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Mechanical effects of third-order movement in self-ligated brackets by the measurement of torque expression

Thomas W. Major,[a] Jason P. Carey,[b] David S. Nobes,[c] Giseon Heo,[d] and Paul W. Major[e]
Edmonton, Alberta, Canada

Introduction: Axial rotation of orthodontic wire produces buccal or lingual root movement and is often referred to as third-order movement or "torque expression." The objective of this study was to quantify torque expression in 3 self-ligation bracket systems (Damon Q, Ormco, Orange, Calif; In-Ovation R, GAC, Bohemia, NY; and Speed, Strite Industries, Cambridge, Ontario, Canada) during loading and unloading. **Methods:** A stepper motor was used to rotate a wire in a fixed bracket slot from –15° to 63° in 3° increments, and then back to –15°. The bracket was mounted on top of a load cell that measured forces and moments in all directions. **Results:** Damon's and In-Ovation's maximum average torque values at 63° were 105 and 113 Nmm, respectively. Many Speed brackets experienced premature loss of torque between 48° and 63°, and the average maximum was 82 Nmm at 54°. The torque plays for Damon, In-Ovation, and Speed were 11.3°, 11.9°, and 10.8°, respectively. **Conclusions:** Generally, In-Ovation expressed the most torque at a given angle of twist, followed by Damon and then Speed. However, there was no significant difference between brackets below 34 Nmm of torque. From a clinical perspective, the torque plays between brackets were virtually indistinguishable. (Am J Orthod Dentofacial Orthop 2011;139:e31-e44)

Edgewise orthodontic treatment involves rectangular wires placed into rectangular bracket slots. Axial rotation of the orthodontic wire in the bracket creates a force couple that produces buccal or lingual root movement relative to the tooth crown.[1] In the orthodontic literature, this type of tooth movement is often called "root torque" or third-order movement. Also, the terms "torque" and "torque expression" refer to the physical moment generated in the bracket in newton millimeters (Nmm).

From the University of Alberta, Edmonton, Alberta, Canada.
[a]Research associate, Department of Mechanical Engineering, Faculty of Engineering.
[b]Associate professor, Department of Mechanical Engineering, Faculty of Engineering.
[c]Assistant professor, Department of Mechanical Engineering, Faculty of Engineering.
[d]Assistant professor, Orthodontic Graduate Program, Department of Dentistry, Faculty of Medicine and Dentistry.
[e]Professor, and program director, Orthodontic Graduate Program, Department of Dentistry, Faculty of Medicine and Dentistry.
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Reprint request to: Paul W. Major, Room 4051, Dentistry/Pharmacy Centre, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada T6G 2N8; e-mail, major@ualberta.ca.
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Torque expression is a function of wire properties, bracket slot dimension and bracket design, archwire dimension, and degrees of wire twist relative to the bracket slot.[1-8] The angle in degrees that the wire is twisted is called the "angle of twist" or the "torque angle." The "zero position" is the position defined as having an angle of 0° where the wire must twist an equal angle in the positive and negative directions to engage the bracket slot walls. The term "torque play" is the angle at which the wire just engages the slot, meaning that the "torque play region" is the range of angles at which there is approximately no torque expression. This is also called the "engagement angle."

Torque expression is also influenced by the ligation method.[9] In passive ligation, the wire is free to rotate in the slot until the edges of the rectangular wire contact the sides of the bracket slot. As the wire is twisted to the limit of the torque play region, a force couple is generated. In active ligation, the wire is pressed against the base of the slot. The interaction of the active ligation method (wire, ligature, or active bracket door) creates a second force couple. In the case of self-ligation brackets where a clip presses against the wire, the force can act on the edge of the wire and alter the zero position. As the wire rotates, the interaction of the clip against the wire might contribute to torque expression.

Previous studies have evaluated torque expression and torque play for a variety of bracket and wire types.[3,9] Some authors have acknowledged the potential role of bracket deformation, but to date the effects of wire or bracket elastic and plastic deformations have not been quantified.[2,4,10] Elastic deformation is a nonpermanent deformation. Plastic deformation occurs under higher loads than elastic deformation and is permanent. To date, no published studies have evaluated both the loading and unloading torque values associated with archwire twist and return to zero position.

The objective of this study was to quantify torque expression in 3 self-ligation bracket systems during loading ("increasing angle") and unloading ("decreasing angle"). The loading and unloading curves will be used to characterize the combined bracket and wire deformations.

