.014 VERSUS .016 IN ALIGNMENT AND LEVELING:
DOES IT MAKE A DIFFERENCE?

Bryan C. Whitecotton

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Approved by:

Ching-Chang Ko

Tung T. Nguyen

Feng-Cheng Lin

ABSTRACT

Bryan C. Whitecotton: .014 Versus .016 in Alignment and Leveling:
Does it Make a Difference?
(Under the direction of Ching-Chang Ko)

Objective: From an intuitive clinical standpoint, a more rigid archwire such as .016 should demonstrate greater efficacy for stage one tooth movement than a more flexible archwire such as .014. However, there is little to no clinical data to support this theory. This study hypothesizes that archwire dimension affects efficacy of tooth movement in Stage I orthodontic treatment due to variation in force magnitude, and this effect is independent of time due to constant force of superelastic wires. **Materials and Methods:** A prospective, randomized clinical trial was performed featuring 9 patients (18 dental arches) using .014 and .016 archwires. Double-blinded distribution of archwires was performed with intraoral scans obtained at 3 times points (baseline, 6 weeks, and 12 weeks). Digital measurements were performed based on Little's Irregularity Index by a single examiner using Ortho Insight 3D. Geomagic was also used to assess Euclidean rigid motion with 6 degrees of freedom for all canines. 2-way repeated ANOVA was utilized, with the main effects being archwire dimension and time. **Results:** The first time interval showed greater reduction in incisor irregularity. Difference in mean translation was statistically significant between .014 and .016 in all 3 planes, as well as between the first and second time intervals for the z axis only. Finally, interaction between archwire dimension and time interval for translation was significant in the y and z planes. **Conclusions:** Archwire

dimension does have an impact on efficacy of alignment, and alignment is, in fact, not

independent of time.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CAD/CAM   Computer-Aided Design and Computer-Aided Manufacturing

CuNiTi   Copper Nickel-Titanium

NiTi   Nickel-Titanium

SS   Stainless Steel

STL   Stereolithography File

TMA   Titanium Molybdenum Alloy

LIST OF SYMBOLS

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A REVIEW OF THE LITERATURE

The Why of Orthodontic Treatment

Orthodontics is an interesting topic of discussion in the dental and medical fields, as it often lands firmly between seemingly paradoxical ends – specifically whether it can be deemed a medically-necessary procedure or just an esthetically-driven treatment. Liu notes that malocclusion is "neither a disease nor a life-threatening condition," but does acknowledge what is clearly a matter of fact: orthodontics is in significantly high demand.[1] A natural question that arises from this scenario is, quite simply, why? What is it that drives individuals to make a possibly uncomfortable temporal and monetary commitment to affect change on something that is often not truly necessary? What one must acknowledge when pondering this question is that esthetic concerns have an enormous impact on what people are willing to sacrifice in terms of both their time and finances. While there certainly are cases that can be proven to have a clear medical benefit, Howells explains that often it is an esthetic concern related to dentofacial appearance that is the most important factor accounting for the pursuit of orthodontic treatment.[2]

Interesting to note in this discussion is that even though a decision can be driven by esthetics, the implications can, and often do, go far beyond what some might perceive as vanity or simply wanting to "look good." Feu points out that there is currently an upward trend in recognition of the fact that oral issues can have significant physical as well as psychosocial implications, while also emphasizing that different people with similar degrees of malocclusion may have completely different self-perception of their dental/orthodontic situation.[3] This can

lead to vast differences when it comes to the impact of a particular orthodontic issue for a given individual. For example, consider two people with similar ectopically erupted canines – one person may be willing to make a significant financial commitment to undergo orthodontic treatment because it bothers him or her that much, while the other person in the scenario may have never given it a second thought. While some patients certainly seek treatment for perceived oral health benefits, Kiyak found that most patients do, in fact, focus on esthetic and social considerations when seeking orthodontic treatment.[4]

<u>The Who of Orthodontic Treatment</u>

After beginning to understand what drives an individual to seek orthodontic treatment, it is worthwhile to determine who these people actually are in terms of specific categorization. Proffit summarized the state of malocclusion in the United States based on the third National Health and Nutrition Examination Survey, explaining that only 35% of adults have well-aligned lower incisors, nearly 60% have some degree of orthodontic treatment need, and that even a small percentage of those in the very lowest income group commit to orthodontic treatment.[5] This last point once again places emphasis on the fact that people are willing to sacrifice when it comes to the perceived benefits of orthodontics. Along with this, it has been noted that parents who have high aspirations for their child's success will be more prone to seek treatment for that child.[6]

Another development that has manifested itself in recent years is the undeniable increase in the number of adults who undergo orthodontic therapy. Pabari cites three specific factors to which this adult orthodontic phenomenon can be attributed: improved esthetics of orthodontic appliances, increased awareness of the oral and mental health benefits of treatment, and progress

in terms of the social acceptability of undergoing treatment as an adult.[7] The implications of the first aforementioned factor (improved esthetics) have been far-reaching in the orthodontic world, specifically as it pertains to the increase in adult patients and the subsequent increase in the use of clear aligner therapy. Clear aligners will not be discussed at length in this review, but this topic is certainly worth mentioning as a key development in the field of orthodontics.

