

## Review Article

# Torque Expression in Stainless Steel Orthodontic Brackets

### *A Systematic Review*

Amy Archambault<sup>a</sup>; Ryan Lacoursiere<sup>a</sup>; Hisham Badawi<sup>b</sup>; Paul W. Major<sup>c</sup>; Jason Carey<sup>d</sup>; Carlos Flores-Mir<sup>e</sup>

#### **ABSTRACT**

**Objective:** To evaluate the quantitative effects on torque expression of varying the slot size of stainless steel orthodontic brackets and the dimension of stainless steel wire, and to analyze the limitations of the experimental methods used.

**Materials and Methods:** In vitro studies measuring torque expression in conventional and self-ligating stainless steel brackets with a torque-measuring device, with the use of straight stainless steel orthodontic wire without second-order mechanics and without loops, coils, or auxiliary wires, were sought through a systematic review process.

**Results:** Eleven articles were selected. Direct comparison of different studies was limited by differences in the measuring devices used and in the parameters measured. On the basis of the selected studies, in a 0.018 inch stainless steel bracket slot, the engagement angle ranges from 31 degrees with a 0.016 × 0.016 inch stainless steel archwire to 4.6 degrees with a 0.018 × 0.025 inch stainless steel archwire. In a 0.022 inch stainless steel bracket slot, the engagement angle ranges from 18 degrees with a 0.018 × 0.025 inch stainless steel archwire to 6 degrees with a 0.021 × 0.025 inch stainless steel archwire. Active stainless steel self-ligating brackets demonstrate an engagement angle of approximately 7.5 degrees, whereas passive stainless steel self-ligating brackets show an engagement angle of approximately 14 degrees with 0.019 × 0.025 inch stainless steel wire in a 0.022 inch slot.

**Conclusions:** The engagement angle depends on archwire dimension and edge shape, as well as on bracket slot dimension, and is variable and larger than published theoretical values. Clinically effective torque can be achieved in a 0.022 inch bracket slot with archwire torsion of 15 to 31 degrees for active self-ligating brackets and of 23 to 35 degrees for passive self-ligating brackets with a 0.019 × 0.025 inch stainless steel wire. (*Angle Orthod.* 2010;80:201–210.)

**KEY WORDS:** Systematic review; Self-ligation; Torque

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<sup>a</sup> M.S. Graduate student, Orthodontic Graduate Program, University of Alberta, Edmonton, AB, Canada.

<sup>b</sup> PhD Graduate student, Orthodontic Graduate Program, University of Alberta, Edmonton, AB, Canada.

<sup>c</sup> Professor, Dentistry (Orthodontics), University of Alberta, Edmonton, AB, Canada.

<sup>d</sup> Associate Professor, Mechanical Engineering, University of Alberta, Edmonton, AB, Canada.

<sup>e</sup> Associate Professor, Orthodontic Graduate Program, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, AB, Canada.

Corresponding author: Dr Carlos Flores Mir, Director of the Cranio-Facial and Oral-Health Evidence-Based Practice Group (COEPG), 4051 Dentistry/Pharmacy Centre, University of Alberta, Edmonton, Alberta, Canada, T6G 2N82 (e-mail: carlosflores@ualberta.ca)

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## INTRODUCTION

Torque can be defined from a mechanical or from a clinical point of view. Mechanically, it refers to the twisting of a structure about its longitudinal axis, resulting in an angle of twist. Torque is a shear-based moment that causes rotation. Clinically, in orthodontics, it represents the buccopalatal crown/root inclination of a tooth, and it is an orthodontic adaptation used to describe rotation around an x-axis. When applied in an orthodontic archwire/bracket interaction, it describes the activation generated by twisting an archwire in a bracket slot.<sup>1</sup> Orthodontists define torque around the dental arch such that the x-axis follows the curve of the arch. Torque, in this sense, would be rotation perpendicular to the long axis of the tooth. This

