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Exploring bracket torque expression: A comparative in vitro study of new self-ligating bracket designs and archwire geometries

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Keywords

Orthodontics
Biomechanics
Torque
Bracket design
Archwire geometry

Summary

Objective > This in vitro study aimed to evaluate the torque expression efficiency when it is integrated into the bracket slot versus the bracket base. Additionally, the impact of archwire geometry (rectangular vs. rhomboid) on torque expression has been examined.

Material and methods > The torque expression was evaluated in a full arch printed maxillary model, focusing on tooth #11, which was positioned within an alveolus filled with Typodont wax. Three different types of brackets were utilized: conventional metallic bracket (MinidiamondTM), self-ligating bracket with torque in base (Damon Q2TM), and a new self-ligating bracket design with torque in slot (Damon UltimaTM). Two variations of archwires were used: rectangular and rhomboid stainless steel, measuring 0.019 × 0.025 inches and 0.019 × 0.0275 inches, respectively, from ORMCOTM. The study included seven groups: six experimental groups and a control group, with 15 measurements in each group, totaling 105 torque measurements. Optical impressions were taken of the tooth's original position and its final position after torque expression. STL files were superimposed using GEOMAGIC software to calculate the percentage of torque expression.

Results > The self-ligating bracket with torque in slot (Damon UltimaTM) shows significantly higher torque expression than the self-ligating bracket with torque in base (Damon Q2TM) with a rectangular stainless steel archwire ($P = 0.00015$). The UltimaTM bracket also demonstrates higher torque expression than both the Q2TM and conventional 22° brackets with a rhomboid stainless

steel archwire ($P < 0.003$). No significant difference in torque expression was found between the rectangular and rhomboid stainless steel archwires for any bracket group ($P > 0.05$).

Conclusions > The self-ligating bracket with torque in slot shows comparable torque expression effectiveness to the conventional bracket, outperforming the self-ligating bracket with torque in base. Archwire geometry does not significantly impact torque expression.

Introduction

Orthodontic torque refers to the twist or rotational force applied to an archwire within the bracket slot (third-order curvature), intended to incline the tooth in the buccal or lingual direction. This twist helps control the orientation of the tooth, ensuring proper alignment and positioning within the dental arch [1]. In orthodontic treatment, achieving proper torque expression is a significant challenge considering non-modifiable factors such as anatomy of the crown, initial skeletal discrepancies, and muscular pressures exerted by lips, cheeks, and tongue, and modifiable factors such as bracket type, bracket bonding height, arch wire sequence, and orthodontic mechanics [2-8].

To enhance treatment quality and address factors affecting torque expression, orthodontic techniques have evolved, including the introduction of pre-informed brackets in the 1970s and later the development of self-ligating brackets. Passive self-ligating brackets, though popular in orthodontics, are proven to be less effective in torque expression due to their design [9]. Traditionally, self-ligating brackets typically integrate torque at the bracket base. However, a newer design has shifted torque application into the bracket slot, purportedly for improved effectiveness. Additionally, some manufacturers suggest using archwire forms such as rhomboid-shaped wires to enhance torque control. It is important to assess whether these suggested changes effectively enhance torque control in clinical practice.

Since no other research has specifically investigated the comparative effectiveness of torque integration in the slot versus in the base of a self-ligating bracket, as well as compared to a conventional bracket, the primary objective of the study is to evaluate the new bracket design with torque integrated into the slot (Damon Ultima™) compared to the previous generation with torque integrated into the base (Damon Q2™) and a conventional bracket, in terms of torque control and expression. The null hypothesis of the study is that there will be no significant difference in torque expression between the bracket designs with torque integrated into the slot or in the base, whether they are self-ligating or conventional.