Emphasis on Treatment Efficiency

With a baseline understanding of who seeks orthodontic treatment and why they do so, it is possible to delve deeper into specific treatment goals and biomechanical factors impacting whether or not those objectives are achieved. One goal of orthodontic treatment that has become increasingly important both to practitioners and patients is treatment efficiency: the ability to produce a quality result in the most reasonable amount of time possible. In the realm of increased efficiency of orthodontic treatment, much of the research has focused on the idea of accelerated tooth movement. Uribe describes three main categories of accelerated tooth movement: biologic, mechanical/physical, and surgically-facilitated.[8] Examples of biologic intervention can include techniques such as local administration of Vitamin D [9] or specific prostaglandin receptor agonists.[10] In the mechanical/physical category, examples include application of pulsed electromagnetic fields [11] and the increasingly popular (and tirelessly marketed) cyclic loading (vibration) technology.[12] Finally, surgically-facilitated interventions would include piezocision-assisted orthodontic treatment [13] as well as corticotomy-induced orthodontic movement.[14]

With all of this fascinating research in orthodontics, it is somewhat ironic that there are still questions as to which archwires are most appropriate for various stages of treatment. Practitioners who are concerned with the "next big thing" in accelerated tooth movement could

very likely be using archwires that are not giving them ideal tooth movement efficiency. This is a topic well worth re-visiting, even in the midst of an era with what some may consider to be much more intriguing research. It is time to get back to the basics of archwires, but utilizing other exciting technological advances that will hopefully shed new light on old questions.

Stages of Orthodontic Treatment

In order to appropriately discuss archwires in various stages of orthodontic treatment, it is important to accurately define those stages. Begg was the first to delineate three stages of treatment,[15] which Proffit refers to specifically as alignment and leveling (Stage I), correction of molar relationship and space closure (Stage II), and finishing (Stage III).[6] Typically, superelastic wires such as Nickel-Titanium (NiTi) or Copper Nickel-Titanium (CuNiTi) are used in the initial stage of treatment to achieve alignment, although smaller rigid archwires in a braided form can be used. In contrast to the superelastic wires, a more rigid archwire such as Titanium Molybdenum Alloy (TMA) or Stainless Steel (SS) is typically used in the second and third stages. For the remainder of this review, the focus will be primarily on the first stage of orthodontic treatment, and even more specifically on the alignment aspect of Stage I.

For brackets with .022 inch slots, McLaughlin defines the initial stage of treatment as "the tooth movements needed to achieve passive engagement of a steel rectangular wire of .019/.025 dimension and of suitable archform."[16] Shroff describes leveling and aligning as the initial step in the "mechanical execution" of a particular treatment plan,[17] going on to explain that the most typical alignment sequence involves placing wires of increasing stiffness in brackets bonded in ideal position on malaligned teeth. As mentioned in the closing paragraph of the previous section, while there is a biological consensus regarding the idea of light continuous

force for tooth movement, there is still a lack of consensus when it comes to which archwire in the alignment sequence is the most ideal for initiating resolution of malalignment.

Initial Archwires for Alignment and Leveling

Superelastic wires such as NiTi and CuNiTi have overwhelmingly solidified themselves as the archwires of choice for the alignment aspect of the first stage of orthodontic treatment. This is due in large part to the fact that a light, continuous force can be maintained over an extended period of time and over a vast range of deflection.[6] However, the ideal superelastic archwire material, as well as the ideal dimension, has yet to be determined. Along with material and dimension, friction plays a critical – and somewhat controversial – role in orthodontic alignment. Too much friction can lead to binding and notching of archwires, as Kusy so masterfully tested and described;[18] however, recent studies have begun to demonstrate the usefulness, and even necessity, of friction to achieve alignment, which further complicates the search for the ideal Stage I wire.

Just as accelerated tooth movement was touched on in the efficiency segment, one would be remiss to fail to mention yet another point of debate, and occasional contention: traditional versus self-ligating brackets. While many practitioners are adamant about self-ligating brackets allowing for more efficient resolution of dental crowding, randomized controlled trials such as those conducted by Fleming and Johansson have demonstrated no significant difference in efficacy of traditional brackets compared with either active or passive self-ligating appliances.[19,20] Anand also acknowledged that factors such as archwire sequence likely have a greater impact in terms of treatment effects than the type of bracket used for a particular case.[21] Even Chen's systematic review found that the only statistically significant advantages of self-

ligating brackets compared to conventional were decreased chair time and minimally reduced incisor proclination.[22]

With the impact of bracket type determined to be negligible, it makes the question of the archwires themselves that much more critical in the quest for maximum treatment efficiency. As stated previously, superelastic materials tend to be the wire of choice for most clinicians in Stage I treatment. However, in the early days of NiTi archwires, Evans was unable to demonstrate superiority of the superelastic wires compared to multi-stranded SS archwires that were much less expensive.[23] With the advent of thermoelastic (heat-activated superelastic) archwires such as CuNiTi and NeoSentalloy, many clinicians have embraced these as their initial archwires of choice, often due to the increased deflection range while maintaining low unloading force. In contrast to this trend of thinking among practitioners, Pandis states that the difference between laboratory and clinical settings appears to make any laboratory-based claims of CuNiTi superiority obsolete.[24] This theory has been further advanced by Jian's systematic review of the literature, which found insufficient evidence to determine a difference between thermoelastic and traditional superelastic archwires, going on to say there is "no reliable evidence… that any specific arch wire material is better or worse than another with regard to speed of alignment."[25]

