RESEARCH PAPER

Comparative Evaluation of Torque Expression in Damon Q, SmartClip, and Empower 2 Brackets Using 3D Finite Element Analysis

Dr. Sushmitha K[1], Dr. Siddarth Arya[2], Dr. Lohith D[3], Dr. Toshitha G[4]

[1]PG Student, Department of Orthodontics, Rajarajeswari Dental, College and Hospital, Bangalore
[2]Professor, Department of Orthodontics, Rajarajeswari Dental College and Hospital, Bangalore
[3]Assistant Professor, Department of Orthodontics, Rajarajeswari Dental College and Hospital, Bangalore
[4]PG Student, Department of Orthodontics, Rajarajeswari Dental College and Hospital, Bangalore
Email: [1]sushmitharai21@gmail.com, [2]sidflanker@gmail.com, [3]lohithlmd96@gmail.com, [4]dr.toshitha08@gmail.com

ABSTRACT
Background: Torque expression is influenced by bracket design, slot geometry, and bracket positioning, all of which affect the efficiency of orthodontic tooth movement. Variations in self-ligating bracket systems may produce differences in biomechanical response during torque application.
Aim: To evaluate and compare torque expression among Damon Q, SmartClip, and Empower 2 self-ligating brackets using three-dimensional finite element analysis.
Materials and Methods: A three-dimensional finite element study was performed on maxillary anterior teeth using Damon Q, SmartClip, and Empower 2 brackets bonded at varying vertical heights (3 mm, 4 mm, 5 mm, and 6 mm). A 0.019” × 0.025” stainless steel archwire was engaged in 0.022” slot brackets, and torsional forces were applied. Total deformation, directional deformation, root apex stress, cervical stress, and periodontal ligament (PDL) stress were evaluated.
Results: Torque expression and stress distribution increased progressively with increasing bracket height in all groups. Damon Q demonstrated the highest total deformation and stress values, followed by SmartClip and Empower 2. At 6 mm bracket height, Damon Q exhibited maximum deformation and greater PDL stress concentration compared to the other bracket systems. Empower 2 consistently showed the lowest biomechanical response. Statistically significant differences were observed among all three bracket systems.
Conclusion: Torque expression is significantly influenced by bracket design and vertical bracket positioning. Gingival bracket placement increased torque expression and stress concentration in all bracket systems. Among the evaluated brackets, Damon Q demonstrated superior torque expression, while Empower 2 exhibited comparatively lower biomechanical response.
Keywords: Torque expression, finite element analysis, self-ligating brackets, Damon Q, SmartClip, Empower 2, orthodontic biomechanics.
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INTRODUCTION
Orthodontic treatment aims to achieve optimal dental esthetics, functional occlusion, and long-term stability through precise three-dimensional control of tooth movement. Proper control of the buccolingual inclination of anterior teeth is particularly important for establishing ideal occlusal relationships, harmonious smile esthetics, and stable anterior guidance.[1]
Torque in orthodontics refers to the labiolingual or buccolingual inclination of a tooth produced when a rectangular archwire engages the walls of a rectangular bracket slot, generating a rotational moment that moves the crown and root in opposite directions.[2] Effective torque expression depends on adequate archwire–slot engagement; however, residual clearance between the archwire and bracket slot often results in partial loss of prescribed torque.[2]
Several factors influence torque expression, including tooth anatomy, archwire dimensions, bracket slot morphology, bracket positioning, and the degree of wire engagement within the bracket slot.[3] Even minor variations in vertical bracket positioning can alter the interaction between the archwire and bracket slot, thereby affecting the magnitude of torque expressed on the tooth.
The vertical placement of the orthodontic bracket significantly influences the efficiency of torque expression because it alters the distance between the point of force application and the centre of resistance of the tooth. Brackets positioned closer to the centre of resistance demonstrate improved torque control

and reduced unwanted tipping movements, whereas brackets positioned farther away may produce less efficient root movement.[4]

Self-ligating brackets have gained considerable popularity due to advantages such as reduced friction and improved archwire engagement. These systems are broadly classified into active and passive types depending on their clip mechanism. Although self-ligating brackets are widely used clinically, limited studies have comparatively evaluated torque expression among different self-ligating systems.[5]

Finite element analysis (FEA) is a reliable numerical method used to evaluate stress distribution and biomechanical response in orthodontics under simulated clinical conditions.[6] Therefore, the present study was undertaken to evaluate and compare torque expression among Damon Q, SmartClip, and Empower 2 self-ligating brackets at varying vertical bracket heights using three-dimensional finite element analysis.

