Figure 3.2.3.2.E. scanning the printed models with TRIOS intraoral scanner.

3.2.4. Fourth Phase; Superimposition and 3D Comparison:

3.2.4.1. Segmenting the Reference Models

To compare the attachments, the reference models were imported to the Geomagic Control X software (3D Systems, South Carolina, USA). Then each reference model was segmented to generate small islands on the whole model to be later split and merged to isolate the attachments from the whole model as the target areas to be compared (Figure 3.2.4.1.A and 3.2.4.1.B.).

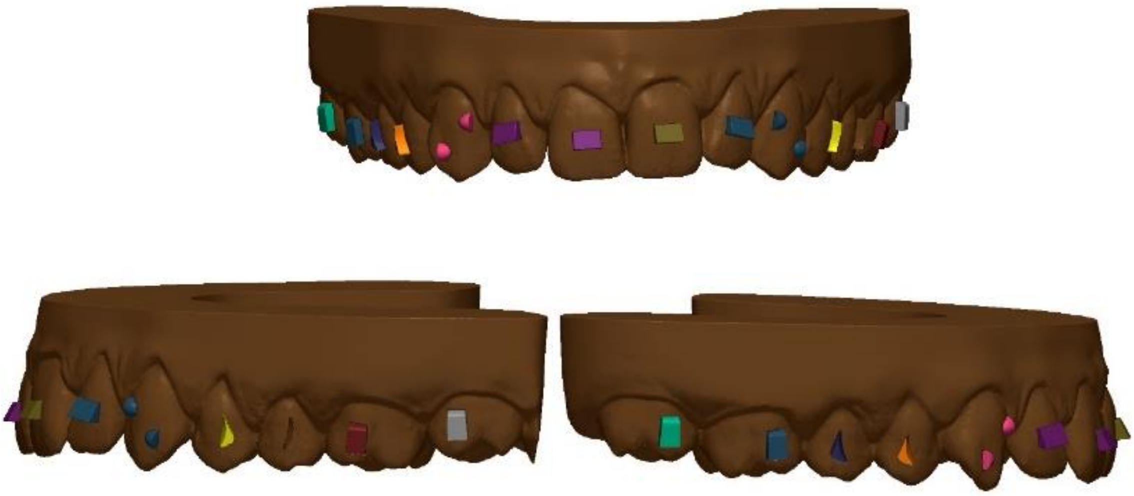

Figure 3.2.4.1.A. Isolating each attachment separately from the whole upper SLA model.

Figure 3.2.4.1.B. Isolating each attachment separately from the whole lower SLA model.

3.2.4.2. **Superimposing and Aligning the Models:**

The corresponding test model generated by each printer was imported separately to be superimposed over the reference model. For the superimposition step, initial alignment was made first. However, the initial alignment only allows to align the whole test model to the whole reference model, so best fit alignment was then activated which allows to select a specific area -in this study was the whole model except the attachments- upon which the models will be aligned accordingly. The best fit alignment function also ensures the optimal alignment of the models according to the preference area (Figure 3.2.4.2.A. - 3.2.4.2.D.). Best-fit alignment is a special alignment function in the software that uses an interactive least-square fitting algorithm to compare the minimum distance variation from every measured point in a master model with those of a reference cast. Both initial alignment and best fit alignment were automated by the software using the corresponding buttons that applies a special algorithm to achieve accurate alignment of the models to eliminate human-errors.

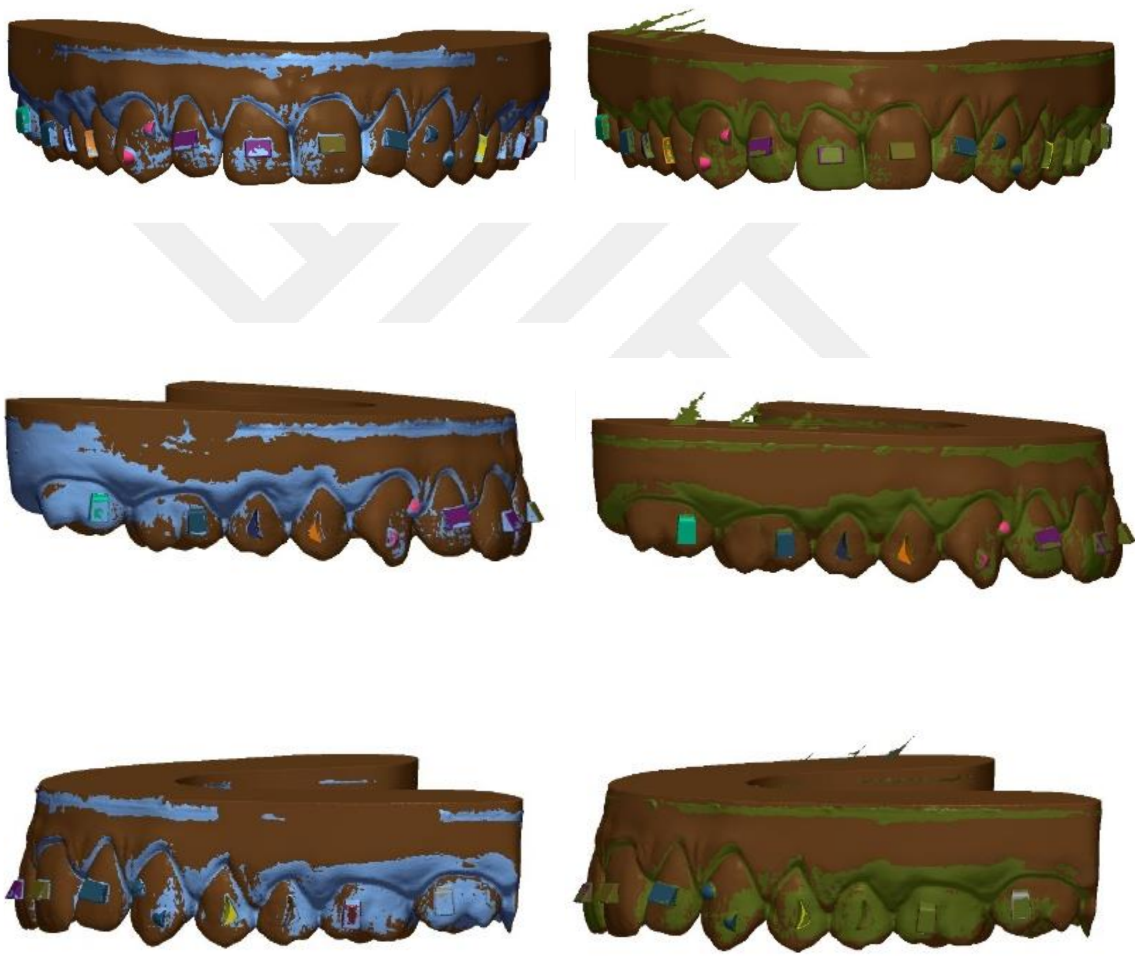

Figure 3.2.4.2.A. Best Fit Alignment for the maxillary SLA models.

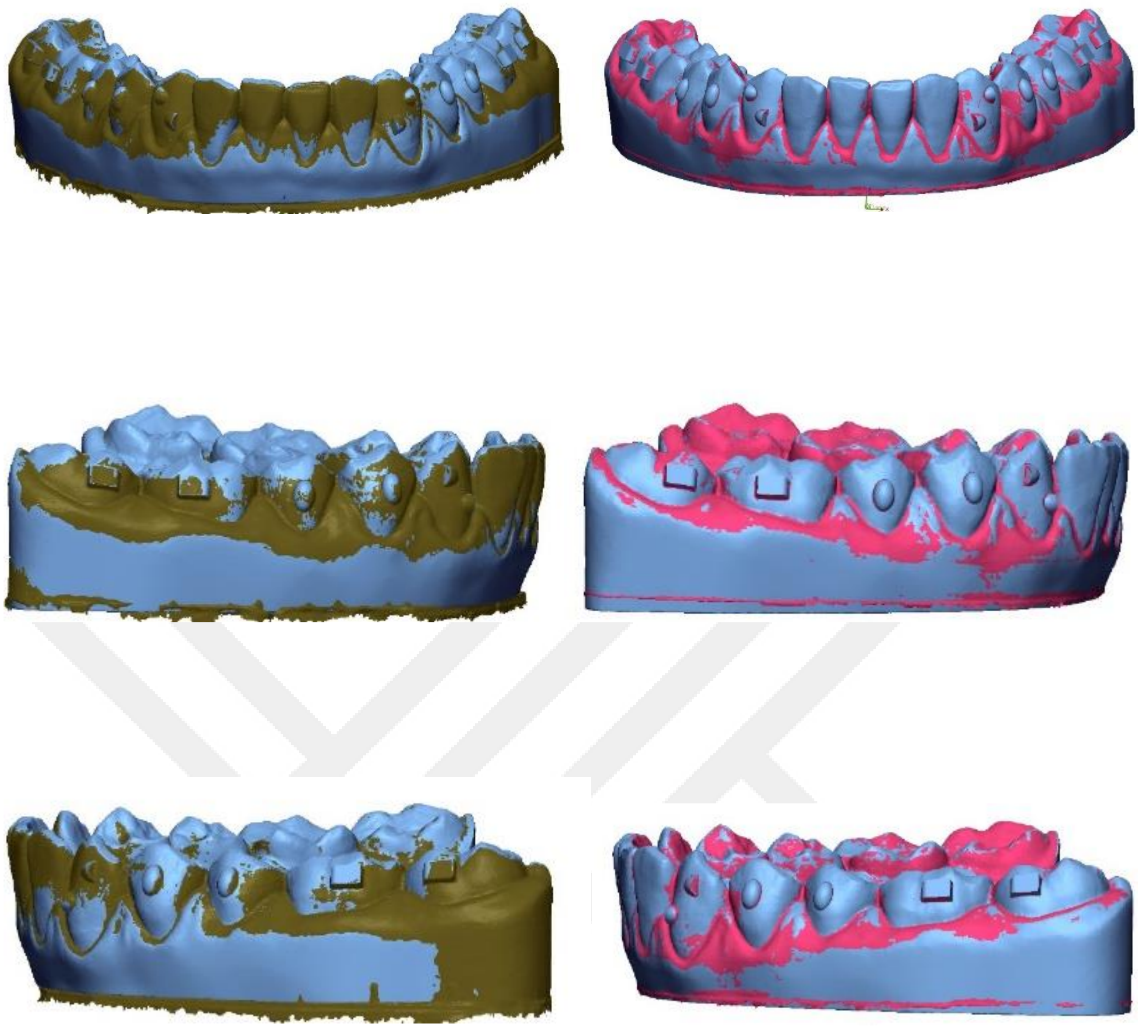

Figure 3.2.4.2.B. Best Fit Alignment for the mandibular SLA models.

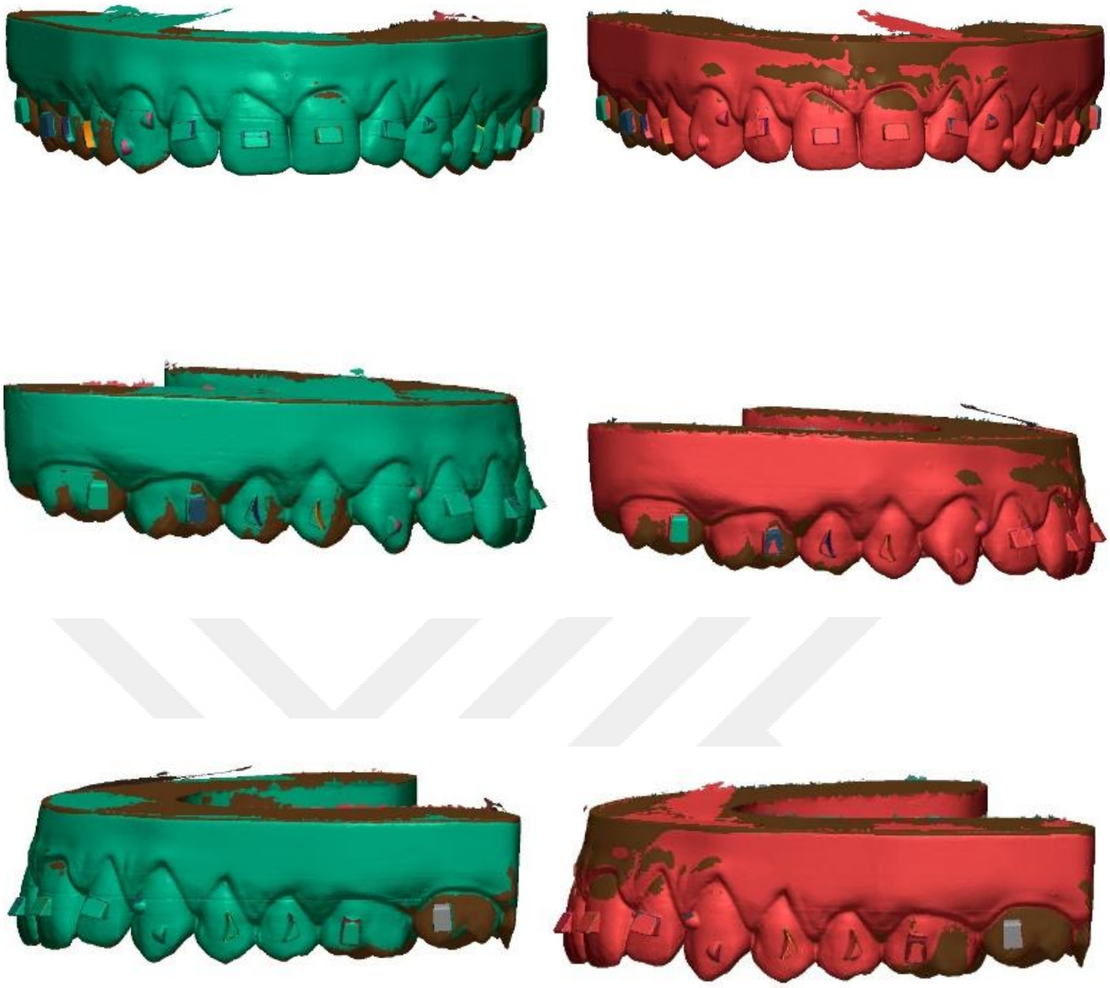

Figure 3.2.4.2.C. Best Fit Alignment for the maxillary DLP models.

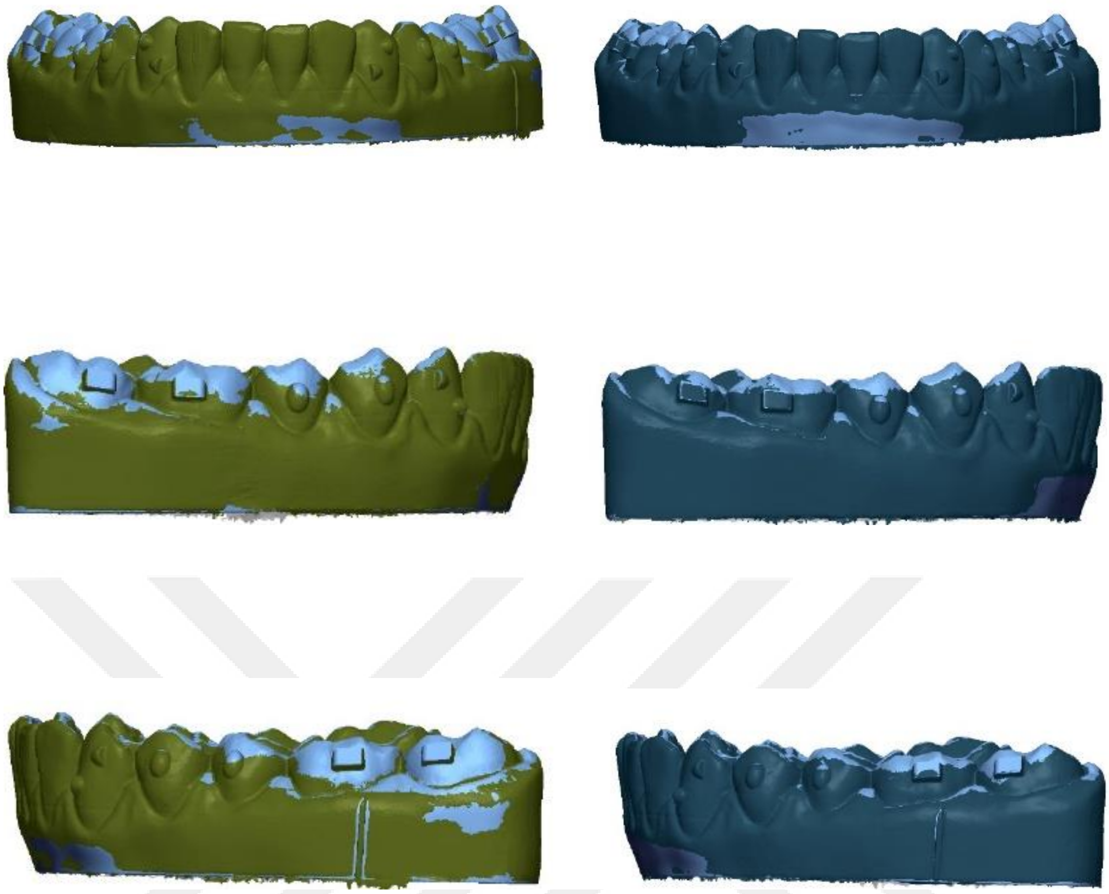

Figure 3.2.4.2.D. Best Fit Alignment for the mandibular DLP models.

