Mathematical Prediction of Torque Loss for Different Archwire Dimensions and Shapes in Different Bracket Slots

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ABSTRACT: Factors contributing to torque expression or crown inclination include archwire cross-sectional diameter, bracket slot dimensions, beveling of archwire edges, bracket deformation, tooth morphology, and bracket positioning. Of these, the archwire cross-sectional diameter and the bracket dimensions are factors that are most standardized in terms of third order torque control. The purpose of this study is to mathematically predict the degree of torque expression realized for different archwire dimensions in different bracket slots. **Methods**: Interaction between bracket slot dimensions, archwire dimensions, and prescription torque are trigonometrically established variables in predicting theoretical torque loss as a conditional equation. The predictive torque expression or loss is determined mathematically by varying these factors in solving the conditional equations. **Results**: There is an average torque loss between 2 to 4 degrees for every size of rectangular archwire reduction in both 0.022 and 0.018 inch wide bracket slots. Slightly more torque loss was shown with a bracket to wire depth of 0.022 inch compared to that of 0.025 inch depth when factoring rectangular archwires. For squared archwires, significant more torque loss was demonstrated compared to rectangular shapes as the size of the archwire is reduced. **Conclusions**: The realization of torque expression is best controlled with the application of larger rectangular shaped archwires placed in brackets with a greater amount of archwire to bracket depth. Clinicians may consider improving third order control by using high torque prescriptions or adding torque to the archwire.

Key words: Torque expression, torque loss, bracket prescriptions, archwire shape, archwire size

Proper anterior and posterior buccolingual inclination or torque are very important factors in establishing correct occlusal relationships, an esthetic smile line, and proper anterior and posterior functional guidance [1]. Many factors contribute to the degree of realized torque expression (or loss) in the interaction between Edgewise archwires and bracket design. These include variations in the width and depth dimensions of the archwire and the bracket slot interface, irregularities in the manufacturing process of brackets that preclude proper engagement, differences in the stiffness of wire alloys engaged to the bracket slot, variations between actual and reported bracket torque values, ligation modes, bracket positioning (particularly on contoured surfaces), and variations in tooth crown morphology or size observed among different populations or even in the same arch [2]. Of these variables, the relationship of the archwire cross sectional diameter and the bracket dimensions are the most important factors that allow control of third order movements. For torque to be maximally expressed, edges of the archwire must engage the Edgewise bracket slot in a "twisting" action. Any dimensional slackness or "slop" in this interactive relationship of the archwire edge to the bracket slot allows rotational slippage of the wire-slot interface and a resultant loss in torque expression. The purpose of this study is to mathematically predict the

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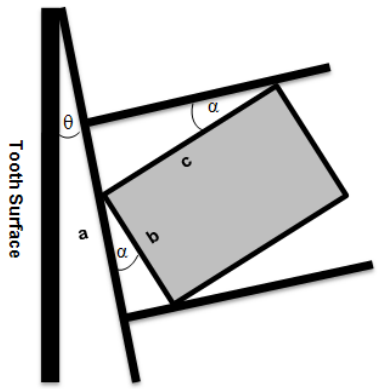
degree of torque expression or loss realized for different archwire shapes (square, rectangular) and archwire sizes in relation to differing width and depth dimensions in Edgewise bracket slots.

MATHEMATICAL METHODOLOGY

In physics, torque is defined as a vector that measures the tendency of a force to rotate an object about some axis [3]. The magnitude of a torque is defined as force times its lever arm [4]. Just as a force is a push or a pull, a torque can be thought of as a twist. In an orthodontic context, torque refers to a controlled change in labio-lingual crown root angulation as well as to the amount of twist applied to an edged archwire in bracket engagement [5]. In order for controlled torque to be expressed as a rectangular or square shaped archwire engages an Edgewise archwire slot, the cross-sectional diagonal dimension of the archwire must be greater than the width of the slot such that the edges of the archwire engage the bracket slot as illustrated in Figure 1. Round wires or rectangular/square wires that are too dimensionally small to engage their edges can spin or sit passively within the bracket slot and result in a lack of torque expression. The interaction between the bracket slot dimensions (a), the archwire dimensions (b, c), and the prescription torque (θ) in the bracket are trigonometrically established variables in predicting theoretical torque loss (α) as a conditional equation.

