

# Frictional Resistance in Self-Ligating Orthodontic Brackets and Conventionally Ligated Brackets

## *A Systematic Review*

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### ABSTRACT

**Objective:** To compare the amount of expressed frictional resistance between orthodontic self-ligating brackets and conventionally ligated brackets in vitro as reported in the literature.

**Methods:** Several electronic databases (Medline, PubMed, Embase, Cochrane Library, and Web of Science) were searched without limits. In vitro studies that addressed friction of self-ligating brackets compared with conventionally ligated brackets were selected and reviewed. In addition, a search was performed by going through the reference lists of the selected articles to identify any paper that could have been missed by the electronic searches.

**Results:** A total of 70 papers from the electronic database searches and 3 papers from the secondary search were initially obtained. After applying the selection criteria, only 19 papers were included in this review. A wide range of methods were applied.

**Conclusions:** Compared with conventional brackets, self-ligating brackets produce lower friction when coupled with small round archwires in the absence of tipping and/or torque in an ideally aligned arch. Sufficient evidence was not found to claim that with large rectangular wires, in the presence of tipping and/or torque and in arches with considerable malocclusion, self-ligating brackets produce lower friction compared with conventional brackets. (*Angle Orthod.* 2009;79: 592–601.)

**KEY WORDS:** Friction; Self-ligation; Brackets; Systematic review; In vitro

### INTRODUCTION

Friction is defined as the resistance to motion when one object moves tangentially against another.<sup>1</sup> During mechanotherapy involving movement of the bracket relative to the wire, friction at the bracket-wire interface may prevent the attainment of optimal force levels in the supporting tissues.<sup>2</sup> Therefore, a decrease in fric-

tional resistance tends to benefit the hard and soft tissue response.<sup>3</sup> It has been proposed that approximately 50% of the force applied to slide a tooth is used to overcome friction.<sup>4</sup> Other factors that affect frictional resistance include saliva,<sup>5</sup> archwire dimension and material,<sup>6–8</sup> angulation of the wire to the bracket,<sup>9</sup> and mode of ligation.<sup>10,11</sup>

The term *self-ligation* in orthodontics implies that the orthodontic bracket has the ability to engage itself to the archwire<sup>12</sup> and is therefore assumed to reduce friction by eliminating the ligation force. These bracket systems have a mechanical device built into the bracket to close off the edgewise slot. Two types of self-ligating (SL) brackets have been developed: those that have a spring clip that presses against the archwire and those in which the SL clip just closes the slot, creating a tube, and does not actively press against the wire. With every SL bracket, whether active or passive, the movable fourth part of the bracket is used to convert the slot into a tube.<sup>13</sup>

SL brackets are not new to orthodontics; in the mid-1930s, the first SL bracket, the Russell attachment,

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**Table 1.** Search Dates, Search Strategies, and Number of Results for Each Database

Database	Search Strategy	Number of Results	Number of Selected Papers
Medline (from 1950 to April week 2 2008)	((Orthodontic bracket*) or (exp Orthodontic Brackets)) AND (self ligat* or self ligation)	60	18
PubMed (from 1950 to April 14, 2008)	Same as Medline	60	18
Embase (from 1988 to 2008 week 15)	Same as Medline	0	0
Web of Science (up to April 14, 2008)	[(TS=orthodontic bracket*) AND ((TS=self ligat*) OR (self ligation))]	40	13
Cochrane Library (up to April 14, 2008)	Same as Medline	4	0
Manual search	Searched the reference lists of selected articles	3	1
Total	NA	167	50
Duplicates	NA	92	31
Total after removing duplicates	NA	72	19

was introduced in an attempt to enhance clinical efficiency by reducing ligation time.<sup>14</sup> However, there has recently been resurgence in the use of SL brackets.<sup>15</sup>

Although reduced friction has been reported to be one of the advantages of SL,<sup>16,17</sup> the issue of friction

and SL brackets is still controversial,<sup>16</sup> as some studies have reported the reduction in friction with SL brackets to be significant while others claim that SL brackets produce similar or higher friction compared with conventional brackets.<sup>10,18</sup>

