May 2016

The Effect of Attachment Placement and Location on Rotational Control of Conical Teeth Using Clear Aligner Therapy

Pouya Momtaz
University of Nevada, Las Vegas, momtaz@unlv.nevada.edu

THE EFFECT OF ATTACHMENT PLACEMENT AND LOCATION ON ROTATIONAL CONTROL OF CONICAL TEETH USING CLEAR ALIGNER THERAPY

By

Pouya Momtaz

Bachelor of Arts - Psychology
Boston University
2002

Doctor of Dental Medicine
Tufts University School of Dental Medicine
2011

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science – Oral Biology

School of Dental Medicine
Division of Health Sciences
The Graduate College

University of Nevada, Las Vegas
May 2016

Thesis Approval

The Graduate College
The University of Nevada, Las Vegas

April 27, 2016

This thesis prepared by

Pouya Momtaz

entitled

The Effect of Attachment Placement and Location on Rotational Control of Conical Teeth Using Clear Aligner Therapy

is approved in partial fulfillment of the requirements for the degree of

Master of Science – Oral Biology
School of Dental Medicine

James Mah, D.D.S, D.M.Sc.
Examination Committee Chair

Richard Walker, D.D.S.
Examination Committee Member

Clifford Seran, D.M.D.
Examination Committee Member

Bob M. Martin, D.D.S.
Examination Committee Member

Brendan O'Toole, Ph.D.
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D.
Graduate College Interim Dean

Abstract

Objective: To determine the optimal method to correct rotations of conical teeth using thermoplastic appliances with and without attachments.

Introduction: Despite the increasing popularity of clear aligner therapy there are still questions as to its effectiveness, efficiency, case selection and limitations. It has been reported that the full prescription for clear aligners is not expressed, and that the mean accuracy of any type of tooth movement using clear aligners is only 41% (Drake, 2012). One of the major limitations of clear aligner therapy is correction of rotated conical teeth, especially canines and premolars (Kravitz, 2008). According to Simon, et al. (2014) mandibular premolar derotation has the lowest predictability of movement and accuracy with clear aligners. This is due to the fact that conical teeth lack interproximal undercuts, and as result the aligner tends to slip as derotation is attempted (Kravitz, 2008; Simon, 2014). Clear aligner manufacturers therefore recommend the use of resin bonded attachments, interproximal reduction, overcorrection, auxiliaries, or adjusting aligners with thermopliers in order to achieve derotation of conical teeth.

Materials and Methods: The design of this study is prospective and experimental. This research will be a comparative study to examine the effect of attachment location and the number of attachments on rotational control of conical teeth. Rotational control without attachments or adjustments will be compared to rotational control with attachments, or with the use of a clear aligner adjusting plier (Hu-Friedy Vertical Rectangular Adjustment Plier). Total de-rotation will be recorded as an angular measurement after placement of each aligner, as measured on a digital scan (Ortho Insight 3D, Chattanooga, TN) using Geomagic Design software (3D Systems, Cary, NC).

Results: Results of a one-way ANOVA showed that there were no statistically significant differences between 7 of the 9 groups. The group with a rectangular attachment on the buccal surface of tooth #29 had the highest overall observable rotational correction.

Conclusions: Attachments appear to improve rotational correction of the lower right second premolar. Increasing the number of attachments does not appear to aid rotational control, as the group with a single buccal attachment had the highest overall rotational correction. Multiple attachments, and adjusting aligners using the Hu-Friedy vertical rectangular adjusting plier on the lingual surface of the thermoformed aligner appear to impede rotational correction in this study.

Acknowledgements

I would first like to thank my mentor and research committee chairman Dr. James Mah for his guidance throughout the course of this project. I would also like to thank committee members Dr. Bob Martin, Dr. Cliff Seran, Dr. Brendan O'Toole and Dr. Richard Walker for their advice and encouragement.

In addition I would also like to acknowledge:

- Dr. Kim Mai and Dr. Naren Chelian for allowing me to use their scanners to complete this project
- Ryan Swanson of Great Impressions Lab for his assistance fabricating the research model
- Park Dental Research for their guidance using the Juell 3D OC Flash 3-D printer
- Dr. Ray Stewart of Bay Materials for generously supplying the aligner material used in this study

Table of Contents

List of Tables

List of Figures

Chapter 1 : Introduction

As the number of adults seeking orthodontic treatment has been increasing in recent years, so too has the demand for esthetic orthodontic treatment. The esthetic treatment modalities available to patients and clinicians currently include clear aligners and ceramic or lingual fixed appliances. Clear aligner therapy is one of the fastest growing segments of the orthodontic market, and is advantageous since clear aligners are nearly invisible and are removable. Orthodontic treatment using clear aligners allows the patient to maintain better oral hygiene, thereby reducing the risk of decalcification and caries often seen with traditional fixed appliances. However, little is understood about the effectiveness of clear aligner therapy, often leading to the need for case refinements, or mid-course corrections if aligners are no longer tracking. The decision must then be made to compromise treatment without fully correcting tooth positions, or discontinue aligner therapy and place fixed appliances.

Although the use of clear aligners to correct alignment of teeth is a popular treatment choice for clinicians and patients, this treatment modality is not a new concept. H.D. Kesling first described the positioning of teeth without bands and wires with what he called a Tooth Positioning Appliance in (Kesling, 1945). With this approach, fixed appliances are removed approximately 4-6 months prior to the anticipated debanding date. Final finishing and artistic positioning of teeth are completed using the tooth positioner, which could then also be used as a final retainer. Using the Kesling tooth positioner, impressions are taken and two plaster models are fabricated. Teeth are then dissected from the set-up model, and teeth are re-arranged in wax to the desired arch form, axial positioning, and occlusion (Kesling, 1945, 1956). The fabricated positioner is a one-piece vulcanite rubber appliance that covers all surfaces of maxillary and mandibular teeth and made to fill the freeway space. The purpose of filling the freeway space is

to have a layer of rubber between upper and lower teeth that will maintain pressure on teeth while the positioner is worn (Elsasser, 1949).

It was Kesling's vision that the tooth positioner be used for more than just final positioning and retention. He acknowledged that major tooth movements could be accomplished by sequentially repositioning teeth on the wax set-up and fabricating a series of positioners (Kesling, 1945; Bunch 1961). This vision was carried further by Henry I. Nahoum, who described the vacuum formed dental contour appliance in 1964. Nahoum describes a method where a plastic sheet is heated to molding temperature and vacuum formed over a dental cast. This differs with Kesling's tooth positioner in that maxillary and mandibular appliances are separate. This appliance can be used as a retainer after orthodontic treatment or fabricated to move teeth, similarly to the method Kesling described by re-setting teeth in wax on a model. According to Nahoum, anterior spaces and minor rotations can be corrected using this appliance but corrections are limited to the six anterior teeth. Sheridan et al. (1985) also described aligning teeth using a technique which included interproximal reduction of teeth and clear Essix aligners. Using this technique, teeth were individually dissected from a model and repositioned. A major disadvantage of this technique was that a new impression and tooth set-up was needed for each sequential attempted tooth movement (Joffe, 2003).

Since then, several companies have emerged, including Invisalign and Clear Correct. Invisalign was founded in 1997 and uses 3-dimensional (3-D) graphic imaging and computer-aided design/computer-aided modeling techniques to fabricate a series of aligners in order to achieve desired tooth movements (Boyd, 2001; Djeu, 2005; Joffe, 2003; Miller, 2002). These aligners are fabricated from thin plastic of 0.030-inch thickness which fits over the buccal, lingual (palatal) and occlusal surfaces of the teeth (Boyd, 2001). The aligners are worn a

minimum of 20 hours per day and advanced to the next aligner in the series every 2 weeks. Each aligner is designed to move teeth 0.25 to 0.3 mm (Boyd, 2001; Kwon, 2008). To correct rotations, each aligner is designed to produce 2°-3° rotational change (Simon, 2014).

Despite the increasing popularity of clear aligner therapy there are still questions as to its effectiveness, efficiency, case selection and limitations. It has been reported that the full prescription for clear aligners is not expressed, and that the mean accuracy of any type of tooth movement using clear aligners is only 41% (Drake, 2012). One of the major limitations of clear aligner therapy is correction of rotated conical teeth, especially canines and premolars (Kravitz, 2008). According to Simon, et al. (2014) premolar derotation has the lowest predictability of movement and accuracy with clear aligners. This is due to the fact that conical teeth lack interproximal undercuts, and as a result the aligner tends to slip as derotation is attempted (Kravitz, 2008; Simon, 2014). Current recommendations include the use of resin bonded attachments, interproximal reduction, overcorrection, auxiliaries, or adjusting aligners with thermopliers in order to achieve derotation of conical teeth.

Much of the treatment design and effects to correct rotated teeth with clear aligners is largely anecdotal. The purpose of this study is to assess the efficiency of derotation of conical teeth without using attachments, and various attachment locations to assess the ideal location for placement of attachments. In order to evaluate the potential attachment locations, the following questions are proposed.

Research Questions and Hypotheses

1. Does the use of resin bonded attachments improve rotational control of conical teeth?

   H_0: No, resin bonded attachments do not improve rotational control of conical teeth.

   H_A: Yes, resin bonded attachments improve rotational control of conical teeth.

2. Does placing attachments on teeth adjacent to the rotated tooth improve rotational control of a conical tooth?

   H_0: No, placing attachments on teeth adjacent to the rotated tooth does not improve rotational control of conical teeth.

   H_A: Yes, placing attachments on teeth adjacent to the rotated tooth does improve rotational control of conical teeth.

3. Does adjusting clear aligners using the Hu-Friedy Vertical Clear Aligner adjustment plier improve rotational control of conical teeth?

   H_0: No, adjusting clear aligners using the Hu-Friedy Vertical Clear Aligner adjustment plier does not improve rotational control of conical teeth.

   H_A: Yes, adjusting clear aligners using the Hu-Friedy Vertical Clear Aligner adjustment plier does improve rotational control of conical teeth.

Chapter 2 : Literature Review

The market for clear aligner continues to grow rapidly, however little is understood about the effectiveness of this treatment modality. There have been very few studies performed about forces delivered by clear aligners. According to a systematic review in 2005 by LaGravere and Flores-Mir, much of the literature about clear aligner therapy is limited to case reports and clinical opinions; they report only two studies that were higher level clinical trials. Based on the systematic review, no conclusions could be made about the indications for or limitations of clear aligner therapy (LaGravere, 2005). This study provides an in-vitro model to study rotational movements using clear aligners and this review will cover the history of clear aligner therapy, advances in intraoral scanning, 3-Dimensional fabrication of dental models, and fabrication of clear aligners.

History of Removable Thermoplastic Appliances

In 1945 H.D. Kesling envisioned an appliance that was effective under functional forces that guided teeth into ideal positions without the use of bands and wires (Kesling, 1945, 1946, 1956). From this vision, he developed the tooth positioning appliance, which is a one-piece rubber appliance that is fabricated based on an ideal tooth setup. The appliance is utilized after much of the major tooth movements are made using traditional bands and wires. During this time, the teeth are slightly mobile from previous orthodontic treatment and will respond more readily to the force applied by the positioner (Kesling, 1946). This treatment adjunct was estimated to reduce the total treatment time in bands and wires by as much as 6 months (Kesling, 1945). This would benefit the practitioner by reducing chair time taken by each patient, and benefit the patient by reducing the amount of time spent with bands and wires.

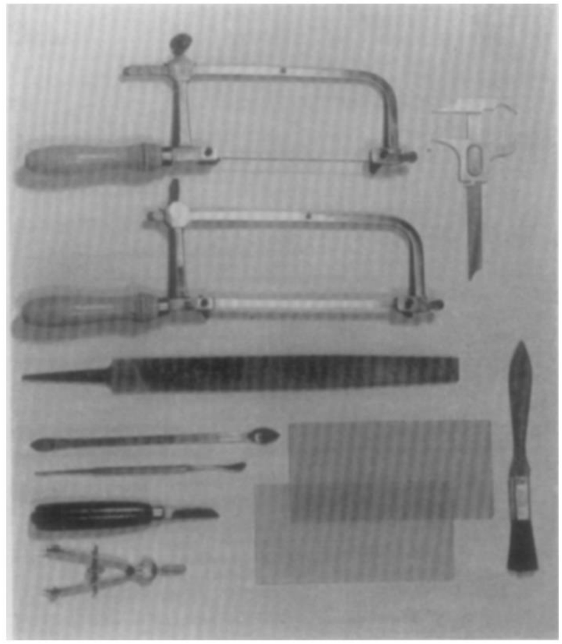


Figure 2-1: Instruments used to create diagnostic set-up (Kesling, 1956)

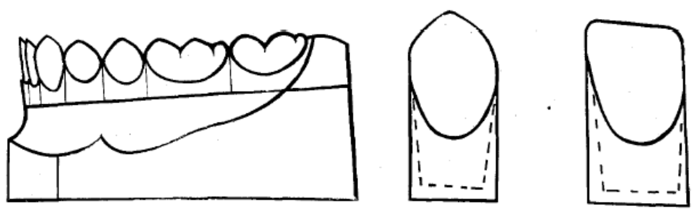


Figure 2-2: Diagram indicating procedure for dissecting and trimming teeth for tooth positioner set-up (Kesling, 1946)

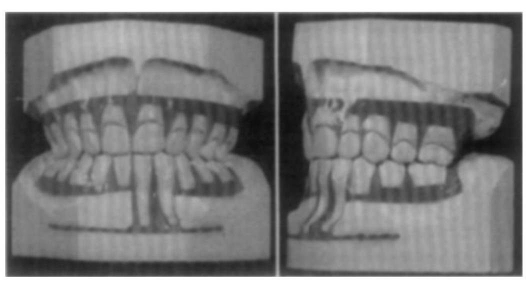


Figure 2-3: Final Set-up for tooth positioner fabrication (Kesling, 1956)

Figure 2-4: Final fabricated tooth positioner (Kesling, 1956)

The Tooth Positioning Appliance makes it possible for clinicians to refine cases without going through months of arch wire bending and adjustments. Since the positioner is fabricated from a pliable rubber, it is able to slip over teeth and is an active appliance against teeth which are not in alignment with the ideal set-up. It is recommended to wear the positioner for 4 hours daily and while sleeping for 6-8 weeks. The positioner can be used for final retention or a new set of retainers can be fabricated for the patient following active treatment (Kesling, 1946, Elsasser, 1949).

Kesling's vision was carried further by H.I. Nahoum, who first described what he called the "vacuum formed dental contour appliance" in 1964. The appliance is fabricated by molding a sheet of plastic to a dental cast using a vacuum forming machine. Nahoum acknowledged that the appliance can be used after orthodontic treatment for retention, or for minor orthodontic treatment limited to the upper and lower anterior teeth. He describes a process similar to Kesling's process for fabricating a tooth positioner, where teeth are dissected from a dental model, repositioned in wax, and the appliances is vacuum formed over the adjusted model (Nahoum, 1964; Ponitz, 1971).

The advancement of clear aligner therapy continues with Sheridan's utilization of Essix material (Raintree Essix, New Orleans, LA) to produce larger sequential tooth movements

(Sheridan, 1993; Sheridan, 2004). Sheridan describes mechanics of tooth movement using composite mounding and thermoform adjusting pliers. This method does not involve dissecting teeth from a stone model and repositioning them in wax. Instead, the model is modified with block-out compound to create space towards the desired direction of movement. 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. The magnitude and direction of tooth movement is dependent on the size and location of the composite mound. Sheridan recommends starting with a 1mm mound and incrementally increasing up to 3mm until the desired tooth position is achieved.

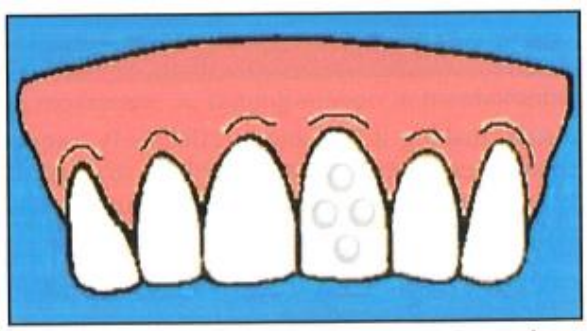


Figure 2-5: Composite mound locations to effect various tooth movements (Sheridan, 2004)

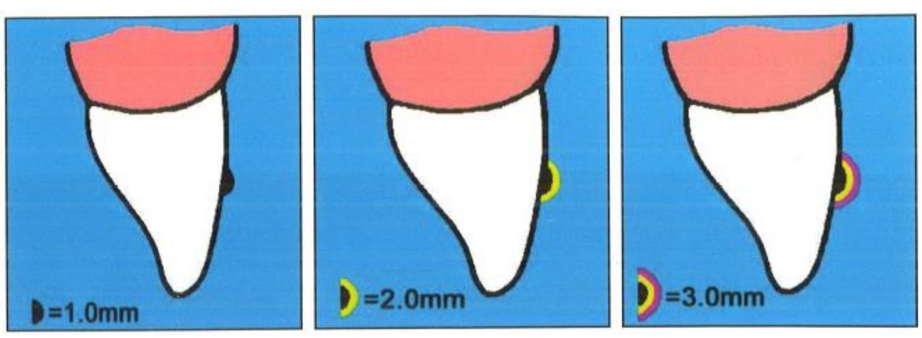


Figure 2-6: Incremental addition to composite mound for sequential tooth movement (Sheridan, 2004)

As advancements have been made in digital technology, so too have there been major advances in clear aligner therapy. Align Technology developed the Invisalign appliance in 1997; however they were not the first to utilize digital technology for planning tooth movements. The history of computer aided treatment planning for orthodontics actually dates back to 1970 (Biggerstaff, 1970). Biggerstaff describes a computer model to visualize realignment of dentition from a malocclusion to a "normal" occlusion. Since Biggerstaff, other authors have discussed the use of computer technology for orthodontic treatment planning (Faber, 1978; Alcañiz, 1996; Kuroda, 1996; Ahmed, 1997). Furthermore, the entire sequence of obtaining digital models, digital treatment planning, and rapid prototyping of models was described by E.E. Hemayed in 1996.

The first step for clear aligner treatment involves taking an impression of each dental arch. This can be accomplished using polyvinylsiloxane (PVS) or alternatively, a digital scan can be taken. The impressions or scan are then sent to a clear aligner manufacturer, where 3-D software is used to digitally move the desired teeth. Movements are planned 0.25-0.33mm per aligner, and rotation corrections are planned 2º-3º per aligner. Once digital setups are complete, models are fabricated using 3-D printing technology and a clear aligner of 0.030-inch thickness is fabricated for each stage (Boyd, 2001).

The concept of bonded composite attachments was first introduced by Martin Martz in 1988. He described a removable tooth positioning appliance, and proposed bonded composite "buttons" to provide or increase undercuts which an aligner could engage in order to facilitate the desired tooth movements (Martz, 1988). Since then, clear aligner manufacturers have adopted this concept, and recommend bonded attachments to facilitate difficult tooth movements. According to Boyd, rotation of lower premolars and extrusion of teeth are two of

the most challenging movements to accomplish with clear aligners. He recommends placing bonded composite attachments achieve these difficult movements. Clear aligners are to be worn for a minimum of 20 hours per day, and typically worn for 2 weeks prior to progressing to the next aligner (Boyd, 2001; Joffe, 2003; Bollen 2003; Clements, 2003).

Despite the long history of clear aligner therapy, little is understood about the mechanism of action of aligners, force delivery, limitations, and indications. The information available is limited mainly to clinical opinion and case reports. In 2007, Kravitz et al. conducted a prospective clinical study to evaluate the efficacy of clear aligner therapy using Invisalign. They found the overall accuracy of tooth movement to be 41% and found that rotations of canines greater than 15 degrees had significantly lower accuracy at 32.2%. In a study by Simon et al., results showed that premolar derotation had an accuracy of only 40%.

