Slot deformation of various stainless steel bracket due to the torque force of the beta-titanium wire

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Abstract. Stainless steel bracket slot deformation effects the force applied to teeth and it can impede tooth movement and prolong orthodontic treatment time. The aim of this study is to determine the slot deformation due to torque of a 0.021 x 0.025 inch Beta Titanium wire with a torsional angle of 30° and 45° for five different bracket brands: y, 3M, Biom, Versadent, Ormco, and Shinye. The research also aims to compare the deformation and amount of torque among all five bracket brands at torsional angles of 30° and 45°. Fifty stainless steel edgewise brackets from the five bracket group brands (n=10) were attached to acrylic plates. The bracket slot measurements were carried out in two stages. In the first stage, the deformation was measured by calculating the average bracket slot height using a stereoscopy microscope before and after application of torque. In the second stage, the torque was measured using a torque measurement apparatus. The statistical analysis shows that slot deformations were found on all five bracket brands with a clinical permanent deformation on the Biom (2.79 µm) and Shinye (2.29 µm) brackets. The most torque was observed on the 3M bracket, followed by the Ormco, Versadent, Shinye, and Biom brackets. When the brands were compared, a correlation between bracket slot deformation and the amount of torque was found, but the correlation was not statistically significant for the 3M and Ormco brackets and the Biom and Shinye brackets. There is a difference in the amount of torque between the five brands with a torsional angle of 30° (except the 3M and Ormco brackets) and those with a torsional angle of 45°. The composition of the metal and the manufacturing process are the factors that influence the occurrence of bracket slot deformation and the amount of torque. A manufacturing process using metal injection molding (MIM) and metal compositions of AISI 303 and 17-4 PH stainless steel reduce the risk of deformation.

1. Introduction
A bracket is one of the passive components of a fixed orthodontic appliance that will channel the force applied by the wire to the teeth resulting in the movement of the teeth. Bracket material with good mechanical properties is required; thus, a bracket must be resistant to deformation due to the force of the wire. The mechanical properties of the bracket are influenced by the stainless steel metal composition and the manufacturing process [1,2]. Deformation of the bracket will affect the force applied to the tooth, thereby inhibiting the movement of the tooth and extending the orthodontic treatment time. Deformation is a change in shape and size due to force. Orthodontic wire force is one type of force that will be delivered to the bracket [3,4]. Wire is one of the active components of a fixed orthodontic appliance that serves to transmit the force through the bracket for tooth movement. The optimal force to move the teeth should be able to stimulate cellular activity without fully compressing the blood vessels and periodontal ligament (PDL). One way to produce optimal force is to use a wire material with low stiffness because the force will be weak and continuous. One of the materials that has a low stiffness is the beta-titanium wire [1,5].

Beta-titanium wire was first introduced by Charles Burstone in 1980. It consists of 78% titanium, 11.5% molybdenum, 6% zirconium, and 4.5% tin. Beta-titanium wire has several advantages; it has low elastic modulus, large spring back, low stiffness, and good formability and join ability, and it is
resistant to corrosion. However, its drawback is that it has low friction. Its advantages make it an excellent material for the finishing stage in orthodontic treatment. A 0.021x0.025-inch beta-titanium wire in a 0.022x0.025-inch bracket slot is the optimal wire for finishing because it approaches the size of the bracket slot so it will maximize the torque that is generated [1,5]. In orthodontics, torque is one of the movements that occur in teeth due to the torsion/rectangular wire twist in the rectangular bracket slot. Torque is required to ideally position a tooth in the labio palatal and bucco lingual fields so it produces good occlusion. Lacousiere et al. [4] stated that torque is influenced by several factors, such as the bracket, the wire, the wire twisting degree, the wire play and the bracket slot, the ligation method, and the shape of the wire edge. However, some studies have suggested that deformation of the bracket slot is the most important factor in the resulting torque [1,4].