With both bracket type and archwire material being ruled out as significant clinical difference-makers for efficient alignment, one of the only remaining variables to analyze is archwire dimension. In spite of the vast number of studies relating to orthodontic archwires, very few have compared various dimensions within the same material. Instead, the overwhelming majority of investigations have involved searching for differences based on dissimilar materials within the same dimension. In one of the few studies focused primarily on initial archwire dimension, Montasser conducted in vitro testing of two different sizes of NiTi wires and four

different bracket systems, coming to the conclusion that "increasing the diameter from 0.014 to 0.016 increased the correction achieved by up to 15% in certain bracket-archwire combinations, but it decreased the correction by up to 25% in other combinations."[26] This demonstrates potential for clinical significance within certain bracket systems, which could be valuable information for practitioners. It also implies a need for further investigation, ideally with in vivo studies to begin determining whether initial archwire dimension could be a relevant differentiating factor in treatment efficiency.

Malalignment Indices and Little's Irregularity Index

Investigating a clinical question such as the impact of archwire dimension on alignment efficiency requires an important decision to be made: what metrics or parameters will be used to adequately compare the dimensions and subsequently yield accurate results? One option for this comparison is to use the classic "crowding" measurement. Howe defined dental crowding as a "disparity in the relationship between tooth size and jaw size which results in imbrication and rotation of the teeth."[27] Bernabe takes a semantically different approach in his description of crowding, explaining that it occurs when the "space required for alignment of the permanent teeth exceeds the space available in the dental arch."[28] With either definition, an issue that can arise in measuring or estimating crowding is the fact that it is dependent on an assumption of the base archform into which the teeth should ideally fit. Because of this inherent subjectivity, two practitioners or investigators could realistically interpret a given amount of crowding in an arch as being different by up to several millimeters. Clinically, this may not make a significant difference in the majority of cases, but particularly for research purposes, it would be ideal to have a measurement system that is more objective.

Dr. Robert Little recognized this need for greater objectivity, calling dental crowding "one of the most ambiguous terms in the dental vocabulary," while decrying both its subjectivity and wide range of interpretation.[29] While there were a number of other numerical indices describing malocclusion in Little's day, he defined his "Irregularity Index" as the sum of five measurements representing the linear distance between adjacent anatomic contact points of the mandibular anterior teeth. By starting with a more objective baseline rather than estimating the location/dimension of the ideal arch, Little argued that this index was more reliable and repeatable than most others, especially as it pertains to the vague term of crowding.

This begs the question as to what the research has shown over the years in regard to the reliability of Little's Irregularity Index. Macauley came to the conclusion that he could not advocate for the use of this index to predictably determine the outcome of treatment modalities, due to what he describes as limited accuracy and precision in the measurement technique.[30] This reiterated what was found just two years prior by Sjogren, who focused on reporting the issue of unsatisfactory inter-examiner reliability when utilizing the Little Index.[31] Little himself acknowledged that the Irregularity Index is not without its flaws; however, the shortcomings he noted were not related to examiner error or differences, but rather inherent issues such as assessment of cases with spacing or those with significant buccolingual displacement of individual teeth. He noted this often translates to a high index in spite of the fact that it is relatively easy to treat, assuming there is adequate arch length for alignment [29]. The greater concern for most practitioners and investigators are the aforementioned errors based on subjectivity of measurement, but there are some exciting developments over the last several years that present an opportunity to overcome some of these challenges – namely, intraoral scanning and digital models.

Intraoral Scanners and Digital Models for Orthodontic Assessment

Intraoral scanning is without question one of the greatest advances in modern dentistry, from the standpoint of both patient comfort as well as certain aspects of treatment efficiency. The ability to take accurate impressions without the use of alginate or other traditional materials is often much more tolerable for patients, particularly those patients who are ardently averse to impressions due to a gag reflex. Burhardt found that a majority of patients preferred digital impressions over the alginate method, in spite of the fact that alginate impressions can be completed in less time.[32] In terms of efficiency, while the chairside time with intraoral scanners may be longer, Grunheid found that factoring in processing time for traditional impressions revealed no significant difference in overall time requirement between the two methods.[33] One must also take into account the ability to send digital impression files to dental laboratories for items such as crowns, which can have a huge impact on treatment scheduling and timing for the general practitioner. For orthodontists specifically, sending those same files can mean having appliances, retainers, or even aligners arrive in a much more timely manner.