3.2.4.3. **3D Comparison and Generating Reports:**

The 3D compare function button was selected to initiate the comparison. The previous step of applying the 3D comparison function only to the selected area of data was repeated to limit the comparison only to the attachments. At this time only the attachments that are to be compared were selected for comparison.

Nominal range, also referred to as tolerance range; is the permissible limit of variation allowed between each point in the reference model and the test model. It has two terminals (maximum and minimal) above and below which the test model starts to show a significant deviation from the reference model. The maximum nominal and minimum nominal were set to 0.05mm and -0.05mm, respectively. A higher percentage of points in the set range and smaller standard deviation suggested more stable printed results and lower deviation from the source file.

Another spectrum that measures the deviation was used called the critical range, also known as the threshold range. It also has two terminals (maximum and minimum). The critical values were set at 0.25mm and -0.25mm, respectively. Any location in the test file that deviating more than 0.25 mm in either direction was determined to be beyond the top and lower boundaries.

For each comparison, a full report with an accompanying colored map was retrieved to indicate the proportion of points in each superimposition that fall within the nominal range and the percentage of points that fall within the critical range, both positively and negatively. The colored map evaluates the degree and location of the discrepancy between the test and source files. The green region designates that the average deviation is within the range of the nominal maximum and lowest values, and the amount of green distribution in the color map directly designates the consistency between the printed and reference models. The shift from yellow to red represents an increase in positive deviation (widening and thickening relative to the reference model), while the transition from light blue to dark blue represents an increase in negative deviation (narrowing and thinning compared with the reference model).

The level of variation between each tested attachment and its matching reference attachment was represented using the root mean square (RMS) value generated by the program and included in the extracted reports. The root mean squared error (RMS) value is a standard approach for determining the mean value of errors or variations by directly comparing two data sets with identical coordinate systems. It is employed as a criterion for comparing two sets of N-dimensional vector sets after superimposition, which corresponds in our study to comparing the groups of data composed of the overlaid models' attachments. The RMS value conveys the following information about the accuracy of a matching data group: A greater estimated RMS value implies a greater difference between the reference and measurement data, while a lower calculated RMS value suggests a smaller difference (Figure 3.2.4.3.A. – 3.2.4.3.F.). Additionally, the Mean RMS was determined for all attachments within each printing method group, as well as for distinct attachment groups.

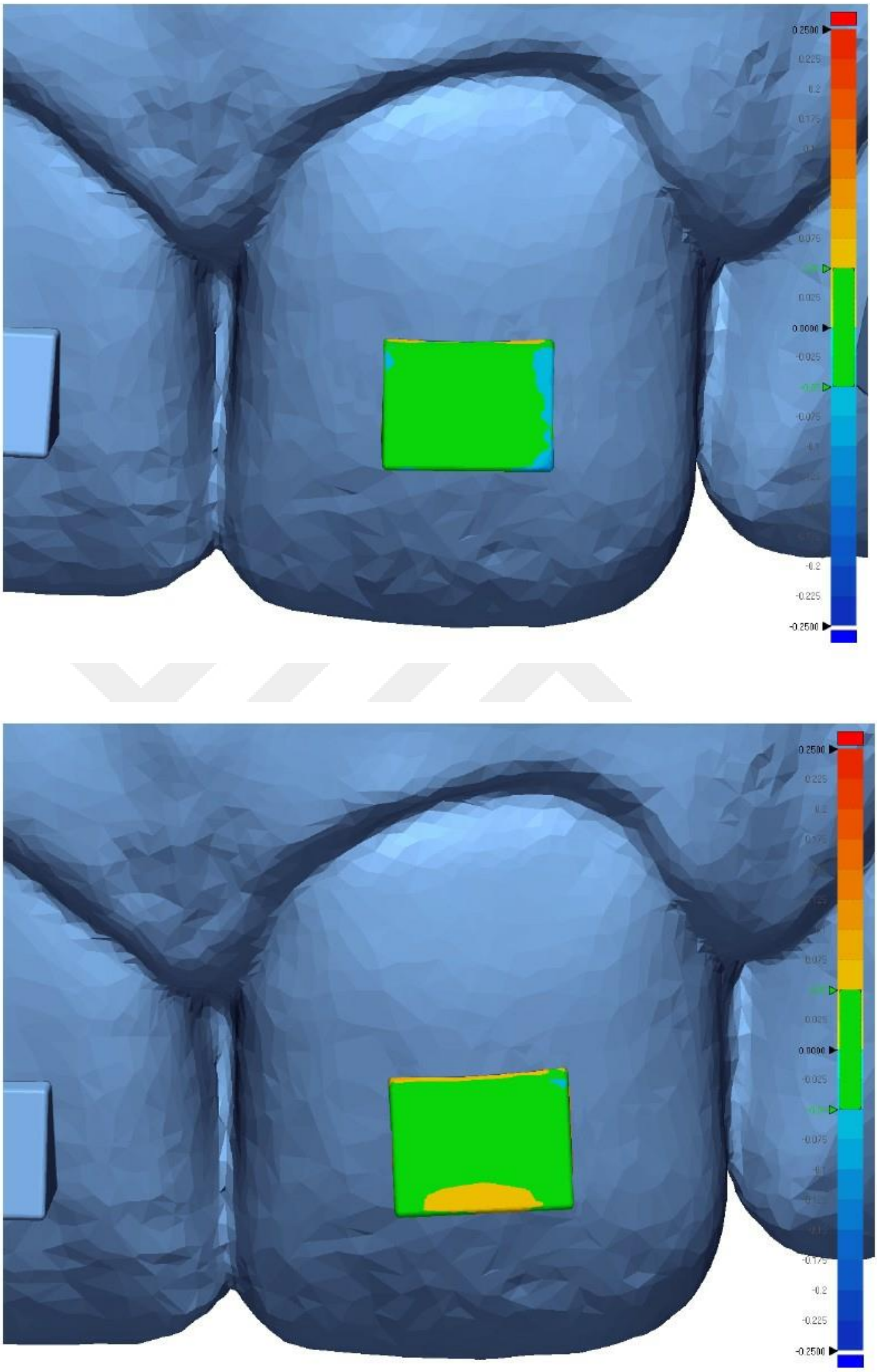

Figure 3.2.4.3.A. A representative image of superimposing horizontal beveled rectangular attachment on tooth #21 printed by SLA on the top and DLP on the bottom.

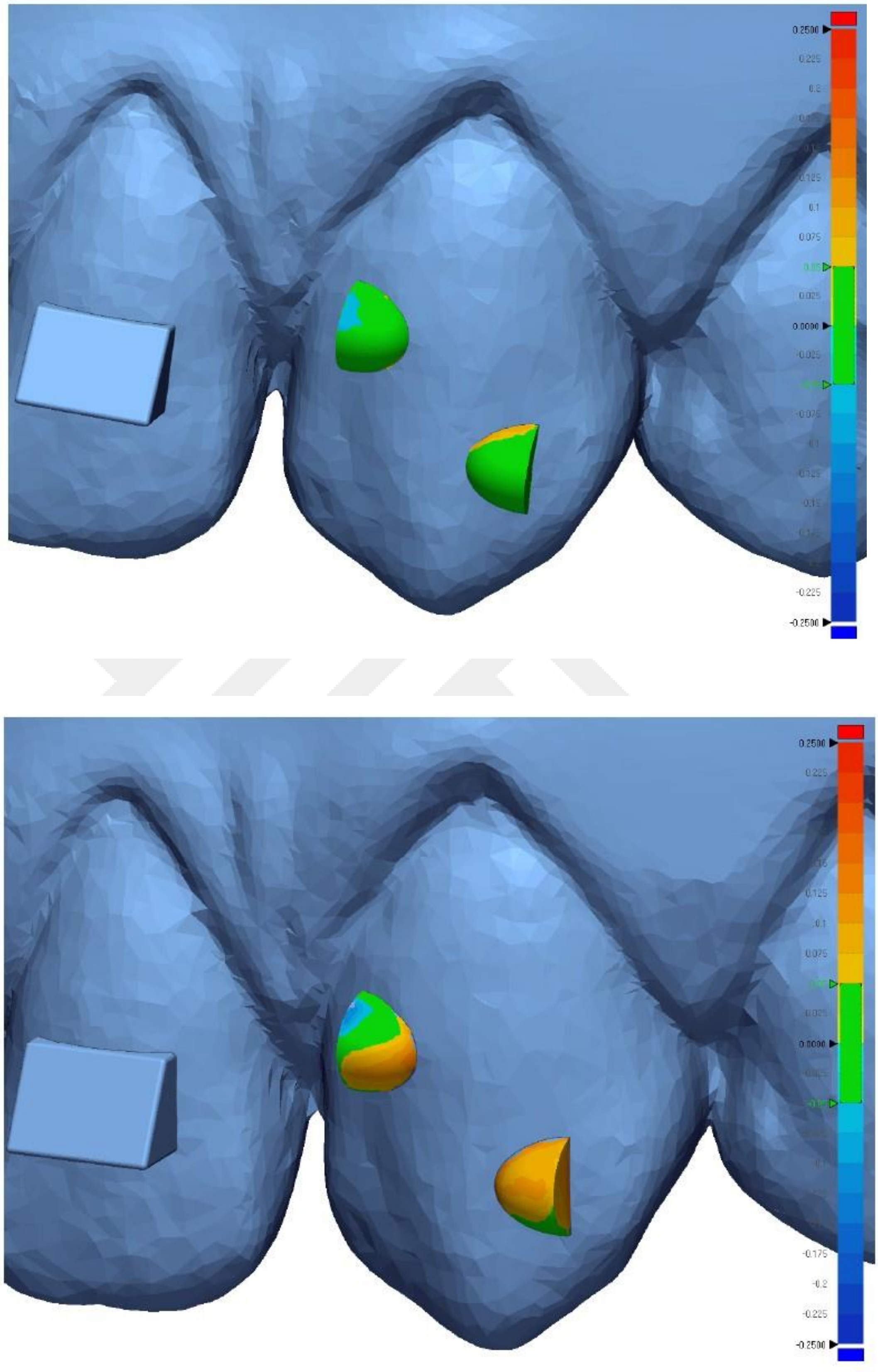

Figure 3.2.4.3.B. A representative image of superimposing double hemi-ellipsoid attachment on tooth #23 printed by SLA on the top and DLP on the bottom.

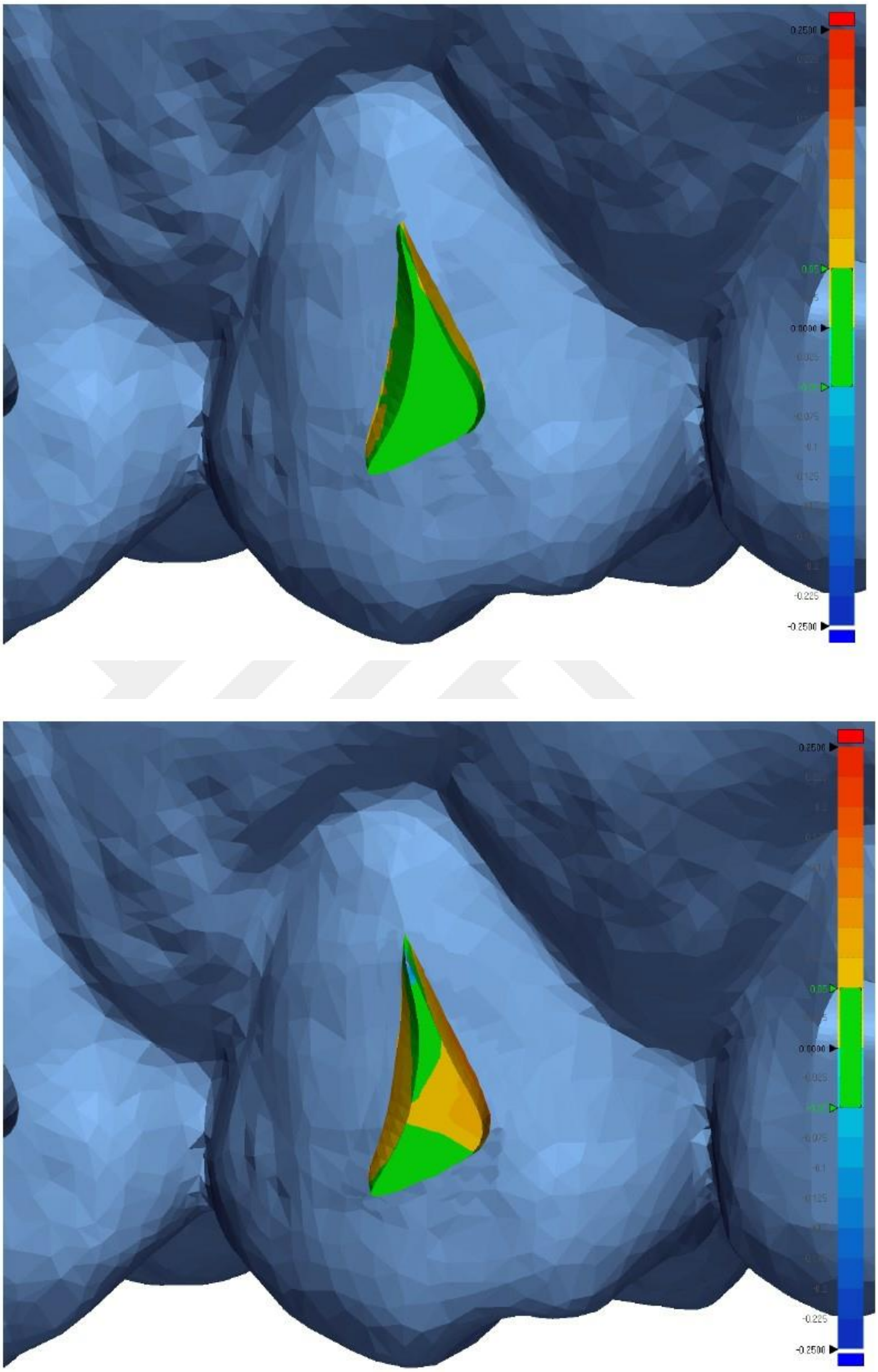

Figure 3.2.4.3.C. A representative image of superimposing rotational attachment on tooth #25 printed by SLA on the top and DLP on the bottom.