**Table 1.** Database Search and Results

Database	Keywords	Results	Articles Selected		% of Total Final Selected Articles (11) Found by Database <sup>a</sup>
			Full Articles Retrieved for Evaluation	Based on Final Inclusion Criteria	
Medline	(1) Torque OR (2) torque.mp (3) orthodontic brackets (4) orthodontic bracket\$.mp. (5) orthodontic wires (6) orthodontic wires\$.mp. (1 or 2) AND (3 or 4 or 5 or 6)	176	32	8	73
PubMed	Torque AND (orthodontic brackets or orthodontic bracket <sup>a</sup> or orthodontic wires or orthodontic wire <sup>a</sup> )	196	31	8	73
Embase	(1) Torque (2) orthod\$.mp. 1 AND 2	175	7	3	27
Web of Science	(1) Torque <sup>a</sup> AND orthod <sup>a</sup>	99	8	4	36
Scopus	(1) Torque AND orthod <sup>a</sup>	359	14	7	70
EBMR	(1) Torque.mp. (2) orthod\$.mp. 1 AND 2	351	36	9	82
All EBM Reviews	(1) Torque.mp. (2) orthod\$.mp. 1 AND 2	351	35	9	82

<sup>a</sup> Including 2 articles found in hand-search.

could be generated by a rotation through a moment or couple of forces. The terms “moment,” “torsional moment,” “couple,” “biomechanical torque,” and “third-order torque” appear to be used interchangeably in the orthodontic literature to indicate the same loading condition, although an understanding of the biomechanical implications of them will not necessarily result in pure torque.

Clinically, torque control is often required in the maxillary incisors for an ideal interincisal angle, adequate incisor contact, and sagittal adjustment of the dentition in order to achieve an ideal occlusion.<sup>2</sup> A large variation between prescriptions exists with respect to incisor torque values. Maxillary central incisor torque ranges from 12 degrees in the Roth prescription to 22 degrees in the Bioprogressive prescription.<sup>3</sup>

Depending on magnitude of torsion, the stiffness or resilience of the wire cross section, wire size, edge bevel and manufacturer tolerance, bracket slot size and manufacturer tolerance, engagement angle of the wire in the bracket slot, experimental measurement technique, bracket placement as related to tooth morphology,<sup>4,5</sup> and inclination of the tooth, the archwire moves the root of a tooth through the alveolar bone via localized pressure and tension generated by torsion in the archwire.<sup>2</sup> Most orthodontic treatment is carried out with less than full-dimension archwires, leading to lack of cohesive contact between the bracket and the wire; this is known as torsional play or the engagement angle.<sup>6</sup>

The current literature on torque expression in orthodontic brackets consists of theoretical models and discussions; in vitro studies employing various measurement devices, brackets, and wire dimensions; and in vivo studies indirectly measuring torque expression via tooth inclination. It is difficult to predict the amount of torque expression that a clinician can expect from a given bracket and archwire combination. This system-

atic review is intended to evaluate the quantitative effects of varying the slot size of stainless steel orthodontic brackets and the dimension of stainless steel wire on torque expression. It is our intention to help the clinician to better understand the variables involved in generating torque moments when selecting stainless steel archwires for torque expression.

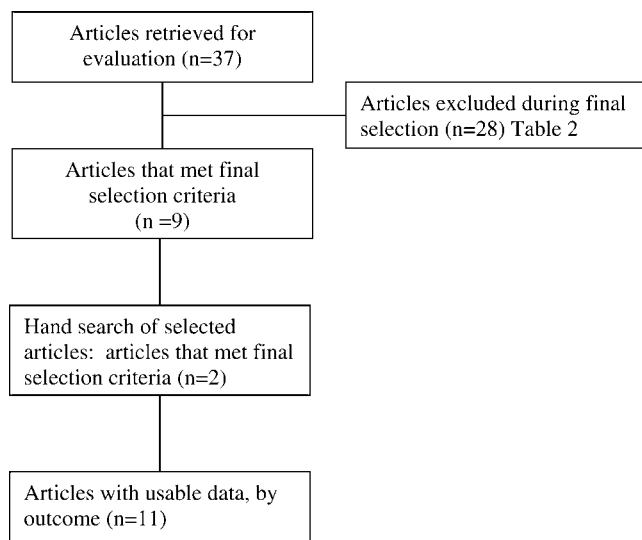
## MATERIALS AND METHODS

A computerized database search was conducted using Medline, Embase, EBMR (Evidence-Based Medicine Reviews), EBM All Reviews, PubMed, Scopus, and Web of Science to search the literature up until June 27, 2008.

Terms and their respective truncations used in the literature search (Table 1) were specific to each database. Searches were conducted with the help of a senior librarian who specializes in the Health Sciences. The selection process was carried out together by 2 researchers. The inclusion criterion, “Measurement of torque expression in orthodontic brackets,” was chosen to initially select potential articles from the published abstract results of the database search.

