ORTHODONTIC LOAD QUANTIFICATION LEVELING A DEEP CURVE OF SPEE WITH DIFFERENT ARCHWIRE DESIGNS

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ORTHODONTIC LOAD QUANTIFICATION
LEVELING A DEEP CURVE OF SPEE WITH DIFFERENT ARCHWIRE DESIGNS

by

Ahmed Yehia Shawky Ahmed Youssef, D.D.S.

A Thesis submitted to the Faculty of the Graduate School,
Marquette University,
in Partial Fulfillment of the Requirements for
the Degree of Master of Science

Milwaukee, Wisconsin

August 2024
ABSTRACT

ORTHODONTIC LOAD QUANTIFICATION
LEVELING A DEEP CURVE OF SPEE WITH DIFFERENT ARCHWIRE DESIGNS

Ahmed Yehia Shawky Ahmed Youssef, D.D.S.
Marquette University, 2024

Objective: This study aimed to quantify the effects of different materials, sizes of the continuous archwires in leveling the exaggerated curve of Spee. We used an orthodontic force tester apparatus to measure the forces and moments delivered by the archwires to the brackets attached to the sensors of one quadrant of the arch (from 1st incisor to 2nd molar). The hypothesis is that there is no difference in the load and moments between the incisors when the curve of Spee is leveled with the three different mechanical designs being tested.

Methods: An orthodontic force tester (OFT) was used to measure the forces and moments delivered by the archwires to brackets attached from the first incisor to the second molar. Dentoforms simulating an exaggerated curve of Spee were made from CBCT scans. Zero-preservation .022”x.028” brackets were used and the archwires were ligated using elastomeric ligatures. Archwires with 3 types of material, reverse curve of Spee nickel titanium [rNiTi], stainless steel step down [SSSD], and titanium molybdenum step down [TMASD]) in one size of .016”x.022” were tested (n=10). The NiTi archwire had a prefabricated reverse curve of Spee, and the SSSD and TMASD archwires had bilateral 1.0 mm stepdown bends between the canine and second incisor and the second incisor and first incisor, respectively. For statistical analysis, variance analysis (ANOVA) was used to examine the differences in the effects of different archwire materials and designs on the incisors and molars in relation to leveling the curve of Spee. A p-value less than 0.05 was considered statistically significant.

Results: Comparing the archwires, the rNiTi design had the least force generation on the incisor and molar, followed by the TMASD, then the SSSD design had the greatest, while the TMASD design and SSSD were similar in forces. The rNiTi design had the greatest moment generation on the incisors, followed by the SSSD, then TMASD had the least; however, for the molar, all wires were similar in moment generation.

Conclusion: The hypothesis is rejected. Force and moment distributions in a quadrant illustrate significant differences between the incisors and the premolars and molars. For archwire force comparisons on the incisors and molars, rNiTi displayed the least force, followed by TMA then SS. For archwire moment comparisons on the incisors, rNiTi displayed the greatest moment, followed by TMA then SS. For archwire moment comparisons on the molars, rNiTi, TMA, and SS had similar moment generation.
ACKNOWLEDGEMENTS

Ahmed Yehia Shawky Ahmed Youssef, D.D.S.

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CHAPTER 1
INTRODUCTION

The human dentition is part of a dynamic biological relationship of the masticatory system that serves the functional and esthetic needs of the body (Nelson 2015). A natural phenomenon in the human dentition is the occlusal curvature, termed the curve of Spee (COS), by Graf Von Spee (Spee 1980). By definition, it is defined as an anatomical curve that begins with the mandibular canine and follows the buccal cusps of the premolar and molar teeth within the bounds of the natural dentition seen in the sagittal plane (Spee 1980, Nelson 2015). Although the understanding of why and how a COS exists is limited, it is believed that it is due to a combination of factors, which include growth of the orofacial complex, development of the neuromuscular system, and the eruption of teeth (Marshall 2008).

The growth of the orofacial complex stimulates the development of the COS, as the depth of the COS is minimal in the deciduous dentition, and its greatest increase occurs with the eruption of the first permanent molar and first incisor eruption reaching its maximum depth with the eruption of the second permanent molar (Karani 2018, Osborn 1987). The neuromuscular system development and position of the mandible sagittally and vertically in relation to the cranium has been related to the COS (Marshall 2008, Karani 2018). An increase in COS is seen with cephalic facial patterns and short mandibular bodies (Karani 2018, Osborn 1987). The eruption of teeth is an additional factor contributing to the development of the COS (Osborn 1993). The mandibular first molars supercede their maxillary antagonists by 1 to 2 months and mandibular permanent incisors supercede their maxillary antagonists by 6 to 12 months (Marshall 2008). Since the mandibular permanent
teeth erupt before their maxillary antagonists, this is indicative that COS development is a dental event (Marshall 2008).