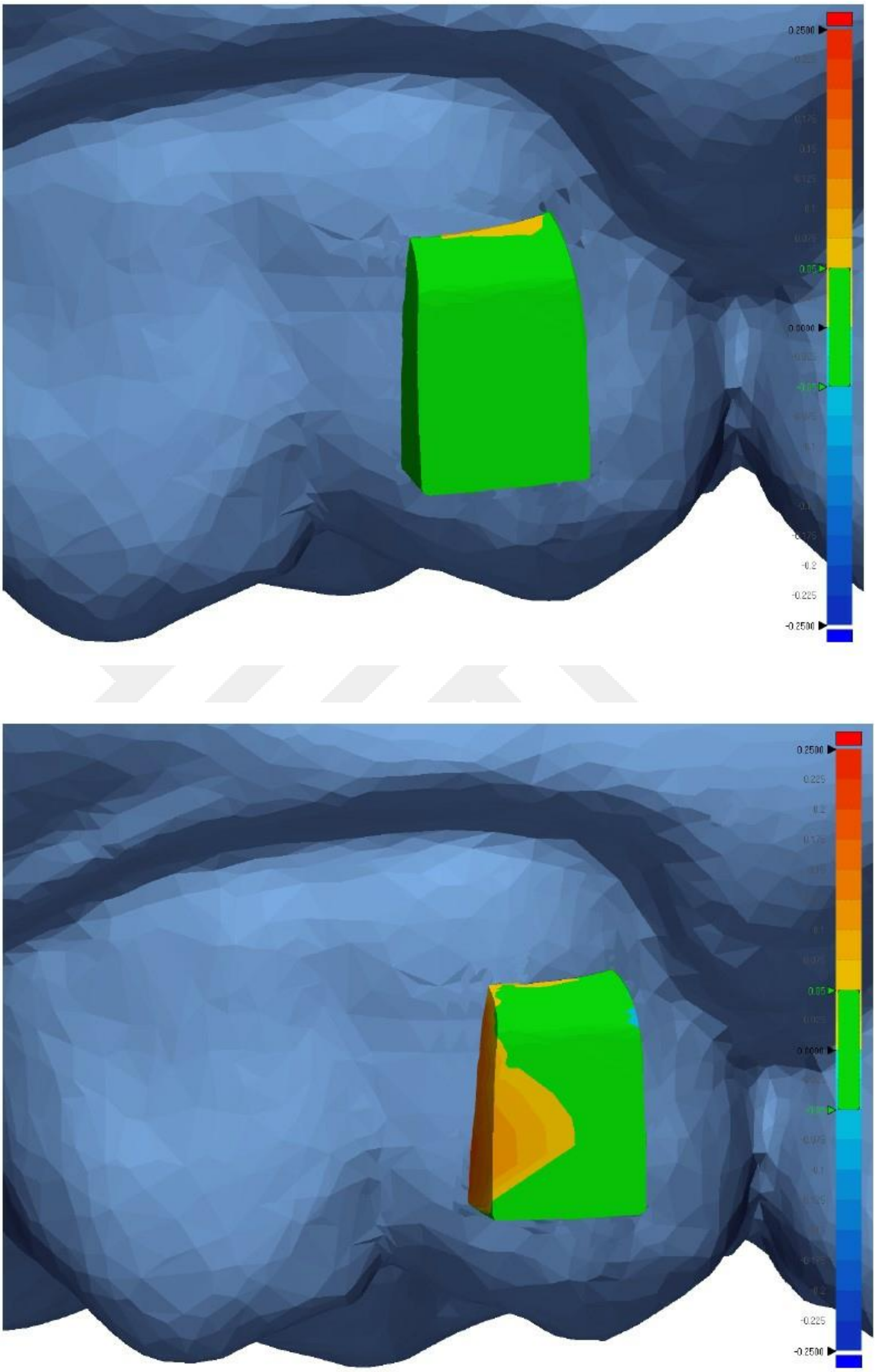

Figure 3.2.4.3.D. A representative image of superimposing vertical rectangular attachment on tooth #16 printed by SLA on the top and DLP on the bottom.

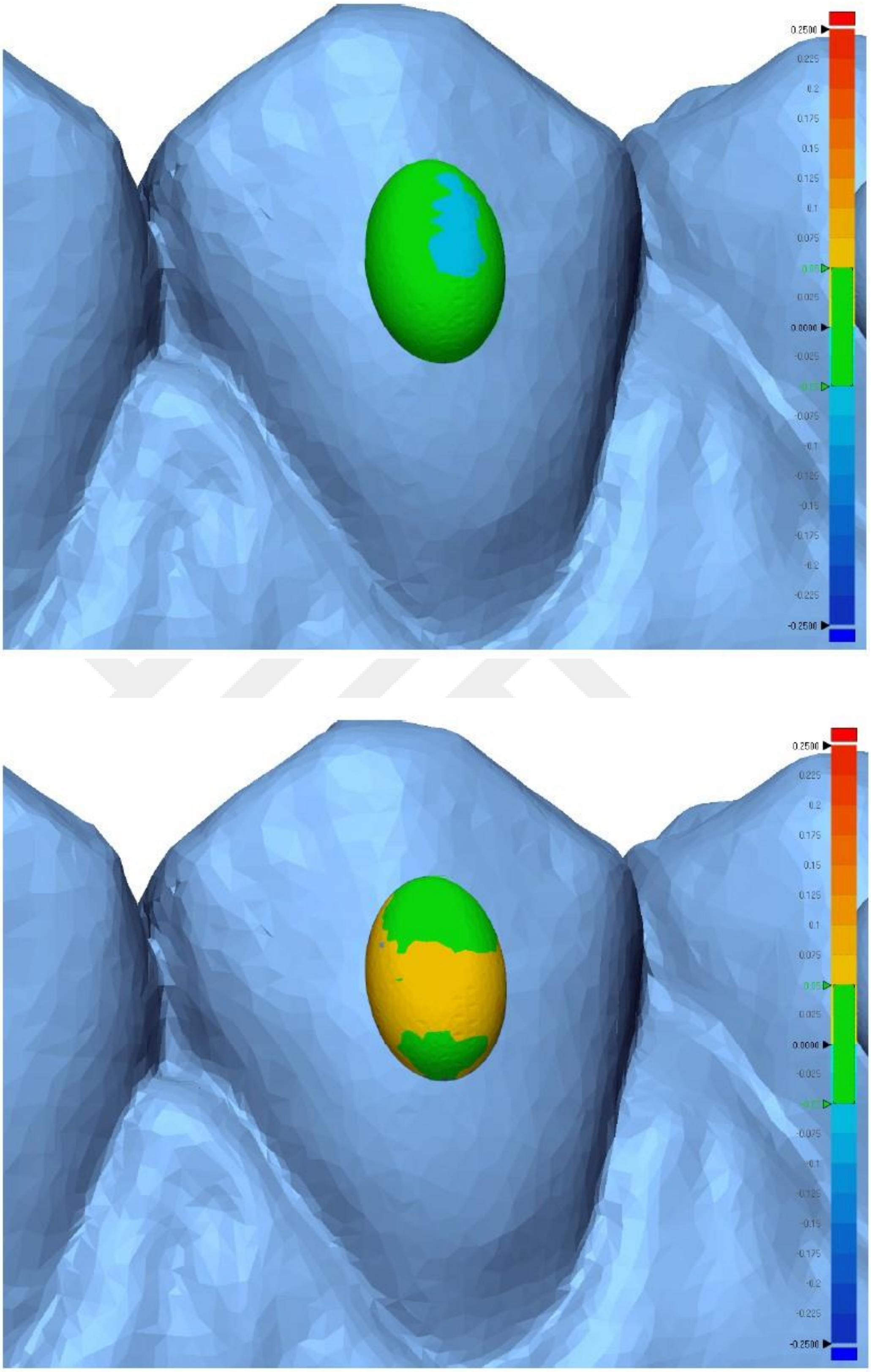

Figure 3.2.4.3.E. A representative image of superimposing ellipsoid attachment on tooth #34 printed by SLA on the top and DLP on the bottom.

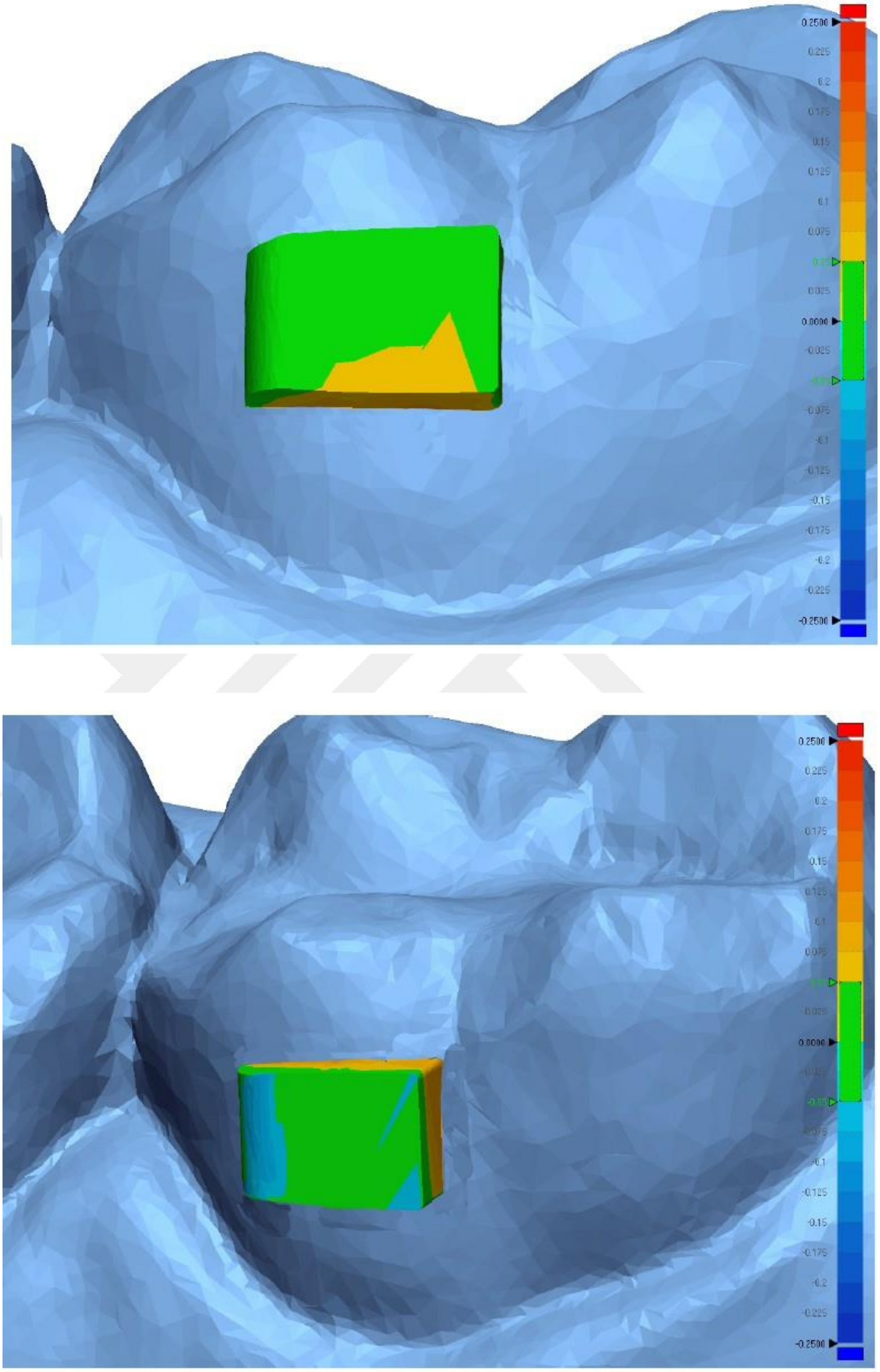

Figure 3.2.4.3.F. A representative image of superimposing horizontal rectangular attachment on tooth #37 printed by SLA on the top and DLP on the bottom.

3.2.5. Statistical Methods:

Data of the study was analyzed using IBM SPSS statistics (Statistical Package for Social Sciences) software version 22.0 (IBM Corp., Chicago, USA), and expressed as number, mean ± standard deviation. Conformity of the parameters to the normal distribution was assessed by the Kolmogorov Smirnov and Shapiro Wilks test. Two way ANOVA test was used to evaluate the joint effect of print techniques and attachments on RMS. Oneway ANOVA Test (post hoc Tukey HSD test) and Student's t test were used for data analysis of test results. Statistical significance was accepted as $p<0.05$.

Based on the observed effect sizes, an experimental statistical power analysis has been carried on to determine the size of the sample: the sample size calculation was done by using PASS 15 Power Analysis and Sample Size Software (NCSS, LLC. Kaysville, Utah, USA, 2017). In a oneway ANOVA study, sample sizes of 8, 8, 8, 8, 8, and 8 are obtained from the 6 groups whose means are to be compared. The total sample of 48 subjects achieves 81% power to detect differences among the means versus the alternative of equal means using an F test with a 0,05 of significance level. The size of the variation in the means is represented by their standard deviation which is 0.56. The common standard deviation within a group is assumed to be 1.00.

4. RESULTS

The common influence of printing methods and attachments on RMS was given in Table 4.1.

There is a statistically significant difference between printing techniques in terms of RMS averages (p:0.000; $p<0.05$). There is a statistically significant difference between attachments in terms of RMS averages (p:0.024; $p<0.05$). The joint effect of printing techniques and attachments on RMS is also statistically significant (p:0.000; $p<0.05$). Detailed analyzes of the above-mentioned results are shown in (Tables 4.2. - 4.5.)

Table 4.1. Common influence of printing methods and attachments on RMS.

	Type III Sum of Squares	**df**	**Mean Square**	**F**	**p**
Printing technique	0.019	1	0.019	157.507	0.000***
Attachment	0.002	5	0.000	2.747	0.024*
Printing technique *** Attachment	0.003	5	0.001	5.218	0.000***

Two Way ANOVA Test **(***) p <0.001, (*) p <0.05**

The comparison between different attachments shapes was given in (Table 4.2.) by means of (RMS mean), to analyze the effect that different attachments' geometries have on final attachment accuracy.

There is a statistically significant difference between attachments in terms of RMS averages (p:0.024; $p<0.05$) (Table 4.2.) and (Figure 4.1.). As a result of post hoc analyzes to determine which attachments are responsible of the significance; RMS mean of the Ellipsoid group was found to be significantly lower than the Horizontal Rectangular and Optimized Rotation groups (p_1:0.030; p_2:0.035; $p<0.05$). There is no statistically significant difference between other attachment groups ($p>0.05$) (Table 4.3.).

Table 4.2. Comparison between attachments' configurations and their possible effect on their printing accuracy.

		RMS		
		n	**Mean ± SD**	**p**
Attachment	Beveled Horizontal Rectangular Attachment	16	0.049±0.019	0.024*
	Optimized Root Control	16	0.051±0.018	
	Horizontal Rectangular	16	0.055±0.012	
	Vertical Rectangular	16	0.051±0.024	
	Optimized Rotation	16	0.055±0.025	
	Ellipsoid	16	0.043±0.011	

Two Way ANOVA Test **(*) p<0.05**

Table 4.3. Post hoc comparisons between attachments groups.

