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An Indirect Torque Loss Evaluation in Ceramic Brackets

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Abstract

Objective: An indirect torque loss evaluation between the slot height and wire dimensions in different ceramic conventional and self-ligating brackets manufacturers. Material and Methods: 30 slot heights of five upper right incisors from 04 commercially available bracket systems were analyzed using a profile projector and 40 stainless steel wires from 04 different manufacturers (width, height and the edge bevel) were measured with a digital micrometer, and a vision-measuring machine. A mathematical formula was used to compare the results of the actual torque loss values versus the theoretical. Results: all brackets were oversized and varied from 0.598 mm (the highest mean) to 0.566 mm (the lowest mean). The real height of the wires differed from those stated by the manufacturers falling within the range – 6.68% and + 0.39% and the width + 0.13% to + 0.93%. Due to the huge variety of the edge bevel, there has been a difference between the actual torque loss and the nominal from 9.95° to 15.56°. Conclusions: torque loss is related to the differences shown between the slot heights, wire dimensions, consequently, affecting orthodontics movements that require more torque control like finishing procedures.

Keywords: Torque; Orthodontic Brackets; Orthodontic Wires

Introduction

The twisting of the wire within the bracket slot produces a physical force moment measured in Newton/mm – Nmm in which will represent the buccolingual crown/root inclination of a tooth and a rotation perpendicular to its long axis. This torsion is called torque or third-order movement and the angle to which the wire has been twisted in degrees is the torque angle [1-4].

Torque is essential in establishing the correct buccolingual positioning of the tooth, inter-arch relationship, proper esthetic smile line and anterior guidance [3-5]. However, some factors may influence torque expression, such as, the amount of force applied, the size and slot geometry, arch wire dimensions, like, the height, width and the edge bevel [1,5-16]. Thus, leading to a lack of contact between the wire and the bracket slot resulting in a loss, which is called "torque loss" or "torque play" [1,2,4,8,13,15-17].

Torque loss may directly alter the incisors positioning, compromising orthodontic finishing procedures. As a result, some researchers began to question if, indeed, there was a difference between what was stated from manufacturers (brackets slots and wires´ tolerances) and if so, what side effects might arise during the treatment. Thus, experiments demonstrated that orthodontic materials could present different dimensions from what was expected and hence having a negative effect on torque expression, consequently, increasing torque loss [1,6,9-17]. Since then, several methods have been used to evaluate orthodontic materials, like, a digital micrometer [1,11,15], to assess the height and width of the wire; an electronic microscope [1,6,10,13,18], a profile projector [11] and a stereomicroscope [9] to measure the slot height. Considering the edge bevel, a vision-measuring machine (optical microscope) was used to gauge the four corners of the wire [6]. Furthermore, to evaluate the torque expression and torque loss (in a direct way), researchers have been using a torque measurement device in association with a lathe [2,3,7] and an orthodontic measurement system simulation [5,14,19], OMSS. On the other hand, to determine the torque loss in an indirect form, mathematical formulas were developed to analyze if the edge bevels [1,6] could influence in this factor [9,12,15,20].Thus, due to the high importance of the subject and the increase in the number of patients searching for esthetics, there was a huge interest, not only professional, but also commercial, in developing different types of ceramic brackets, to be considered a very resistant esthetic material and widely used in orthodontic practice [5,8-9,11,21]. However, until now, there is little information from experiments that evaluated torque loss in an indirect form considering the slot height, wire dimensions and the edge bevel. Hence, the objective of this study was to indirectly assess the torque loss in different ceramic conventional and self-ligating brackets manufacturers.

Materials and Methods

The study consisted of, an experimental group 1 evaluating twenty slot heights of commercially available self-ligating ceramic brackets represented by the upper right central incisor (0.022 inch) from 3M/Unitek (Clarity SL®); GAC, (Inovation C®), American Orthodontics, (Empower Clear®) and Forestadent, (Quicklear®). Furthermore, an experimental group 2 analyzing ten slot heights of the upper right incisor, conventional ligated ceramic brackets, 3M/Unitek (Clarity Conventional®, Clarity Advanced®). Forty stainless steel archwires (0.019" X 0.025") from four different manufacturers, 3M/Unitek, Ortho Organizers, Morelli and Abzil/3M, were chosen for the assessment of the dimensions: height, width and the edge bevel (Table 1).