<b>Figure 1.</b> Methodological score used in the review
<p><b>I. Study Design (4√)</b></p> <p>A. Objective – objective clearly formulated (√)</p> <p>B. Sample Size – considered adequate and estimated before collection of data (√)</p> <p>C. Baseline characteristics – similar baseline characteristics (√)</p> <p>D. Co-interventions (√)</p> <p><b>II. Study Measurements (5√)</b></p> <p>E. Measurement method –appropriate to the objective (√)</p> <p>F. Blind measurement – blinding (examiner √, statistician √)</p> <p>G. Reliability - described (√), adequate level of agreement (√)</p> <p><b>III. Statistical Analysis (5√)</b></p> <p>H. Statistical analysis – appropriate for data (√); combined subgroup analysis (√)</p> <p>I. Confounders (co-interventions) –confounders included in analysis (√)</p> <p>J. Statistical significance level – P value stated (√); confidence intervals (√)</p> <p><b>IV. Other (1√)</b></p> <p>K. Clinical significance (√)</p>
<b>Maximum number of √s = 15</b>

**Figure 1.** Methodological score used in the review.

**Table 2.** Methodological Scores for the Selected Papers<sup>a</sup>

Author	Objective (✓)	Sample size (✓)	Baseline Characteristics (✓)	Co-interventions (✓)	Measurement Method (✓)	Blinding (Examiner ✓, Statistician ✓)
Cacciafesta et al 2003 <sup>13</sup>	✓	✓	✓	✓	✓	××
Franchi et al 2008 <sup>37</sup>	✓	✓	✓	✓	✓	××
Griffiths et al 2005 <sup>20</sup>	✓	/	/	✓	✓	//
Henao and Kusy 2004 <sup>27</sup>	✓	✓	✓	✓	✓	××
Henao and Kusy 2005 <sup>26</sup>	✓	✓	✓	✓	✓	××
Kim et al 2008 <sup>36</sup>	✓	✓	✓	✓	✓	××
Loftus et al 1999 <sup>1</sup>	✓	✓	✓	✓	✓	//
Read-Ward 1997 <sup>28</sup>	✓	✓	✓	✓	✓	××
Redlich et al 2003 <sup>18</sup>	✓	✓	✓	✓	✓	××
Reicheneder et al 2007 <sup>29</sup>	✓	✓	✓	✓	✓	××
Shivapuja and Berger 1994 <sup>3</sup>	✓	/	✓	✓	✓	××
Sims et al 1993 <sup>11</sup>	✓	/	✓	✓	✓	××
Sims et al 1994 <sup>22</sup>	✓	✓	✓	✓	✓	××
Smith et al 2003 <sup>40</sup>	✓	✓	✓	✓	✓	××
Tecco et al 2005 <sup>30</sup>	✓	✓	✓	✓	✓	××
Tecco et al 2007 <sup>31</sup>	✓	✓	✓	✓	✓	××
Thomas et al 1998 <sup>32</sup>	✓	✓	✓	/	✓	××
Voudouris 1997 <sup>24</sup>	✓	✓	✓	✓	✓	××
Yeh et al et al 2007 <sup>33</sup>	✓	✓	✓	✓	✓	××

<sup>a</sup> ✓ indicates good; /, average; ×, poor.

Practitioners need to decide whether self-ligation will be beneficial to their specific treatment plan for each individual patient. To make this decision, they need to know if friction between brackets and archwires is significantly reduced by self-ligation in a clinically meaningful quantity and also if this reduction is limited to certain circumstances. Only a conventional review<sup>19</sup> has been previously published, which presented an overview of the status of self-ligation in the early 2000s. The aim of this systematic review was to compare in an in vitro setting the amount of expressed frictional resistance that orthodontic SL brackets produce compared with conventional brackets.