To be clear, digital impressions would only be worth the increase in patient comfort and efficiency if they were as accurate, or even more accurate, than the traditional methods. Grunheid's study of digital tooth measurements determined that "tooth-width measurements on digital models can be as accurate as, and might be more reproducible and significantly faster than, those taken on plaster models."[34] Ender found that while there were higher local deviations for digital impressions, they do produce equal and even higher precision than certain traditional materials.[35] In spite of these positive results in terms of the promise of digital impressions for the future of dentistry and orthodontics, Goracci's systematic review of the literature acknowledged

that the scientific evidence accumulated thus far regarding intraoral scanning is not exhaustive, and as is frequently the case in science, more research is needed to verify these relatively early findings.[36]

With the understanding that the trend in research findings demonstrates at least equivalent accuracy between digital and traditional impressions, the conversation comes full circle with the confluence of Little's Irregularity Index and digital impressions generated from intraoral scans. More specifically, the question becomes whether or not using digital impressions can make up for the shortcomings of the Little Index noted in previous paragraphs. Dowling investigated this very question and found that using digital models can reduce subjectivity associated with choosing contact points as well as the struggle associated with precisely measuring contact point displacement on a physical cast, thereby improving the reliability of Little Index measurements.[37] In Burns' study on the reliability of the Little Index for the upper arch, he came to the conclusion that this particular index is not the most appropriate for orthodontic research with either impression method, but he did acknowledge that variability of contact point displacement was decreased with digital impressions relative to traditional.[38]

Effects of Modern CAD/CAM Appliances on Alignment and Leveling

In discussing the impact of intraoral scanning on orthodontics, it is important to mention the CAD/CAM (computer-aided design/computer-aided manufacturing) implications of these developments. The most obvious example of CAD technology in orthodontics is that of Invisalign, which was briefly mentioned in a previous paragraph. However, many other manufacturers are beginning to utilize this technology, ranging from custom lingual brackets with Incognito to custom indirect bonding setups with Insignia, and even custom archwires

through SureSmile. These are just a few of the advances that have helped to lead the way in what could be termed an orthodontic digital revolution, which has been advanced in large part due to the increased availability of intraoral scanning.

As far as the direct impact of these CAD/CAM technologies on orthodontic treatment, a number of studies have been conducted relative to the modalities mentioned in the previous paragraph. Grauer found that fully customized lingual orthodontic appliances were accurate in achieving the majority of the goals planned in the initial digital setup.[39] Al Mortadi expanded on the use of CAD/CAM in orthodontics, incorporating AM (additive manufacturing) to fabricate removable appliances such as Andresen and sleep-apnea devices.[40] Acknowledging that there are still some limitations in the technology, Larson reported that the effectiveness of computer-assisted treatment with SureSmile varies based on both tooth type and movement limitations.[41] Muller-Hartwich later seemed to overcome some of those limitations, arriving at the conclusion that SureSmile custom archwires generated through CAD/CAM processes can be implemented with high precision and good clinical success.[42]

While all of these developments in digital orthodontics are both exciting and inspiring, one of the most impactful in terms of the discussion of efficacy and efficiency in treatment is Brown's study, which found that an entirely customized appliance was more efficient in terms of treatment duration.[43] Understanding and implementing information such as this, in conjunction with answers to other efficiency questions such as archwire composition and dimension, can continue to bring practitioners closer to being as efficient as possible in treatment. This increased efficiency undoubtedly benefits the orthodontist, but even more importantly, it ultimately benefits the patient.

Conclusions

As with any endeavor, scientific or otherwise, it is important to have a baseline understanding of what has led to the current state of affairs. In a very broad and general sense, this review has established who tends to seek orthodontic treatment, as well as why they do so. It also focused on current trends in orthodontic treatment, specifically as it relates to treatment efficiency and some contentious topics such as self-ligating versus traditional brackets. Defining the stages of orthodontic treatment allowed for exploration of some trends associated with Stage I treatment – particularly concentrating on initial archwires. To summarize these research findings, the evidence to this point appears to imply that specific brackets and archwires are essentially irrelevant as it pertains to efficiency of alignment. However, while the evidence certainly suggests that bracket type and archwire material are of little significance, there is reason to believe that further investigation into archwire dimension could yield clinically significant results that could have an impact on the field of orthodontics.

All of these developments and findings lead to this specific investigation, in which it is hypothesized that archwire dimension affects efficacy of tooth movement in the alignment and leveling stage of orthodontic treatment due to variation in force magnitude, and this effect is independent of time due to constant force of superelastic wires. Specifically, an attempt will be made to determine whether there is a statistically significant difference between .014 and .016 CuNiTi archwires. Achievement of this goal will rely on utilization of Little's Irregularity Index as well as Euclidean rigid motion concepts with 6 degrees of freedom[44] measured on digital models generated directly from intraoral scans. It is expected that this study, ideally along with others in the future, has potential to demonstrate statistical significance of archwire dimension, which could prove to be valuable clinical information for the practicing orthodontist.

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<u>Introduction</u>

One goal of orthodontic treatment that has become increasingly important both to practitioners and patients is treatment efficiency: the ability to produce a quality result in the most reasonable amount of time possible. In the realm of increased efficiency of orthodontic treatment, much of the research has focused on the idea of accelerated tooth movement. Uribe describes three main categories of accelerated tooth movement: biologic,[1,2] mechanical/ physical,[3,4] and surgically-facilitated,[5,6] with various treatment modalities falling under each of these categories.[7] With all of this fascinating research in orthodontics, it is somewhat ironic that there are still questions as to which archwires are most appropriate for various stages of treatment. It is time to get back to the basics of archwires, utilizing some exciting technological advances that will hopefully shed new light on old questions.

