Original Article

Orthodontic forces and moments of three-bracket geometries

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ABSTRACT

Objectives: To test the hypothesis of Burstone and Koenig that a three-bracket geometry can be simplified into two adjacent two-bracket geometries, to evaluate the impact of a third bracket on two-bracket geometries, to identify the force systems of 36 three-bracket geometries using archwires of different materials, and to apply these principles to clinical scenarios.

Materials and Methods: A custom-designed orthodontic force jig supported three force transducers fitted with passive self-ligating brackets (Brackets A, B, and C). In Experiment 1, the force system of a three-bracket geometry was compared with two adjacent two-bracket geometries. In Experiment 2, 36 three-bracket geometries were tested when straight wires of varying materials were engaged.

Results: Experiment 1 results showed that the force system of a three-bracket geometry could be simplified into two adjacent two-bracket geometries. Experiment 2 results showed that the impact of the third bracket (Bracket C) affected the force system of the adjacent bracket only (Bracket B), with Bracket C having no statistically significant effect on the force systems at Bracket A. A distinct pattern of forces and moments was found in each of the 36 three-bracket geometries.

Conclusions: In this study, we experimentally validated the hypothesis of Burstone and Koenig, showing that a three-bracket geometry can be simplified into two adjacent two-bracket geometries. The force system of 36 three-bracket geometries was determined, assisting clinicians with better anticipating previously unpredicted and undesirable movements, thereby improving treatment efficiency. (*Angle Orthod*. 2025;95:379–388.)

KEY WORDS: Orthodontic forces; Orthodontic moments; Three-bracket geometries; Indeterminate; Determinate; Burstone and Koenig

INTRODUCTION

Orthodontic treatment uses force systems producing a physiological cascade of biological reactions resulting in tooth movement.[1] While each patient's individual response may be variable and unpredictable, the orthodontist has full control of the force systems and their application. Understanding biomechanical principles should increase the efficiency and predictability of tooth movement[2] and help to eliminate undesirable side effects.[3,4]

Andrews' straight wire concept has become popular with its continuous unbent wire engaging multiple maligned brackets.[5] This creates an indeterminate force system, from which it is difficult to quantify the forces and moments acting on each tooth.[4,6] This is significant because continuous arch mechanics may result in secondary malocclusions, including canting of the occlusal plane, deepening of overbite, opening of anterior open bite, and damage to the supporting periodontium.[1,3] Further studies are needed to understand the biomechanical implications when using continuous arch mechanics.[1,3]

To simplify the understanding of an indeterminate force system of an entire arch, Burstone and Koenig[6] theorized that the arch can be divided into two-tooth units. They identified the force systems produced by a straight 0.016-inch stainless steel wire engaged between two brackets at six different angulations to each other, known as geometries. They proposed that, by summing

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the force systems of adjacent two-tooth geometries, the indeterminate force systems in an entire arch can be determined.[6] This theory has yet to be tested experimentally.

Existing studies of three or more brackets have diverged from the six geometries of Burstone and Koenig,[6] and authors have studied scenarios including vertically displaced high canine malocclusion,[7–11] passive vs active ligation,[8,9] lingual appliances,[12] and molar intrusion.[13] No studies exist in which authors have directly expanded on the two-bracket geometries of Burstone to three-bracket geometries and how this could be applied in the clinical setting. In building upon the fundamental concepts, the findings from this study could reduce the development of secondary malocclusions, therefore improving treatment predictability and efficiency following alignment.

Specific Objectives

In this study, we used an orthodontic force jig (OFJ; Figure 1A, B), and aimed to do the following:

(1) Test the hypothesis that a three-bracket geometry can be derived from two adjacent two-bracket geometries (Figure 2A).
(2) Evaluate the impact of a third bracket on two-bracket geometries.
(3) Identify the force systems of 36 three-bracket geometries, using wires of different materials, and apply these principles to clinical scenarios.

MATERIALS AND METHODS

Apparatus Setup

A custom-built OFJ to support three force transducers (Nano 17 Sensor, ATI Industrial Automation, Apex, NC) was constructed to represent three teeth in a linear configuration (Figure 1A). Three passive self-ligating brackets (Empower 2, 0.022 × 0.028-inch slot, American Orthodontics, Sheboygan, Wis) with 0° tip and torque were bonded to a 0.5 mm thick aluminum wafer (STANDA UAB, Vilnius, Lithuania) with Transbond XT Light Cure Adhesive (3M Orthodontics, Monrovia, Calif). A 0.021 × 0.025-inch stainless-steel wire was used as a guide to align the brackets to the transducers. The round aluminum stages had adjustable micrometer screws with 0.25 mm resolution to allow for precise angulation changes. The interbracket distance was set at approximately 21 mm to simulate the same interbracket distance used in the study by Burstone and Koenig[6] (Figure 1B). The OFJ was linked to a USB-6225 data acquisition device (National Instruments, Austin, Texas), which allowed the force systems to be viewed by a custom developed LabVIEW program (National Instruments). To collect data, a straight wire was engaged in the brackets. After the force systems stabilized, data collection was performed. Prior to the next experiment, the transducers were reset and calibrated using the LabVIEW software.