## MATERIALS AND METHODS

A systematic computerized search of electronic databases was undertaken in Medline, PubMed, Embase, Cochrane Library, and Web of Science until April 2008. The following search strategy (with the use of Boolean operators) was used in Medline: ((Orthodontic bracket\*) OR (exp Orthodontic Brackets) AND (self ligation\* OR self ligation)). A similar strategy was adapted for use in PubMed, Embase, Cochrane Library, and the Web of Science database. Specific search dates and the search strategies are illustrated in Table 1. No limits were applied to the electronic searches. Duplicate results were identified and removed.

Abstracts of the retrieved results were scrutinized, and papers that seemed to meet our initial selection criteria defined (in vitro studies that addressed friction of SL brackets) were identified. Papers were excluded at this stage if they were descriptive, editorial, letter,

in vivo, not investigating SL brackets, or were studying other properties of SL brackets rather than friction. For papers that did not have any abstract except the title available on Medline/PubMed, the full text was retrieved.

Full articles were obtained from the abstracts/titles that met the initial selection criteria. Papers were then evaluated according to the methodological score outlined in Figure 1 to identify papers of acceptable quality (final selection criteria). Minimal quality consisted of a minimal sample size of five per subgroup analyzed and statement of *P* value and confidence interval for the results. Table 2 shows the methodological scores for the finally selected papers.

Selection of the articles at each stage was performed by two researchers. The selections were then discussed, and discrepancies were resolved so that final selections were agreed on by both researchers. Furthermore, a secondary (manual) search was then performed by going through the reference lists of the selected articles to identify any paper that met the initial inclusion criteria but was missed by the electronic searches.

## RESULTS

### Search Process

Sixty hits were obtained from Medline and PubMed. From the 40 hits retrieved from Web of Science, 30 also appeared in Medline/PubMed. All of the four hits retrieved in the Cochrane Database were also found among Medline/PubMed results. Embase returned no

**Table 2.** Extended

Reliability Testing (✓/✓)	Statistical Analysis (Appropriate ✓, Combined Subgroup ✓)	Confounders Included in Analysis (✓)	Statistical Significance (P Value ✓, Confidence Interval ✓)	Clinical Significance (✓)	Total Score (Out of 15)
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	11
✓✓	✓✓	✓	✓✓	✓	13
✓✓	✓✓	✓	✓✓	✓	13
✓✓	✓✓	✓	✓✓	✓	14
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	10.5
××	✓✓	✓	✓✓	✓	10.5
✓✓	✓✓	✓	✓✓	✓	12.5
✓✓	✓✓	✓	✓✓	✓	12.5
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	10.5
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	10.5
××	✓✓	✓	✓✓	✓	11
××	✓✓	✓	✓✓	✓	11

results. After removing the duplicates, the total number of hits (from all the electronic searches together) was 70 (Table 1).

Based on the initial inclusion criteria, 46 of 70 results were excluded based on their abstracts. A total of 24 papers (from the electronic search) met the initial selection criteria.<sup>1,3,10,11,13,18,20–37</sup> However, in our second (final) stage of selection, 6 papers were eliminated because of undetermined sample size,<sup>23,25,34</sup> very small sample size,<sup>10,35</sup> or not reporting any standard deviations (or confidence intervals) and *P* values.<sup>21</sup>

The secondary (hand) search of the reference lists of the selected papers resulted in three additional papers.<sup>38,39,40</sup> All met the initial selection criteria, but two<sup>38,39</sup> were excluded at the second (final) selection stage because of small sample sizes. A summary of the selection process is illustrated in Figure 2.

### Selected Articles

A summary of key methodological data and the results from the selected studies can be found in Table 3. More specific information of the comparisons made, wires used, methodological process, and so forth can be read in Appendix 1.

### DISCUSSION

Regarding the final selected studies, it can be said that the variability of the experimental methods among the selected *in vitro* studies may explain the inconsistency of the selected study results. Although most of the studies published in orthodontics talk about evaluating friction they actually evaluate resistance to slid-

ing which is not interchangeable with friction. For the purpose of this discussion the term friction will be used although is not correct. This will facilitate reading and understanding of the discussion.