Figure 1. Diagram of the archwire / bracket slot relationship: prescription torque (θ), theoretical torque loss (α) due to different archwire dimensions (b: wire width and c: wire depth), and bracket slot (a).



From the diagram in Figure 1, a trigonometrical relationship between archwire and bracket slot dimensions establishes a formula for determining theoretical torque expression or loss. That equation is:

$$a = b\cos\alpha + c\sin\alpha$$

By rearranging the variables, a quadratic equation is derived as follows:

$$(b^2 + c^2)\sin^2\alpha - 2ac\sin\alpha + (a^2 - b^2) = 0$$

This quadratic equation in turn gives a set of solutions:

$$\sin\alpha = \frac{ac \pm b\sqrt{b^2 + c^2 - a^2}}{(b^2 + c^2)}$$

with the condition that:

$$0 \leq \sin\alpha \leq 1$$

By solving these conditional equations, the theoretical torque loss (α) is calculated by [6, 7]:

$$\alpha = \sin^{-1}\left[\frac{ac \pm b\sqrt{b^2 + c^2 - a^2}}{(b^2 + c^2)}\right] \quad (*)$$

Torque expression is always less than or equal to the prescription torque of the bracket due to the ability to clinically "fill the slot" with an edged archwire. This is called effective torque and is calculated as:

$$(\theta - \alpha)$$

There are three different scenarios that can occur when the prescribed equation (*) is solved for α:

1. If $0 \leq \alpha < \theta$, the width of the bracket slot is always smaller than the cross-sectional diagonal dimension of the archwire, effective torque is expressed as (θ - α).

2. If $\theta \leq \alpha \leq \beta$, where β is the angle at which the width of the bracket slot is equal to the cross-sectional diagonal dimension of the archwire determined by:

$$a = \sqrt{b^2 + c^2}$$

With this condition, there is no effective torque expressed. The archwire engages in the bracket slot passively; but has no spinning or twisting effect.

3. If $\alpha > \beta$, the width of the bracket slot is greater than the cross sectional diagonal dimension of the archwire. The archwire can spin or passively stay in the bracket slot and torque control is totally lost.

The prescribed mathematical formula was utilized to determine for rectangular and square shaped archwires of varied standard dimensions the effective torque expression (i.e. torque loss) realized if interfaced with rectangular shaped Edgewise bracket slots of 0.022 inch and 0.018 inch vertical width and 0.022 and 0.025 inch depths respectively.

RESULTS

Theoretical torque loss for different dimensional rectangular and squared archwires in association with placement in either 0.022 or 0.018 inch bracket slots with depths of 0.022 and 0.025 inches are shown in Tables 1 and 2, respectively. Graphic presentation of the degrees of torque loss between the varying archwire sizes for different rectangular and squared archwires in 0.022 and 0.018 inch bracket slots, again with varied depths of 0.022 and 0.025 inches; are shown in Figures 2 and 3, respectively. For rectangular shaped archwires, there is an average torque loss between 2 to 4 degrees for every size of archwire reduction in width for both bracket slots of 0.022 and 0.018 inches. Slightly more torque loss is expressed when the wire-bracket depth is at a 0.022 inch wire depth compared to that of 0.025 inch wire depth. For square-shaped archwires, significant more degrees of torque loss are expressed as the archwire size dimensions are reduced. Thus, crown torque is expressed most effectively with the use of rectangular shaped archwires that more closely approximate the engaged bracket widths and that exhibit a concurrent larger archwire depth to "more fully fill" the bracket slot.

