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Finite Element Evaluation Of Tip And Torque In Three Different Conventional And Self-Ligating Orthodontic Brackets

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ABSTRACT
This study aimed to evaluate tip and torque expression in three conventional pre-adjusted edgewise brackets and three self-ligating brackets using finite element analysis (FEA). The assessment involved enagement of 0.021×0.025" SS wires for tip and torque analysis.
Three conventional brackets (3M Unitek Gemini, Mini Master – American Orthodontics, Mini Diamond Twin – Ormco) and three self-ligating brackets (3M Smartclip, Empower 2 –American Orthodontics, Damon Q – Ormco) for permanent maxillary right central incisor, lateral incisor, and canine were analyzed. Precise digital models were created, and FEA was conducted to simulate wire engagement and stress response.
Conventional brackets showed tip and torque values closer to ideal especially under stiffer wire engagement & Self-ligating brackets exhibited larger deviations from normal tip and torque values.
It was concluded that Empower 2 and 3M Smartclip self-ligating brackets performed better in enhancing torque control when compared to standard values. However, 3M Unitek Gemini conventional brackets showed more predictable tip and torque expression.
Keywords: *Conventional brackets, Finite element analysis, Self-ligating brackets, Tip, Torque.*

INTRODUCTION

The primary objectives of orthodontic treatment are stability, aesthetics, and functional occlusion. At the end of active treatment, all teeth must have an optimum axial inclination as one of the requirements for achieving a functional occlusion. This axial inclination is determined by inbuilt tip (mesiodistal angulation) & torque (buccolingual inclination) values incorporated in the bracket system. The advancement of orthodontic instruments and materials has improved orthodontic treatment quality, enabling the goal of perfect occlusion more achievable. Over the years, clinicians have considered how bracket design can help achieve these objectives [1].

A wide variety of bracket prescriptions are currently available in the orthodontic market, each incorporating specific inbuilt tip and torque values. These values play a significant role in determining the final aesthetic and functional outcomes of orthodontic treatment and are collectively referred to as the bracket prescription [2]. Torque is typically expressed when a rectangular archwire engages the bracket slot at an angle, establishing two-point contact. To fully express the intended torque, either a torque-specific bracket or an appropriately contoured archwire is required [3].

The most commonly used bracket slot dimensions in clinical orthodontics are 0.018 × 0.025 inches and 0.022 × 0.028 inches. When using a 0.018 slot, a 0.018 × 0.025-inch stainless steel (SS) wire is considered optimal for expressing the full prescription. In comparison, for a 0.022 slot, a 0.019 × 0.025-inch SS wire is typically used, although it may not achieve full expression of the prescription. Despite manufacturers' claims of adherence to standardized prescriptions, variations in bracket slot dimensions can occur during manufacturing. These discrepancies between the stated and actual measurements may affect the accuracy of tooth movement and ultimately compromise treatment outcomes. Some commercially available brackets have been reported to be oversized by as much as 24%. Such deviations can significantly hinder the expression of torque and tip values, especially in

techniques that rely on the "prescription finish." [4]
Therefore, the accuracy of slot dimensions is of paramount importance in ensuring predictable clinical results. It is essential for manufacturers to maintain strict dimensional control during production to preserve the integrity of the built-in design features of the brackets across all teeth—for a consistent and optimal treatment outcome [5].
MBT & Self-ligating brackets are among the most commonly used brackets system in Orthodontics. Therefore, this study aims to assess the effectiveness of tip & torque values by comparing with standard prescription values to ensure improved treatment outcomes. [6].

MATERIALS & METHODS

2.1 Source of data:
The present study will be a Finite Element study carried out on three commercially available conventional pre-adjusted brackets of Permanent Maxillary Central Incisor, Lateral Incisor & Canine obtained from respective companies (3M Unitek Gemini series brackets, Mini master-American Orthodontics brackets, Mini diamond twin-Ormco brackets) & three commercially available Self-ligating brackets of Permanent Maxillary Central Incisor, Lateral Incisor & Canine obtained from respective companies (3M Unitek smartclip brackets, Empower 2-American Orthodontics series brackets, Damon Q-Ormco brackets) using 0.021x0.025 SS wire & the model is constructed with measured dimensions using modelling software (Scanner tool used is EinScan SE Desktop 3D).
2.2 method of collecting data:
Conventional pre-adjusted edgewise brackets for Maxillary Right Central Incisor, Lateral Incisor and Canine from three respective companies are selected for comparison which are grouped as