MATERIALS & METHODS

2.1 Source of data:

The present study was designed as a three-dimensional finite element analysis to evaluate and compare torque expression among different self-ligating orthodontic bracket systems at varying vertical bracket heights. The study included three commercially available passive self-ligating bracket systems used for the maxillary right central incisor: SmartClip brackets (3M Unitek), Empower 2 brackets (American Orthodontics), and Damon Q brackets (Ormco), all having a 0.022-inch slot dimension.

A 0.019 × 0.025-inch stainless steel archwire was used for the simulation to evaluate the biomechanical interaction between the archwire and bracket slot during torque application. The geometrical models of the brackets were reconstructed based on their exact dimensions using computer-aided design (CAD) and reverse engineering techniques. For accurate geometric representation, the brackets were scanned using a three-dimensional scanner, and the obtained data were utilized to generate detailed three-dimensional models suitable for finite element analysis.

A three-dimensional model of the maxillary right central incisor along with the periodontal ligament and supporting alveolar bone was constructed using modelling software. The periodontal ligament was modeled as a uniform layer surrounding the root surface to simulate physiological stress distribution during orthodontic tooth movement.

2.2 Method of collecting data:

Three self-ligating bracket systems for the maxillary right central incisor were selected for comparison and grouped as follows:

- Group 1 – Damon Q- Ormco brackets
- Group 2 – 3M Unitek Smartclip Brackets
- Group 3 – American orthodontics Empower 2 series- brackets

Figure 1: Damon Q Ormco brackets

Figure 2: 3M Unitek smartclip brackets

Figure 3: American Empower 2 brackets

Each bracket system was evaluated at 6 mm bracket height measured from the incisal edge of the tooth:

Archwire dimension used:

• 0.019 × 0.025-inch stainless steel archwire

2.3 Procedure

The study was carried out to evaluate and compare torque expression and stress distribution produced by different self-ligating bracket systems bracket height of 6mm using finite element analysis.

Initially, a three-dimensional model of the maxillary right central incisor was developed along with the surrounding periodontal ligament and alveolar bone structures. The geometries of the tooth and supporting tissues were constructed using modelling software based on anatomical dimensions obtained from standard orthodontic references. The periodontal ligament was modelled as a thin uniform layer around the root surface to simulate physiological tooth support.

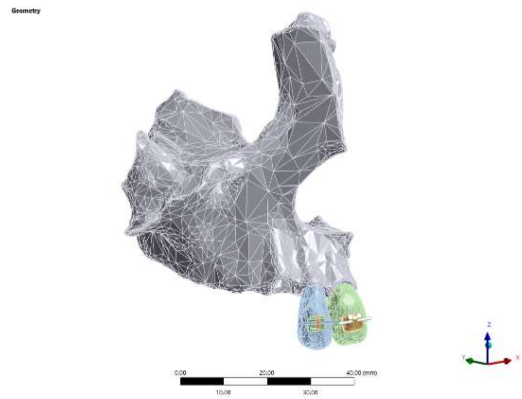


Figure 4: 3D skull structure with brackets & wire fixed on the tooth

Following this, three-dimensional models of SmartClip, Empower 2, and Damon Q self-ligating brackets were created using reverse engineering techniques. The bracket geometries were reproduced according to their measured dimensions obtained through three-dimensional scanning procedures. A 0.019 × 0.025-inch stainless steel archwire was also modelled and incorporated into the bracket slots to reproduce clinical orthodontic mechanics during torque application.

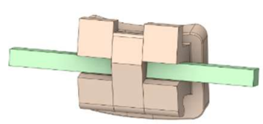


Figure 5: Group 1 – Damon Q (Ormco

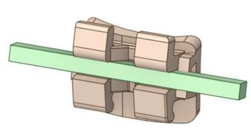


Figure 6: Group 2 – 3M Unitek SmartClip

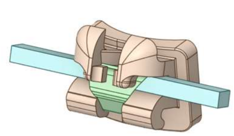


Figure 7: Group 3 – Empower 2

Each bracket was positioned on the labial surface of the maxillary central incisor at vertical height of 6 mm from the incisal edge. The assembled tooth–bracket–archwire models were then imported into finite element analysis software for simulation and analysis.

Meshing of the models was performed using tetrahedral finite elements to generate a detailed network of nodes and elements representing the tooth, periodontal ligament, alveolar bone, brackets, and archwire. Appropriate material properties such as Young's modulus and Poisson's ratio were assigned to all structures based on values reported in previous orthodontic biomechanical studies. All materials were considered homogeneous, isotropic, and linearly elastic for the purpose of the analysis.