Table 1: Theoretical torque loss for different rectangular (0.022 and 0.025 inch wire depth) and squared archwires in 0.022 inch bracket slot

Wire size (in)	*Slot size (in)*	*Calculated torque loss α (o)*
0.022 x 0.022	0.022	0.00
0.021 x 0.021	0.022	2.80
0.020 x 0.020	0.022	6.06
0.019 x 0.019	0.022	9.96
0.018 x 0.018	0.022	14.80
0.017 x 0.017	0.022	21.22
0.016 x 0.016	0.022	31.48
0.022 x 0.022	**0.022**	**0.00**
0.021 x 0.022	**0.022**	**2.66**
0.020 x 0.022	**0.022**	**5.45**
0.019 x 0.022	**0.022**	**8.37**
0.018 x 0.022	**0.022**	**11.42**
0.017 x 0.022	**0.022**	**14.61**
0.016 x 0.022	**0.022**	**17.95**
0.015 x 0.022	**0.022**	**21.43**
0.014 x 0.022	**0.022**	**25.06**
0.013 x 0.022	**0.022**	**28.84**
0.022 x 0.025	0.022	0.00
0.021 x 0.025	0.022	2.33
0.020 x 0.025	0.022	4.75
0.019 x 0.025	0.022	7.24
0.018 x 0.025	0.022	9.82
0.017 x 0.025	0.022	12.48
0.016 x 0.025	0.022	15.21
0.015 x 0.025	0.022	18.03
0.014 x 0.025	0.022	20.91
0.013 x 0.025	0.022	23.85

Figure 2: Torque loss (degrees) between archwire sizes for different rectangular and squared archwires in 0.022 inch bracket slot.

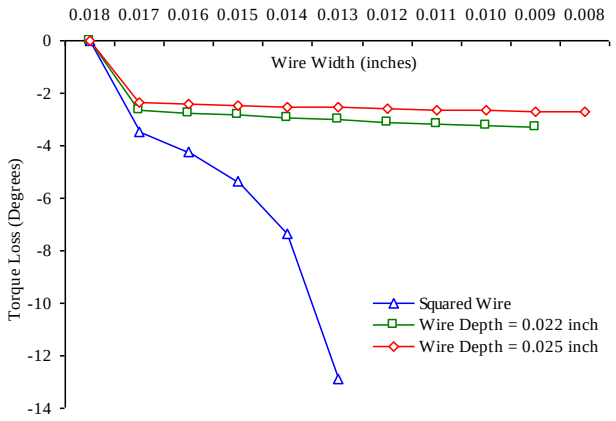
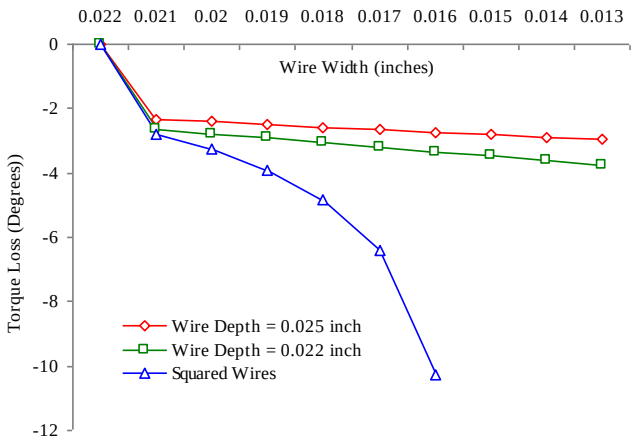


Table 2: Theoretical torque loss for different rectangular (0.022 and 0.025 inch wire depth) and squared archwires in 0.018 inch bracket slot.

