9-2022

Force Comparison of Rotational Tooth Movements for Loop-Design and Traditional Aligners

Robert Olsen

LOMA LINDA UNIVERSITY
School of Dentistry
in conjunction with the
Faculty of Graduate Studies

Force Comparison of Rotational Tooth Movements for Loop-Design and Traditional Aligners

by

Robert Olsen

A Thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

September 2022

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree of Master of Science.

____ Chairperson

V. Leroy Leggitt, Professor of Orthodontics and Dentofacial Orthopedics

Mohammed Toufic Jeiroudi, Professor of Orthodontics and Dentofacial Orthopedics

Kitichai Rungcharassaeng, Professor of Orthodontics and Dentofacial Orthopedics

ACKNOWLEDGEMENTS

I would like to express my gratitude for everyone involved in helping me complete my thesis. I would like to first off thank Dr. Martz for his efforts in starting a new aligner company and for providing all the study models and aligners needed. I would also like to thank my committee, Dr. Leggitt, Jeiroudi and Rungcharassaeng for providing consistent advice and direction. I would like to thank Dr. Oyoyo for providing statistical analysis. Another thank you goes to the LLUSD for sponsoring the project. Finally I would also like to thank my wife, Ariel Olsen, for providing endless support into allowing me to put so much effort and time into this project.

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ABBREVIATIONS

F	Force
Tq	Torque
AFL	ArchForm Loop clear aligners
T	Traditional clear aligners
ORR	Orthodontic root resorption
MB	Mesio-buccal
ANOVA	Analysis of Variance
OTM	Orthodontic tooth movement
NiTi	Nickel Titanium
PDL	Periodontal ligament
PVC	Poly-vinyl chloride
PETG	Polyethylene terephthalate glycol
IPR	Inter-proximal reduction
LDR	Load deflection rate
ABO	American Board of Orthodontics
N	Newtons
N-mm	Newtons per millimeter
CAD	Computer aided design
CAM	Computer aided manufacturing

ABSTRACT OF THE THESIS

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Robert Olsen

Master of Science in Orthodontics and Dentofacial Orthopedics
Loma Linda University, September 2022
Dr. V. Leroy Leggitt, Chairperson

Introduction

This study aimed to evaluate the force (F) and torque (Tq) exerted on a rotated canine and molar tooth by two different aligner systems. An ArchForm loop clear aligner (AFL) was compared to a traditional clear aligner (T) with the force (F) and torque (Tq) compared. A reduction in F and Tq with AFL aligners could possibly decrease the incidence of Orthodontic Root Resorption (ORR), while also creating more effective forces for tooth movement.

Materials and Methods

Two types of T aligners varying by material thickness were compared to two types of AFL aligners varying by loop width. All aligners were designed by ArchForm Design Software. A maxillary canine and molar were tested separately with both F and Tq in the X, Y and Z axis evaluated. The test tooth was cut out of a study model and mounted onto a load cell. The aligners were individually placed over the study model, the test tooth was rotated 2 degrees mesial-buccally (MB) and the force values were recorded.

Results

To differentiate test results based on the X, Y and Z vectors of force and torque, ANOVA tests were performed. To further compare each aligner type to each other a Games-Howell Post-Hoc test was run. Statistically significant differences in F and Tq were seen among aligner groups for each tooth type and axis.

Conclusions

1) There was statistically significant difference in F and Tq among aligner type for each tooth type and axis.
2) AFL aligners showed a statistically significant reduction in F and Tq when compared to .040 T aligners as well as in the large majority of .030 T aligners
3) The difference in the width of the loop within the AFL aligners had a statistically significant effects on the large majority of the F and Tq values.
4) The difference in the material thickness within the T aligners had statistically significant effects on all of the F and Tq values for molar teeth.
5) Further studies are needed to truly see the clinical significance and benefits of this novel aligner design

CHAPTER ONE

REVIEW OF LITERATURE

Introduction

Optimal tooth movement within the field of Orthodontics has been described as moving a tooth as quickly as possible with the least amount of side effects to the tooth and surrounding tissues. One of the main adverse effects that is almost consistently seen in Orthodontic Tooth Movement is root resorption. For many years the orthodontic specialty has been developing different mechanics to move teeth at this optimal rate. One of mechanics developed is the advent of clear aligners for orthodontic treatment. Aligners are thin, transparent shells that move teeth in small increments if worn diligently. However, research within this review has shown that aligners underperform when compared to conventional fixed appliances in a few tooth movements such as torque, bodily movement, large rotations and extrusion. This literature will review the basics of tooth movement and biomechanics of tooth movement, the evolution of orthodontic mechanics, specifically with clear aligners, the difficult tooth movements mentioned, and some factors that have been attributed to the shortcomings seen with aligners.

Literature Review

Many theories have been developed over the years as to how teeth move throughout the mouth. Technology has allowed the biology/physiology of tooth movement to be defined and understood better than ever. The study of the cells in the periodontal ligament and surrounding alveolar bone has led to the development of the pressure-tension theory. This theory suggests that when there is compression force on a tooth, and therefore the periodontal ligament, force subjected periodontal ligament progenitor cells differentiate into osteoclasts resulting in bone resorption. Alternatively, on the tension side of the periodontal ligament, progenitor cells differentiate into tension-associated osteoblasts resulting in bone apposition. This ideal tooth movement is often referred to as direct resorption and is associated with lighter force application to the tooth, which according to Masella, et al.[4] is around +/- 50-100 g/tooth. This lighter force helps move teeth and surrounding periodontal ligament through the alveolar bone at an ideal rate with tissue and cell preservation as well as vascular patency. When heavier forces are applied to the tooth, blood vessels are compressed too tightly, thus causing necrotizing forces causes injury to the periodontal ligament, cell death, cell-free periodontal ligament and adjacent bone zones.

Looking at a model (Figure 1) created by Quinn and Yoshikawa[5] helps our understanding even better.

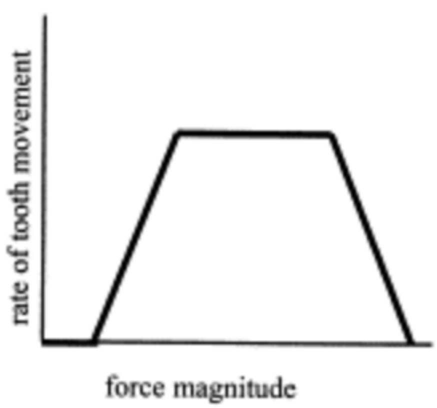

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Figure 1. A model of relationship between force magnitude and velocity of tooth movement, as proposed by Quinn and Yoshikawa.[5]

The model suggests that a certain threshold of force is needed to even move teeth in the first place. After the threshold is exceeded a positive linear relationship exists between force magnitude and rate of tooth movement up until a certain level. A plateau is then reached where optimal tooth movement occurs in a range of magnitude of force. A further increase of force leads to a decrease in the rate of tooth movement until it stops completely. When prolonged application of controlled forces are applied to teeth, remodeling of the tooth socket occurs as well and usually optimal tooth movement follows.

Because each tooth has a different surface area, there must then be an optimal force that moves each type of tooth at an optimal rate. Storey and Smith[6] were the first to report this optimal force theory and they believed that for canine retraction forces of 150 to 200 g were optimal. Other various hypotheses have been made over the years on stress magnitude and tooth movement rate. However, the individual heterogeneity, stress distribution in the periodontal ligament and lack of experimental control have made the results unclear. Yee et al.'s[7] study measured the rate and the amount of orthodontic tooth movement under heavy (300 g) and light (50 g) forces for 12 weeks using Nickel-Titanium (NiTi) closing coils. Each participant had maxillary first premolar extractions and needed canine retraction treatment. The results showed that lighter force moved teeth at a faster rate during the first 4 weeks, but from 4 weeks until 12 weeks the heavier force moved the teeth faster. An important finding in the study was that although heavier forces seemed to have the advantage for the majority of the time period, they lost their advantage because a greater amount of unwanted clinical side effects were seen in the heavy force patients. These results in mind helps to define the term "optimal" when defining tooth movement. While it is unclear through many studies whether heavy or light forces will move teeth faster, it is not unclear that unwanted side effects are more apparent with heavy forces. Because it is our fiduciary duty as medical professionals to do no harm, optimal rate of tooth movement should be defined as not just the quickest rate of tooth movement, but as the ideal rate of movement with the least amount of adverse side effects accompanying it.

It is important to have a brief understanding of the biomechanics of tooth movement to help understand how the different appliances actually work. Each tooth has a center of rotation and a center of resistance. The type of movement that will occur in the depends on the relation of the force to each of these points. If a force passes directly through the center of resistance, then pure bodily movement or translation would occur. If pure translation does not occur, then there must have been some tipping of the tooth. The point at which the tooth rotates is known as the center of rotation. Because the center of resistance has been defined as one third the root length apically above the alveolar crest and along the facial axis, it is impossible to place a force moving directly through that point.[5] To achieve bodily movement another force needs to be applied to the bracket, along with the force applied in the direction of tooth movement, which will counter the tipping that would occur otherwise.[8] As a result bodily movement is usually more difficult than tipping a tooth.

If only moving teeth was as simple as placing the right force on the teeth and watching them move. An array of factors also contribute to the complexity of moving teeth at an optimal rate. Even when an Orthodontist applies all the right mechanical forces to the teeth sometimes teeth move very slowly, don’t move at all or they move but unwanted side effects occur anyways. Some of side effects that can accompany un-ideal and sometimes ideal forces placed on the teeth by Orthodontists include tooth discoloration, jaw pain, tooth mobility, periodontal complications, decalcification, loss of tooth vitality, enamel wear and root resorption. Root resorption, unlike the other factors is one of primary concern because it is the only adverse effect that occurs in almost every patient.[6] The reason this adverse outcome is rarely avoided is because orthodontists use the inflammatory process which causes root resorption to move the teeth. The question for practitioners is usually not whether if root resorption will occur, but rather how much and how can it be controlled. In order to answer these questions, understanding the etiology of Orthodontic Root Resorption (ORR) is key. Many factors have been suggested and studied in their possible contribution to OIRR such as previous trauma, bottled-shaped roots, genetics, hispanic race, intrusion and torque forces, jiggling forces, hormones, allergies, oxygen deficiencies, cortical bone contact, previous root resorption, extraction treatment and asthma to name a few. Obviously individual variation and susceptibility exist, but the main three factors who have been most widely accepted and least controversial as associated with ORR are the magnitude of force, the duration of force and the distance the apex of the tooth moves.[3]

In a study by Harris et al.[9] fifty-four maxillary premolars which were planned for extraction for orthodontic treatment were intruded for 28 consecutive days with either no force (0 g) being the control group, light force being 25 g and heavy force being 225 g. The teeth were then extracted without root damage and analyzed. The results showed that the mean volumes of the resorption craters in the light and heavy force teeth were 2 and 4 times greater than the control group respectively. The root resorption volume proved to be directly proportional to the amount of force applied. These findings suggest that the magnitude of force is directly correlated to the amount of root resorption.

There are factors that the Orthodontist can control when trying to decrease that risk of unwanted side effects such as the treatment mechanics and the material properties in the orthodontic appliances they choose to use. Orthodontic archwires are one of the most important components of the fixed orthodontic appliance. Many properties are needed to obtain the ideal archwire. These properties include esthetics, friction, weldability, formability, resilience and springback. This ideal archwire would also be able to move teeth with light, continuous force, thereby minimizing patient discomfort, root resorption and hyalinization. Also, the archwire should be able to behave elastically over a period of time, ranging from a number of weeks to months. Although archwires have evolved and improved in many aspects over the years, currently there is still no archwire that can boast all of these characteristics.[10] As a result, Orthodontists are usually required to use different archwires for different phases of treatments and for different mechanics. Currently there are 4 different major types of archwires used today: stainless steel, cobalt chromium, niti and beta-titanium. The niti alloys have 3 subdivisions- conventional, pseudo-elastic and thermoelastic, with the latter two having super-elastic properties.

Stainless steel archwires have been used since the 1940's and are still used very successfully during certain phases of Orthodontic treatment. It's low cost, excellent formability and good mechanical properties have allowed it to be very popular for many years. However, it has very high stiffness in comparison to other wires. Per one unit of deactivation stainless steel delivers approximately 5-6 times the force than that of conventional niti archwires. This makes stainless steel wires not ideal for light continuous forces and prone to many adverse side effects for the patient's teeth and surrounding periodontium.[11]

Cobalt Chromium was introduced in the 1950's as well as it's nickel alloy. This nickel alloy provide an advantage over stainless steel in that it was available in 4 levels of resilience. Also, it's strength and formability were able to be modified by heat treatment. Beta-titanium archwires were developed in the 1970's and they provided good formability like stainless steel archwires but contained a huge advantage by delivering lower forces. They also have the ability to be welded, but unfortunately, they have a higher incidence/tendency to fracture and have a very high coefficient of friction.[11]

Niti conventional alloy was developed in the 1960's which exhibited a shape memory effect. This wire contains a 50:50 composition of nickel and titanium and has a large working range and low elastic modulus in comparison to other wires.[11] This shape memory effect helped substantially in initial phases of treatment because when it was heat-treated and deformed into a new shape, the material remembered its shape before heat-treatment while delivering light continuous forces. While this wire was the closest thing to ideal, it still exhibited limited formability and high friction forces.