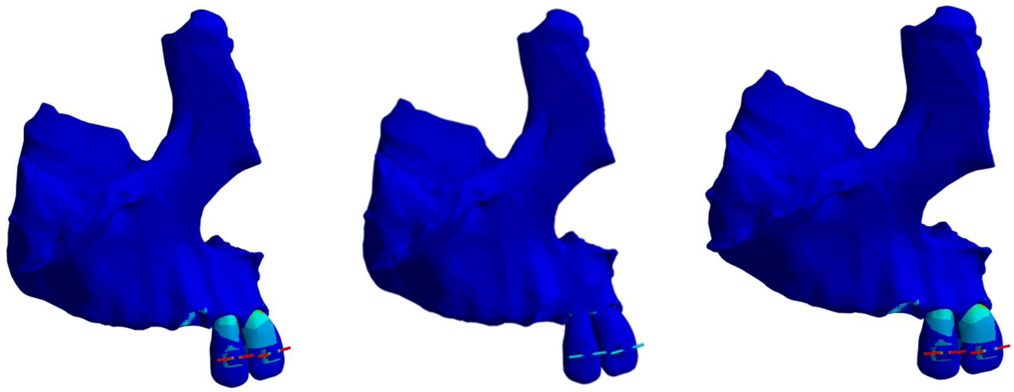
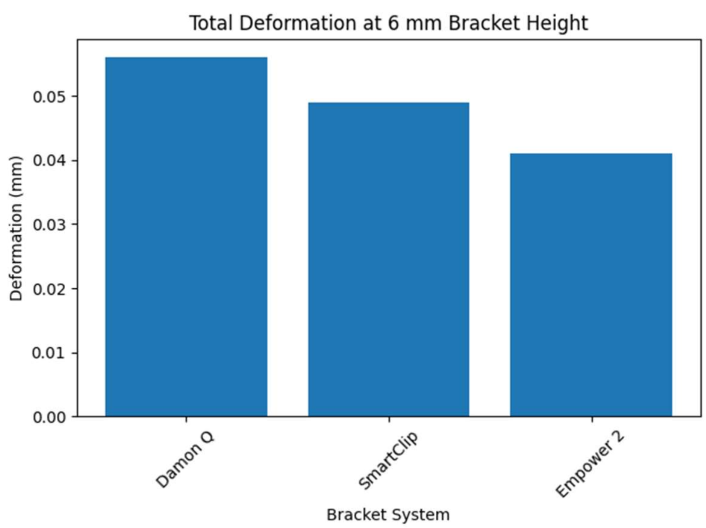


Figure 8,9,10: FE models of central and lateral incisor with Damon Q Brackets, 3M Unitek Smartclip bracket and American orthodontics Empower 2 series- brackets respectively.

Boundary conditions and constraints were applied to simulate clinical conditions. Torque forces were then applied through the archwire–bracket assembly to produce third-order movement of the maxillary central incisor. The resulting biomechanical response was evaluated by analyzing total deformation, root apex stress, cervical cervical stress values.

The stress distribution and deformation patterns produced by SmartClip, Empower 2, and Damon Q brackets at different vertical bracket heights were recorded, analyzed, and compared using finite element analysis.

RESULTS



The bar chart illustrates the total deformation observed in the maxillary central incisor when different self-ligating bracket systems were positioned at a bracket height of 6 mm from the incisal edge. Among the three bracket systems evaluated, Damon Q brackets demonstrated the highest total deformation (0.056 mm), indicating greater torque expression compared to the other bracket systems. SmartClip brackets showed a moderate level of deformation (0.049 mm), whereas Empower 2 brackets exhibited the lowest deformation (0.041 mm).These findings suggest that Damon Q brackets produced greater biomechanical response at the 6 mm bracket position, followed by SmartClip and Empower 2 brackets. The increased deformation observed with Damon Q brackets may be attributed to differences in bracket design, slot geometry, and mechanical interaction between the archwire and bracket slot.

Table no 7-total deformation in Maxillary Right Lateral Incisor

Bracket System	Total deformation
Damon Q	0.051
SmartClip	0.045
Empower 2	0.038

The total deformation values observed at 6 mm vertical bracket height differed among the three passive self-ligating bracket systems. Damon Q brackets demonstrated the highest total deformation (0.051 mm), followed by SmartClip brackets (0.045 mm), while Empower 2 brackets exhibited the lowest deformation (0.038 mm). These findings indicate that Damon Q produced the greatest torque expression at the 6 mm bracket position, whereas Empower 2 showed comparatively lower torque expression. The results suggest that bracket design influences the magnitude of deformation and torque expression under identical loading conditions.