Testing Procedure

Experiment 1. The force systems of a three-bracket geometry were determined when a 0.016-inch NiTi wire was engaged with Brackets A, B, and C all angled at 30° (Class 1.1). Protractors were used to calibrate the angles between the brackets for error. Data collection was triggered manually to record the forces and moments 15 times, with 5 second intervals between each recording. The average of these data points was used as the final recording.

The force systems of two adjacent Class 1 two-bracket geometries were then determined. A 0.016-inch NiTi wire was engaged into Brackets A and B only first, with the force systems recorded using the same acquisition protocol, followed by engagement and recording into Brackets B and C only. To calculate the mathematical three-bracket geometry, the vertical forces and moments on Bracket B were summed, while the force systems on Brackets A and C remained unchanged.

The resulting vertical forces and moments were compared between the three-bracket geometry and two adjacent two-bracket geometries.

Experiment 2. In this experiment, we aimed to replicate the six two-bracket geometries of Burstone and Koenig[6] in following the same angulation-to-angulation ratio. The ratios from Classes 1 to 6 were 1, 0.5, 0, −0.5, −0.75, and −1, respectively. As Bracket B was fixed at 30° for all geometries, the angulation at Bracket A was 30° for Class 1, 15° for Class 2, 0° for Class 3, −15° for Class 4, −22.5° for Class 5, and −30° for Class 6.

When a third bracket (Bracket C) was added, it was angled with the same six angulations. For example, from Classes 1.1 to 1.6, Brackets A and B were angled at 30°, and Bracket C was angled at 30° for Class 1.1, 15° for Class 1.2, 0° for Class 1.3, −15° for Class 1.4, −22.5° for Class 1.5, and −30° for Class 1.6. A total of 36 different three-bracket geometries were tested in Experiment 2.

Seven different wires of 60 mm length were tested: 0.016-inch NiTi, 0.016-inch beta-titanium (TMA), 0.016-inch stainless-steel (SS), 0.016 × 0.022-inch NiTi, 0.019 × 0.025-inch NiTi, 0.020-inch Supercable™ coaxial NiTi (SC), and 0.018-inch NiTi.

For each three-bracket geometry, data collection was manually recorded 15 times with 5 second intervals between each recording. Negligible variations were observed among the 15 data acquisitions, so the average of these points was used as the final recording. The wire was then removed and the force transducers