Material and methods

Study model

Design and modeling using BLENDER software of a complete upper dental arch from tooth #17 to #27. All teeth are fixed on a base, excluding tooth #11. The alveolus of tooth #11 is emptied

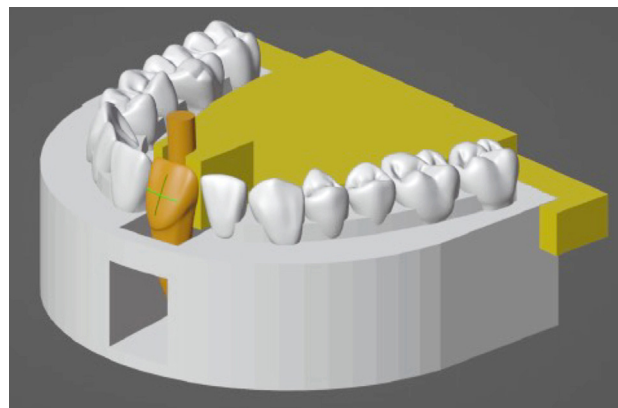


FIGURE 1

Study model design. The upper dental arch is depicted in grey, with teeth fixed on the base. Tooth number 11 is highlighted in orange, featuring a cross-shaped reference on the buccal side and a cylinder on the palatal side. The transfer tray is shown in yellow

and widened to allow freedom for root movements during torque expression, then filled with Typodont wax.

Tooth #11 is designed, including both the crown and the root. A cross-shaped reference point is placed at the center of the buccal face of the tooth to ensure reproducibility of test bracket position. Four geometric markers are arranged on its palatal side:

- three millimeter-sized spheres are positioned to allow stable and reproducible reseating of the tooth in the transfer (retention elements);
- one cylinder is used to represent the long axis of the test tooth, facilitating the extraction of a vector during the analysis of STL files by GEOMAGIC software.

A transfer tray enabling the repositioning of the test tooth between each manipulation has been modeled with broad support surfaces on the rigid base to ensure stability. All elements were printed using the Stratasys Objet30 Dental Prime 3D printer, using the solid RGD525 resin (figure 1).

Brackets

Conventional brackets (Torque = 0°) were passively bonded to the entire arch, except on the test tooth (#11) where the studied bracket was attached. The characteristics of the four brackets used to bond tooth #11, which were all 0.022 x 0.028 inches, are presented in figure 2.





				
Company	<i>Ormco™</i>	<i>Ormco™</i>	<i>Ormco™</i>	<i>Ormco™</i>
Model	<i>Minidiamond</i>	<i>Minidiamond</i>	<i>Damon Q2</i>	<i>Damon Ultima</i>
Material	Stainless steel	Stainless steel	Stainless steel	Stainless steel
Tooth	11	11	11	11
Torque	0°	+22°	+22°	+20°
Torque placement	Torque in the base	Torque in the base	Torque in the base	Torque in the slot
Slot dimensions	0.022 in x 0.028 in	0.022 in x 0.028 in	0.022 in x 0.028 in	0.022 in x 0.028 in
Ligature	Conventional	Conventional	Passive Self-ligating	Passive Self-ligating

FIGURE 2 Characteristics of the four bracket types used in the study groups, according to the manufacturers' specifications

Archwires

Three archwires of two different materials and two different sections were used. The characteristics of which are detailed in figure 3.

For each bracket group, two types of archwires were tested:

- rectangular stainless steel archwire 0.019 × 0.025 inches ORMCO™;
- rhomboid stainless steel archwire 0.019 × 0.0275 inches ORMCO™.

A 0.019 × 0.025 NiTi archwire was used for initial alignment, followed by the insertion of the stainless steel archwire.

This results in seven sub-groups detailed in figure 4.