- Group 1 – 3M Unitek Gemini series brackets
- Group 2 – Mini Master - American orthodontics brackets
- Group 3 – Mini diamond twin -Ormco brackets

Self-ligating brackets for Maxillary Right Central Incisor, Lateral Incisor and Canine from three respective companies are selected for comparison which are grouped as

- Group 4 - 3M Unitek Smartclip Brackets
- Group 5 – Empower 2- American orthodontics brackets
- Group 6 – Damon Q- Ormco brackets

Archwire dimensions: 0.019x0.025 SS wire & 0.021x0.025 SS
2.3 Procedure:
This study is carried out to evaluate the Tip & Torque in three different conventional pre-adjusted edgewise brackets & three different self-ligating brackets using 0.021x0.025 SS wire
Conventional pre-adjusted edgewise brackets for Maxillary Right Central Incisor, Lateral incisor & Canine are selected for comparison which are grouped as

- Group 1 - 3M Unitek Gemini series brackets
- Group 2 – Mini Master - American Orthodontics Brackets
- Group 3 –Mini Diamond twin- Ormco brackets

Self-ligating brackets for Maxillary Right Central Incisor, Lateral incisor & Canine are selected for comparison which are grouped as

- Group 4 – 3M Unitek Smartclip series brackets
- Group 5 – Empower 2- American Orthodontics Brackets
- Group 6 –Damon Q-Ormco brackets

A 3-Dimensional tooth model of right permanent central incisor, lateral incisor & canine is constructed and then the bracket model is also constructed for each group of conventional pre-adjusted edgewise brackets & self-ligating brackets with the measured dimensions using modelling software by reverse engineering technology (scanner tool used is Autodesk Meshmixer 3.5.0)
A total of six tooth models are prepared. Then the brackets are fixed on the tooth model and 0.021x0.025 SS wire is inserted in the slot.
The FE model is generated with software and the meshed model is imported to FE analysis software.
Design: Ansys Spaceclaim R24.1
Scanning pre-process tool: Autodesk meshmixer 3.5.0

For calculation of tip of the brackets, facial view of the brackets is scanned under Stereomicroscope with 10X magnification. The obtained images are then calibrated using software ANSYS

3D SCANNER	Solutionix C
Camera resolution	2x5.0 MP
Point Spacing	0.028-0.157 mm
3D Scanning area	90/175/350/500 mm
3D Scanning Principle	Phase- shifting optical triangulation
Dimension	315x270x80 mm
Weight	2.3kg
Light source	Blue LED
Interface	USB 3.0
Power	B Type AC 100-240 V,47-63 Hz

WORKBENCH R24.1. The tip of the bracket is calculated by measuring the angle between long axis of the bracket & horizontal line connecting the lower border of the upper wings. The complementary angle of the value obtained is the tip of the bracket.

For calculation of torque of the brackets, the lateral view of the brackets is scanned under stereomicroscope with 10X magnification. The obtained images are scanned using ANSYS WORKBENCH R24.1 & torque of the bracket is calculated by measuring the angle between long axis of the bracket base & long axis of the slot base.

These measured values are compared with conventional pre-adjusted edgewise standard values and self-ligating standard values

Table 1: Standard tip & torque values of conventional pre-adjusted edgewise and self-ligating brackets

TOOTH	TIP	TORQUE
MAX. CENTRAL INCISOR	4^{O}	17^{O}
MAX. LATERAL INCISOR	8^{O}	10^{O}
MAX. CANINE	8^{0}	-7^{O}

Table 2: Scanner Details

Tooth	**Conventional pre-adjusted edgewise brackets**			**Self-ligating brackets**		
	3M Unitek Gemini	**Mini master-American orthodontics**	**Mini diamond twin-Ormco**	**3M Unitek Smart clip**	**Empower 2-American orthodontics**	**Damon Q-Ormco**
Central Incisor	4.21	5.15	4.91	5.19	6.82	5.24
Lateral Incisor	7.86	8.16	7.46	8.42	9.15	8.66
Canine	7.98	7.29	7.59	8.42	8.55	8.15

STATISTICAL ANALYSIS

Since this is a finite element study, statistical analysis is not required.