The inaccuracies of clear aligner therapy are a source of frustration for both clinicians and patients. When teeth are not moving as expected by the digital simulation, the decision must be made for mid-course correction, case refinement after the current set of aligners is complete or to discontinue aligner therapy and transition to fixed appliances. In a study conducted by Bollen in 2003, all patients who completed their first set of aligners required refinement or transition to fixed appliances to achieve the original pretreatment goals. Orthodontists report that 70-80% of cases do not achieve pre-treatment goals and require further treatment (Sheridan, 2004). One of the most common reasons for refinement or converting to fixed appliances is uncorrected rotations (Sheridan, 2004).

Digital Scanning Technology

Digital scanning offers many advantages to an orthodontic practice. It virtually eliminates problems associated with model storage or breakage. Scanned models allow for

quicker access and easier communication with patients and colleagues (Santoro, 2003). Numerous studies have been conducted to determine the accuracy of digitized dental models. Despite using different scanning methods, when virtual models from scans are compared to conventional plaster models, all studies conclude that scanners provide digital models that are reliable and clinically acceptable for orthodontic practice (Santoro, 2002; Zilberman, 2002; Fleming, 2010; Patzelt, 2013; Moreira, 2014; Lemos, 2015). Santoro et al., concluded that measurements for overbite and tooth width are statistically significant, but not clinically relevant and there are no significant differences in measurements for overjet.

Digital scans have also been compared to models obtained using cone-beam computed tomography (CBCT) (Tarazona, 2011; Wiranto, 2012; Kim, 2014). In 2012, Wiranto et al. concluded that intraoral scanning is as valid and reliable as CBCT scanning of alginate impressions for diagnostic purposes. Tarazona compared dental measurements from CBCT models and digital models and found no clinical differences between the two measuring techniques (2011). A study by Kim et al. compared CBCT models, plaster models, and digital models using the Ortho Insight 3D laser scanner (2014). They found excellent agreement among the three groups, with a mean difference in measurements from 0.08mm to 0.23mm. Lastly, Akyalcin et al. concluded in 2013 that iTero scanned dental arches are interchangeable with those obtained from CBCT.

Existing scanners are based on different scanning technologies including confocal microscopy, optical coherence tomography, active and passive stereovision and triangulation (Logozzo, 2014). Confocal laser scanning microscopy involves the passing of a laser beam focused by an objective lens. Scattered and reflected laser light is then re-collected by the lens and processed by a computer to fabricate an image (Lagozzo, 2014). The iTero is an example of

a digital impression system that uses this technology. It uses red laser beam light to generate illuminated areas intraorally and a 3-D image is constructed based on the intensity of light rays returning to the lens. The advantage of using an iTero scanner is that it is not necessary to apply a coating powder to the patient's teeth prior to scanning. However as a result, a color wheel must be added to the system, resulting in a larger scanner head than other systems (Logozzo, 2014).

Rapid Prototyping Technology

A significant milestone for clear aligner manufacturing companies was the introduction of rapid prototyping technology. Charles Hull is credited with the invention of stereolithography 3-D printing in 1984 (Groth, 2014). The technology has undergone rapid growth, rising from 6 patents applications in 1984, to 146 by 2012 (Park, 2015). Rapid prototyping can be divided into 2 groups: subtractive rapid prototyping and additive rapid prototyping. With subtractive rapid prototyping, the process begins with a material (often polyurethane) block which is milled into the desired 3-D object. The additive rapid prototyping method produces a 3-D object by incrementally adding layers (Kim et al, 2014). This technology 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. Tooth movement stages can now be planned digitally using 3-D software, and each treatment stage model can be constructed using rapid prototyping for subsequent aligner fabrication.

Various techniques exist for additive rapid prototyping and two techniques commonly used for dentistry are stereolithography and poly-jet photopolymerization. Stereolithography is the method of additive manufacturing used by Align Technology, the makers of Invisalign. It takes 3-D data collected from a scan and slices the data into a series of layers. A build platform

moves through a vat of liquid resin. Each layer is polymerized at the surface of the resin, until the final model is completed. At the end, the final product can be accessed for removal by elevating the platform from the vat of resin (Sharma, 2015). Stereolithography is commonly used to fabricate dental arches for orthodontic purposes and surgical guides for implant placement. Stereolithography is also the type of technology utilized by the Juell 3D OC Flash 3-D printer, which was used to fabricate the models used in this study. However, the Juell 3D uses digital light processing (DLP) to cure an entire layer, reducing the total time it takes to fabricate a model.

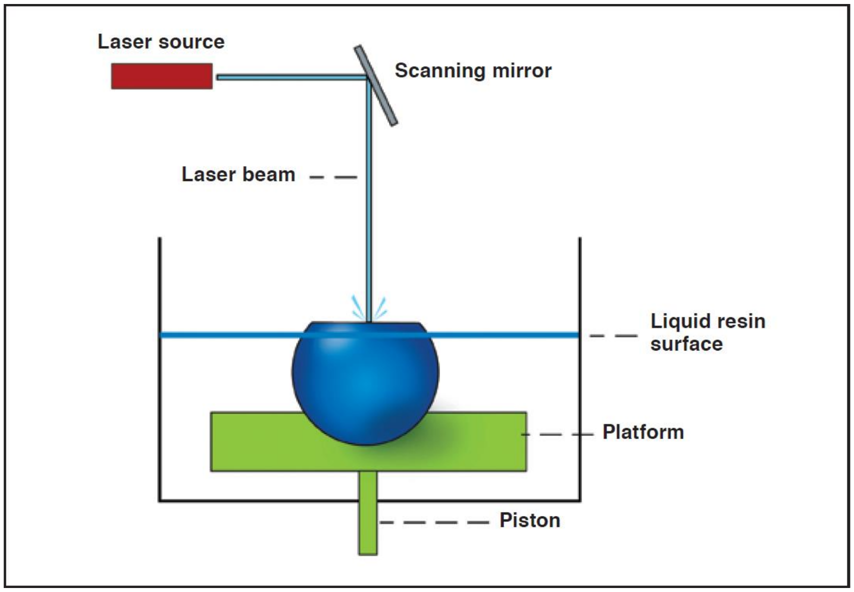


Figure 2-7: Diagrammatic representation of Stereolothography (Groth, 2014)

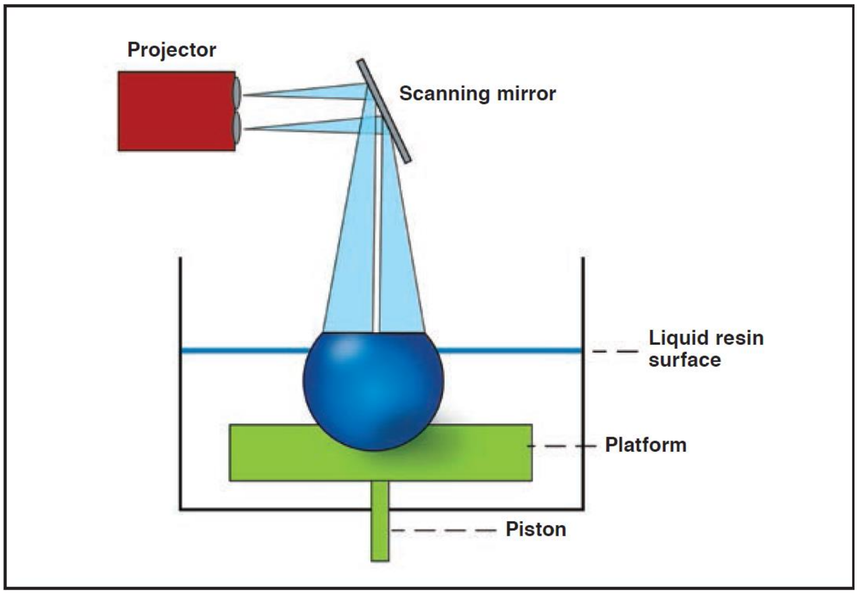


Figure 2-8: Diagrammatic representation of Digital Light Processing (DLP) printer (Groth 2014)

Another method of additive rapid prototyping is poly-jet photopolymerization (PPP), which is currently being used by the clear aligner manufacturer ClearCorrect. This technology differs from stereolithography because instead of having a vat of liquid resin that the build platform moves through, PPP utilizes print heads that extrude resin layer by layer. Each layer is immediately cured with UV light as it is laid down (Sharma, 2014; Groth, 2014).

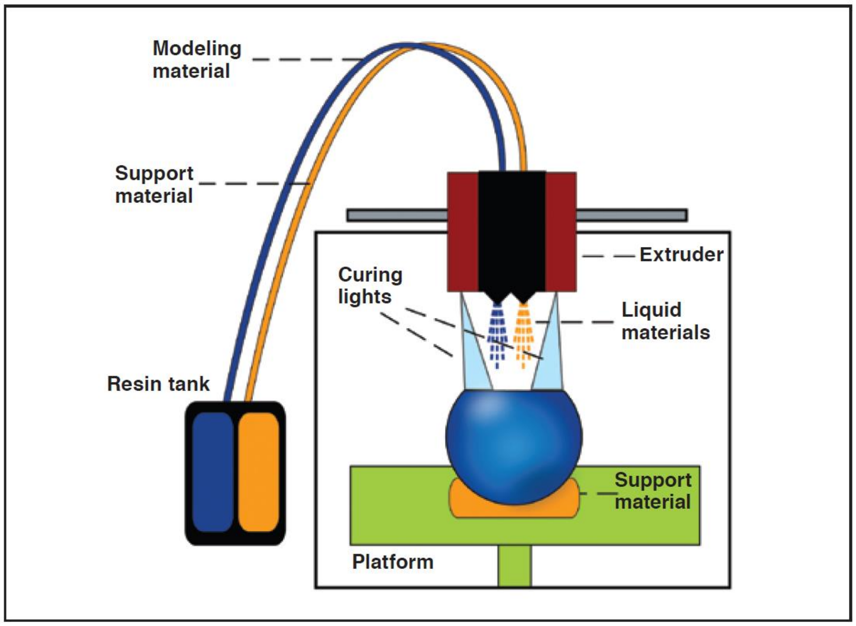


Figure 2-9: Diagrammatic representation of PolyJet PhotoPolymer printer (Groth 2014)

There have been a number of studies assessing the accuracy of models fabricated using rapid prototyping techniques (Cuperus, 2012; Kim, 2013; Groth, 2014; Ren, 2014; El-Katatny, 2010). Kim et al., studied accuracy of subtractive rapid prototyping and found that differences in linear measurements taken from plaster and rapid prototyping models fell in the range of 0.07mm-0.33mm. Ren et al., compared plaster models against three rapid prototyping techniques: digital light processing, jetted photopolymer, and 3D printing. They performed Bolton analyses on all models, and measured clinical crown heights. Results showed that the Bolton differences were at most 1.24mm in the anterior region and 2.26mm overall and the clinical height differences were only on average -0.02mm. El-Katatny et al., analyzed the differences when fabricating skull and mandible replicas using Fused Deposition Modelling. Results of this study found that replicas deviated 0.24% with skull models, and 0.22% with mandibular models. All studies have concluded that although there are observable differences, rapid prototyping is highly accurate and produces reliable models. Ren concludes that models

produced with rapid prototyping techniques are accurate, show low systemic differences, and are interchangeable with plaster models.

Thermoplastic Materials

Thermoplastic materials are characterized by their ability to be reformed into a new product while maintaining their previous characteristics (MacDonald, 2006). There are several thermoplastic materials available today, but the most commonly used for orthodontic purposes are polypropylene, polyester, and polyurethane. Materials are chosen based on clinical preference or recommendations from manufacturers. Each material, however, has different properties and it is important to select a material based on its intended application. In addition, thermoplastic polymers are sensitive to factors such as temperature, humidity, thermoforming procedures, and time after deformation, all of which can impact their mechanical properties (Ryokawa, 2006).

Properties of thermoplastic materials are influenced both by forming methods and the conditions under which they are being used (Ryokawa, 2006; Hahn, 2009). An appliance formed under high pressure will form a better fitting appliance, which will in turn increase friction and improve aligner effectiveness on displaced teeth (Hahn, 2009). An appliance formed under high pressure will also deliver significantly higher forces due to a more intimate fit (Kohda, 2013). It has also been found that appliances with higher material thickness deliver higher forces (Kohda, 2013).

Dr. Ray Stewart founded Bay Materials, the company that manufactures Zendura, in 1999. Zendura is a polyurethane material which is widely used for orthodontic retainers and aligners. Its advantages include of high strength, deformation resistance, and stain resistance – all of which make it an excellent material for clear aligners and retainers (Zendura Properties,

2016). According to tests conducted by Intertek Plastics Technology Laboratory, Zendura is superior to other commonly used thermoplastics in crack resistance (impact strength) and stain resistance.

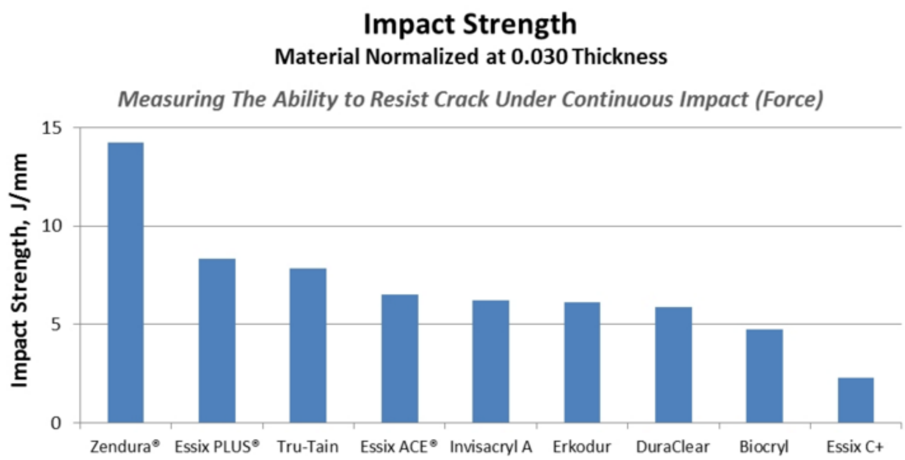


Figure 2-10: Impact strength of commonly used thermoplastic materials (Zendura Properties, 2016)

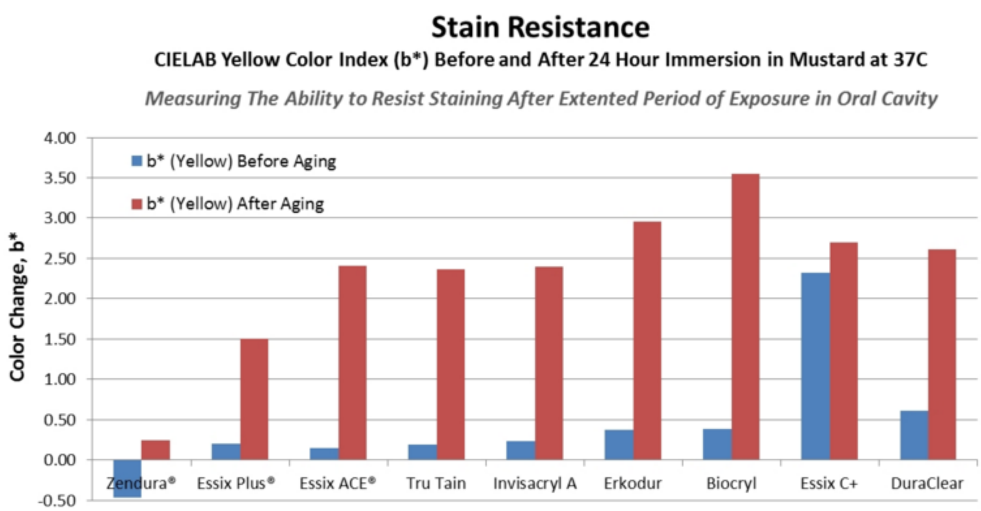


Figure 2-11: Stain resistance of commonly used thermoplastic materials (Zendura Properties, 2016)

For clear aligner therapy, aligner toughness is very important because the aligner must be able to withstand the stresses present in an intraoral environment. Stress retention is important to ensure that the aligner material is able to apply continuous force to move teeth into alignment

without deformation. Zendura is also unique because the material can be annealed. Annealing involved heat treating the polymer and this enhances its properties, particularly improving stress relaxation (Stewart, 2014). Annealing is a complex process and was not performed for this study. However, due to its favorable properties, Zendura was selected as the aligner material for this thesis.

Thermoforming Process

Thermoforming is a ubiquitous manufacturing process that can be traced back to Ancient Egyptians who used the oldest known thermoplastic material, tortoise shells. Using hot water to make the shells soft and moldable, the Egyptians were thought to fabricate containers from the shells (MacDonald, 2006). Today, thermoforming is one of the most common manufacturing processes, used in industries such as automotive, food and beverage packaging, pharmaceutical packaging, and medical devices. In dentistry, thermoforming has several applications including custom tray fabrication, splints, bite planes, temporary crown and bridge fabrication, mouthguards, and orthodontic appliances (Allred, 1958; Allred, 1968).

In the simplest terms, thermoforming is the process of molding a material using heat and is assisted by the use of vacuum or air pressure. The most common technique involves softening a plastic sheet using a heat source and draping the plastic sheet over a mold to achieve the desired shape (Michaud, 2011). Vacuum or air pressure is used to achieve more intimate contact with the mold (MacDonald, 2006; Allred 1968).

Although thermoforming was developed during World War II, its use in dentistry began when H.I. Nahoum introduced the vacuum formed dental contour appliance in 1964. This appliance fabrication process has been used in dentistry for over 50 years now, but still presents challenges because it is affected by numerous variables. One challenge is achieving uniform

material thickness throughout the appliance. Material thickness is dependent on every step of the thermoforming process.

The first step involves preparation of the model which serves as the mold for the thermoformed appliance. It has been noted that material thickness is affected by the extent and speed of material stretching (Kumar, 2014). The average thinning at occlusal surfaces is 46% for posterior teeth and 47-60% for the incisor and canine region (Del Rossi, 2007). In 2007, Del Rossi concluded that the material is thinnest where it is stretched the farthest due to the greater distance that the plastic must travel. This was confirmed in 2013 by Kumar and again in 2015 by Farrington, who found that material thickness is greatest where it contacts the mold first and least where is contacts last. It is recommended to keep a dental model at the minimum height possible, with the ideal height found to be 20mm (Del Rossi, 2007). An additional concern to model height is model inclination. In 2015, Farrington noted that material thickness can be influenced by model inclination. If the anterior teeth of a dental model are angulated up 45 degrees, anterior material thickness will improve, but at the expense of posterior material thickness.

The next step involves the heating phase, which is dependent on the type of machine and heating element used (Takahashi, 2015). Uniform heat distribution is critical for fabricating a satisfactory appliance, however polymers are poor conductors of heat and this leads to a tendency for uneven heat distribution (Kumar, 2013; Puehringer, 2013). Areas where the temperature is too low will lead to an inaccurate capture of mold contours. Conversely, areas where the temperature is too high will lead to greater thinning of the thermoplastic sheet and result in tearing (Kumar, 2013). For clear aligner therapy, force delivery is dependent on factors such as material thickness and accuracy of capture of mold contours (Kwon, 2008; Kohda,

2013), therefore it is imperative to have an understanding of the thermoforming process and the variables that may affect the properties of the aligners produced.

Chapter 3 : Material and Methods

Fabrication of Study Models

Study model fabrication began with taking an impression of a Kilgore 200 typodont (Kilgore International , Coldwater, MI) using Kromopan 100 impression material (Kromopan USA, Morton Grove, IL). Typodont teeth were placed into the impression in the positions of teeth #28, #29 and #30 and secured in place using clear utility wax (Henry Schein Dental). Next, models were poured up using Type III blue stone (Gibraltar, Henry Schein Dental). The models were then trimmed to allow 15mm of land area to prevent breakage, and trimmed apically until the root apices of the typodont teeth were flush to the bottom of the model. This allowed placement of aligners without distorting the vertical position of the teeth.