Although the development of the COS is indicative to be a dental event, it can be correlated with various occlusal relationships (Marshall 2008). COS is described as being the deepest in class II relationships and is flatter with class I and class III subjects (Al-Amiri 2015). Moreover, the depth of the COS was greatest in Class II Div 1, followed by Class II Div 2, then Class I and Class III, but differences between Class II Div 1 and Class II Div 2 were insignificant (Al-Amiri 2015). COS severity is directly proportional to the overjet and overbite; therefore, an increase in either generally results in a deeper COS. Anterior teeth without a vertical stop will tend to continue to erupt and contribute to deepening the COS, which can result in a traumatic bite (Shannon 2004, Veli 2015).

It was proposed that individuals with good occlusion exhibit a flat to mild COS; therefore, leveling the COS should be a treatment goal in orthodontic treatment (Andrews 1972). The purpose of the curve of Spee is to allow for protrusive disocclusion of the posterior teeth by the combination of anterior guidance and condylar guidance (Xu 2004). Therefore, it is important to know standard values and normal variations for occlusal curvatures, not only for examination, but for treatment of occlusal disharmony (Xu 2004). If the occlusal curvature values exceed normal limits, then it would be characterized as a deep curve of Spee (Fig. 1).

![Illustration of an exaggerated curve of Spee in the mandibular arch.](image-url)
A deep curve of Spee is associated with an increased overbite (Proffit 2013). Correction of deep overbite is related to stability of the occlusion and one of the objectives of orthodontic treatment (Bergersen 1988). During orthodontic treatment, the curve of Spee is leveled by bringing the buccal cusps of the posterior teeth and incisal edges of the anterior teeth into a horizontal plane level to correct an increased overbite (AlQabandi 1999). There are a myriad of methods and techniques to achieve such a correction, and a few of them will be evaluated in this experimental study. An increased overbite can be corrected by anterior intrusion, posterior extrusion, or a combination of both (AlQabandi 1999). Proclining the lower incisors can also be done to decrease the vertical overlap and achieve a more ideal anterior coupling (AlQabandi 1999).

The purpose of this study is to investigate different methods to achieve the correction of an increased overbite through different rectangular archwire designs that include leveling the curve of Spee. The hypothesis is that there is no difference in the load on the incisors when the curve of Spee is leveled with arch wires that are prefabricated with a reverse curve of Spee design versus stepdown designs in the anterior segment. The findings from this study should aid clinicians in choosing appropriate mechanotherapy techniques to accommodate the treatment objectives for leveling the curve of Spee with continuous archwire mechanics. Therefore, the objectives of this study were to (1) develop a reliable and accurate method to experimentally measure the orthodontic loads on the teeth using continuous archwire; (2) quantify the loads experimentally for various appliance designs; and (3) quantify the effects of wire material on leveling the curve of Spee and level of overeruption on the loads.
CHAPTER 2
LITERATURE REVIEW

Curve of Spee Overview
The curve of Spee was introduced by Ferdinand Graf von Spee in 1890 and describes the curvatures of the occlusal surfaces of the teeth when viewed from a sagittal plane. The curve of Spee extends from the tip of the lower canine along the buccal cusps of the posterior teeth to the anterior border of the ramus. Understanding and managing the curve of Spee is essential in orthodontic treatment because it is important in the functional and esthetic demands of the orofacial complex. (Spee 1890)

Von Spee claimed that the curve of Spee is important for efficient mastication and occlusal function (Spee 1890). The understanding and management of the curve of Spee have evolved with significant improvements in orthodontics and is one of Andrews six keys of occlusion (Andrews 1972). The curve of Spee aids in the mastication and processing of food bolus by increasing the crush-shear ratio between the posterior teeth during mastication. It also contributes to the stability of the dentition and the temporomandibular joint by distributing occlusal forces during function (Nayar 2015). An exaggerated curve of Spee can lead to malocclusions and is associated with different skeletal patterns and presentations. Conversely, a flattened curve of Spee can lead to decreased masticatory efficiency and decreased group function or canine guidance (Proffit 2013, Baldridge 1969).

In orthodontic treatment, the curve of Spee and its severity are accounted for in diagnosis and treatment planning for the correction of dental malocclusions. Addressing a deep or exaggerated curve of Spee is a common treatment objective, presenting itself clinically as a deep bite, and is part of the first part of orthodontic treatment, leveling and
alignment. There are many techniques to level the curve of Spee using continuous archwire mechanics that involve opening the bite in order to achieve a balanced occlusal relationship.

Several studies have investigated the impact leveling the curve of Spee has on orthodontic treatment outcomes (Andrews 1972, Baldridge 1969). The occlusal plane is not only corrected with leveling the curve of Spee, but leveling the curve of Spee has proven to contribute to better long-term stability of orthodontic treatment results (Andrews 1972). An exaggerated curve of Spee can be overcorrected during treatment, and it can lead to flattened occlusal arches and an unesthetic smile arc.