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RESULTS

TIP: For central incisors, the conventional brackets demonstrated moderate deviations from the normal value of 4°, with 3M Unitek Gemini brackets showing the closest alignment at 4.21° & Among self-ligating brackets, the deviations were more pronounced, particularly for Empower 2 brackets, which show a significant increase to 6.82°.

For lateral incisors, with a normal value of 8°, the conventional brackets such as 3M Unitek Gemini align closely with the ideal at 7.86°. In contrast, self-ligating brackets exhibit larger deviations, with Empower 2 showing the highest value at 9.15°, indicating a significant increase in tip angle.

For canine, the normal tip value of 8° sees minimal deviation in conventional brackets, with 3M Unitek Gemini brackets aligning closely at 7.98°. Among self-ligating brackets, Empower-2 performed well at 8.55°, demonstrating improved tip control for canines. (Table 3 & Figure 1)

Table 3: values of tip

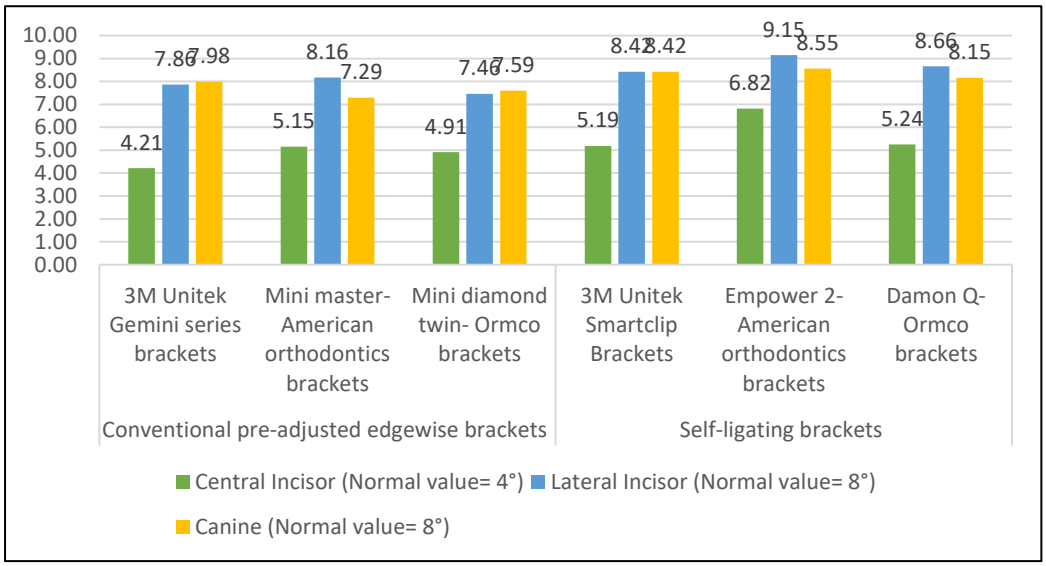

Figure 1: Values of tip

TORQUE: For central incisors, with a normal value of 17°, conventional pre-adjusted edgewise brackets show minimal deviations. Among these, 3M Unitek Gemini series brackets align closest to the normal at 17.15°. Self-ligating brackets demonstrate significantly greater deviations, particularly Empower 2 brackets, which show the highest value of 22.1846°, This suggested that self-ligating brackets, while offering greater torque control, result in pronounced deviations.

For lateral incisors, the normal value of 10° sees larger deviations across all brackets. Conventional brackets such as 3M Unitek Gemini series align closely with the normal at 10.89°. Self-ligating brackets show significantly higher torque values, with Empower 2 brackets leading at 26.182°. These deviations highlight the greater torque levels achieved by self-ligating brackets for lateral incisors.

For canines, with a normal value of -7°, the torque values vary significantly among brackets. Conventional brackets generally remain closer to the normal value, with 3M Unitek Gemini series at -5.1656° and Mini Diamond Twin at -6.182°. Self-ligating brackets show more significant deviations, with Empower 2 reaching -10.584°, These findings suggested that self-ligating brackets provide enhanced torque control for canines. (Table 4 & Figure 2)