Bracket	**Root Apex Stress - Central Incisor** at 6mm
Damon Q	5.9
SmartClip	5.2
Empower 2	4.3

At 6 mm vertical bracket height, the Von Mises stress at the root apex varied among the three passive self-ligating bracket systems. Damon Q brackets demonstrated the highest stress value (5.9 MPa), followed by SmartClip brackets (5.2 MPa), while Empower 2 brackets exhibited the lowest stress value (4.3 MPa). The results indicate that Damon Q transmitted greater torque forces to the root apex compared to SmartClip and Empower 2. The higher stress concentration observed with Damon Q suggests greater torque expression, whereas Empower 2 produced comparatively lower biomechanical stress under identical loading conditions.

Bracket	Cervical Region Stress 6 mm
Damon Q	4.7
SmartClip	4.1
Empower 2	3.5

At 6 mm vertical bracket height, the cervical region stress was highest in the Damon Q bracket system (4.7 MPa), followed by SmartClip (4.1 MPa) and Empower 2 (3.5 MPa). Damon Q demonstrated greater stress concentration in the cervical region compared to the other bracket systems. SmartClip exhibited intermediate stress values, while Empower 2 showed the lowest cervical stress. These findings indicate variations in stress distribution among the bracket systems under identical torque loading conditions.

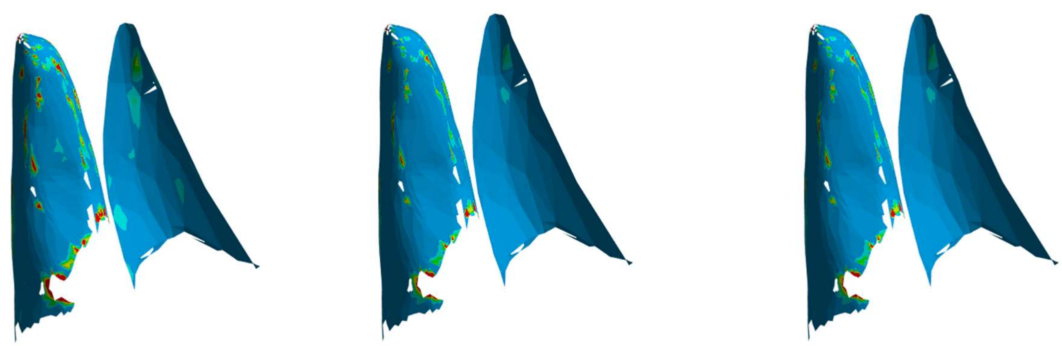


Figure 13,14,15: Finite Element Analysis (FEA) simulation model evaluating the von missile stress observed in Damon Q, 3M Unitek Smart clip and Empower 2 brackets respectively

DISCUSSION

Torque control of maxillary incisors is an essential aspect of orthodontic treatment because it plays a major role in achieving proper anterior guidance, ideal occlusion, facial esthetics, and long-term stability. Proper buccolingual inclination of the maxillary incisors is particularly important for maintaining a harmonious smile line and functional occlusal relationship. Efficient torque expression depends largely on the effective transmission of rotational forces from the archwire to the tooth through the bracket–archwire interface.[2] Variations in bracket design, slot geometry, ligation mechanism, manufacturing precision, and archwire engagement may therefore influence the amount of clinically expressed torque.

The present finite element study was conducted to evaluate and compare torque expression among three passive self-ligating bracket systems—Damon Q, SmartClip, and Empower 2. The results of the study demonstrated distinct differences in biomechanical behavior among the evaluated bracket systems. Damon Q brackets consistently exhibited the highest total deformation and stress values, followed by SmartClip, whereas Empower 2 demonstrated the lowest biomechanical response. These findings indicate that Damon Q brackets provide superior torque transmission and greater torque expression compared to the other evaluated self-ligating bracket systems.

In finite element analysis, total deformation represents the displacement produced within the tooth–periodontal ligament complex as a result of the applied torsional force. Increased deformation indicates that the rotational moment generated at the bracket–archwire interface is effectively transmitted to the tooth structure.[2] Therefore, brackets demonstrating greater deformation are considered to possess more efficient torque expression characteristics. In the present study, Damon Q showed greater deformation values compared to SmartClip and Empower 2, indicating enhanced rotational control and improved third-order tooth movement.

The findings of the present investigation are in agreement with previous studies reported in the literature. Bernisha R.P et al.[2] stated that increased total deformation corresponds to improved torque expression because greater displacement reflects more efficient transmission of torsional forces through the bracket–archwire system. Similarly, Magesh et al.[23] evaluated bracket slot deformation during torque application using finite element analysis and demonstrated that greater deformation and stress concentration are associated with increased torque transmission.