Studies have implemented a more robust evaluation of the curve of Spee by utilizing cone-beam computed tomography and digital scans to analyze a curve of Spee with greater precision; therefore, allowing for a better understanding of individual variations and how to customize treatment planning (Kelley 2021). Research has shown the relationship between the curve of Spee and various skeletal and dental relationships, which can lead to a better understanding of the severity of the curve of Spee and the treatment interventions that can be implemented (Farella 2002). Unequivocally, a curved arch, or a deep curve of Spee, has a greater circumference than a flat arch, or a flat curve of Spee; however, the amount of additional arch circumference required to level the curve of Spee is not as apparent (Nayar 2015). A generality is that 1 mm of arch circumference is required to level 1 mm of the curve of Spee; however, that is going to be dependent on the presenting skeletal and dental pattern and the mechanics used (Germane 1992, Woods 1986).
**Curve of Spee Class II Malocclusions**

The relationship between the curve of Spee and Class II malocclusion is significant, influencing its diagnosis and treatment planning in orthodontics. More specifically, a significant correlation was found between individuals with Class II Division 1 malocclusions and an exaggerated curve of Spee (Pandis 2010). In individuals who present with Class II malocclusions, an exaggerated curve of Spee needs to be leveled and is a critical component of successful treatment (Marshall 2008).

Alternate biomechanical approaches to leveling a deep curve of Spee was presented using segmented arch techniques to control vertical dimensions in Class II malocclusions (Burstone 1966, Weiland 1996). A continuous archwire was also described with a reverse curve of Spee design that engaged all mandibular teeth to correct a deep curve of Spee (Dake 1989, Weiland 1996). This continuous archwire method exhibited a tendency for incisor intrusion and proclination, while also causing mandibular premolar and molar extrusion. (Dake 1989, Weiland 1996, Carcara 2001, Bernstein 2007).

Conventional orthodontic continuous arch mechanics are found to be most stable when leveling a curve of Spee (Weiland 1996). Although the curve of Spee is deeper in class II cases, it is flatter in class III cases (Nayar 2015). On average, from 100 adolescent patients, the depth of the curve of Spee was the greatest at 4.3 mm in class II malocclusions and the least at 2 mm in class III malocclusions. In addition to this, the radius of the curve of Spee is less in class II cases while it is more in class III occlusion (Nayar 2015).
**Curve of Spee Class III Malocclusions**

Correction of a curve of Spee in surgical cases is best addressed through orthognathic surgery, which will lead to enhanced stability (Sugawara 2002). Individuals with class III presentations can present with variations in curve of Spee where some individuals had a flattened or reverse COS (Liou 1998). In some severe cases, although it is less common, some patients had a curve of Spee that is reversed upwards instead of downwards (Liou 1998).

**Orofacial Correlations**

Craniofacial morphology are one of the many factors that influence the development of the COS, but it is influenced to a minor extent by the vertical craniofacial dimension (Farella 2002, Baydas 2004). It is moreso influenced by the horizontal position of the condyle and the mandible with respect to the anterior cranial base (Farella 2002).

**Leveling Curve of Spee**

There has been variations among different orthodontic techniques for leveling deep curves of Spee (Bench 1977, Graber 1969). Some debate focuses on which technique achieves the most effective overbite correction and the most stable long-term results. The most effective and stable method for leveling the COS has had very little investigation; however, clinicians following the Tweed philosophy of orthodontic treatment use continuous archwires with a reverse curve of Spee to create flatten exaggerated occlusal planes.
Continuous archwire

A long-term cephalometric study found that leveling the Curve of Spee using the continuous archwire technique occurs through a combination of premolar extrusion and, to a lesser extent, incisor extrusion. This method is highly effective for leveling the Curve of Spee in patients with Class II Division I deep bite malocclusions treated without extractions, particularly when the initial Curve of Spee is 2–4 mm (Bernstein 2007).

Comparison between rectangular and round archwires

The effects of both rectangular and round full continuous archwires in leveling the curve of Spee was investigated and it was found that in both groups, the lower incisors proclined with uncontrolled tipping, even with negative torque prescriptions on the anterior segment. This is likely due to the intrusive force exerted by the archwire, which is positioned labially to the center of resistance of the lower incisors. (AlQabandi 1999). Although a comparison was done between rectangular and round archwires, there has not been quantification of forces and moments in leveling a COS before.
CHAPTER 3
MATERIALS AND METHODS

A natural curvature of the human dentition was simulated using dentition from a cone-beam computed tomography scan of a dentoform model. The teeth were segmented using MIMICS [version 17.0; Materialise, Leuven, Belgium] and 3D printed utilizing Form 3B (Formlabs Inc, Somerville, Mass) for accurate clinical tooth positioning. One dentoform was digitally assembled and printed for simulation of the curve of Spee. A new orthodontic force system (OFT) was used to measure the 3D loads delivered to the following 7 teeth: the second molar to the first incisor (Fig. 2). The dentoform was installed on the OFT system. Seven Industrial Automation Nano17 load cells (ATI Industrial Automation, Apex, NC) were attached to seven teeth to measure the forces and moments in a six-axis system. The remaining teeth were also fixed to the OFT in their clinical positions (Fig. 3,4).