A consistent agreement was found among the reviewed studies that SL brackets produce lower friction compared with conventional brackets when coupled with small round archwires,<sup>3,13,20,24,26–32,36,40</sup> whereas only one study<sup>18</sup> disagreed. Some discussion of these studies may shed some light in this regard. As for findings of both this study and another conflicting study that was not included in the review,<sup>10,18</sup> the flexibility of the spring clip of active SL brackets, which can actively engage the wire in the presence of tipping, may explain the controversy. Tipping is a constant phenomenon during sliding tooth movements, and it always occurs when orthodontic force is applied to a tooth.<sup>31</sup> For this reason, teeth will tip until contact is established between the archwire and the diagonally opposite corners of the bracket wings.<sup>29</sup> Tipping and torquing forces therefore can affect the frictional resistance during space closure.<sup>32</sup> The spring clip of both Speed and Time brackets, two types of active SL brackets, is flexible, which also means it is an active clip. Therefore, when it is subjected to a constant force in any one of rotational, tip, and torque spatial planes during the movement of the archwire through the slot, the spring clip will be maintained continuously in a displaced condition while the archwire is pulled past it. In other words, the archwire is actively engaged by the spring clip and pressed into the slot.

Unlike most other studies, in the studies by Bednar<sup>10</sup> and Redlich et al,<sup>18</sup> the brackets were made to tip rel-

**Table 3.** Summary of Selected Papers

Author	Sample Size	Tested Brackets		
		Self-ligating Metal		
		Passive	Active	Esthetic Passive
Cacciafesta et al 2003 <sup>13</sup>	270	Damon		Oyster (FRC)
Franchi et al 2008 <sup>37</sup>	180	Damon, SmartClip Carriere		Opal-M
Griffiths et al 2005 <sup>20</sup>	70	Damon		
Henao and Kusy 2004 <sup>27</sup>	480	Damon	In-Ovation, Speed, Time	
Henao and Kusy 2005 <sup>26</sup>	100	Damon	In-Ovation, Speed, Time	
Kim et al 2008 <sup>36</sup>	785	Damon2, Damon3, In-Ovation SmartClip	Speed, Time 2	
Loftus et al 1999 <sup>1</sup>	120	Damon		
Read-Ward et al 1997 <sup>28</sup>	480	Activa	Speed, Mobil-lock	
Redlich et al 2003 <sup>18</sup>	450		Time	
Reicheneder et al 2007 <sup>29</sup>	480			Oyster (FRC), Opal (resin)
Shivapuja and Berger 1994 <sup>3</sup>	84	Activa, Edge-lok	Speed	
Sims et al 1993 <sup>11</sup>	96	Activa,	Speed	
Sims et al 1994 <sup>22</sup>	180	Activa		
Smith et al 2003 <sup>40</sup>	504	Damon	Speed, Time	
Tecco et al 2005 <sup>30</sup>	300	Damon	Time-Plus	
Tecco et al 2007 <sup>31</sup>	200	Damon	Time-Plus	
Thomas et al 1998 <sup>32</sup>	200	Damon	Time,	
Voudouris 1997 <sup>24</sup>	144	Damon (A-company), Interactwin (Ormco)	Sigma	
Yeh et al 2007 <sup>33</sup>	720	Damon, SmartClip		

<sup>a</sup> Modified conventional or novel brackets<sup>32</sup> (also called reduced-friction brackets).<sup>18</sup>

ative to the archwire; therefore, the above theory may explain why the findings of these two studies do not agree with the others. Sims et al<sup>22</sup> and Reicheneder et al<sup>29</sup> also allowed tipping of the brackets relative to the wire in their studies, but both studied only passive SL brackets. This may imply that passive SL brackets may exert less friction than active ones when round wires are used in specific clinical situations. Unlike the studies by Bednar<sup>10</sup> and Redlich et al,<sup>18</sup> in studies by Shivapuja and Berger<sup>3</sup> and Thomas et al,<sup>32</sup> the bracket was locked in place so that the slot was parallel to the archwire. This way, the bracket width while rotating (torque) as a factor contributing to friction was eliminated.<sup>32</sup> Shivapuja<sup>3</sup> argued that without simulating angulation, each system can be compared equally. However, Shivapuja admits that this portion of their study is really a comparative study and in no way was capable of simulating clinical conditions with all the attended variables. Tecco et al<sup>31</sup> also admitted that lack of reproducibility of tipping was a limitation of their study. It has been previously reported that as the bracket to archwire angulation increases, so does the frictional resistance of a particular bracket and archwire combination.<sup>9</sup>