Treatment stage is commonly divided into 3 categories: alignment and leveling (Stage I), correction of molar relationship and space closure (Stage II), and finishing (Stage III).[8,9] Typically, superelastic wires such as Nickel-Titanium (NiTi) or Copper Nickel-Titanium (CuNiTi) are used in the initial stage of treatment to achieve alignment, and while there is a biological consensus regarding the idea of light continuous force for tooth movement, there is still a lack of consensus when it comes to which archwire material and dimension in Stage I

is the most ideal for initiating resolution of malalignment. Along with composition and size, friction plays a critical – and somewhat controversial – role in orthodontic alignment.[10] Many practitioners adamantly argue that self-ligating brackets allow for more efficient resolution of dental crowding, in spite of clinical trials and systematic reviews that have demonstrated otherwise.[11-13] If the impact of bracket type is negligible, what about the archwires themselves? Many clinicians have embraced thermoelastic archwires such as CuNiTi and NeoSentalloy as their initial archwires of choice, once again in spite of a number of studies that have found no significant difference between heat-activated and traditional superelastic wires.[14,15]

Furthermore, although there have been a significant number of studies relating to orthodontic archwires, very few have compared various dimensions within the same material. In one of the few studies focused primarily on initial archwire dimension, .014 and .016 NiTi wires were compared in vitro with four different bracket systems, with mixed results in terms of which wire demonstrated greater correction.[16] This study implies potential for clinical significance within certain bracket systems, as well as the need for further investigative research, which could be valuable information for practitioners.

While "crowding" is the classical measurement of choice in orthodontics, it is not without its shortcomings, particularly the subjectivity involved in identifying the ideal archform.[17] Little attempted to overcome this inherent subjectivity with his Irregularity Index, defined as the sum of five measurements representing the linear distance between adjacent anatomic contact point of the mandibular anterior teeth.[18] Over the years, some have come to the conclusion that the Little Index is not a reliable technique for reasons such as accuracy in measurement technique as well as issues with inter-examiner reliability.[19,20] However, there are some exciting developments

over the last several years that present an opportunity to overcome some of these challenges – namely, intraoral scanning and digital models.

Intraoral scanning is without question one of the greatest advances in modern dentistry, from the standpoint of both patient comfort as well as certain aspects of treatment efficiency.[21,22] Even so, digital impressions would only be worth the increase in patient comfort and efficiency if they were at least as accurate as traditional methods, which multiple studies have proven to be the case.[23,24] The question then becomes whether or not these technological advances can overcome some of the flaws associated with Little's Irregularity Index. Studies on this topic have found that digital models can reduce both the subjectivity and variability associated with choosing contact points, increasing the reliability of this index as a research method.[25,26]

All of these developments and findings lead to this specific investigation, in which it is hypothesized that archwire dimension affects efficacy of tooth movement in the alignment and leveling stage of orthodontic treatment due to variation in force magnitude, and that this effect is independent of time due to constant force of superelastic wires. Specifically, an attempt will be made to determine whether there is a statistically significant difference between .014 and .016 CuNiTi archwires. Achievement of this goal will rely on utilization of Little's Irregularity Index as well as Euclidean rigid motion concepts with 6 degrees of freedom measured on digital models generated directly from intraoral scans.[27] It is expected that this study, along with others in the future, has potential to demonstrate statistical significance of archwire dimension, which could prove to be valuable clinical information for the practicing orthodontist.

Materials and Methods

This prospective, randomized clinical trial was approved by the Institutional Review Board at the University of North Carolina at Chapel Hill, and consisted of 9 patients separated into two treatment groups based on the initial archwires they received: .014 CuNiTi (n=4) and .016 CuNiTi (n=5). Each patient received the same dimension archwire for both the maxillary and mandibular arches. Random number generation was used by a third party to assign identification numbers to the individual sets of archwires in order to blind their distribution. This trial included patients between the ages of 10 and 45 previously diagnosed with malocclusion, but otherwise healthy. More specific inclusion criteria included non-extraction treatment in the maxilla and mandible, initial Little Index between 3 and 9 mm (with no spacing), presence of all permanent anterior teeth, and appropriate consent to participate in the study. Specific exclusion criteria included: systemic diseases (e.g. diabetes, hypertension, TMD, craniofacial syndromes, etc.) and periodontal pocketing of anterior teeth greater than 4mm. There was no exclusion based on race, gender, or ethnicity.