Fig 2. Orthodontic force test apparatus with software interface, simulator, and load cells.
The load cells of the OFT are stationary while the positions of teeth were determined from the computerized tomography scan data. The center of the bracket on each of the teeth were identified. The information is used to transform the 3D load from the load cells to the brackets. Each tooth was printed with an adaptor that was attached to it digitally and printed along with the crown (Fig. 3) such that it can be attached to the corresponding load cell and maintain its clinical position. Based on this assembly, each tooth can consistently and easily be installed to the OFT system and ensure the tooth maintains its position during experimentation. Once the teeth are placed on the OFT, it is possible to perform orthodontic tests on the simulated dentoform for force measurement.

A well-established clinical protocol was followed where an orthodontic clinician mounted the brackets and archwires to the OFT dentoform model. One set of zero-prescription 0.022 x 0.028-in slot size brackets (3M Unitek, Monrovia, CA, USA) and Ovoid archwires (3M Unitek, Monrovia, CA, USA) of similar dimension, 0.016 x 0.022-in, with 3 types of materials: nickel-titanium \([\text{rNiTi}]\) in a prefabricated reverse curve of Spee design, titanium molybdenum alloy \([\text{TMASD}]\) in a stepdown design, and stainless steel \([\text{SSSD}]\) in a stepdown design between the canine and second incisor and between the second incisor and the first incisor.

**Fig 3.** Prefabricated .016”x.022” reverse curve of Spee archwire prior to engagement into arch. **Fig 4.** Step down 3-3 and 2-2 on .016”x.022” SS/TMA archwire prior to engagement into arch.
The stepdown designs were standardized with a 1.0-mm stepdown plier by an orthodontic clinician. As a result, 3 experimental groups were formed with 10 tests being run in each group [Table 2].

After each test, the OFT was calibrated each time. The load cell readings were transformed into the load on the bracket following an establish algorithm in the software (Department of Mechanical Engineering, Indiana University Purdue University, Indianapolis, Ind). The transformation was validated prior to testing by applying a known force (100 g) on the bracket and then it was compared with the transformed load that was measured using a load cell (Fig. 5). This known force was applied in each axis to assess for any deviation in transformations.

<table>
<thead>
<tr>
<th>Tooth</th>
<th>(X_T-X_L)</th>
<th>(Y_T-Y_L)</th>
<th>(Z_T-Z_L)</th>
<th>Δθ_z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Incisor</td>
<td>9.11507</td>
<td>-10.8564</td>
<td>17.771</td>
<td>0</td>
</tr>
<tr>
<td>Lateral Incisor</td>
<td>0.16304</td>
<td>-13.60118</td>
<td>17.771</td>
<td>-145</td>
</tr>
<tr>
<td>Canine</td>
<td>10.70008</td>
<td>-10.65578</td>
<td>17.771</td>
<td>57</td>
</tr>
<tr>
<td>First Premolar</td>
<td>13.70372</td>
<td>3.21754</td>
<td>17.771</td>
<td>72</td>
</tr>
<tr>
<td>Second Premolar</td>
<td>9.22103</td>
<td>-11.79536</td>
<td>17.771</td>
<td>-103</td>
</tr>
<tr>
<td>First Molar</td>
<td>13.20274</td>
<td>6.38625</td>
<td>17.771</td>
<td>85</td>
</tr>
</tbody>
</table>

Table II. Experimental groups used in this study

<table>
<thead>
<tr>
<th>Mechanics</th>
<th>Material</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Curve of Spee</td>
<td>NiTi</td>
<td>0.016 x 0.022</td>
</tr>
<tr>
<td>Stepdown 1.0 mm, 3-2-2-3</td>
<td>TMA</td>
<td>0.016 x 0.022</td>
</tr>
<tr>
<td>Stepdown 1.0 mm, 3-2-2-3</td>
<td>SS</td>
<td>0.016 x 0.022</td>
</tr>
</tbody>
</table>
The standard error of the system was accounted for by subtracting the generated noise in the system from the data after the load cells were initially set to zero. Load cells measured force and moment components on the teeth, which were imported into data acquisition software (LabVIEW, Department of Mechanical Engineering, Indiana University Purdue University, Indianapolis, Ind). The force-moment coordinate system is represented along with sign conventions and associated tooth movements (Fig. 6, Table 3). The experiments for each group were repeated 10 times using new archwires and elastomeric ties. An analysis of variance was used to examine the effects of the archwire material with a level of significance set at 5% (p < 0.05).