As for large rectangular archwires, there seems to be controversy among the evaluated papers. Some of

them reported that with large rectangular archwires, the friction of SL brackets was not lower compared with conventional brackets,<sup>1,26-28,31</sup> while others claimed that SL brackets produced lower friction compared with conventional brackets.<sup>11,13,24,30,32,37,40</sup> However, half of the latter group<sup>13,30,32,40</sup> still confirmed that even though friction of SL brackets was lower compared with conventional brackets, friction increased as the archwire size increased. So in general, these findings are in agreement with several studies that have previously reported that friction increases as wire dimension increases<sup>6,8</sup> and that frictional force is generally greater with rectangular wires than with round wires.<sup>7,35</sup> A reason why rectangular wires produced an increased friction even in SL brackets is that, as the bracket slot is filled, the differences between SL and conventional brackets are minimized. This is related to less tipping allowed before teeth are straightened back by the wire resilience. This cycle occurs at a faster rate with more slot play.

Regarding differences in friction between passive and active SL brackets, some controversy exists. Six of the 11 studies<sup>11,24,25,32,36,40</sup> reported that passive brackets generated a lower level of friction compared with the active group, while 2 studies<sup>3,27</sup> reported no differences. The remaining 3 studies<sup>28,30,31</sup> did not ob-

**Table 3.** Extended

Tested Brackets		Ligatures	Test State	Specific Funding Elastic
Conventional		Used With Conventional Brackets		
Metal	Esthetic			
Victory SS	Elastic	Dry	No	
STEP		Elastic, Slide	Dry	No
	Inspire		Dry and wet (water)	No
MD_SDS, MD-GAC, TE, MMHT		Elastic	Dry and wet (saliva)	No
Mini-Diamond		Elastic	Dry	No
Mini-Diamond	Clarity	Elastic	Dry	No
Victory SS	Clarity (ceramic with SS slot), Transcend (ceramic)	Stainless steel	Wet (artificial saliva)	No
Ultratrim		Steel	Dry and wet (unstimulated saliva)	No
OmniArch, NuEdge, <sup>a</sup> Discovery, <sup>a</sup> Synergy, <sup>a</sup> Friction Free <sup>a</sup>		Elastic	Not mentioned	No
	Allure, Inspire, Transcend, Image (FRC)	Elastic	Wet (artificial saliva)	Yes (from Opal manufacturers)
Standard Metal Twin	Ceramic series 2000	Steel, elastic	Wet (artificial saliva)	No
Minitwin		Elastic	Dry	No
Minitwin, Standard		Elastic	Dry	No
Victory	Clarity (ceramic with SS slot), Transcend (ceramic)	Elastic	Dry	No
Victory		Elastic	Dry	No
Victory		Elastic, Slide	Dry	No
Standard Twin, Tip Edge		Elastic	Not mentioned	No
American Master Series, (Ormco) Diamond, (A-company Twin)		Elastic, metal	Dry	No
Synergy <sup>a</sup>		Elastic	Dry	No

serve a consistent trend. The difference in friction between passive and active SL brackets have been attributed to the fact that the former group of brackets form a rigid tube when closed, applying no direct force to the wire.<sup>11</sup> Other possible explanations for the results could be differences in archwires tested and diverse brackets tested.