In the 1980's the 2 super-elastic niti alloys were developed. Each of these archwires were very similar to the conventional niti archwire in that they possessed the shape memory effect while also being super-elastic. Rather than being heat treated, upon distortion and insertion into the patient's mouth, the warmth from the patient's mouth activates the appliance and begins to return to its original shape. This very clinically relevant and useful characteristic is called thermo-elasticity. These wires were manufactured to establish its shape memory at body temperature and its force plateau with optimal tooth movement rates.[11]

Although the materials are obviously very important to the Orthodontic practitioner, the treatment mechanics have possibly an even greater effect on achieving optimal forces and rate of tooth movement. The conventional bracket system which has been most widely accepted and successful has been the edgewise system. In 1928, Angle developed the edgewise bracket system where a slot was created in the bracket to help create 3-dimensional control of the tooth. This control was obtained by using a rectangular slot with a rectangular wire fitting into it. Although this idea was a huge breakthrough for the field, there was still a large amount of clinician chair time spent bending wires to get teeth to move in the desired direction. In 1979 Andrews took this idea to even new height by having each bracket with a specific prescription that would move the teeth into its ideal occlusal position. This removed the need for a large amount of the bends needed using original edgewise brackets.[11]

More recently, clear aligners were introduced mostly as an aesthetic alternative to fixed braces. Clear aligners are mostly clear to translucent and are somewhat flexible. This flexibility allows for the aligners to slowly engage the teeth and for transmission of forces. The plastic polyurethane material that is usually used allows for these characteristics. Other popular material used in the fabrication of aligners are poly-vinyl chloride (PVC) and polyethylene terephthalate glycol (PETG). PVC aligners are very elastic and when they are exposed to moderate loads causing plastic deformation. Because of this elasticity, the optimal wear time is around 14 hours per day, which is much less than the usual 22 hours per day recommendation. A force is generated and transferred to the teeth from the deformations in the aligner. PETG is less elastic but is very time and wear resistant. It is a light very clear material with some elasticity allowing for gradual tooth movements. Both materials require a different thickness of aligner for differing tooth movements but never exceed 1mm.[12]

Aligners have changed the field of orthodontics. More and more patients are willing to undergo orthodontic treatment as a result of this treatment option which is becoming more and more viable. More and more requests are coming from professional athletes and those in the show business, as well as from adults and adolescents. Some of the reasons for this are the esthetic alternative to bulky metal braces and the ability to remove the appliance. However, compliance is needed for aligners to be successful and so orthodontists need to be realistic in how they can confidently recommend this treatment method to. They also need to understand that although aligners have many improvements still needed, compliance is often one of the main reasons that projected movements aren't tracking as planned. Extensive and careful treatment planning and diagnosis by the clinician is needed to have successful outcomes with aligner therapy.

Like braces, aligners have evolved in an attempt to improve tooth movements. The idea of aligners first came out in the 1940's but this first generations success was limited and it's clinical use was almost impractical. A laboratory class I occlusion wax up was used for fabrication of this pliable rubber appliance. Only minor tipping movements could be achieved. The first invisible retainer was developed thirty years later in the 1970's, but still, the same idea of pre-positioned teeth on a study model was used. Just like 30 years previous, a new set-up had to be created for every tooth movement. And with the same idea yielded the same results, achieving only minor tipping movements.

Even until the early 90's, the only change within the aligner system was the use of interproximal reduction or filing small amounts of enamel between teeth to created space. Even then, the technology had not been invented and a new impression was needed at every visit to create a new set-up.[8]

It wasn't until 1999 that Invisalign® system used computer-aided design (CAD) as well as computer-aided manufacturing (CAM) which really removed the impartibility of using aligners. Doctors could now take a single impression and create multiple teeth set-ups off of it. This system has gone through 3 generations of aligners to get where it is at today, each time evolving to attempt to improve the ability to move teeth. First generation aligners relied alone on the aligner to move the teeth without the use of any sort of attachments of elastics.[8] In a study by Djeu et al[13], 96 patients were divided into 2 groups. 48 patients were treated with first generation aligners and 48 with conventional braces. The American Board of Orthodontics phase III examination evaluated posttreatment records compared to pretreatment records. Treatment outcome, duration, strengths and weaknesses of Invisalign in comparison to braces. Results showed that Invisalign did not treat malocclusions as well as braces. Invisalign cases lost 13 more Objective Grading Score points than the braces group and the passing rate was 27% lower. Consistent lower scores were seen for Overjet, occlusal relationships, buccolingual inclination and occlusal contacts. The largest deficiencies were seen in Invisalign's inability to correct large anteroposterior discrepancies as well as occlusal contacts. However, Invisalign demonstrated the ability to consistently close spaces, correct marginal ridge height and anterior rotations. At this stage of aligners evolution clinicians really had to use judgement into which patients would be able to be predictably treated using this modality.

Second generation aligners were developed shortly after where the use of attachments as a well as inter-maxillary elastics were highly encouraged.[8] Clinicians still had to request composite buttons to be placed on the facial surface of the teeth instead of the manufacturers placing them automatically where they are needed. However limited success was reported with this generation as well with certain tooth movements. In 2008-2009 Kravitz et. al[14] performed a study to evaluate the effectiveness of second generation Invisalign aligners with the use of attachments and interproximal reduction (IPR) to rotate canines. A total of 53 canines were treated either with attachments only, with IPR only and with Invisalign only. The final treatment outcomes were compared to the predicted virtual post-treatment outcome using Invisalign's measurement software called ToothMeasure. The result showed that the treatment by all 3 groups only achieved 35.8% mean accuracy of canine rotation. Interestingly there were no significant differences between the 3 groups. This showed that attachments introduced in the second-generation aligners did not seem to improve overall treatment accuracy in the rotation of canines. When studying other tooth movement Krieger et al.[15] found that second generation aligners showed the ability to correct minor anterior crowding, however a large discrepancy in its ability to reduce overbites.

Changes were obviously still needed in the way aligners delivered force in order for them to have better control of tooth movements and to be a viable treatment option for orthodontists. The biggest difference with this new generation of aligners is in the way it attempts to use attachments in similar ways conventional brackets produce force on the teeth.[8] Third generation aligners now have attachments automatically built into them where certain movements are needed such as extrusions, de-rotations and when any sort of root movements are needed. When root torque is needed indentations are created in the aligners as well which place increased pressure on specific parts of the crown to create a moment of couple resulting in torque. Practitioners can also modify or request for non-precision attachments to be placed on teeth. Ellipsoid, beveled and rectangular attachments are very common types of attachments. Ellipsoid attachments have been recommended by Invisalign® to be used for all teeth minus molars.[14] When used singly they are meant to act in the same manner that wider brackets do with fixed braces and are meant for greater rotational control. In pairs these attachments are meant to help with root movements by creating a moment of couple to upright roots as well as to achieve bodily movements through creating a moment of couple and moment of force. For extrusion or intrusion, beveled attachments are recommended by Invisalign®. Just like fixed brackets they have an active border which should limit the slipping between aligner and tooth, resulting in teeth tracking as planned. For large mesio-distal movements and sometime bodily movement, rectangular attachments are recommended by Invisalign®. In conventional edgewise fixed braces, the clinician will progress through a series of archwires from light and flexible to stiffer, such as niti to Stainless Steel. Aligners are used in a similar way using attachments. To start off the attachments are not fully engaged but become more and more engaged and active as treatment progresses.

Many 3rd generation aligner systems are in use today which use different material but when put in the hands of a proficient clinician, many of these systems have reported successful outcomes. A study by Ercoli et al[12] tested treatment outcomes and highlighted the material properties of the Nuvola and Fantasmino systems. Navulo aligners are made of PETG and Fantasmino aligners are made of PVC. As explained previously, both differ in characteristics such as elasticity and wear resistance. The results of the study confirmed that differences were seen throughout treatment such as higher performance with Fantasmino system but less compliance due to bulkier material size, however both materials showed good treatment efficiency. This study solidified the need for good treatment planning and diagnosis on the part of the Orthodontist in choosing when aligners are a viable treatment option.

Although the third-generation aligners have evolved significantly both in mechanics and material, there are still very few advantages of using Aligners when compared to fixed appliances. Other than esthetics, some reports of decreased ORR[16] and the ability for the patient to remove the appliance, there are very few advantages to using aligners over conventional therapy, and therefore less research is focused on these advantages. Probably the main advantage with Aligner Therapy is the ability to have continuous, light forces more often than with conventional fixed braces. This would lead some to believe that this would lead to a reduction in adverse side effects such as ORR and possibly even an elimination of it in the future. A study done by Iglesias-Linares et al[17] took 372 patients treated with either Invisalign of fixed appliances and root resorption following treatment was analyzed. Interestingly, no significant difference was found between the type of appliance use and the predisposition for Orthodontically induced external apical root resorption.

Although root resorption still occurs with aligner therapy many studies suggest that the prevalence and severity is usually less than with fixed appliances. Yuan et al[16] compared the prevalence and severity of apical root resorption when comparing aligner therapy with fixed appliances using CBCT. 373 roots from the 6 anterior maxillary and mandibular teeth from 70 patients were analyzed. The prevalence of root resorption in the clear aligner group was 56.3% and the severity was 0.13 ± 0.47 mm. For the fixed appliance group the prevalence of root resorption was 82.11% and severity was 1.12 ± 1.34 mm. The fixed appliance group was significantly greater in both categories.

With the recent advent of human mouth model force systems, force being placed on the teeth can be determined with great accuracy. A study performed by Badawi et al[18] tested a high canine malocclusion on a human mouth models using transducers, which measured the forces and moments acting on the canine and adjacent teeth using passive and conventional ligation technique. The main highlight of this study was the mean error of force between the 14 transducers was only 1.54%. As a result many studies have compared the forces placed on orthodontically treated teeth while simulating many types of fixed and aligner therapy. One such study by Duong and Kuo[19] compared the load deflection rates (LDR) of 17^2 Stainless Steel (SS) wires, 17^2 niti wires and 0.030 mm clear aligner material when applying a 0-10% strain. The results showed that the aligners showed a greater LDR than the niti wire, but less than the SS, also meaning a lower initial force level than the SS but a higher level of initial force that the niti wires.

The main disadvantage of aligner therapy is the difficulty in achieving many Orthodontic tooth movement when compared to conventional fixed appliances and as a result, many studies focus on these comparisons. In facts, many orthodontists report that in order to finish 70-80% of their Invisalign cases mid-course correction, refinements or conversion to fixed appliances are needed. Many studies have been published evaluating which specific movements are less effective at treating with aligners. Many other studies focus on factors that could be attributing to these shortcomings such as mechanics, material properties, thickness and manufacturing process.[19]

Some of the more common movements that aligners have struggled to achieve are extrusion, torque, large rotational and bodily movements. Studies comparing achieved vs predicted tooth movements using aligners have demonstrated 29.1% in canine rotational movements, 29.6% in extrusive movements, 37.6% in labial crown movements and 41% for total tooth movement accuracy.[11] In a follow-up study done by Kuncio et al, comparing retention accuracy of Invisalign and conventional braces showed that Invisalign cases even had more relapse, particularly in the maxillary anterior region.[20] This result however is more likely to have less to do with the mechanics of the clinician and more to do with a lack of compliance from the patient.

In a study done by Patterson et al.,[21] Invisalign was used on 80 adult patients to do comprehensive orthodontic treatment on class I and class II malocclusions. Predicted tooth movements into ideal occlusion were compared to achieved movements using Invisalign. The parameters being evaluated were according to the American Board of Orthodontics Model Grading System, including alignment, marginal ridges, buccolingual inclinations, occlusal contacts, occlusal relationships, overjet and interproximal contacts, overbite and AP relationships. After treatment was completed improvements were seen in only total ABO scores, alignment and interproximal contacts. Although there were improvements, they were still less than the expected outcomes with the total ABO scores in the class I and class II cases improving by 21.9 and 12.86% respectively. Alignment improved by 64.99 and 66.60% and interproximal contacts 75.48 and 85.92%. The amount of overbite correction achieved was 28.8% and 38.9% for the class I and class II groups and only 6.8% over overbite correction for the class II group.

Another study done by Kravitz[22] further solidified the results from Patterson's study. 37 patients and a total of 401 anterior teeth were evaluated which were treated with Invisalign and measured on virtual treat models. The amount of predicted tooth movement was also compared to the amount of achieved after treatment. Movements studied expansion, constriction, intrusion, extrusion, mesiodistal tip, labiolingual tip and rotation. The mean accuracy of tooth movement was 41% with the least accurate movement was extrusion at 29.6% with maxillary central incisors at 18.3% and mandibular incisors at 24.5%. Mesiodistal tipping of mandibular canines only had 26.9% accuracy. Rotational movements all achieved around 50% accuracy except for maxillary and mandibular canines which were 32.2% and 29.1% respectively. This article contributed these findings to the fact that the crowns of canine teeth are round and smooth when compared to teeth like incisors. Accentuating this even farther the article showed that rotational movements greater that 15 degrees decreased the accuracy significantly. These numbers for the canines can be somewhat misleading when compared to a whole unit as over one quarter of all teeth achieved greater than 70% accuracy of movements.

In order for aligners to produce movements such as extrusion the aligners need to be able to apply force by grabbing an undercut surface. Commonly, in cases such as an open bite, these extrusive movements are needed on incisors which have very smooth surfaces and minimal undercuts making it even more difficult. Even with the use of attachments, sometimes not enough force is able to be produced because the aligner poorly grasps the tooth during vertical pull. As mentioned in Kravitz study,[14] extrusive movements had the least mean accuracy rates, particularly in the maxillary and mandibular incisors central incisors. Many other studies have reported larger deviation and lower predictability in vertical movements that other movements.[23]

To improve the predictability of this tooth movement, placing a gingival bevel rectangular attachment near the incisal edge of the aligner has been recommended in The insiders Guide to Invisalign Treatment Textbook by Barry J. Glaser.[24] Placing it more incisally is where the material is the stiffest and provides for a better grip. It has also been recommended that even when minor extrusions are needed, overcorrection, attachments and auxiliaries are needed. Other methods such as using elastics connected to the button on the tooth or combining extrusive movements with predictable movements such as retraction to help improve the accuracy and predictability. These suggestions have not been published through research but are recommendations by doctors heavily involved in many Invisalign® cases. However, a study done by Savignona[25] compared extrusion on a central incisor with different attachment designs in different locations. The 4 different groups were a rectangular palatal attachment, rectangular buccal attachment, ellipsoid buccal attachment and no attachment. The palatal rectangular attachment displayed the most tooth displacement with the lowest undesired forces. The no attachment group displayed the least amount of tooth displacement. However, placing a palatal attachment is not always a viable option due to overjet running into the mandibular incisal edges.

As mentioned previously, bodily movement is also a very difficult movements to achieve with clear aligners. Even aligner companies, who at all measures are trying to promote their products warn practitioners that bodily movements are more challenging and complex and large movements may be more suited with conventional fixed braces. Brezniak[26] expounded on this principle by explaining that in order for bodily movement to occur a force and a moment are needed. This moment is produced in edgewise fixed braces when there is full engagement between the archwire and the slot which contacts the opposite walls of the bracket slot producing a couple, which is essential for bodily movement. Putting this even further into context for us, Brezniak explains that in order to produce 100 g of bodily movement on a central incisor, likely the force will be applied roughly 10 mm away from the center of resistance, resulting on a need of 1000 g of force to produce this desired movement. One may think that since the clear plastic appliance envelops the whole crown it should be able to produce a lot of force. The reality is, however, that even with attachments, physical law of the basic structure and behavior of the clear plastic aligners are not able to produce such force without being distorted significantly.