Torque expression primarily depends on the interaction between the rectangular archwire and the bracket slot. When a rectangular archwire is engaged within a bracket slot and subjected to torsional activation, a couple is generated between the wire and slot walls, resulting in labiolingual root movement. Effective engagement between the archwire and bracket slot allows better transfer of this rotational moment to the tooth. Any increase in slot clearance or reduction in wire–slot contact may decrease the amount of effective torque expressed clinically.

Among the evaluated bracket systems, Damon Q demonstrated superior torque expression compared to SmartClip and Empower 2. This superior biomechanical performance may be attributed to its precision-engineered slot dimensions and reduced slot clearance, which minimize the "play" between the archwire and bracket slot. Reduced slot play permits more effective engagement of the archwire within the bracket slot and enhances transmission of torsional forces. In addition, the passive slide mechanism of Damon Q forms a fourth wall around the archwire, improving wire control during third-order movement.

The present findings are supported by the study conducted by Thushar et al.[6], who compared torque expression among passive self-ligating brackets using finite element analysis and reported that Damon Q exhibited greater torque values than SmartClip brackets under similar conditions. The authors suggested that the passive slide mechanism of Damon Q permits more efficient wire engagement, whereas the NiTi clip system of SmartClip may undergo elastic deformation during torque application, thereby reducing effective contact between the archwire and slot walls.

SmartClip brackets demonstrated intermediate deformation and stress values in the present study, indicating moderate torque efficiency. Although SmartClip brackets provide relatively effective torque control, the flexibility of the NiTi clips may reduce the rigidity of the bracket–archwire interaction during torsional activation. This may explain the lower torque transmission observed in comparison with Damon Q brackets.

Empower 2 brackets consistently demonstrated the lowest deformation and stress values among all evaluated systems, indicating comparatively lower torque expression. These findings may be attributed to differences in bracket slot geometry, clip design, and the interaction between the archwire and bracket slot. Greater slot clearance and reduced wire engagement may result in decreased transmission of torsional forces to the tooth structure.

Von Mises stress values observed within the root apex and the cervical region further supported the deformation findings. Damon Q demonstrated the highest stress concentration, followed by SmartClip and Empower 2. Increased stress values indicate greater transfer of orthodontic forces from the bracket–archwire assembly to the tooth–periodontal ligament complex. Sardarian et al.[16] reported similar findings and concluded that increased stress within the periodontal ligament is associated with greater torque expression generated by the bracket–archwire system.

Bernisha et al.[2] also demonstrated that higher von Mises stress values correspond to improved transmission of torsional forces and enhanced third-order control. According to their findings, increased deformation and elevated stress distribution within the tooth–periodontal ligament complex are important indicators of effective torque transmission during orthodontic mechanics.

The findings of the present study emphasize that bracket design and slot characteristics significantly influence torque expression in self-ligating bracket systems. Differences in slot precision, clip mechanism, and wire–slot interaction can alter the

efficiency of torque transmission and thereby affect clinical outcomes. Among the evaluated systems, Damon Q demonstrated superior torque expression and biomechanical performance, while Empower 2 exhibited comparatively lower torque efficiency.
Clinically, efficient torque expression is essential for achieving accurate root positioning, proper incisor inclination, and stable treatment outcomes. Therefore, understanding the biomechanical behavior of different self-ligating bracket systems may assist clinicians in selecting appropriate appliances for cases requiring precise torque control. However, since the present study was conducted using finite element analysis under simulated conditions, the results should be interpreted cautiously when extrapolating them directly to clinical situations. Further experimental and clinical investigations are necessary to validate these findings under actual intraoral conditions.

CONCLUSION

The findings of the present finite element study demonstrate that torque expression varies significantly among different passive self-ligating bracket systems. Among the evaluated brackets, Damon Q exhibited the highest total deformation and stress values, indicating superior torque transmission and more efficient third-order control. SmartClip demonstrated moderate torque expression, whereas Empower 2 showed comparatively lower biomechanical response.
The differences observed among the bracket systems may be attributed to variations in slot geometry, bracket design, clip mechanism, and archwire–slot interaction. Greater deformation and stress distribution within the tooth–periodontal ligament complex were associated with improved transmission of torsional forces and enhanced torque expression.
The study emphasizes that bracket design plays a critical role in determining torque efficiency during orthodontic treatment. Understanding the biomechanical behavior of different self-ligating bracket systems may help clinicians select appropriate appliances for cases requiring precise torque control and accurate root positioning.
However, since the present study was conducted under simulated finite element conditions, further clinical and experimental investigations are required to validate these findings under actual intraoral conditions.

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