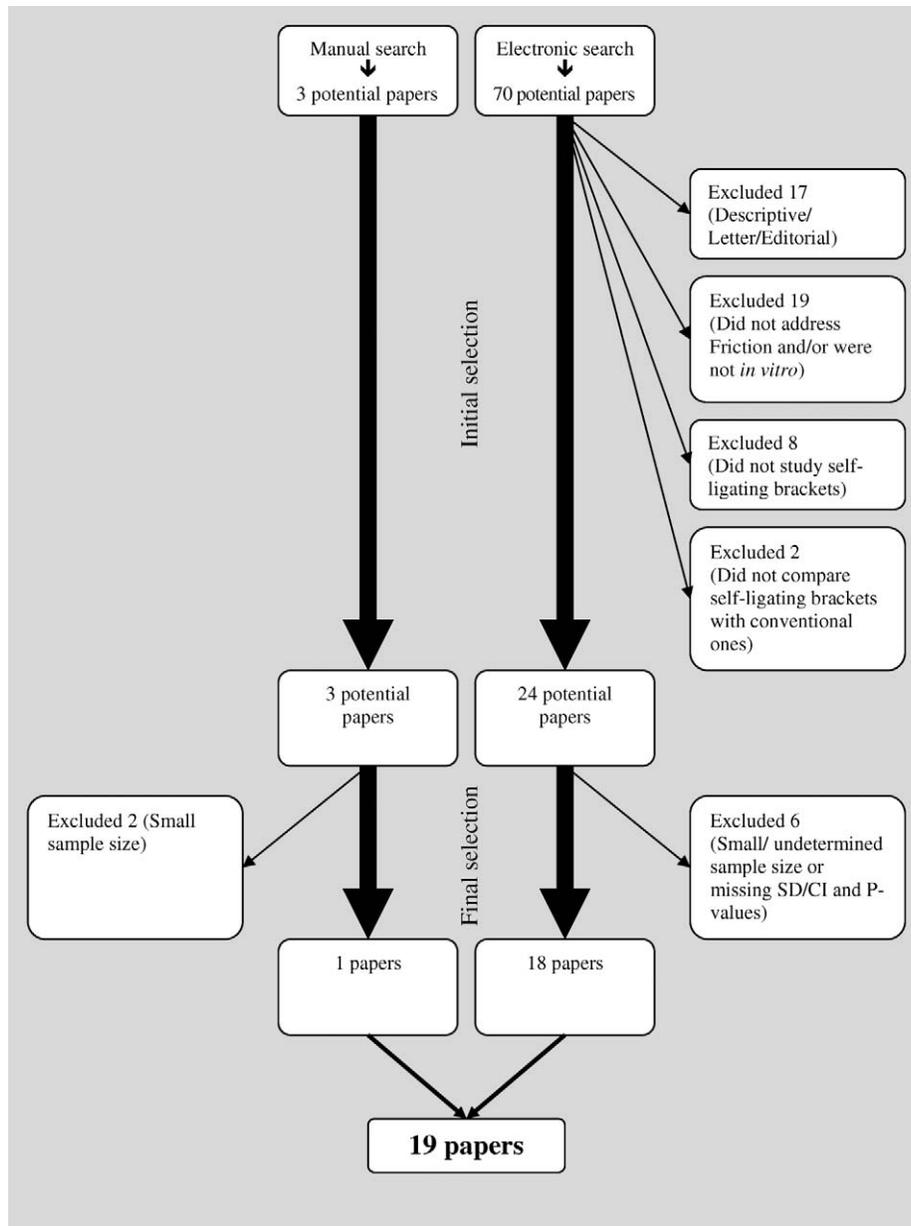
All selected articles used a consistent 0.022-in bracket slot size for all studies, and therefore conclusions regarding the influence of bracket slot size change on frictional resistance cannot be drawn. According to Smith et al,<sup>40</sup> "bracket slot size may not influence the frictional resistance," but some of the studies identified by the initial inclusion criteria did suggest that frictional resistance decreases as slot size increases.<sup>2</sup> The explanation here is that the friction when related to slot size is more a function of the dimension of the archwire engaged.