Once potentially adequate abstracts were selected, full articles were retrieved in a second selection process. The following additional (final) selection criterion was chosen to select articles for inclusion in this systematic review: “In vitro studies measuring torque expression in new stainless steel brackets with a torque-measuring device with straight stainless steel orthodontic wire without second-order mechanics and without loops, coils or auxiliary wires.”

Studies that measured friction, bracket deformation/failure, wire torsion, bracket position, or tooth morphology without evaluating torque were excluded. Theoretical studies of torque expression without practical application also were excluded.



**Figure 1.** Flow diagram of the literature search.

The QUOROM statement checklist was followed; however, several points did not apply to this systematic review in that it was a review of in vitro studies rather than randomized control trials. Validity was assessed by critically examining the torque-measuring devices and methods employed in each study.

## RESULTS

Thirty-seven abstracts met the initial inclusion criteria. Once the full articles were retrieved, only 9 met the final inclusion criteria. Reasons for exclusion at the final selection stage are stated in the Appendix. A hand-search of the reference lists in the 9 articles that met the final inclusion criteria identified 2 additional articles. A total of 11 articles met the final inclusion criteria (Figure 1). Two studies<sup>2,7</sup> were intended to evaluate torque expression in plastic brackets but were included because they used metal brackets as a control. The study by Hixson<sup>8</sup> was intended to evaluate changes in bracket slot tolerance following recycling of metal brackets. Because baseline values using new metal brackets were measured, this part of the data was included in this systematic review. Two articles in Chinese<sup>9,10</sup> were excluded because of language as no translator for the dialect was available.

The methods and results of each selected article have been summarized in Table 2. Several variables were measured to represent torque expression; however, results on measurement of the engagement angle will be emphasized.

The angle of twist of the archwire in degrees at 20 Nmm was measured by Meling<sup>11</sup> and Odegaard.<sup>12</sup> The maximum torquing moment in Ncm at 20 degrees of archwire torsion was measured by Gmyrek<sup>7</sup> and Har-

zer.<sup>2</sup> Morina<sup>13</sup> measured the maximum torquing moment in Nmm at 20 degrees of archwire torsion, as well as torque loss. Results indicate that Morina<sup>13</sup> noted mean moments of 8.0 Nmm for the Speed bracket (Strite Industries, Cambridge, Ontario, Canada) and 7.8 Nmm for the Damon 2 bracket (Ormco Corporation, Orange, CA, USA) with a 0.019 × 0.025 inch stainless steel wire in a 0.022 inch slot with the orthodontic measuring and simulation system (OMSS). Testing the same wire and bracket slot combination, Badawi<sup>6</sup> recorded 5.5 to 12.4 Nmm, depending on bracket brand, with Speed (Strite Industries, Cambridge, Ontario, Canada) measuring 11.9 Nmm and Damon 2 (Ormco Corp, Orange, CA, USA) measuring 5.5 Nmm. Gmyrek's experiments with the precision lathe produced results that resemble those of Badawi.<sup>6</sup> At 30 degrees of torsion, Gmyrek reported a moment of 2.09 Ncm (20.9 Nmm). Badawi<sup>6</sup> measured the moment of the couple at 24 and 36 degrees with values of 5.5 to 12.4 Nmm at 24 degrees and 21.0 to 27.8 at 36 degrees. In addition, Badawi<sup>6</sup> measured the engagement angle from the archwire twist to the moment graph as the point at which a positive torque moment was detected after the initial lag period. The torque in g-cm was measured at 5 degree intervals by McKnight.<sup>5</sup> The torque moment was measured in g-cm at 5 degree intervals by Feldner.<sup>14</sup> Fischer-Brandies<sup>15</sup> measured the engagement angle in degrees at 0, 1, and 3 Ncm of torque loading. The values chosen to be evaluated in this systematic review were those measured at 0 Ncm to represent the contact angle. The engagement angle was measured in degrees. In a 0.018 inch bracket slot, it ranged from 31 degrees with a 0.016 × 0.016 inch archwire to 4.6 degrees with an 0.018 × 0.025 inch archwire. In a 0.022 inch bracket slot, the engagement angle ranged from 18 degrees with an 0.018 × 0.025 inch archwire to 6 degrees with a 0.021 × 0.025 inch archwire.<sup>4,6,8,11,12,15</sup>

## DISCUSSION

The current systematic review identified 11 in vitro studies in which conventional and self-ligating metal brackets that quantified torque expression were used under different working conditions and different torque parameters were measured. These studies were dissimilar in the methods and parameters tested. So that a meaningful conclusion would be drawn, studies measuring the same parameter were compared.