A study by Cortana[27], which will be expanded on further ahead, shows us that forces of even half of the 1000 g example distorted the aligner significantly, causing other undesired forces on the teeth. Most of the force from the clear plastic aligner is exerted at the occlusal part and is reduced very quickly as you move gingivally. The distortion usually occurs in the occlusal part with the most force resulting in occlusal forces leading to intrusion. This phenomenom is known as the water melon seed effect. Extrusion is then needed, which again is an almost impossible task depending on the amount needed.

Some clinicians including Dr. Glaser have reported having success with bodily movement following some recommendations. To move central incisors bodily either optimized root control attachments or vertical rectangular attachments to provide additional push surfaces in combination with virtual gable bends requested in each Clincheck. Since the full extent of the gable bends will not be expressed, Dr. Glaser recommends adding an additional 15 degrees tip for each tooth, resulting in 30 degrees.[21]

Another biochemical limit that has not quite been overcome is the control of root movements, such as the labiolingual inclination of incisors, or torque**.** One of the reasons for this is the clear aligner software is only set up to display crown movements rather than roots, not predicting the patient's final occlusion as a result. Torquing forces require a tipping force which is caused by deformation of the gingival portion of the aligner. A resulting force is also needed which is created when the tooth moves against the incisal edge of the inner opposite surface. Because the gingival portion of the aligner is less stiff and more elastic, the force needed to produce torque is very difficult. The more the root needs to move, the more difficult this movement becomes.

In a study by Jiang et al[28], incisor movements of 69 patient who underwent non-extraction clear aligner therapy were studied. CBCT was used to measure the tooth movement accuracy of pure tipping, controlled tipping, translation and torque. Pure tipping was very predictable at 79% and the least being torque at 35.21%. Labial root torque was significantly more predictable than lingual, and labial movement of the mandibular incisors was significantly more predictable than in the maxilla.

To help improve this predictability, the use of power ridges are usually recommended.[24] Power ridges are meant to deliver force at specific points, usually at the gumline on the facial surface and tooth edge on the palatal surface to cause lingual root torque. However, although power ridges produce a greater moment than attachments, similar accuracy has been shown with the use of attachments, so either can be used. Another limitation with the movement is that the aligner tend to lift up and not have a close adaptation around the tooth, leading to distortion of the appliance and therefore unwanted forces, mainly intrusion.

A study done by Cortona et al[27] further expounds on the need for the use of attachments for rotational movements on smooth surface teeth. Lower right second premolar was rotated 30 degrees and aligners without attachments, single attachment on the buccal surface of the rotated tooth and then 3 attachments placed on the buccal surface of the rotated premolar and both adjacent teeth were considered. Both 1.2 and 3.0 degrees of activation were performed making a total of 6 groups. The amount of rotational movement, stress placed on the periodontal ligament, aligner deformation and stress on aligner were measured and discussed. Overall, the rotational movements were 0.23 degrees higher in the attachment's groups than those without attachments. While the group with one attachment as well as 3 attachments that were activated 3 degrees produced the most rotational movement (0.61 and 0.54 degrees), they also placed the most stress force on the periodontal ligament with forces of 418 g/cm^2 and 560 g/cm^{2,} respectively, both of which are well above optimal force levels and can cause hyalinization of the periodontal ligament. The results suggested that the optimal amount of activation of aligners was 1.2 degrees and should not exceed 2 degrees of rotation for each aligner. These values seemed to deliver force levels on the periodontal ligament that fit with the optimal force paradigm of biology of tooth movement.

The study also demonstrated that all aligners that were activated by 3 degrees exhibited a loss of anchorage on the adjacent first premolar, with lingual displacement occurring in all groups ranging from 0.0085-0.035 mm. Unpredictably intrusive forces were seen on the ipsilateral 2^{nd} molar in the attachment groups which were activated by 3 degrees. The study suggests that the most likely result of these lingual and intrusive forces are because of the increased activation and mismatch between target tooth and aligner, leading to stiffness increase in the aligner during wear, and leading to these undesired and unpredictable movements. The results showed that with more attachments there was greater amounts of these undesirable movements leading to greater aligner stiffness, further supporting this phenomenon. Other interesting results showed that the attachment groups that were activated by 3 degrees showed the highest amount of aligner deformation of 0.28 mm at the second molar with a mean buccal displacement of this tooth of 0.0285 mm per aligner. The fact that the greatest aligner deformation occurred in the most distal portion of the aligner begs the question as to whether material, shape and mechanical properties of the aligner play a more important part in the aligner than most think. The increase in stiffness during activation also suggests that elasticity in the aligner material may be a key factor in influencing aligner therapy outcomes.

With material elasticity as a component speculated to be a part of aligner that needs to be improved, A study done by Drake et al[29] wanted to see whether the lack of accuracy rates were possibly due to aligner material fatigue over the two-week period for each aligner prescription. If this were the case, then one could predict that replacing aligners with the same prescription each week would increase the rate of tooth movement. A control group who changed their aligners every two weeks were compared to the study group of 15 adults with minor incisor malalignment who were the weekly aligner group. No significant difference in the amount of tooth movement was found between the groups in the 8-week period. The conclusions suggests that although 4.4 times more tooth movement occurs within the first week of aligner wear, material fatigue does not play a significant role in the rate of tooth movement.

A study by Barbagallo et al.[1] found contradicting evidence however in the study of removable thermoplastic appliance material. Eight patients with moderate malocclusion and a palatally positioned upper first premolar wore a series of aligners for 8 weeks. Each aligner was to be worn for 2 weeks with 0.5 mm of movement designer for each. The pressure against the palatal surface of the upper first premolar was evaluated at the insertion of each aligner along with the retrieval. The results showed a rapid force diminish with a mean insertion force of 5.12 N and a mean retrieval force of -2.67 N with a mean force of 1.12 N over the 2-week period. They went on to explain that the force change was likely not linear but more realistically exponential. There are a couple explanations as to this dramatic reduction in force over two weeks. Optical microscopic analysis revealed that considerable changes were seen in the properties of the aligner materials after 2 weeks of intraoral wear. Wear of contact points, cracking, distortion, wear of contact points, calcified proteinaceous biofilms, abrasion of cusp tips and increased hardness of buccal segments all were present after two weeks. Another explanation is that with time passage the tooth moved nearly 0.5 mm away from the palatal segment leading to a decreased force level. However with both these explanations in mind the study concluded that they are not convincing enough to account for the amount of diminished force seen and that greater elasticity and springiness is needed in the aligner material.

With studies suggesting that greater elasticity and springiness is needed in clear aligners, one may wonder whether the physical design of the aligner would aid in this cause. A study done by Hahn et al[2] tested the forces delivered by 2 different materials of Aligner material made with 2 different thicknesses. Once again, this study confirmed that the materials showed differences in the force values of the same thickness once again confirming that material itself can be a contributing factor to unideal forces leading to unideal rate of tooth movement. The aligners with greater thickness were overall significantly higher than those with thinner material confirming the question as to whether the physical design of the aligner is important. Perhaps the most interesting finding though is that the tipping forces produced by the thicker 1.0 mm aligners were 3-11 times higher than the ideal forces for tooth movement put forth by Proffit[3] and the thinner 0.8 mm aligners delivered forces that are 3-8 times too strong.

This creates the question as to whether there is a way to alter the physical design of the aligner material to have the elasticity and springiness needed to reduce deformation and force decay, while at the same times producing ideal forces on the teeth for tooth movement. The aim of my study will be to test whether placing a loop design overtop each tooth which span from tooth to tooth will provide more flexibility and lighter forces when compared to traditional aligners of the same thickness. Different dimensions of the loop design will be tested on a benchtop ATI Force sensor which will measure the forces in the X, Y and Z axis placed on this new design of a 2-degree rotated canine and then molar separately. Once again, the hope is that just as niti wire allows for more flexibility and lower forces in the arch wire than Stainless Steel, a loop built into the clear aligner tray could possibly provide the same benefits when compared to traditional aligners.

These lower forces could hopefully come close to ideal forces on teeth are create optimal tooth movement with reduced unwanted side effects such as ORR.

Summary

As has been demonstrated in the literature, many movements such as extrusion, torque, rotational movements and bodily movements can be more difficult to achieve. However, with proper mechanical technique such as the proper use of attachments many doctors have demonstrated proficient treatment. As the material and mechanics have evolved, so has their ability to move teeth. With improvements in ability to measure force systems and in aligners themselves, it can be implied that aligner therapy will continue improve as well. With the increasing demand for clear aligners today, it would be wise for clinicians to, rather than avoiding them due to fear of the shortcomings found in research, but to strive to become proficient in clear aligner therapy.

CHAPTER TWO

FORCE COMPARISON OF ROTATIONAL TOOTH MOVEMENTS FOR LOOP-DESIGN AND TRADITIONAL ALIGNERS

Abstract

Objective

This study aims to evaluate the force (F) and torque (Tq) exerted on a rotated canine and molar by two different aligner systems. An ArchForm loop clear aligner (AFL) will be compared to a traditional clear aligner (T) with the aim of seeing a reduction in F and Tq placed on the teeth. This reduction in F could possibly decrease the incidence of orthodontic root resorption (ORR), while creating more effective forces for tooth movement at the same time.

Materials and Methods

Two types of T aligners varying by material thickness were compared to two types of AFL aligners varying by loop width. All aligners were designed by ArchForm Design Software. A canine and molar were tested separately for both F and Tq in the X, Y and Z axis. The test tooth was cut out of a study model and mounted onto a load cell. The aligners were individually placed over the model, the test tooth was rotated 2 degrees mesio-buccally and the F and Tq recorded. The methods are broken down into the following stages: 3D model fabrication, aligner fabrication, testing and statistical analysis.

Results

To differentiate test results based on the X, Y and Z vectors of force and torque, ANOVA tests were performed. To further compare each aligner type to each other a Games-Howell Post-Hoc test was run. Statistically significant differences in F and Tq were seen among aligner groups for each tooth type and axis.

Conclusion

1) There was statistically significant difference in F and Tq among aligner type for each tooth type and axis.
2) There was a statistically significant reduction in F and Tq in all AFL aligners when compared to the T aligners except for in the .030 T and both AFL aligners for F in the molar Y-axis and Tq in the molar X-axis.
3) The width of the loop within the AFL aligners had a statistically significant effect on the large majority of the F and Tq values.
4) The material thickness within the T aligners had statistically significant effects on all of the F and Tq values for molar teeth.

Introduction

Optimal tooth movement within the field of Orthodontics has been described as moving a tooth as quickly as possible with the least amount of side effects to the tooth and surrounding tissues. One of the main adverse effects that is almost consistently seen in orthodontic tooth movement (OTM) is root resorption. For many years the orthodontic specialty has been developing different mechanics to move teeth at this optimal rate and with the least amount of side effects. One of treatment methods that strive to produce optimal tooth movement is clear aligners. Aligners are thin, transparent shells of polyurethane plastic material that move teeth in small increments if worn diligently. However, many authors conclude that aligners underperform when compared to conventional fixed appliances in a few tooth movements such as torque, bodily movement, large rotations and extrusion.

Although some clear aligner studies have shown that there is a reduction in force distributed to the periodontal ligament (PDL), resulting in less root resorption, in clear aligners when compared to traditional braces, other studies have shown that clear aligners of varying thickness still greatly exceed optimal force ranges for optimal tooth movement as recommended by Proffit.[1,2,3] Another flaw in the traditional clear aligner system is the lack of elasticity of the material. When the elastic limit of the material is exceeded and an aligner is being forced to engage fully on the teeth, plastic deformation of the material can occur.[2]

To overcome these pitfalls that traditional clear aligners possess, an innovative AFL design of clear aligners has been developed and refined. AFL aligners have been manufactured similarly to traditional clear aligners but contain interproximal cuts on both buccal and lingual surfaces of the teeth in which movement is desired. Also, additional loops of plastic extend above the gingival margin both buccally and lingually which begin mesial and distal and converge in the center of the applicable teeth. The theory is that the alterations to the physical design of the aligners will allow the aligners to more accurately engage the teeth with little to no deformation. Another theory is that the added elasticity will produce lower, more optimal force distribution to the teeth and PDL, ultimately leading to more favorable tooth movement with less ORR.

The purpose of this study is to evaluate the F and Tq exerted on a rotated canine and molar by varying AFL and T aligners.

Null Hypothesis

There was no statistically significant difference in the F or Tq produced between T and AFL aligners in either a two degree rotated maxillary canine or molar.

Significance of Study

Because of the alteration to the physical design of the aligners the hope is that there will be a reduced force distribution to the teeth in which desired movements are targeted. If the patient had significant movements needed on all the teeth, as such in a comprehensive case, then the alteration to the aligners would be excessive with interproximal, incisal slits and loops throughout the whole aligner. The result would be an excessive reduction in force, a reduction which may be too large to make the trays clinically relevant or effective at moving the teeth in an effective and timely manner. AFL aligners are more clinically relevant in limited case situations where a minimal amount of teeth need correction. This way the tray will only be altered to a degree in which optimal force levels can be maintained.

The ultimate aim is that the reduction of force along with the increased elasticity will result in a reduction of ORR, treatment time as well as patient discomfort.

Materials and Methods

3D Model Fabrication

Two identical maxillary typodont models (M-1560, Columbia Dentoform Teaching Solutions) were needed to allow for testing of the canine and molar separately. These were poured up with a proper base created as well. These models were deemed close to ideal according to Andrew's 6 Keys of ideal occlusion. These models were evaluated and agreed upon by two dentists. A 3D scan was obtained from these models using the iTero Element 2 scanner (iTero Element 2, Align, Inc. A stereolithography (STL) file was created from the scan and uploaded to Blender software (Blender, version 3.2.2). Conventional attachments measured 2mm horizontally and 3mm vertically were added to the buccal surface, centered mesially and distally, to teeth #4-14 to imitate a real aligner case trying to promote rotational forces on teeth. 3D models were then printed from the STL files using a Formlabs 3 printer (Formlabs Inc). Once the master casts were printed they were removed from the printer and placed in a Formwash rinse for 20 minutes. The models were then cured for 20 minutes in a FormCure unit automatically timed, at a temperature of 40 degrees Celcius.