![Fig 5. Validation of load cell outputs utilizing a known force.](image)

![Fig 6. Force-moment coordinate system.](image)

<table>
<thead>
<tr>
<th>Table III. Force-moment sign conventions.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sign</strong></td>
</tr>
<tr>
<td>$F_x$</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>$F_y$</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>$F_z$</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>$M_x$</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>$M_y$</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>$M_z$</td>
</tr>
<tr>
<td>-</td>
</tr>
</tbody>
</table>
CHAPTER 4
RESULTS

Average values for forces and moments along with standard deviations for each group of wires were calculated (Table 4). From the six-axis force-moment system, \( F_z \) and \( M_x \) were synchronous with the intrusive force and lingual or buccal root torque (Fig 6, Table 3). The magnitudes of the other force components and the other moment components are also portrayed but are not compared for the purposes of this study; therefore, our study focused on \( F_z \) and \( M_x \).

Evaluating the posterior segment, the magnitudes of the extrusive forces on the first molar were about 0.22 N (rNiTi), 0.54 N (TMASD), and 0.72 N (SSSD), which correlates to 22.43 g, 55.06 g, 73.42 g, respectively (Table 4). Conversely, the magnitudes of the intrusive forces on the second molar were about 0.31 N (rNiTi), 0.43 N (TMASD), 0.4 N (SSSD), which correlates to 31.61 g, 43.85g, 40.79g, respectively (Table 4). Although the first and second molars exhibit opposing magnitudes of forces, a similar behavior is observed between the first and second premolars.

Table IV. Average values for force and moments and standard deviations.