### Engagement Angle

The engagement angle was selected for comparison between studies because it was the parameter that was tested by most of the studies. The engagement angle was measured directly in the study by

**Table 2.** Methodology of selected articles (see Key at bottom of Table 3)

Author	Measurement device	Variable measured	Error measurements	Bracket
Fischer-Brandies <sup>15</sup>	Fixed bracket, design not specified Use of ligatures not mentioned	Torque play (degrees) at 0 Ncm of torque loading <sup>i</sup>	Control measurements were made for torque application.	Ultratrim Dentaurum edgewise brackets (0.018 slot ss) upper central incisor Inter-bracket distance: not specified
Gmyrek <sup>7</sup>	Clinical Simulation Experiment: OMSS (Orthodontic Measuring and Simulation System) Wire ligatures were used	Maximum torquing moment (Ncm) at 20 Degrees of labial crown torque <sup>ii</sup>	Each bracket-archwire combination was measured five times.	MINI-MONO (0.018 slot ss) upper central incisor Inter-bracket distance: 6 mm
Gmyrek <sup>7</sup>	Activating Experiment: Precision lathe. Thermal cycling in saliva substitute. Pre-shaped ligature wires used	Maximum torquing moment (Ncm) up to 30 degrees of archwire twist <sup>ii</sup>	See above	MINI-MONO (0.018 slot ss) upper central incisor Inter-bracket distance: 6 mm
Harzer <sup>2</sup>	OMSS Wire ligatures were used	Median of maximum torquing moment (Ncm) at a 20 degree labial crown torque <sup>iii</sup>	See above	MINI-MONO (0.018 slot ss) maxillary left central incisor Inter-bracket distance: 6 mm
Harzer <sup>2</sup>	See above	Moment/torque ratio, (Nmm/degree) <sup>iii</sup>	See above	See above
Morina <sup>13</sup>	OMSS Wire ligatures were used for non self-ligating (sl) brackets	Mean maximum torquing moment (Nmm) at 20 Degrees of labial crown torque	Each bracket-wire combination was measured 5 times	Speed (ss, sl, Strite Industries) Damon 2 (ss, sl Ormco Corp.) Ultratrim (ss, Dentaurum), Discovery (ss, Dentaurum) All 0.022 inch slot Inter-bracket distance: 6 mm
Morina <sup>13</sup> Odegaard <sup>12</sup>	See above Novel plate/rod/crossbar apparatus Elastic ligatures were used	Torque loss Intercept linear stress/strain curve Play = Intercept/2 <sup>ii</sup>	See above Total: error measurements taken. Each type of wire was tested with 5 brackets	See above Five Ormco wide twin Siamese brackets with (0.018 slot ss) zero torque and angulation Inter-bracket distance: 7 mm
Odegaard <sup>12</sup>	See above	Degree of twist for a load of 16.25 Nmm (degrees)	See above	See above
Meling <sup>11</sup>	Further development on instrument used in Odegaard study <sup>12</sup> Use of ligatures not mentioned	Torsional play based on intercept with deformation axis (degrees)	Correct orientation of brackets was tested. 400 double measurements were taken at 10 Nmm.	Standard edgewise brackets (0.018 slot ss) (tooth not specified) Inter-bracket distance: 4 mm
Meling <sup>11</sup>	See above	Angle of twist at 20 Nmm (degrees)	See above	See above
Badawi <sup>6</sup>	Novel device with a multi-axis force/torque transducer	Moment of the couple (torque moment) at 24 degrees of torsion (Nmm)	Five Damon 2 brackets and wire measured 10 times each at 4 angles of torsion	Self-ligating maxillary right central incisors: Damon 2 (Ormco) In-Ovation R (GAC) Speed (Strite Ind.) Smart clip (3M) Inter-bracket distance: 5 mm
Badawi <sup>6</sup>	See above	Moment of the couple (torque moment) at 36 degrees of torsion (Nmm)	See above	See above
Badawi <sup>6</sup> Sebanc <sup>4</sup>	See above Commercial Torque Meter model 783-C-2 Power Instruments Inc., Skokie, Illinois Use of ligatures not mentioned	Torsional play (degrees) Deviation angle (degrees)= torsional play	See above Several readings were taken along each segment of straight wire.	See above Maxillary right central incisor brackets prescription zero, in 0.018 and 0.022 slot sizes from American Orthodontics, Ormco Co. and Unitek Co. Inter-bracket (tie-wing) distance: approximately 3 mm