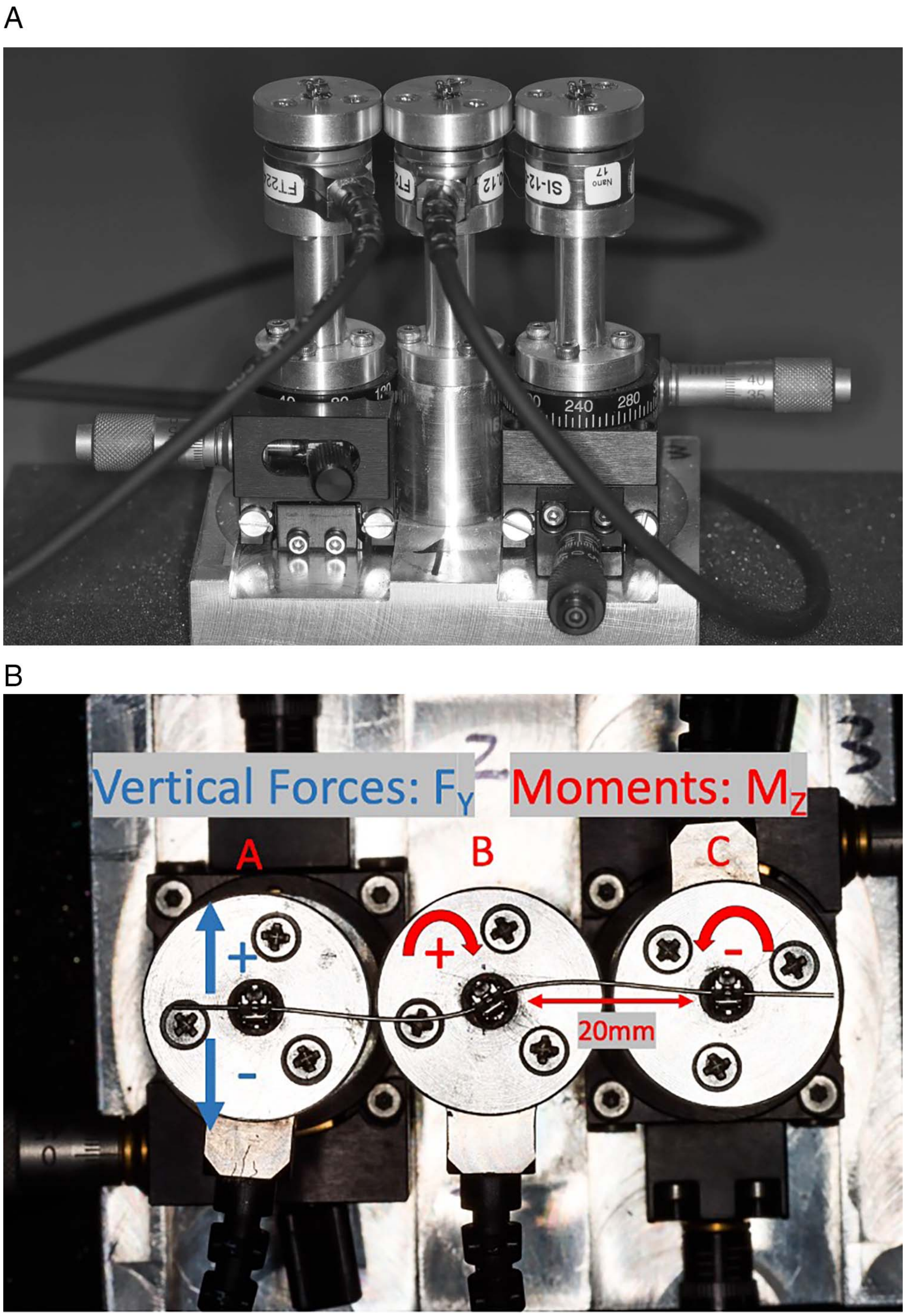

Figure 1. (A) Orthodontic force jig (OFJ). (B) Cartesian coordinate system of Brackets A, B, and C. F_Y relates to extrusion and intrusion forces. M_Z relates to moments.

recalibrated before the next experiment. A total of 252 wires were used in Experiment 2.

Analysis of Orthodontic Force

A Cartesian coordinate system was used to measure forces in the Y and Z axes (Table 1).

Forces were measured in Newtons (N) with the Y axis being the vertical axis (occlusogingival), and the Z axis being the transverse axis (buccolingual). Moments were measured in Newton-millimeters (Nmm).

Analytical Methods

In this study, we focused on the forces in the F_Y axis, which evaluated the extrusive and intrusive forces, and moments in the M_Z axis, which evaluated clockwise and counterclockwise moments resulting in mesial and distal