Figure 3-1: Kilgore 200 Mandibular Dentoform


Figire 3-2: Typodont teeth positioned into impression


Figure 3-3: Typodont teeth secured with utility wax

Initial rotation of the lower right second premolar was achieved by using an apparatus fabricated for this study. This apparatus was designed to secure the base of the model at a consistent position while a hinged arm extended over the model. The hinged arm could be lowered to a reproducible position on the fabricated model. A hard acrylic cap was fixed to the upper arm as well as a 360° protractor. The acrylic cap was fit to the occlusal surface of the lower right second premolar and this would allow free rotation of the tooth. Once tooth #29 was rotated 30°, an acrylic stent was fabricated and reinforced with laser-welded steel wire. This stent would allow for resetting teeth to their original positions after each experimental trial.

Figure 3-4: Apparatus utilized to create initial 30° rotation of lower right second premolar

Figure 3-5: Acrylic stent fabricated to reproduce premolar rotation

Figure 3-6: Final typodont with lower right second premolar rotated

In order to achieve rotation of the lower right second premolar, the distal surface of tooth #28 and the mesial surface of tooth #30 required 0.25mm of reduction, which was accomplished with a diamond disc bur and measured using interproximal reduction gauges. Reference points were placed distal to the lower right second molar and at the cusp tip of the lower left canine using a ¼" round bur. A reference line was also placed through the occlusal surface of the lower right second premolar. These reference markers were placed to allow measurement of rotational change.

Attachments were placed using a vertical rectangular attachment template (Reliance Orthodontic Products. Itasca, IL), Assure Plus (Reliance Orthodontic Products) and Transbond LR (3M Unitek, Monrovia, CA). A master model was fabricated by placing attachments on the buccal and lingual surfaces of teeth #28, #29 and #30. The attachment template was fabricated from the master model using clear polyvinylsiloxane (Rocky Mountain Orthodontics, Denver, CO). This template was then utilized to ensure attachments would be placed on all models in reproducible and accurate positions.

Figure 3-7: Clear PVS attachment template

Models were then randomly assigned to one of nine groups:

- Group 1: No attachments placed or aligner adjustments made
- Group 2: No attachments placed. Rotation correcting adjustment made to each aligner using Hu-Friedy vertical rectangular adjusting plier on buccal surface of #29.
- Group 3: No attachments placed. Rotation correcting adjustment made to each aligner using Hu-Friedy vertical rectangular adjusting plier on lingual surface of #29.
- Group 4: No attachments placed. Rotation correcting adjustment made to each aligner using Hu-Friedy vertical rectangular adjusting plier on buccal and lingual surfaces of #29.
- Group 5: Rotation attachment placed on buccal surface of #29 (vertical rectangular attachment, Reliance Orthodontic Products)
- Group 6: Rotation attachment placed on lingual surface #29 (vertical rectangular attachment, Reliance Orthodontic Products)
- Group 7: Rotation attachments placed on buccal and lingual surfaces of #29 (vertical rectangular attachment, Reliance Orthodontic Products)
- Group 8: Rotation attachments placed on buccal surfaces of teeth #28, 29 and 30 (vertical rectangular attachment, Reliance Orthodontic Products)

- Group 9: Rotation attachment placed on buccal and lingual surfaces of teeth #28, 29 and 30 (vertical rectangular attachment, Reliance Orthodontic Products).

Scanning Models Using iTero Scanner

The original intent of this study was to exclusively use the OrthoInsight 3D (MotionView 3D, Chattanooga, TN) scanner for all scans made. However, due to the limited access of the laser beam for desktop scanners, composite attachments were not captured well, particularly on the lingual surfaces of the teeth. As a result, initial scans were made using the iTero Scanner (Align Technology, San Jose, CA). The advantage of using an intraoral scanner was the range of motion permitted by the scanner camera which allows for better capturing of undercuts and lingual attachments. Initial scans were exported in STL format.

Post Scan Processing

When scans are made they are represented by a point cloud which must then be configured to obtain a 3-dimensional model image. The STL file type is the most commonly used file type and uses triangles to construct a 3-D image from the point cloud. The STL file format is the oldest and most widely used file type, but it is also the least accurate and least detailed due to its simplicity. This study utilized the OBJ (Alias Wavefront) file type, which uses more complex polygons to construct a 3D image, and maintains more details such as color and texture. There were three complications presented by using the iTero scanner. First, the only file type available for export is STL. Secondly, exported scans did not have a flat base, and a flat base is preferred to facilitate 3-D printing. Third, despite being a common file type, there was an apparent incompatibility when transferring the iTero scanned information into MotionView 3D software for treatment setups. This incompatibility resulted in models that were

not "water-tight" which in CAD/CAM terms refers to a 3-D model that has voids or holes in the model. To correct these issues, iTero scans had to undergo an additional step of processing using mesh repair software. MeshMixer (Autodesk Research, San Francisco, CA) was utilized to repair the mesh and correct voids. This software was also used to add a base to the models and had the ability to export the corrected models in the OBJ file format which was used for the remainder of the study.

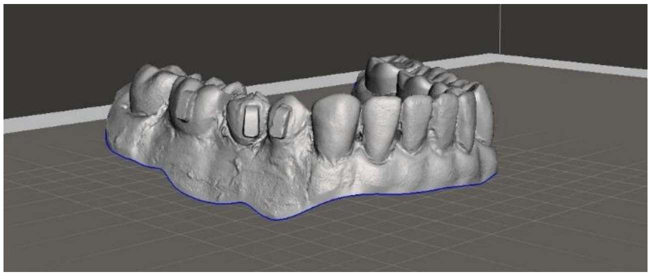


Figure 3-8: iTero scanned model prior to adding a base and mesh repair

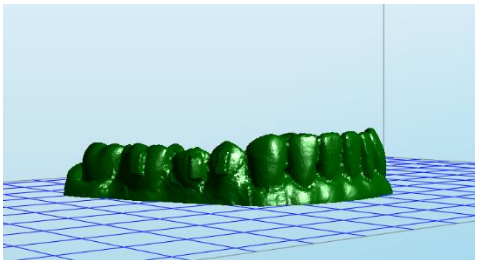


Figure 3-9: Model after processing using MeshMixer as visualized in Juell 3D software

Aligner Treatment Planning and Staging Using Motion View Software

OBJ format digital models were imported into MotionView 3D software for treatment planning. A treatment plan was prepared to correct rotation of tooth #29 by 3° per aligner for a series of 10 aligners. No other tooth positions were altered. The 10 aligner treatment models for each group were exported in OBJ format for 3-D printing.

Fabricating Resin Models using Juell 3D Flash OC

The Juell 3D OC Flash printer (Park Dental Research, New York, NY) was utilized in this study to fabricate the 90 total resin models used in this study. The Juell 3D printer uses a stereolithography method of additive manufacturing with a digital light processing (DLP) projector to cure each resin layer. Four digital models were placed on the build platform at a time and slice thickness was set at 50 microns. Once fabrication was complete, models were removed from the build platform and rinsed in a 70% isopropyl alcohol bath for five minutes. Models were then placed in a UV sterilizer for two hours to achieve final cure.

Fabricating Aligners

Once final cure was achieved, aligners were fabricated using Zendura (Bay Materials, Fremont, CA) and a MiniStar S pressure forming machine (Great Lakes Orthodontics, Tonawanda, NY). Zendura sheets were heated for 40 seconds and immediately pressure formed over each dental model. Aligners were trimmed with a straight edge approximately 1-2mm from the gingival margins (Cowley, 2012).

Conducting Trials

Each model was placed in an ice water bath (5ºC) for 10 minutes initially to ensure that the aligner is placed on the model without distorting the wax or initial tooth positions. While the model was in the ice bath, its corresponding aligner was placed in a water bath set at 37 ºC to simulate body temp. Each aligner was then placed on its corresponding model and placed in a hot water bath (Sheldon Manufacturing, Inc, Model W20M) set at 50°C for 10 minutes. Since the aligner material is designed to be used in an intraoral environment, its properties could not guaranteed to be unaltered at high temperatures. For this reason, models were placed on stone

platforms designed to elevate the model out of the hot water bath until the water level was just short of the apical margin of the aligner. This allowed heating of the wax by the hot water without exposing the aligner to high temperatures. The ambient temperature at the surface of the water bath was measured at 38°C. Models were placed in the hot water for 5 minutes then placed on a flat surface and occlusal pressure was applied to the aligner to simulate occlusal forces and ensure complete seating of the aligners. The models were then returned to the hot water bath for an additional 5 minutes. After heating, models were placed back in the ice water bath for 10 minutes prior to removing the aligner, and the model was taken to the OrthoInsight scanner for scanning.

Digital scans were taken initially and after each of 10 sequential aligners in order to assess both total rotation as well as per aligner rotation correction. Digital scans were taken using the Ortho Insight 3D laser desktop scanner (Motion View, LLC) and scans were exported in OBJ format. Model analysis and measurement of rotation correction per aligner was completed using GeoMagic Design software (3D Systems, Inc).

Measuring Angles Using Geomagic Design

Digital models were imported into Geomagic Design software and oriented so that the occlusal surface was parallel to the X-Z axis. Once the correct orientation was achieved, lines were drawn according to the references markers placed on the models. A first line was drawn from the point distal to the lower right second molar to the cusp tip of the lower left canine. A second line was drawn through the occlusal reference line on the lower right second premolar. An angular measurement was then calculated at the inner angle of their point of intersection.

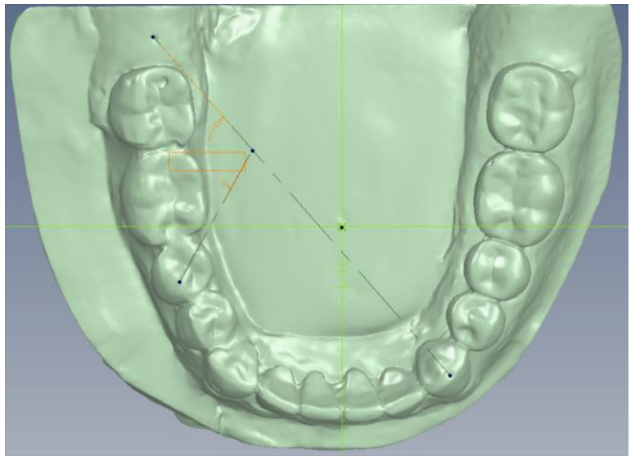


Figure 3-10: Example of angular measurement taken using Geomagic Design

Statistical Analysis

Statistical analysis of the data was performed using IBM SPSS. Statistical tests run on the data included one-way analysis of variance and used a significance level of $p<0.05$. Calculations were also made for mean rotational change for each of the 10 aligners per group, mean rotational change per aligner per group overall, overall rotational change, and percentage of the intended 30° rotational correction achieved.

Chapter 4 : Results

The experiment was repeated 3 times. Results are presented below for each trial and also for the mean values for all three trials.

Group	Aligner 1	Aligner 2	Aligner 3	Aligner 4	Aligner 5	Aligner 6	Aligner 7	Aligner 8	Aligner 9	Aligner 10
1	1.53	1.54	1.91	2.07	1.53	1.63	1.78	2.1	2.29	1.86
2	1.01	1.01	2.2	1.73	1.8	1.88	1.48	1.11	1.45	1.66
3	0.32	1.03	-0.7	-0.97	-0.24	-0.09	-0.2	-1.15	-1.68	-0.82
4	-8.61	-4.49	-10.11	-0.85	-7.98	-1.39	-3.01	-0.66	-3.18	-1.73
5	2.03	1.6	1.83	2.8	2.64	2.67	2.72	2.94	1.75	2.59
6	1.48	1.17	0.89	1.02	2.37	2.04	2.87	2.5	2.85	2.84
7	1.61	1.31	2.3	1.35	1.5	2.31	2.94	2.78	1.19	2.93
8	0.53	1.96	0.25	1.08	1.84	1.86	1.98	2.39	1.96	2.04
9	1.13	0.58	0.75	1.19	0.46	0.39	0.53	0.63	0.73	0.76

Table 4-1: First trial indicating degrees of rotation for each aligner

Group	Aligner 1	Aligner 2	Aligner 3	Aligner 4	Aligner 5	Aligner 6	Aligner 7	Aligner 8	Aligner 9	Aligner 10
1	1.71	1.72	2.25	1.41	1.85	1.73	1.75	1.66	1.97	2.09
2	1.03	0.91	2.6	1.97	1.34	2.05	1.15	1.62	1.66	1.6
3	0.37	0.89	-0.69	-1.59	-0.3	-0.83	-0.61	-1.06	-1.31	-0.19
4	-9.29	-5.26	-0.4	-9.46	-12.8	-1.53	-1.31	-4.57	-0.32	-1
5	1.71	2.53	1.92	2.27	2.69	2.21	2.46	2.21	1.93	2.24
6	2.99	1.43	0.62	1.65	2.51	2.59	2.94	2.57	2.3	2.96
7	2.23	1.76	1.16	0.92	2.07	2.37	2.09	2.42	2.49	2.82
8	1.42	1.16	0.24	0.73	2.5	1.79	2.76	2.28	1.39	2.11
9	0.9	0.98	0.88	1.05	1.07	0.89	0.99	0.49	1.47	1.13

Table 4-2: Second trial indicating degrees of rotation for each aligner

Group	Aligner 1	Aligner 2	Aligner 3	Aligner 4	Aligner 5	Aligner 6	Aligner 7	Aligner 8	Aligner 9	Aligner 10
1	1.57	1.65	2.1	1.43	1.57	1.74	2.1	1.77	1.75	1.82
2	0.99	0.82	2.4	1.6	1.39	2.12	1.46	1.39	1.32	1.69
3	0.41	0.87	-0.67	-1.61	-0.37	-0.99	-0.43	-0.79	-1.11	-0.67
4	-8.07	-5.67	-4.91	-4.11	-11.52	-0.91	-0.37	-1.6	-3.8	-3.01
5	2.01	1.77	2.21	2.32	2.68	1.8	2.36	1.53	2.92	1.42
6	1.99	1.52	1.11	2.37	2.6	1.63	2.17	2.04	2.58	2.02
7	1.86	1.68	1.29	1.21	1.68	2.19	1.99	2	2.91	2.74
8	0.88	0.8	0.91	1.04	2.93	2.95	1.5	2	1.64	2.18
9	1.05	0.69	1.04	0.78	0.87	0.44	0.66	0.66	0.9	0.94

Table 4-3: Third trial indicating degrees of rotation for each aligner

Group	Aligner 1	Aligner 2	Aligner 3	Aligner 4	Aligner 5	Aligner 6	Aligner 7	Aligner 8	Aligner 9	Aligner 10
1	1.6	1.64	2.09	1.64	1.65	1.7	1.88	1.84	2	1.92
2	1.01	0.91	2.4	1.77	1.51	2.02	1.36	1.37	1.48	1.65
3	0.37	0.93	-0.69	-1.39	-0.3	-0.64	-0.41	-1	-1.37	-0.56
4	-8.66	-5.14	-5.14	-4.8	-10.77	-1.28	-1.56	-2.28	-2.43	-1.91
5	1.92	1.97	1.99	2.46	2.67	2.23	2.51	2.23	2.2	2.08
6	2.15	1.37	0.87	1.68	2.49	2.09	2.66	2.37	2.58	2.61
7	1.9	1.58	1.58	1.16	1.75	2.29	2.34	2.4	2.2	2.83
8	0.94	1.31	0.47	0.95	2.42	2.2	2.08	2.22	1.66	2.11
9	1.03	0.75	0.89	1.01	0.8	0.57	0.73	0.6	1.03	0.94

Table 4-4: Mean rotational change per aligner for all three trials

Group	Mean Rotation Per Aligner	Mean Total Rotation	Percentage of 30° Rotation Corrected
1	1.81	17.96	59.87
2	1.56	15.48	51.6
3	-0.51	-5.06	-16.87
4	-4.17	-43.97	-146.57
5	2.21	22.25	74.17
6	2.13	20.87	69.57
7	2.08	20.03	66.77
8	1.68	16.37	54.57
9	0.85	8.34	27.8

Table 4-5: Mean rotational change per aligner for each group, mean total rotational change, and percentage of rotation corrected.