Ceramics Brackets*	Manufacturer	Pescription/Charac-teristics	Torque/Tip
Inovation C®	GAC	Roth/active	+ 12º + 5º
Quicklear®	Forestadent	Roth/passive	+ 12º + 5º
Clarity SLTM	3M/Unitek	MBT/passive	+ 17º + 4º
Empower Clear®	American Orthodontics	Roth/active-passive	+ 12º + 5º
Clarity Adv®	3M/Unitek	Roth/conventional	+ 12º + 5º
Clarity Conv®	3M/Unitek	Roth/conventional	+ 12º + 5º
Archwires	**Manufacturer**	**Material**	**Size**
USA	3M/Unitek	Stainless steel	0.019" × 0.025"
USA	Ortho Organizers	Stainless steel	0.019" × 0.025"
BRAZIL	Abzil/3M	Stainless steel	0.019" × 0.025"
BRAZIL	Morelli	Stainless steel	0.019" × 0.025"

*3M/Unitek, Monrovia, Ca/USA; GAC, York, Philadelphia, USA; American Orthodontics, Sheboygan, Wisconsin, USA; Forestadent, Pforzheim, Germany
** 3M/Unitek, Monrovia, CA/USA; Ortho Organizers, San Marcos, CA/USA; Morelli, Sorocaba, SP/Brazil; Abzil/3M, São José do Rio Preto/SP, Brazil

Table 1: Brackets and archwires investigated in the Study

Figure 1: Profile Projector

Figure 2: Bracket slot positioning and references axis lines, X (horizontal) and Y (vertical)

Brackets slot heights were measured using a Profile Projector [11] (Mitutoyo Profile Projector), PJ–A 3.000, Japan (Figure 1). The samples were, randomly, chosen and each bracket slot was positioned on an acrylic pedestal linked to a 90^{o} arm, so that, all self-ligating system doors remained open during the measurements. The Profile Projector had two reference axis lines, horizontal (X) and vertical (Y) that guided and kept the correct alignment of the bracket slot while being assessed (Figure 2). So, after being positioned, the bracket slot image was projected and magnified (20 times) on the screen, thus slot height was gauged on the horizontal wall and then, recorded. The digital readout protractor facilitated the measurements. The same operator carried out the study evaluations and repeated after 45 days.

Ten arch wires of each manufacturer were cleaned (70% of alcohol), randomly selected, and the average of the terminal portion of each wire (the most reliable part), approximately 10 mm, was used for measurement purposes [1,6,17]. To test the height and width of the wires, a digital micrometer (0.001 mm, Mitutoyo, Japan) was used (Figure 3) and two operators measured the samples. The same procedure was repeated after 45 days, inter, intra-examiner reliability, reproducibility of the study and method error were analyzed.

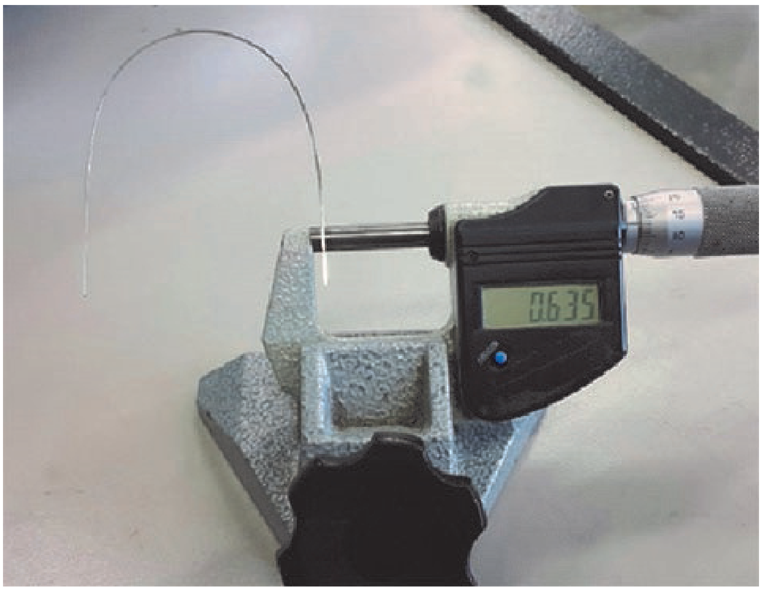


Figure 3: Digital micrometer

To evaluate the four corners of the edge bevel and, consequently, calculate the radius, a vision-measuring machine [6] (optical microscope, Quick Scope, Mitutoyo, Japan) was used (Figure 4). Each arch wire was placed in a proper acrylic pedestal, so that, the ending part of the wire remained under an optical microscope lens and the image was captured, processed and projected on the computer screen. The examiner marked four points corresponding to the central and terminal parts of the curve, in the edge bevel, and, consequently, using digital image analysis software, the radius of the curvature was found (Figure 5). After 45 days, the same operator tested all samples.