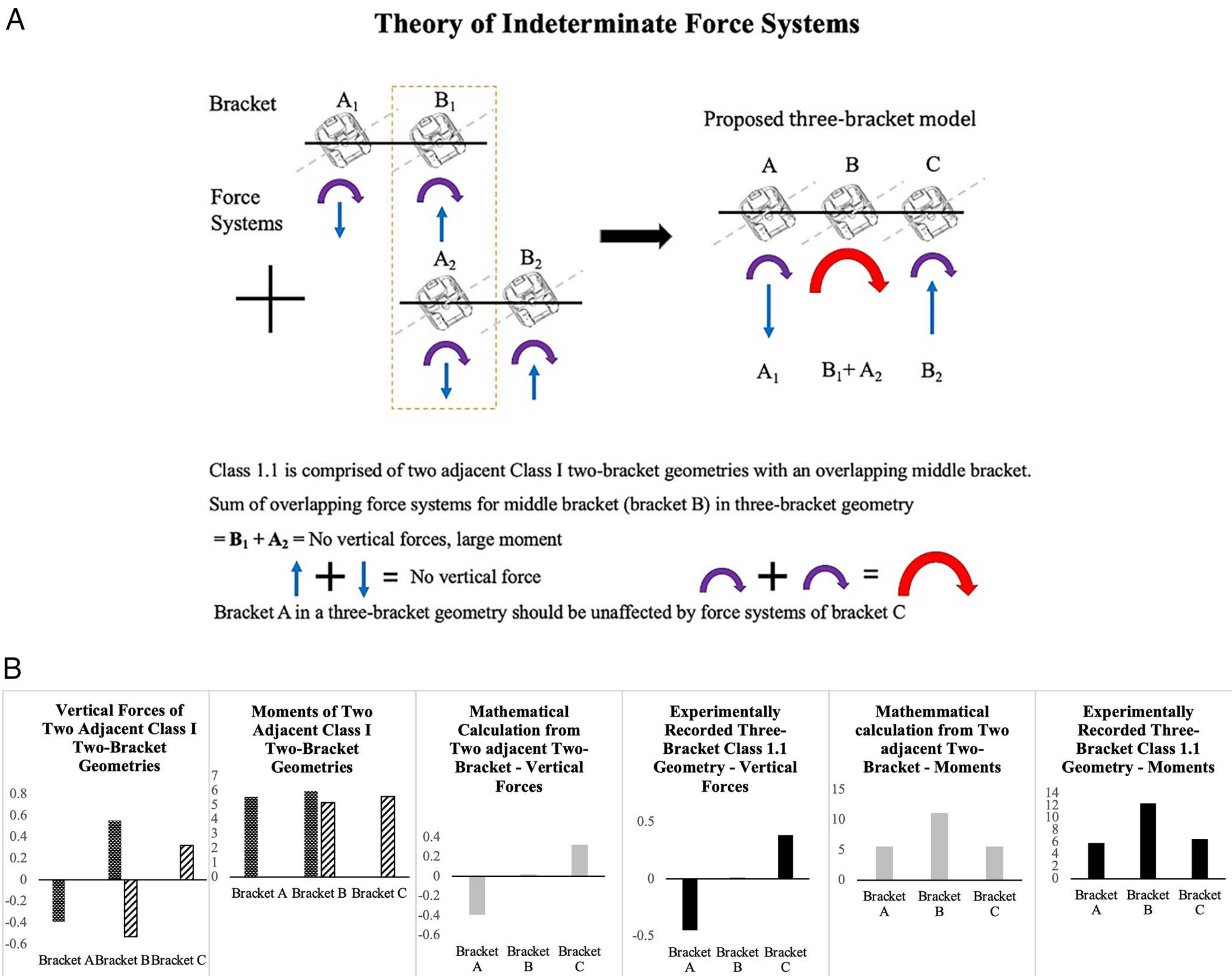

Figure 2. (A) The hypothesis of Burstone and Koenig.[6] (B) Mathematical calculation of two adjacent Class I two-bracket geometries vs experimentally recorded forces and moments of a Class 1.1 three-bracket geometry with .016 NiTi. Forces are shown in Newtons (N), moments in Nmm. The first two graphs show forces and moments of two adjacent Class I two-bracket geometries as proposed by Burstone and Koenig.[6] The next pair of graphs show the vertical forces measured in this study mathematically (calculated from two bracket geometries) and experimentally (recorded from three-bracket geometries). The last pair of graphs show the moments measured in this study mathematically and experimentally. The mathematical calculations and experimentally recorded results were similar.

root tip. Data analysis was performed using Microsoft® Excel (Microsoft Excel for Windows, Version 16.44), Redmond, Washington. In Experiments 1 and 2, the 15 recordings were averaged and graphed. In the mathematical summation, values recorded at Bracket B of two adjacent two-bracket geometries were summed. This was compared with experimental recording at Bracket B of a three-bracket geometry. In Experiment 2, the forces and moments of each wire were graphed in Class 3.3.

Table 1. Cartesian Coordinate System Sign Conventions

Force System	Bracket A, B and C
F_Y (+)	Intrusion
F_Y (−)	Extrusion
M_Z (+)	Distal crown tip
M_Z (−)	Mesial crown tip

Statistical Analysis

Two-way analysis of variance (ANOVA) models were used to test the effect of class and wire on the vertical forces and moments of Brackets A and B (relative to the changing angulation of Bracket C). The model assumptions were tested, and the data satisfied the requirements for two-way ANOVA linear regressions. The data were analyzed using R Core Team 2023 (Version 4.3.0; R Foundation for Statistical Computing, Vienna, Austria).

Table 2. Influence of Bracket C Angulation Changes on the Vertical Forces at Bracket A[a]

Bracket C Angulation	Mean (95% CI) 0.1	0.2	0.3	0.4	0.5	0.6	P Value
Class 1	−0.75 (−0.82, −0.69)	−0.68 (−0.75, −0.62)	−0.69 (−0.76, −0.62)	−0.66 (−0.73, −0. 60)	−0.64 (−0.71, −0.58)	−0.63 (−0.70, −0.57)	.154
Class 2	−0.88 (−0.91, −0.84)	−0.88 (−0.91, −0.85)	−0.86 (−0.90, −0.83)	−0.87 (−0.90, −0.83)	−0.86 (−0.89, −0.83)	−0.86 (−0.89, −0.82)	.903
Class 3	−0.69 (−0.71, −0.68)	−0.70 (−0.71, −0.69)	−0.69 (−0.70, −0.68)	−0.69 (−0.70, −0. 69)	−0.70 (−0.72, −0. 69)	−0.69 (−0.70, −0.67)	.660
Class 4	−0.38 (−0.40, −0.37)	−0.38 (−0.40, −0.36)	−0.38 (−0.40, −0.37)	−0.35 (−0.37, −0.33)	−0.38 (−0.40, −0.36)	−0.38 (−0.40, −0.36)	.125
Class 5	−0.28 (−0.30, −0.25)	−0.28 (−0.31, −0.25)	−0.27 (−0.30, −0.24)	−0.27 (−0.30, −0.24)	−0.24 (−0.27, −0.22)	−0.24 (−0.27, −0.22)	.217
Class 6	−0.05 (−0.09, −0.01)	−0.05 (−0.09, −0.01)	−0.01 (−0.05, 0.03)	0.01 (−0.03, 0.05)	0 (−0.04, 0.04)	−0.03 (−0.07, 0.01)	.135