The test tooth is placed in wax within the arch according to a reference position determined by the transfer tray. An optical impression of this position is made, serving as the reference impression to which all other impressions are compared. An optical


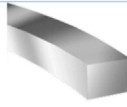

			
Material	CuNiTi	Stainless steel (SS)	Stainless steel (SS)
Dimension	0.019 in x 0.025 in	0.019 in x 0.025 in	0.019 in x 0.0275 in
Section	Rectangular	Rectangular	Rhomboid
Company	<i>Ormco™</i>	<i>Ormco™</i>	<i>Ormco™</i>

FIGURE 3 Archwires characteristics, according to the manufacturers' specifications

Bracket	Archwire
Conventional Minidiamond Group (Torque = 0°)	Rectangular SS .019x.025 inches archwire
Conventional Minidiamond 22 Group (Torque = +22°)	Rectangular SS .019x.025 inches archwire
	Rhomboid SS .019x.0275 inches archwire
Damon Q2 Group (Torque = +22°)	Rectangular SS .019x.025 inches archwire

FIGURE 4 Combinations of brackets and archwires of each of the 7 sub-groups

impression is made after each archwire change. The test tooth is repositioned in its reference position after the insertion of the stainless steel archwire to reproduce the procedure for each group.

Hot water immersion

Between each arch change, the model is immersed in a hot water bath at 55 °C for 3 minutes, then cooled in open air for 5 minutes. The water was heated using a resistor equipped with a thermostat.

Digital scanning

The impressions were made using a laboratory scanner (3Shape D2000), and the files were saved in STL format and exported to the analysis software.

Analysis software

The GEOMAGIC software (Control X 2022.1.0) was used for result extraction. Each STL file was exported to this software and aligned with the reference model using the stable elements of the base (all teeth except tooth #11). The major axis of tooth

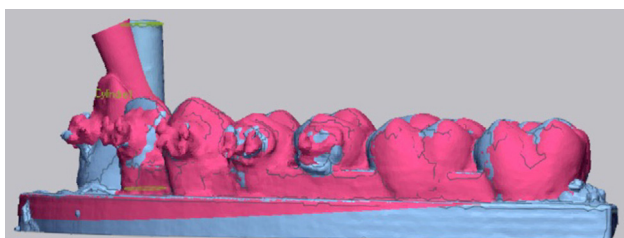


FIGURE 5
Superimposition of two STL files

#11 was then identified digitally using the cylinder present on the test tooth. The vector passing through the centre of the two cylinders was extracted, and the angle formed between these two vectors was measured. The results are expressed as percentages for comparability and analysis. The procedure has been automated, and the software automatically generates a report containing the various values for each superimposition (figure 5).

Bracket bonding methodology

To ensure reproducibility, a cross-shaped marker was digitally positioned at the centre of the buccal surface of tooth #11, and the test bracket was then bonded at the centre of this marker. Subsequently, the brackets were passively bonded to the entire arch using a standard-sized stainless steel archwire.

Evaluation criterion

The primary evaluation criterion is the amount of torque expressed by the maxillary right central incisor during the insertion of different orthodontic archwires into various brackets. Given the torque prescription variations among brackets, the measured values, expressed in degrees, were converted

into percentages using the formula below to make the different groups comparable:

$$\text{Torque Efficiency (\%)} = \frac{\text{Achieved Torque}}{\text{Manufacturer's Specified Torque}} \times 100$$

Statistical analysis

Following a pilot study, a power analysis was performed using the EpiR package to calculate the appropriate sample size for the study. This analysis ensured that there were sufficient measurements to detect a statistically significant difference between the groups, with a significance level (α) of 0.05 and a statistical power of 0.95. The analysis revealed that 15 measurements per group were necessary to detect differences under these conditions.

Given the non-normal distribution of some groups and the violation of homogeneity of variances, non-parametric statistical tests were applied. A Kruskal-Wallis test was conducted to compare torque expression across the six bracket and archwire groups. Dunn's post-hoc tests with Bonferroni correction were performed to identify specific pairwise differences. All analyses were conducted using IBM SPSS V26 software, with significance declared when the *P*-value was less than 0.05.

Results

A total of 90 measurements were conducted, with 15 repetitions for each of the 7 included groups. All samples followed the measurement protocol to completion.