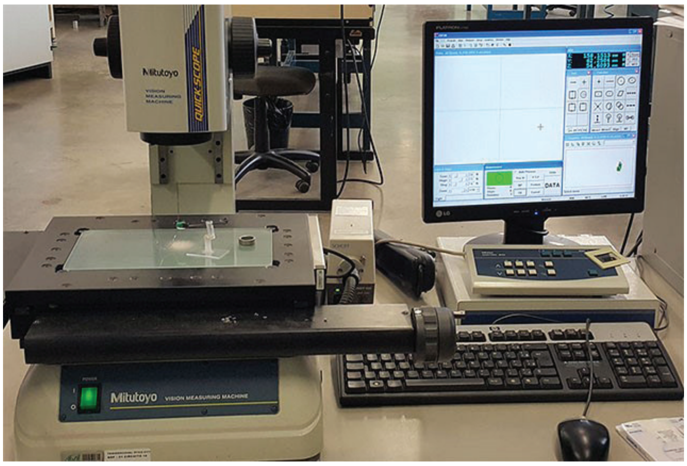


Figure 4: Vision-measuring machine

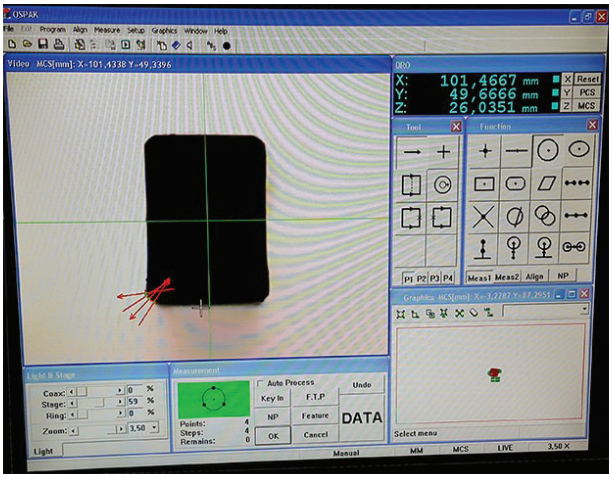
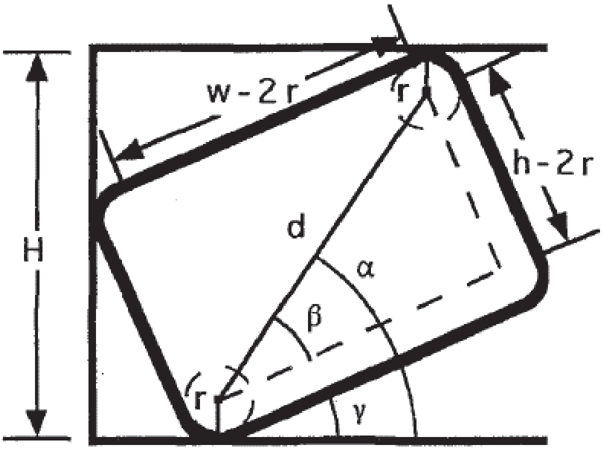


Figure 5: Processed image showing the four points of the edge bevel´s curvature

A mathematical formula proposed by Meling *et. al* [1], was used to first determine the diagonal of the wires, then, the actual value of torque loss from all combinations of brackets slot heights and arch wires dimensions. (Figures 6 and 7).



$$d = \sqrt{(w-2r)^2 + (h-2r)^2}$$

Figure 6: Meling *et. al* diagram; (H) slot height; (w) wire width; (h) wire height; (r) radius of the edge bevel; (d) diagonal

$$\gamma = arcsen\frac{H-2r}{d} - arcsen\frac{h-2r}{d}$$

Figure 7: Torque loss formula (γ)