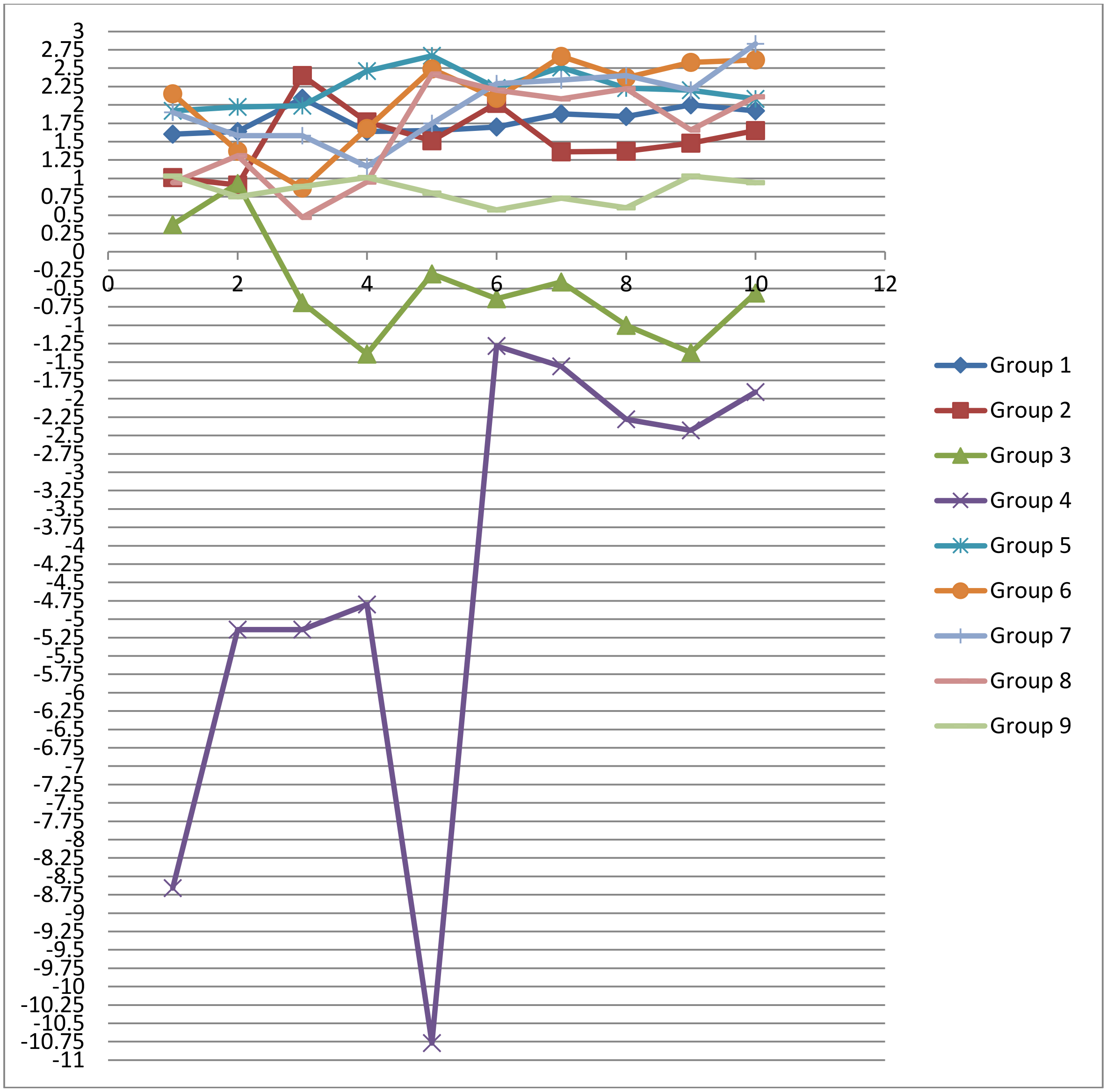


Figure 4-1: Mean rotation change for each aligner for each group

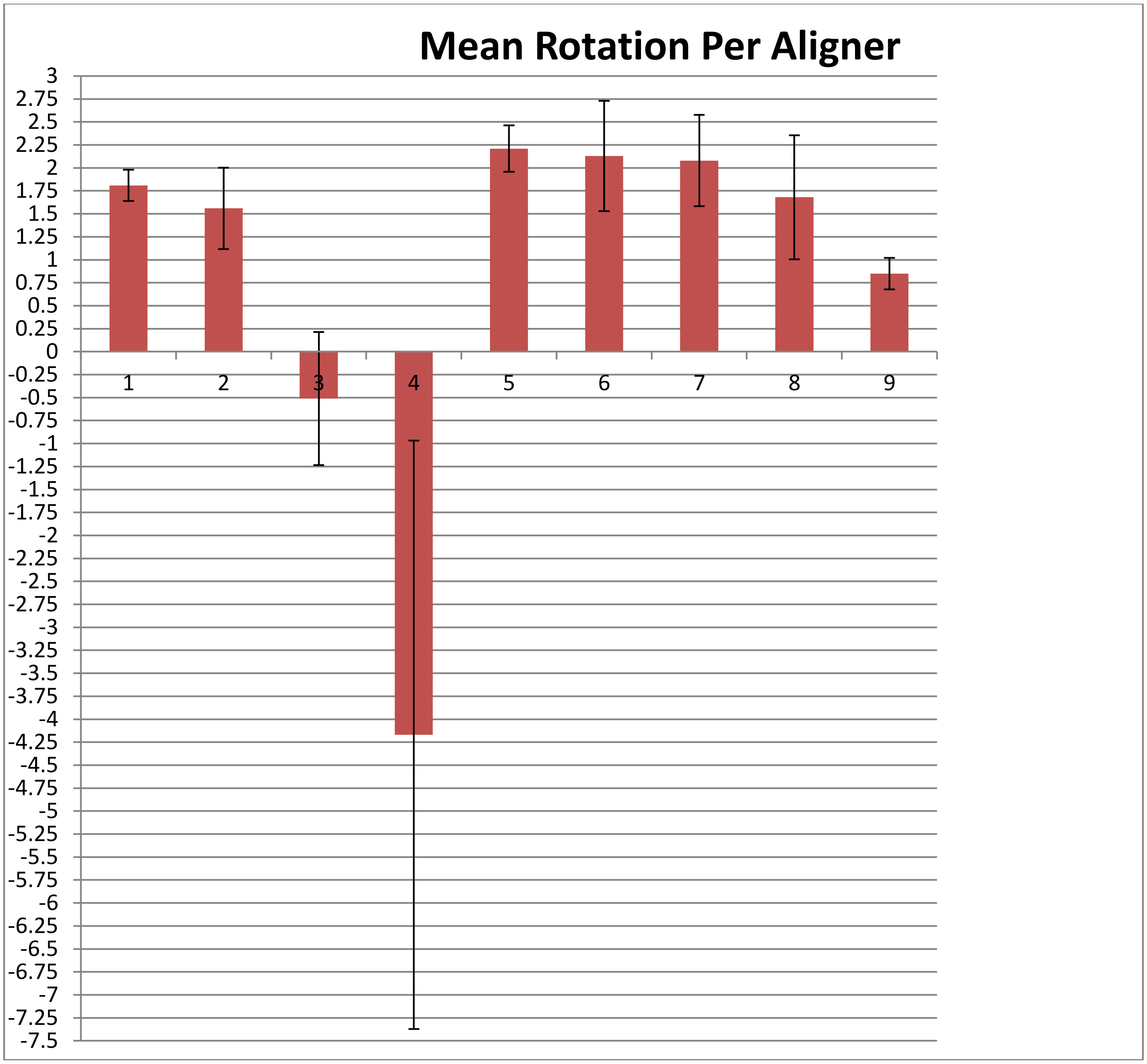


Figure 4-2: Mean rotation per aligner for all 10 aligners for each group

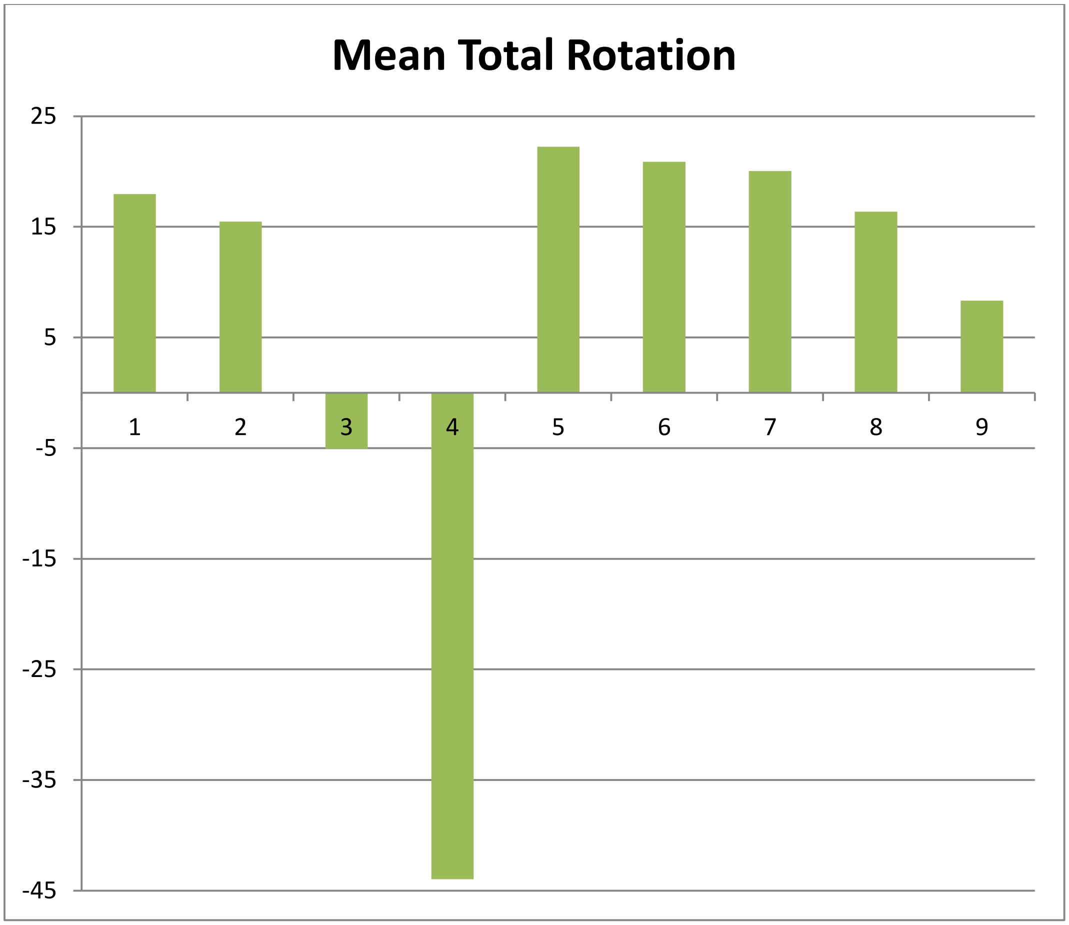


Figure 4-3: Mean total rotation for each group after a series of 10 aligners

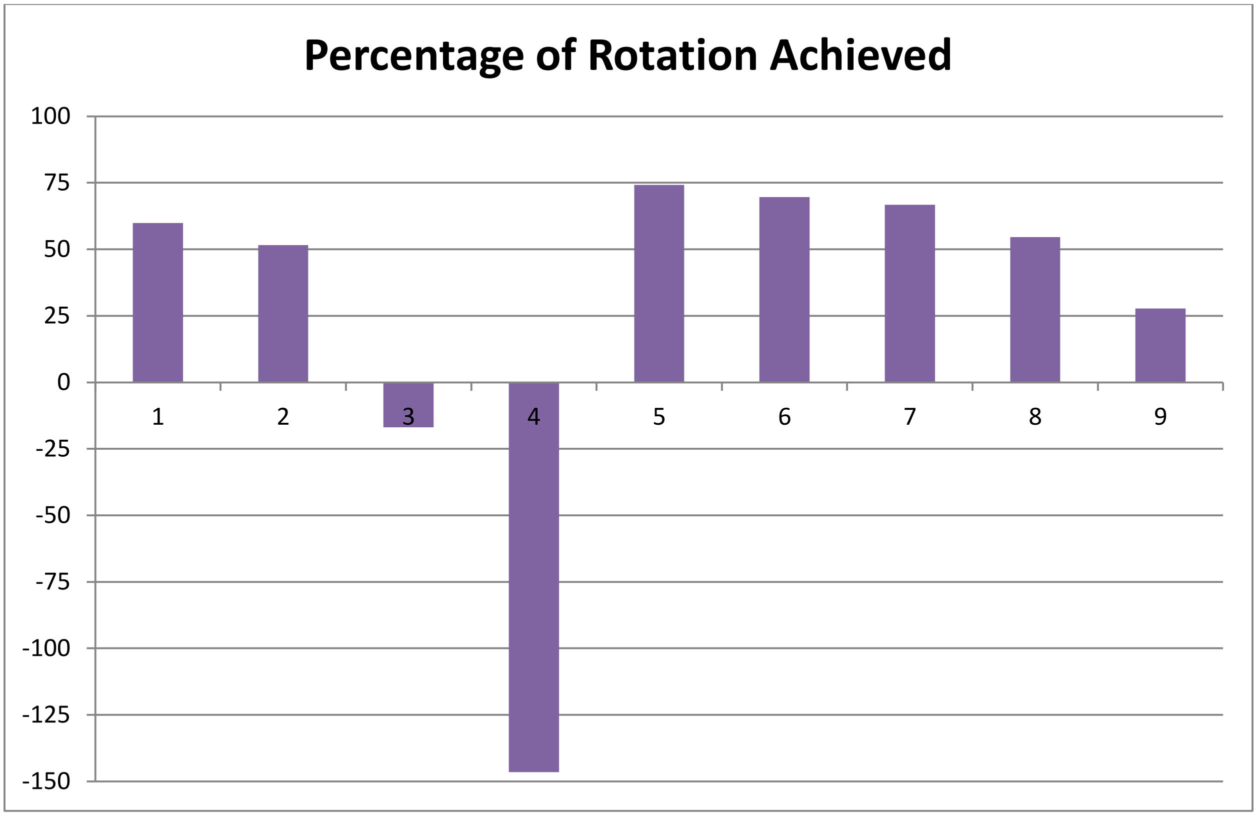


Figure 4-4: Percentage of initial 30-degree rotation corrected

A one-way ANOVA was run to test the variance between the nine groups with the significance level set at $P<0.05$. The difference between groups 1, 2, 5, 6, 7, 8 and 9 were statistically insignificant. Groups 3 and 4 had statistically significant differences as compared to the remaining groups. See Appendix A for the complete descriptive statistics and ANOVA tables.

Chapter 5 : Discussion

Clear aligner therapy is a rapidly growing segment of the orthodontic market. According to the American Association of Orthodontists, the number of adults seeking orthodontic treatment grew by 58% from 1994-2010. In 2013, Align Technology estimated that 31% of adult orthodontic cases were treated using the Invisalign system. In contrast to adolescents, adults typically have higher esthetic demands, and although they may desire orthodontic treatment, they are more likely to reject treatment due to esthetics. Two surveys were cited by Rosvall, et al in 2009. In one survey, it was found that 62% of adult patient would reject treatment with a visible appliance despite their desire to have their malocclusion corrected. In another study, it was found that 33% of adults would be unwilling to wear visible fixed appliances to correct their malocclusion. Due to the rising esthetic demands of orthodontic patients, efforts have been made to provide esthetic treatment solutions, including lingual braces, ceramic or plastic brackets, and clear plastic aligners. Over 90% of adults surveyed, clear aligners were an acceptable form of treatment and they were willing to pay an additional mean fee that was $610 more than traditional treatment with metal brackets.

Despite the rapid growth in demand for clear aligner therapy, very little is understood about its mechanism of action, indications and limitations. Few randomized clinical trials have been conducted and much of the rationale for current treatment practices is based on anecdotal information, clinical opinion, and case reports. The goal of this study was to develop an in-vitro study model that could be applied to testing the efficacy of treatment using clear aligners. This study focused on controlling rotation of round teeth, which has widely been reported as one of the most challenging movements to achieve with clear aligners, following extrusion (Rossini, 2014; Kravitz, 2007; Simon, 2014). Composite attachments, overcorrection, and adjusting

aligners with thermoform adjusting pliers are three of the ways that clinicians attempt to improve rotational control of round teeth (Kravitz, 2008). This study assessed the differences between attachment location, number of attachments, and aligner adjustments. Although observable differences were present among all groups, only two groups exhibited statistically significant results.

Clinical Relevance and Theoretical Implications

One way to overcome challenges presented by clear aligner therapy is to use aligners as an adjunct to fixed appliances. The clinician can first place fixed appliances to align the teeth, and then take impressions after rotations are corrected to continue treatment with aligners. Alternatively, treatment can initiate with clear aligners, and transition to fixed appliances to achieve the movements that were not accomplished using clear aligners. However, for the segment of patients that are strongly opposed to fixed appliances, they may reject orthodontic treatment altogether, or the decision could be made to compromise treatment goals in order to limit movements to those which can be accomplished using clear aligners.

Many authors report that cases treated with clear aligners do not achieve pre-treatment goals with the first set of aligners and typically require further treatment (Bollen, 2003; Sheridan, 2004; Boyd, 2005). When aligners fail to track as intended in the digital set up, this is a source of frustration for both patients and clinicians. If the decision is made for mid-course correction, new impressions must be taken, a new treatment simulation planned out, and new aligners made. If aligner fit is still acceptable, another option is to complete the current set of aligners and address the unsuccessful movements during refinement.

There are currently many different clear aligner products available today. Although certain generalizations can be made about clear aligner therapy overall, each system is different

and must be studied independently. There are many variables associated with clear aligner treatment, including but not limited to computer processing of impressions (digital or conventional), rapid prototyping, type of plastic sheet used for thermoforming, and type of thermoforming machinery used. Even within the same system all properties and characteristics cannot be guaranteed to be the same. This study tested an in-office clear aligner treatment solution which presents its own set of advantages and disadvantages.

One advantage of this system is the complete control that the clinician has over the treatment plan and how tooth movements are staged. There is no need to send impressions to an aligner company, which may become distorted during the shipping process. Furthermore, it would no longer be necessary to wait for a technician to devise a treatment plan. Since the clinician has control over tooth movements, he/she would not need to communicate back and forth with a technician to revise the proposed treatment plan. This could prove to save time for the clinician and speed up start time for the patient, especially once the clinician becomes proficient in digital treatment planning and staging.

An in-office clear aligner system is very challenging for clinicians to integrate into their practice. The first challenge would be to overcome the skepticism and fear of integrating new technology in their practice. Next is the associated costs – purchases would include a digital scanner, treatment planning software, 3-D printer and liquid resin needed to print models, aligner material and a positive pressure thermoforming machine. In addition there are the costs associated with training staff to fabricate models and aligners. Lastly, and perhaps the biggest challenge, is the steep learning curve associated with all new technology incorporated into a practice. For the present study a desktop scanner (Ortho Insight) was initially used, which has the advantage of not having to do a chairside scan. However, one would need a conventional

impression, or a poured up stone model of the patient's teeth to scan. During the impression taking or stone model fabrication processes, possible inaccuracies or expansion and shrinkage could be introduced. Another disadvantage encountered in this study was the inability to accurately capture undercuts produced by attachments, in particular the inability to accurately capture lingual attachments. As a result, if using the Ortho Insight scanner, it is recommended to invest in a separate treatment planning software that allows for digital addition of attachments.

Due to the inaccuracy of initial scans using the Ortho Insight scanner, the present study utilized the iTero intraoral scanner for the first set of scans. The scanner wand allows for 360° access around the model and permitted capture of attachments and undercuts. Previous studies have confirmed the accuracy of the iTero scanner as compared to original scanned models, polyvinylsiloxane impressions, and CBCT generated models. However, a criticism of intraoral scanning is often wand size and patient comfort, as well as speed of taking a digital impression. Inaccuracies in scanning technology often are attributed to differences in materials being scanned and translucency. In an intraoral environment, the scanner must be able to differentiate between teeth and gingiva, overcome the translucency of dentition, and battle challenges posed from the patient's tongue and the presence of saliva. While an experienced user may be able to complete a scan in several minutes, a new user would require much more time, and the increased chair time needed for scans compared to taking conventional impressions is often a topic of debate.

The next step in the process is importing the models into treatment planning software. In this study, it was necessary to "repair" iTero scans and correct voids prior to importing the scan data into MotionView 3D, as explained in chapter 3. Scans taken by Ortho Insight did not require any mesh repair and it is conceivable that when using the same system for digital scanning and digital treatment planning, this additional step would be unnecessary. Once the

scanned data was imported into the Motion View software, several additional steps were necessary prior to planning a digital treatment plan. These steps included digitally separating teeth, verifying landmarks automatically detected by the software, and adjusting occlusion. This study found that the MotionView 3D was user-friendly and simple to understand and use. Although only one tooth was being moved in this study, it would take approximately 10 minutes to complete the model processing steps, complete the treatment plan, and export the staged models.

The biggest challenge encountered by this study was at the digital model fabrication phase. Although many of the challenges can be attributed to operator inexperience, there are several common problems associated with 3-D printing, the majority of which were encountered during the course of this study. The most common problem observed during this study was the problem of initial build layer not sticking to the build axis. The Juell 3D OC Flash 3-D printer has a nickel-plated build platform, and the machine uses a Teflon sheet to level each layer prior to curing. Often the initial build layer would cure against the inner surface of the Teflon, separate, and lift off from the build platform. This would cause a build failure as the same layer of resin would be cured against the Teflon until the build is “complete”. Unfortunately, due to the mechanism by which models are fabricated using the stereolithography technique, it is practically impossible to know that a build has failed until it has run to completion. Several factors could cause this problem, including the condition of the build plate, age of resin, intensity and length of cure, and the position of the build platform. It must be ensured that the Teflon sheet is tight against the build platform, as any small air gaps could lead to a failed build.