[a] CI indicates confidence interval. The impact of Bracket C angulation changes did not cause a statistically significant difference in the mean vertical forces (N) expressed on Bracket A for all the wires tested ($P > .05$).

RESULTS

Experiment 1

Class I two-bracket geometries. An intrusive force existed on Bracket A and an extrusive force on Bracket B. Both brackets experienced a clockwise moment for the first two-bracket geometry. An intrusive force existed on Bracket B and an extrusive force on Bracket C, with both brackets also experiencing clockwise moments for the second two-bracket geometry.

Mathematically, when the intrusive and extrusive forces at Bracket B were summed as theorized, these forces cancelled each other out, while the two clockwise moments at Bracket B increased. The vertical forces and moments on Brackets A and C remain unchanged (Figure 2B).

Class 1.1 three-bracket geometry. Experimental values of a Class 1.1 three-bracket geometry were almost equal to the mathematical summation from two adjacent Class I two-bracket geometries (Figure 2B). The minor differences noted were not significant and likely were due to experimental limitations. This experimentally validated the hypothesis of Burstone and Koenig[6] (Objective 1).

Experiment 2

The impact of angulation changes of Bracket C resulted in statistically significant differences on the vertical forces and moments on Bracket B but not on Bracket A (see Tables 2 through 5). This finding demonstrated that the impact of Bracket C was limited to the adjacent Bracket B only (Objective 2). The relative force systems were consistent for all 36 three-bracket geometries (Objective 3; Figure 3). Negligible variations were observed among the 15 data acquisitions for each three-bracket geometry. The greatest force systems were produced by 0.016-inch SS, followed by 0.019 × 0.025-inch NiTi, 0.016 × 0.022-inch NiTi, 0.016-inch TMA, 0.018-inch NiTi, 0.016-inch NiTi, and 0.020-inch SC.

DISCUSSION

The seminal study by Burstone and Koenig[6] was the first to present, in a simplified and organized way, the complexity of indeterminate force systems into six two-bracket geometries. To date, limited evidence has been found to build directly upon the initial theory of Burstone and Koenig.[6] Authors of existing two-bracket experimental studies have shown that two-bracket theoretical simulations could not be accurately reproduced in the laboratory setting.[12–14] It is unknown whether the differences from the computer simulations have any clinical significance.

In this laboratory study, we expanded upon the existing literature by adding a third bracket to the existing six two-bracket geometries as described by Burstone and Koenig.[6] As the right bracket in the original two-bracket geometries remained unchanged, this (Bracket B) remained unchanged in the 36 three-bracket

Table 3. Influence of Bracket C Angulation Changes on the Moments at Bracket A[a]

Bracket C Angulation	Mean (95% CI) 0.1	0.2	0.3	0.4	0.5	0.6	P Value
Class 1	10.5 (10.1, 10.9)	10.5 (10.07, 10.9)	10.7 (10.31, 11.2)	10.4 (9.98, 10.8)	10.1 (9.63, 10.5)	10.1 (9.6, 10.5)	.164
Class 2	9.1 (8.9, 9.4)	9.3 (9.1, 9.5)	9.3 (9.1, 9.6)	9.3 (9.1, 9.4)	9.2 (9.0, 9.5)	9.2 (9.0, 9.5)	.730
Class 3	4.4 (4.3, 4.5)	4.4 (4.3, 4.5)	4.4 (4.3, 4.5)	4.3 (4.2, 4.5)	4.4 (4.3, 4.5)	4.4 (4.3, 4.5)	.824
Class 4	−0.4 (−0.7, −0.2)	−0.5 (−0.7, −0.3)	−0.4 (−0.7, −0.2)	−0.6 (−0.8, −0.4)	−0.4 (−0.6, −0.2)	−0.5 (−0.7, −0.3)	.865
Class 5	−2.3 (−2.5, −2.2)	−2.4 (−2.5, −2.2)	−2.3 (−2.4, −2.1)	−2.4 (−2.5, −2.2)	−2.4 (−2.5, −2.2)	−2.6 (−2.7, −2.4)	.100
Class 6	−5.1 (−5.5, −4.8)	−5.1 (−5.4, −4.8)	−5.4 (−5.7, −5.1)	−5.6 (−6.0, −5.3)	−5.5 (−5.8, −5.2)	−5.3 (−5.6, −5.0)	.13

[a] CI indicates confidence interval. The impact of Bracket C angulation changes did not cause a statistically significant difference in the mean moments (Nmm) expressed on Bracket A for all the wires tested ($P > .05$).