Along with the development of science and ASEAN Free Trade Area, Indonesia distributes various brands of stainless steel metal brackets with varying prices and without quality control from the government. This prompted the authors to conduct research on slot deformation for some existing stainless steel metal bracket products in Indonesia, and determine how the torque force affects the beta-titanium wires applied to the brackets. This study’s findings can help orthodontists choose a high quality stainless steel bracket and know the torque force on the beta-titanium wire so they can maximize patient treatments.

2. Materials and Methods

This experimental study was conducted in a biomedical laboratory at the Universitas Indonesia, and at Surya Sarana Dinamika, in Bandung, Indonesia. The research sample consisted of the five following brands of Edgewise standard stainless steel slot brackets (0.022-inch central left incisive tooth): 3M Dynaloc (USA), Biom (China), Versadent (USA), Ormco (Mini Diamond, USA), and Shinye (China). The study used a self-assembled torque test instrument that had been calibrated. The torque test device consisted of a translational table for the sample bracket setting, a sample clamp, a crosshead, a servomotor, a chart recorder, and an amps–volts-ohms (AVÖ) meter. The Cool Muscle brand servomotor twists the wire and the chart recorder displays a large torque force based on the twist angle of the wire in units of gram centimeter gram (gm-cm). The study also used a V12 stereoscopic discovery microscope (Carl Zeiss Micro Imaging GmbH, Germany) connected to a computer device and an Axiocam, as well as Zen lite software, a rectangular acrylic plate bracket (39 mm long, 6 mm wide, and 18 mm high), Loctite glue 495, and beta-titanium wire (0.021x0.025 inches).

A torque test device was used, and validity and reliability testing was conducted. A validity test was performed to determine the accuracy of the measuring instrument after calibration. A reliability test was performed by conducting intra-observer conformance tests that aim to verify the consistency of an observer. The observer performed the calibration of the measuring point and conducted the intra-observer conformity test. The intra-observer suitability test was performed using the Bland-Altman test and test-retest methods. The test-re-test method was used to determine the accuracy of the measurements made using the stereoscopic microscope twice at different times. The Bland-Altman test was used to determine the outliers / measurement values at different times. The research used 50 Edgewise standard stainless steel slot brackets (022-inch central left incisor teeth) divided into five groups (n = 10): group A (3M), group B (Biom), C group (Versadent), group D (Ormco), and group E (Shinye). Bracket selection was conducted randomly to disguise the identity of the brackets. Each bracket was identified by inserting it into the acrylic plastic plate and assigning a serial number to the sample. Randomization was conducted by a person other than the researcher who knew the serial number of bracket and recorded it in the research book. The identity of the bracket brand was only revealed after the research was completed.

The dimensions of the acrylic plate were based on the vertical and horizontal guidelines previously mentioned, and the plate was assigned a sample number using markers. Next, the brackets were attached to the acrylic plate with Loctite glue 495 according to the manufacturer’s guidelines, and then placed under a stereoscopic microscope for the first test. In the first test, the deformation was measured by calculating the average bracket slot height in the lateral direction using Zen lite software.
The height measurement of the bracket slot was conducted by making two lines, one for the outer line of the bracket (A) and one for the inner line of the bracket (B). The measurement results were obtained using the formula: A + B/2. After the first test, a 0.021x0.025-inch beta-titanium wire was mounted on to a bracket slot attached to the acrylic plate and ligated using elastomeric rubber. Then, after placing the acrylic plate in the torque test device, the acrylic placement was aligned with the end of the crosshead; the distance was 6 mm from the midpoint of the wing bracket to the crosshead (the inter-bracket distance inside the mouth). The torque test was performed by twisting the wire with an average crosshead speed of 4°/minute, which was programmed into the servomotor. The chart recorder displayed the natural torque in gram centimeter (gm-cm) units. Then, the servomotor automatically stopped at a 45° angle. The second test was then performed, the measurement of both bracket slot heights after the torque test in the lateral direction. The height of the bracket slot obtained from the second test was the same as the height obtained in the first test. was analyzed using SPSS software, Kruskal-Wallis test, and the Post Hoc Mann Whitney test.