Aligner Fabrication

The master cast was centered in the embedding plate of a Scheu MiniStar vacuum-forming machine (Scheu Inc.), The vertical line passed through the central incisors and the horizontal line passed through interproximal contacts of the 1st and 2nd bicuspids of the right and left quadrants. Clear aligner sheets from Zendura (9169) (Bay Materials, LLC) were used (1mm x 125mm circle) and were secured into the Scheu machine. The recommended code was selected, prompting a pressure $\geq$ 4 bar, a heating time of 35 seconds for .030" aligners and 40 seconds for .040" aligners and a temperature of 220 Celcius. One hundred and eleven .040" and thirty-seven .030" thickness clear aligners over the 3D printed models were created. Thirty seven of the .040" AFL aligners with a 2.5 mm loop width and another 37 .040" AFL with a 2.0 mm loop width were created also. These dimensions were created using ArchForm Alignermaker software v. 1.8.1, (ArchForm Inc.). This same software controlled the milling of the AFL Loops with a 5-axis pocket NC Desktop milling machine. For the AFL aligners there are four loops total for each rotated tooth. The loops extend both mesial and distal to the adjacent teeth mesial and distal of the tooth being tested and are located on both the buccal and lingual. The lingual loops for both the AFL groups are 2.0 mm in width. As shown in Figure 2 the confluence of the two half loops is at the center of the canine and molar. Each loop is extended to a height of 3 mm above the gingival margin of the tooth. Each of the AFL aligners also have separating cuts inter-proximally on both the mesial and distal sides. These cuts were milled using the Archform software and are 0.5 mm in diameter. These cuts did not remove any of the tray material from the teeth being tested but only the material on the adjacent teeth.

Figure 2. Printed model with AFL aligner and 2 mm X 3 mm buccal attachments seated on the maxillary arch. 2.5mm loop width. Vertical interproximal cuts are seen in the aligners on the mesial and distal of the test tooth #14.

The T aligners were designed so that the material was 1mm gingival to the margin of all the teeth on both the buccal and lingual surfaces. After all the aligners were fabricated, tooth #11 was carefully cut out of the 3D printed model on the mesial and distal sides. The cuts did not impinge on the tooth being tested, but rather will remove a small part of each adjacent teeth (#10 and #12).

Testing

To anchor the model into place a concrete cinderblock was used. Using a concrete saw, a slot in the top, middle section of the cinderblock, with enough room for the model to fit passively with no resistance was cut. Plaster secured the model firmly into place. A load cell (Nano 17-E, ATI Industrial Automation) was placed underneath the model with the sensor arm directly underneath the tooth being tested; in this case it is tooth #11 as seen in Figure 3. When the ATI force sensor was in its correct position it was cemented to the cinderblock for stability. Tooth #11 that was cut out from the model was placed into a .040” T aligner and placed on the study model. The arm of the load cell was manually adjusted so that the tooth was in the same position it was before being cut out of the model. The tooth was then bonded with composite resin (Densply, Inc.) and cured to the ATI force sensor arm for 45 seconds.

Figure 3. Canine tooth fastened to ATI Industrial Automation load cell (Nano-17-E).

For each individual aligner, the aligners were seated fully on the test model, the ATI force sensor was calibrated to zero and then the sensors arm attached to the test tooth was rotated, manually, 2 degrees mesial-buccal. After 5 seconds a photo of the values was taken and then input into excel. The six values recorded were the overall force value in the x, y and z axis, as well as the rotational torque in the x, y and z axis. The force sensor was then manually turned back to zero degrees rotation to its original position. The model was carefully removed. This process was carefully repeated for each of the 148 aligners.

Once all of the data for the canine was collected and recorded the model was removed from the cinderblock and the canine tooth was carefully removed from the ATI force sensor arm. The upper left molar (tooth #14) was then cut out from the second identical master model both mesially and distally using a lab bur, ensuring that no portion of the tooth being tested was removed. The model was stabilized to the cinderblock in the same position as the previous model. All of the same steps mentioned earlier for the canine were repeated for the molar tooth. Table 1 displays the 8 different test groups that were tested varying by tooth type, loop width and material thickness.

Table 1. Eight different test groups vary in either test tooth, material thickness, or loop width. These aligners will be tested separately for F and Tq in the x, y, z axis

Group	# Aligners	Loop Width (mm)	Material Thickness (IN)	Values Tested
1- Molar	37	N/A	0.03	Force X, Y, Z Torque X, Y, Z
2- Canine	37	N/A	0.03	Force X, Y, Z Torque X, Y, Z
3- Molar	37	N/A	0.04	Force X, Y, Z Torque X, Y, Z
4- Canine	37	N/A	0.04	Force X, Y, Z Torque X, Y, Z
5- Molar	37	2.0	0.04	Force X, Y, Z Torque X, Y, Z
6- Canine	37	2.0	0.04	Force X, Y, Z Torque X, Y, Z
7- Molar	37	2.5	0.04	Force X, Y, Z Torque X, Y, Z
8- Canine	37	2.5	0.04	Force X, Y, Z Torque X, Y, Z

Statistical Analysis

The sample size was calculated at 80% power and at an alpha = 0.05. Clinical significance was determined to be 15% or greater difference and was decided by the research committee. Once all aligners were tested, the means and standard deviations were calculated for each aligner type, torque/force and for each X, Y and Z vector. Since results were based off of ranked data, the determination of normal distribution of data was irrelevant. To differentiate test results based on the X, Y and Z vectors of force and torque, Jamovi version 2.2.5.0 was used to run one-way ANOVA tests for each vector. Games-Howell Post-Hoc tests were then used to further compare test results between tooth type, aligner type and torque/force.

Results

The p-values in Table 2 were obtained through the Welch's one-way ANOVA tests. The individual comparisons calculated from the Games-Howell Post-Hoc tests between groups are shown by letters a, b, c and d by the values in Table 2. When two values contain the same letter, no statistically significant difference is observed. Figures 4, 5 and 6 show the mean F (N) and Tq (N-mm) values plotted against tooth and aligner type in the X, Y and Z axis, respectively.

Table 2. Comparison of Force (N) and Torque (N-mm) produced by .030 T, .040 T, 2.0 AFL and 2.5 AFL aligners using one-way ANOVA with post-hoc pairwise Tukeys test at alpha= 0.05.

		.030 T	**.040 T**	**2.0 AFL**	**2.5 AFL**	
Tooth	**Axis- Force (N)/ Torque (N-mm)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-value**
C	**X-F**	2.55[a] (0.311)	2.69[a] (0.455)	0.331[b] (0.0909)	0.508[c] (0.143)	<.001*
	Y-F	-1.37[a] (0.539)	-1.23[a] (0.533)	-0.178[b] (0.0632)	-0.281[c] (0.0753)	<.001*
	Z-F	-1.36[a] (0.805)	-1.11[a] (0.842)	-0.143[b] (0.0458)	-0.161[b] (0.0851)	<.001*
M	**X-F**	1.84[a] (0.792)	2.39[b] (0.407)	0.470[c] (0.0974)	0.710[d] (0.130)	<.001*
	Y-F	0.0424[a,c] (0.301)	0.272[b] (0.226)	0.114[a] (0.042)	0.0589[c] (0.0635)	<.001*
	Z-F	-0.820[a] (0.64)	-1.26[b] (0.789)	-0.0739[c] (0.095)	0.0123[d] (0.165)	<.001*
C	**X-Tq**	45.8[a] (12.1)	41.5[a] (8.07)	5.50[b] (2.06)	8.88[c] (2.52)	<.001*
	Y-Tq	82.9[a] (9.74)	86.7[a] (13.4)	11.0[b] (2.45)	15.4[c] (7.08)	<.001*

	Z-Tq	-23.4[a] (8.04)	-19.0[b] (6.19)	-2.17[c] (0.563)	-3.25[d] (0.986)	<.001*
M	**X-Tq**	0.367[a,c] (8.86)	-5.38[b] (6.98)	-1.14[a] (1.14)	0.664[c] (1.67)	<.001*
	Y-Tq	40.8[a] (17.9)	51.9[b] (8.13)	8.69[c] (1.91)	14.3[d] (2.96)	<.001*
	Z-Tq	-25.2[a] (10.2)	-35.4[b] (9.36)	-12.5[c] (2.25)	-13.9[d] (2.32)	<.001*

a, b, c, d Different letters denote statistically significant difference
*statistically significant difference

The results that can be drawn from Table 2 are:

1) There was statistically significant differences in F and Tq among aligner types for each tooth type and axis.
2) There was a statistically significant reduction in F and Tq in 2.0 and 2.5 AFL aligners when compared to the .040 T aligners. The 2.0 and 2.5 AFL aligners also showed a statistically significant reduction in F and Tq when compared to the .030 T aligners, except for the F in molar Y-axis and Tq in molar X-axis.
3) When comparing 2.0 and 2.5 AFL aligners, statistically significant differences in F and Tq were observed in all groups, except for the F on the canine Z-axis.
4) When comparing .030 and .040 T aligners, statistically significant differences in F and Tq were observed in all axis of molar teeth. The only statistically significant difference seen between T aligners for the canine tooth was the Tq in the Z-axis.

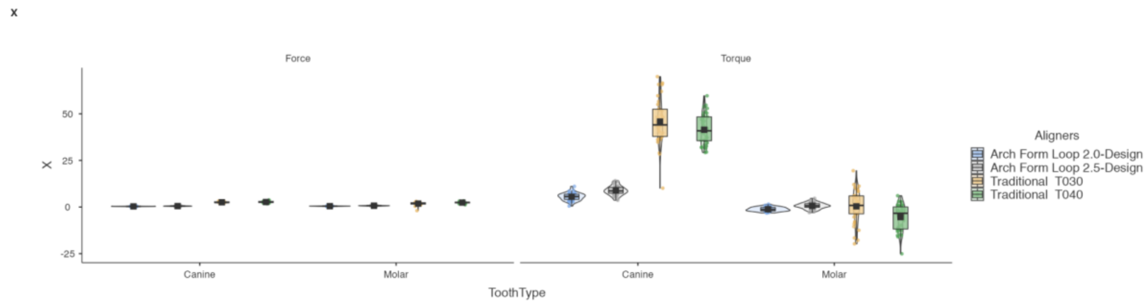

Figure 4. X-Axis F (N) and Tq (N-mm) plotted against tooth type (canine and molar) and aligner type (2.0 AFL, 2.5 AFL, .030 T and .040 T).

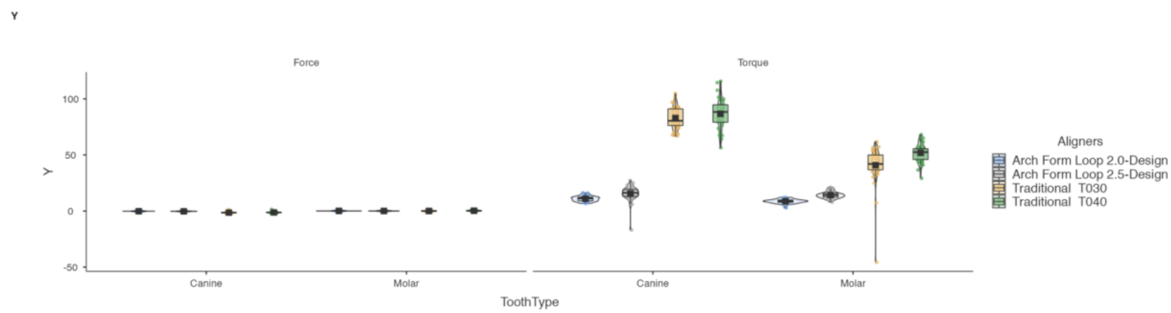

Figure 5. Y-Axis F (N) and Tq (N-mm) plotted against tooth type (canine and molar) and aligner type (2.0 AFL, 2.5 AFL, .030 T and .040 T).

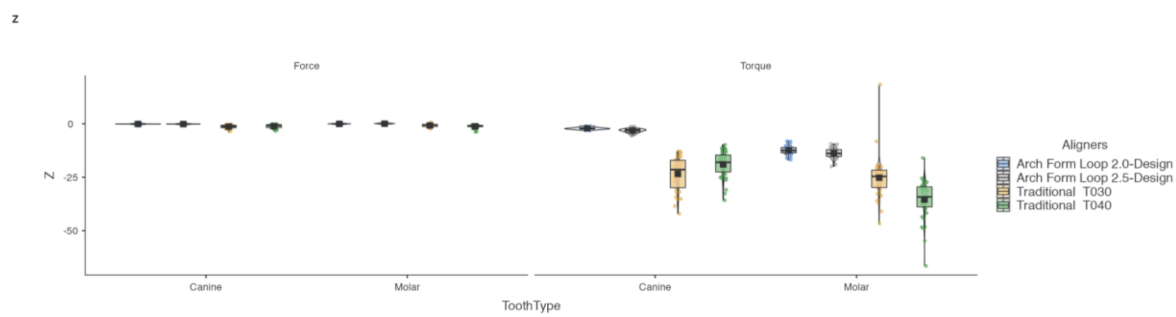

Figure 6. Z-Axis F (N) and Tq (N-mm) plotted against tooth type (canine and molar) and aligner type (2.0 AFL, 2.5 AFL, .030 T and .040 T).

Discussion

To obtain results, Tq and F in the X,Y and Z axis for each of the 4 aligner types were compared against each other on a canine and molar tooth separately. The values were analyzed individually as well as collectively in groups. When comparing the differences in F and Tq between AFL and T aligners, the null hypothesis was rejected for the Tq and F. Statistically significant differences were see in F and Tq values among aligners types for each tooth type and axis.

As for comparing the F and Tq between AFL and T aligners, there was a statistically significant reductions between all .040 T aligners and AFL aligners. The same held true for the .030 aligners except for the F in molar Y-axis and Tq in molar X-axis.

Perhaps more relevant is the fact that not only were most reductions of F and Tq in AFL aligners compared to T aligners were found to be statistically significant, but a large majority of those reductions in F and Tq were much greater than the clinical significance of 15% set forth. When comparing the AFL to the T aligners, the AFL aligners showed a clinically significant reduction in F and Tq in all except for 2.5 AFL vs .030 T aligners for F molar Y-axis and Tq molar X-axis. These comparisons showed a slightly larger F in the 2.5 AFL aligners than the .030 T aligners. This is most likely due to the reduced thickness of material in the .030 T aligner.

The AFL aligners contain interproximal cuts on both buccal and lingual surfaces of the teeth in which movement is desired. Also, additional loops of plastic extend above the gingival margin both buccally and lingually which begin mesial and distal and converge in the center of the applicable teeth. The purpose of these physical alterations to the AFL aligners is to increase the elasticity and reduce the force and torque applied to the desired teeth. As a result, it can be expected that there is clinically and statistically significant reductions in F and Tq in the large majority of the AFL aligners when compared to the T aligners.