The outcomes were compared with those stated by the ISO 27020:2010 European Committee for Standardization (NSAI Standard). The correlation coefficient p was chosen ($p > 0.01$) as a significance level of 1% and for the statistical analysis; a Statistical Package for the Social Sciences (SPSS) 2.2 version-Windows was used. The variables were expressed as means Maximum/Minimum and Standards Deviations (SD) and the normality of the data was verified using the Shapiro-Wilk test. Since the normality was confirmed for all variables, that is, having a normal distribution, $p > 0.01$, parametric test, like, Student's *t* test, was used for checking the differences between both measurements and the reference value, in an independent sample, or, intra, inter-examiner reliability, for paired samples.

Results

Student´s test (Table 2) between both measurements and the same examiner demonstrated that all values found were higher than 0.01 (p > 0.01, significance mean) showing a normal distribution within the measurements. When comparing to the ISO 27020:2010 European Committees for Standardization (NSAI Standard), the slot height should have a nominal size of 0.559 mm, but the results demonstrated that there were differences between the samples. Slot heights were oversized at a range of 0.566 mm (+1.2%) for Clarity Conventional (3M/Unitek) to 0.598 mm (+ 6.9%), Clarity Advanced (3M/Unitek). Although, American Orthodontics brackets´ mean did not show any significance difference in relation to the nominal size ($p = 0.010$) (Table 3).

Brackets	1st Measurement		2nd Measurement		p (1) (T Student)
	Mean	SD	Mean	SD	
3M/UNITEK CLARITY ADV.	0.598	0.0072	0.591	0.0098	**0.374**
3M/UNITEK CLARITY CONV	0.566	0.0025	0.564	0.0051	**0.631**
FORESTADENT	0.590	0.0042	0.590	0.0070	**0.951**
AMERICAN ORTHODONTICS	0.567	0.0040	0.571	0.0024	**0.083**
3M UNITEK/ CLARITY SL	0.577	0.0043	0.585	0.0086	**0.065**
GAC	0.568	0.0028	0.570	0.0048	**0.523**

(1) Student t test Significance value – paired samples – p value

Table 2: First and second slot heights measurements outcomes (n=6)

Brackets	Measurements(1)		Mean	SD	IC 99%	Reference (2) value 0.559 mm	P(3)
	Min	Max					
3M/UNITEK CLARITY ADV.	0.585	0.602	**0.598**	0.0072	0.583-0.613	**+ 6.9 %**	0.001
3M/UNITEK CLARITY CONV	0.562	0.568	**0.566**	0.0025	0.560-0.571	**+ 1.2 %**	0.004
FORESTADENT	0.586	0.596	**0.590**	0.0042	0.582-0.599	**+ 5.6 %**	0.001
AMERICAN ORTHODONTICS	0.561	0.572	**0.567**	0.0040	0.559-0.576	**+ 1.5 %**	0.010
3M UNITEK/ CLARITY SL	0.573	0.584	**0.577**	0.0043	0.568-0.586	**+ 3.2 %**	0.001
GAC	0.566	0.573	**0.568**	0.0028	0.563-0.574	**+ 1.7 %**	0.002

(1) Mean - Minimum/Maximum measurements values
(2) Reference Value 0.559 mm - ISO 27020:2010 (NSAI Standard)
(3) Students' t test significance value – reference value

Table 3: Slot heights measurements

Wires-stainless steel	Mean(1)	SD	IC 99%	Diference: Mean-Ref	% Reference (2) value	p (3)(T Student)
3M/Unitek						
0.019”	**0.4813**	0.0013	0.4799-0.4827	-0.0017	**-0.35%**	0.003
0.025”	**0.6358**	0.0018	0.6340-0.6376	0.0008	**+0.13%**	0.182
Morelli						
0.019”	**0.4860**	0.0029	0.4831-0.4889	0.0030	**+0.62%**	0.009
0.025”	**0.6349**	0.0013	0.6336-0.6362	-0.0001	**-0.02%**	0.811
Ortho Organizers						
0.019”	**0.4524**	0.0018	0.4506-0.4542	-0.0306	**-6.68%**	0.001
0.025”	**0.6370**	0.0034	0.6335-0.6405	0.0020	**+0.31%**	0.093
Abzil/3M						
0.019”	**0.4849**	0.0016	0.4833-0.4865	0.0019	**+0.39%**	0.004
0.025”	**0.6409**	0.0039	0.6369-0.6449	0.0059	**+0.93%**	0.001