<table>
<thead>
<tr>
<th>Archwire Material &amp; Design</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>rNiTi</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( F_x ) (N)</td>
<td>-1.54 ± 0.002</td>
<td>0.87256 ± 0.003</td>
<td>-2.4144 ± 0.003</td>
<td>-0.57478 ± 0.004</td>
<td>-1.0802 ± 0.006</td>
<td>0.94127 ± 0.002</td>
<td>-0.97175 ± 0.001</td>
</tr>
<tr>
<td>( F_y ) (N)</td>
<td>-0.07 ± 0.004</td>
<td>0.54876 ± 0.004</td>
<td>-0.33982 ± 0.004</td>
<td>-1.5642 ± 0.004</td>
<td>1.1669 ± 0.004</td>
<td>-0.89135 ± 0.002</td>
<td>-0.43886 ± 0.002</td>
</tr>
<tr>
<td>( F_z ) (N)</td>
<td>20.64 ± 0.003</td>
<td>-1.95 ± 0.005</td>
<td>-27.62 ± 0.005</td>
<td>-2.22 ± 0.006</td>
<td>0.16 ± 0.005</td>
<td>-0.22 ± 0.003</td>
<td>0.31 ± 0.002</td>
</tr>
<tr>
<td>( M_x ) (Nm)</td>
<td>53.457 ± 0.067</td>
<td>65.366 ± 0.064</td>
<td>-34.92 ± 0.064</td>
<td>-38.911 ± 0.046</td>
<td>-25.815 ± 0.057</td>
<td>-7.4679 ± 0.037</td>
<td>3.0469 ± 0.029</td>
</tr>
<tr>
<td>( M_y ) (Nm)</td>
<td>260.07 ± 0.017</td>
<td>-42.401 ± 0.033</td>
<td>-96.543 ± 0.033</td>
<td>-25.936 ± 0.025</td>
<td>11.833 ± 0.104</td>
<td>-36.98 ± 0.031</td>
<td>14.909 ± 0.018</td>
</tr>
<tr>
<td>( M_z ) (Nm)</td>
<td>142.89 ± 0.035</td>
<td>3.1054 ± 0.026</td>
<td>38.343 ± 0.026</td>
<td>41.74 ± 0.023</td>
<td>18.548 ± 0.041</td>
<td>5.3030 ± 0.039</td>
<td>10.072 ± 0.022</td>
</tr>
<tr>
<td><strong>TMASD 3-3 2-2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( F_x ) (N)</td>
<td>-1.67 ± 0.003</td>
<td>0.89464 ± 0.004</td>
<td>-2.4406 ± 0.004</td>
<td>-0.84626 ± 0.004</td>
<td>-1.6387 ± 0.137</td>
<td>1.1328 ± 0.002</td>
<td>-1.3864 ± 0.001</td>
</tr>
<tr>
<td>( F_y ) (N)</td>
<td>-4.5 ± 0.003</td>
<td>0.30135 ± 0.003</td>
<td>-0.6666 ± 0.004</td>
<td>-1.0846 ± 0.003</td>
<td>2.0745 ± 0.068</td>
<td>-1.8132 ± 0.002</td>
<td>0.043395 ± 0.002</td>
</tr>
<tr>
<td>( F_z ) (N)</td>
<td>21 ± 0.003</td>
<td>-2.63 ± 0.004</td>
<td>-28.44 ± 0.007</td>
<td>-4.31 ± 0.014</td>
<td>0.52 ± 0.01</td>
<td>-0.54 ± 0.003</td>
<td>0.43 ± 0.002</td>
</tr>
<tr>
<td>( M_x ) (Nm)</td>
<td>51.205 ± 0.057</td>
<td>64.793 ± 0.036</td>
<td>-355.58 ± 0.045</td>
<td>-62.147 ± 0.041</td>
<td>-3.5028 ± 0.541</td>
<td>-3.6166 ± 0.04</td>
<td>2.3776 ± 0.034</td>
</tr>
<tr>
<td>( M_y ) (Nm)</td>
<td>259.73 ± 0.024</td>
<td>-41.515 ± 0.05</td>
<td>-10.16 ± 0.023</td>
<td>7.504 ± 0.075</td>
<td>23.43 ± 0.862</td>
<td>-36.822 ± 0.034</td>
<td>17.044 ± 0.019</td>
</tr>
<tr>
<td>( M_z ) (Nm)</td>
<td>142.17 ± 0.029</td>
<td>6.04057 ± 0.038</td>
<td>38.782 ± 0.021</td>
<td>40.04 ± 0.03</td>
<td>-0.96067 ± 0.582</td>
<td>6.2771 ± 0.034</td>
<td>7.8547 ± 0.021</td>
</tr>
<tr>
<td><strong>SSSD 3-3 2-2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( F_x ) (N)</td>
<td>-1.85 ± 0.002</td>
<td>0.62841 ± 0.003</td>
<td>-2.4136 ± 0.005</td>
<td>-0.81542 ± 0.007</td>
<td>-1.0136 ± 0.009</td>
<td>0.9801 ± 0.004</td>
<td>-1.1644 ± 0.001</td>
</tr>
<tr>
<td>( F_y ) (N)</td>
<td>-3.84 ± 0.005</td>
<td>0.42673 ± 0.004</td>
<td>-0.26772 ± 0.004</td>
<td>-2.0059 ± 0.004</td>
<td>2.0341 ± 0.005</td>
<td>-2.2512 ± 0.003</td>
<td>0.30593 ± 0.002</td>
</tr>
<tr>
<td>( F_z ) (N)</td>
<td>20.83 ± 0.003</td>
<td>-2.84 ± 0.005</td>
<td>-27.7 ± 0.01</td>
<td>-2.14 ± 0.007</td>
<td>0.48 ± 0.006</td>
<td>-0.72 ± 0.003</td>
<td>0.4 ± 0.002</td>
</tr>
<tr>
<td>( M_x ) (Nm)</td>
<td>52.148 ± 0.09</td>
<td>63.554 ± 0.044</td>
<td>-346.32 ± 0.043</td>
<td>-37.619 ± 0.062</td>
<td>-25.423 ± 0.062</td>
<td>-2.461 ± 0.059</td>
<td>1.6755 ± 0.02</td>
</tr>
<tr>
<td>( M_y ) (Nm)</td>
<td>259.14 ± 0.024</td>
<td>-41.956 ± 0.033</td>
<td>-92.625 ± 0.026</td>
<td>22.763 ± 0.186</td>
<td>-10.798 ± 0.162</td>
<td>-36.955 ± 0.063</td>
<td>18.488 ± 0.019</td>
</tr>
<tr>
<td>( M_z ) (Nm)</td>
<td>141.82 ± 0.043</td>
<td>1.6481 ± 0.025</td>
<td>39.034 ± 0.045</td>
<td>40.848 ± 0.062</td>
<td>18.185 ± 0.075</td>
<td>5.1118 ± 0.08</td>
<td>8.9076 ± 0.024</td>
</tr>
</tbody>
</table>

Note. Values are presented as mean ± standard deviation.
The magnitudes of the extrusive forces on the first premolar were about 2.22 N (rNiTi), 4.31 N (TMASD), and 2.14 N (SSSD), which correlates to 226.38 g, 439.50 g, 218.22 g, respectively (Table 4). Conversely, the magnitudes of the intrusive forces on the second premolar were about 0.16 N (rNiTi), 0.52 N (TMASD), 0.48 N (SSSD), which correlates to 16.32 g, 53.03g, 48.95g, respectively (Table 4).

In evaluating the anterior segment quantitively, the magnitudes of the intrusive forces on the first incisor were about 20.64 N (rNiTi), 21 N (TMASD), and 20.83 N (SSSD), which correlates to 2104.7 g, 2141.4 g, 2124.06 g, respectively (Table 4). The first incisor intrusive forces created by rNiTi was the least of the archwires; however, it was not significantly different in the first incisor between TMASD and SSSD (Fig. 9); however, the second incisor had significant differences between the archwire designs in intrusive forces (Fig. 7). On average, SSSD wires were about 2 times higher than that of rNiTi wires with the same size, and 1.5 times higher with the TMASD wires in comparison to rNiTi (Fig. 9).