**Table 2.** Continued

Author	Measurement device	Variable measured	Error measurements	Bracket
McKnight <sup>5</sup>	Instron machine Use of ligatures not mentioned	Torquing force = force vs angular deflection (g)	None reported	0.022 Roth prescription "A" company ss bracket maxillary left central incisor (torque: 12 degrees) Inter-bracket distance: 8 mm
Feldner <sup>14</sup>	Torque transducer, brackets bonded to porcelain teeth held by dye stone Elastic ligatures used	Torque in millivolts converted to gm-cm with a calibrated conversion chart at 5 degree intervals beginning at 5 degrees	None reported	Mini Diamond, Ormco (0.022 inch) edgewise upper right central incisor Inter-bracket distance: 6 mm
Hixson <sup>8</sup>	Torque meter Model #783-C-2 Power Instruments Inc., Skokie, Illinois (adapted) Use of ligatures not mentioned	Torque play (degrees)	None reported	(0.022 slot ss) standard edgewise "A" company: mandibular canine American Orthodontics : maxillary lateral Ormco: maxillary lateral Inter-bracket distance: not specified

Fischer-Brandies.<sup>15</sup> On the other hand, the engagement angle can be measured indirectly from the twist/moment curve through several different methods. One can measure the archwire torsion when a positive torque moment is first observed, as did Badawi.<sup>6</sup> This is probably the best method in that it uses real data points rather than extrapolated points to identify the angle at which a positive torque moment is produced. One may estimate the engagement angle by extrapolating the linear portion of the twist/moment curve back to the x-axis.<sup>11,12</sup> Alternatively, the engagement angle can be measured by converging the data from both clockwise and counterclockwise torsion and finding the midpoint between the two x-intercepts.<sup>4,8</sup> Extrapolating from the linear portion of the twist/moment curve assumes a relationship that does not exist because we know that there is a "lag" prior to the critical contact angle, when the archwire is not engaged in the bracket slot. This method does not account for the twist from the time the wire engages the bracket to the point at which the relationship between the angle of twist and the moment is linear. Rather, it is assumed that the relationship is linear immediately.

Fisher-Brandies<sup>15</sup> applied 3 torque values (0, 1, and 3 Ncm), Results at 0 Ncm were utilized in this systematic review as this loading condition represents the critical contact angle. A value of 1 Ncm was deemed to be clinically relevant, whereas 3 Ncm was deemed to be an excessive amount of torque from a clinical point of view; however, the study was designed to test the weaknesses of the slot wire system. Because the value at which torque becomes clinically relevant is unknown, this method may be arbitrary. Gmyrek<sup>7</sup> has

suggested that the range of clinically effective torque is between 5 and 20 Nmm.

### Experimental Measurement Devices Used to Quantify Torque Expression

A total of 8 devices were used to measure torque expression in its various forms in the 11 studies. Several studies measured torque expression using different styles of lathes.<sup>5,7,8,14</sup> Inaccuracy may occur if the pulley does not fit tightly around the lathe, thus producing an axial force. To prevent this axial force development and consequent energy loss, a pulley that exerts a force couple could be used. In addition, the wire may distort or twist within the lathe, leading to frictional torque loss. Gmyrek,<sup>7</sup> Harzer,<sup>2</sup> and Morina<sup>13</sup> used the OMSS<sup>16</sup> to measure the maximum torquing moment. This device has 6 degrees of load measuring freedom. It ensures that only torque in a single plane is present (buccal-lingual) by automatically adjusting itself through a load sensor feedback system. Torque values were smaller for the OMSS experiments conducted by Gmyrek<sup>7</sup> and Harzer<sup>2</sup> than for Gmyrek's activating experiment.<sup>2,7</sup> Torque loss was attributed to increased play caused by adjacent bracketed teeth embedded in wax, as opposed to other in vitro studies, such as the activating experiment by Gmyrek,<sup>7</sup> in which a device firmly clamps a test bracket or a series of brackets on both sides. Badawi et al<sup>6</sup> developed a novel apparatus while also using a 6 degree of freedom multiaxis force/torque transducer. Torque was measured as the wire was twisted; all other forces and moments were kept to zero by device alignment. Ver-