Steel SL brackets were consistently reported to show lower friction compared with ceramic and polycarbonate conventional brackets.<sup>1,3,13,20,36,40</sup> This is probably due to the increased roughness and porosity of ceramic, which leads to a higher coefficient of friction compared with stainless steel.<sup>1,3</sup> These findings are in agreement with previous studies that reported friction to be higher with ceramic brackets (conventional) compared with steel brackets (conventional).<sup>7,41</sup>

Esthetic (fiberglass-reinforced composite [FRC] and resin) SL brackets were reported to have lower friction compared with conventionally ligated esthetic (ceramic and FRC) brackets,<sup>29</sup> which may be related to the mechanical binding of elastomeric tie and the ceramic bracket surface of conventional brackets.<sup>3</sup>

As with any in vitro study, none of the evaluated papers included in this review can accurately simulate what really happens in clinical situations because of variables such as masticatory forces<sup>20</sup> and oral functions,<sup>30,31</sup> different degrees of malocclusion,<sup>26,27,33</sup> width and compressibility of PDL,<sup>1</sup> tooth rotation,<sup>24,38</sup> torque at the wire-bracket interface,<sup>23</sup> bracket/archwire angulation,<sup>25,28</sup> and temperature and moisture.<sup>29,31</sup>

Clinicians should be cautioned that although in vitro findings are a useful guide to anticipated clinical behavior, the observed clinical performance might be quite different.<sup>42</sup> Furthermore, leveling and alignment of malposed teeth, which begins as part of the initial stage of orthodontic treatment, should be accomplished with flexible archwires.<sup>33</sup> Therefore, experiments with small round archwires in the absence of malalignment may not accurately reproduce what actually happens in clinical situations. A rectangular archwire is often used to complete the initial leveling and aligning stage, express rotation control, and start torque control; it is also usually recommended for



**Figure 2.** Flow chart of the selection process.

space closure (after teeth are well leveled and aligned),<sup>22</sup> retraction (during which teeth may tip or rotate), and finishing.<sup>33</sup> Therefore, experiments with rectangular archwires should preferably incorporate tipping and rotation in their testing settings for the conclusions to be applicable to all phases of orthodontic treatment. Only a few of the studies considered malocclusion in their experiments; all agreed that as malocclusion increased, friction increased as well, regardless of the bracket type or wire size.<sup>26,27,33,36</sup> A novel approach mimicking malocclusions using a three-dimensional setup with nanotechnology transducers appears to have great potential to help us understand

the complexity of intra-arch biomechanics and its impact on frictional resistance among other mechanical aspects of orthodontics.<sup>43</sup>

Some limitations were identified that should be considered in future reviews. Because of the theoretical differences between active and passive self-ligation brackets, a specific analysis considering subgrouping the studies could have added more depth to the discussion. The same would apply to differences in slot size and bracket prescriptions. Because of the limited number of studies finally selected, further subgrouping will not deem information with enough sample size to warrant meaningful conclusions.

## CONCLUSIONS

- Compared with conventional brackets, SL brackets maintain lower friction when coupled with small round archwires in the absence of tipping and/or torque in an ideally aligned arch.
- There is not enough evidence to claim that with large rectangular wires, in the presence of tipping and/or torque and in arches with considerable malocclusion, SL brackets produce lower friction compared with conventional brackets.
- Most of the evaluated studies agreed that friction of both self-ligated and conventional brackets increased as the archwire size increased.

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## APPENDIX 1

### Speed Brackets

Shivapuja and Berger<sup>3</sup> and Kim et al<sup>36</sup> reported lower frictional forces for SPEED self ligating (SL) brackets compared with conventional brackets when coupled with round (0.014, 0.016, or 0.018 in) archwires. Henao and Kusy<sup>26</sup> reported that, when coupled with up to 0.020- × 0.020-in archwires, SPEED yielded lower friction compared with conventional brackets and that friction of both bracket designs were most comparable when coupled with the 0.016- × 0.022-in, 0.016- × 0.025-in, and 0.020- × 0.020-in archwires. Read-Ward et al<sup>28</sup> reported that SPEED brackets demonstrated significantly lower frictional resistance in comparison to conventional steel brackets for the 0.020-in wires, but for the 0.021- × 0.025-in and 0.019- × 0.025-in wires, the differences between the brackets were statistically less significant. Henao and Kusy<sup>27</sup> reported that SPEED brackets produced sig-

nificantly less friction than conventional brackets when coupled with 0.014-in archwires. But the difference was not significant for the 0.016- × 0.022-in and 0.019- × 0.025-in archwires. Smith et al<sup>40</sup> reported lower friction for SPEED brackets compared with conventional brackets regardless of the archwire size.