(1) Mean measurements values (mm)
(2) Reference Value - ISO 15841:2006 (0.483 mmm X 0.635 mm)
(3) Student t test significance value

Table 4: Results of the dimensions of the archwires (n = 4)

Using Shapiro´s-Wilk test in wires dimensions outcomes (inter and intra-examiner measurements), the significance values (*p*) were higher than 0.010 in all measurements, as a result, the samples had a normal distribution for a level of 1%. As demonstrated in (Table 4) and according to ISO 15841:2006 (National Standards Authority of Ireland) the 0.019" X 0.025" stainless steel wires should measure 0.483 mmm X 0.635 mm. related to the stated values, there were significant differences in real dimensions from the ideal. In the study, of the four archwires considered, the height was greater than claimed in 2 cases and smaller in 2. The width was greater than ideal in 3 and smaller in 1. The most oversized was Abzil/3M (height +0.39%, width +0.93%) and the most undersized Ortho Organizers (height – 6.68%).

Analyzing the four corners of the wires to ascertain the edge bevel´s radius, a large variety was demonstrated in each one, expressed by the differences found in the standard deviations mean values, due to shape, and irregularities presented. Therefore, Morelli had the lowest mean value (0.071 mm), followed by Ortho Organizers (0.072 mm), 3M/Unitek (0.075 mm) and Abzil/3M (0.106 mm) (Table 5).

0.019" X 0.025"	Min	Max	Mean	IC 99%	SD
3M/Unitek	0.065	0.084	**0.075**	0.069-0.081	0.006
Morelli	0.060	0.090	**0.071**	0.060-0.082	0.011
Ortho Organizers	0.054	0.083	**0.072**	0.061-0.084	0.011
Abzil	0.077	0.117	**0.106**	0.090-0.122	0.015

Table 5: Results of the radius of the edge bevels, mm (n = 6)

After having found all dimensions means values for slot height (H); wire height (h), width (w), the radius of the edge bevel (r), the diagonal (d) and using Meling *et al*. formula [1], torque loss (γ) values were determined and the results were shown in (Table 6). All values found demonstrated that the real torque loss is greater than the ideal at a range between + 9.95º Clarity Conventional X Morelli and + 19.30º Clarity Advanced X Ortho Organizers.

Mean values	Wires			3M/Unitek	Morelli	Ortho Organizers	Abzil/3M
	width	w		0.635	0.634	0.637	0.640
	height	h		0.481	0.486	0.452	0.484
	radius	r		0.07	0.07	0.07	0.10
	diagonal	d		0.58	0.60	0.58	0.50
Brackets slots							
Clarity Conv	Height	H	0.566				
	Torque loss	Y		**10.74**	**9.95**	**14.50**	**11.67**
Clarity Adv	Height	H	0.598				
	Torque loss	Y		**15.34**	**14.43**	**19.30**	**16.94**
Forestadent	Height	H	**0.590**				
	Torque loss	Y		**14.15**	**13.28**	**18.05**	**15.57**
Am Orthod	Height	H	0.567				
	Torque loss	Y		**10.87**	**10.09**	**14.64**	**11.82**
Clarity SL	Height	H	0.577				
	Torque loss	Y		**12.27**	**11.45**	**16.10**	**13.42**
GAC	Height	H	**0.568**				
	Torque loss	Y		**11.01**	**10.22**	**14.79**	**11.98**

Table 6: Torque loss (γ) values according to Meling *et al*. formula (degrees)

Discussion

Researchers, professionals and manufacturers have been questioning if there was a relationship between the stated orthodontic dimensions and torque expression, therefore, affecting torque loss [6,9,12-17]. Following this context, it is mandatory to know the nominal torque loss, and their tolerance limits. Thus, the professionals can be aware of what to use in clinical practice for a better performance and treatment control. So, in 2002, Gmyrek *et al*. [14] demonstrated, that for a combination of a stainless steel wire (0.019" X 0.025") and a bracket slot, (0.022 inches), the nominal torque loss should be 7.2º, however, in this study, the outcomes did not show that. The torque loss values falling within the range + 9.95° and +19.30°, which proved that there was a variation in orthodontic materials dimensions, slot height, width, height and the four corners of the wires´ edge bevel, hence interfering in the radius value. Previous and current investigations, although using different methods to evaluate slot heights, in different material, (metallic conventional and self-ligating brackets and plastic conventional brackets), like an electronic microscope, a Zeiss Axioscope and measuring leaf gauges, corroborated with our findings and demonstrated differences between what was claimed by the manufacturer and its real value [1,8-10,12,15,18]. Self-ligating metallic brackets had a slot height mean 0.599 mm [12], whereas in the study, was 0.566 mm but both were oversized in comparison to Reference