When comparing all the variables between both of the AFL groups there was statistically significant differences between all groups, except for the F on the canine Z-axis. As for the comparisons between both types of T aligners, significant differences were seen 7 of the 12 groups. Interestingly, all of the molar values within the T aligners showed significant differences compared to only 1 of the canine values. Thus, the difference in loop width within the AFL aligners seems to have a large effect on the difference in F and Tq values. As expected, this effect shows that in a large majority of the groups within the AFL aligners, a smaller loop width translates to less F and Tq on the teeth. As for the difference in material thickness within the T aligners, in a majority of the teeth the .040 aligners showed an increase in F and T. However, this proves to only have an effect on the molar teeth and not the canines. Perhaps the larger surface area of the molar is what caused the increase in F and Tq to be expressed in the thicker material.

The F and Tq in the .030 and .040 T aligners on the canine in both the X and Y-axis were not clinically significant. Also when comparing the 2.0 and 2.5 AFL aligners the only groups that were not clinically significant different were the F on the canine in the Z-axis and the Tq on the molar in the Z-axis. These 6 groups were the only groups that were not clinically significant and were all between the same type of aligner.

Studies have been conducted and concluded that certain teeth are more difficult and less predictable to move than others. One particular study concluded that round teeth, particularly canines, are the most difficult teeth to achieve rotations with.[18] With a clinically significant reduction of force applied to the teeth with the AFL aligners, perhaps a more gradual de-rotation of teeth will be more predictable in correcting rotations. . Another study suggests that the optimal amount of activation of T aligners is 1.2 degrees and should not exceed 2 degrees of rotation for each aligner. These values seemed to deliver force levels on the PDL that fit with the optimal force paradigm of biology of tooth movement.[23] Perhaps another advantage of AFL aligners is that the movement per tray could be more than the suggested maximum of 2 degrees without exceeding the optimal force levels, thus not increasing likelihood of ORR.

Conclusion

1) There was statistically significant difference in F and Tq among aligner type for each tooth type and axis.
2) AFL aligners showed a statistically significant reduction in F and Tq when compared to .040 T aligners as well as in the large majority of .030 T aligners
3) The difference in the width of the loop within the AFL aligners had a statistically significant effects on the large majority of the F and Tq values.
4) The difference in the material thickness within the T aligners had statistically significant effects on all of the F and Tq values for molar teeth.
5) Further studies are needed to truly see the clinical significance and benefits of this novel aligner design

CHAPTER THREE

EXTENDED DISCUSSION

Study Limitations

The most obvious short coming of the study performed is evident in the p- values seen. Most of the p- values are very convincingly statistically significant being <.001, with some difference in AFL F and Tq values compared to T aligners being up to 10 times less. Although not proven clinically or through research yet, this potentially means that AFL aligners may be not be able to produce sufficient force needed to move teeth. If the physical properties AFL aligners were to be altered more, with larger loop size for example, or more than 2 degrees activation was applied to the aligners then maybe more clinically relevant F and Tq values would be present. However, this has yet to be studied and more research on this topic is needed to prove these assumptions.

Another limitation of this study is that clear aligners mechanical properties and composition can vary from company to company. In this study only single layer, Zendura clear aligners were tested. Other materials from different companies differ from one another is many ways such as the amount of layers, composition and mechanical properties. The forces exerted and results seen may be different than the current study for these reasons.

Although similar results would be expected to be seen with other teeth, definitive conclusions drawn from this study can only be applied to a canine and molar tooth in the upper left quadrant of the maxillary arch. Other teeth vary in size and shape and whether significant or not, differences would be expected if all teeth types were tested.

A final limitation was that although the each tray was removed by hand. Although great care was taken to remove them in a gentle way, it is not guaranteed that some aligners became more distorted during the removal process than others. The molar tooth was tested the first day and then the canine the second day. If one were to guess, the aligners tested the second day would display more distortion, if there were any, due to being removed from the models twice.

Future Study Direction

The options to extend the scope of this research are countless. One of the possible options would be to expand the range of rotation of the test teeth to see if optimal forces could be maintained. This would be a great advantage to be able to activate each tray further with each aligner resulting in quicker and more efficient tooth movement.

Another possibility would be to test the force decay of the AFL aligners to T aligners. It would be hopeful to see a longer continuous force maintenance with the AFL aligners resulting in better tracking of tooth movement. Other possible options include varying the width of the loops further and material thickness could possibly show larger, more optimal force and torque values. Testing differing tooth types would also be of advantage.

Further down the road, a plethora of clinical studies would become available. One of the most beneficial studies would be the comparison of ORR in AFL compared to T aligners.

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Appendices

Appendix A. Raw Data Tq (N-mm)

Material	Tooth	Aligner	Torque	X-Axis	Y-Axis	Z-Axis
AFL 2.0 Aligner 1	Canine	AFL	Tq	6.758	10.279	-2.178
AFL 2.0 Aligner 2	Canine	AFL	Tq	5.918	8.834	-1.715
AFL 2.0 Aligner 3	Canine	AFL	Tq	3.86	8.393	-1.357
AFL 2.0 Aligner 4	Canine	AFL	Tq	0.536	7.031	-1.187
AFL 2.0 Aligner 5	Canine	AFL	Tq	4.674	12.872	-2.295
AFL 2.0 Aligner 6	Canine	AFL	Tq	5.562	8.467	-2.446
AFL 2.0 Aligner 7	Canine	AFL	Tq	6.972	13.074	-2.379
AFL 2.0 Aligner 8	Canine	AFL	Tq	2.393	15.095	-2.758
AFL 2.0 Aligner 9	Canine	AFL	Tq	3.061	10.159	-1.644
AFL 2.0 Aligner 10	Canine	AFL	Tq	4.127	14.425	-2.562
AFL 2.0 Aligner 11	Canine	AFL	Tq	6.864	12.469	-2.518
AFL 2.0 Aligner 12	Canine	AFL	Tq	6.326	12.321	-2.228
AFL 2.0 Aligner 13	Canine	AFL	Tq	4.127	9.644	-2.42
AFL 2.0 Aligner 14	Canine	AFL	Tq	7.129	9.991	-2.527
AFL 2.0 Aligner 15	Canine	AFL	Tq	6.236	7.998	-2.003
AFL 2.0 Aligner 16	Canine	AFL	Tq	7.144	12.023	-2.094
AFL 2.0 Aligner 17	Canine	AFL	Tq	6.236	12.481	-2.544
AFL 2.0 Aligner 18	Canine	AFL	Tq	3.327	11.322	-2.357
AFL 2.0 Aligner 19	Canine	AFL	Tq	7.496	11.913	-2.32
AFL 2.0 Aligner 20	Canine	AFL	Tq	2.893	7.344	-1.121
AFL 2.0 Aligner 21	Canine	AFL	Tq	8.932	10.19	-1.999
AFL 2.0 Aligner 22	Canine	AFL	Tq	7.529	12.042	-2.769
AFL 2.0 Aligner 23	Canine	AFL	Tq	2.861	10.047	-1.78
AFL 2.0 Aligner 24	Canine	AFL	Tq	5.04	16.294	-2.751
AFL 2.0 Aligner 25	Canine	AFL	Tq	11.076	14.56	-3.064
AFL 2.0 Aligner 26	Canine	AFL	Tq	5.821	9.845	-2.877
AFL 2.0 Aligner 27	Canine	AFL	Tq	7.126	12.47	-2.489
AFL 2.0 Aligner 28	Canine	AFL	Tq	3.419	6.687	-1.123
AFL 2.0 Aligner 29	Canine	AFL	Tq	4.76	8.724	-1.53
AFL 2.0 Aligner 30	Canine	AFL	Tq	5.838	8.466	-1.839
AFL 2.0 Aligner 31	Canine	AFL	Tq	5.627	16.043	-3.216
AFL 2.0 Aligner 32	Canine	AFL	Tq	4.278	9.381	-2.062
AFL 2.0 Aligner 33	Canine	AFL	Tq	8.547	12.163	-2.109
AFL 2.0 Aligner 34	Canine	AFL	Tq	5.339	12.057	-3.026
AFL 2.0 Aligner 35	Canine	AFL	Tq	6.71	9.059	-1.065
AFL 2.0 Aligner 36	Canine	AFL	Tq	3.692	11.984	-2.195
AFL 2.0 Aligner 37	Canine	AFL	Tq	5.446	11.299	-1.92

AFL 2.5 Aligner 1	Canine	AFL	Tq	8.654	12.278	-2.212
AFL 2.5 Aligner 2	Canine	AFL	Tq	3.654	18.363	-3.161
AFL 2.5 Aligner 3	Canine	AFL	Tq	8.453	19.103	-3.26
AFL 2.5 Aligner 4	Canine	AFL	Tq	6.895	5.958	-1.256
AFL 2.5 Aligner 5	Canine	AFL	Tq	6.892	19.65	-5.704
AFL 2.5 Aligner 6	Canine	AFL	Tq	9.23	18.973	-4.091
AFL 2.5 Aligner 7	Canine	AFL	Tq	9.026	14.376	-3.069
AFL 2.5 Aligner 8	Canine	AFL	Tq	7.712	14.687	-2.552
AFL 2.5 Aligner 9	Canine	AFL	Tq	8.615	10.453	-1.996
AFL 2.5 Aligner 10	Canine	AFL	Tq	11.375	15.181	-2.763
AFL 2.5 Aligner 11	Canine	AFL	Tq	10.831	19.088	-3.839
AFL 2.5 Aligner 12	Canine	AFL	Tq	6.457	-16.825	-2.719
AFL 2.5 Aligner 13	Canine	AFL	Tq	10.547	27.205	-4.764
AFL 2.5 Aligner 14	Canine	AFL	Tq	7.956	12.725	-2.265
AFL 2.5 Aligner 15	Canine	AFL	Tq	13.292	22.692	-4.224
AFL 2.5 Aligner 16	Canine	AFL	Tq	6.041	12.863	-2.475
AFL 2.5 Aligner 17	Canine	AFL	Tq	8.52	13.984	-2.529
AFL 2.5 Aligner 18	Canine	AFL	Tq	9.091	16.22	-3.039
AFL 2.5 Aligner 19	Canine	AFL	Tq	4.51	15.081	-2.98
AFL 2.5 Aligner 20	Canine	AFL	Tq	7.418	18.813	-3.2
AFL 2.5 Aligner 21	Canine	AFL	Tq	9.134	16.499	-2.892
AFL 2.5 Aligner 22	Canine	AFL	Tq	11.938	10.905	-2.563
AFL 2.5 Aligner 23	Canine	AFL	Tq	7.821	17.484	-3.367
AFL 2.5 Aligner 24	Canine	AFL	Tq	10.537	25.012	-4.396
AFL 2.5 Aligner 25	Canine	AFL	Tq	13.758	20.651	-3.606
AFL 2.5 Aligner 26	Canine	AFL	Tq	10.812	19.289	-4.894
AFL 2.5 Aligner 27	Canine	AFL	Tq	14.091	19.715	-5.088
AFL 2.5 Aligner 28	Canine	AFL	Tq	10.327	13.164	-3.275
AFL 2.5 Aligner 29	Canine	AFL	Tq	5.289	6.083	-1.363
AFL 2.5 Aligner 30	Canine	AFL	Tq	10.37	17.016	-3.925
AFL 2.5 Aligner 31	Canine	AFL	Tq	8.661	14.382	-2.841
AFL 2.5 Aligner 32	Canine	AFL	Tq	13.147	17.796	-4.222
AFL 2.5 Aligner 33	Canine	AFL	Tq	5.468	13.783	-2.378
AFL 2.5 Aligner 34	Canine	AFL	Tq	6.675	12.869	-2.953
AFL 2.5 Aligner 35	Canine	AFL	Tq	8.452	14.321	-2.901
AFL 2.5 Aligner 36	Canine	AFL	Tq	9.462	16.944	-3.426
AFL 2.5 Aligner 37	Canine	AFL	Tq	7.529	23.052	-3.958
T 030 Aligner 1	Canine	T	Tq	59.695	90.025	-35.319
T 030 Aligner 2	Canine	T	Tq	48.323	91.064	-34.364
T 030 Aligner 3	Canine	T	Tq	65.675	73.932	-18.327
T 030 Aligner 4	Canine	T	Tq	48.118	78.582	-23.335
T 030 Aligner 5	Canine	T	Tq	43.193	80.314	-21.448
T 030 Aligner 6	Canine	T	Tq	47.471	77.892	-25.05
T 030 Aligner 7	Canine	T	Tq	56.61	80.915	-21.339