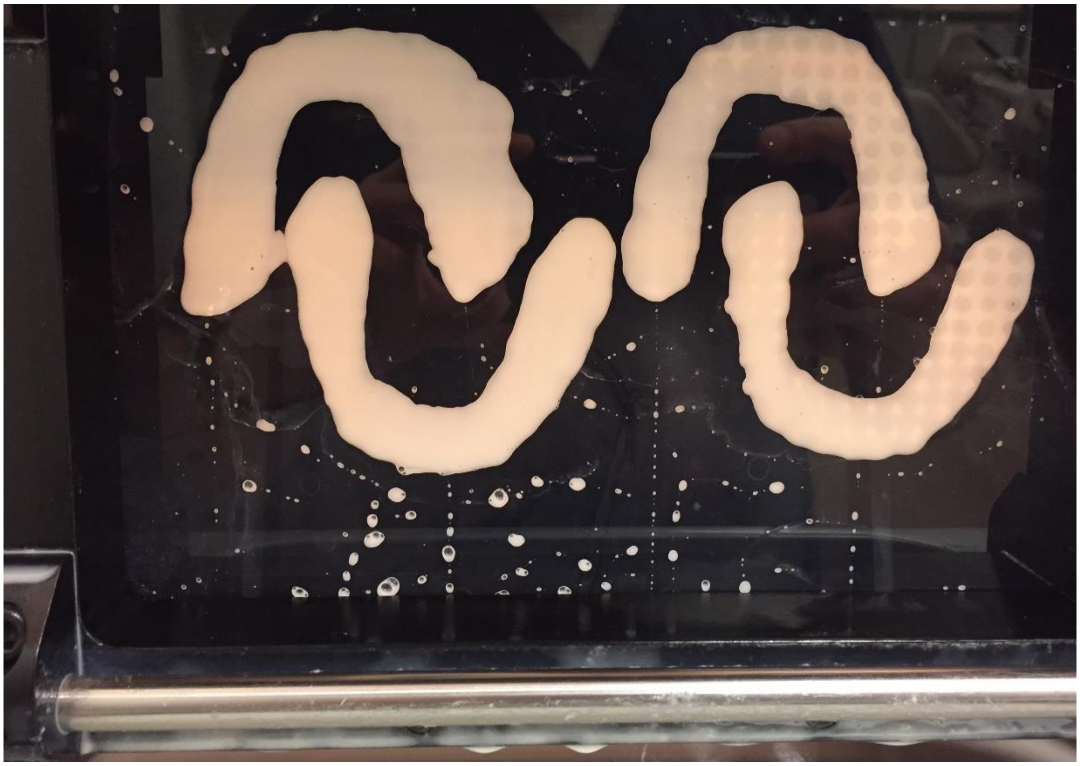


Figure 5-1: Models attached to Teflon sheet instead of build platform

A second common problem is warping of the model. When warpage occurred, part of the model would not stick to the build platform and would become lifted, or curled up away from the build platform. The exact cause of this problem is unclear, but it is believed to follow a similar mechanism to the previously described problem with sticking to the Teflon sheet. One potential explanation could be uneven conditioning of the build platform. If one side is well conditioned, the well-conditioned side would build properly, while the side that is poorly conditioned would curl away from the build platform. There could also be a buildup of residue on the build platform as a result of multiple build cycles. It was found that periodically washing the build platform with 100% acetone for 5 minutes, and then rinsing with 70% isopropyl alcohol for 5 minutes would clean the platform of resin residue and reduce the likelihood of build failures. A third possibility is how tightly the build platform is secured. The build platform is held down by three screws. The screws are meant to be loosened about one-quarter to one-half turn to allow

removal of the build plate for retrieval of fabricated models. To prepare for the next build, the platform is secured down by tightening the three screws. It was noted that over the course of using the machine, partially cured resin had built up around the screws and was impeding adequate tightening of the screws. A possible explanation for model warpage could be that as the Teflon sheet pulled away from the models, the build platform was slightly lifted as well, causing the model to curl. To correct this problem, the arms that secure the build platform were lowered into 100% acetone in order to soften and remove the uncured resin. A tap drill was used to clear the screw threads, and a new set of screws were placed. Once the screws, build platform conditioning, and build platform position were corrected, model warpage was no longer an issue.

Figure 5-2 Model warpage on left side

When a 3-dimensional digital model is imported into the Juell 3-D software, the software virtually "slices" the object in layers of a predetermined thickness, which in this study was set at 50 microns. Another challenge that was faced was that in some instances, layers appeared to not properly stick together. Troubleshooting attempts were unsuccessful as this was not a hardware issue, and was not related to the build platform, Teflon sheet position, or projector intensity and length of cure. It was discovered that this was a software malfunction, and certain layers were being omitted or completely or partially by the software which lead to the subsequent layer not

attaching to the previous layer. The manufacturer was able to correct this issue with a software update.

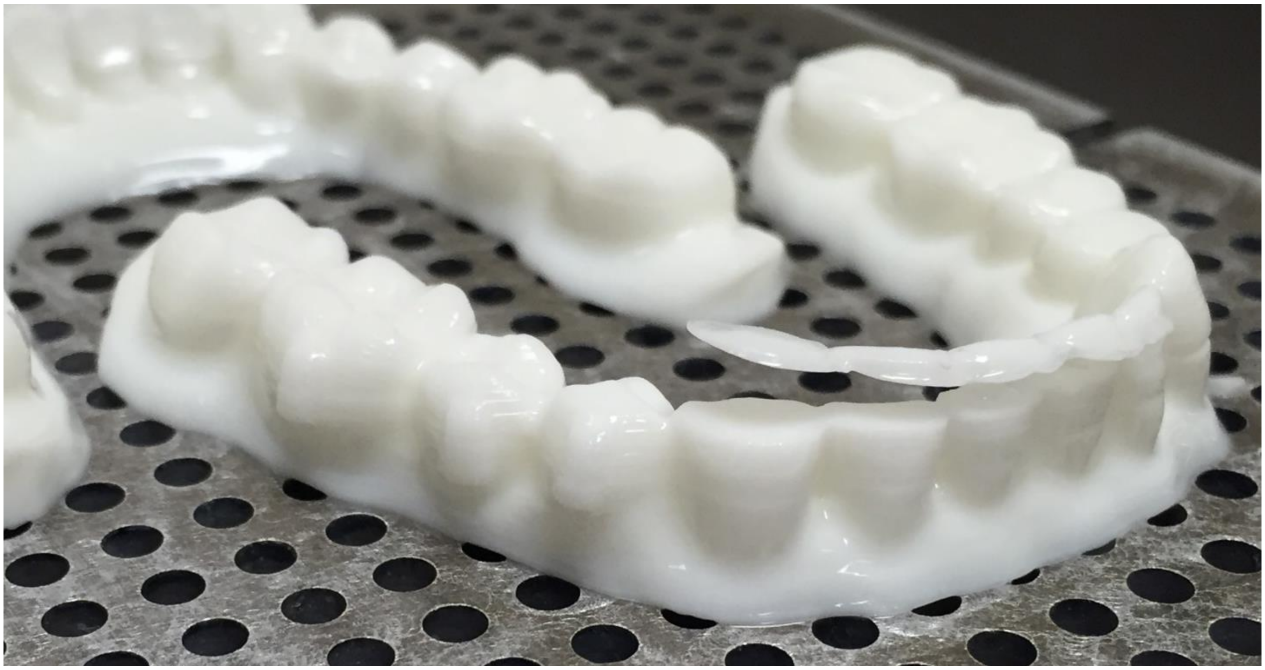


Figure 5-3 Omitted layer from object slicing error

Despite all the complications experienced during the course of the initial builds, the final 60 models were consecutively successfully fabricated without difficulties. This can be attributed to both operator experience and improvements made through hardware and software updates by the manufacturer of the Juell 3D printer. Accuracy of each model was confirmed by measuring inter-canine width, inter-molar width, arch length, and vertical height of central incisors, first premolars and first molars. These measurements were chosen rather than performing a Bolton analysis because longer measurement spans reduce chance of error and bias compared to multiple short span measurements. All models were found to be accurate replicas of the original stone model.

When it comes to clear aligner therapy, the phase with the greatest variability is the thermoforming step. This phase is affected by many factors including how models are prepared,

type of material used and machinery used to thermoform the plastic sheet to the model. In this study, Zendura was the material of choice due to its superior properties as described in Chapter 3. Zendura is high grade medical plastic and exhibits qualities of high strength and high toughness. The stress retention of the material allows it to maintain its shape after conforming to a malocclusion and the strength and toughness withstand the harsh intraoral environment to keep pressure on teeth for movement. The disadvantage of polyurethane polymers is that they tend to absorb moisture, which is why Zendura is supplied individually wrapped in a moisture-barrier bag. It is recommended that a Zendura appliance be fabricate immediately upon opening the moisture-barrier bag or at most 15 minutes after to avoid altering its properties due to moisture absorption.

It is important to note that not all polymers are the same and the mechanical properties of a thermoformed appliance are dependent on many factors and must be selected on the basis of intended use, processing history and conditions of use. Moisture absorption is not unique to Zendura, as all polymer materials will absorb moisture and as a result, undergo hygroscopic expansion (Ryokawa, 2006). This is especially problematic in an intraoral environment, where humidity and moisture levels are high. Hygroscopic expansion may affect the fit and force delivery of an appliance, and ultimately affect the amount of tooth movement achieved. Ryokawa found that although polyurethane materials have high levels of moisture absorption, they also have very low levels of expansion and are highly resilient materials, making them the polymer of choice for orthodontic tooth movement using clear aligners.

After the appropriate material is selected, model preparation and type of thermoforming machinery must be considered. It is recommended to have a model height of about 20mm (Del Rossi 2007). This is because force delivery of a clear aligner is affected by aligner thickness

(Kohda, 2013). Although thermoformed appliances undergo thinning during the fabrication process, it was found that this model height produced aligners with the most consistent thicknesses throughout the appliance (Del Rossi, 2007). The makers of Zendura recommended having a model height no greater than 25mm for fabrication of the optimal aligner (Zendura Pressure Fabrication Instructions, 2016).

Machinery currently used for fabrication of thermoplastic dental appliances include vacuum formers and pressure formers. Vacuum forming machines will typically produce a pressure of about 1 bar (14.5psi), smaller in-office units typically provide 3 bar (43.5psi) while commercial thermoformers can reach a pressure of 6 bar (87psi). Pressure formers are able to provide an appliance that is better adapted to the model (Hahn, 2009) and the makers of Zendura recommend fabricating aligners with a positive-pressure thermoforming machine that can achieve 3 bar (Zendura Pressure Fabrication Instructions, 2016). The current study utilized a ministar S (Great Lakes Orthodontic Products, Tonawanda NY) pressure forming machine, which is capable of producing positive pressure of 3 bar.

Although generalizations can be made for clear aligner treatment overall, the utility of the results of this study are limited to an in-office clear aligner solution using the materials and methods described in chapter 3. Commercial clear aligner companies use different protocols which would affect the overall efficacy of their products. For example commercial pressure thermoforming machines provide positive pressure that is double what was attained in this study. The increased pressure would theoretically produce a better fitting appliance which may in turn produce more effective tooth movement (Hanh, 2009). Additionally, controlled lab environments would minimize the effects of temperature and humidity on thermoplastic material used. Lastly, the Zendura material used for the current study is also used by the second largest

clear aligner company, ClearCorrect. However, the aligners produced by ClearCorrect undergo an additional processing step of annealing. This annealing step puts the aligner through cycles of controlled heating and cooling which ultimately produces an aligner that is stronger and more resistant to cracking and warping (Bay Materials Services, 2016). The annealing of Zendura alters the mechanical properties and efficacy of tooth movement using the aligner material.

Hypothesis Evaluation

Three research questions were evaluated by this study.

1. Does the use of resin bonded attachments improve rotational control of conical teeth?

   Hypothesis:

   The use of resin bonded attachments will improve rotational control of conical teeth.

The hypothesis for question 1 was rejected for all 5 groups with attachments. Statistical analysis revealed that there were no statistically significant differences between the groups with attachments, compared to the group with no attachments. However, observable differences were present. Groups 5, 6 and 7, which had attachments placed only on rotated tooth #29 had on average 3° more total rotational correction than the no attachment group 1, with the single buccal-only attachment group 5 performing the best with 4.31°.

2. Does placing attachments on teeth adjacent to a rotated tooth improve rotational control of a conical tooth?

   Hypothesis:

   Placing attachments on teeth adjacent to the rotated tooth will improve rotational control of a conical tooth.

The hypothesis for question 2 was rejected for the 2 groups (groups 8 and 9) with attachments on teeth #28 and #30 in addition to #29. Statistical analysis revealed that there was no statistically significant difference between groups 8 and 9 as compared to the no-attachment group 1. Again, observable differences were present, with groups 8 and 9 having on average 5.6° less rotational correction than the no attachment group. One of the theories behind placing attachments on teeth #28 and #30 was to use the adjacent as buttresses and attempt increasing the force delivered to tooth #29. It was also theorized that during the thermoforming process, thermoplastic material would flow between the attachments, thus increasing material thickness in the area of tooth #29, which would then theoretically increase force delivery in that target area. In this study, it appeared that multiple attachments impeded the intended movement.

3. Does adjusting clear aligners using the Hu-Friedy Vertical Clear Aligner adjustment plier improve rotational control of conical teeth?

    Hypothesis:

    Adjusting clear aligners using the Hu-Friedy Vertical Clear Aligner adjustment plier will improve rotational control of conical teeth.

The hypothesis for question 3 was rejected for all 3 groups for which the thermoform adjusting pliers were used. The difference between the 3 groups was the location of adjustment made. Group 2 had one adjustment made on the buccal side, group 3 on the lingual, and group 4 attempted to create a force couple by adjusting buccally and lingually. Adjustments were made to provide additional force in the direction of rotation correction. Statistical analysis revealed that there was no statistically significant difference between Group 2 with the no adjustment Group 1, however there was 2.47° less rotation correction with Group 2. There were statistically significant differences when comparing Group 1 to Groups 3 and 4. Both groups 3 and 4

exhibited rotations in direction opposite to the intended direction. This finding could be due to the clinical crown height and convexity. The thermoform adjusting plier used places a 3mm vertical rectangular indentation in the aligner. This indentation is perceived to provide a pressure point against the tooth to provide additional force in the intended direction of movement. In all 3 groups intrusion was observed. It appeared that perhaps the shape and size of the indentation compared to the shape and size of the clinical crown provided an obstacle for the tooth that impeded full seating of the aligner. As a result, apical pressure was applied to the tooth leading to intrusion. On the lingual side, the intrusion was more pronounced and produced a counter moment which rotated the tooth in a direction opposite to that which was intended.

Figure 5-4: Indentation placed by Hu-Friedy vertical rectangular thermoform adjusting plier

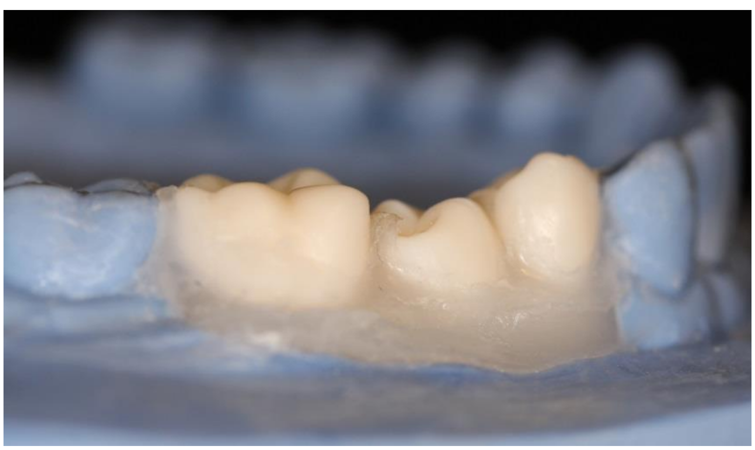


Figure 5-5: Intrusive effect on tooth #29 due to buccal and lingual adjustments made using Hu-Friedy vertical rectangular thermoform adjusting plier

Limitations and Suggestions for Future Research

Clear aligner research has numerous variables and limitations. One consideration is operator error since the same operator carries out each phase of this study from scanning, treatment planning, rapid prototyping, aligner fabrication/trimming, and measuring results using Geomagic Design. However, for this study, the greatest limitation is that it is an in-vitro model. The model utilized typodont teeth embedded in wax, which would lead to results different than that expected in-vivo, where biological factors such as the presence of the periodontal ligament would be a factor. Additionally, a wax model is unable to account for the effects of saliva, occlusal forces, and intraoral wearing on the aligner.

Another major limitation is related to materials and the thermoforming process. Thermoplastic materials are affected by factors such as temperature and humidity. Depending on the current environmental conditions, there could be differences in the mechanical properties of the appliances fabricated. Additionally the thermoforming machine and the pressure used to fabricate aligners will have an impact on results achieved with aligners. There can be variability in the same machine, as the heating element may not heat each sheet of aligner consistently at the same exact temperature. Slight differences in how polymer sheets are formed into aligners can affect their thickness and force delivery to the dentition.

The primary goal of this study was to evaluate of the efficacy of attachments to correct rotation of a mandibular premolar, one the most difficult movements to achieve using clear aligners. The study utilized vertical rectangular attachments, and the Hu-Friedy vertical adjustment plier. Increasing treatment efficiency would benefit clinicians and patients and the clear aligner industry by reducing tooth lag, reducing the need for mid-course correction, and decreasing the time and number of aligners needed for the refinement phase. Further research is

necessary to evaluate different attachment shapes and designs and if they can improve efficacy of tooth movement. Further research is also necessary to evaluate and compare different materials and different thermoforming techniques and their effects on the force delivery properties of aligners. Lastly, different thermoforming adjusting plier shapes can be tested, it is possible that if the size of the indentation produced by the Hu-Friedy vertical adjustment plier was smaller, it may have been more effective.

Conclusions

Analysis of the results of this study yields the following two conclusions. One is that the Hu-Friedy vertical adjusting plier does not significantly improve rotational control of a lower premolar. On the contrary, all of the three groups adjusted with the vertical rectangular plier had the adverse effect of intrusion. Two of those groups also had the unfavorable effect of further rotation as opposed to de-rotation.

The second conclusion is that presence and number of attachments was not significantly more effective than having no attachments. This is in agreement with conclusions by Kravitz, et al, in 2008, and again with Simon, et al, in 2014. Attachments are commonly thought to be analogous to traditional brackets, however clear aligner treatment has a force delivery and tooth movement mechanism that although is not fully understood, and is uniquely different from traditional fixed appliance treatment. It appears from this study that increasing the number of attachments would impede rotational correction, and the two groups (Groups 8 and 9) with the most attachments had the smallest degree of rotational correction of the 5 attachment groups. One possible explanation is that this finding could be attributed to the thermoforming process. Thermoforming with multiple attachments will lead to more thinning of the plastic. In addition, in this study it appeared that the fit of the aligner was reduced when multiple attachments were

present. This is thought to happen because the plastic aligner is meant to flex and conform to a malocclusion, and bring teeth into alignment by resisting deformation and returning to its original shape. The presence of multiple attachments in the same quadrant could make it more difficult for the aligner to stretch and conform to the teeth in that quadrant. It would follow that inadequacies in aligner seating and engagement of attachments would lead to inefficiencies in tooth movement. One study reported similar findings, theorizing that with an aligner that does not fit ideally, attachments could not only decrease force delivery, but in some instances can cause counter-moments and cause movements in the opposite direction (Simon, 2014). It is important for clinicians to use attachments judiciously, taking each patient's unique conditions and circumstances into careful consideration.

Appendix A: Statistical Analysis Tables

Oneway

Descriptives

Angle

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum
					Lower Bound	Upper Bound	
1.00	10	1.7950	.17135	.05419	1.6724	1.9176	1.60
2.00	10	1.5490	.44288	.14005	1.2322	1.8658	.92
3.00	10	-.5060	.72325	.22871	-1.0234	.0114	-1.39
4.00	10	-4.4000	3.20198	1.01256	-6.6906	-2.1094	-10.77
5.00	10	2.2260	.25154	.07954	2.0461	2.4059	1.92
6.00	10	2.0860	.60113	.19009	1.6560	2.5160	.87
7.00	10	2.0030	.49659	.15704	1.6478	2.3582	1.16
8.00	10	1.6370	.67521	.21352	1.1540	2.1200	.47
9.00	10	.8350	.17180	.05433	.7121	.9579	.57
Total	90	.8028	2.29985	.24243	.3211	1.2845	-10.77

Descriptives

Angle

	Maximum
1.00	2.08
2.00	2.40
3.00	.93
4.00	-1.28
5.00	2.67
6.00	2.66
7.00	2.83
8.00	2.42
9.00	1.03
Total	2.83

Test of Homogeneity of Variances

Angle

Levene Statistic	df1	df2	Sig.
12.558	8	81	.000

ANOVA

Angle

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	361.329	8	45.166	33.434	.000
Within Groups	109.422	81	1.351		
Total	470.750	89			

Robust Tests of Equality of Means

Angle

	Statistic[a]	df1	df2	Sig.
Welch	43.134	8	33.047	.000
Brown-Forsythe	33.434	8	12.570	.000

a. Asymptotically F distributed.