Table 4: Values of torque

Tooth	Conventional pre-adjusted edgewise brackets			Self-ligating brackets		
	3M Unitek Gemini series	Mini master- American orthodontics brackets	Mini diamond twin- Ormco	3M Unitek Smart clip	Empower 2- American orthodontics brackets	Damon Q- Ormco brackets

	brackets		brackets	Brackets		
Central Incisor	17.15	19.153	17.668	20.18549	22.1846	21.856
Lateral Incisor	10.89	12.546	11.846	25.1668	26.182	24.6182
Canine	-5.1656	-8.1586	-6.182	-8.183	-10.584	-9.1863

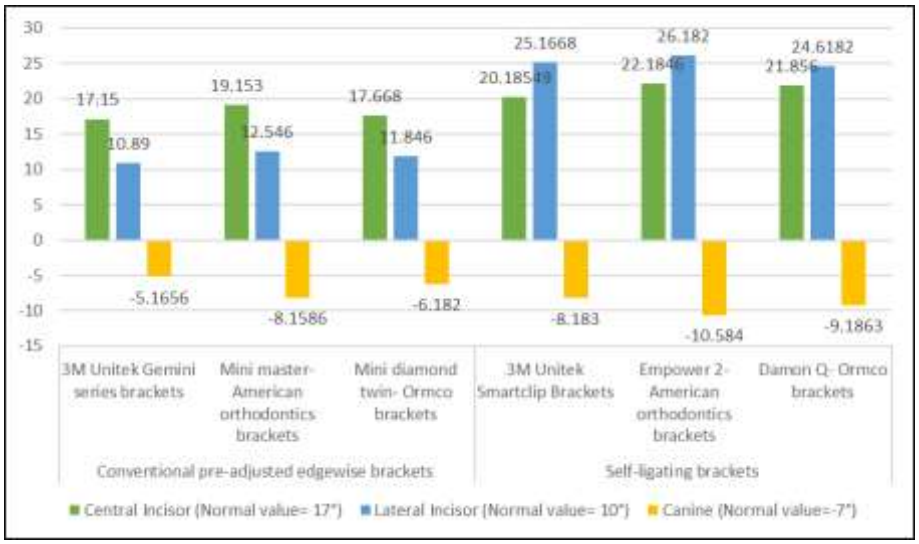

Figure 2: Values of torque

DISCUSSION

The goal of clinical orthodontics has always been to achieve precise, well-aligned tooth positioning with optimal control in all three dimensions [6].

During orthodontic treatment, certain complex combinations of linear forces, moments & couples are developed by the arch wire. These moments are expressed in all three planes of space [1].

Torqueing is commonly done in order to correct the root positions of the anterior teeth. Here, the archwire is twisted & tightly ligated in the slot, which thereby exerts forces on the bracket slot walls. These forces may cause slot deformation. The largest archwire normally used is 0.019 x 0.025inch SS wire in the 0.022-inch slot.

Numerous studies have measured the torque characteristics of the bracket systems by a number of testing apparatus.

Morina et al [7] used the Orthodontic Measurement and Simulation System (OMSS) to measure the maximum torqueing moment of self-ligating bracket systems.

The major components of the OMSS are the two force – moment sensors capable of measuring forces and moments simultaneously in all three planes of space.

Badawi et al [3] developed a novel apparatus with a digital inclinometer to evaluate the torque expression of self-ligating brackets. Torque was evaluated as the wire was twisted, all the other forces and moments were set to zero by device alignment. Vertical and horizontal alignment was maintained between the wire and the bracket during this process.

However, these methods are quite cumbersome and depend on extensive instrumentation and further they fail to graphically display the changes for the clinician to appreciate.

Finite Element Analysis (FEA) is a powerful computer-simulation tool for solving stress-strain problems in the mechanics of solids and structures in engineering. The study of orthodontic

biomechanics requires the understanding of the stress and strain induced by orthodontic forces. Finite element analyses (FEA) offer a means of determining stresses in tooth, ligament, and bone structures for a broad range of orthodontic loading conditions.

Thus, Finite Element Method is considered a superior method for determining stress distribution patterns and resultant force on structures of complex designs and known material properties.

Accordingly, this study was designed to investigate the tip & torque of different conventional pre-adjusted edgewise brackets & self-ligating brackets and arch wire combinations on the tooth and its supporting structures implicating finite element method.