3. Results and Discussion

3.1 Results
The Bland-Altman plot showed data at the lower and upper limit values (-1.162 and 0.566) (Figure 1). The plot showed no significant differences in the intra-observer measurement results at different times (p = 0.449). Table 1 and Table 2 show the average value of the torque on a 0.021x0.025-inch beta-titanium wire on a bracket with torsional angles of 30° and 45°. The most torque force was found on the 3M bracket when the torque angles were 30° and 45°; the lowest torque force was observed on the Biom bracket.

![Figure 1. Bland-Altman plot of the intra-observer measurements](image-url)

Table 1. The torque force on the 0.021x0.025-inch beta-titanium wire on bracket brands with a torsional angle of 30° (gm-cm)

| Bracket Brand | Average | Minimum | Maximum | Standard Deviation |
|---------------|---------|---------|---------|-------------------|
| 3M            | 488.36  | 430.61  | 525.93  | 33.45             |
| Biom          | 239.89  | 213.73  | 363.08  | 25.46             |
| Versadent     | 385.49  | 324.07  | 470.33  | 47.75             |
| Ormeo         | 466.61  | 425.93  | 518.69  | 34.00             |
| Shinye        | 294.22  | 226.10  | 366.44  | 43.92             |
Table 2. The torque force on the 0.021x0.025-inch beta-titanium wire torque force on bracket brands with a torsional angle of 45° (gm-cm)

| Bracket Brand | Average | Minimum | Maximum | Standard Deviation |
|---------------|---------|---------|---------|-------------------|
| 3M            | 625.12  | 570.33  | 697.15  | 33.45             |
| Biom          | 307.47  | 254.91  | 396.1   | 25.46             |
| Versadent     | 535.65  | 458.41  | 590.19  | 47.75             |
| Ormco         | 579.93  | 524.53  | 614.02  | 34.00             |
| Shinye        | 387.76  | 321.36  | 485.08  | 43.92             |

Table 3 shows the differences in torque force among the brackets. Statistical analysis was conducted using a repeated ANOVA test. The repeated ANOVA test showed that there was a significant difference in torque force among the five brackets ($p < 0.05$). To determine which of the bracket brands showed significant differences, post-hoc statistical analysis was performed using the Bonferroni test. The post-hoc analysis results show that significant differences were observed for the Biom bracket ($p = 0.01$), the Versadent bracket ($p < 0.001$), and the Shinye bracket ($p < 0.001$) in comparison to the Ormco bracket. Table 4 shows the slot deformation in the brackets due to torque force with a twist angle of 45°. Statistical analysis was conducted using a paired t-test. The results showed a statistically significant difference in the five brackets ($p < 0.05$). However, the researchers determined that permanent deformation occurs when the difference in the mean height of the bracket slot was $>2\mu$m; thus, clinically permanent deformation occurred in the Biom bracket (2.79 μm) and the Shinye bracket (2.29 μm). Table 5 shows that the differences in slot deformation between the five brackets were due to the torque force. Statistical analysis was conducted using the Kruskal-Wallis test. The results showed a difference in slot deformation between the five brackets due to torque force ($p < 0.05$). To determine which of the five groups have significant differences, post-hoc analysis with Mann-Whitney U test was conducted. Post-hoc analysis (Table 6) showed that there was a significant difference in slot deformation among the brands, except between the 3M and Ormco brackets ($p = 0.853$) and between the Biom and Shinye brackets ($p = 0.315$).

Table 3. The differences in torque force of the 0.021x0.025-inch beta-titanium wire for bracket brands with a torsional angle of 30° and 45° (gm-cm)

| Torque Angle | Bracket Brand | Average | Standard Deviation | $p$-value | Difference of Average | CI 95% |
|--------------|---------------|---------|-------------------|-----------|----------------------|-------|
| 30°          | 3M            | 488.36  | 33.45             | 0.205     | 21.74                | -12.28-5.76 |
|              | Biom          | 239.89  | 25.46             | <0.001    | -226.72              | -260.74-(-192.69) |
|              | Versadent     | 385.49  | 47.75             | <0.001    | -81.12               | -115.14-(-47.10) |
|              | Ormco         | 466.61  | 34.00             | Comparison |                      |       |
|              | Shinye        | 294.22  | 43.92             | <0.001    | -172.39              | -206.42-(-138.38) |
| 45°          | 3M            | 625.12  | 42.51             | 0.022     | 45.19                | 6.97-83.40  |
|              | Biom          | 307.47  | 40.41             | <0.001    | -272.46              | -310-(-234.24) |
|              | Versadent     | 535.65  | 36.40             | 0.024     | -44.28               | -82.49-(-6.06) |
|              | Ormco         | 579.93  | 34.02             | Comparison |                      |       |
|              | Shinye        | 387.76  | 55.47             | <0.001    | -192.17              | -230.38-(-153.95) |