Table 4. Influence of Bracket C Angulation Changes on the Vertical Forces at Bracket B[a]

Bracket C Angulation	Mean (95% CI)						*P* Value
	0.1	0.2	0.3	0.4	0.5	0.6	
Class 1	0.05 (−0.14, 0.24)	0.09 (−0.10, 0.28)	0.42 (0.23, 0.61)	0.68 (0.49, 0.87)	0.80 (0.61, 0.99)	1.01 (0.82, 1.20)	< .0001
Class 2	−0.03 (−0.21, 0.15)	−0.01 (−0.19, 0.17)	0.34 (0.16, 0.52)	0.61 (0.43, 0.79)	0.74 (0.56, 0.92)	0.93 (0.75, 1.11)	< .0001
Class 3	−0.30 (−0.47, −0.13)	−0.24 (−0.40, −0.07)	0.04 (−0.12, 0.21)	0.32 (0.15, 0.49)	0.45 (0.29, 0.62)	0.65 (0.49, 0.82)	< .0001
Class 4	−0.63 (−0.81, −0.44)	−0.60 (−0.78, −0.42)	−0.27 (−0.45, −0.09)	0.06 (−0.17, 0.19)	0.13 (−0.05, 0.31)	0.33 (0.15, 0.51)	< .0001
Class 5	−0.72 (−0.90, −0.54)	−0.68 (−0.86, −0.50)	−0.37 (−0.56, −0.20)	−0.10 (−0.27, 0.08)	0.03 (−0.15, 0.21)	0.22 (0.04, 0.39)	< .0001
Class 6	−0.92 (−1.09, −0.75)	−0.81 (−0.98, −0.64)	−0.57 (−0.74, −0.40)	−0.31 (−0.48, −0.14)	−0.17 (−0.33, 0.00)	0.04 (−0.14, 0.21)	< .0001

[a] CI indicates confidence interval. The impact of bracket C angulation changes caused a statistically significant difference in the mean vertical forces (N) expressed on Bracket B for all the wires tested ($P < .0001$).

geometries, so that the impact of third bracket could be observed clearly. As in the original study, only force systems in the vertical plane were studied to better understand and develop fundamental concepts. Therefore, mesial-distal forces generated from friction at the bracket wire interface were disregarded.

Validation of Hypothesis

In this study, we showed experimentally that the force systems of a Class 1.1 three-bracket geometry force system were equal to two adjacent Class I two-bracket geometries (Objective 1). It also showed that the impact of a third bracket only affected the adjacent bracket (Objective 2). This, therefore, validated the hypothesis of Burstone and Koenig,[6] showing that the complexity of indeterminate force systems can be reduced.

Clinical Relevance of Three-Bracket Geometries

With the force systems of 36 different three-bracket geometries presented in a simplified fashion (Objective 3), clinicians may use these as a reference to treat common scenarios encountered in clinical practice.

Class 3.3 depicts a tooth requiring mesial or distal root tip, while the adjacent teeth are in good alignment, typically occurring during the finishing stages (Figure 4A). In the current study, we showed that, in producing the necessary moment to correct the root tip, it would also produce unwanted moments and vertical forces on the adjacent teeth. It is critical for the clinician to recognize that undesirable tooth movement may occur.

A clinical example is shown in Figure 4B. Here, the canine bracket was rebonded to generate the desirable clockwise moment to upright the tooth. The experimental data suggested that the lateral incisor would experience an undesirable intrusive force as well as a small counterclockwise moment. They also suggested that the premolar would extrude undesirably and experience a small counterclockwise moment. At the following visit, these predicted movements had occurred, with bite opening observed at the lateral incisor and heavier occlusal contact at the premolar. It was also interesting to observe that the bite opening effects were not limited to the adjacent teeth but also extended anteriorly to the central incisors.

In another example (Figure 4C), an upper canine with distal root tip required uprighting. At the following appointments, the adjacent upper right lateral incisor intruded, the upper midline shifted to the right, and the occlusal plane canted. This example showed that correcting one problem resulted in the creation of secondary effects.