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Angle

Tukey HSD

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	.24600	.51979	1.000	-1.4107	1.9027
	3.00	2.30100*	.51979	.001	.6443	3.9577
	4.00	6.19500*	.51979	.000	4.5383	7.8517
	5.00	-.43100	.51979	.996	-2.0877	1.2257
	6.00	-.29100	.51979	1.000	-1.9477	1.3657
	7.00	-.20800	.51979	1.000	-1.8647	1.4487
	8.00	.15800	.51979	1.000	-1.4987	1.8147
	9.00	.96000	.51979	.651	-.6967	2.6167
2.00	1.00	-.24600	.51979	1.000	-1.9027	1.4107
	3.00	2.05500*	.51979	.005	.3983	3.7117
	4.00	5.94900*	.51979	.000	4.2923	7.6057
	5.00	-.67700	.51979	.928	-2.3337	.9797
	6.00	-.53700	.51979	.981	-2.1937	1.1197
	7.00	-.45400	.51979	.994	-2.1107	1.2027
	8.00	-.08800	.51979	1.000	-1.7447	1.5687
	9.00	.71400	.51979	.904	-.9427	2.3707
3.00	1.00	-2.30100*	.51979	.001	-3.9577	-.6443
	2.00	-2.05500*	.51979	.005	-3.7117	-.3983
	4.00	3.89400*	.51979	.000	2.2373	5.5507
	5.00	-2.73200*	.51979	.000	-4.3887	-1.0753
	6.00	-2.59200*	.51979	.000	-4.2487	-.9353
	7.00	-2.50900*	.51979	.000	-4.1657	-.8523
	8.00	-2.14300*	.51979	.003	-3.7997	-.4863
	9.00	-1.34100	.51979	.211	-2.9977	.3157
4.00	1.00	-6.19500*	.51979	.000	-7.8517	-4.5383
	2.00	-5.94900*	.51979	.000	-7.6057	-4.2923
	3.00	-3.89400*	.51979	.000	-5.5507	-2.2373
	5.00	-6.62600*	.51979	.000	-8.2827	-4.9693
	6.00	-6.48600*	.51979	.000	-8.1427	-4.8293
	7.00	-6.40300*	.51979	.000	-8.0597	-4.7463

	8.00	-6.03700*	.51979	.000	-7.6937	-4.3803
	9.00	-5.23500*	.51979	.000	-6.8917	-3.5783
5.00	1.00	.43100	.51979	.996	-1.2257	2.0877
	2.00	.67700	.51979	.928	-.9797	2.3337
	3.00	2.73200*	.51979	.000	1.0753	4.3887
	4.00	6.62600*	.51979	.000	4.9693	8.2827
	6.00	.14000	.51979	1.000	-1.5167	1.7967
	7.00	.22300	.51979	1.000	-1.4337	1.8797
	8.00	.58900	.51979	.967	-1.0677	2.2457
	9.00	1.39100	.51979	.173	-.2657	3.0477
6.00	1.00	.29100	.51979	1.000	-1.3657	1.9477
	2.00	.53700	.51979	.981	-1.1197	2.1937
	3.00	2.59200*	.51979	.000	.9353	4.2487
	4.00	6.48600*	.51979	.000	4.8293	8.1427
	5.00	-.14000	.51979	1.000	-1.7967	1.5167
	7.00	.08300	.51979	1.000	-1.5737	1.7397
	8.00	.44900	.51979	.994	-1.2077	2.1057
	9.00	1.25100	.51979	.295	-.4057	2.9077
7.00	1.00	.20800	.51979	1.000	-1.4487	1.8647
	2.00	.45400	.51979	.994	-1.2027	2.1107
	3.00	2.50900*	.51979	.000	.8523	4.1657
	4.00	6.40300*	.51979	.000	4.7463	8.0597
	5.00	-.22300	.51979	1.000	-1.8797	1.4337
	6.00	-.08300	.51979	1.000	-1.7397	1.5737
	8.00	.36600	.51979	.999	-1.2907	2.0227
	9.00	1.16800	.51979	.386	-.4887	2.8247
8.00	1.00	-.15800	.51979	1.000	-1.8147	1.4987
	2.00	.08800	.51979	1.000	-1.5687	1.7447
	3.00	2.14300*	.51979	.003	.4863	3.7997
	4.00	6.03700*	.51979	.000	4.3803	7.6937
	5.00	-.58900	.51979	.967	-2.2457	1.0677
	6.00	-.44900	.51979	.994	-2.1057	1.2077
	7.00	-.36600	.51979	.999	-2.0227	1.2907
	9.00	.80200	.51979	.832	-.8547	2.4587
9.00	1.00	-.96000	.51979	.651	-2.6167	.6967
	2.00	-.71400	.51979	.904	-2.3707	.9427
	3.00	1.34100	.51979	.211	-.3157	2.9977

4.00	5.23500*	.51979	.000	3.5783	6.8917
5.00	-1.39100	.51979	.173	-3.0477	.2657
6.00	-1.25100	.51979	.295	-2.9077	.4057
7.00	-1.16800	.51979	.386	-2.8247	.4887
8.00	-.80200	.51979	.832	-2.4587	.8547

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

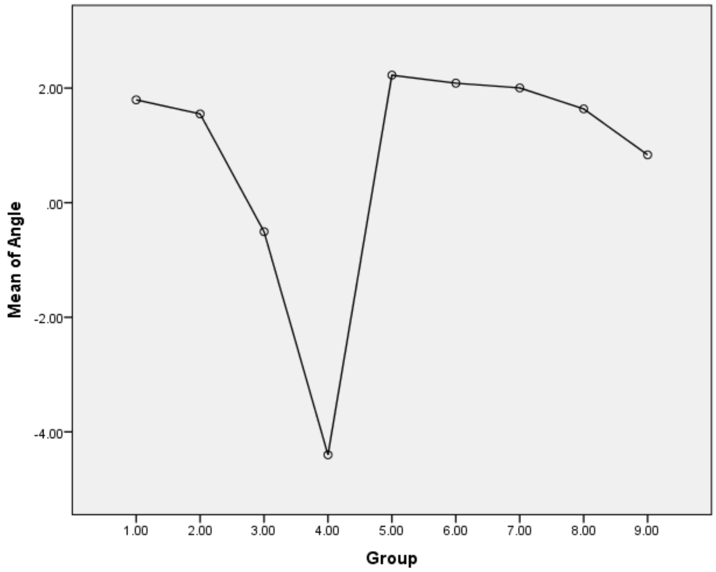
Angle

Tukey HSD[a]

Group	N	Subset for alpha = 0.05		
		1	2	3
4.00	10	-4.4000		
3.00	10		-.5060	
9.00	10		.8350	.8350
2.00	10			1.5490
8.00	10			1.6370
1.00	10			1.7950
7.00	10			2.0030
6.00	10			2.0860
5.00	10			2.2260
Sig.		1.000	.211	.173

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 10.000.

Means Plots



Oneway

Descriptives

Angle

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum
					Lower Bound	Upper Bound	
1.00	10	1.7950	.17135	.05419	1.6724	1.9176	1.60
2.00	10	1.5490	.44288	.14005	1.2322	1.8658	.92
3.00	10	-.5060	.72325	.22871	-1.0234	.0114	-1.39
4.00	10	-4.4000	3.20198	1.01256	-6.6906	-2.1094	-10.77
5.00	10	2.2260	.25154	.07954	2.0461	2.4059	1.92
6.00	10	2.0860	.60113	.19009	1.6560	2.5160	.87
7.00	10	2.0030	.49659	.15704	1.6478	2.3582	1.16
8.00	10	1.6370	.67521	.21352	1.1540	2.1200	.47
9.00	10	.8350	.17180	.05433	.7121	.9579	.57
Total	90	.8028	2.29985	.24243	.3211	1.2845	-10.77

Descriptives

Angle

	Maximum
1.00	2.08
2.00	2.40
3.00	.93
4.00	-1.28
5.00	2.67
6.00	2.66
7.00	2.83
8.00	2.42
9.00	1.03
Total	2.83

ANOVA

Angle

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	361.329	8	45.166	33.434	.000
Within Groups	109.422	81	1.351		
Total	470.750	89			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: Angle

	(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	1.00	2.00	.24600	.51979	1.000	-1.4107	1.9027
		3.00	2.30100*	.51979	.001	.6443	3.9577
		4.00	6.19500*	.51979	.000	4.5383	7.8517
		5.00	-.43100	.51979	.996	-2.0877	1.2257
		6.00	-.29100	.51979	1.000	-1.9477	1.3657
		7.00	-.20800	.51979	1.000	-1.8647	1.4487
		8.00	.15800	.51979	1.000	-1.4987	1.8147
		9.00	.96000	.51979	.651	-.6967	2.6167
	2.00	1.00	-.24600	.51979	1.000	-1.9027	1.4107
		3.00	2.05500*	.51979	.005	.3983	3.7117
		4.00	5.94900*	.51979	.000	4.2923	7.6057
		5.00	-.67700	.51979	.928	-2.3337	.9797
		6.00	-.53700	.51979	.981	-2.1937	1.1197
		7.00	-.45400	.51979	.994	-2.1107	1.2027
		8.00	-.08800	.51979	1.000	-1.7447	1.5687
		9.00	.71400	.51979	.904	-.9427	2.3707
	3.00	1.00	-2.30100*	.51979	.001	-3.9577	-.6443
		2.00	-2.05500*	.51979	.005	-3.7117	-.3983
		4.00	3.89400*	.51979	.000	2.2373	5.5507
		5.00	-2.73200*	.51979	.000	-4.3887	-1.0753
		6.00	-2.59200*	.51979	.000	-4.2487	-.9353
		7.00	-2.50900*	.51979	.000	-4.1657	-.8523
		8.00	-2.14300*	.51979	.003	-3.7997	-.4863
		9.00	-1.34100	.51979	.211	-2.9977	.3157
	4.00	1.00	-6.19500*	.51979	.000	-7.8517	-4.5383
		2.00	-5.94900*	.51979	.000	-7.6057	-4.2923
		3.00	-3.89400*	.51979	.000	-5.5507	-2.2373
		5.00	-6.62600*	.51979	.000	-8.2827	-4.9693
		6.00	-6.48600*	.51979	.000	-8.1427	-4.8293
		7.00	-6.40300*	.51979	.000	-8.0597	-4.7463

	8.00	-6.03700*	.51979	.000	-7.6937	-4.3803
	9.00	-5.23500*	.51979	.000	-6.8917	-3.5783
5.00	1.00	.43100	.51979	.996	-1.2257	2.0877
	2.00	.67700	.51979	.928	-.9797	2.3337
	3.00	2.73200*	.51979	.000	1.0753	4.3887
	4.00	6.62600*	.51979	.000	4.9693	8.2827
	6.00	.14000	.51979	1.000	-1.5167	1.7967
	7.00	.22300	.51979	1.000	-1.4337	1.8797
	8.00	.58900	.51979	.967	-1.0677	2.2457
	9.00	1.39100	.51979	.173	-.2657	3.0477
6.00	1.00	.29100	.51979	1.000	-1.3657	1.9477
	2.00	.53700	.51979	.981	-1.1197	2.1937
	3.00	2.59200*	.51979	.000	.9353	4.2487
	4.00	6.48600*	.51979	.000	4.8293	8.1427
	5.00	-.14000	.51979	1.000	-1.7967	1.5167
	7.00	.08300	.51979	1.000	-1.5737	1.7397
	8.00	.44900	.51979	.994	-1.2077	2.1057
	9.00	1.25100	.51979	.295	-.4057	2.9077
7.00	1.00	.20800	.51979	1.000	-1.4487	1.8647
	2.00	.45400	.51979	.994	-1.2027	2.1107
	3.00	2.50900*	.51979	.000	.8523	4.1657
	4.00	6.40300*	.51979	.000	4.7463	8.0597
	5.00	-.22300	.51979	1.000	-1.8797	1.4337
	6.00	-.08300	.51979	1.000	-1.7397	1.5737
	8.00	.36600	.51979	.999	-1.2907	2.0227
	9.00	1.16800	.51979	.386	-.4887	2.8247
8.00	1.00	-.15800	.51979	1.000	-1.8147	1.4987
	2.00	.08800	.51979	1.000	-1.5687	1.7447
	3.00	2.14300*	.51979	.003	.4863	3.7997
	4.00	6.03700*	.51979	.000	4.3803	7.6937
	5.00	-.58900	.51979	.967	-2.2457	1.0677
	6.00	-.44900	.51979	.994	-2.1057	1.2077
	7.00	-.36600	.51979	.999	-2.0227	1.2907
	9.00	.80200	.51979	.832	-.8547	2.4587
9.00	1.00	-.96000	.51979	.651	-2.6167	.6967

		2.00	-.71400	.51979	.904	-2.3707	.9427
		3.00	1.34100	.51979	.211	-.3157	2.9977
		4.00	5.23500*	.51979	.000	3.5783	6.8917
		5.00	-1.39100	.51979	.173	-3.0477	.2657
		6.00	-1.25100	.51979	.295	-2.9077	.4057
		7.00	-1.16800	.51979	.386	-2.8247	.4887
		8.00	-.80200	.51979	.832	-2.4587	.8547
LSD	1.00	2.00	.24600	.51979	.637	-.7882	1.2802
		3.00	2.30100*	.51979	.000	1.2668	3.3352
		4.00	6.19500*	.51979	.000	5.1608	7.2292
		5.00	-.43100	.51979	.409	-1.4652	.6032
		6.00	-.29100	.51979	.577	-1.3252	.7432
		7.00	-.20800	.51979	.690	-1.2422	.8262
		8.00	.15800	.51979	.762	-.8762	1.1922
		9.00	.96000	.51979	.068	-.0742	1.9942
	2.00	1.00	-.24600	.51979	.637	-1.2802	.7882
		3.00	2.05500*	.51979	.000	1.0208	3.0892
		4.00	5.94900*	.51979	.000	4.9148	6.9832
		5.00	-.67700	.51979	.196	-1.7112	.3572
		6.00	-.53700	.51979	.305	-1.5712	.4972
		7.00	-.45400	.51979	.385	-1.4882	.5802
		8.00	-.08800	.51979	.866	-1.1222	.9462
		9.00	.71400	.51979	.173	-.3202	1.7482
	3.00	1.00	-2.30100*	.51979	.000	-3.3352	-1.2668
		2.00	-2.05500*	.51979	.000	-3.0892	-1.0208
		4.00	3.89400*	.51979	.000	2.8598	4.9282
		5.00	-2.73200*	.51979	.000	-3.7662	-1.6978
		6.00	-2.59200*	.51979	.000	-3.6262	-1.5578
		7.00	-2.50900*	.51979	.000	-3.5432	-1.4748
		8.00	-2.14300*	.51979	.000	-3.1772	-1.1088
		9.00	-1.34100*	.51979	.012	-2.3752	-.3068
	4.00	1.00	-6.19500*	.51979	.000	-7.2292	-5.1608
		2.00	-5.94900*	.51979	.000	-6.9832	-4.9148
		3.00	-3.89400*	.51979	.000	-4.9282	-2.8598
		5.00	-6.62600*	.51979	.000	-7.6602	-5.5918
		6.00	-6.48600*	.51979	.000	-7.5202	-5.4518
		7.00	-6.40300*	.51979	.000	-7.4372	-5.3688

		8.00	-6.03700*	.51979	.000	-7.0712	-5.0028
		9.00	-5.23500*	.51979	.000	-6.2692	-4.2008
	5.00	1.00	.43100	.51979	.409	-.6032	1.4652
		2.00	.67700	.51979	.196	-.3572	1.7112
		3.00	2.73200*	.51979	.000	1.6978	3.7662
		4.00	6.62600*	.51979	.000	5.5918	7.6602
		6.00	.14000	.51979	.788	-.8942	1.1742
		7.00	.22300	.51979	.669	-.8112	1.2572
		8.00	.58900	.51979	.260	-.4452	1.6232
		9.00	1.39100*	.51979	.009	.3568	2.4252
	6.00	1.00	.29100	.51979	.577	-.7432	1.3252
		2.00	.53700	.51979	.305	-.4972	1.5712
		3.00	2.59200*	.51979	.000	1.5578	3.6262
		4.00	6.48600*	.51979	.000	5.4518	7.5202
		5.00	-.14000	.51979	.788	-1.1742	.8942
		7.00	.08300	.51979	.874	-.9512	1.1172
		8.00	.44900	.51979	.390	-.5852	1.4832
		9.00	1.25100*	.51979	.018	.2168	2.2852
	7.00	1.00	.20800	.51979	.690	-.8262	1.2422
		2.00	.45400	.51979	.385	-.5802	1.4882
		3.00	2.50900*	.51979	.000	1.4748	3.5432
		4.00	6.40300*	.51979	.000	5.3688	7.4372
		5.00	-.22300	.51979	.669	-1.2572	.8112
		6.00	-.08300	.51979	.874	-1.1172	.9512
		8.00	.36600	.51979	.483	-.6682	1.4002
		9.00	1.16800*	.51979	.027	.1338	2.2022
	8.00	1.00	-.15800	.51979	.762	-1.1922	.8762
		2.00	.08800	.51979	.866	-.9462	1.1222
		3.00	2.14300*	.51979	.000	1.1088	3.1772
		4.00	6.03700*	.51979	.000	5.0028	7.0712
		5.00	-.58900	.51979	.260	-1.6232	.4452
		6.00	-.44900	.51979	.390	-1.4832	.5852
		7.00	-.36600	.51979	.483	-1.4002	.6682
		9.00	.80200	.51979	.127	-.2322	1.8362
	9.00	1.00	-.96000	.51979	.068	-1.9942	.0742
		2.00	-.71400	.51979	.173	-1.7482	.3202
		3.00	1.34100*	.51979	.012	.3068	2.3752

		4.00	5.23500*	.51979	.000	4.2008	6.2692
		5.00	-1.39100*	.51979	.009	-2.4252	-.3568
		6.00	-1.25100*	.51979	.018	-2.2852	-.2168
		7.00	-1.16800*	.51979	.027	-2.2022	-.1338
		8.00	-.80200	.51979	.127	-1.8362	.2322
Bonferroni	1.00	2.00	.24600	.51979	1.000	-1.4751	1.9671
		3.00	2.30100*	.51979	.001	.5799	4.0221
		4.00	6.19500*	.51979	.000	4.4739	7.9161
		5.00	-.43100	.51979	1.000	-2.1521	1.2901
		6.00	-.29100	.51979	1.000	-2.0121	1.4301
		7.00	-.20800	.51979	1.000	-1.9291	1.5131
		8.00	.15800	.51979	1.000	-1.5631	1.8791
		9.00	.96000	.51979	1.000	-.7611	2.6811
	2.00	1.00	-.24600	.51979	1.000	-1.9671	1.4751
		3.00	2.05500*	.51979	.006	.3339	3.7761
		4.00	5.94900*	.51979	.000	4.2279	7.6701
		5.00	-.67700	.51979	1.000	-2.3981	1.0441
		6.00	-.53700	.51979	1.000	-2.2581	1.1841
		7.00	-.45400	.51979	1.000	-2.1751	1.2671
		8.00	-.08800	.51979	1.000	-1.8091	1.6331
		9.00	.71400	.51979	1.000	-1.0071	2.4351
	3.00	1.00	-2.30100*	.51979	.001	-4.0221	-.5799
		2.00	-2.05500*	.51979	.006	-3.7761	-.3339
		4.00	3.89400*	.51979	.000	2.1729	5.6151
		5.00	-2.73200*	.51979	.000	-4.4531	-1.0109
		6.00	-2.59200*	.51979	.000	-4.3131	-.8709
		7.00	-2.50900*	.51979	.000	-4.2301	-.7879
		8.00	-2.14300*	.51979	.003	-3.8641	-.4219
		9.00	-1.34100	.51979	.421	-3.0621	.3801
	4.00	1.00	-6.19500*	.51979	.000	-7.9161	-4.4739
		2.00	-5.94900*	.51979	.000	-7.6701	-4.2279
		3.00	-3.89400*	.51979	.000	-5.6151	-2.1729
		5.00	-6.62600*	.51979	.000	-8.3471	-4.9049
		6.00	-6.48600*	.51979	.000	-8.2071	-4.7649
		7.00	-6.40300*	.51979	.000	-8.1241	-4.6819