The upper central incisor was preferred for this study because the torque control of upper central incisor is considered of paramount importance in clinical situation. A 3-dimensional model of the right maxillary central incisor, lateral incisor, canine and its supporting structures was generated from a Computed Tomography (CT) scan by a Computer Aided Designing/Computer Aided Engineering (CAD/CAE) program. The white light scanner projected fringe (light) patterns on the bracket and the camera simultaneously captured the images, then advanced software algorithms triangulated and calculated the 3d- coordinates of numerous points spaced all over the surface of the bracket. The part of the bracket that was within the frame got scanned during a single measurement. For scanning the complete bracket measurements were carried out and merged together.

Once the data was imported, the software performed an automatic meshing with defined material properties. The software established contacts automatically and defined them as bonded contact.

In recent days, Self-ligating brackets have been the preferred choice for minimizing mechanical strain and optimizing performance in complex treatments.

Aditya et al [9] evaluated the torque accuracy of MBT prescription 0.022" slot using SEM & found results similar to our study. 5 pre-adjusted metal 0.022" bracket with standard MBT prescription with Agile Abzil brand (3M Unitek), MBT Ormco & Versaden were evaluated. The mean torque angle of bracket Agile brand 3M Unitek & Versaden showed a smaller no. of large torque angle, while Ormco bracket torque angle showed greater than the angle of the MBT prescription torque. This shows a large discrepancy torque angle bracket between Agile brand 3M Unitek, Versaden & Ormco.

Similarly, in our study Torque values revealed distinct differences among brackets. Conventional brackets exhibited predictable control, with 3M Unitek Gemini series aligning closely with normal values for central incisors, lateral incisors, and canines. Self-ligating brackets demonstrated significantly higher torque values, with Empower 2 brackets leading in torque amplification, followed closely by Damon Q and Smartclip brackets.

The amount of axial rotation that the wire is permitted to undergo prior to contacting the slot walls is known as the angle of engagement. In order to assess the torque-play between the various bracket systems, this angle was chosen. The surface area of the bracket slot that the archwire contacts determines the torque expressed once the archwire is engaged in the bracket slot. As a result, the torque indicated by the brackets is inversely proportional to the degree of angle of contact.

The results of this study support the significance of full slot archwire engagement and bracket slot design. They also show that angle of engagement is a clinically significant parameter since it enables us to choose the appropriate archwire dimension to accurately express the intended torquing moment.

Although FEM may produce results with an acceptable degree of accuracy, there are certain drawbacks to this method. Modelling structures as closely as possible to the actual ones is necessary for the analysis to be accurate.

However, with complex designs, some degree of approximation is unavoidable, primarily in terms of the type and quantity of element arrangements. In addition, one needs to understand the assumptions made in the formulation, material characterisation, boundary condition type, and load representations.

Additionally, the time-dependent changes that different materials exhibit and their impact on biological tissues have not been considered by FEA. Each of these elements has an impact on the results validity.

Thus, clinical trials are necessary to evaluate the in-vivo effects of the torque expression by different

bracket-archwire combinations.

CONCLUSION

This study concludes that self-ligating brackets, particularly Empower-2 and 3M Unitek Smartclip brackets, outperform conventional pre-adjusted edgewise brackets in enhancing torque control. However, conventional brackets, especially 3M Unitek Gemini series, exhibit predictable control of tip and torque, aligning closer to normal values, which makes them suitable for standard clinical applications.

The field of orthodontics is increasingly intersecting with advanced technologies such as smart sensors, Artificial intelligence driven diagnostics, and digital biomechanics. A promising direction for future research lies in the development and clinical implementation of smart brackets integrated with micro-sensors that can measure real-time data related to tip and torque expression, force application, and slot deformation during orthodontic treatment. These embedded sensors could detect even minute variations in force vectors, wire engagement, and bracket deformation under physiological conditions such as chewing forces and saliva exposure—offering an accurate reflection of intraoral dynamics often missed by static models like FEA.

Additionally, the integration of artificial intelligence and machine learning algorithms can enhance predictive modeling of tooth movement based on individual patient anatomy, bracket type, and wire properties. Cloud-based platforms can also allow real-time monitoring and remote adjustments, improving treatment efficiency and personalizing orthodontic care.

These innovations have the potential to revolutionize orthodontic biomechanics by creating adaptive, data-driven systems that enhance clinical decision-making and improve long-term treatment outcomes. Future studies could also explore 3D printing customized brackets with embedded electronics, biofeedback systems, and augmented reality-based visualization for orthodontists to better track and control tip, torque, and tooth positioning throughout treatment.

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