Value 0.559 mm - ISO 27020:2010. According to the percentage mean, the data reported increased in dimension from 5% up to 12% to 24%, in metallic conventional and plastic conventional, respectively [8]. The study's outcomes evidenced a percentage from +1.2% Clarity Conventional up to + 6.9% Clarity Advanced (both conventional ligated and from group 2) and from +1.5% American Orthodontics to + 3.2% Clarity SL (both self-ligating and from group 1). The increase in the slot height associated to a great variety in wire dimensions, such as, height (3M/Unitek, - 0.35%; Ortho Organizers, - 6.68%, Morelli + 0.62% e Abzil/3M +0.9%) and the edge bevel´s radius (3M/Unitek 0.075 mm; Ortho Organizers 0.072 mm; Morelli 0.071 mm and Abzil/3M 0.106 mm) had a direct effect on the torque loss. Studies that used similar methodology with a digital micrometer, found differences in torque loss values from + 5° to + 2.5°, although archwires had different dimensions (for a 0.018 slot) from this study, it was proved that these variations were due to material dimensions and the edge bevel [1]. Thus, in daily practice, it would imply an anterior torque loss because of this lack of quality control from the manufacturers [1,9]. Other experiments, that also used formulas but evaluating different materials (Nitinol, Copper NiTi), concluded that the real torque loss differed from the ideal from + 0.98° to + 17.38° and were due to the edge bevel, arch wire dimensions and material [6]. Even though, Sebanc *et al.* [15] used a mathematical formula to calculate the torque loss, but without including the radius of the edge bevel in the equation, it was reported that that the real torque loss was bigger than the nominal from 0.2° à 12.9°. In addition, it was assumed that not only the dimensions of orthodontic materials influenced the torque loss, but also the edge bevel. This conforms to values reported by Joch *et al.* [12] who also used a calculus, without measuring the edge bevel, and hence concluding, that the presence of beveled edges increased torque loss. Furthermore, Lee et al. [9] using Meling´s formula, to indirectly assess the torque loss in ceramic self-ligating brackets, but with different wires, corroborated with this experiment. The findings showed that Empower Clear X .016" X.022" TMA wire had the largest amount of torque loss, assuming that the differences in slot bases and tops were not accurate, having an important role in increasing the theoretical play in all combinations.

The present study supported those findings reported and with the fact that the differences in material dimensions and the radius of the wires´ edge bevel influences in the increase of torque loss [6].

Clinical Implications

It is the professionals' duty to know and properly choose the type of material they are about to use to achieve Orthodontic expertise. On the other hand, manufacturers should provide more information about their products, so that clinicians would estimate better results for the treatment. Torque expression is fundamental to the correct buccolingual inclination, proper smile line and adequate occlusal relationship [3,4].

The outcomes demonstrated differences between the real orthodontic material dimensions and what was stated by manufacturers, thus causing an increase in the torque loss. Despite using preadjusted brackets, this loss could clinically compromise orthodontic movements, mainly the ones that require more control, as well as, incisors retraction, intramaxillary elastics and combined with mandibular advancement appliances. As a result leading to an inappropriate tooth inclination and treatment instability. However, this *in vitro* study did not evaluate torque expression, only the loss, in an indirect form, which is left as a suggestion for a next *in vitro* experiment or a randomized clinical trial. Knowing that other factors could influence torque expression, like, the amount of force applied, tooth morphology, malocclusion, deformation and warping of the wires, slot geometry and type of brackets ligation, and with these factors, other findings could arise and as a result, professionals would have more predictability and quality control of orthodontic movements.

Conclusion

- Differences in orthodontic materials of stated dimensions are responsible for increasing torque loss.
- Real torque loss is greater than the ideal.
- The more variations shown in the four corners of the wire, the highest torque loss was found.