Attachment	Attachment	p
Beveled Horizontal Rectangular Attachment	Optimized Root Control	1.000
	Horizontal Rectangular	1.000
	Vertical Rectangular	1.000
	Optimized Rotation	1.000
	Ellipsoid	1.000
Optimized Root Control	Horizontal Rectangular	1.000
	Vertical Rectangular	1.000
	Optimized Rotation	1.000
	Ellipsoid	0.665
Horizontal Rectangular	Vertical Rectangular	1.000

	Optimized Rotation	1.000
	Ellipsoid	0.030*
Vertical Rectangular	Optimized Rotation	1.000
	Ellipsoid	0.545
Optimized Rotation	Ellipsoid	0.035*

Tukey HSD test (*) p<0.05

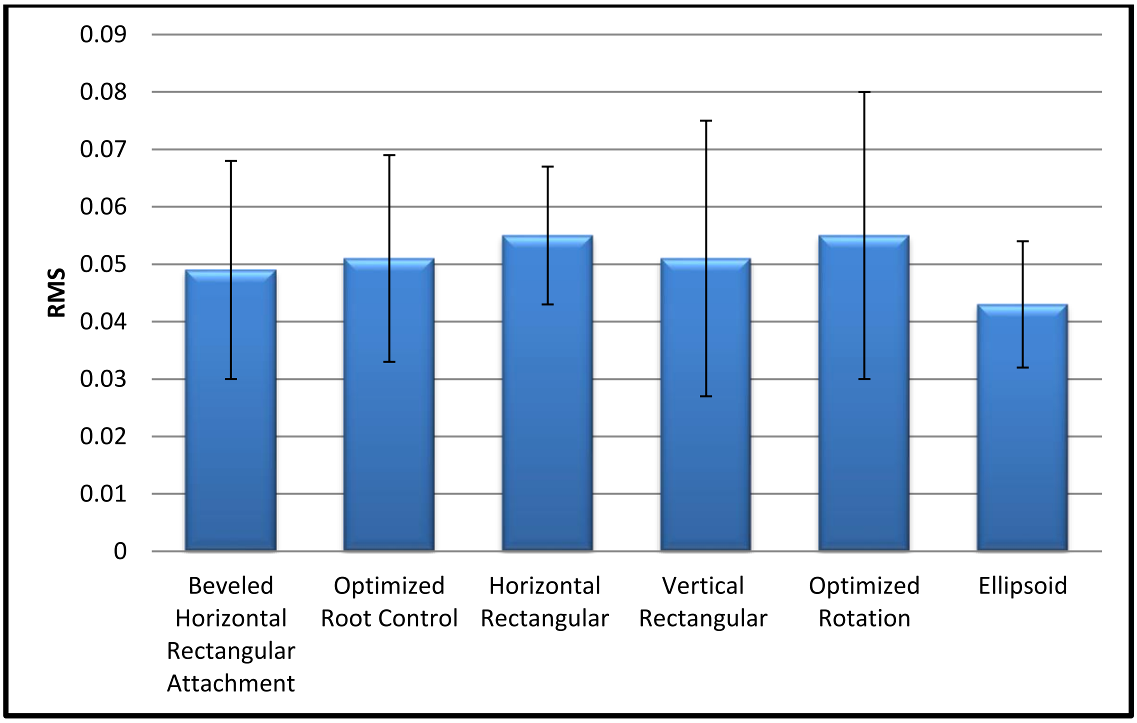

Figure 4.1. Comparison between attachments' configurations and their possible effect on their printing accuracy.

The Intra-group comparison between attachments' groups in each printing technique separately was given in (Table 4.4.) by means of (RMS mean).

When the SLA technique is used there is a statistically significant difference between attachments in terms of RMS averages (p:0.004; p<0.05) (Table 4.4.) and (Figure 4.2.). As a result of post hoc analyzes to determine between which attachments the significance is; RMS mean of the Horizontal Rectangular group was found to be significantly higher than the Beveled Horizontal Rectangular and Vertical Rectangular groups (p_1:0.008; p_2:0.004; $p<0.05$). There is no statistically significant difference between other attachment groups ($p>0.05$) (Table 4.5.).

When the DLP technique is used there is a statistically significant difference between attachments in terms of RMS averages (p:0.005; $p<0.05$) (Table 4.4.) and (Figure 4.3.). As a result of post hoc analyzes to determine between which attachments the significance is; RMS mean of the Ellipsoid group was found to be significantly lower than the Vertical Rectangular and Optimized Rotation groups (p_1:0.013; p_2:0.003; $p<0.05$). There is no statistically significant difference between other attachment groups ($p>0.05$) (Table 4.5.).

Table 4.4. Intra-group comparison of attachment groups for each printing techniques separately.

	SLA		DLP	
Attachment	**n**	**Mean ± SD**	**n**	**Mean ± SD**
Beveled Horizontal Rectangular Attachment	8	0.033±0.004	8	0.066±0.011
Optimized Root Control	8	0.036±0.006	8	0.066±0.010
Horizontal Rectangular	8	0.046±0.006	8	0.065±0.010
Vertical Rectangular	8	0.032±0.007	8	0.071±0.017
Optimized Rotation	8	0.036±0.010	8	0.075±0.019
Ellipsoid	8	0.039±0.008	8	0.047±0.013
p		0.004**		0.005**

One way ANOVA Test **(**) p<0.01**

Table 4.5. Post hoc comparisons between attachments groups for each printing technique.

		SLA	DLP
Attachment	**Attachment**	**p**	**p**
Beveled Horizontal Rectangular Attachment	Optimized Root Control	0.964	1.000
	Horizontal Rectangular	0.008**	1.000
	Vertical Rectangular	1.000	0.980
	Optimized Rotation	0.974	0.788
	Ellipsoid	0.523	0.078
Optimized Root Control	Horizontal Rectangular	0.068	1.000
	Vertical Rectangular	0.873	0.982
	Optimized Rotation	1.000	0.795
	Ellipsoid	0.940	0.076
Horizontal Rectangular	Vertical Rectangular	0.004**	0.941
	Optimized Rotation	0.060	0.668
	Ellipsoid	0.395	0.123
Vertical Rectangular	Optimized Rotation	0.894	0.992
	Ellipsoid	0.342	0.013*
Optimized Rotation	Ellipsoid	0.924	0.003**

Tukey HSD test **(**) p<0.01, (*) p<0.05**

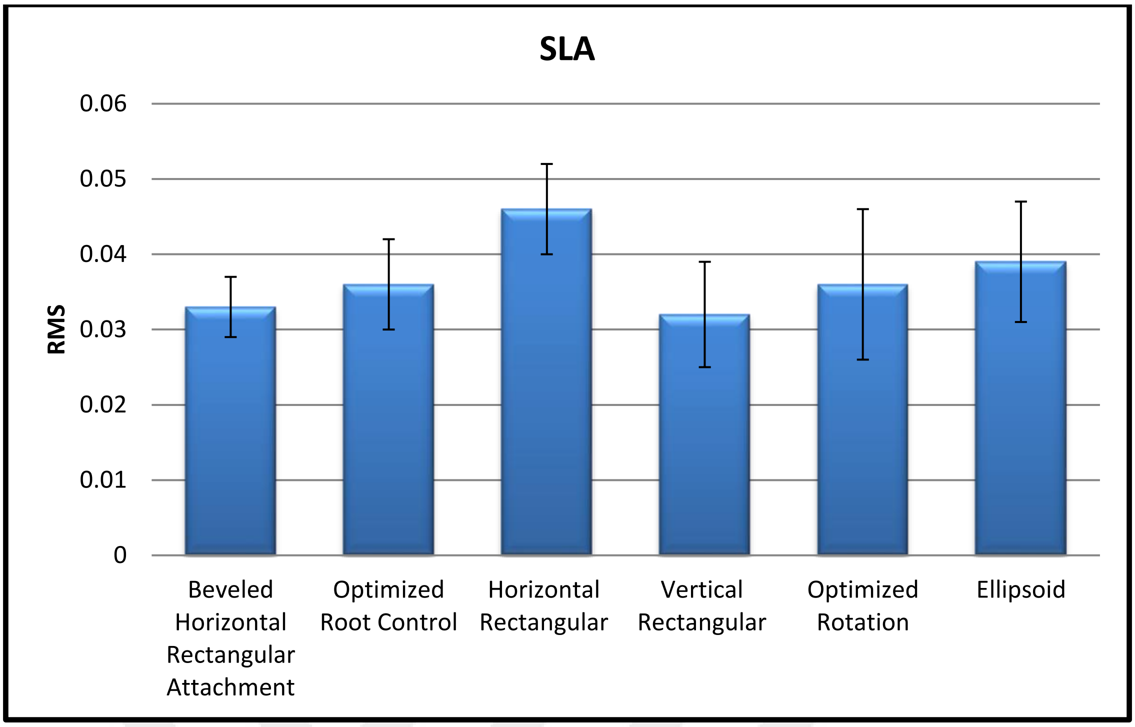

Figure 4.2. Intra-group comparison of attachment groups for SLA printing technique.

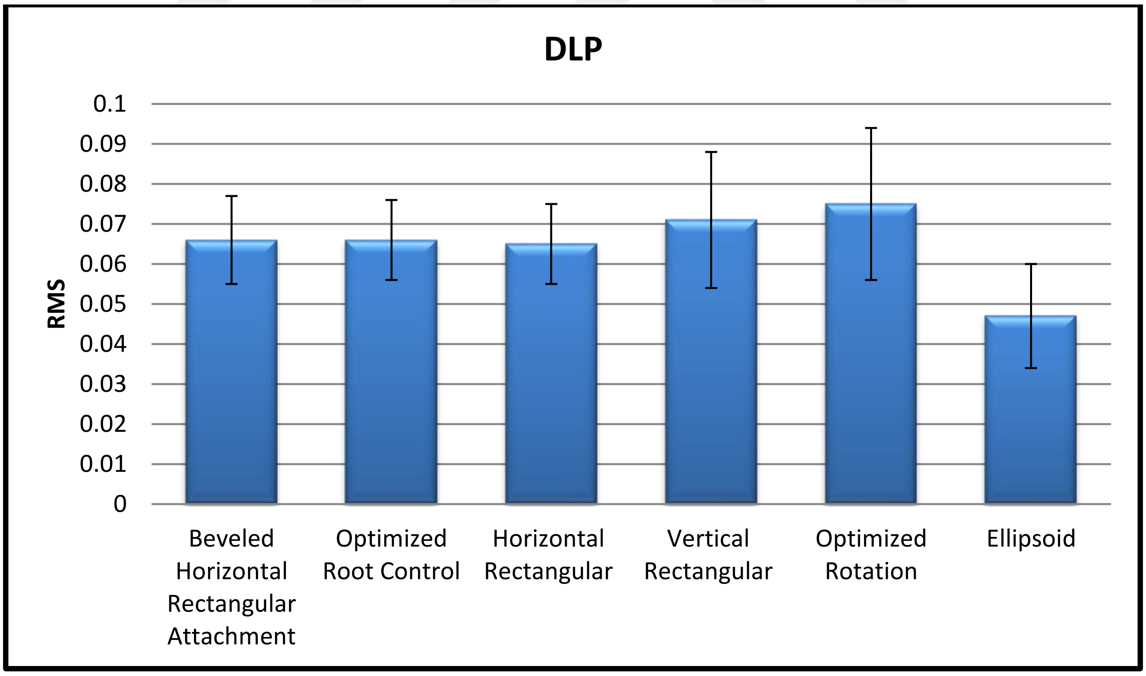

Figure 4.3. Intra-group comparison of attachment groups for DLP printing technique.

The comparison between the two examined printing techniques (SLA and DLP) was given in (Table 4.6.) and (Figure 3.4.) by means of (RMS mean), to analyze the influence that a printing technique have on the printing accuracy of the attachments.

RMS mean of DLP technique is statistically significantly higher than SLA technique (p:0.000; p<0.05).

Table 4.6. Comparison between printing techniques

		RMS		
		n	**Mean ± SD**	**p**
Printing technique	SLA	48	0.037±0.008	0.000***
	DLP	48	0.065±0.016	

Two Way ANOVA Test **(***) p<0.001**

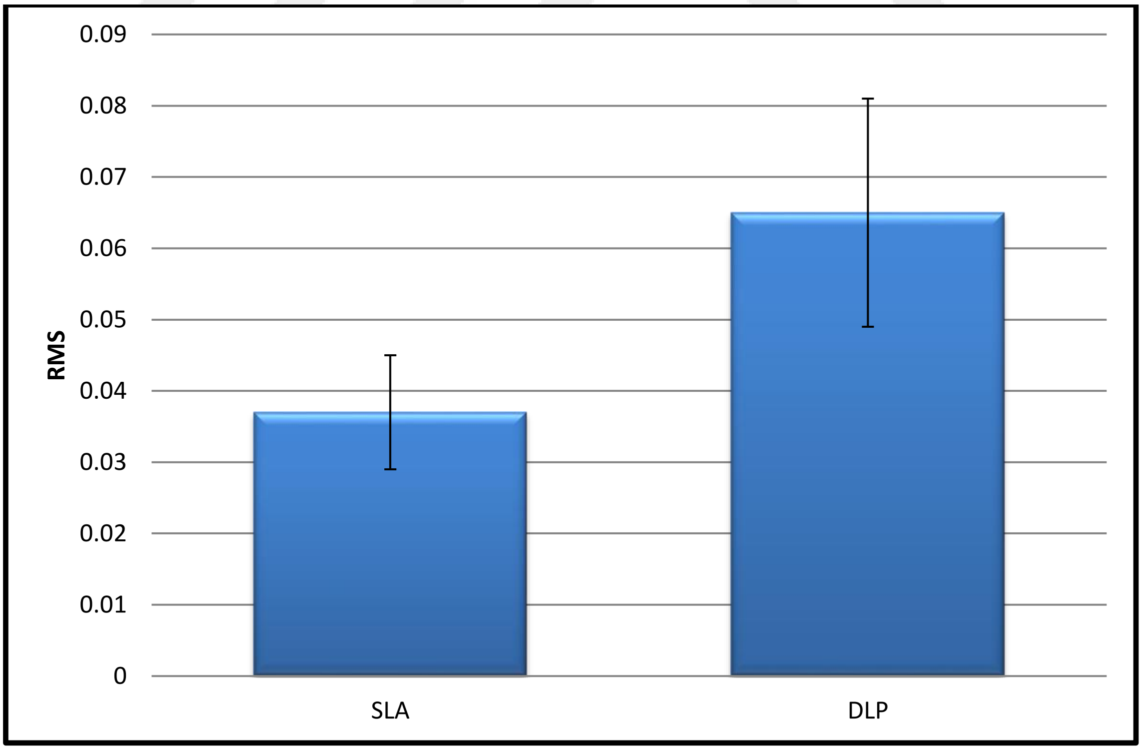

Figure 4.4. comparison between printing techniques.

The Inter-group comparison between the two printing techniques for each attachment group separately was given in (Table 4.7.) by means of (RMS mean).

When using the Beveled Horizontal Rectangular Attachment; RMS mean of DLP technique is statistically significantly higher than SLA technique (p:0.000; p<0.05). When using the Optimized Root Control attachment; RMS mean of DLP technique is statistically significantly higher than SLA technique (p:0.000; p<0.05). When using the Rectangular Horizontal attachment; RMS mean of DLP technique is statistically significantly higher than SLA technique (p:0.000; p<0.05). When using the Vertical Rectangular attachment; RMS mean of DLP technique is statistically significantly higher than SLA technique (p:0.000; p<0.05). When using the Optimized Rotation attachment; RMS mean of DLP technique is statistically significantly higher than SLA technique (p:0.000; p<0.05). When using the Ellipsoid attachment; there is no statistically significant difference between SLA and DLP in terms of RMS averages (p:0.161; p>0.05).