T 030 Aligner 8	Canine	T	Tq	38.239	70.769	-19.367
T 030 Aligner 9	Canine	T	Tq	52.497	92.02	-20.624
T 030 Aligner 10	Canine	T	Tq	10.126	74.768	-35.385
T 030 Aligner 11	Canine	T	Tq	66.488	80.267	-35.092
T 030 Aligner 12	Canine	T	Tq	42.106	85.162	-26.418
T 030 Aligner 13	Canine	T	Tq	40.29	68.594	-17.086
T 030 Aligner 14	Canine	T	Tq	52.485	96.951	-21.816
T 030 Aligner 15	Canine	T	Tq	48.299	80.902	-42.076
T 030 Aligner 16	Canine	T	Tq	69.949	87.583	-31.412
T 030 Aligner 17	Canine	T	Tq	49.534	90.907	-32.693
T 030 Aligner 18	Canine	T	Tq	51.539	79.878	-21.135
T 030 Aligner 19	Canine	T	Tq	37.837	80.449	-15.485
T 030 Aligner 20	Canine	T	Tq	44.067	93.149	-22.169
T 030 Aligner 21	Canine	T	Tq	62.019	87.085	-18.657
T 030 Aligner 22	Canine	T	Tq	65.749	92.478	-38.466
T 030 Aligner 23	Canine	T	Tq	29.046	66.817	-13.094
T 030 Aligner 24	Canine	T	Tq	54.997	97.145	-29.916
T 030 Aligner 25	Canine	T	Tq	37.266	79.492	-15.488
T 030 Aligner 26	Canine	T	Tq	36.482	68.315	-12.862
T 030 Aligner 27	Canine	T	Tq	36.193	101.161	-23.498
T 030 Aligner 28	Canine	T	Tq	34.86	77.312	-15.564
T 030 Aligner 29	Canine	T	Tq	36.804	67.866	-14.797
T 030 Aligner 30	Canine	T	Tq	40.994	75.415	-13.665
T 030 Aligner 31	Canine	T	Tq	51.89	92.735	-27.349
T 030 Aligner 32	Canine	T	Tq	36.235	72.8	-13.112
T 030 Aligner 33	Canine	T	Tq	39.767	83.268	-20.112
T 030 Aligner 34	Canine	T	Tq	43.58	91.256	-25.012
T 030 Aligner 35	Canine	T	Tq	43.67	104.753	-31.797
T 030 Aligner 36	Canine	T	Tq	45.671	80.016	-19.755
T 030 Aligner 37	Canine	T	Tq	28.467	76.225	-14.38
T 040 Aligner 1	Canine	T	Tq	32.194	66.966	-11.476
T 040 Aligner 2	Canine	T	Tq	48.386	82.056	-14.646
T 040 Aligner 3	Canine	T	Tq	31.528	98.332	-17.563
T 040 Aligner 4	Canine	T	Tq	54.607	76.216	-16.743
T 040 Aligner 5	Canine	T	Tq	45.112	100.057	-22.537
T 040 Aligner 6	Canine	T	Tq	35.84	83.761	-30.869
T 040 Aligner 7	Canine	T	Tq	47.308	82.93	-25.706
T 040 Aligner 8	Canine	T	Tq	50.389	107.689	-19.003
T 040 Aligner 9	Canine	T	Tq	37.896	101.483	-16.945
T 040 Aligner 10	Canine	T	Tq	31.774	88.307	-16.331
T 040 Aligner 11	Canine	T	Tq	35.576	70.265	-12.089
T 040 Aligner 12	Canine	T	Tq	33.407	79.135	-13.058
T 040 Aligner 13	Canine	T	Tq	48.913	87.649	-15.138
T 040 Aligner 14	Canine	T	Tq	32.689	64.161	-12.597

T 040 Aligner 15	Canine	T	Tq	39.466	73.588	-12.838
T 040 Aligner 16	Canine	T	Tq	59.656	114.489	-25.469
T 040 Aligner 17	Canine	T	Tq	53.83	94.952	-26.309
T 040 Aligner 18	Canine	T	Tq	50.34	99.667	-25.11
T 040 Aligner 19	Canine	T	Tq	29.258	56.437	-9.796
T 040 Aligner 20	Canine	T	Tq	40.893	85.116	-19.026
T 040 Aligner 21	Canine	T	Tq	35.935	67.285	-11.692
T 040 Aligner 22	Canine	T	Tq	43.781	88.48	-19.289
T 040 Aligner 23	Canine	T	Tq	34.472	67.602	-11.728
T 040 Aligner 24	Canine	T	Tq	29.501	92.081	-23.585
T 040 Aligner 25	Canine	T	Tq	48.374	78.954	-14.351
T 040 Aligner 26	Canine	T	Tq	41.742	91.607	-21.832
T 040 Aligner 27	Canine	T	Tq	35.864	88.855	-18.035
T 040 Aligner 28	Canine	T	Tq	41.372	90.354	-20.078
T 040 Aligner 29	Canine	T	Tq	35.827	80.415	-18.334
T 040 Aligner 30	Canine	T	Tq	31.941	98.298	-16.719
T 040 Aligner 31	Canine	T	Tq	42.018	81.284	-15.72
T 040 Aligner 32	Canine	T	Tq	51.04	90.323	-16.439
T 040 Aligner 33	Canine	T	Tq	46.985	88.858	-32.628
T 040 Aligner 34	Canine	T	Tq	52.909	115.74	-21.66
T 040 Aligner 35	Canine	T	Tq	46.134	94.716	-35.818
T 040 Aligner 36	Canine	T	Tq	37.19	86.06	-18.157
T 040 Aligner 37	Canine	T	Tq	40.236	91.962	-24.744
AFL 2.0 Aligner 1	Molar	AFL	Tq	-1.92	9.614	-10.192
AFL 2.0 Aligner 2	Molar	AFL	Tq	-2.094	8.452	-13.959
AFL 2.0 Aligner 3	Molar	AFL	Tq	-2.07	6.798	-8.216
AFL 2.0 Aligner 4	Molar	AFL	Tq	-0.801	9.211	-15.944
AFL 2.0 Aligner 5	Molar	AFL	Tq	-2.166	9.893	-13.98
AFL 2.0 Aligner 6	Molar	AFL	Tq	-0.67	12.204	-16.621
AFL 2.0 Aligner 7	Molar	AFL	Tq	0.357	11.537	-13.462
AFL 2.0 Aligner 8	Molar	AFL	Tq	-3.124	9.121	-8.7
AFL 2.0 Aligner 9	Molar	AFL	Tq	-1.378	9.029	-12.534
AFL 2.0 Aligner 10	Molar	AFL	Tq	-1.822	7.774	-10.262
AFL 2.0 Aligner 11	Molar	AFL	Tq	-0.025	11.935	-12.92
AFL 2.0 Aligner 12	Molar	AFL	Tq	-0.943	8.01	-16.046
AFL 2.0 Aligner 13	Molar	AFL	Tq	-2.223	7.662	-8.168
AFL 2.0 Aligner 14	Molar	AFL	Tq	-1.577	10.985	-15.791
AFL 2.0 Aligner 15	Molar	AFL	Tq	-2.967	8.177	-8.125
AFL 2.0 Aligner 16	Molar	AFL	Tq	-0.795	9.025	-14.587
AFL 2.0 Aligner 17	Molar	AFL	Tq	-3.159	9.434	-13.592
AFL 2.0 Aligner 18	Molar	AFL	Tq	-1.448	8.029	-11.647
AFL 2.0 Aligner 19	Molar	AFL	Tq	-2.276	8.498	-12.882
AFL 2.0 Aligner 20	Molar	AFL	Tq	-0.251	6.511	-10.839
AFL 2.0 Aligner 21	Molar	AFL	Tq	1.51	8.942	-13.831

AFL 2.0 Aligner 22	Molar	AFL	Tq	-0.356	6.713	-11.477
AFL 2.0 Aligner 23	Molar	AFL	Tq	0.209	9.673	-11.546
AFL 2.0 Aligner 24	Molar	AFL	Tq	-0.202	2.79	-10.417
AFL 2.0 Aligner 25	Molar	AFL	Tq	-1.526	6.744	-12.262
AFL 2.0 Aligner 26	Molar	AFL	Tq	-2.365	8.425	-12.105
AFL 2.0 Aligner 27	Molar	AFL	Tq	-0.928	7.808	-11.131
AFL 2.0 Aligner 28	Molar	AFL	Tq	0.041	5.342	-13.18
AFL 2.0 Aligner 29	Molar	AFL	Tq	-0.946	10.368	-11.976
AFL 2.0 Aligner 30	Molar	AFL	Tq	-0.652	6.899	-12.498
AFL 2.0 Aligner 31	Molar	AFL	Tq	-1.568	8.826	-12.359
AFL 2.0 Aligner 32	Molar	AFL	Tq	0.211	10.014	-10.965
AFL 2.0 Aligner 33	Molar	AFL	Tq	0.862	11.52	-16.889
AFL 2.0 Aligner 34	Molar	AFL	Tq	0.34	10.248	-13.398
AFL 2.0 Aligner 35	Molar	AFL	Tq	-1.317	8.573	-13.411
AFL 2.0 Aligner 36	Molar	AFL	Tq	-1.947	6.596	-13.053
AFL 2.0 Aligner 37	Molar	AFL	Tq	-2.24	10.056	-12.495
AFL 2.5 Aligner 1	Molar	AFL	Tq	-0.731	15.702	-11.524
AFL 2.5 Aligner 2	Molar	AFL	Tq	-2.954	14.253	-10.878
AFL 2.5 Aligner 3	Molar	AFL	Tq	0.531	10.071	-11.542
AFL 2.5 Aligner 4	Molar	AFL	Tq	0.764	13.969	-14.367
AFL 2.5 Aligner 5	Molar	AFL	Tq	2.241	12.833	-12.439
AFL 2.5 Aligner 6	Molar	AFL	Tq	-0.162	15.964	-14.572
AFL 2.5 Aligner 7	Molar	AFL	Tq	3.033	11.913	-19.952
AFL 2.5 Aligner 8	Molar	AFL	Tq	4.647	13.192	-13.4
AFL 2.5 Aligner 9	Molar	AFL	Tq	0.767	7.971	-16.374
AFL 2.5 Aligner 10	Molar	AFL	Tq	0.517	18.744	-19.037
AFL 2.5 Aligner 11	Molar	AFL	Tq	1.805	12.361	-13.911
AFL 2.5 Aligner 12	Molar	AFL	Tq	2.101	21.265	-16.143
AFL 2.5 Aligner 13	Molar	AFL	Tq	-0.688	13.375	-14.799
AFL 2.5 Aligner 14	Molar	AFL	Tq	1.923	13.168	-14.881
AFL 2.5 Aligner 15	Molar	AFL	Tq	-2.048	15.134	-13.738
AFL 2.5 Aligner 16	Molar	AFL	Tq	3.492	10.111	-16.771
AFL 2.5 Aligner 17	Molar	AFL	Tq	1.973	15.841	-15.943
AFL 2.5 Aligner 18	Molar	AFL	Tq	1.391	15.315	-12.875
AFL 2.5 Aligner 19	Molar	AFL	Tq	0.545	17.727	-15.107
AFL 2.5 Aligner 20	Molar	AFL	Tq	0.48	14.691	-12.052
AFL 2.5 Aligner 21	Molar	AFL	Tq	-1.613	12.194	-12.102
AFL 2.5 Aligner 22	Molar	AFL	Tq	2.48	18.82	-13.415
AFL 2.5 Aligner 23	Molar	AFL	Tq	-0.736	14.605	-14.024
AFL 2.5 Aligner 24	Molar	AFL	Tq	1.713	12.643	-15.35
AFL 2.5 Aligner 25	Molar	AFL	Tq	0.764	12.6	-14.543
AFL 2.5 Aligner 26	Molar	AFL	Tq	0.839	11.543	-9.637
AFL 2.5 Aligner 27	Molar	AFL	Tq	-1.446	11.651	-10.542
AFL 2.5 Aligner 28	Molar	AFL	Tq	-0.182	11.651	-11.866

AFL 2.5 Aligner 29	Molar	AFL	Tq	3.134	20.197	-15.68
AFL 2.5 Aligner 30	Molar	AFL	Tq	0.054	15.85	-13.385
AFL 2.5 Aligner 31	Molar	AFL	Tq	0.762	16.415	-13.368
AFL 2.5 Aligner 32	Molar	AFL	Tq	1.563	14.26	-15.452
AFL 2.5 Aligner 33	Molar	AFL	Tq	-0.126	10.327	-13.473
AFL 2.5 Aligner 34	Molar	AFL	Tq	-1.594	14.376	-11.26
AFL 2.5 Aligner 35	Molar	AFL	Tq	-1.832	13.873	-9.443
AFL 2.5 Aligner 36	Molar	AFL	Tq	0.487	14.273	-14.825
AFL 2.5 Aligner 37	Molar	AFL	Tq	0.658	19.415	-15.575
T 030 Aligner 1	Molar	T	Tq	-12.458	24.936	-25.354
T 030 Aligner 2	Molar	T	Tq	5.764	7.321	-8.233
T 030 Aligner 3	Molar	T	Tq	2.788	53.055	-28.298
T 030 Aligner 4	Molar	T	Tq	-3.655	48.319	-37.383
T 030 Aligner 5	Molar	T	Tq	-1.028	-45.679	18.32
T 030 Aligner 6	Molar	T	Tq	2.924	41.952	-22.951
T 030 Aligner 7	Molar	T	Tq	11.241	39.599	-23.039
T 030 Aligner 8	Molar	T	Tq	4.832	33.1265	-22.097
T 030 Aligner 9	Molar	T	Tq	9.323	34.978	-24.364
T 030 Aligner 10	Molar	T	Tq	0.305	39.232	-19.257
T 030 Aligner 11	Molar	T	Tq	6.021	45.696	-23.378
T 030 Aligner 12	Molar	T	Tq	8.487	36.764	-20.582
T 030 Aligner 13	Molar	T	Tq	-19.709	61.792	-46.738
T 030 Aligner 14	Molar	T	Tq	-5.349	41.833	-35.368
T 030 Aligner 15	Molar	T	Tq	-1.097	32.106	-20.239
T 030 Aligner 16	Molar	T	Tq	12.076	47.61	-24.938
T 030 Aligner 17	Molar	T	Tq	-17.811	49.944	-31.044
T 030 Aligner 18	Molar	T	Tq	-9.081	46.115	-36.089
T 030 Aligner 19	Molar	T	Tq	-10.523	41.135	-29.83
T 030 Aligner 20	Molar	T	Tq	3.023	57.218	-33.598
T 030 Aligner 21	Molar	T	Tq	9.733	47.85	-20.215
T 030 Aligner 22	Molar	T	Tq	5.985	53.948	-26.896
T 030 Aligner 23	Molar	T	Tq	-0.337	35.582	-21.689
T 030 Aligner 24	Molar	T	Tq	-3.56	40.293	-32.715
T 030 Aligner 25	Molar	T	Tq	-7.846	54.364	-27.307
T 030 Aligner 26	Molar	T	Tq	10.469	40.756	-23.068
T 030 Aligner 27	Molar	T	Tq	0.53	49.682	-23.736
T 030 Aligner 28	Molar	T	Tq	5.098	40.195	-23.292
T 030 Aligner 29	Molar	T	Tq	-16.565	40.538	-31.877
T 030 Aligner 30	Molar	T	Tq	8.39	50.601	-21.216
T 030 Aligner 31	Molar	T	Tq	19.494	56.465	-26.125
T 030 Aligner 32	Molar	T	Tq	-8.153	30.1909	-19.903
T 030 Aligner 33	Molar	T	Tq	-0.134	46.248	-40.947
T 030 Aligner 34	Molar	T	Tq	-3.609	52.729	-24.883
T 030 Aligner 35	Molar	T	Tq	1.215	32.814	-20.718