Description of initial results

The overall characteristics of the results are presented in *table 1*:
 • the conventional 0° rectangular SS brackets exhibited an average torque expression of 101% with a standard deviation of 24%;

TABLE 1
Mean Torque Expression, Standard Deviation, and 95% Confidence Intervals for each bracket and wire geometry group

Group	Average Torque Expression	Standard Deviation (SD)	Lower 95% CI	Upper 95% CI
Conventional 0° Rectangular SS	101%	24%	N/A	N/A
Conventional 22° Rectangular SS	72%	10%	66%	78%
Conventional 22° Rhomboid SS	65%	8%	61%	69%
Q2 Rectangular SS	48%	9%	43%	53%
Q2 Rhomboid SS	47%	4%	45%	49%
Ultima Rectangular SS	74%	4%	71%	76%
Ultima Rhomboid SS	71%	7%	68%	75%

Average Torque Expression: the mean torque expression for each group. Standard Deviation (SD): the variation in torque expression within each group. Lower 95% CI and Upper 95% CI: the 95% confidence interval for the mean torque expression, providing the range within which the true mean is likely to fall. N/A: Not applicable.

- the conventional 22° rectangular SS brackets showed an average torque expression of 72% with a standard deviation of 10%;
- the conventional 22° rhomboid SS brackets had an average torque expression of 65% with a standard deviation of 8%;
- the Q2 rectangular SS brackets demonstrated an average torque expression of 48% with a standard deviation of 9%;
- the Q2 rhomboid SS brackets displayed an average torque expression of 47% with a standard deviation of 4%;
- the Ultima rectangular SS brackets recorded an average torque expression of 74% with a standard deviation of 4%;
- the Ultima rhomboid SS brackets had an average torque expression of 71% with a standard deviation of 7%.

The 95% confidence intervals (CI) provide a range within which we are 95% confident the true mean torque expression for each group lies. Narrower confidence intervals, such as those for the Q2 rhomboid SS brackets (45% to 49%), indicate a more precise estimate of the mean, while wider intervals, like those for the conventional 22° rectangular SS brackets (66% to 78%), suggest more variability and less precision in the estimate.

Statistical analysis

Comparison of bracket types (table II)

When using a rectangular SS archwire:

- the Ultima bracket shows a significantly higher torque expression than the Q2 bracket ($P = 0.00015$);

- no significant difference is observed between the Ultima bracket and the conventional 22° bracket ($P = 1.000$);
- no significant difference is observed between the conventional 22° bracket and the Q2 bracket ($P = 0.089$).

When using a rhomboid SS archwire:

- the Ultima bracket exhibits a significantly higher torque expression than both the Q2 bracket ($P = 0.00001$) and the conventional 20° brackets ($P = 0.003$).

Comparison of Archwire Sections (table II)

- For the conventional 22° brackets, no significant difference in torque expression was observed between the rectangular and rhomboid SS arch sections ($P = 0.728$).
- For the Q2 brackets, no significant difference in torque expression was observed between the rectangular and rhomboid SS arch sections ($P = 1.000$).
- For the Ultima brackets, no significant difference in torque expression was observed between the rectangular and rhomboid SS arch sections ($P = 0.576$).

The non-parametric analysis confirms that torque expression differs significantly between certain bracket types depending on the archwire shape used, while no significant differences were found between different archwire shapes within the same bracket type.

TABLE II

Pairwise Comparisons of Torque Expression between bracket types and wire geometry using Dunn's Test with Bonferroni Correction

Group 1	Group 2	Adjusted <i>P</i> -value
Ultima Rhomboid SS	Conventional 22° Rhomboid SS	1.000
Ultima Rhomboid SS	Conventional 22° Rectangular SS	1.000
Ultima Rhomboid SS	Ultima Rectangular SS	1.000
Ultima Rhomboid SS	Q2 Rectangular SS	0.00015
Ultima Rhomboid SS	Q2 Rhomboid SS	0.00001
Conventional 22° Rhomboid SS	Conventional 22° Rectangular SS	0.846
Conventional 22° Rhomboid SS	Ultima Rectangular SS	0.732
Conventional 22° Rhomboid SS	Q2 Rectangular SS	0.063
Conventional 22° Rhomboid SS	Q2 Rhomboid SS	0.009
Conventional 22° Rectangular SS	Ultima Rectangular SS	1.000
Conventional 22° Rectangular SS	Q2 Rectangular SS	0.315
Conventional 22° Rectangular SS	Q2 Rhomboid SS	0.063
Ultima Rectangular SS	Q2 Rectangular SS	0.009
Ultima Rectangular SS	Q2 Rhomboid SS	0.001
Q2 Rectangular SS	Q2 Rhomboid SS	1.000