	8.00	-6.03700*	.51979	.000	-7.7581	-4.3159
	9.00	-5.23500*	.51979	.000	-6.9561	-3.5139
5.00	1.00	.43100	.51979	1.000	-1.2901	2.1521
	2.00	.67700	.51979	1.000	-1.0441	2.3981
	3.00	2.73200*	.51979	.000	1.0109	4.4531
	4.00	6.62600*	.51979	.000	4.9049	8.3471
	6.00	.14000	.51979	1.000	-1.5811	1.8611
	7.00	.22300	.51979	1.000	-1.4981	1.9441
	8.00	.58900	.51979	1.000	-1.1321	2.3101
	9.00	1.39100	.51979	.324	-.3301	3.1121
6.00	1.00	.29100	.51979	1.000	-1.4301	2.0121
	2.00	.53700	.51979	1.000	-1.1841	2.2581
	3.00	2.59200*	.51979	.000	.8709	4.3131
	4.00	6.48600*	.51979	.000	4.7649	8.2071
	5.00	-.14000	.51979	1.000	-1.8611	1.5811
	7.00	.08300	.51979	1.000	-1.6381	1.8041
	8.00	.44900	.51979	1.000	-1.2721	2.1701
	9.00	1.25100	.51979	.661	-.4701	2.9721
7.00	1.00	.20800	.51979	1.000	-1.5131	1.9291
	2.00	.45400	.51979	1.000	-1.2671	2.1751
	3.00	2.50900*	.51979	.000	.7879	4.2301
	4.00	6.40300*	.51979	.000	4.6819	8.1241
	5.00	-.22300	.51979	1.000	-1.9441	1.4981
	6.00	-.08300	.51979	1.000	-1.8041	1.6381
	8.00	.36600	.51979	1.000	-1.3551	2.0871
	9.00	1.16800	.51979	.985	-.5531	2.8891
8.00	1.00	-.15800	.51979	1.000	-1.8791	1.5631
	2.00	.08800	.51979	1.000	-1.6331	1.8091
	3.00	2.14300*	.51979	.003	.4219	3.8641
	4.00	6.03700*	.51979	.000	4.3159	7.7581
	5.00	-.58900	.51979	1.000	-2.3101	1.1321
	6.00	-.44900	.51979	1.000	-2.1701	1.2721
	7.00	-.36600	.51979	1.000	-2.0871	1.3551
	9.00	.80200	.51979	1.000	-.9191	2.5231
9.00	1.00	-.96000	.51979	1.000	-2.6811	.7611

	2.00	-.71400	.51979	1.000	-2.4351	1.0071
	3.00	1.34100	.51979	.421	-.3801	3.0621
	4.00	5.23500*	.51979	.000	3.5139	6.9561
	5.00	-1.39100	.51979	.324	-3.1121	.3301
	6.00	-1.25100	.51979	.661	-2.9721	.4701
	7.00	-1.16800	.51979	.985	-2.8891	.5531
	8.00	-.80200	.51979	1.000	-2.5231	.9191

*. The mean difference is significant at the 0.05 level.

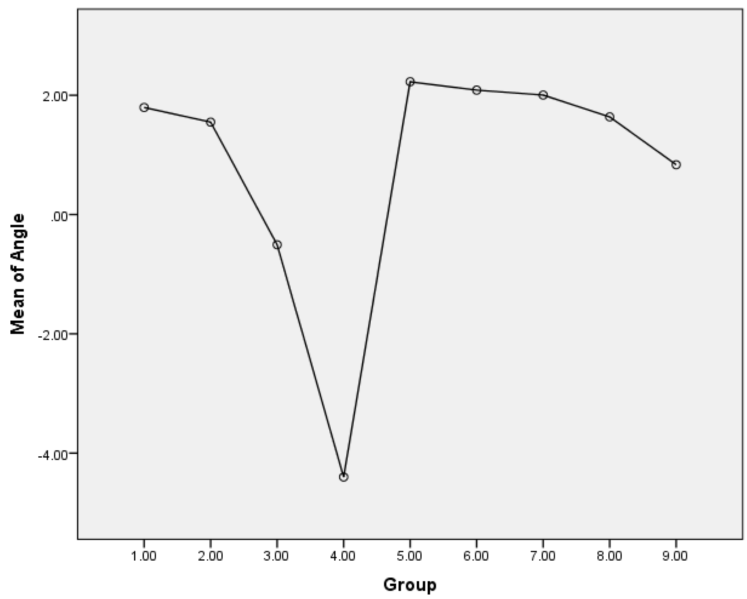
Homogeneous Subsets

Angle

	Group	N	Subset for alpha = 0.05		
			1	2	3
Tukey HSD[a]	4.00	10	-4.4000		
	3.00	10		-.5060	
	9.00	10		.8350	.8350
	2.00	10			1.5490
	8.00	10			1.6370
	1.00	10			1.7950
	7.00	10			2.0030
	6.00	10			2.0860
	5.00	10			2.2260
	Sig.		1.000	.211	.173

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 10.000.

Means Plots



Mean of Angle
2.00
.00
-2.00
-4.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
Group

References

Ahmed, M., Yamany, S., Hemayed, E., Ahmed, S., Roberts, S., & Farag, A. (1997). 3D reconstruction of the human jaw from a sequence of images. Paper presented at the pp. 646-653. doi:10.1109/CVPR.1997.609394

Akyalcin, S., Cozad, B., English, J., Colville, C., & Laman, S. (2013). Diagnostic accuracy of impression-free digital models. *American Journal of Orthodontics and Dentofacial Orthopedics, 144*(6), 916-922. doi:10.1016/j.ajodo.2013.04.024

Akyalcin, S., Dyer, D., English, J., & Sar, C. (2013). Comparison of 3-dimensional dental models from different sources: Diagnostic accuracy and surface registration analysis. *American Journal of Orthodontics and Dentofacial Orthopedics, 144*(6), 831-837. doi:10.1016/j.ajodo.2013.08.014

Alcañiz, M., Chinesta, F., Monserrat, C., Grau, V., & Ramón, A. (1996). An advanced system for the simulation and planning of orthodontic treatments. Paper presented at the *, 1131.* pp. 511-520. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwzV3Pa8IwGA0iDDYG25zD_WI57SKOtrGtPeygYz8ObgzUs9Q2hYK20tbL_vp9X5MmVed9V7Vi2ufL-768vBDCrCejt8MJIbeYZ_aj0GCusbAXIRtwN3SjAPT7wF7Y2wlDjeocVf3aP3_wO4r4z8lnLBcFvtKi9Fp1q3Mb1N8YNGWcBMtNuZ0lB-LArOO8u3fhMCt9RCKNoxbcia32vQ-P4lRmsBal9cirY3GYaK-BiI5W7sY8XskDxERkgTxDCTUsrihB0ZxgpKzyw6sSYLgMfFzlH5nxz1ZXF08E51IUK9vyJ5rGM0D7VmP4PfM32ugbys2A9d5HVQJj38qBms-

rsTgQl9WDQkkwJxfM7mBeIxP5qIr6TTkFCfa2Je8LIWBbhp4kK2PAztypHI0OUKfhDRz
7ESPbV2EcFM886c0moA5M0LzYR5rMKqazGHNYX65vl5qBWVC46eAzjHUU619iIHJ
XUjlQ90g17MTAMeU2SNebvKaMpuekrfeM0m8FyAvS4EmLnFXgoxJ8LXJSS8C8JONh
QitoUAENCtCgAA2qoUEBGrSCBk0jWoMG1dBok4e31-nLR0_8zvlaJKnM1V1jV-
TUxy0deCE87bBDqOWaPIps3wgHIOqtwPc9G25dv88jgEIQXZPOoa-
7OfzWLTnWSLojzSLb8HvSxPCyX6I6fzs

Align Technology. (2014). *Strategic growth drivers.* Retrieved 04/02, 2016, from http://investor.aligntech.com/alignar_final_7-8-14/strategic-growth-drivers.html

Allred, H., Gear, V. D., Inglis, A. T., & Jenkins, M. A. (1968). The application of thermoforming techniques in dentistry. *The Dental Practitioner and Dental Record, 19*(1), 2-7. Retrieved from
http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V3JasMwEBWhvRRKa
emWLqBD6c3GlmRLPvQQui-
3pL0aWQsEEickLvTzK9mWrab0B3q1jReNPPNmewMARmEUbOgESiPJGZURozpNJY6
F0hLrFOMiMQhX_GQYGji_sT_2XwTvpaXbIoDVfGHhad0c5Whb21LYsqonvvkw1d7jr
mmUXHqERnWmQbppALXf6vbLbLZqwqZd6ulRNbXbH2FXVPxc9wzX6ijsirNflJ3e0AS
9w1EfhTA_LevKrDrNGsdGs7bRC6dZs187qFWTnr2lvSVy2fcNA9WVDTJmx3kidm1p0e
dyKqobVQbvY2OBLauQdclf3_wcY-
qTjdkUU9u55V7W8sOKxfJz7WGKyT7Ya50BOGqEeAAGqjwEzCw-9AQIFxr-
ECDsBQinJewEeATGD_eT26egnW8RLEnCAo4oE4hyggSjPEVIxRnPDJTINLWNrYwb
MEmMB14oo1ZTGussYQYRyowwVWh0DHa57YIoq7pbUp4CmGRSCmZ8ekIKQkXKG

dbmGTxSSaQ14UNw1Xxvvmy4THKUr1FuGWINbsZJjFlefVVDcLJxmVv5sz_PnIOdfl9cgG1tfiJ1CbYsK9g3LPJGKQ

Allred, H., Gear, V. D., Inglis, A. T., & Jenkins, M. A. (1968). Thermoforming--a new aid in dentistry. *The Dental Practitioner and Dental Record, 18*(12), 419-422. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1LT4NAEN4YvZgYo_H9SDioFwNh2QWWg4fG9-Nm9Ur2RdKkpU1LE3--syxsEeMf8AocgJmd-eb1DUIkCkK_ZxMY44IJrKhZ9UAwFlRqGklWaAii0zr_1mEYchvsVtf-ieDnk6nBouCVfJ-bpeHXfKRs32tZ1evdupjUaMqdnYqcddiL6rKCaqn_6yC1VY7xeG5zpK7O9Khto_Zn4DqIn-sB4dr2BK4T-0WbVQ02wx0MVikHOKHMNbw5M4oxmNEmVfHLjC5da7Q1irQxita_UjuH_JP6uueSXKMgAzwRpQm-MkToEzWS1Y0u_Y938LmGR8gE4a9v3api0qUXM0WlZlarfWPDCCuns-WigyKGO2i7gf_ewIptF63pcg9d9kXmgcg8EJk3Kj0nsn00fLgf3j75zfoKf0Zj7McqxoUmPBE0EhqAmkiyQnISS8GUZjxKCMl0WOhMUkw1oxirJBYSzlQqYh1GB2iLmymHsqqnIdUR8mTGMyF0AVEghLGyEKlIIO4IM5kSpjg_Rhf26_KZ5SrJo3wR5YYBFnAxYHWC8-qrOkaHvcfa_3zy551TtLlShTO0UcAh0edo3bB-fQNxWjmU

Bay Materials, L. (2016). *About our services.* Retrieved 04/01, 2016, from https://baymaterials.com/services.html

Bay Materials, L. (2016). *Pressure fabrication instructions.* Retrieved 04/01, 2016, from http://www.zenduradental.com/pages/instructions

Bay Materials, L. (2016). *Zendura properties and applications.* Retrieved 3/14, 2016, from http://www.zenduradental.com/pages/properties

Biggerstaff, R. H. (1970). Computerized diagnostic setups and simulations. *Angle Orthodontist, 40*(1), 28-36. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1NS8QwEB10UVwQ8Wt1_YAevFbapE2bgwfxA8-6nkuTTGUPW5dtF9Rfb9Kku92Cf8Brk5R2JjzehMx7AJTcBn4PE5jikiVByjU2FjLIlcZNijKXEQkVwZ7C0MrCbf3sPyS-9WmY_mguqexNOqPKWmG9nFtF5mo6c65dVZecNgbN5Ye5brgwvtKfZe26g9pj9KYPxuo4vrq2BmVb6IyxzOrEoEVB6tMWqtACH49icy-TdpHRCilt7AAHc-kG-s5nOn4x0bWRtd_pKVi3I0bMfKamsr7D0n9_29aVcpq0VbCrkTW7Ia3JofnEIey65R2KsGM6dpZVhwhMDuHAMXjv3kb-CLawPIa9R2yCtfg-gdtuBrx1BjybAU9nwOtk4BQmz0-Thxff2VL48yjmPo15RFBhQkRYhILJIhIsTNFgp6nOkBMpMUpIIVQsCBcBETRVeaFQaLLJ6Qj2c9O9UNZNl6M6By_JCz1VUy9DtzhKkfA0TygGQpebKYvHMLL_ns2tBknmgjKGGxuL1QDJKpIZydcwSjRAM5bVX_UYznrTuKkVWcAv_nrzJQzXe-cKBvViidcwMCJfv31VNWQ

Bollen, A., Huang, G., King, G., Hujoel, P., & Ma, T. (2003). Activation time and material stiffness of sequential removable orthodontic appliances. part 1: Ability to complete treatment. *American Journal of Orthodontics and Dentofacial Orthopedics, 124*(5), 496-501. doi:http://dx.doi.org/10.1016/S0889-5406(03)00576-6

Boyd, R. L., & Waskalic, V. (2001). Three-dimensional diagnosis and orthodontic treatment of complex malocclusions with the invisalign appliance. *Seminars in Orthodontics, 7*(4), 274-293. doi:10.1053/sodo.2001.25414

Bunch, W. B. (1961). Orthodontic positioner treatment during orthopedic treatment of scoliosis. *American Journal of Orthodontics, 47*(3), 174-204. doi:10.1016/0002-9416(61)90089-6

Clements, K. M., Bollen, A., Huang, G., King, G., Hujoel, P., & Ma, T. (2003). Activation time and material stiffness of sequential removable orthodontic appliances. part 2: Dental improvements. *American Journal of Orthodontics and Dentofacial Orthopedics, 124*(5), 502-508. doi:http://dx.doi.org/10.1016/S0889-5406(03)00577-8

Cowley, D. P., Mah, J., & O'Toole, B. (2012). The effect of gingival-margin design on the retention of thermoformed aligners. *Journal of Clinical Orthodontics : JCO, 46*(11), 697-705. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1Na9wwEBVpCLRQQtKvbNOCLu2lOFiWbEuHHpI0oQT6QbuB3oxkSUkOa4fNBpp_35mVVjam_QM9-GDL-KAnj95I740I4cVRnk1igiraylXK2NwzpAya2bzV2tVwp0U1qTCUDNjDs_8F-KDSQCKIZxDdwEezhV5erZWvqNiIWwQflkiZN5wRqeCiRxILJBTo-VUX1fF_Ia_JUInbPpDZdutqz7i8cHH6Le1r4HLdw2BkH7xkX_R1kuiOZTfzvg_y5hOU6saBG9ckWBHNeaM4ix4BGc5EOXIhtCpRZhA9fo1jb1x-jGOMjSJpFWS7cVKu83KYsDab9JN5LKkLeSWFQsvReyyfvrA37eqj67LLn48gN5eYof-4_J6yclnlLJWUX-tNExXZQWfQ_d2IcMz3yG7sbHocEN4nW657Rh5_QrzwgL7n5CsgTQPStPd0gjQNSNO-owAsTUjjq2Ok6QbpF2R-fjY__ZzF4zGyW4GaFmWZcKbFCmpWG17Bz8StYcro0svc-

BaouqwLDRkwTEt5a2tbKOcL7zFtNfwlearRRYEjBIC0B4RCbmzg4tZLIUqH1Ru9Esa4kn FX12xGXoW-aW5DLZSm4FxBn4oZeRc6a2hp7oombyRkxFi2gEnZrH6vZuRg8l5C6_W_mw7Jk2GYvS Hbq-W9e0u2seLYHwKkZco

Cuperus, A. M., Schols, J. G. J. H., Bronkhorst, E. M., Breuning, K. H., Harms, M. C., & Rangel, F. A. (2012). Dental models made with an intraoral scanner: A validation study. *American Journal of Orthodontics and Dentofacial Orthopedics, 142*(3), 308-313. doi:10.1016/j.ajodo.2012.03.031

Del Rossi, G., & Leyte-Vidal, M. (2007). Fabricating a better mouthguard. part 1: Factors influencing mouthguard thinning. *Dental Traumatology, 23*(3), 149-154. doi:10.1111/j.1600-9657.2006.00436.x

Djeu, G., Shelton, C., & Maganzini, A. (2005). Outcome assessment of invisalign and traditional orthodontic treatment compared with the american board of orthodontics objective grading system. *American Journal of Orthodontics & Dentofacial Orthopedics, 128*(3), 292-298. doi:10.1016/j.ajodo.2005.06.002

Drake, C. T., McGorray, S. P., Dolce, C., Nair, M., & Wheeler, T. T. (2012). Orthodontic tooth movement with clear aligners. *ISRN Dentistry, 2012*, 657973. doi:10.5402/2012/657973

El-Katatny, I., Masood, S. H., & Morsi, Y. S. (2010). Error analysis of FDM fabricated medical replicas. *Rapid Prototyping Journal, 16*(1), 36-43. doi:10.1108/13552541011011695

Elsasser, W. A. (1950). Some observations on the history and uses of the kesling positioner. *American Journal of Orthodontics*, *36*(5), 368-374. doi:10.1016/0002-9416(50)90076-5

Faber, R. D., Burstone, C. J., & Solonche, D. J. (1978). Computerized interactive orthodontic treatment planning. *American Journal of Orthodontics, 73*(1), 36-46. doi:10.1016/0002-9416(78)90100-8

Farrington, T., Coward, T., Onambele-Pearson, G., Taylor, R. L., Earl, P., & Winwood, K. (2015). The effect of model inclination during fabrication on mouthguard calliper-measured and CT scan-assessed thickness. *Dental Traumatology,* doi:10.1111/edt.12213

Fleming, P., Marinho, V., & Johal, A. (2011). Orthodontic measurements on digital study models compared with plaster models: A systematic review. *Orthodontics & Craniofacial Research, 14*(1), 1-16. doi:10.1111/j.1601-6343.2010.01503.x

Groth, C., Kravitz, N. D., Jones, P. E., Graham, J. W., & Redmond, W. R. (2014). Three-dimensional printing technology. *Journal of Clinical Orthodontics : JCO, 48*(8), 475-485. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1NS8NAEF20CAoifrd-QC6eJCVJs8nk4EGqInpQtAVvZbO7gR6sJbaC_96ZbLvZtvoHvGZJyOZthrezM-8x1onagb8UE3hQpAK5R1REIpAcOazMpVRc4Q-nk8qIzlEYsr6X9bX_AXypta9Itd8oblxS7s74QSzm0Vc5qe2TpNMc3LCOKhFnyho8dJ_qUp0Pk4wxwgTO-nosxdewMojF4EnxtK7PmTsC6LL8rrsfnD7tqoLHzUGEsa2AW-gJAOOB0tYmlGYx9zFavLmxNgZnTYETOGNzr0Vk_I6QREQOAyPntKSKbYdIIf1dDeXkSo_8_us6br-