Paired t-test results

Table 4. Slot deformation of the brackets due to the torque force of a 0.021x0.025-inch beta-titanium wire with a torsional angle of 45° (μm)

| Groups | Average Before | Standard Deviation Before | Average After | Standard Deviation After | $p$-value | Difference of Average Minimum | Maximum |
|--------|----------------|---------------------------|---------------|--------------------------|-----------|------------------------------|---------|
|       | Before         |                           | After         |                          |           |                              |         |
Table 5. Differences in the slot deformation of the brackets due to the torque force of a 0.021x0.025-inch beta-titanium wire with a torsional angle of 45° (μm)

|        | Average | Standard Deviation | Median | Minimum | Maximum | p-value |
|--------|---------|--------------------|--------|---------|---------|---------|
| 3M     | 0.44    | 0.26               | 0.37   | 0.17    | 0.87    | <0.001  |
| Biom   | 2.79    | 1.05               | 2.87   | 0.94    | 4.52    |         |
| Versadent | 0.98   | 0.37               | 0.93   | 0.50    | 1.64    |         |
| Ormco  | 0.47    | 0.27               | 0.49   | 0.05    | 0.95    |         |
| Shinye | 2.29    | 1.38               | 2.09   | 0.23    | 4.87    |         |

Kruskal-Wallis test

Table 6. Differences in the slot deformation of the brackets among the brands due to the torque force of a 0.021x0.025-inch beta-titanium wire with a torsional angle 45°

|        | Biom | Versadent | Shinye | Ormco |
|--------|------|-----------|--------|-------|
| 3M     | 0.001| 0.001     | 0.001  | 0.853 |
| Biom   | 0.001| 0.015     | 0.002  | 0.000 |
| Versadent | 0.315 | 0.015     | 0.000  |       |
| Shinye | 0.002| 0.000     |        |       |

Post Hoc analysis with Mann-Whitney test

3.2 Discussion

This research study used torque and servomotor test devices that were assembled based on the research of Lime et al. [6], Nishio [7], Lacoursiere [4], and Major [8]. A 0.021x0.025-inch beta-titanium wire was selected because it is the optimal wire for producing torque because it approaches the size of the bracket slot and it has good mechanical properties.4,6-10. The great uniformity of torque force in the beta-titanium wire with torsional angles of 30° and 45° is shown in Table 1 and Table 2. The results of this study differ from the findings reported by Lime et al. [6], in which the torque force in brackets at torsional angles of 30° and 45° was 526.1 gm-cm and 789.2 gm-cm, respectively. The differences in the results may be due to differences in the brand of bracket, the bracket system, the wire, and the torque testing device. Lime et al. used Dentaurum brackets with a 5% tip+11° torque and a stainless steel wire (0.021x 0.025) [6].

The difference in torque force is more significant in the 3M, Versadent, and Ormco brackets in comparison to the Biom and Shinye brackets (Table 3). The investigators suspect that this is due to the inconsistency of the bracket slot geometry, the metal component of the bracket material that does not produce good mechanical properties, and the bracket manufacturing procedures. This is consistent with the finding reported by Lacousiere et al. [4], which stated that torque is influenced by several factors: the bracket, the wire, the play between the wire and the bracket, the ligation method, and the wire torque angle. In the present study, the inconsistency of the bracket slot geometry shape was most prevalent in the Biom and Shinye brackets. This is probably caused by the brazing process that was used to manufacture the bracket. Eliades [9] stated that a procedure using brazing may result in an inconsistent bracket shape; this could trigger a galvanic effect thereby decreasing the bracket strength. Siargosa et al. [10] stated that brackets manufactured using a metal injection molding (MIM) process...
have better mechanical properties than those manufactured using brazing. MIM uses an injection molding machine as is done to manufacture plastics, resulting in the same geometry of the bracket slot [9,10].