T 030 Aligner 36	Molar	T	Tq	5.936	46.87	-29.537
T 030 Aligner 37	Molar	T	Tq	0.856	53.988	-24.619
T 040 Aligner 1	Molar	T	Tq	2.725	51.398	-35.238
T 040 Aligner 2	Molar	T	Tq	2.923	61.515	-30.831
T 040 Aligner 3	Molar	T	Tq	-3.268	43.793	-28.32
T 040 Aligner 4	Molar	T	Tq	-15.247	43.386	-30.458
T 040 Aligner 5	Molar	T	Tq	-3.347	64.035	-41.734
T 040 Aligner 6	Molar	T	Tq	0.81	55.814	-48.904
T 040 Aligner 7	Molar	T	Tq	1.1	55.502	-31.371
T 040 Aligner 8	Molar	T	Tq	-3.689	55.425	-34.563
T 040 Aligner 9	Molar	T	Tq	-1.542	61.708	-36.374
T 040 Aligner 10	Molar	T	Tq	-5.409	41.724	-29.725
T 040 Aligner 11	Molar	T	Tq	-12.61	53.744	-26.678
T 040 Aligner 12	Molar	T	Tq	1.088	51.625	-37.375
T 040 Aligner 13	Molar	T	Tq	-3.939	52.505	-31.972
T 040 Aligner 14	Molar	T	Tq	3.048	53.879	-34.16
T 040 Aligner 15	Molar	T	Tq	-25.086	68.12	-48.238
T 040 Aligner 16	Molar	T	Tq	6.076	57.661	-38.857
T 040 Aligner 17	Molar	T	Tq	-1.193	48.978	-43.527
T 040 Aligner 18	Molar	T	Tq	-3.987	58.337	-28.826
T 040 Aligner 19	Molar	T	Tq	-5.702	44.707	-28.486
T 040 Aligner 20	Molar	T	Tq	-2.252	29.171	-15.994
T 040 Aligner 21	Molar	T	Tq	-7.237	53.26	-28.967
T 040 Aligner 22	Molar	T	Tq	0.087	50.241	-36.011
T 040 Aligner 23	Molar	T	Tq	-14.633	51.126	-54.717
T 040 Aligner 24	Molar	T	Tq	-2.489	52.295	-35.108
T 040 Aligner 25	Molar	T	Tq	-0.491	55.426	-34.247
T 040 Aligner 26	Molar	T	Tq	-10.937	43.076	-26.844
T 040 Aligner 27	Molar	T	Tq	-12.324	36.624	-25.532
T 040 Aligner 28	Molar	T	Tq	-12.316	54.599	-44.529
T 040 Aligner 29	Molar	T	Tq	-11.799	51.864	-29.501
T 040 Aligner 30	Molar	T	Tq	-15.941	50.451	-30.492
T 040 Aligner 31	Molar	T	Tq	-9.803	45.959	-34.175
T 040 Aligner 32	Molar	T	Tq	-2.668	65.115	-37.305
T 040 Aligner 33	Molar	T	Tq	-2.033	41.07	-29.803
T 040 Aligner 34	Molar	T	Tq	-13.174	53.842	-27.297
T 040 Aligner 35	Molar	T	Tq	-15.226	63.274	-66.47
T 040 Aligner 36	Molar	T	Tq	0.77	52.69	-39.855
T 040 Aligner 37	Molar	T	Tq	0.603	45.607	-48.309

Appendices

Appendix B. Raw Data F (N)

Material	Tooth	Aligner	Force	X-Axis	Y-Axis	Z-Axis
AFL 2.0 Aligner 1	Canine	AFL	F	0.316	-0.22	-0.134
AFL 2.0 Aligner 2	Canine	AFL	F	0.271	-0.186	-0.124
AFL 2.0 Aligner 3	Canine	AFL	F	0.261	-0.122	-0.079
AFL 2.0 Aligner 4	Canine	AFL	F	0.216	-0.028	-0.199
AFL 2.0 Aligner 5	Canine	AFL	F	0.399	-0.158	-0.165
AFL 2.0 Aligner 6	Canine	AFL	F	0.26	-0.18	-0.143
AFL 2.0 Aligner 7	Canine	AFL	F	0.047	-0.218	-0.097
AFL 2.0 Aligner 8	Canine	AFL	F	0.493	-0.072	-0.143
AFL 2.0 Aligner 9	Canine	AFL	F	0.313	-0.097	-0.107
AFL 2.0 Aligner 10	Canine	AFL	F	0.448	-0.155	-0.241
AFL 2.0 Aligner 11	Canine	AFL	F	0.384	-0.221	-0.129
AFL 2.0 Aligner 12	Canine	AFL	F	0.372	-0.189	-0.122
AFL 2.0 Aligner 13	Canine	AFL	F	0.298	-0.138	-0.17
AFL 2.0 Aligner 14	Canine	AFL	F	0.305	-0.234	-0.159
AFL 2.0 Aligner 15	Canine	AFL	F	0.248	-0.199	-0.106
AFL 2.0 Aligner 16	Canine	AFL	F	0.368	-0.224	-0.123
AFL 2.0 Aligner 17	Canine	AFL	F	0.387	-0.206	-0.157
AFL 2.0 Aligner 18	Canine	AFL	F	0.352	-0.126	-0.203
AFL 2.0 Aligner 19	Canine	AFL	F	0.367	-0.238	-0.196
AFL 2.0 Aligner 20	Canine	AFL	F	0.227	-0.09	-0.073
AFL 2.0 Aligner 21	Canine	AFL	F	0.312	-0.283	-0.116
AFL 2.0 Aligner 22	Canine	AFL	F	0.362	-0.25	-0.163
AFL 2.0 Aligner 23	Canine	AFL	F	0.316	-0.096	-0.11
AFL 2.0 Aligner 24	Canine	AFL	F	0.511	-0.173	-0.237
AFL 2.0 Aligner 25	Canine	AFL	F	0.452	-0.349	-0.145
AFL 2.0 Aligner 26	Canine	AFL	F	0.296	-0.185	-0.14
AFL 2.0 Aligner 27	Canine	AFL	F	0.386	-0.225	-0.122
AFL 2.0 Aligner 28	Canine	AFL	F	0.208	-0.116	-0.072
AFL 2.0 Aligner 29	Canine	AFL	F	0.27	-0.153	-0.132
AFL 2.0 Aligner 30	Canine	AFL	F	0.258	-0.183	-0.052
AFL 2.0 Aligner 31	Canine	AFL	F	0.495	-0.179	-0.163
AFL 2.0 Aligner 32	Canine	AFL	F	0.285	-0.142	-0.182
AFL 2.0 Aligner 33	Canine	AFL	F	0.374	-0.268	-0.18
AFL 2.0 Aligner 34	Canine	AFL	F	0.374	-0.189	-0.221
AFL 2.0 Aligner 35	Canine	AFL	F	0.277	-0.208	-0.094
AFL 2.0 Aligner 36	Canine	AFL	F	0.375	-0.13	-0.182
AFL 2.0 Aligner 37	Canine	AFL	F	0.347	-0.174	-0.108
AFL 2.5 Aligner 1	Canine	AFL	F	0.373	-0.261	-0.047
AFL 2.5 Aligner 2	Canine	AFL	F	0.575	-0.135	-0.244

AFL 2.5 Aligner 3	Canine	AFL	F	0.591	-0.268	-0.144
AFL 2.5 Aligner 4	Canine	AFL	F	0.174	-0.217	-0.055
AFL 2.5 Aligner 5	Canine	AFL	F	0.644	-0.292	-0.473
AFL 2.5 Aligner 6	Canine	AFL	F	0.583	-0.306	-0.191
AFL 2.5 Aligner 7	Canine	AFL	F	0.447	-0.28	-0.138
AFL 2.5 Aligner 8	Canine	AFL	F	0.446	-0.254	-0.176
AFL 2.5 Aligner 9	Canine	AFL	F	0.315	-0.269	-0.097
AFL 2.5 Aligner 10	Canine	AFL	F	0.461	-0.355	-0.138
AFL 2.5 Aligner 11	Canine	AFL	F	0.596	-0.341	-0.155
AFL 2.5 Aligner 12	Canine	AFL	F	0.515	-0.213	-0.143
AFL 2.5 Aligner 13	Canine	AFL	F	0.837	-0.329	-0.198
AFL 2.5 Aligner 14	Canine	AFL	F	0.386	-0.246	-0.108
AFL 2.5 Aligner 15	Canine	AFL	F	0.704	-0.418	-0.153
AFL 2.5 Aligner 16	Canine	AFL	F	0.415	-0.197	-0.061
AFL 2.5 Aligner 17	Canine	AFL	F	0.432	-0.265	-0.138
AFL 2.5 Aligner 18	Canine	AFL	F	0.51	-0.287	-0.063
AFL 2.5 Aligner 19	Canine	AFL	F	0.46	-0.148	-0.15
AFL 2.5 Aligner 20	Canine	AFL	F	0.58	-0.228	-0.16
AFL 2.5 Aligner 21	Canine	AFL	F	0.522	-0.279	-0.045
AFL 2.5 Aligner 22	Canine	AFL	F	0.329	-0.379	-0.228
AFL 2.5 Aligner 23	Canine	AFL	F	0.541	-0.241	-0.124
AFL 2.5 Aligner 24	Canine	AFL	F	0.785	-0.325	-0.19
AFL 2.5 Aligner 25	Canine	AFL	F	0.642	-0.41	-0.087
AFL 2.5 Aligner 26	Canine	AFL	F	0.637	-0.353	-0.117
AFL 2.5 Aligner 27	Canine	AFL	F	0.601	-0.445	-0.347
AFL 2.5 Aligner 28	Canine	AFL	F	0.414	-0.311	-0.203
AFL 2.5 Aligner 29	Canine	AFL	F	0.205	-0.169	-0.126
AFL 2.5 Aligner 30	Canine	AFL	F	0.534	-0.331	-0.205
AFL 2.5 Aligner 31	Canine	AFL	F	0.445	-0.257	-0.131
AFL 2.5 Aligner 32	Canine	AFL	F	0.547	-0.402	-0.251
AFL 2.5 Aligner 33	Canine	AFL	F	0.431	-0.172	-0.174
AFL 2.5 Aligner 34	Canine	AFL	F	0.412	-0.231	-0.23
AFL 2.5 Aligner 35	Canine	AFL	F	0.441	-0.236	-0.067
AFL 2.5 Aligner 36	Canine	AFL	F	0.527	-0.302	-0.266
AFL 2.5 Aligner 37	Canine	AFL	F	0.729	-0.229	-0.152
T 030 Aligner 1	Canine	T	F	2.91	-1.946	-3.581
T 030 Aligner 2	Canine	T	F	2.802	-1.534	-2.41
T 030 Aligner 3	Canine	T	F	2.261	-1.899	-0.326
T 030 Aligner 4	Canine	T	F	2.402	-1.417	-1.487
T 030 Aligner 5	Canine	T	F	2.433	1.281	-1.303
T 030 Aligner 6	Canine	T	F	2.362	-1.455	-1.491
T 030 Aligner 7	Canine	T	F	2.353	-1.617	-0.508
T 030 Aligner 8	Canine	T	F	2.172	-1.165	-1.305
T 030 Aligner 9	Canine	T	F	2.692	-1.51	-0.507

T 030 Aligner 10	Canine	T	F	2.553	-1.512	-2.226
T 030 Aligner 11	Canine	T	F	2.718	-2.067	-2.373
T 030 Aligner 12	Canine	T	F	2.572	-1.253	-1.889
T 030 Aligner 13	Canine	T	F	2.106	-1.269	-1.076
T 030 Aligner 14	Canine	T	F	2.826	-1.529	-0.825
T 030 Aligner 15	Canine	T	F	2.824	-1.592	-3.592
T 030 Aligner 16	Canine	T	F	2.878	-2.146	-1.917
T 030 Aligner 17	Canine	T	F	2.901	-1.437	-1.983
T 030 Aligner 18	Canine	T	F	2.464	-1.63	-1.104
T 030 Aligner 19	Canine	T	F	2.448	-1.226	-0.679
T 030 Aligner 20	Canine	T	F	2.781	-1.343	-1.298
T 030 Aligner 21	Canine	T	F	2.555	-1.887	-0.477
T 030 Aligner 22	Canine	T	F	3.086	-1.849	-1.352
T 030 Aligner 23	Canine	T	F	2.034	-0.93	-0.688
T 030 Aligner 24	Canine	T	F	2.993	-1.745	-1.567
T 030 Aligner 25	Canine	T	F	2.413	-1.255	-1.128
T 030 Aligner 26	Canine	T	F	2.073	-1.15	-0.511
T 030 Aligner 27	Canine	T	F	2.982	-1.097	-1.322
T 030 Aligner 28	Canine	T	F	2.356	-1.092	-0.656
T 030 Aligner 29	Canine	T	F	2.072	-1.196	-0.629
T 030 Aligner 30	Canine	T	F	2.234	-1.264	-0.288
T 030 Aligner 31	Canine	T	F	2.828	-1.571	-2.313
T 030 Aligner 32	Canine	T	F	2.202	-1.2	-1.057
T 030 Aligner 33	Canine	T	F	2.459	-1.251	-1.437
T 030 Aligner 34	Canine	T	F	2.746	-1.352	-1.382
T 030 Aligner 35	Canine	T	F	3.189	-1.34	-1.854
T 030 Aligner 36	Canine	T	F	2.452	-1.447	-0.961
T 030 Aligner 37	Canine	T	F	2.352	-0.93	-0.691
T 040 Aligner 1	Canine	T	F	2.091	-0.973	-0.197
T 040 Aligner 2	Canine	T	F	2.531	-1.465	-0.237
T 040 Aligner 3	Canine	T	F	3.088	-1.058	-1.01
T 040 Aligner 4	Canine	T	F	2.258	-1.729	-0.84
T 040 Aligner 5	Canine	T	F	3.108	-1.476	-2.369
T 040 Aligner 6	Canine	T	F	2.506	-1.048	-2.938
T 040 Aligner 7	Canine	T	F	2.554	1.466	-2.057
T 040 Aligner 8	Canine	T	F	3.373	-1.805	-2.175
T 040 Aligner 9	Canine	T	F	3.195	-1.195	-0.455
T 040 Aligner 10	Canine	T	F	2.752	-1.099	-0.651
T 040 Aligner 11	Canine	T	F	2.186	-1.084	-0.245
T 040 Aligner 12	Canine	T	F	2.502	-1.067	-0.198
T 040 Aligner 13	Canine	T	F	2.69	-1.501	-0.436
T 040 Aligner 14	Canine	T	F	1.992	-0.981	-0.315
T 040 Aligner 15	Canine	T	F	2.275	-1.235	-0.467
T 040 Aligner 16	Canine	T	F	3.761	-1.901	-1.825