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References

1. Meling TR, Ødegaard J, Seqner D (1998) On the bracket slot height: A methodologic study. Am J Orthod Dentofacial Orthop 4: 387-93.

2. Badawi HM, Toogood RW, Carey JP, Heo G, Major PW (2008) Torque expression of self-ligating brackets. Am J Orthod Dentofacial Orthop 5: 721-8.

3. Archambault A, Lacoursiere R, Badawi H, Major PW, Carey J, et al. (2010) Torque Expression in Stainless Steel Orthodontic Brackets A Systematic Review. Angle Orthod 1: 201-10.

4. Major TW, Carey JP, Nobes DS, Heo G, Major PW (2011) Mechanical effects of third order movement in self-ligated brackets by the measurement of torque expression. Am J Orthod Dentofacial Orthop 1: 31-44.

5. Morina E, Eliades T, Pandis N, Jäger A, Bourauel C (2008) Torque expression of self-ligating brackets compared with convencional metallic, ceramic, and plastic brackets. Eur J Orthod 3: 233-8.

6. Lombardo L, Arreghini A, Bratti E, Mollica F, Spedicato G, et al. (2015) Comparative analysis of real and wire-slot play in square and rectangular archwires. Angle Orthod 5: 848-58.

7. Major TW, Carey JP, Nobes DS, Heo G, Melenka GW, et al. (2013) An investigation into the mechanical characteristics of select self-ligated brackets at a series of clinically relevant maximum torquing angles: loading and unloading curves and bracket deformation. Eur J Orthod 6: 719-29.

8. Cash AC, Good AS, Curtis RV, McDonald F (2004) An Evaluation of Slot Size in Orthodontic Brackets --are standards as expected? Angle Orthod 4: 450-3.

9. Lee Y, Lee D-Y, Kim Y-Ji R (2016) Dimensional accuracy of ceramic self-ligating brackets and estimates of theoretical torsional play. Angle Orthod 86: 804-9.

10. Attia KH, Elkordy SA, Elkoussy M, Abouelezz AM (2018) Are self-ligating brackets' slots dimensions accurate. Int Orthod 4: 613-22.

11. Nishio C, Mendes Ade M, Almeida MA, Tanaka E, Tanne K, et al. (2009) Evaluation of esthetic brackets resistance to torsional forces from the archwire. Am J Orthod Dentofacial Orthop 1: 42-8.

12. Joch A, Pichelmayer M, Weiland F (2010) Bracket slot and archwire dimensions: manufacturing precision and third order clearance. J Orthod 4: 241-9.

13. Brown P, Wagner W, Choi H (2015) Orthodontic bracket slot dimensions as measured from entire bracket series. Angle Orthod 4: 678-82.

14. Gmyrek H, Bourauel C, Richter G, Harzer W (2002) Torque capacity of metal and plastic brackets with reference to materials, application, technology and biomechanics. J Orofac Orthop 2: 113-28.

15. Sebanc J, Brantley W, Pincsak J, Conover JJ (1984) Variability of effect root torque as a functional of edge bevel on orthodontic archwires. Am J Orthod Dentofacial Orthop 1: 43-51.

16. Dalstra M, Eriksen H, Bergamini C, Birte M (2015) Actual versus theoretical torsional play in conventional and self-ligating bracket systems. J Orthod 2: 103-13.

17. Ødegaard J, Meling E, Meling T (1994) An evaluation of the torsional moments developed in orthodontic applications. An in vitro study. Am J Dentofacial Orthop 4: 392-00.

18. Brauchli LM, Steineck M, Wichelhaus A (2012) Active and passive self-ligation: a myth? Part I: torque control. Angle Orthod 4: 663-9.

19. Katsikogianni EN, Reimann S, Weber A, Karp J, Burauel C (2015) A comparative experimental investigation of torque capabilities induced by conventional and active, passive self-ligating brackets. Eur J Orthod 4: 440-6.

20. Kusy RP (2004) Influence on binding of third-order torque to second-order angulation. Am J Orthod Dentofacial Orthop 6: 726-32.

21. MCKnight MM, Jones SP, Davies EH (1994) A study to compare the effects of simulated torquing forces on pre-adjusted orthodontic brackets. Br J Orthod 4: 359-65.