**Table 3.** Torque play results of selected articles

Author	18 × 22	18 × 25	18 × 18	19 × 25	21 × 25	21.5 × 28
Fischer-Brandies <sup>15</sup>						
Gmyrek <sup>7</sup>	1.94					
Gmyrek <sup>7</sup>	2.80					
Harzer <sup>2</sup>	2.22	1.17				
		0.54				
Harzer <sup>2</sup>	1.24					
Morina <sup>13</sup>				8.0 (3.7)		
				7.8 (4.0)		
				12.3 (5.5)		
				7.5 (3.3)		
Morina <sup>13</sup>				10.9 (2.1)		
				11.1 (2.9)		
				6.6 (4.7)		
				11.1 (2.9)		
Odegaard <sup>12</sup>		5.3				
		2.52				
Odegaard <sup>12</sup>		9.2 ± 0.57				
Meling <sup>11</sup>			7.2 <sup>ii</sup>			
Meling <sup>11</sup>		9.7 (8.3–12.0)	14.6 <sup>iii</sup>			
Badawi <sup>6</sup>				Damon 2: 5.5 (3.9)		
				In-Ovation: 12.4 (6.9)		
				Smart Clip: 6.5 (5.4)		
				Speed: 11.9 (5.2)		
Badawi <sup>6</sup>				Damon 2: 23.2 (9.6)		
				In-Ovation: 27.8 (12.5)		
				Smart Clip: 21.0 (9.5)		
				Speed: 22.4 (6.7)		
Badawi <sup>6</sup>				7.5 (Speed, In-Ovation)		
				15.0 (Damon 2, Smart Clip)		
Sebanc <sup>4</sup>		18.0 (16.6-20.1)		12.4 (10.9-23.7)	6.13 (4.5-8.3)	
McKnight <sup>5</sup>		7.60 (2.80)		8.64 (4.04)	22.30 (4.82)	
		16.50 (5.80)		17.30 (7.56)	45.93 (8.20)	
		30.90 (9.61)		34.70 (15.21)	87.67 (12.02)	
		48.30 (13.71)		57.70 (26.35)	151.83 (15.31)	
Feldner <sup>14</sup>						41.8 (21.8)
						126.4 (25.4)
						219.4 (28.9)
						315.7 (31.8)
						410.8 (33.4)
						499.4 (35.5)
Hixson <sup>8</sup>					8.4 (1.0)	
					9.9 (1.4)	
					8.7 (1.5)	

<sup>i</sup> Value for the Standard rectangular wire (3M/Unitek)<sup>14</sup>, Straight arch (Forestadent)<sup>15</sup> and Edgewise rod wire (Ormco)<sup>16</sup>, other wires slipped in slot therefore, no torque transmission was possible. Torque play was averaged for five brands of archwires per dimension; however, standard deviations could not be averaged.

<sup>ii</sup> No standard deviation (range) recorded.

<sup>iii</sup> Standard deviations in graphic form in the article.

#### KEY

1. Ultratrim (Dentaurum, Ispringen, Germany)
2. MINI-MONO (Forestadent, Pforzheim, Germany)
3. SPEED (Strite Industries, Cambridge, Ontario, Canada)
4. Damon 2 (Ormco Corporation, Orange, CA, USA)
5. Discoverysl (Dentaurum, Ispringen, Germany)
6. (Ormco Corporation, Glendora, CA, USA)
7. In-OvationR (GAC, Bohemia, NY, USA)
8. Smart Clip (3M Unitek, Monrovia, CA, USA)
9. (American Orthodontics, Sheboygan, Wis, USA)
10. (3M Unitek, Monrovia, CA, USA)
11. ('A' Company, Johnson & Johnson, CA, USA)
12. Mini Diamond (Ormco Corporation, Glendora, CA, USA)
13. Remanium (Dentaurum, Ispringen, Germany)
14. Standard rectangular wire (3M Unitek, Monrovia, CA, USA)
15. Straight arch (Forestadent, Pforzheim, Germany)
16. Edgewise rectangular wire (Ormco Corporation, Glendora, CA, USA)
17. Standard arch wire (Ortho Organizers, Carlsbad, CA, USA)

tical and horizontal alignment was maintained between the wire and the bracket during this process. The apparatus consisted of a wire support substructure and alignment dies on either side of a bracket on a dual turntable system secured over the sensor.