The following sequence was followed for each of the 9 patients enrolled in the clinical trial. Preliminary assessment of patients for potential inclusion in the study was performed using initial records obtained by the treating resident. Patients who were deemed to be appropriate for the trial were then recruited at their case presentation appointment, and consent/assent was obtained. On the day of recruitment and consent acquisition, upper and lower alginate impressions were obtained, as well as a baseline (T_0) intraoral scan using the 3M True Definition scanner. The alginate impressions were poured, and indirect bonding setups were completed by the primary investigator using Ormco Mini Diamond twin brackets, followed by fabrication of indirect bonding trays using Opal Lumiloc/Emiluma indirect bonding materials. After this

fabrication was complete, the indirect bonding trays were distributed to the treating resident to complete the bonding appointment. The archwires were distributed in double-blind fashion immediately following bonding, in the order dictated by the aforementioned random number generator. Only Ormco silver elastomeric rings were used for engaging the archwire to the brackets. The standard single-tie method was used for all teeth in the first 6-week interval; however, for the second interval, "figure-8" elastomeric ligation was acceptable based on the provider's clinical judgment.

Immediately following the bonding appointment, patients were scheduled to return 6 weeks later for their next visit. Upon arrival at the first post-bonding appointment, both archwires were removed and assessed visually for any permanent damage or deformation. The patient then underwent a second intraoral scan (T_1), followed by placement of the same original archwires, tied in as noted in the previous paragraph. Following this first archwire adjustment appointment, the next visit was once again scheduled at a 6-week interval. When the patient returned for the second post-bonding appointment, the archwires were once again removed, but this time they were cleaned and collected into their original research study packaging. The patient then underwent a third and final intraoral scan (T_2). At this point, the treating resident was free to proceed with treatment as he or she and the attending faculty deemed appropriate, as the patient's participation in the study was complete.

After obtaining all intraoral scans, the .stl files were imported into 3Shape's OrthoAnalyzer software, where they were properly oriented and digitally based. From there, the based digital models were exported to a second software, Ortho Insight 3D, where the teeth were digitally separated. Within this same program, anterior tooth contact points were precisely discerned, generating accurate width measurements of the teeth. After this, a formula created

within the software calculated the Little Index measurements for the 5 anterior contact points of interest, which were then added together to establish the overall Little Index for the upper and lower arches at each timepoint.

Additionally, the native .stl files generated from the scan were imported into the Geomagic software, where the superimposition method was employed to assess Euclidean rigid motion with 6 degrees of freedom for all 4 canines in each subject. These 6 degrees of freedom involve translation in 3 planes of space (x, y, and z) measured as the linear distance between a specified point on the canine at each time interval, as well as 3 angle measurements generated from those same points via superimposition of the original and final spatial orientation. Specifically, the x axis accounts for extrusion and intrusion, with extrusion producing a positive value and intrusion producing a negative value. The y axis represents distal or mesial translation, with distalization being positive and mesialization being negative. Finally, the z axis represents in-out or lingual and buccal movements, with lingual being positive and buccal being negative.

In terms of the statistical analysis for both the maxillary and mandibular dentition, the three timepoints were compared within each archwire, as well as both archwires across each time point. The primary statistical method was a two-way repeated measurement ANOVA, with the main effects being archwires and time. A post-hoc comparison between archwires was completed based on the Bonferroni correction, and a P-value less than 0.05 was considered statistically significant.

Results

The difference in mean Little Index reduction between .014 and .016 (Figure 1a) was not statistically significant ($p = 0.201$). However, the difference in mean reduction between the first

and second 6-week intervals (Figure 1b) was statistically significant (p = 0.049). Finally, when the interaction between both archwire dimensions and both time intervals (Figure 1c) was tested, the results were not statistically significant (p = 0.531).

For the translation aspect of the rigid motion arm of the study, the difference in mean translation between .014 and .016 (Figure 2a, Table 1) was found to be statistically significant in all 3 planes (x: p = 0.017, y: p = 0.014, z: p = 0.005). The difference in mean translation between the first and second 6-week intervals (Figure 2b, Table 2) was not significant in the x or y planes (x: p = 0.075, y: p = 0.059), but was statistically significant in the z axis (p = 0.0002). When the interaction between the archwires and time intervals (Table 3) was tested, the results were not statistically significant in the x (Figure 2c) axis (p = 0.085), but were significant in the y (Figure 2d) and z (Figure 2e) planes (y: p = 0.037, z: p = 0.018). For the rotation aspect of the rigid motion portion of the study, the difference in rotation was not found to be statistically significant for any comparison within any of the 3 planes of space.

Discussion

As noted in the previous section, the difference in Little Index between the 2 archwire dimensions was not statistically significant, although the p-value of 0.201 demonstrated a trend toward .014 showing greater reduction. This finding is interesting in that intuitively, it is often thought that a larger wire will generate greater movement and alignment, and it appears that the opposite of this presupposition may be true. This could be due to multiple factors, with possibilities including differences in wire engagement (which could have been affected by ligation with elastomerics) or differences in friction between the two dimensions.

Secondly, it was determined that the mean reduction in Little Index was greater across both dimensions in the first 6-week interval relative to the second, and this finding was statistically significant. This idea of a lull or truncation in orthodontic movement is not a new discovery. In fact, this phenomenon has played a critical role in the efforts to develop accelerated treatment modalities. The question becomes whether this truncation of force has a biological or mechanical origin, or possibly a combination of both. In other words, would something such as actually switching to a new wire make a difference, or is it simply the biology of tooth movement that causes this decrease in rate of alignment in the second 6-week interval? The precise answer to that question is still unknown, in spite of what different companies and their representatives may say. It is a matter of fact that NiTi does undergo force decay, so there could be merit to the idea of the forces of the wire not being as consistent as orthodontists are led to believe. In any respect, it is informative to understand that this statistical difference in intervals occurred irrespective of dimension. Finally, with regard to assessment of interaction between the dimension and time interval components, there was no statistically significant difference in terms of irregularity and no particular p-value trends worth noting.