BNuEv_We78YYkCK1qPL4lKUDP7neIxwb1AU0_HXrR22U7Mwy8a4PnHlvTo322eUO1XGTHd8AuVnD15rh6Na6HrHd32-ve-zOPC3-MU_ZDkYFGjiYoocxlAjHkoRa51DxQJKWTFx1ARgt5JCXPcWqpUImWhQIFGaSdI7YtqBWC1gOio5rM45LO0nQeCchjJNhZp8hSGUiRaBWptGixYzPlwdgImgzmH6PFmuYb2BHyIMconfDfhuIEAAn0yZ_PO2Vb9Wo5Y41JOdXnrEFCYT-Uj0mu

Hahn, W., Dathe, H., Fialka-Fricke, J., Fricke-Zech, S., Zapf, A., Kubein-Meesenburg, D., et al. (2009). Influence of thermoplastic appliance thickness on the magnitude of force delivered to a maxillary central incisor during tipping. *American Journal of Orthodontics and Dentofacial Orthopedics, 136*(1), 12.e1. doi:10.1016/j.ajodo.2008.12.015

Hahn, W., Engelke, B., Jung, K., Dathe, H., Fialka-Fricke, J., Kubein-Meesenburg, D., et al. (2010). Initial forces and moments delivered by removable thermoplastic appliances during rotation of an upper central incisor. *Angle Orthodontist, 80*(2), 239-246. doi:10.2319/033009-181.1

Hemayed, E., Yamany, S., & Farag, A. (1996). *Three dimensional model building in computer vision with orthodontic appliances* (Technical Report No. TR-CVIP 96)

Joffe, L. (2003). Features section: Current products and practice invisalign ®: Early experiences. *Journal of Orthodontics, 30*(4), 348-352. doi:10.1093/ortho/30.4.348

Kesling, H. D. (1945). The philosophy of the tooth positioning appliance. *American Journal of Orthodontics and Oral Surgery, 31*(6), 297-304. doi:10.1016/0096-6347(45)90101-3

Kesling, H. D. (1946). Coordinating the predetermined pattern and tooth positioner with conventional treatment. *American Journal of Orthodontics and Oral Surgery, 32*(5), 285-293. doi:10.1016/0096-6347(46)90053-1

Kesling, H. D. (1956). The diagnostic setup with consideration of the third dimension. *American Journal of Orthodontics, 42*(10), 740-748. doi:10.1016/0002-9416(56)90042-2

Kim, J., Heo, G., & Lagravere, M. (2014). Accuracy of laser-scanned models compared to plaster models and cone-beam computed tomography. *Angle Orthodontist, 84*(3), 443-450. doi:10.2319/051213-365.1

Kim, J., Kim, K., Kim, W., Kim, J., & Kim, H. (2014). Accuracy and precision of polyurethane dental arch models fabricated using a three-dimensional subtractive rapid prototyping method with an intraoral scanning technique. *The Korean Journal of Orthodontics, 44*(2), 69-76. doi:10.4041/kjod.2014.44.2.69

Kim, S., Lee, S., Cho, S., Jeong, C., Jeon, Y., Yun, M., et al. (2014). Comparison of the accuracy of digitally fabricated polyurethane model and conventional gypsum model. *The Journal of Advanced Prosthodontics, 6*(1), 1-7. doi:10.4047/jap.2014.6.1.1

Kohda, N., Iijima, M., Muguruma, T., Brantley, W. A., Ahluwalia, K. S., & Mizoguchi, I. (2013). Effects of mechanical properties of thermoplastic materials on the initial force of thermoplastic appliances. *Angle Orthodontist, 83*(3), 476-483. doi:10.2319/052512-432.1

Kravitz, N., Kusnoto, B., Agran, B., & Viana, G. (2008). Influence of attachments and interproximal reduction on the accuracy of canine rotation with invisalign - A prospective clinical study. *Angle Orthodontist, 78*(4), 682-687. doi:10.2319/060107-263

Kumar, P. S., Kumar, G. K., Kommoji, S., Banerjee, R., & Ghosh, A. K. (2014). The effect of material characteristics and mould parameters on the thermoforming of thick polypropylene sheets. *Journal of Plastic Film & Sheeting, 30*(2), 162-180. doi:10.1177/8756087913497387

Kuroda, T., Motohashi, N., Tominaga, R., & Iwata, K. (1996). Three-dimensional dental cast analyzing system using laser scanning. *American Journal of Orthodontics & Dentofacial Orthopedics, 110*(4), 365-369. doi:10.1016/S0889-5406(96)70036-7

Kwon, J., Lee, Y., Lim, B., & Lim, Y. (2008). Force delivery properties of thermoplastic orthodontic materials. *American Journal of Orthodontics and Dentofacial Orthopedics, 133*(2), 228-234. doi:10.1016/j.ajodo.2006.03.034

Lagravere, M. O., & Flores-Mir, C. (2005). The treatment effects of invisalign orthodontic aligners - A systematic review. *Journal of the American Dental Association, 136*(12), 1724-1729.

Lemos, L., Rebello, I., Vogel, C., & Barbosa, M. (2015). Reliability of measurements made on scanned cast models using the 3Shape R700 scanner. *Dentomaxillofacial Radiology, 44*(6) doi:10.1259/dmfr.20140337

Logozzo, S., Kilpela, A., Makynen, A., Zanetti, E., & Franceschini, G. (2014). Recent advances in dental optics - part II: Experimental tests for a new intraoral scanner. *Optics and Lasers in Engineering, 54*, 187-196. doi:10.1016/j.optlaseng.2013.07.024

Macdonald, S. (2005). Thermoforming. () doi:10.1002/0471786586.ch4

Martz, M. G. (1988). *Removable tooth positioning appliance and method* (433/6 ed.). Colorado/USA: A61C 7/00.

Michaud, R. A., & Giacomin, A. J. (2011). Sheet temperature in thermoforming. *Journal of Plastic Film & Sheeting, 27*(4), 293-330. doi:10.1177/8756087911411134

Miller, R. J., & Derakhshan, M. (2002). The invisalign system: Case report of apatient with deep bite, upper incisor flaring, and severe curve of spee. *Seminars in Orthodontics, 8*(1), 43-50. doi:10.1053/sodo.2002.28182

Moreira, D. D., Gribel, B. F., Torres, G. D. R., Vasconcelos, K. d. F., de Freitas, D. Q., & Ambrosano, G. M. B. (2014). Reliability of measurements on virtual models obtained from scanning of impressions and conventional plaster models. *Brazilian Journal of Oral Sciences, 13*(4), 297-302. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V09a8MwEBUhSwul9JP0i2rqYhIcK7bjoUNpGgodCm06B9uSwNDYwU4y5NdXp5NtJZA_0FW2hW097k6nd-8IYd7A7e_ZBLXP4lw5E54EiRfIOBbxkElfiIh7wk_krsJQp-4E2Y79h4UHkjGKb5vD8yYJqE8GNlmJJSPQAkeNJJAbUFGnrjOpUmxhpIUkFoYjm1em-M3ipy9V0A3yijjLzslwGW8znTuxYt3P0oiOAGm7WWPoClrieROe1wMenYmmmba8oCx

BIgFoJBQQaG_1zaxoE-TQYEQn-LNcPQ_f73wZNrnpJlalUJ75i5zCD6D4Olw40xhJ1k3eAytNjZEOQmUYPaz5HAh7DIuoG8vOLASPbDMdhZbHZ67XesOaAbDnJBvqYuCqPb3aZXpPoM2-4Fm6ehZ5_-cbZAxY4Ne7egwGIN7Ue_76lUGRNi2W68qKYmZn5NQsCX1B2JyTjsgvyNEE1hW6_l2SyoIPLSS14UOLnBr4UFx4WsOHAnxoDR940IIPVfChNnyogY-Z5Yo8Tt9mr-99fOf5EhVQ5s1PYNfkJIZSjHylSzZ5j1B1MQhjPxmGYz5KpIz8KFWuJJXuOFXxo39Deoemuz186Y4cAwow-3VPuqtyLR5IF0TH_gDFK3Ut

Nahoum, H. I. (1964). The vacuum formed dental contour appliance. *The New York State Dental Journal, 30*(9), 385-390.

Park, S., Kim, J., Lee, H., Jang, D., & Jun, S. (2016). Methodology of technological evolution for three-dimensional printing. *Industrial Management & Data Systems, 116*(1), 122-146. doi:10.1108/IMDS-05-2015-0206

Patzelt, S. B. M., Emmanouilidi, A., Stampf, S., Strub, J. R., & Att, W. (2014). Accuracy of full-arch scans using intraoral scanners. *Clinical Oral Investigations, 18*(6), 1687-1694. doi:10.1007/s00784-013-1132-y

Ponitz, R. J. (1971). Invisible retainers. *American Journal of Orthodontics, 59*(3), 266-&. doi:10.1016/0002-9416(71)90099-6

Puehringer, J. F., Zitzenbacher, G., & Spreitzer, C. (2013). Study of heat absorption in thermoforming for transparent and filled polystyrene. *International Polymer Processing, 28*(1), 14-23. doi:10.3139/217.2595

Ren, Y., Huddleston Slater, J. J. R., & Hazeveld, A. (2014). Accuracy and reproducibility of dental replica models reconstructed by different rapid prototyping techniques. *American Journal of Orthodontics and Dentofacial Orthopedics, 145*(1), 108-115. doi:10.1016/j.ajodo.2013.05.011

Rossini, G., Parrini, S., Castroflorio, T., Deregibus, A., & Debernardi, C. (2015; 2014). Efficacy of clear aligners in controlling orthodontic tooth movement: A systematic review. *Angle Orthodontist, 85*(5), 881-889. doi:10.2319/061614-436.1

Rosvall, M. D., Fields, H. W., Ziuchkovski, J., Rosenstiel, S. F., & Johnston, W. M. (2009). Attractiveness, acceptability, and value of orthodontic appliances. *American Journal of Orthodontics & Dentofacial Orthopedics, 135*(3), 276.e1-276.e12. doi:10.1016/j.ajodo.2008.07.011

Ryokawa, H., Miyazaki, Y., Fujishima, A., Miyazaki, T., & Maki, K. (2006). The mechanical properties of dental thermoplastic materials in a simulated intraoral environment. *Orthodontic Waves, 65*(2), 64-72. doi:10.1016/j.odw.2006.03.003

Santoro, M., Galkin, S., Teredesai, M., Nicolay, O. F., & Cangialosi, T. J. (2003). Comparison of measurements made on digital and plaster models. *American Journal of Orthodontics & Dentofacial Orthopedics, 124*(1), 101-105. doi:10.1016/S0889-5406(03)00152-5

Sharma, A. (2015). Rapid prototyping technology for prosthodontics. *International Journal of Clinical Dentistry, 7*(4), 327-336. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V3PS8MwFH6IXgSRicr8hTl5q9YkbdeDhzEVQU9unkebpGyCbaHdYf-

9eUl_ZMP9A17T0oZ84X0vj_d9AWD03ve2YkKmiUamWcA1f2SaRESgaJT4I5XKUHJjyOc4DHU3cvZj_wH4z6Rcova_qIt6bdVQXfncNBWWKPRY6ONoXret7t99P_tmebDJVSetfvIZm4uquu8dnhrraxNhqsXKrSE8Bk4NwYa9mMVGf2VZwYxRFnGs4oRurIycLcGduMeswL-hUMb-cLfeYp2uFzBEhxidNfI7NDv_kUtRP6nc-5pqXkWvIDxov3-07BqOrF97N2O0eBVFuaqctGA2gONmjcjY4nACeyo_hQeDAXEwID0GRGNANjE4g9vXl9nkzbP_mJfWAmTeTZqew1GCWgR8XS-vHAIRKqCxn6aMUcElk3GG1yByX1Hhp5LFFzDc9bnL3Y-u4LCH7hoOMr1L1Q3so-3WLz61GVQ

Sheridan, J. J., LeDoux, W., & McMinn, R. (1993). Essix retainers: Fabrication and supervision for permanent retention. *Journal of Clinical Orthodontics : JCO, 27*(1), 37-45. Retrieved from http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1dS8MwFA1DBQURv50fkAfxRTrSJP0SfJA5kTkRdIJvpWlS2IOlrBvs55vbdGk38Q_42pYWctJ7T27OPUGI0R5x1mICnD8gKXWFT0RIqAhloMCakAVuJlggVx2GOkupTnPtPwA_0LN8cQsyQujrqxRvWSKmdW2u2iwo5wWEiHIpMywgPOegCpgCh7ZY_SattpEStnv0ijavXJ7hG8P-m63WQE-hNJXVYc8WokdKs_WFFfWZauDrxBDo96b8YMR-tvzQagcIzfEnPWWiaMQ9RweKr3aYNRYAK9PJxExj-lJnX-41iWm5Gb-Wr6yKULONUPMNegMu6d9yks7uVe58fuiEDCZDsEJ_GdnVd-gT11rHV7rSLWj8mZctPjHeR3v1mOIHA-AB6qj8EG0_wujD-XtH6LECElsg73ALRqxhxC0YsYYRWxixhfEYjZ8G4_6zU5954RTco45SyhOpm_GAZJ7gJA1lFgmPqZSlXJA01YQ-8RIZur5kisgg1Q8xqaM0E74MXHqCdhNojQD4NWTyDGElQ8lpkPlKMi4jkXBBidA0lPlc

rw_dLjo1AxEXxuAkXg5sF12v34lLGoOhLLgi8Sjw4tlidv7nCy7QTjNnLtFmpv8sdYU2wCrsB1HjT_M

Sheridan, J. J. (1985). Air-rotor stripping. *Journal of Clinical Orthodontics : JCO, 19*, 43-59.

Sheridan, J. J. (2004). The readers' corner. 2. what percentage of your patient are being treated with invisalign appliances? *Journal of Clinical Orthodontics : JCO, 38*, 544-545.

Sheridan, J. J., Armbruster, P., Nguyen, P., & Pulitzer, S. (2004). Tooth movement with essix mounding. *Journal of Clinical Orthodontics : JCO, 38*(8), 435-41.

Simon, M., Keilig, L., Schwarze, J., Jung, B., & Bourauel, C. (2014). Treatment outcome and efficacy of an aligner technique - regarding incisor torque, premolar derotation and molar distalization. *Bmc Oral Health, 14*(1), 68. doi:10.1186/1472-6831-14-68

Stewart, R. F., & Lahlouh, J. G. (2014). In Bay Materials L. (Ed.), *Method of reducing stress relaxation in polymer articles and articles formed thereby* (528/44 ed.). California/USA: C08G 18/82.

Takahashi, M., Koide, K., Satoh, Y., & Iwasaki, S. (2015). Heating methods for reducing unevenness softening of mouthguard sheets in vacuum-pressure formation. *Dental Traumatology,* doi:10.1111/edt.12254

Tarazona, B., Llamas, J. M., Cibrian, R., Gandia, J. L., & Paredes, V. (2011). A comparison between dental measurements taken from CBCT models and those taken from a digital method. *European Journal of Orthodontics, 35*(1), 1-6.

Van der Meer, W. J., Ren, Y., Nolthenius, H. E. T., Engelbrecht, W. P., & Wiranto, M. G. (2013). Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. *American Journal of Orthodontics and Dentofacial Orthopedics, 143*(1), 140-147. doi:10.1016/j.ajodo.2012.06.018

Zilberman, O., Huggare, J. Å. V., & Parikakis, K. A. (2003). Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. *Angle Orthodontist, 73*(3), 301-306. Retrieved from
http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1La9wwEBYlBFooIX1vm
4IOoZfgstLIr0MPIUnprYUml16MbI-
DCdkNa2_b9Bf0Z1cjybay2UPOhd3DyvID62P2m9HMN4yB_DiPNmyCaFBryMwHyqaEqkEJ
WDYVFYnoVGwoDI1qBdPY_7DwZ6N-
97D_bwba2qde9Msl5aS3f9y2gQ15_GprM3Y9RQu7o7Uvxg1S0l2q5QoxqqkjgFPzOPrZrmwFC
m3_GA93QfqvtrtOF9Je2_p5cUmJjOO8bky4-
dGS0JYPxX6dgHZJLXgdzMZU3G_Gt78i1mst1PGdoAXcMcEQwWAn0VndXMWUFAqhWU
4hgB8ENhZ89OO-TLb9-6fimMLYFUrs-
ED66dd1W_WfcBFdfCepAUjiwfP2frlhVHJorEhPFpCRXaoNWnejjuxWemKpyPk-2_M-
BD92a_-MPcLFc_b4FO1LXd2-YH8nDPBlww0G-IAB-
5swwAkD3CwqJwxwiwEeYoBbDPAQA3b6PQxwjwEeYIA7DLxkF5_Pzk--
RL7lRnQjkiSOVJw3eSZSyCtVStSZEGBcfm384nmmUORlDCpFwyvTuCrTWpR5rvJKJLHAr
FYpvGJPNZVm0K3M4tdvGNdNpkqtDU_MtEKptS4NSU-
qpG4kAuKMvXavu7hxAiuFoDiAYcozduje_3hEFp0sSNBWUZfsVMmi_92bC2xMMyw8zbPE

XsCu23hkK0xmbL5lGjGYwo9ftfQtOpxOOQyBMJ5IPlMGKpHSqhTMmHjItBOvx086FP3bhz
30O_bEJpbacOAB2-lXa3zPdkiF7R-yhM4F

Curriculum Vitae

Pouya Momtaz DMD

Las Vegas, Nevada
momtazdmd@gmail.com

EDUCATION

Present	Residency in Orthodontics and Dentofacial Orthopedics Masters in Oral Biology *University of Nevada Las Vegas, School of Dental Medicine* Tests: Part one of ABO complete Graduation: May 2016
2013	Fellowship in Orthodontics and Dentofacial Orthopedics *University of Nevada Las Vegas, School of Dental Medicine*
2012	General Practice Residency *St. Barnabas Hospital*
2011	Doctor of Dental Medicine *Tufts University School of Dental Medicine*
2002	Bachelor of Arts Psychology *Boston University*

ORTHODONTIC EXPERIENCE/CERTIFICATIONS

2012-Present	Experience with: edgewise appliances, self-ligating appliances, clear aligners, Temporary Anchorage Devices, headgear, indirect bonding, and CBCT.
2014	Invisalign Certification
2014	2 week Tweed Course in Tucson, AZ
2014	Laser Certification
2012	CBCT Certification

EMPLOYMENT/ EXPERIENCE

2012- present	Aces Dental – General Dentist
2003-2011	Dana-Farber Cancer Institute – Pharmacy Technician
2004-2006	Beth Israel Deaconess Medical Center – Pharmacy Technician

RESEARCH

2014-Present	The effect of attachment placement and location on rotational control of conical teeth using clear aligner therapy
2011-2012	Evaluation of Er,Cr:YSGG laser instrumentation in regaining bone and clinical attachment level in periodontically involved teeth
2010-2011	ELISA tests for p63 antibodies in chronic ulcerative stomatitis
2007-2011	Comparison of oral cancer screening techniques with surgical biopsy results
2001-2002	Visual perception and learning

HONORS AND AWARDS

2005	Partners in Excellence Award

PROFESSIONAL/ACADEMIC MEMBERSHIPS

2011-Present	American Dental Association
2012-Present	American Association of Orthodontists
2007- 2011	American Student Dental Association