Group 1 and Group 2: the groups being compared. Adjusted *P*-value: the Bonferroni-adjusted *P*-value to control for multiple comparisons.

Discussion

Methodological consideration

The use of brackets from the same manufacturer

The study employed brackets from the same manufacturer to ensure a fair and unbiased comparison. This approach aimed to evaluate a new bracket generation, Damon Ultima™, against the previous generation, Damon Q2™, knowing that the difference between the two generations is the location of the torque, eliminating potential variations in manufacturing techniques that may influence slot size and the passive or active engagement of the archwire in the slot [9,10].

Bracket bonding protocol

A reference mark on the facial side of the "test" teeth facilitated precise bracket placement, ensuring accurate torque expression, and avoiding potential bias due to vertical variations [11]. When the bracket is bonded more gingivally, torque expression is reduced, resulting in extrusion; when bonded more incisally, torque expression is increased, causing relative intrusion.

In vitro studies and challenges in translating results to clinical reality

The study was conducted on a model comparable to a typodont, with lower movement resistance than in a healthy periodontal tissue. However, this initial phase is necessary before undertaking an in vivo study, which presents various biases, such as individual variability in muscular tonicity, masticatory function, and skeletal discrepancy that influence torque expression [12].

Bracket aging and environmental variables

The brackets used were new and clean, not accounting for the aging process and environmental factors in the oral cavity such as acidity, dietary variations, and mineral-rich saliva [13]. These parameters were not considered in our simulation model, although they could potentially affect torque expression since it alters the surface condition of the slots [14].

Archwire transition

Initial alignment with a NiTi archwire was necessary before inserting a stainless steel archwire to minimize torque differentials and prevent bracket debonding or plastic deformation of the archwire. The higher elastic modulus of NiTi aided in reducing the torque differences between the test tooth and adjacent teeth.

Regarding the 0° conventional bracket group

The bracket with a 0° torque prescription served as a reference in the study, expected to provide complete torque expression due to minimal root movement. Results from this group should be interpreted as methodological rather than clinical and therefore differently from the self-ligating brackets with torque in base, the self-ligating brackets with torque in slot, and 22° conventional groups.

Discussion of results

In the study, conventional brackets, as reviewed by Al-Thomali et al. [10], are known for providing more precise torque expression compared to self-ligating brackets. However, the Ultima brackets in our study demonstrated torque expression as satisfactory as conventional 20° brackets tested ($P > 0.05$). Several factors were considered for interpreting these results.

Slot and archwire geometry

Ultima brackets and archwires differ in that they have rounded edges in both the bracket slot and the archwire, potentially creating a third point of contact during arch torsion (figure 6). This design feature may influence torque expression, especially considering that the Ultima™ archwire is wider (0.0275 inches) compared to conventional rectangular archwires (0.025 inches) [15,16].

The rounding of the edges inside the bracket slot and the increased wire size work together to compensate for any potential loss of torque information, making the performance of Damon Ultima brackets comparable to that of conventional brackets and the rhomboid wires comparable to the rectangular archwires. Both designs are superior to Q2™ brackets in terms of torque expression.

These results align with a recently published in vitro study, which found that passive self-ligating brackets with a 0.028" slot depth provide significantly greater torque expression compared to those with a 0.026" slot depth, particularly at higher torsion angles, indicating better torque control in orthodontic treatment [17].