Once again, for the rigid motion portion of the study, .014 and .016 demonstrated significantly different translation values in all 3 planes. Table 1 shows the type of movement that each archwire demonstrated in the 3 planes (i for intrusion, e for extrusion, d for distalization, m for mesialization, l for lingual movement, and b buccal movement). The "plus" symbol indicates that it was a relatively greater amount of that particular movement within a given axis. The "underline" represents statistical significance in a given plane, and the "asterisk" indicates which absolute value was greatest in each axis. So, for the dimension comparison, .014 demonstrated intrusion while .016 showed extrusion, with the extrusion value of .016 being greater than the

intrusion of .014. In the y axis, both wires caused distalization, more of which occurred with .014. Finally, while .014 demonstrated slight lingual movement, .016 showed buccal translation of a greater magnitude. These findings are quite interesting as they appear to indicate that different archwire dimensions could be more effective than others at particular directional movements. For example, in this case, perhaps .016 is more efficient at resolving vertical discrepancies. This does make intuitive sense from the standpoint of utilizing the increased rigidity of .016, as these vertical movements are not relying as heavily on full engagement within the bracket slot.

Secondly, the difference between the 2 time intervals was only statistically significant in the bucco-lingual aspect, although the other 2 planes trended heavily toward significance (p = .075 for intrusion/extrusion and p = .059 for mesio-distal movement). Table 2 shows that extrusion occurred in both intervals, with more extrusion in the 6-12 week timeframe. Distalization also occurred in both intervals, but with greater distalization found from 0-6 weeks. Additionally, slight lingual movement occurred from 0-6 weeks, with significantly more buccal movement seen in the 6-12 week interval. It is interesting to note the asterisk in the second interval for the x and z axes, indicating greater movement relative to the first 6 weeks, which was not necessarily expected based on the Little Index findings.

In terms of the results for interaction between the archwires and time intervals for the 3 planes, there was no statistically significant difference in the x axis (p = .085), but the differences in both the y and z axes were significant. Table 3 indicates that the greatest amount of movement in the x axis occurred in the 0-6 week interval in the form of extrusion. In the y axis, the greatest movement was distalization with .014, also in the first time interval. Finally, in the z axis, the most movement occurred as buccal translation with .016 in the 6-12 week interval. One point

worth discussing in a bit more detail is the distalization occurring with .014. These findings coincide with recent laboratory research conducted by Gibson et al that has been submitted for publication. Specifically, the results of this study show distal movement of the canines during alignment, which Dr. Gibson proved to be evidence of expansion in stage I of treatment. What was used to explain this phenomenon is the idea of constraint, which basically implies that when deflection (and in this case, greater deflection of .014 relative to .016) reaches a critical point, the wire can no longer slide and it translates into a spring-like force similar to that of an open coil, which pushes the canine distally. What is particularly intriguing is the fact that this distal movement is greater with .014 than it is with .016, which also goes along with the counter-intuitive trend that was found in the Little Index portion of the study.

Finally, none of the rotational components demonstrated statistical significance. Some theories for why this may have been the case include the relatively stringent selection criteria, particularly the idea that severity of initial rotations was limited based on the necessity of full seating with elastomeric ligation. Alternatively, or perhaps in combination with the first point, it could simply have been an issue of insufficient time in these particular intervals to resolve rotations to a statistically significant extent.

In terms of limitations of this study, the most glaring is the less than ideal sample size. In spite of the relatively low number of subjects, a large amount of data was generated. Specifically, for the Little Index aspect of the study, there were 270 measurements that were generated from 540 specifically designated landmarks. Additionally, for the rigid motion portion, there were 108 measurements generated for each of the 6 degrees of freedom, for a total of nearly 650 data points. In spite of these numbers, the conclusions would of course be considered stronger had there been a greater sample size. Another limitation was potential bonding errors, which could

include inaccurate or less than ideal bracket placement in the indirect bonding setup, or issues with the bonding itself. A third limitation was human error in contact point selection for generation of the Little Index, as well as point selection for the rigid motion aspect of the study.

Conclusions

The results obtained through analysis of the data allow for acceptance of the first aspect of the hypothesis, which stated that archwire dimension does have an impact on efficacy of alignment. The specific trend associated with this finding was that .014 appears to demonstrate a greater impact on alignment than the more rigid .016 . For the second aspect of the hypothesis, the study results lead to rejection of the idea that alignment is independent of time due to constant force of superelastic wires, as both segments of the study showed a statistically significant difference between the first and second time intervals. Of course, further clinical trials with larger sample sizes are critical in terms of confirming what was found in this study.