Three articles measuring the engagement angle increased archwire twist incrementally<sup>6,11,12</sup>; however, another<sup>2,4,8</sup> took only 4 data points for each clockwise and counterclockwise archwire twist and assumed a linear torque/twist relationship, extrapolating back to the x-axis to calculate the engagement angle. Collection of additional data points would have provided a more accurate curve.

### Other Factors Affecting Measured Torque

According to several authors, the mean engagement angle measured was greater than the theoretical engagement angle because the wires were undersized and had rounded edges.<sup>4,11,15</sup> Another factor that can increase the engagement angle is bracket slot dimension. When torque is applied, notching of the slot walls and additional widening of the slot by up to 0.016 mm can occur.<sup>15</sup> Bracket deformation does not increase the engagement angle but does affect the amount of torque delivered by the archwire twist. Elastic ligatures were found to have a restraining effect on the amount of torque expression, but this effect was of limited duration.<sup>11,12</sup>

### Torque Expression in Self-Ligating Metal Brackets

Two recent studies have tested torque expression in metal self-ligating brackets.<sup>6,13</sup> A comparison may be made between the results of these studies, both of which tested  $0.019 \times 0.025$  inch wire in the 0.022 inch bracket slot; however, Badawi<sup>6</sup> measured the moment of the couple at 24 degrees of labial crown torque, whereas Morina<sup>13</sup> measured the moment of the couple at 20 degrees of labial crown torque. Morina<sup>13</sup> noted no significant difference between the moments generated by the Speed and Damon 2 brackets, whereas Badawi<sup>6</sup> found a significant difference between the 2 brackets. The 2 active, self-ligating brackets in Badawi's study, In-Ovation R (GAC, Bohemia, NY, USA) and Speed, showed similar results to the OMSS studies by Gmyrek<sup>7</sup> and Harzer,<sup>2</sup> whereas the passive self-ligating brackets (Damon 2 and Smart Clip (3M Unitek, Monrovia, CA, USA)) demonstrated lower torsional moments. We would expect to see lower torque values in the OMSS experiments because of torque loss caused by adjacent brackets; however, in the study by Badawi,<sup>6</sup> Damon 2 exhibited a lower moment than in the study by Morina.<sup>13</sup> However, if the standard deviations are considered, this difference is minimized.

The difference between active and passive self-ligating bracket designs was evident. If one considers the range of clinically effective torque to be between 5 and 20 Nmm,<sup>7</sup> this range can be attained at 15 to 31 degrees of torsion with the active self-ligating brackets, and at 22.5 to 34.5 degrees with the passive self-ligating brackets, with a  $0.019 \times 0.025$  inch stainless steel archwire in a 0.022 inch slot.<sup>6</sup>

When the results of torque tests on multiple wires from different companies were averaged, no statistically significant difference was noted in the engagement angle between the 0.018 inch slot and the 0.022 inch slot for the wire sizes tested (0.018 inch slot:  $0.016 \times 0.016$  inch,  $0.016 \times 0.022$  inch,  $0.017 \times 0.025$  inch; 0.022 inch slot:  $0.018 \times 0.025$  inch,  $0.019 \times 0.025$  inch,  $0.021 \times 0.025$  inch).<sup>4</sup> Six studies<sup>4,6,8,11,12,15</sup> measured the engagement angle and therefore can be compared, although differences in wires tested and bracket slot dimensions tested limit the comparison.

### Clinical Relevance of the Results

Clinical research is needed to determine the average amount of tooth movement in degrees produced by the range of torsion resulting in 5 to 20 Nmm of torque expression. With this information, the clinician will be able to calculate the amount of torque moment required in a particular clinical situation. Standardized bracket slot, archwire dimensions and edge bevel are required to accurately predict torque expression.

Overall, these studies indicate that the engagement angle is clinically significant and variable and is affected by archwire dimension and edge shape, as well as by bracket slot dimension. This variable torsional play was found to be greater than the theoretical nominal values published previously by Dellinger<sup>17</sup> and Creekmore.<sup>18</sup> In a 0.018 inch bracket slot, the published nominal values are 9.62<sup>17</sup> according to Dellinger<sup>17</sup> and 16.7<sup>18</sup> according to Creekmore<sup>18</sup> for a  $0.016 \times 0.016$  inch stainless steel archwire, and 1.50<sup>17</sup> according to Dellinger<sup>17</sup> and 2.0<sup>18</sup> according to Creekmore<sup>18</sup> for an  $0.018 \times 0.025$  inch archwire, in contrast to the values found in this systematic review, of 31 degrees and 4.6 degrees, respectively. In a 0.022 inch bracket slot, the published nominal values for play are 11.02<sup>17</sup> according to Dellinger<sup>17</sup> and 14.8<sup>18</sup> according to Creekmore<sup>18</sup> for a  $0.018 \times 0.025$  inch stainless steel archwire and 1.74<sup>17</sup> according to Dellinger<sup>17</sup> and 3.9<sup>18</sup> according to Creekmore<sup>18</sup> for a  $0.021 \times 0.025$  inch archwire; this systematic review found these values to be 18 degrees and 6 degrees, respectively. In light of these findings, clinicians should consider the magnitude of the engagement angle when selecting