The distributions of Fz among the teeth had similar patterns among the tested groups (Fig 7). There were nonsignificant differences between the second incisor and the posterior segment (Fig. 7). In comparing the canine to the posterior segment, there were no significant differences between the canine and the posterior segment (Fig. 7). There were significant differences between the first incisor and the canine in the forces and moments exhibited on them (Fig. 7). In comparing archwire designs, the second incisor exhibited an intrusive force that is 68% (rNiTi) and 92% (TMASD) compared to that of the SSSD (Fig. 9). For the extrusive forces on the molar, it was 30% (rNiTi) and 75% (TMASD) compared
to that of the SSSD extrusive force (Fig. 9). There was not significant differences between the TMASD and SSSD in incisor intrusive or molar extrusive forces (Fig. 9).

The distributions of $M_x$ among the teeth were positive on the incisors and negative on the molars (Fig. 8). There was significant differences in $M_x$ between the first incisor in comparison to the canine-second molar segment (Fig. 8). The canine had the greatest moment followed by the second incisor and first incisor (Fig. 8). In comparing archwire design, $M_x$ was highest on the incisor with rNiTi and lowest with SSSD, although TMA was similar to SSSD (Fig. 10). For example, for the 0.016 x 0.022 in SSSD archwire, the $M_x$ on the central incisor was 53 N-mm., which was less than that of the rNiTi archwire, which had the greatest expression of $M_x$ (Fig. 10). This pattern can be exhibited across different archwire groups with varying intensity (Fig. 10). In general, the magnitudes of $M_x$ were greatest on the incisors for rNiTi, whereas they were similar in the TMASD and SSSD across all three groups than on the molar.

The three factors of archwire size, archwire material, and method of leveling the curve of Spee significantly impact the loads on the teeth. An analysis of variance indicated significant effects on incisor flaring with the rNiTi wire ($p<0.05$). Incisor intrusion and molar extrusion for TMASD and SSSD had similar $M_x$ and $F_z$, except for the rNiTi ($p<0.05$) on the incisors. For the step mechanics with the TMA and SS archwires, the $F_z$ in SS on the incisors was 1.5x greater than the TMA and 2x greater than rNiTi. When comparing incisor intrusion and molar extrusion between TMASD and SSSD step mechanics, they were similar.
Fig 7. Distribution of Fz with different archwire designs. 1: Central Incisor 2: Lateral Incisor 3: Canine 4: 1\textsuperscript{st} Premolar 5: 2\textsuperscript{nd} Premolar 6: 1\textsuperscript{st} Molar 7: 2\textsuperscript{nd} Molar. (+) Intrusive (-) Extrusive. (*) p<0.05 between the central incisor and back teeth (canine-second molar).

Fig 8. Distribution of Mx with different archwire designs. 1: Central Incisor 2: Lateral Incisor 3: Canine 4: 1\textsuperscript{st} Premolar 5: 2\textsuperscript{nd} Premolar 6: 1\textsuperscript{st} Molar 7: 2\textsuperscript{nd} Molar. (+) LRT (-) BRT (*) p<0.05 between the central incisor and back teeth (canine-second molar).
Fig 9. Intrusive and extrusive forces exhibited on the incisors and molars. (*) p<0.05.

Fig 10. Lingual Root Torque (LRT) exhibited on the incisors and Buccal Root Torque (BRT) exhibited on the molars. (*) p<0.05.
Leveling an exaggerated COS is a treatment goal in orthodontic treatment and is one of the six characteristics to normal occlusion as described by Andrews, who indicated that a normal COS is flat to mildly curved for the best intercuspation (Andrews 1972). To obtain this treatment goal in orthodontic treatment, several studies have compared treatment techniques to correct an exaggerated COS and the stability of such a correction, which included molar extrusion, incisor intrusion, incisor proclination (Carter 1998, Al-Amiri 2015, Wong 2016). Extrusion of the posterior teeth is preferred in a patient with a short vertical dimension; however, this method is more prone to relapse due to neuromuscular tendencies and musculature rebound (Al-Buraiki 2005). For every millimeter of molar extrusion, the incisor overlap decreases by 1.5-2.5 mm, so it is best done with caution (Bernstein 2007).

Incisor intrusion would be preferred in patients with a large vertical dimension, where molar extrusion should be avoided; however, external apical root resorption is a risk factor with incisor intrusion (Al-Buraiki 2005, Harris 2000). Although incisor proclination occurs while leveling the COS, its severity is dependent on the mechanics being used (Bernstein 2007, Al-Buraiki 2005). There are claims that incisor proclination is the predominant occurrence when leveling the COS, such that for every 1 mm in leveling the COS, the mandibular incisors were proclined 4 degrees without an increase in arch width (Kumar 2012).