Engagement angle

According to the formula developed by Meling et al. for calculating the theoretical torque play, increasing arch width in Ultima brackets may decrease the engagement angle, enhancing torque transmission [18]. However, the Ultima archwires have undertaken angle rounding. Rounding off rectangular archwires

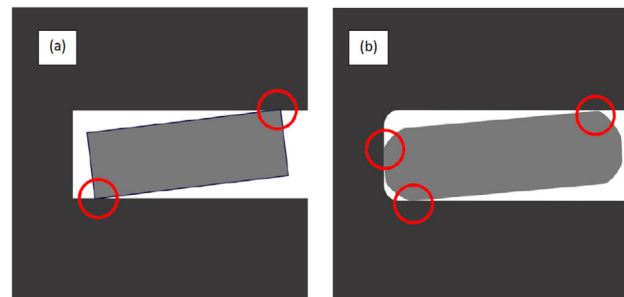


FIGURE 6

Points of contact between the archwire and the bracket groove during archwire torsion. (a) Rectangular arch and groove (b) Rectangular arch and groove with rounded edges

leads to material loss and reduced arch stiffness [19]. In fact, this can lead to a material loss ranging from 7 to 8%, resulting in a reduction in stiffness of 15 to 19% and potentially reducing torque expression [20]. Therefore, The Damon Ultima™ arch-wire is intentionally widened (0.019×0.0275 inches) to compensate the material loss, preserving arch stiffness, and contributing to maintaining optimal torque expression [21]. It can be assumed that the increased archwire width and modified geometry create more contact points, allowing for a more significant moment of force. Nevertheless, further studies are necessary to confirm this hypothesis.

Torque location

Ultima brackets have torque information in the bracket's slot, differing from other brackets with torque information in the base. This may influence torque expression and requires further study [22]. One theory is that the position of the torque application relative to the long axis of the tooth significantly affects its expression. Specifically, when torque is applied farther from the long axis, the moment of force increases. This is because the moment of force is the product of the torque applied and the distance from the axis of rotation. Therefore, applying torque at a location farther from the long axis of the tooth (such as at the base of the bracket) results in a greater moment of force, potentially enhancing the effectiveness of the torque.

Ligature method

For the conventional brackets, we have used elastic ligatures, which allow more arch play. This play may have potentially affected torque expression negatively compared to self-ligating brackets with a rigid fourth wall, suggesting that the method of ligating could have influenced the results [23].

Recommendations for future studies

Our protocol remains an in vitro study, which, by its nature, had to omit many biological parameters inherent to the oral

environment that could have influenced the obtained results. To extend this work, it would be interesting to conduct a larger-scale study, such as controlled and randomized clinical trials or a split-mouth design, to assess the bracket performances within the oral environment.

In addition, although intra-observer reliability (ICC) and inter-observer reliability (Fleiss' Kappa coefficient) are critical for validating the consistency of measurements, these analyses were not conducted in this study. Future research should incorporate these reliability measures to strengthen the validity of the findings.

Conclusions

According to the results of our study, the Damon Ultima bracket (ORMCO) appears to be as effective for torque expression as a conventional bracket. However, both of these brackets outperform the Damon Q2™ bracket in terms of torque expression. Regarding the geometry of the arch wire (rhomboid or rectangular), it does not seem to have a direct impact on torque expression, suggesting that torque expression is directly related to the bracket's design itself.

Contribution: Vincent Thomas: main researcher conducting the in vitro study and writing the main manuscript.
Gaëlle Dol: critically read and corrected the manuscript for clarity and accuracy.
Ziad Tannouri: translated and formatted the main manuscript for coherence and accessibility.
Olivier François: designed the study model and established the experimental framework.
Emmanuel Nicolas: provided statistical analysis expertise and coordinated research efforts.
Delphine Soulier-Peigue: critically read and corrected the manuscript for clarity and accuracy.
Marwan El Helou: supervised and served as senior author throughout the research and writing process.

Disclosure of interest: The authors declare that they have no competing interest.

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