bracket prescription and/or torque to be added in the finishing stages.

This systematic review did not attempt to compare self-ligating brackets vs conventional brackets. Nine of the 11 selected articles measured torque expression in conventional brackets, whereas only 2 measured torque expression in self-ligating brackets, and 1 study<sup>13</sup> measured both.

From a clinical perspective, initial proclination or retroclination of the anterior teeth and/or buccal or lingual crown inclination of the posterior teeth will affect the engagement angle and the final position of the teeth. This produces variability in the clinical response to a given archwire and bracket combination.

## CONCLUSIONS

- The measured engagement angle is greater than theoretical values and is highly variable.
- For conventional stainless steel orthodontic brackets with a 0.018 inch stainless steel bracket slot, the engagement angle ranges from 31 degrees with a 0.016 × 0.016 inch stainless steel archwire to 4.6 degrees with a 0.018 × 0.025 inch stainless steel archwire. In a 0.022 inch stainless steel bracket slot, the engagement angle ranges from 18 degrees with a 0.018 × 0.025 inch stainless steel archwire to 6 degrees with a 0.021 × 0.025 inch stainless steel archwire.
- Active stainless steel self-ligating brackets demonstrate an engagement angle of approximately 7.5 degrees, whereas passive stainless steel self-ligating brackets show an engagement angle of approximately 14 degrees with 0.019 × 0.025 inch stainless steel wire in a 0.022 inch stainless steel bracket slot. Clinically effective torque can be achieved with archwire torsion of 15 to 31 degrees for active self-ligating brackets and 22.5 to 34.5 degrees for passive self-ligating brackets with 0.019 × 0.025 inch stainless steel wire in a 0.022 inch stainless steel bracket slot.<sup>6</sup> This difference is due in part to a larger engagement angle in the passive self-ligating brackets compared with the active self-ligating brackets.

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**APPENDIX.** Articles Not Selected From the Initial Abstract Selection List With Reasons for Exclusion

Article	Reason Excluded
Andreasen <sup>1</sup>	Non–stainless steel wires, in vivo study
Bachmann <sup>2</sup>	Graphic data lacking detail
Bai <sup>3</sup>	Language: Chinese
Bantleon <sup>4</sup>	Only auxiliary wires used for torquing
Foglio <sup>5</sup>	Did not measure torque
Foglio <sup>6</sup>	Did not measure torque
Broadbent <sup>7</sup>	Did not measure torque expression
Cassarino <sup>8</sup>	Only auxiliary wires used for torquing
Flores <sup>9</sup>	Did not measure torque expression
Engel <sup>10</sup>	Grey literature (thesis abstract)
Gioka <sup>11</sup>	Review article
Gurgel <sup>12</sup>	Non–stainless steel wires
Isaacson <sup>13</sup>	Did not measure torque expression
Kapur-Wadhwa <sup>14</sup>	Review article
Kesling <sup>15</sup>	Only auxiliary wires used for torquing
Knosel <sup>16</sup>	In vivo study
Meling <sup>17</sup>	Non–stainless steel wires
Meling <sup>18</sup>	Concurrent second-order activation
Meling <sup>19</sup>	Non–stainless steel wires
Nasiopoulos <sup>20</sup>	In vivo study
Owen <sup>21</sup>	Did not measure torque expression
Pandj <sup>22</sup>	In vivo study (clinical trial)
Rosarius <sup>23</sup>	In vivo study
Siatkowski <sup>24</sup>	Did not measure torque expression
Steyn <sup>25</sup>	Did not account for “play,” does not measure pure torque
Ugur <sup>26</sup>	Did not use a torque-measuring device (measured faciolingual crown inclination on models)
Wagner <sup>27</sup>	Measured torsional stiffness, not torque expression (wire property only)
Zhang <sup>28</sup>	Language: Chinese

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