Incisor proclination is masked by an increase in arch width, especially as the intercanine widths are markedly increased (Braun 1999). Incisor proclination can be
attributed to intrusive forces being applied by the archwire anterior to the center of resistance (Baydas 2004). The proclination of the incisors is undesirable because of instability posttreatment and the periodontium is put at risk (Pandis 2010). Preformed reverse curve nickel titanium archwires typically increase the intercanine width over that of the natural human arch form; therefore, reducing incisor proclination and the potential harmful effects of leveling with rectangular cross-sectional archwires in combination with torqued incisor brackets (Braun 2001). Braun and Schmidt evaluated gender differences in the COS between men and women and found no differences in the shape of COS and no differences between Class I or Class II individuals (Braun 1956).

As previously mentioned, the varying biting forces in high-angle and low-angle subjects significantly impact the balance between molar extrusion and incisor intrusion or flaring (Farella 2002). The higher masticatory forces in the low-angle group can prevent the overeruption of the posterior teeth, enabling the archwire forces to intrude and procline the mandibular incisors (Bench 1977). In the same manner, the biomechanics play an important role during orthodontic leveling of the dental arch. The archwire placed in the brackets of the mandibular incisors creates an intrusion force. At the same time, a moment to tip the crowns facially is created by distance of the brackets forward from the center of resistance of the teeth (Braun 1997). In buccally tipped incisors, the magnitude of this moment encourages incisor proclination (Braun 1997).

To quantitatively evaluate these behaviors, the OFT system is capable of measuring orthodontic loads on teeth in simulated clinical scenarios. The accuracy of the dentition being printed with the 3D printer, Form 3B, has been proven to meet the requirements of clinical applications (Wang 2021, Chen 2021). The OFT allows for an accurate simulation
of clinical scenarios by reconstructing patient computerized tomography scans, which allows for orthodontic appliance installation following a clinical protocol, and then it can measure 3D loads on multiple teeth, which ensures that the data recorded is reliable and clinically relevant.

The load distribution from the various archwires designs in leveling the curve of Spee was qualitatively described previously; however, the magnitudes of the loads and moments in a clinical setting have yet to be reliably quantified (Bernstein 2007, AlQabandi 1999). The effects on the posterior teeth were localized for the stepdown mechanics in TMASD and SSSD and the coupled moments on the other teeth diminished as the distance increased from the stepdown bends towards the posterior segment. The archwire material affected the load on the teeth. The degree of incisor intrusion was significantly affected by the biomechanics used. With the same wire size and stepdown mechanics, the $F_z$ on the incisors was linearly correlated between wire materials TMASD and SSSD. The magnitudes of the intrusion and extrusion force on the neighboring teeth was significant, especially with the stiffer archwire. The results from our study suggest that you can double the intrusion force by changing from rNiTi to SSSD mechanics.

Although it is expected that the archwire size would impact the load on teeth, all archwires used in our study were of similar dimension; however, further studies can investigate difference archwire sizes. Previous studies have suggested that force on teeth is proportional to the wire stiffness, and that stiffness is not proportional to the wire’s diameter (AlQabandi 1999, Kumar 2012). The results of this study quantifies the magnitudes of loads on the teeth, which can aid clinicians to choose the proper archwire for clinical applications of correcting a deep bite. The magnitudes are important because
an archwire performs properly only if used within its elastic range. It is imperative to understand the factors of archwire size, archwire materials, and their effects on the load delivered to teeth in order to improve treatment for patients. Clinically, the leveling of the curve of Spee relies on various dental parameters according to the skeletal vertical pattern. From the findings in this study and the combination of a clinician’s clinical judgement, one can deploy the leveling mechanics necessary based on the patient’s clinical presentation by utilizing both, the quantitative and qualitative, findings from this study to aid in obtaining the desired orthodontic treatment objective.
CHAPTER 6
CONCLUSION

CONCLUSION

1. The hypothesis is rejected as there are significant differences in load in the anterior segment on the incisors between the archwire designs.

2. For archwire comparisons, the forces on the incisors and the molars were the least with the rNiTi, followed by TMASD, then SSSD. Conversely, the moments on the incisors were the greatest with the rNiTi, followed by TMASD, then SSSD. The TMASD and SSSD were similar in forces and moments among the different archwire designs. However, the moments on the molars were similar across all the different archwire designs.

3. Intruding an overerupted anterior segment using a continuous archwire effects primarily the anterior teeth and its immediate neighboring teeth, especially with step-bend mechanics versus reverse curve of Spee mechanics.

4. Force and moment distributions in a quadrant illustrate significant differences between the incisors and the premolars and molars.

5. The magnitude of the intrusive force, $F_z$, and second-order moment, $M_x$, can be adjusted by altering the material of the archwire.
REFERENCES


Kelley N, Tabbaa S, Vezina GC, El-Bialy T. Cone-beam Computed Tomography Analysis of the Relationship between the Curve of Spee and the Collum Angle of