Differences in bracket geometry were also found in the five bracket brands examined in this present study. The 3M, Versadent, and Ormco brackets have a square slot shape, sharp edges, and aligned edges between the upper and lower slot walls. The Biom and Shinye brackets have an outwardly divergent slot shape; they have an angle of 90° and rounded slot corners, so the contact between the bracket slot and the wire is reduced. The contact between the reduced bracket slot and the wire decreases the size of the resulting torque force [11]. The manufacturer has the freedom to determine the metal composition of a bracket. The metal composition will affect the mechanical properties of a stainless steel bracket and the amount of torque force. Previous studies have suggested that the mechanical properties of a bracket, including hardness and modulus elasticity, affect the torque force; the higher the bracket hardness, the greater the torque force. Type 17-4 PH and 303 stainless steel brackets have better mechanical properties than 316 and 304 stainless steel brackets [3,12]. This present research study excludes Biom and Shinye brackets because after the first shoot via a stereoscopic microscope, a permanent deformation/deformation defect was observed in them. The information presented in Table 4 shows that permanent deformation occurred in the Biom (2.79 μm) and Shinye (2.29 μm) brackets. This is possibly due to the brazing process used to manufacture the brackets resulting in the fusion of the bracket base components. This results in insufficient bracket wings, and it impacts the metal composition of the bracket [9,10,12].

The metal composition affects the mechanical and physical properties of brackets, and this is a major factor in the occurrence of bracket deformation. The composition of 3M metal bracket material is austenitic AISI type 303 stainless steel. The composition of Ormco brackets is bridge type AISI 17-4 PH stainless steel, and the composition of Versadent brackets is austenitic stainless steel. The metal composition of these three brands of brackets produces good mechanical properties and reliable hardness so that the risk of deformation is low. The Biom and Shinye factories do not reveal the composition of their metal brackets, so they possibly have poor mechanical properties and insufficient hardness making it easy for the brackets to deform. This is consistent with the research findings reported by Gioka and Eliades [13]; they stated that bracket breakage is likely to occur in metals with insufficient hardness due to the contact between the rectangular wire and the bracket slot [3,13]. This present study found that the greatest deformation occurring on the outer line of the bracket (A) compared to the inner line of the bracket (B). This occurs because there is more stress on the outer line (A) of the bracket than the inner line of (B). This study has some drawbacks; the crosshead has a rounded geometry shape, which is different than the rectangular shape of the 0.021x0.025-inch beta-titanium wire, making it difficult to fix the wire properly while twisting the wire with a torque angle of 15°. In addition, it is difficult to find alignment between the crosshead and the wire to be twisted that has been ligated into the bracket slot. It is important to obtain alignment because if it is not parallel, the torque force generated from the chart recorder will be large because the force generated from the wire is greater.

4. Conclusion
The results of this study showed that there were significant differences in the deformation of the bracket slots in the five groups of brackets. The smallest deformation was observed in the 3M bracket, followed by the Ormco, Versadent, Shinye, and Biom brackets. However, a clinically permanent deformation occurred in the Shinye and Biom brackets. The 3M bracket had the highest average torque force in the 0.021x0.025-inch beta-titanium wire with torsional angles of 30° and 45° in the five groups of brackets, respectively, followed by the Ormco, Versadent, Shinye, and Biom brackets. Using the bracket deformation test and the torque force results for the five brackets, the study found that there is a significant difference in the bracket deformation between the brands, except between the 3M bracket and the Ormco bracket and the Biom bracket and the Shinye bracket. The torque test results showed that there is a significant difference in the torque force with a torsional angle of 30° in
three of the five brackets (no significant difference in the torque force with a 30° torsional angle was found for the 3M and Ormco brackets). A significant difference in the torque force with a torsional angle of 45° was observed for all five brackets.

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