These clinical examples showed that, although Class 3.3 was correct in predicting the resulting force systems, the magnitude of these responses varied. This difference in orthodontic tooth movement is multifactorial and may be due to individualized biologic responses to the orthodontic force as well as genetic, age, and environmental

Table 5. Influence of Bracket C Angulation Changes on the Moments of Bracket B[a]

Bracket C Angulation	Mean (95% CI)						*P* Value
	0.1	0.2	0.3	0.4	0.5	0.6	
Class 1	21.6 (20.5, 22.8)	21.8 (20.7, 23.0)	21.6 (20.5, 22.8)	19.7 (18.6, 20.9)	18.6 (17.5, 19.8)	17.2 (16.0, 18.3)	< .0001***
Class 2	21.2 (20.1, 22.3)	22.0 (20.9, 23.1)	20.8 (19.7, 21.9)	19.4 (18.3, 20.4)	18.7 (17.6, 19.7)	17.1 (16.1, 18.2)	< .0001***
Class 3	19.7 (18.6, 20.8)	20.2 (19.1, 21.3)	19.2 (18.1, 20.3)	18.2 (17.1, 19.3)	17.5 (16.4, 18.6)	15.8 (14.7, 16.9)	< .0001***
Class 4	17.8 (16.7, 19.0)	18.8 (17.6, 19.9)	17.8 (16.6, 19.0)	15.6 (14.5, 16.8)	15.6 (14.4, 16.7)	13.5 (12.4, 14.7)	< .0001***
Class 5	16.8 (15.4, 18.3)	17.7 (16.3, 19.2)	16.9 (15.5, 18.4)	15.8 (14.4, 17.3)	14.5 (13.0, 15.9)	12.8 (11.4, 14.2)	.0003**
Class 6	16.0 (14.5, 17.5)	15.8 (14.3, 17.3)	15.9 (14.4, 17.4)	14.6 (13.1, 16.1)	13.9 (12.3, 15.4)	11.5 (10.0, 13.0)	.0010*

[a] CI indicates confidence interval. The impact of Bracket C angulation changes caused a statistically significant difference in the mean moments (Nmm) expressed on Bracket B for all the wires tested, where * $P < .01$, ** $P < .001$, *** $P < .0001$.

Figure 3. Thirty-six three-bracket geometries.

influences.[15,16] Other factors may have included anatomical site, age, occlusion, anchorage, masticatory muscles, supporting periodontium, location of the center of resistance, resting tongue position, tongue pressure, and systemic conditions.[15,17,18] The authors of these studies showed that, although the level and direction of the force systems are within the control of the orthodontist, the magnitude and rate of tooth movement vary.

Clinical Management

Clinicians may apply the 36 three-bracket geometries to achieve predictable orthodontic tooth movement in