MATERIAL AND METHODS

The torque measurement device, previously used by Badawi et al[9] and modified for this study, is shown in Figure 1. The key assemblies for measuring torque and angle are the wire and motor assembly and the load cell assembly. The modified load cell assembly consists of 2 translational stages and 1 rotational stage (Thorlabs, Newton, NJ), a 6-axis load cell (ATI Industrial Automation Nano 17 Multi-Axis force/torque transducer, Apex, NC), and the bracket mount on which sits the orthodontic bracket. Through the mount, the load cell measures forces and moments at the bracket slot. By using a FaroArm (FARO USA, Lake Mary, Fla) to determine the location of the bracket slot in relation to the designed load cell origin, a transformation is applied to the data so that the final data set of forces and moments are those at the slot of the bracket. By using the left-hand rule for torque (T) direction, the transformation equation is

$$T_x = T_{x'} - \left(F_{y'} \times \Delta z\right) + \left(F_{z'} \times \Delta y\right)$$

where the x direction is the parallel to the long axis of the wire and bracket slot, the z direction is vertical against the bracket base, and the y direction is perpendicular to both x and z, with the origin at the bracket slot center. X', y', and z' are the equivalent coordinates, but with the origin located at the load cell. The measured distances between the load cell origin and the slot center, Δx, Δy, and Δz, are shown in Figure 2. The left-hand rule is used for torque direction in the equation to match the coordinate calibration output from the load cell. The 3-dimensional Cartesian (x′, y′, and z′) force and moment data are collected through a data acquisition card (DAC 16-bit E series NI PCI-6033E, National

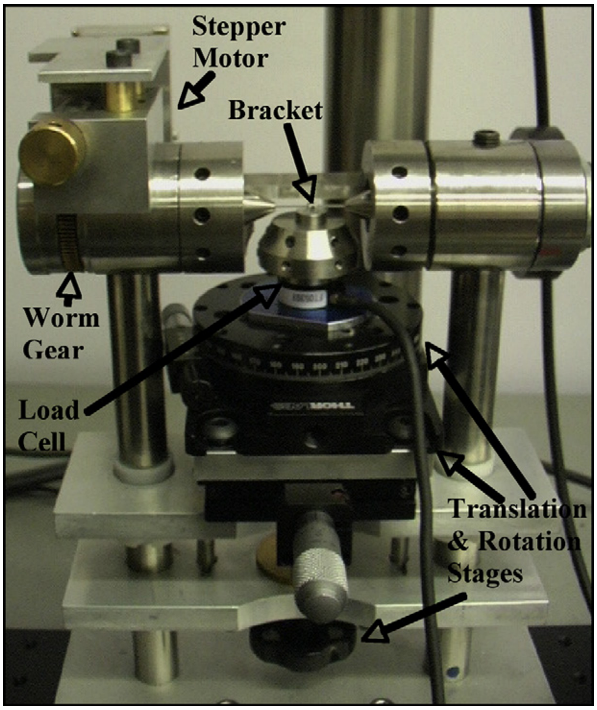

Fig 1. Apparatus showing the bracket and load cell.

Instruments, Austin, Tex) and logged with commercial software (LabWindows CVI, National Instruments). The data are exported to a spreadsheet, and the transformation is applied so that the final data output of torque is at the slot center.

The motor and wire assembly consists of 2 dies with rectangular slots that clamp tightly onto 0.019 × 0.025-in stainless steel orthodontic wire (Ormco, Orange, Calif). The distance between the 2 fixing dies was 15 mm. The entire wire assembly was rotated by a worm gear stepper motor (Cool Muscle CM1-C-11L30, Myostat Motion Control, Newmarket, Ontario, Canada). The stepper motor was controlled by custom software, and the angle was accurately measured by using the motor's internal control loop at any time.

After the wires were tightened into the dies, they were dropped into the bracket slot at the initially estimated zero position. By using the translation and rotation stages, the forces were zeroed within 0.01 N in the y and z directions by using the 2 translational stages, and the moments were zeroed to within 0.08 Nmm in the z direction by using the rotational stage. Preload forces in the x direction cannot be easily controlled and reach a maximum of 0.3 N. However, the x-direction forces have no direct impact on T_x, as can be seen in the equation. Preload torque in the y direction cannot be controlled, because it depends on the bracket