Wire size (in)	*Slot size (in)*	*Calculated torque loss α (o)*
0.018 x 0.018	0.018	0.00
0.017 x 0.017	0.018	3.48
0.016 x 0.016	0.018	7.70
0.015 x 0.015	0.018	13.05
0.014 x 0.014	0.018	20.39
0.013 x 0.013	0.018	33.26
0.018 x 0.022	**0.018**	**0.00**
0.017 x 0.022	**0.018**	**2.65**
0.016 x 0.022	**0.018**	**5.40**
0.015 x 0.022	**0.018**	**8.25**
0.014 x 0.022	**0.018**	**11.18**
0.013 x 0.022	**0.018**	**14.20**
0.012 x 0.022	**0.018**	**17.30**
0.011 x 0.022	**0.018**	**20.47**
0.010 x 0.022	**0.018**	**23.70**
0.009 x 0.022	**0.018**	**26.97**
0.018 x 0.025	0.018	0.00
0.017 x 0.025	0.018	2.32
0.016 x 0.025	0.018	4.71
0.015 x 0.025	0.018	7.16
0.014 x 0.025	0.018	9.67
0.013 x 0.025	0.018	12.23
0.012 x 0.025	0.018	14.83
0.011 x 0.025	0.018	17.48
0.010 x 0.025	0.018	20.15
0.009 x 0.025	0.018	22.84
0.008 x 0.025	0.018	25.55

Figure 3: Torque loss (degrees) between archwire sizes for different rectangular and squared archwires in 0.018 inch bracket slot.



DISCUSSION

Correct torque or crown inclination is particularly critical in establishing an esthetic smile line, proper anterior and posterior guidance, and a solid class I relationship [1]. In order for torque to be fully expressed, an archwire must completely fill the bracket slot. It is very seldom that a bracket slot is fully filled and as a result the anterior teeth often lingually tip due to torque loss. It is important to understand this potential for torque loss with differing archwire and bracket dimensions, especially during retraction of anterior teeth in extraction cases.

Results from different plots of torque loss show that torque expression is a function of the interaction between wire width, wire depth, bracket width, and bracket depth. The closer the wire to bracket width interaction along with a larger wire/bracket depth, the better the torque control (Figure 2 & 3). Of three different width and depth combinations of archwire and bracket size studied, only squared archwires potentially spin in the bracket slot if the wire is small enough. When this happens, torque control is totally lost and squared wires behave similar to round wires. In the case of rectangular archwires (0.022 and 0.025 inch wire depth), wires do not spin in the bracket slot due to the diagonal dimensions of the wire being greater than the bracket slot dimension.

Sebanc evaluates the variability of effective root torque as a function of edge bevel on different types of stainless steel, nickel-cobalt, and beta titanium archwires with different bracket slots of 0.022 and 0.018 inch size. He found that the average edge bevel contribution to the measured deviation angle varied from 0.2º to 12.9º for the various wire-bracket groups, and the average percentage contribution from 3 to 63%. The edge bevel contribution to the deviation angle was higher for stainless steel wires than for nickel-cobalt wires. The highest deviation angles and edge bevel contributions were found for beta titanium wires [8]. Another factor that can contribute to torque loss is variations in the size of the bracket slot. According to A.C. Cash, the bracket slot dimensions were oversized by 5% - 24% compared to those stated by the manufacture [9]. An equally important factor that contributes to torque loss is variations in the dimensions of the archwire.

A study by Kusy and Whitley shows that 30% of 26 archwires were larger than the stated sizes, the rest were smaller than advertised [10, 11]. Thus, the use of oversized bracket slots and undersized archwires may exaggerate the degrees of torque loss. Other factors that can further contribute to torque loss include irregularities from the manufacturing process of brackets that may preclude proper engagement, variations between actual and reported bracket torque values, ligation modes, bracket placement errors, and variations in tooth crown morphology or size observed among different populations or even in the same arch [2]. These factors can contribute to the loss of torque.

CONCLUSIONS

1. For rectangular archwires (0.022 or 0.025 inch wire depth), there is an average torque loss between 2 to 4 degrees for every size of archwire reduction in either 0.022 or 0.018 inch bracket slots with slightly more torque loss on 0.022 inch wire depth compared to that of 0.025 inch wire depth.

2. For squared archwires, significantly more torque loss occurs as the size of the archwire is reduced.

3. Crown torque is controlled most effectively with larger archwire to bracket depth.

Because there are many variables that contribute to torque loss clinically, it is recommended that clinicians should use the high torque prescription or add torque to the archwire to offset these variations.

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