Table 4.7. Inter-group comparison of printing techniques for each attachment groups separately**.**

	SLA		DLP		
Attachment	**n**	**Mean ± SD**	**n**	**Mean ± SD**	**p**
Beveled Horizontal Rectangular Attachment	8	0.033±0.004	8	0.066±0.011	0.000***
Optimized Root Control	8	0.036±0.006	8	0.066±0.01	0.000***
Horizontal Rectangular	8	0.046±0.006	8	0.065±0.01	0.000***
Vertical Rectangular	8	0.032±0.007	8	0.071±0.017	0.000***
Optimized Rotation	8	0.036±0.01	8	0.075±0.019	0.000***
Ellipsoid		0.039±0.008		0.047±0.013	0.161

Student t test **(***) p<0.001**

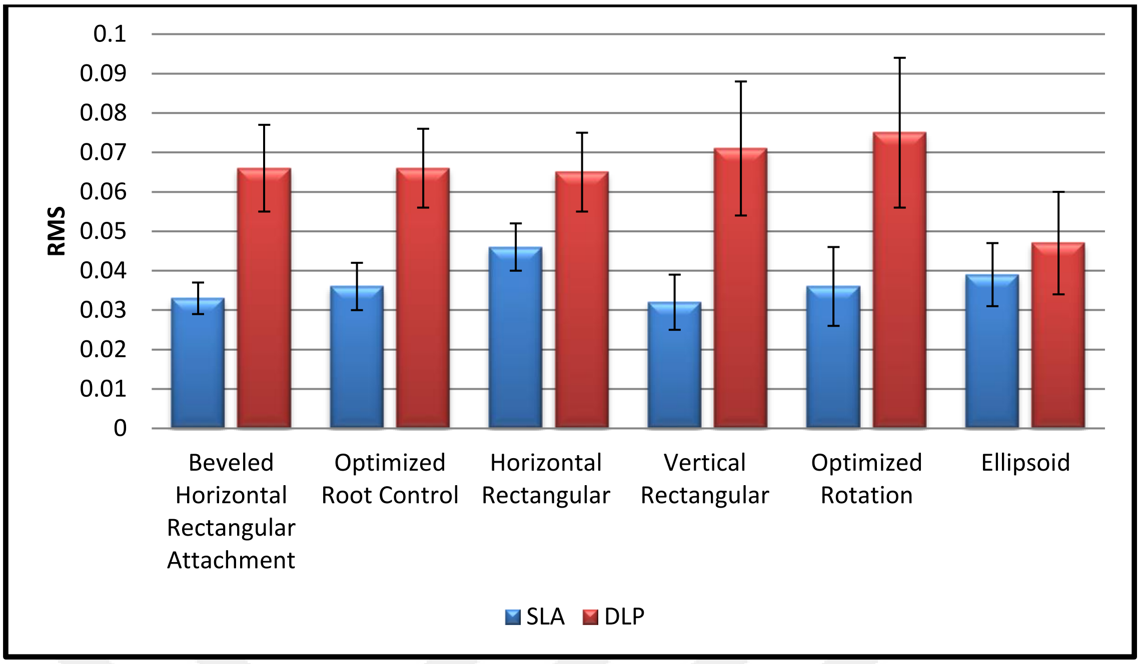

Figure 4.5. Inter-group comparison of printing techniques for each attachment groups separately.

5. DISCUSSION

5.1. Discussion of Purpose and Methods:

Nowadays, individuals are increasingly concerned about the appearance of their teeth (1,29,31–33,156). This didn't only lead them to seek orthodontics treatment to treat teeth mal-alignments, but also seeking the most aesthetic approach to achieve their demands. This has given the opportunity for new and more aesthetic treatment approaches to become popular over the past few years, with clear aligner therapy being the most popular (31–34). The advent of digital orthodontics using optical impressions together with the invention of 3D printing didn't only increase the efficiency of this treatment modality, but also, it's performance in treating complex malocclusion cases (35,45,53,56,68–72,77,132). Digital orthodontics is the new trends nowadays and has taken the most advantage of optical scanning and 3D printing. Digital data allowed patients' records to be recalled anytime for planning a treatment on a 3D digital model or by bringing it into physical form by printing it using 3D printing technology for appliances fabrication (23–25,27,117,126,128–131,146,157–159).

Clear aligners have undergone many modifications such as different material types, thicknesses and the design of the margin and its extension to improve their clinical performance since they have been first introduced (17,19,47,51,56,59,60,63,90,91). Nevertheless, the incorporation of attachments became an integral part in clear aligner therapy. As emphasized by all authors, the use of attachments became mandatory for achieving a predictable and satisfactory treatment results (21,58,63,96–100,102–104). Once the attachments are added to the teeth surfaces, they become one object with the teeth hard tissue, modifying the tooth surface anatomy and likewise modifying what is going to be captured by the optical scanner.

Attachments are one of the milestones in clear aligner therapy. Several studies evaluated different attachment geometries, sizes and locations (19,21,22,63,91,97,99,100,103–106). Dasy et al. (19) has evaluated the effect of attachments on retention when added to clear aligner. In their study they compared two different attachments (ellipsoid and beveled) with a control group having no attachments at all. They demonstrated that the use of attachments increases the retention significantly compared with no use of attachments. They also added that the beveled attachments were significantly superior to ellipsoid attachments. These finding came in coincidence with the results founded by Al Noor et al. (91) who determined that adding beveled attachments lead to the significant increase in the retention. Ravera et al. (103) and Garino et al. (104) have demonstrated the importance of using vertical rectangular attachments on posterior teeth to improve the root control during molars distalization. Elkholy et al. (21) investigated the efficiency of three different shapes of aligner attachment geometry (quarter-sphere, vertical-ellipsoid, and pyramidal) during derotation of a mandibular canine. The quarter-sphere geometry induced the highest rotational moment together with counteracting the unwanted intrusive forces during derotation. Comba et al. (97) evaluated canine distalization with rectangular attachment and optimized attachment. He found that rectangular attachment would cause intrusion and distal crown tipping during canine distalization, while optimized attachments are more efficient in achieving bodily translation. Costa et al. (22) performed a 3D evaluated of the force generated during extrusion of upper central incisors by three geometrically different attachments modified from ellipsoid, rectangular and beveled attachments by modifying the active surface of each attachment. They concluded that shape of attachment can affect the intensity and direction of force. Goto et al. (105) analyzed the possible effect of changing attachments shape, size and location on the predictability of canines distalization during closing an extraction space. He noted no influence of changing the attachment shape, size or location on the tipping of the canine during space closure. However, the study only investigated placing the attachments on the buccal surface of the canine. He also assumed that the effect of the attachment might be more dependent on the morphology of the crown. In contrast, Zhouyan et al. (99) compared the effect of changing the thicknesses and locations of rectangular attachments for correcting the rotation of maxillary canine teeth. The results showed that increasing the attachment thickness has a direct relationship with stress value of periodontal ligaments and thus canine displacement. Moreover, he confirmed that changing the location of the attachment vertically had a significant influence on controlling canine rotation, with occlusal placed attachment providing better control that apically placed ones, while changes in mesial and distal directions were irregular. However, the two previous studies didn’t address the lingual surface or the tooth and only limited the investigation to examine the attachments on different locations of the buccal surface. In contrast, Kim et al. (106) examined the optimal shape and position of attachments to be placed on lower canine during extrusion, intrusion, rotation and torque movements on both buccal and lingual surfaces. He suggested that the placement of attachments on the lingual surface of the tooth provides optimal torque control and effective tooth movement rather than the buccal surface. He also added that the use of cylindrical attachment sums for a better contact angle between the attachment and the aligner and thus a better stress distribution. Savignano et al. (100) has compared the performance of clear aligners in exerting extrusion movement to central incisor using three designs of attachments differs in shape and location (rectangular palatal, a rectangular buccal, and an ellipsoid buccal attachment) with the one using no attachments. He confirmed that extrusion of central incisor cannot be achieved without attachments, and emphasized that the use of rectangular palatal attachment's configuration was the best to exert incisor extrusion. Moreover, several materials for attachments and varies bonding protocols have been also examined. (93–95)

The concept behind clear aligner therapy is based on generating precise forces that are precisely calculated with the ideal magnitude and direction within the biological rate of the periodontium measured by artificial intelligence using a special software. These forces are incorporated and programmed into the aligners to be delivered to the teeth and the attachments mounted on it, and the interaction between the aligner and the attachments' active surfaces will result in moving the teeth (160). Cai et al. (89) analyzed the force system given by attachments, and showed that the attachment could be optimized to help the tooth move effectively. He also added that the most important factor affecting the attachment's efficiency was found to be the active surface direction, which can be optimized by the moment-to-force ratio needed by the movement. According to Kim et al. (106) the use of cylindrical attachment sums for a better contact angle between the attachment and the aligner and thus a better stress distribution. Savignano et al. (100) added that attachment position has stronger influence on the outcome movement compared to its shape due to its effect on the active surface of the attachment. Considering the small size and recommendations to optimize the attachments to achieve more efficient movements, molding and bonding them with their exact size, shape and location is crucial, as error in their bonding can impede the planned movement or result in an unplanned one (93). Giving the small recommended incremental advancement of each planned movement in the aligner which ranges between 0.1-0.3mm and 3-5 degrees of rotation per aligner(160), an insignificant error below this range of movement can add on by moving forward with the aligners which will end up by becoming significant with the teeth losing the track at very early stage of the treatment. Therefore, in order to exactly achieve the predetermined amount and direction of teeth movements, preservation of the forces resulting from aligner/attachments interaction is mandatory. According to Zhouyan et al. (99), he compared the effect of changing the thicknesses of rectangular attachments for correcting the rotation of maxillary canine teeth. The results showed that increasing the attachment thickness has a direct relationship with stress value of periodontal ligaments and thus canine displacement.

The aforementioned arguments indicate that an accurate reproduction of the digitally designed attachments is crucial and need to be taken in account. The first translation of attachments from digital to physical form is by printing them mounted on the dental model upon which the aligners will be fabricated using a 3D printer. In literature, only limited studies have addressed different 3D printing technology in orthodontics. Most of the studies have only compared the accuracy of study dental models replicated from conventional plaster models or digital models by 3D printers using different printing techniques (23,25–28,131). Only very few studies have compared different printing techniques with each other,(24,151,153) but still, none of them has gone beyond evaluating the study models. And to the best of our knowledge, no study has ever evaluated the impact that different printing techniques may have on the accuracy of the attachments. Therefore, in this study we aimed to evaluate the efficiency of two 3D printing techniques commonly involved in clear aligners' fabrication (SLA and DLP) from attachments perspective, by measuring the dimensional deviation of the attachments from their corresponding digital ones using 3D superimposition analysis. This will help us to investigate whether or not a significant difference in attachments’ accuracy is present between these two printing techniques, which in turn will allow to make better selection for a 3D printer regarding accuracy, while considering other aspects of 3D printing phase in clear aligners’ fabrication such as cost and the consumed printing time.

Clear aligners can be fabricated from either one of the brand-name commercial companies that have an established product in the market, by fabricating the aligners themselves in a process known by in-house aligners’ fabrication. The later contains complicated clinical labor for the orthodontist and requires the dedication of more doctor’s time and perhaps additional staff to get the job done throughout the whole phases of aligner fabrication. In the present study, the design of the attachments should be uniform and standardized to obtain accurate measurements. The dimensions of the attachments from Align Technology company, the inventor of the Invisalign appliance, were published and have been used by the author as a template to design the attachments with some modifications in their design using a special CAD software. By these designs it was aimed to include all the attachments that are commonly used between different clear aligner companies, and by which most of the time are being referred to as conventional attachments, except for the Optimized Rotation attachment. No intrusion attachment was used in the study as intrusion is normally achieved by using anchorage attachments on the posterior teeth, or optimized support attachments on the adjacent teeth while intrusion forces are being exerted by the aligner itself.

Various software products are available to custom- design appliances digitally. Each orthodontist and/or laboratory should choose a dental analysis and appliance design software according to their preferences in terms of user-friendliness of the design procedures, time involved in the preparation of the digital design and pricing option. There are two options for dental CAD software: either to purchase generic 3D manipulation software (generic CAD or G-CAD) or a dedicated dental program (dedicated CAD or D-CAD) tailored specifically for dental needs (161). G-CAD software are usually difficult to use as they are not customized to be used for dental work; orthodontic module for instance, and when it comes to aligners' fabrication, they don't offer the user with the necessary tool for segmenting the teeth and staging (162,163). Although G-CAD software lack optimization according to the user interest which cause it to require a more prolonged learning phase, however, some users may find it advantageous over the D-CAD software, as it is unencumbered by the provided appliance design possibilities accompanying these software, freeing the user from the design limitations and unleash the user creativity in designing appliances. As for the D-CAD software, they offer different modules dedicated to facilitate the user experience according to the field of interest with an interacting interface that interacts with the user to guide him through the process. (164,165). More or less, all D-CAD software share the same method of aligner design, varying only in the sophistication of the design options they provide, for example, the possibility of importing CBCT scans and other tools to help the operator design the aligners. No matter the fee schedule, all of these software packages provide the operator with various tools that improve the quality of treatment planning, such as precise values of every scheduled tooth movement, the ability to stage each movement separately, and visualization of the anticipated occlusal contacts.(64) Predetermined attachment forms are provided within various orthodontic D-CAD software but they can also be designed individually in another G-CAD software and imported into the D-CAD software. However, the attachments' library of most D-CAD software was clearly overlooked by their companies as it doesn't embrace the necessary attachments' designs for clear aligners' treatment in general and for this study in specific manner. In addition, when using these attachments geometries provided by any of the D-CAD software, and due to the slight convexity of the labial/buccal surfaces of the teeth and the flat basal surface of the attachments, it was detected that an accurate adaptation of the attachments over the labial/buccal surface of teeth is not possible without pressing the attachment into the labial/buccal surface of the tooth to seal the margin between the them. This will cause some loss in the attachment prominence ~~which~~ that in turn complicates the present study. In order to solve this, all attachments have been designed from scratch by the author and modified from the basal surface to facilitate their adaptation over the convex labial/buccal surface of each tooth by slightly concaving the basal surface of each attachment. By doing so, the author was able to mount the attachment on the tooth without disturbing its prominence while attempting marginal seal with the tooth surface (Figures 2.2.1.1.A. - 2.2.1.1.F.). This implies standardizing all attachments' dimensions by maintaining its original dimensions similar to the digital version. Therefore, in the present study, Rhinoceros 3D (G-CAD) software was used to design the attachments as special modifications were necessary in the attachments' design to cope with this study which couldn't be provided by any of the D-CAD software.

Although the use of special feature tools was not needed in this study, we found that a D-CAD software would be more user-friendly when cleaning the models and prepare them to receive the predesigned attachments. The most popular D-CAD software for in-house aligners fabrication is the 3Shape Ortho Analyzer. In the present study, the 3Shape Ortho Analyzer software was used to prepare the models and import the attachments to the teeth. After several unsuccessful attempts to design attachments that are compatible with the Ortho Analyzer software using different G-CAD software, we were eventually capable of achieving this using Rhinoceros 3D software.

Achieving a deviation that falls within the range of clinical tolerance is dictated by many interrelated factors, primarily; the type of printing technique, the type and layer thickness of the printing material and the orientation of the object that is to be printed.

The most common printing technology in dental practice and aligner fabrication is the resin-based printing technology or the so-called Vat polymerization printing technology. It utilizes a photosensitive polymer that is to be cured by a light source. The commonly used printing methods that embrace the resin-based printing technology are the Stereolithographic apparatus (SLA) and the Digital light processing (DLP).

The material properties (accuracy, resilience, rigidity, flexibility, chemical and thermos-cycling resistance, fracture resistance, shade, translucency, opacity and esthetics), the biocompatibility and the ability to sterilize the printed items if needed and the type of the 3D printing technology that is to be used is important in the decision of the printing material(134,159,166,167). The printing materials that have been used were as recommended by the printers' manufacturers. Since the XFAB 2500PD printer that utilizes SLA technique has a closed system, it doesn't accept other resin type than the one recommended by the manufacturer, and Invicta 907 resin material from the same company was used as the printing material. While for the AccuFab-D1 printer that utilizes DLP technique, it has an open system and the KeyModel Ultra resin material from Keystone Industries company was used. In order to reduce printing errors, the occlusal plane of the 3D printed model was aligned parallel to the platform and the build angle was set to 180◦ to locate the tooth cusp away from the platform as suggested by Favero et al.(168). The same orientation protocol was later adopted by, Zhang et al. (160) and Choi et al. (151).