T 040 Aligner 17	Canine	T	F	3.042	-1.772	-1.599
T 040 Aligner 18	Canine	T	F	3.165	-1.697	-1.885
T 040 Aligner 19	Canine	T	F	1.747	-0.894	-0.275
T 040 Aligner 20	Canine	T	F	2.622	-1.252	-1.095
T 040 Aligner 21	Canine	T	F	2.096	-1.101	-0.279
T 040 Aligner 22	Canine	T	F	2.716	-1.431	-1.206
T 040 Aligner 23	Canine	T	F	2.101	-1.058	-0.368
T 040 Aligner 24	Canine	T	F	2.778	-1.016	-1.336
T 040 Aligner 25	Canine	T	F	2.399	-1.506	-0.554
T 040 Aligner 26	Canine	T	F	2.771	-1.406	-1.287
T 040 Aligner 27	Canine	T	F	2.693	-1.136	-0.719
T 040 Aligner 28	Canine	T	F	2.717	-1.214	-0.834
T 040 Aligner 29	Canine	T	F	2.393	-1.044	-0.896
T 040 Aligner 30	Canine	T	F	3.079	-1.03	-0.642
T 040 Aligner 31	Canine	T	F	2.48	-1.353	-0.869
T 040 Aligner 32	Canine	T	F	2.776	-1.562	-0.59
T 040 Aligner 33	Canine	T	F	2.837	-1.316	-2.495
T 040 Aligner 34	Canine	T	F	3.648	-1.637	-1.955
T 040 Aligner 35	Canine	T	F	3.311	-1.68	-3.35
T 040 Aligner 36	Canine	T	F	2.52	-1.058	-0.576
T 040 Aligner 37	Canine	T	F	2.747	-1.18	-1.963
AFL 2.0 Aligner 1	Molar	AFL	F	0.468	0.109	-0.077
AFL 2.0 Aligner 2	Molar	AFL	F	0.461	0.168	-0.042
AFL 2.0 Aligner 3	Molar	AFL	F	0.326	0.126	0.01
AFL 2.0 Aligner 4	Molar	AFL	F	0.551	0.084	-0.053
AFL 2.0 Aligner 5	Molar	AFL	F	0.528	0.152	0.14
AFL 2.0 Aligner 6	Molar	AFL	F	0.704	0.117	-0.145
AFL 2.0 Aligner 7	Molar	AFL	F	0.574	0.091	-0.067
AFL 2.0 Aligner 8	Molar	AFL	F	0.447	0.155	-0.04
AFL 2.0 Aligner 9	Molar	AFL	F	0.489	0.137	-0.106
AFL 2.0 Aligner 10	Molar	AFL	F	0.398	0.134	0.002
AFL 2.0 Aligner 11	Molar	AFL	F	0.601	0.103	0.015
AFL 2.0 Aligner 12	Molar	AFL	F	0.472	0.139	-0.206
AFL 2.0 Aligner 13	Molar	AFL	F	0.372	0.119	0.002
AFL 2.0 Aligner 14	Molar	AFL	F	0.614	0.1	-0.008
AFL 2.0 Aligner 15	Molar	AFL	F	0.385	0.17	0.079
AFL 2.0 Aligner 16	Molar	AFL	F	0.508	0.128	-0.071
AFL 2.0 Aligner 17	Molar	AFL	F	0.556	0.209	-0.153
AFL 2.0 Aligner 18	Molar	AFL	F	0.446	0.126	-0.046
AFL 2.0 Aligner 19	Molar	AFL	F	0.484	0.158	-0.252
AFL 2.0 Aligner 20	Molar	AFL	F	0.346	0.05	-0.083
AFL 2.0 Aligner 21	Molar	AFL	F	0.494	0.034	-0.005
AFL 2.0 Aligner 22	Molar	AFL	F	0.371	0.056	-0.124
AFL 2.0 Aligner 23	Molar	AFL	F	0.52	0.025	-0.111

AFL 2.0 Aligner 24	Molar	AFL	F	0.234	0.061	-0.262
AFL 2.0 Aligner 25	Molar	AFL	F	0.405	0.135	-0.188
AFL 2.0 Aligner 26	Molar	AFL	F	0.451	0.148	0.111
AFL 2.0 Aligner 27	Molar	AFL	F	0.431	0.11	-0.196
AFL 2.0 Aligner 28	Molar	AFL	F	0.331	0.096	-0.195
AFL 2.0 Aligner 29	Molar	AFL	F	0.523	0.102	-0.001
AFL 2.0 Aligner 30	Molar	AFL	F	0.367	0.089	-0.046
AFL 2.0 Aligner 31	Molar	AFL	F	0.483	0.126	-0.056
AFL 2.0 Aligner 32	Molar	AFL	F	0.503	0.054	0.022
AFL 2.0 Aligner 33	Molar	AFL	F	0.633	0.087	-0.155
AFL 2.0 Aligner 34	Molar	AFL	F	0.554	0.066	-0.04
AFL 2.0 Aligner 35	Molar	AFL	F	0.479	0.143	-0.086
AFL 2.0 Aligner 36	Molar	AFL	F	0.353	0.149	-0.196
AFL 2.0 Aligner 37	Molar	AFL	F	0.529	0.171	-0.107
AFL 2.5 Aligner 1	Molar	AFL	F	0.731	0.074	0.104
AFL 2.5 Aligner 2	Molar	AFL	F	0.67	0.146	0.03
AFL 2.5 Aligner 3	Molar	AFL	F	0.489	0.02	-0.029
AFL 2.5 Aligner 4	Molar	AFL	F	0.723	0.047	0.007
AFL 2.5 Aligner 5	Molar	AFL	F	0.623	0.118	-0.013
AFL 2.5 Aligner 6	Molar	AFL	F	0.788	0.114	0.076
AFL 2.5 Aligner 7	Molar	AFL	F	0.718	-0.069	-0.455
AFL 2.5 Aligner 8	Molar	AFL	F	0.628	-0.053	0.152
AFL 2.5 Aligner 9	Molar	AFL	F	0.561	-0.014	-0.56
AFL 2.5 Aligner 10	Molar	AFL	F	0.932	0.016	-0.306
AFL 2.5 Aligner 11	Molar	AFL	F	0.644	-0.045	-0.244
AFL 2.5 Aligner 12	Molar	AFL	F	1.007	0.066	0.165
AFL 2.5 Aligner 13	Molar	AFL	F	0.699	0.126	-0.002
AFL 2.5 Aligner 14	Molar	AFL	F	0.649	0.016	0.093
AFL 2.5 Aligner 15	Molar	AFL	F	0.748	0.166	0.082
AFL 2.5 Aligner 16	Molar	AFL	F	0.539	-0.059	-0.096
AFL 2.5 Aligner 17	Molar	AFL	F	0.809	0.047	0.138
AFL 2.5 Aligner 18	Molar	AFL	F	0.761	-0.007	0.119
AFL 2.5 Aligner 19	Molar	AFL	F	0.867	0.086	0.159
AFL 2.5 Aligner 20	Molar	AFL	F	0.699	0.073	0.08
AFL 2.5 Aligner 21	Molar	AFL	F	0.6	0.127	-0.02
AFL 2.5 Aligner 22	Molar	AFL	F	0.895	-0.025	0.198
AFL 2.5 Aligner 23	Molar	AFL	F	0.732	0.121	-0.029
AFL 2.5 Aligner 24	Molar	AFL	F	0.612	0.068	-0.028
AFL 2.5 Aligner 25	Molar	AFL	F	0.65	0.054	-0.032
AFL 2.5 Aligner 26	Molar	AFL	F	0.558	0.035	0.141
AFL 2.5 Aligner 27	Molar	AFL	F	0.545	0.116	0.019
AFL 2.5 Aligner 28	Molar	AFL	F	0.595	0.093	0.127
AFL 2.5 Aligner 29	Molar	AFL	F	0.974	-0.041	0.067
AFL 2.5 Aligner 30	Molar	AFL	F	0.769	0.111	0.107

AFL 2.5 Aligner 31	Molar	AFL	F	0.818	0.107	0.049
AFL 2.5 Aligner 32	Molar	AFL	F	0.723	0.05	0.174
AFL 2.5 Aligner 33	Molar	AFL	F	0.54	0.083	-0.09
AFL 2.5 Aligner 34	Molar	AFL	F	0.683	0.115	0.068
AFL 2.5 Aligner 35	Molar	AFL	F	0.632	0.12	0.094
AFL 2.5 Aligner 36	Molar	AFL	F	0.728	0.074	0.024
AFL 2.5 Aligner 37	Molar	AFL	F	0.947	0.102	0.087
T 030 Aligner 1	Molar	T	F	1.137	0.484	-1.564
T 030 Aligner 2	Molar	T	F	0.413	-0.252	-0.394
T 030 Aligner 3	Molar	T	F	2.341	0.009	-0.318
T 030 Aligner 4	Molar	T	F	2.218	0.191	-0.892
T 030 Aligner 5	Molar	T	F	-1.902	0.005	0.713
T 030 Aligner 6	Molar	T	F	1.81	-0.043	-0.506
T 030 Aligner 7	Molar	T	F	1.72	-0.324	-0.54
T 030 Aligner 8	Molar	T	F	1.479	-0.056	-0.204
T 030 Aligner 9	Molar	T	F	1.566	-0.316	-0.326
T 030 Aligner 10	Molar	T	F	1.693	0.086	-0.396
T 030 Aligner 11	Molar	T	F	1.947	-0.146	-0.519
T 030 Aligner 12	Molar	T	F	1.566	-0.245	-0.433
T 030 Aligner 13	Molar	T	F	3.022	0.704	-2.374
T 030 Aligner 14	Molar	T	F	1.986	0.266	-1.91
T 030 Aligner 15	Molar	T	F	1.342	0.126	-0.472
T 030 Aligner 16	Molar	T	F	2.087	-0.198	-0.027
T 030 Aligner 17	Molar	T	F	2.3	0.704	-1.401
T 030 Aligner 18	Molar	T	F	2.311	0.275	-1.49
T 030 Aligner 19	Molar	T	F	2.015	0.353	-1.319
T 030 Aligner 20	Molar	T	F	2.574	-0.062	-0.938
T 030 Aligner 21	Molar	T	F	1.983	-0.302	-0.492
T 030 Aligner 22	Molar	T	F	2.397	-0.144	-0.522
T 030 Aligner 23	Molar	T	F	1.52	0.0317	-0.711
T 030 Aligner 24	Molar	T	F	1.974	0.225	-1.711
T 030 Aligner 25	Molar	T	F	2.332	0.307	-1.111
T 030 Aligner 26	Molar	T	F	1.679	-0.353	-0.846
T 030 Aligner 27	Molar	T	F	2.213	0.053	-0.716
T 030 Aligner 28	Molar	T	F	1.723	-0.073	-0.377
T 030 Aligner 29	Molar	T	F	1.922	0.641	-2.159
T 030 Aligner 30	Molar	T	F	2.109	-0.22	-0.538
T 030 Aligner 31	Molar	T	F	2.457	-0.571	-0.201
T 030 Aligner 32	Molar	T	F	1.373	0.34	-1.067
T 030 Aligner 33	Molar	T	F	2.374	0.012	-1.581
T 030 Aligner 34	Molar	T	F	2.322	0.168	-0.9
T 030 Aligner 35	Molar	T	F	1.426	0.038	-0.341
T 030 Aligner 36	Molar	T	F	2.179	-0.212	-1.296
T 030 Aligner 37	Molar	T	F	2.32	0.067	-0.453

T 040 Aligner 1	Molar	T	F	2.42	-0.071	-1.394
T 040 Aligner 2	Molar	T	F	2.645	0.037	-0.428
T 040 Aligner 3	Molar	T	F	1.946	0.142	-1.027
T 040 Aligner 4	Molar	T	F	1.948	0.697	-0.832
T 040 Aligner 5	Molar	T	F	2.82	0.337	-0.941
T 040 Aligner 6	Molar	T	F	2.893	-0.137	-2.213
T 040 Aligner 7	Molar	T	F	2.47	0.15	-1.171
T 040 Aligner 8	Molar	T	F	2.525	0.316	-1.002
T 040 Aligner 9	Molar	T	F	2.725	0.232	-0.6
T 040 Aligner 10	Molar	T	F	1.859	0.293	-1.202
T 040 Aligner 11	Molar	T	F	2.311	0.57	-0.757
T 040 Aligner 12	Molar	T	F	2.443	0.18	-0.692
T 040 Aligner 13	Molar	T	F	2.406	0.304	-0.733
T 040 Aligner 14	Molar	T	F	2.399	0.048	-1.129
T 040 Aligner 15	Molar	T	F	3.324	0.801	-2.603
T 040 Aligner 16	Molar	T	F	2.644	0.001	-1.17
T 040 Aligner 17	Molar	T	F	2.561	-0.051	-2.285
T 040 Aligner 18	Molar	T	F	2.45	0.26	-0.938
T 040 Aligner 19	Molar	T	F	1.959	0.239	-1.004
T 040 Aligner 20	Molar	T	F	1.231	0.133	-0.491
T 040 Aligner 21	Molar	T	F	2.242	0.241	-1.527
T 040 Aligner 22	Molar	T	F	2.441	0.043	-1.062
T 040 Aligner 23	Molar	T	F	2.835	0.499	-3.838
T 040 Aligner 24	Molar	T	F	2.48	0.132	-1.036
T 040 Aligner 25	Molar	T	F	2.48	0.175	-0.696
T 040 Aligner 26	Molar	T	F	1.989	0.445	-1.285
T 040 Aligner 27	Molar	T	F	1.716	0.437	-0.988
T 040 Aligner 28	Molar	T	F	2.739	0.4	-1.56
T 040 Aligner 29	Molar	T	F	2.215	0.513	-0.826
T 040 Aligner 30	Molar	T	F	2.221	0.673	-0.638
T 040 Aligner 31	Molar	T	F	2.136	0.51	-1.559
T 040 Aligner 32	Molar	T	F	2.784	0.189	-1.276
T 040 Aligner 33	Molar	T	F	1.937	0.236	-0.604
T 040 Aligner 34	Molar	T	F	2.276	0.517	-0.994
T 040 Aligner 35	Molar	T	F	3.193	0.386	-3.702
T 040 Aligner 36	Molar	T	F	2.506	-0.023	-1.923
T 040 Aligner 37	Molar	T	F	2.274	0.2	-0.483