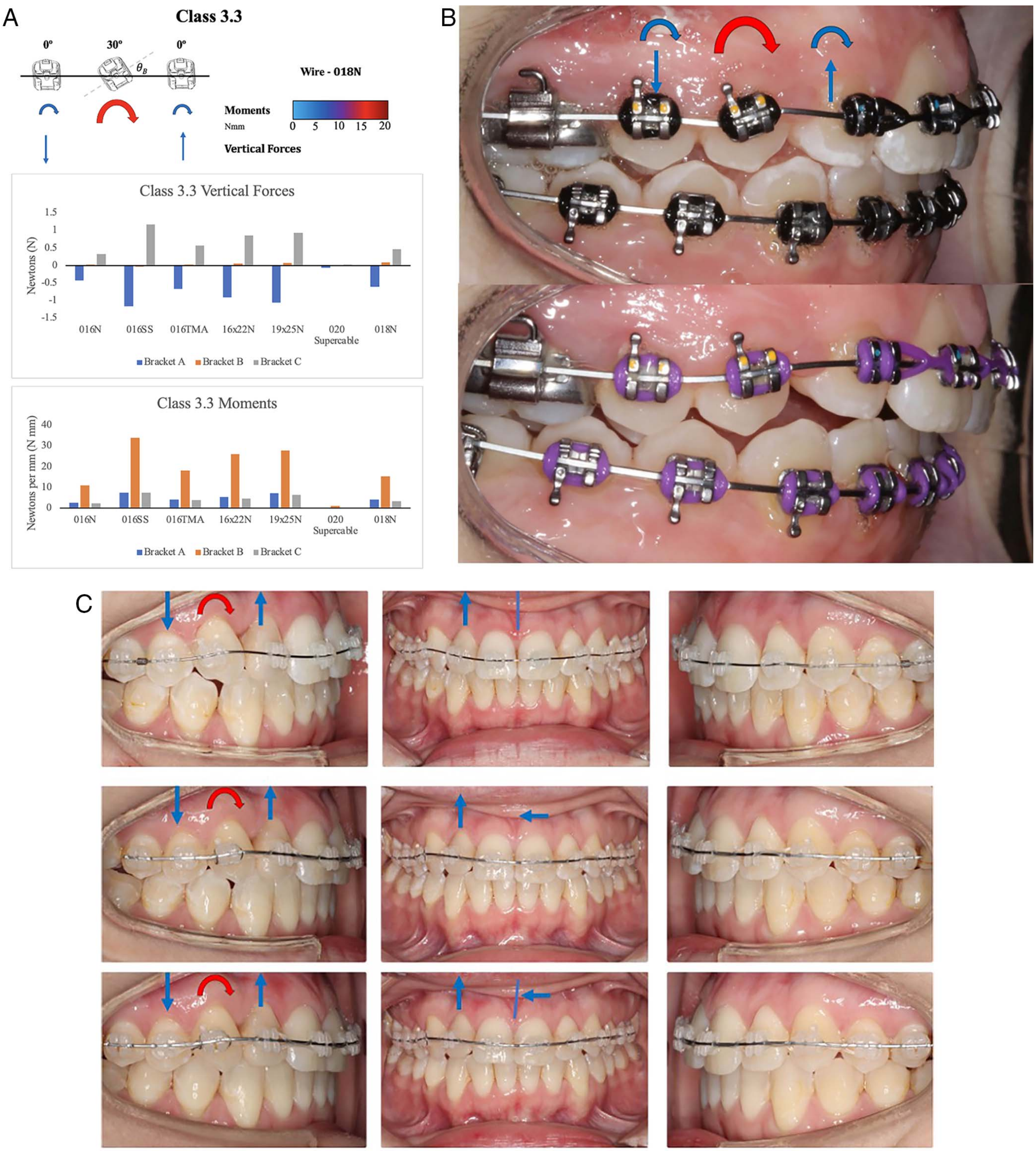

Figure 4. (A) Geometry and force systems. Top: Force system of Class 3.3 geometry in a 0.018 NiTi wire. Middle: Experimentally measured vertical forces in a Class 3.3 geometry among wires (N = NiTi). Bottom: Experimentally measured moments in a Class 3.3 geometry among wires (N = NiTi). (B) Clinical example of Class 3.3. Tooth 13 was rebonded to upright (due to distal root tip), resulting in negative biomechanical side effects on 12 and 15. (C) Second Example of Class 3.3. Bonding of 13 to correct the distal root tip resulted in intrusion of 12, upper midline shift, and canting of the occlusal plane and upper midline at the following visits.

clinical practice. If known in advance, undesirable tooth movements may be negated following bonding of brackets with other mechanics, including piggyback and segmental mechanics, elastics, and cantilevers.[3] Otherwise, to help with management of expectations, patients could be prewarned of these side effects.

Although the literature reflects uncertainty regarding the optimum force that should be applied during orthodontic tooth movement, authors of studies have found that high forces (>250 g) resulted in more adverse effects.[19,20] In this study, we showed that lighter wires resulted in less biomechanical side effects, potentially limiting the degree of secondary malocclusion formation. Alternatively, effective management might include rebonding teeth early in treatment to allow more time for correction of undesirable side effects and to maintain the corrected position longer to aid in retention.

Limitations

This experiment had the limitations of a laboratory-based study; factors such as saliva, temperature, and occlusion that are present in an oral physiological environment were not considered. We also did not consider the biological response from the periodontium and alveolar bone that ultimately results in orthodontic tooth movement.

In their original study, Burstone and Koenig[6] did not consider the intrabracket interactions between the bracket and wire. More specifically, they did not reflect the amount of play in the bracket slot, which is influenced by wire cross-section, material, slot size, and bracket type. This introduced an element of complexity that was present but not accounted for in the original study. Additionally, the experiments were evaluated in the second order in a linear configuration and, therefore, did not consider the curve of Spee and the curvature of the arches. The study was limited to self-ligating brackets, and the interbracket distance was large. Any minor errors in the data may also be attributed to sensor sensitivity and human error.

Nevertheless, the primary goal of the study was to evaluate the impact of a third bracket on the two-bracket geometries of Burstone and Koenig,[6] while accepting the limitations of an in vitro study. Future researchers could consider evaluating the impact of multiple brackets arranged in an arch, friction and direction control, leveling the curve of Spee, and other forms of malocclusion including rotations. This could be done experimentally or through finite element analysis.

CONCLUSIONS

- In this study, we experimentally validated the hypothesis of Burstone and Koenig,[6] showing that a three-bracket geometry can be simplified into two adjacent two-bracket geometries.
- The impact of the third bracket (Bracket C) on the force systems of the two-bracket geometries of Burstone and Koenig[6] seems to be limited to the adjacent bracket (Bracket B), with no statistically significant change on Bracket A. Clinically, this means that the effect of bracket positioning will largely impact the adjacent teeth.
- A consistent pattern of forces and moments was found in 36 three-bracket geometries, which has the potential to assist clinicians in recognizing typical clinical presentations and, thus, to prevent unpredicted movements.

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