The layer thickness, or sometime referred to as the layer height, is sometimes used to resemble the vertical resolution of a 3D printer and is measured by dots per inch (dpi) which also corresponds to a certain value in microns (µm). A higher resolution or by other words; a greater (dpi) or a smaller value by µm indicates greater accuracy (134). However, higher resolution doesn't always necessitate higher accuracy of a print as other aspects of 3D printing related to the printer being used and the associate technicalities are influential in the resultant accuracy. Beside of being very limited, it was found that discussions regarding the selection of the appropriate layer thickness are controversial in the literature (160,168). A previous study has examined the effect of three different layer thicknesses (100µm, 50µm and 25µm) on the printing accuracy using SLA and DLP printing technologies and has found that the accuracy of SLA printers increases by decreasing the layer thickness from 100µm to 25µm, while a layer thickness of 50µm generates the optimal accuracy for DLP printers. Moreover, DLP technology when compared with SLA technology prints faster and has a higher printing accuracy when the layer thickness is set to 100µm (160). These results suggest that the accuracy increases with the decrease in layer thickness, which is in accordance with the general knowledge. According to the author, by good understanding to the principle of SLA and DLP technologies, resin-based printing technologies are based on building layers one by one over each other, however, since the majority of borders of a dental model are diagonal borders with little vertical or horizontal linear borders, these layers don't lay in a uniform constant order on the z-axis or XY-plane. In such cases, the layer thickness determines the number of discrete points on the edge. A thinner layer will generate more discrete points thereby producing a smoother and more detailed surface, making the print more accurate. In contrast, a thicker layer has fewer discrete points and longer distance between them, resulting in an obvious stair-stepping effect at the edge that affects the overall accuracy. However, as mentioned before, although a smaller layer height will likely allow for more detail in a printed piece and an improved surface finish, it does not always mean that the printed piece is more accurate than those printed with larger layer settings. Similarly, another study that has analyzed the absolute average deviation of dental models printed on 25, 50 and 100µm layer height from the master model have concluded the absolute opposite. It was found that an object printed on 100µm layer height produced from Form2 printer using SLA printing technique is more accurate than the ones printed on 50µm, and the latter being more accurate than that printed on 25µm layer height (168). Interestingly, the same phenomenon has been addressed in another study when using EncaDent printer that applies DLP technique; i.e., when the layer thickness was reduced to 30µm and 20µm, the printing accuracy decreased accordingly (160). Both authors tried to give a sensible explanation of this phenomenon by pointing out to the possibility that an attempt to increase the resolution by reducing the layer thickness, the number of layers required to print a given part increases. And by increasing the resolution or by other words reducing the layer thickness used in printing, there is a 4-fold increase in layer quantity of the same print from 100µm to 25µm layer heights. If part of the area deviates from the ideal boundary in each layer when selecting higher-resolution settings in the Z-direction, the increased number of layers will also increase the potentials for error, artifacts, and failure over the course of a print, which could result in decreased accuracy of the printed part (160,168). Providing the limitation and the controversy regarding the optimal layer thickness that can provide the closest print to the digital object in regard to accuracy, it may confidently be commended that a higher resolution doesn't always mean a higher accuracy of a print, and that an ideal resolution is also dependent on other factors. Since the ideal layer thickness recommended for printing dental models isn’t provided decisively in the literature, and in order to achieve a balance between the accuracy and the possibility for an error to occur, it was decided to use a layer thickness of 50μm. The aim was to increase the resolution and hence the accuracy, yet not to the utmost, as increasing the layer thickness may increase the opportunity for an error or an artifact to occur as well.

The evaluation of the capability of 3D printers to produce reliable replicas in orthodontics should be discussed according to the desired clinical task assigned for the 3D printer. Interestingly, the majority of studies that have compared the accuracy and reproducibility of 3D printed models fabricated by different types of printers were done by applying linear comparison between plaster models and the related 3D printed models(23,25–28,131). They showed that even though plaster casts show very little volumetric changes when compared to 3D printed models, likewise, some printing techniques such as digital light processing (DLP) have similar low mean differences as plaster models. Other techniques such as SLA can show slightly more differences with variant degrees, but anyhow, for clinical purposes, it seems unlikely that these differences can have a high impact on the interpretation of these models and they were delegated as being appropriate for selected application in orthodontics. Another study has analyzed the linear measurements obtained on teeth of digital models versus SLA printed models by comparing them to natural teeth on a human skull (154). The study concluded that the differences in measurements on the digital models were generally smaller than those for the stereolithographic models. However, when compared to natural dentition, the differences were clinically insignificant and both models were considered to be valid and reproducible.

Nevertheless, the process from data acquisition to reconstruction of a 3D printed dental model is a nonlinear spatial process, and its evaluation method should also be three-dimensional (169). In addition, human subjective factors, such as measurement error, are inevitable. Compared to the traditional two-dimensional (2D) linear distance measurement and evaluation method, 3D evaluations based on computerized algorithms take into account the 3D spatial structure of complex tooth anatomy, which undoubtedly provides more clinically relevant information and can minimize artificial error (160). Up to now, there has been little research applying 3D evaluations on the accuracy of 3D printing of full dental arches (24,151,153,168,170).

Until recently, the implementation of 3D comparison software for quantitative evaluation of the consistency between the test and reference file was very limited in orthodontics, and the accuracy of printed dental models is largely evaluated based on traditional manual linear distance measurement. A recent study confirmed that 3D superimposition analysis is reliable and superior to that of traditional manual measurements (24). Furthermore, alignment and superimposition procedures, as well as 3D comparison, are all accomplished via special software, which avoids artificial errors inherent to manual measurement. In addition, the calculation covers every point in the digital model, fully reflecting all deviations in the 3D space, which is considered as a more comprehensive and reliable evaluation approach. For complex and irregular surfaces such as dental models, the traditional method of linear distance evaluation can only select limited points or segments for measurement, and the results cannot fully characterize the form error of the entire surface (171). According to Nur et al. (172), to overcome the shortcomings of 2D linear measurement, an adjunctive 3D evaluation was also recommended, which become more useful when small objects are being examined. Therefore, in the present study, in order to analyze the volumetric variations of the attachments after being printed using two different 3D printers, the use of 3D comparison instead of linear comparison was used.

In addition of being used as a reliable diagnostic measure, the application of 3D printing technology can also be utilized for appliances' fabrication, which by common sense will require a superior surface characteristics and accuracy compared to these of diagnostic models. Therefore, the selection of a printer should be determined thoughtfully according to its intended application while considering the performance offered by the printer. Although no specific standards exist for assessing the accuracy of replicated dental models, various thresholds have been suggested in the literature as being clinically acceptable ranging from 0.16 to 0.50mm (116,160,171,173–177). Stevens et al. (175) determined that any measurement differences less than 0.16 mm were considered clinically insignificant. Fleming et al. (116) has considered a difference of up to 0.4mm to be acceptable regarding the deviation of the print accuracy if the printed model is used for analysis and diagnosis purposes. Whereas in accordance with the ABO OGS (American Board of Orthodontics Objective Grading System) standard, the linear distance deviation within 0.5mm of a study model can be considered acceptable, but it may not be sufficiently accurate to manufacture orthodontic appliances (178). Quimby et al. (176) suggested a difference of about 0.1mm between natural teeth and corresponding models is clinically acceptable for appliances fabrication. In a study comparing conventional and digital impressions of the complete dentition, Ender et al.(171) found that the average accuracy was about 0.05 mm. Kasparova et al. has documented that the linear distance deviation of printed model is acceptable at 0.2 mm since the measurement error of plaster model itself is close to this range.(131) Other authors have defined the acceptable 3D deviation limit to be at 0.25mm (179).

The parameters of "accuracy" used in this study described the trueness of printed dental models, suggesting their consistency with the digital source files. Smaller average absolute deviation represents a smaller average of the shortest distance between each point in the test model and corresponding point in the reference model, indicating higher average agreement between the test model and the reference model. Notably, parameter settings for detecting deviation ranges are extremely important in Geomagic control X software. Currently, the main application of 3D printed models is mainly represented by the fabrication of clear aligners, which requires a range of tooth movement between 0.1-0.3 mm per aligner. In this regard, the average absolute deviation of less than 0.05 mm is considered sufficient if the printed model is used to make clear aligners(160), and based on this the nominal range was set to be ± 0.05 mm (160). For the same reason, and based on all the reviewed studies in this regard, differences beyond 0.25 mm were considered clinically unacceptable, so the critical range; also known as threshold, was set to be ± 0.25 mm. This range falls within these previously reported limits, and are in consistence with what was proposed by Favero et al. (168), Camardella et al. (24) and Zhang et al. (160).

5.2. Discussion of Results:

Attachments are an integral part of clear aligners' treatment. They tend to increase the surface area against which the aligners will be pushing. Exerting the desired amount and direction of force to the tooth is highly dependable on the morphology, size and location of the attachment to achieve the final desired outcome of tooth movement. Therefore, it is necessary to investigate accurate reproduction of different attachments' configurations generated by 3D printing from the original digital attachments. The comparison of the attachment groups in the present study (Table 4.2.) showed significant differences independent of the printing technique ($P=0.024$; $p<0.05$). As provided by

(Table 4.3.), the RMS mean value of the Ellipsoid group was the lowest with 0,043±0,011 μm, while the RMS mean values of the Horizontal Rectangular and Optimized Rotation groups registered the highest values with 0,055±0,012 μm and 0,055±0,025 μm, respectively. This indicate that the Ellipsoid attachments registered the least deviation from the corresponding gold standard digital attachments, while the Horizontal Rectangular and Optimized Rotation attachments' groups showed the greatest deviation from the corresponding gold standard digital attachments. Regardless of the printing technique that has been used, these 3 groups of attachments were responsible for this statistical significance. This also indicates that the geometry of the attachments plays a role in the dimensional accuracy of the printed attachments.

In the literature, several studies examined the possible factors that may affect the final accuracy of the printed object such as the build angle, the need for support structure, the printed object geometry, the printing technique, the layer thickness, the position the object on the print platform, the type of the printing material, whether printed solely or within a group of objects and the ideal orientation of the digital model on the printing platform. However, each of these studies focused on addressing no more than one or two of the aforementioned factors, as standardizing all these factors in one research environment is not possible (157,158,180–200). In addition, there will always be a compensation in one dimension at the expense of the other with different orientations (181–184). Tanoto et al. (184) studied the relationship between different printing parameters and their possible generated responses on printing accuracy. Each orientation showed some degree of violation in one of the dimensions.

A general rule in the 3D printing technology may suggest that slopping or curved surfaces may appear gradually stepped appearing like a stairsteps, while vertical and horizontal edges of about 90 degrees angles appears to be smooth. This is due to the fact that in 3D printing technology the layers are horizontally rendered (Figure 5.2.1.) (201). Alexander et al. (202), Lan et al.(195) and Frank et al.(203) suggested that the accuracy of any printed object is mainly jeopardized by the stair-stepping effect. It is impossible to overcome this feature entirely, however, they suggested orienting the object that is to be printed by directing the greatest area of its faces to be perpendicular or parallel to the XY-plane. In the attachments' geometries present in this study, the ellipsoid attachment with a dome-like shaped surface would be expected to show the greatest deviation values, while horizontal and vertical rectangular attachments would be expected to show the lowest deviation values. However, this study revealed opposite results. Even though all surface angles of the vertical and horizontal rectangular attachments measure 90 degrees, this is only true in the 3D space while neglecting their orientation in the 3 spatial axes in relation to these of the printing platform. Therefore, the factors that affect the orientation of the attachments should also be analyzed to get the final statements about this topic. Firstly, when the attachments were placed on the teeth, they have been oriented following the tooth axes in 3 dimensions. Which means that the final orientation of attachments in relation to the printing platform will be influenced by the presence of any tipping or rotation in the teeth. This will be translated into a slight rotation of the attachments in one or more axis, and thus deteriorating the 90 degrees' surface angles, giving rise to the ladder-like surface appearance. The more the number of space axes along which the attachments rotate are involved, and the more the surface angles deviate above or below 90 degrees, the more the stair-steps appearance of the surface become apparent, and hence, the more deviation from the corresponding reference attachment (the more the increase in the RMS values) becomes evident. The effect of this can be seen the most on the Horizontal Rectangular attachments attached to the lower molar that show some mesial tipping in their inclination.

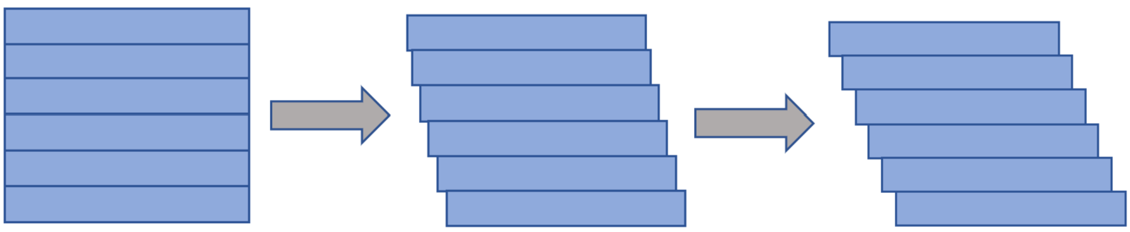

Figure 5.2.1. The stair-steps appearance becomes more visible as the printed surface becomes diagonal.

The final orientation of the attachments is also influenced by their location on the tooth surface and their distance from the vertical long axis of the tooth. Because the Horizontal Rectangular, Vertical Rectangular and the Optimized Rotation attachments were placed more medially away from the vertical long axis of the tooth, and hence, the effect of rotation of the tooth along any axis will be magnified and more alteration of the

90 degrees' surface angles will be witnessed, which as suggested will be translated to a deterioration in the accuracy. As for the Ellipsoid attachment, they were place in the middle third of the buccal tooth surface, almost coincident to the vertical long axis of the tooth, so the effect of rotation of the tooth along any axis of the space will be minimally translated as a deviation in accuracy. This can partly give an explanation of the Ellipsoid attachment having the highest accuracy (lowest RMS value), while the Horizontal Rectangular and Optimized Rotation attachments showing the lowest accuracy (Highest RMS value) among all attachments' geometries. Similarly, the Vertical Rectangular attachment from the DLP group showed low accuracy (High RMS value).

Lastly, the shape of the curved dental arch and the alignment of the teeth along the arch influence the final orientation of the attachments in the same way. The effect of this is more apparent in posterior teeth, as the arch curvature tends to exaggerate by moving posteriorly, providing that the models were oriented in coincidence with the 3 axes of the printing platform. This can somewhat explain why does Horizontal Rectangular attachment located on the posterior teeth showed the lowest accuracy (Highest RMS value).

However, the nature of these effects is not necessarily cumulative, instead, when present at the same time, they may sometimes compensate for each other according to the magnitude and direction of rotation along each spatial axis together with the attachment's positions and alignments along the dental arch. All of the previously discussed factors regarding the orientation will determine the final orientation of the attachments in relation to the printing platform, making the prediction of the final result of printing accuracy impossible.

The relationship between all the factors that brings out the final quality of the printed models is a trade-off relationship (204). This extremely compound relationship is being culminated with the printing layer thickness (Z-resolution). Several authors have emphasized achieving the best accuracy by finding the best orientation-layer thickness combination. According to Farzadi et al. (194) the optimum dimensional accuracy can be obtained by selecting the best combination of the two processing factors; layer thickness and printing orientation. Consistently, Park et al. (205) stated that the fit of the 3D printed prosthesis varied depending on the build orientation and the layer thickness. Along the same, Ko et al. (196) concluded that the build angle and the layer height interact at a statistically significant level to affect the dimensional accuracy of 3D-printed dental models. On one hand, the use of small layer thickness (50 microns) has been associated with a smooth transition of the dome-shaped surface of the ellipsoid attachment that may explain why it measured the smallest deviation. On the other hand, reducing the printing layer thickness will increase required number of layers to build each attachment specially in the vertically oriented attachments. This will magnify the micro-deficiencies built in each layer while moving vertically layer by layer, making vertically positioned attachments more prone to this effect. Along with all the previously mentioned reasons, this can explain why Vertical Rectangular and Optimized Rotation attachment have registered the highest deviation (highest RMS) values among other attachments.