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Table 1. Rigid Motion Results (Dimension)

Archwire Dimension	Intrusion/ Extrusion (x)	Mesialization/ Distalization (y)	Lingual/ Buccal (z)
.014	<u>i</u>	<u>d+</u> *	<u>l</u>
.016	<u>e</u> *	<u>d</u>	<u>b</u> *

Table 1 represents comparison of .014 and .016 for directionality of translational movement of the canines in all subjects in 3 planes (x, y, and z), with indicators of relative increased magnitude for similar direction ("+"), greatest magnitude of movement in a given plane ("*"), and statistical significance ("_") set at $p < 0.05$.

Table 2. Rigid Motion Results (Time)

| Time Interval (Weeks)	Intrusion/ Extrusion (x)	Mesialization/ Distalization (y)	Lingual/ Buccal (z)
0-6	e	d+ *	<u>l</u>
6-12	e+ *	d	<u>b</u> *

Table 2 represents comparison of first and second 6-week intervals for directionality of translational movement of the canines in all subjects in 3 planes (x, y, and z), with indicators of relative increased magnitude for similar direction ("+"), greatest magnitude of movement in a given plane ("*"), and statistical significance ("_") set at $p < 0.05$.

Table 3. Rigid Motion Results (Interaction)

Archwire Dimension	Time Interval (Weeks)	Intrusion/ Extrusion (x)	Mesialization/ Distalization (y)	Lingual/ Buccal (z)
.014	**0-6**	i	<u>d++</u> *	<u>l</u>
	6-12	e	<u>d+</u>	b+
.016	**0-6**	e++ *	<u>m</u>	b
	6-12	e+	<u>d</u>	<u>b++</u> *

Table 3 represents interaction of archwire dimension and time interval for directionality of translational movement of the canines in all subjects in 3 planes (x, y, and z), with indicators of relative increased magnitude for similar direction ("+"), greatest magnitude of movement in a given plane ("*"), and statistical significance ("_") set at $p < 0.05$.

Figure 1. Little Index Reduction based on a) Dimension, b) Time, and c) Interaction between Dimension and Time
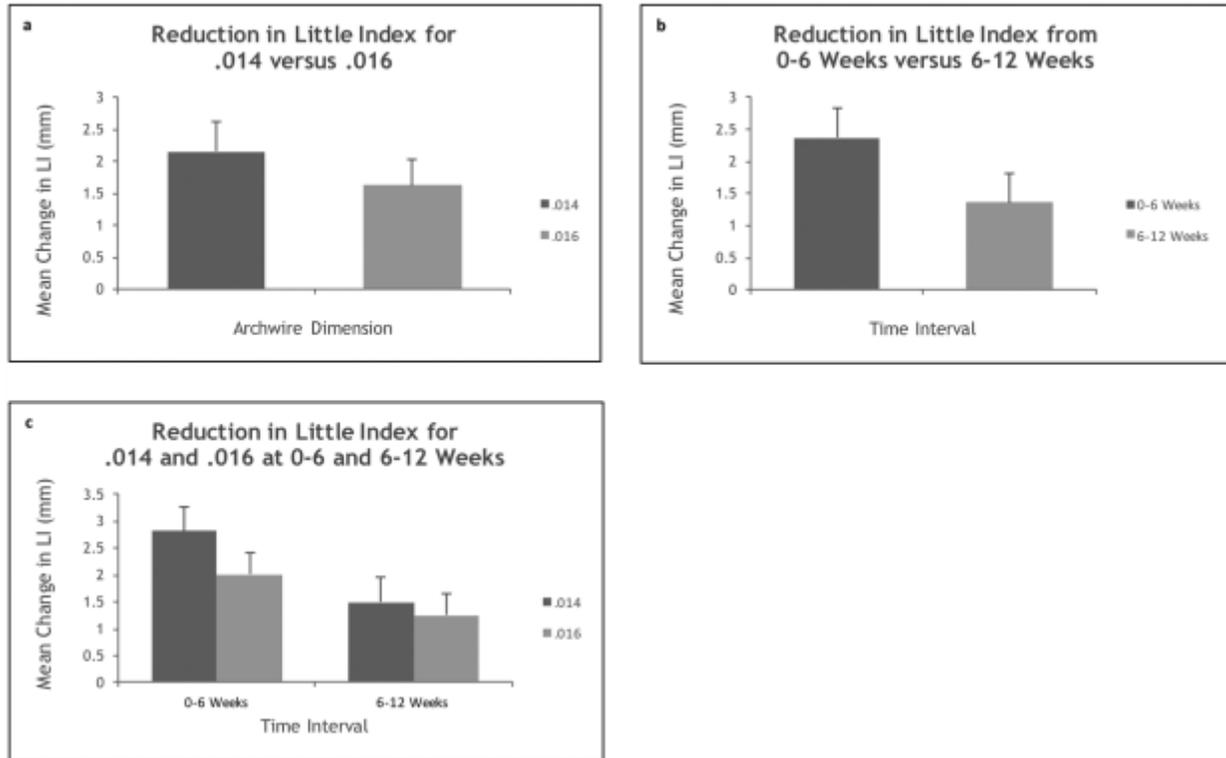
Figure 2. Translational Movement in 3 Planes based on a) Dimension and b) Time, as well as Interaction between Dimension and Time in the c) X, d) Y, and e) Z axes