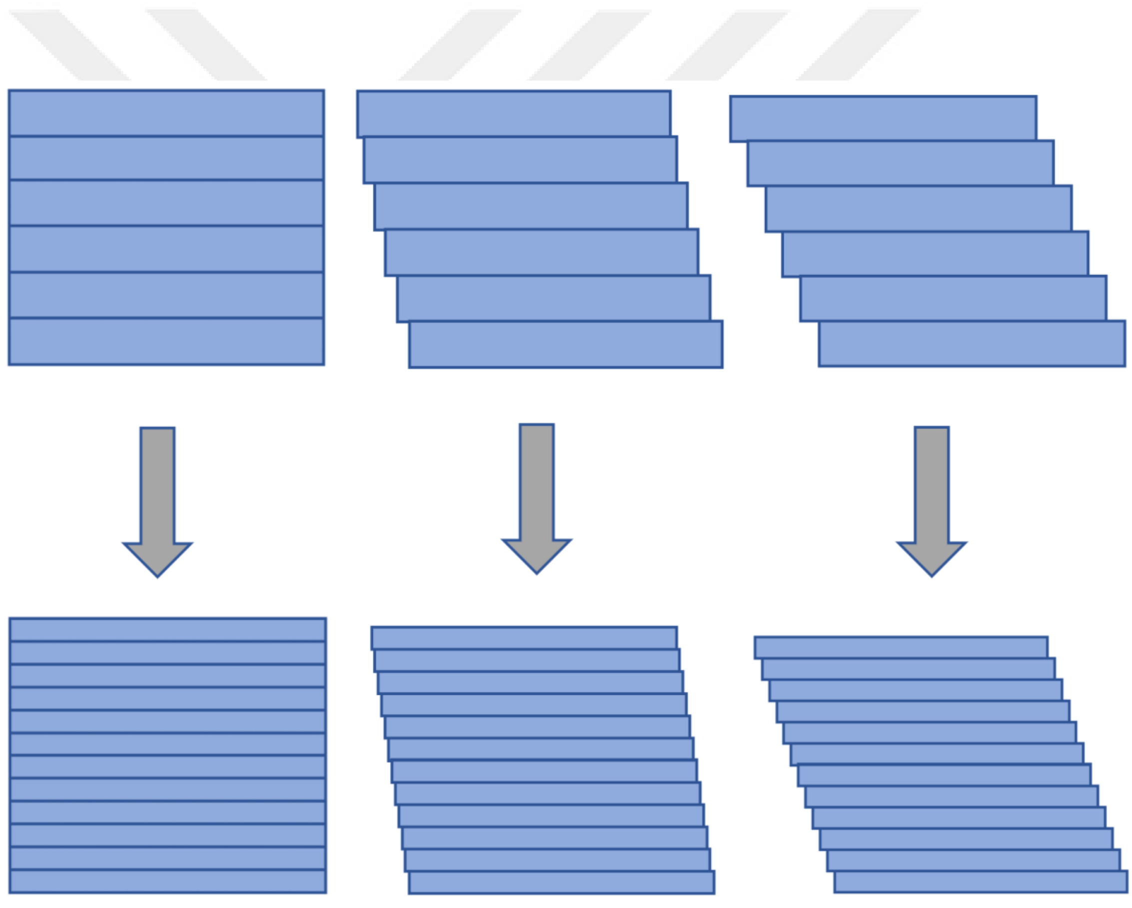

Figure 5.2.2. The effect of reducing the layer thickness on sloped surfaces.

In order to eliminate the possibility of one printing technique being solely or more responsible than the other for these findings, we investigated the attachments' groups again but this time for each printing technique separately. A more thorough Intra-group comparison between attachments' groups in each printing technique separately was introduced in (Table 4.4.) by means of (RMS mean). The results came out to be significant for the attachment groups printed by both techniques registering (P:0.004 and 0.005, $p<0.05$) for SLA-attachments and DLP-attachments, respectively.

Interestingly, when analyzing the significant attachment groups in each printing technique separately as shown in Table 4.5., the results were in constant with what was found in Table 4.3. For the SLA technique, the Beveled Horizontal Rectangular Attachment, Vertical Rectangular Attachment and Horizontal Rectangular Attachment groups were responsible for this significant difference. The RMS mean value of the Beveled Horizontal Rectangular Attachment group and the Vertical Rectangular attachment group measured the lowest with 0.033±0.004 µm and 0.032±0.007 µm respectively, while the Horizontal Rectangular Attachment group measured the highest value of 0.046±0.006 µm. This indicated that the Beveled Horizontal Rectangular Attachment group and the Vertical Rectangular Attachment group registered the least deviation from the corresponding gold standard digital attachments, while the Horizontal Rectangular Attachment group registered the greatest deviation from the corresponding gold standard digital attachment. As for the DLP technique, the Vertical Rectangular Attachment, Optimized Rotation Attachment and Ellipsoid Attachment groups were responsible of this significant difference. The RMS mean value of the Vertical Rectangular Attachment and the Optimized Rotation Attachment groups measured the highest with 0.071±0.017 µm and 0.075±0.019 µm respectively, while the Ellipsoid Attachment group measured the lowest of 0.047±0.013 µm. This indicates that the Vertical Rectangular Attachment and the Optimized Rotation Attachment groups registered the greatest deviation from the corresponding gold standard digital attachments, while the Ellipsoid Attachment group registered the least deviation from the corresponding gold standard digital attachment. Nevertheless, since our findings about the significant attachments groups not only differ between both printing techniques but also with these of the previous tables, these findings came to support our previous findings of the apparent geometrical effect on the accuracy outcomes, as well as to point out at the presence of possible effect of the different printing techniques on the accuracy outcomes.

The effect that a printing technique may have over the printing accuracy was confirmed by (Table 4.6.) which shows a statistically significant difference between printing techniques (P=0.000) regardless the different attachments groups. The RMS mean of DLP technique is statistically significantly higher than that of the SLA technique, with the RMS mean values being 0,037±0,008 μm and 0,065±0,016 μm, respectively. Which reveals that both printing techniques can influence the accuracy of the printing outcome, with the DLP technique showing more deviation than the SLA technique.

These findings were further emphasized statistically by an Inter-group comparison between the two printing techniques for each attachment group, separately, expressed in (Table 4.7.) by means of (RMS mean), to eliminate the possibility of one or more attachment groups being responsible of these findings and to analyzes the possible effect that both printing techniques may have over the printing accuracy for each attachment group separately. The table states that in all the attachments groups that were printed using the DLP printer, they registered a higher statistically significant RMS mean, separately, in comparison to the same group printed with the SLA printer, except for the Ellipsoid Attachment group. These results emphasize that the SLA printer is more efficient in printing Attachments than the DLP printer.

The findings of the present study were in accordance with that have been reported by Choi et al. (151) and Sim et al. (152) Both studies compared SLA and DLP printed models with a reference typodont model consisting of inlay preparation, single crown unit preparation and 3-unit bridge preparation. The SLA printer was capable of producing a print of higher reproducibility than DLP technique in all preparations with close proximity in the inlay preparation. They used the explanation given by Dikova et al. (206) to justify their findings as being a result of the different polymerization technique used in each printer. Since the DLP printer polymerizes one layer of monomer per single radiation, this causes the light source (LED) to refract at a certain angle and to scatter depending on the optical properties of the printing resin monomer. This results in a larger area extending beyond the boundaries being irradiated by the scattered light. As for the SLA printer, the boundaries are less violated by the laser beam for two reasons; First, the distribution of the energy of the laser beam along its cross-section results in a variable penetration of the beam through the monomer, with the deeper penetration being alongside the axis of the beam and decreases toward the periphery, which result in a less scattering of the light. Moreover, the laser beam in the SLA technique penetrate the monomer surface and photo-polymerize it incrementally (strips), which result in the entire layer being formed by overlapping the polymerized strips. As a result of the incremental nature of phot-polymerization of the SLA technique as well as the overlapping between the polymerized strips, a more complete polymerization is obtained and a smaller amount of residual monomer remains. This in turn results in more accurate dimensions with less deformation.

In addition to Dikova et al. (192) interpretations, it’s a mandatory to understand that in the technology of 3D printing, the problem is always compound, and a trade-off is always present regarding printer specifications, as no printer is capable of performing all the recommendations ideally, that’s why a clinician should be wise when selecting a 3D printer that fulfills his clinical requirements. However, relying on the printer’s specifications provided by the manufacturers to determine which printer produces more accurate attachments may not always be dependable. Although the term “accuracy” is well understood, the means to achieve the optimal accuracy is still misunderstood. Some manufacturers may utilize deceptive statements and technical specifications to deceive potential consumers. They frequently misrepresent layer height, laser spot size, or pixel size as "accuracy," despite the fact that these specifications have no direct bearing on the accuracy of the printed objects. While most manufacturers refer to accuracy in terms of a single value (e.g., 50 microns or 75 microns), these are somewhat deceptive and express only the printer's resolution limit (vertical resolution) (204). Nevertheless, pushing the printer to work on its maximum capability doesn’t necessarily bring out the best performance and printing quality out of it.

However, in contrast to what is prevalent, a printer’s resolution is more determined by the basic unit of each printer; also known as the basic core element, which is the smallest feature the printer can reproduce within a single layer. In 3D printing, the smallest feature element is more relevant in determining the printer’s resolution (207,208). The importance of the smallest feature element can be summarized in two aspects, its size and its shape. The size of the basic core element is also given as the XY resolution (horizontal resolution), which is more dominant in the printer’s resolution than the Z resolution (vertical resolution) often provided by the manufactures (201). Going back to the previous findings, these may be attributed to many reasons. Firstly, the integral correlation between the XY resolution and the Z resolution. If the XY resolution of a printer is questionable (printing outside the edges), this can lead to more errors being built within each printed layer horizontally, and which happened to be the case with the DLP printer as explained previously. If this was accompanied with increasing the Z resolution or, by other words, reducing the layer height or thickness will require more layers to print the attachments. The more layers there are, the more the accumulated errors within the external surface of the attachments will be, and the more the mismatching ridges of the external surface of the printed attachments will appear significant (Figure 5.2.3.). And because the used layer thickness is relatively small, this compound issue is what believed to have been taken place. Therefore, a thinner layer or greater Z resolution is not always reliable indicator for a better performance, and the printing quality is more dependent on the geometry of the attachments along with the XY resolution.

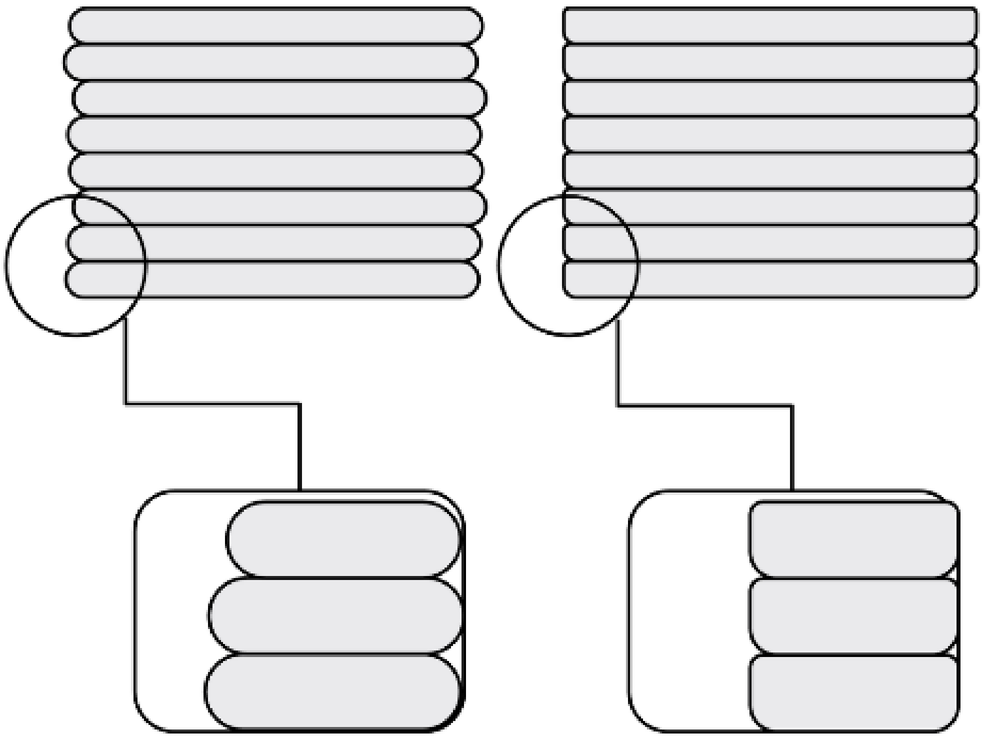

Figure 5.2.3. The relationship between the XY-resolution and Y-resolution. (201)

In addition to the apparent effect of the size of the basic feature element, also known as the XY-resolution, the shape of the basic feature element is also important, and the different in its shape between both printing techniques may also have had an influence on the results of the present study. In SLA technique, the shape basic feature element is defined by the circular shape of the laser spot, while in the DLP printer, it is defined by the squared-shape pixel, making numerical parameters of its size (XY resolution) alone insufficient to compare the different techniques (Figure 5.2.4.). In many cases, giving only the XY or Z resolution is only a kind of a statistical splurging. It may provide some insight, but it does not always correspond to the accuracy, precision, or print quality (207).

Figure 5.2.4. Difference in the shape of the basic core element between SLA and DLP printers.(207)

As mentioned earlier, DLP printers consist of a digital projector that fires to the building platform a cross-sectional image of the object being printed, representing one layer. This image consists of multiple square pixels, which when printed will resemble a 3D layer formed from small rectangular cubes called voxels. This contributes for the greatest difference between both printing techniques. Since the projector is basically a digital screen, the pixelated reflected image has a fixed matrix of pixels relative to the build area, rendering the external surface and the boarders of the printed attachment deviating either positively or negatively from the reference attachment. While in contrast, the laser beam of SLA printer can more efficiently trace the boarders on any XY coordination, due to the shape of the laser beam spot and the ability of the laser controlling arm to move in very short distances between two basic feature element incidences, allowing for some degree of overlapping between each basic feature element and the next one. This means that SLA printers, can more accurately imitate the surface of the attachments even if the laser spot size is bigger than the DLP pixel size. Figure 5.2.5. shows how printing the same curved surface will appear using SLA printer versus DLP printer due to different shape of the basic core element.

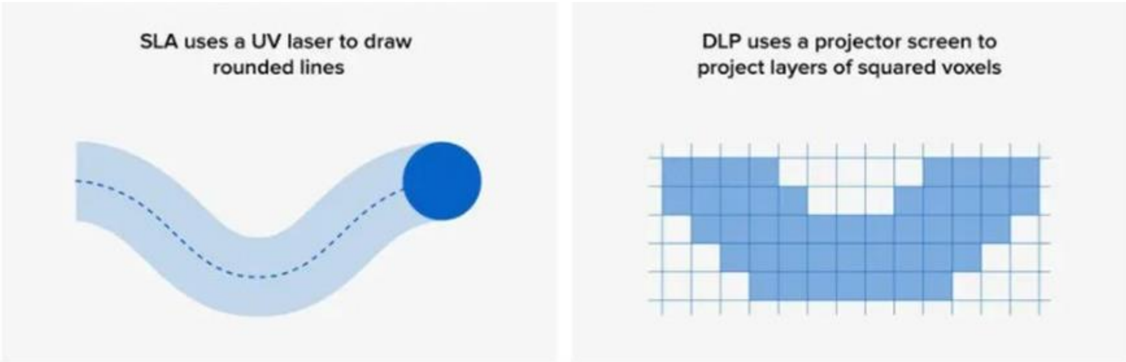

Figure 5.2.5. A demonstration of how can the difference in shape of the basic core element between both printers affect the external surface of the printed object. (201)

Furthermore, since the models are printed in horizontal layers, horizontal lines may be visible regardless the 3D printing technique being used. However, because DLP renders images using rectangular voxels, there is also an effect of vertical voxel lines (Figure 5.2.6.) (207). This phenomenon has rendered the exterior of the DLP attachments rougher compared to SLA attachments.

Figure 5.2.6. A demonstration of a longitudinal and sagittal sections in DLP print, while only the shape on right will appear with a cross section taken from SLA print. (207)

Conversely, when analyzing the studies in the literature that considered the reproducibility of dental models printed with either SLA or DLP printers from plaster or digital dental models, almost all of them have concluded that DLP models can register smaller deviation from the corresponding plaster models compared to the SLA models, rendering DLP models more reliable to replace plaster models (23–25,153). In the study of Kim et al. (153), they assumed that DLP technique produces more accurate models compared to SLA technique. He built his assumption from his understanding to the nature of the different printing technique for each printer, by which in his opinion will render the SLA printer prone to error caused by the mirror that moves the laser beam. However, the DLP technique uses a projector to cure the material layer by layer; this reduces the error associated with repeated printing. However, this result disagreed with their assumption. They justified this contradiction to be the result of using non equal resolution with the different printing techniques, where a smaller layer thickness was used with the SLA technique (50 um) compared to a higher layer thickness used with the DLP printer (75 um). They also attributed part of his findings to the use of scan spray on the DLP models due to their high reflection of light, which might have added to the thickness of the models. In regard to the conflicted results in the literature (151,152), we could elicit an interesting recognition that as far as we know, hasn't been given any attention in the literature before, which is the build volume. If you take a deeper look at both parties of contradicting findings, these who found that DLP prints are more accurate have carried their study on dental models, while the others who suggested that SLA prints are more accurate, including the present study, all have carried their studies on a much smaller objects; which are the attachments in our case, and 3 shapes of teeth preparations by the others, the thing that provoked us to assume that the build volume is responsible of this contradiction. To further elaborate in this, other than the basic core element, the resolution of a DLP printer is also dependent on the projector, which defines the number of pixels available. If one moves the projector away from the optical window, this will widen the available build area, however, at the same time the pixels get bigger, which decrease the resolution, and vice versa (Figure 5.2.7.). While in the SLA printers, the accuracy of the print is completely independent of the build volume, as no projector is being used, which makes it capable of printing small and large objects both at high resolution (207).

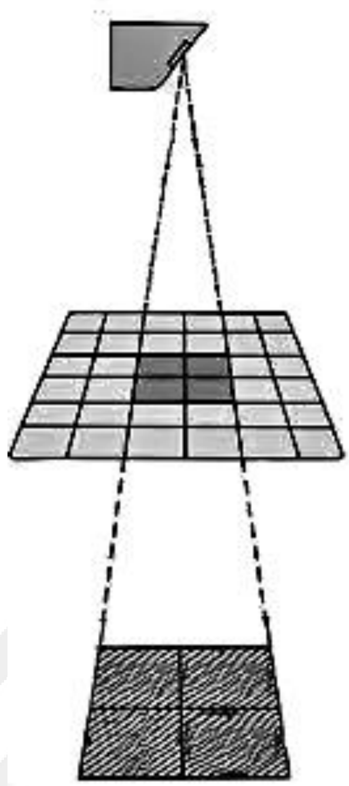

Figure 5.2.7. The effect of adjusting the distance between the projector and the micro mirrors.

In order to help future studies of similar topic to be conducted, it’s important to highlight the limitations of this study. Firstly, both printers used different printing resin material as the SLA printer (XFAB 2500PD) used a closed system that allows using only a printing material from the same company as the printer. There are some printers in the market that use an opened system that allows using different printing materials. It’s wise to consider such printers for the future to standardize an important factor that can influence the resultant accuracy of the printed models. Also, we only considered one layer thickness in our studies and focused more on the technique. Knowing the great influence of the layer thickness on the accuracy of the printed models, it’s also wise to evaluate other thicknesses and how they may compensate for challenging orientations. Moreover, since it’s not practical to print one or two models at a time in the process of fabricating clear aligners as conducted in our study, printing a patch of models in one print cycle while considering different distances between the models should be evaluated from accuracy perspective.

Lastly, one should consider other factors such as cost, printing time and accuracy with different layer thicknesses when selecting a 3D printer, with the understanding that increased resolution or reduced printing layer height does not necessarily mean increased accuracy. Ultimately, decisions regarding selection of a 3D printer should be driven by the envisioned application of the printer in the clinic and the associated requirements to be of clinical utility after considering the previous factors. We recommend re-evaluating the print accuracy of dental models used for aligners fabrication using different combinations of layer thicknesses and print orientation.

6. CONCLUSION

- SLA technique-based printers are more capable of accurately reproducing clear aligner attachments than DLP technique-based printers. This may be due to the less light scattering of the beam that penetrates the surface for each resin layer. Moreover, the circular shape of the of SLA printers' basic feature element aids in producing more accurate boundaries of the printed object.
- The accuracy of DLP-printed objects is more dependable on the build volume than that of SLA-printed object, making SLA printers more suitable to be used in clear aligners' fabrication.
- Accuracy and precision are nearly hard to comprehend merely based on technical specs. Ultimately, the best strategy to assess a 3D printer is to examine its performance and the range of settings optimization allowed to produce the best printing outcomes in relation to our intentional clinical application of these attachments.
- The geometry of the attachments plays a role in the resultant accuracy. However, all attachments are of simple geometries other factors such as the orientation of the attachments, the used printing layer thickness and the printing techniques used may be more influential in determining the final accuracy.
- In regard to only the printing technique, the most accurate attachments configuration in SLA printer are the Beveled Horizontal and Vertical Rectangular attachments while in the DLP printer it is the Ellipsoid attachment. On the other hand, the least accurate attachment in SLA printer is the Horizontal Rectangular attachment, while for the DLP printer are the Vertical Rectangular and Optimized Rotation.
- The orientation of the attachments in relation to the printing platform is influential in the resulting accuracy. However, it's impossible to predict the final orientation of the attachments in relation to the printing platform which can be affected by the inclination, rotation and tipping of the teeth on that the attachments were placed, as well as the distance of the attachment to the long axis of the tooth along with the arch curvature. So, it may be advised to orientate the model so that the greatest amount of the area of the attachments' active surfaces on the teeth of critical movements are directed horizontal or perpendicular to the printing platform.

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8. APPENDICES

8.1. ETHICAL APPROVAL

T.C. YEDİTEPE ÜNİVERSİTESİ
GİRİŞİMSEL OLMAYAN KLİNİK ARAŞTIRMALAR
ETİK KURULU

Versiyon No 1.0
Sayfa 1 / 2

KARAR FORMU

21.12.2021

ETİK KURUL BİLGİLERİ		
	Etik Kurulun Adı	Yeditepe Üniversitesi Girişimsel Olmayan Klinik Araştırmalar Etik Kurulu
	Açık Adres	
	İnternet Sayfası	
	Telefon	
	E-posta	

DEĞERLENDİRİLEN BELGELER		
	Islak imzalı başvuru dosyası, CD'si ve elektronik başvuru	☒
	Araştırma başlığı ve araştırmacıların isimleri	☒
	Başvuru dilekçesi	☒
	Araştırmanın;	☒
	• Niteliği	☒
	• Önemi ve özgün değeri	☒
	• Amaç ve hedefleri	☒
	• Yöntemi	☒
	• Yönetimi	☒
	• Yaygın etkisi	☒
	• Araştırma bütçesi (Mevcutsa)	☒
	• Süresi ve uygunluğu (Zaman cetveli)	☒
	• Kaynakları	☒
	Araştırma izin belgesi / belgeleri	☒
	Bilgilendirilmiş Gönüllü Olur Formu (yapılan araştırmaya özel olarak hazırlanmış)	☒
	Taahhütname-1 Dünya Tıp Birliği Helsinki Bildirgesinin son versiyonunun ve Sağlık Bakanlığı'nın ilgili tüm kılavuzlarının okunmasına dair taahhüt	☒
	Taahhütname-2 Daha önce yapılmış etik kurul başvuruları mevcut olup olmadığına dair taahhüt	☒
	Taahhütname-3 Araştırma sırasında araştırma bütçesinde yer almayan ve gönüllünün kendisine veya Sosyal Güvenlik Kurumuna ek yük getirecek hiçbir işlem uygulanmayacağına dair taahhüt	☒
	Taahhütname-4 COVID-19 hastalarında tedavi yaklaşımları ve bilimsel araştırmalar genelgesi okunmasına dair taahhüt	☒
	Araştırmacıların her birisine ait özgeçmiş formu	☒
	Ek belgeler (Varsa kullanılan ölçek izinleri vb.)	☒

KARAR BİLGİLERİ		
	Başvuru Numarası	202110099
	Toplantı Tarihi	19.11.2021
	Toplantı Yeri	Çevirim içi (Google Meet)
	Karar No	17

Araştırmanın Başlığı: Evaluation of 3D printers accuracy in printing attachments of clear aligners

Araştırmacılar: Dt. Ammar Qawasmi, Doç. Dr. Rahime Burcu Nur Yılmaz

T.C. YEDİTEPE ÜNİVERSİTESİ
GİRİŞİMSEL OLMAYAN KLİNİK ARAŞTIRMALAR
ETİK KURULU

Versiyon No
1.0
Sayfa 2 / 2

BAŞVURU NUMARASI: 202110099

KARAR 21.12.2021

☒ **KABUL**	☐ **RET** ☐ *KAPSAM DIŞI (GİRİŞİMSEL)* ☐ *BİLİMSEL VE/VEYA ETİK KURALLARA AYKIRI* ☐ *BİR SORUMLU ARAŞTIRMACININ (TEZ İSE TEZ DANIŞMANI), BİR TOPLANTIYA **İKİ (2) ADETTEN FAZLA ÇALIŞMA BAŞVURUSUNDA** BULUNMASI* ☐ *KURUM İÇİ BAŞVURULARINDA **YEDİTEPE UZANTILI E-POSTA HESABI** İLE GİRİŞ YAPILMAMIŞ OLMASI* ☐ *ŞARTLI KABULDE BELİRTİLEN REVİZYONLARIN ZAMANINDA VE/VEYA İSTENİLDİĞİ ŞEKİLDE YAPILMAMIŞ OLMASI*

Araştırmanın Başlığı	Evaluation of 3D printers accuracy in printing attachments of clear aligners
Araştırmacılar	Dt. Ammar Qawasmi, Doç. Dr. Rahime Burcu Nur Yılmaz

8.2. PATIENT CONSENT

Tarih: 09.12.2021

T.C. YEDİTEPE ÜNİVERSİTESİ

GİRİŞİMSEL OLMAYAN KLİNİK ARAŞTIRMALAR

ETİK KURULU

BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU

ÇALIŞMANIN ADI: Şeffaf plak ataşmanı üretiminde 3D yazıcıların doğruluğunun değerlendirilmesi

ÇALIŞMANIN AMACI

Bir araştırma çalışmasına katılmanız istenmektedir. Bu çalışmaya katılmaya karar vermeden önce, araştırmanın neden yapıldığını ve neleri içereceğini anlamanız önemlidir. Lütfen metnin devamında belirtilen bilgileri dikkatlice okuyunuz. Açık olmayan bir bölüm varsa veya çalışma hakkında daha fazla bilgi almak isterseniz araştırmacıya danışabilirsiniz.

Bu çalışmanın amacı, ortodonti tedavisinde kullanılan şeffaf plakların üretiminde yer alan iki farklı 3 boyutlu yazıcının doğruluğunu değerlendirmektir. 3D yazıcıların kullanımı, şeffaf plakların üretim sürecinin önemli bir aşamasını oluşturmaktadır. Sonuç olarak, bu çalışma, hastaların dişlerinin orjinal haline mümkün olduğunca yakın bir kopyasını üretmek için farklı yazıcılar tarafından kullanılan iki farklı üretim tekniğinin verimliliğine odaklanmaktadır.

ÇALIŞMA AŞAMALARI

Çalışmamızda, fakültemizde hastaların bilgisi ve onayı dahilinde şeffaf plak tedavisine başlayacak olan hastalardan rutin olarak alınan diş tarama kayıtları kullanılacaktır. Tarama kaydı, bir diş taramasının işlenmesi ve hazırlanmasını içeren laboratuvar aşamalarından geçerek bu aşamanın ardından üzerinde şeffaf bir plak üretilebileceği fiziksel olarak basılmış bir model üretmek için iki farklı 3D yazıcı kullanarak bu çalışmada kullanılacaktır. İki farklı yazıcı kullanılarak fiziksel olarak basılan bu modellerin doğruluğu, özel bir yazılım kullanılarak görüntü çakıştırma ve 3D karşılaştırma yöntemleri ile karşılaştırılacaktır.

RİSKLER

Bu çalışma, şeffaf plak tedavisi görmekte olan siz hastalarımızın klinik tedavilerinden ayrı bir temelde yürütülecektir. Çalışmaya katılacak olan gönüllü hastalarımızın şeffaf plaklarla devam eden tedavisi açısından herhangi bir risk mevcut değildir.

Çalışmaya katılmayı kabul ettikten sonra çalışmaya katılımınızı istediğiniz zaman sonlandırabilirsiniz.

ÇALIŞMANIN YARARLARI

Bu çalışmaya katılmanızın size doğrudan bir yararı olmayacaktır. Ancak, bu çalışmadan elde edilen bilgilerin, en uygun 3D yazıcıyı seçme konusunda daha iyi karar vermemize yardımcı olabileceğini umuyoruz. Böylelikle daha büyük bir hasta grubunun geleneksel yaklaşımlar yerine şeffaf plaklar ile tedavi yaklaşımından faydalanması sağlanabilecektir.

GİZLİLİK

Bu araştırma çalışmasının amaçları doğrultusunda yorumlarınız anonim olmayacaktır. Araştırmacı, gizliliğinizi korumak için aşağıdakiler de dahil olmak üzere her türlü çabayı gösterecektir:

- Gönüllü katılımcının kimliğini ifşa edebilecek hiçbir kişisel fotoğraf kullanılmayacaktır.

Katılımcı Adı Soyadı: İmza:

• Tüm araştırma notlarında ve belgelerinde kullanılacak olan katılımcılara kod adları/numaraları atanacak ve gönüllü hasta isimleri kullanılmayacaktır.

İLETİŞİM BİLGİLERİ

Bu çalışma ile ilgili sorularınız varsa veya araştırma katılımcısı olarak haklarınız hakkında sorularınız varsa, ya da süreç içerisinde olursa imza bölümünde iletişim bilgileri yer alan araştırmacı ile iletişime geçebilirsiniz.

GÖNÜLLÜ KATILIM

Bu çalışmaya katılımınız gönüllüdür. Bu araştırmaya katılıp katılmamak size kalmış. Bu çalışmaya katılmaya karar verirseniz, sizden bir onam formu imzalamanız istenecektir. Onam formunu imzaladıktan sonra, herhangi bir zamanda ve herhangi bir sebep göstermeksizin çalışmadan ayrılma ve çalışmaya katılmama hakkına sahipsiniz. Bu çalışmadan ayrılmanız, varsa araştırmacı ile olan ilişkinizi etkilemeyecektir.

ONAY

Bilgilendirilmiş gönüllü olur formundaki tüm açıklamaları okudum. Bana yukarıda konusu ve amacı belirtilen araştırma ile ilgili yazılı ve sözlü açıklama aşağıda adı belirtilen araştırmacı tarafından yapıldı. Araştırmaya gönüllü olarak katıldığımı, istediğim zaman gerekçeli veya gerekçesiz olarak araştırmadan ayrılabileceğimi biliyorum. Söz konusu araştırmaya, hiçbir baskı ve zorlama olmaksızın kendi rızamla katılmayı kabul ediyorum.

Katılımcı Adı Soyadı: **Telefon:** **Adres:** **Tarih:** **İmza:**	**Araştırmacı Bilgileri:** **İmza**

8.3. CURRICULUM VITAE

Personal Informations

Name	Ammar	**Surname**	Qawasmi
Place of Birth		**Date of Birth**	
Nationality		**TR ID Number**	
E-mail		**Phone number**	

Education

Degree	Department	The name of the Institution Graduated From	Graduation year
Doctorate			
Master			
University	Oral and Dental Surgery	**October University for Modern Sciences and Arts**	2016
High school	-		

All the grades must be listed if there is more than one (KPDS, ÜDS, TOEFL; EELTS vs),

Languages	Grades (#))

Work Experience (Sort from present to past)

Position	Institute	Duration (Year - Year)
Orthodontist	Private clinic	Jun 2022 – Present
Orthodontist	Private clinic	Jun 2021- Dec 2021
General Dental Practitioner	Private Clinic	Jul 2017- Jul 2018
Trainee	Private Clinic	Jul 2016- Jun 2017
Internship	Jordanian Ministry of Health	May 2016- May 2017