### Damon Brackets

Cacciafesta et al,<sup>13</sup> Tecco et al,<sup>30</sup> Thomas et al,<sup>32</sup> Voudouris,<sup>24</sup> Franchi et al,<sup>37</sup> Smith et al,<sup>40</sup> and Kim et al<sup>36</sup> reported that Damon SL brackets generated lower frictional resistance than conventional steel brackets. Griffiths et al<sup>20</sup> reported that Damon brackets showed lower resistance to sliding compared with ceramic conventional brackets. Henao and Kusy<sup>27</sup> reported that Damon II SL brackets produced significantly less friction than conventional brackets when coupled with 0.014-in archwires. But the difference was not significant for the 0.016- × 0.022-in and 0.019- × 0.025-in archwires. Henao and Kusy<sup>26</sup> reported that Damon brackets yielded lower friction compared with conventional brackets when coupled with up to 0.020- × 0.020-in archwires. With the 0.016- × 0.025-in archwires, Damon 2 produced higher friction compared with conventional brackets. Tecco et al<sup>31</sup> reported that with 0.016 NiTi archwires, the friction of the Damon II SL brackets was lower than that of conventional brackets but similar to low-friction Slide ligatures. With 0.016- × 0.22-in NiTi archwires, Damon brackets showed lower friction than conventional brackets (with either elastomeric or Slide ligature), while with 0.017- × 0.025-in TMA, no significant difference was seen among the three groups. However, with 0.019- × 0.025-in archwires (NiTi and SS), Slide ligatures generated lower friction compared with Damon brackets and conventional elastomeric ligatures. Loftus et al<sup>1</sup> concluded that frictional forces with Damon SL brackets were similar to that of conventional steel and ceramic (with steel slot) brackets. Yeh et al<sup>33</sup> reported that the Damon SL II brackets produced significantly greater values of friction than the Synergy (conventional modified) brackets, when coupled with 0.019- × 0.025-in archwires, in the simulated 3° and 6° rotation and for third-order angulation. However, no significant difference was reported between Damon and Synergy for second-order intrusions.

### Time SL Brackets

Thomas et al,<sup>32</sup> Smith et al,<sup>40</sup> and Kim et al<sup>36</sup> reported that Time SL brackets yielded lower friction than steel conventional brackets when coupled with either round (0.014, 0.016, or 0.017 in) or rectangular (0.016 × 0.022 in and 0.019 × 0.025 in) archwires. Henao and Kusy<sup>27</sup> reported that Time brackets pro-

duced significantly less friction than conventional brackets when coupled with 0.014-in archwires, but the difference was not significant for the 0.016- × 0.022-in and 0.019- × 0.025-in archwires. Henao and Kusy<sup>26</sup> reported that when coupled with up to 0.020- × 0.020-in archwires, Time brackets yielded lower friction compared with conventional brackets. For the 0.016- × 0.022-in and 0.016- × 0.025-in archwires, Time produced higher friction compared with conventional brackets. Redlich et al<sup>18</sup> reported that Time brackets produced a significantly higher friction force compared with normal friction (conventional) brackets.

Tecco et al<sup>30</sup> reported that Time-Plus SL brackets produced significantly lower frictional resistance than conventional steel brackets. Tecco et al<sup>31</sup> reported that with 0.016-in NiTi archwires, the friction of Time SL brackets was lower than that of conventional brackets but similar to low-friction Slide ligatures. With 0.016- × 0.22-in NiTi archwires, Time brackets showed lower friction than conventional brackets (with either elastomeric or Slide ligature), while with 0.017- × 0.025-in TMA, no significant difference was seen among the three groups. However, with 0.019- in to 0.025-in archwires (NiTi and SS), Slide ligatures generated lower friction compared with Time brackets and conventional elastomeric ligatures.

### In-Ovation Brackets

Kim et al<sup>36</sup> reported lower friction for In-Ovation SL brackets compared with conventional brackets when coupled with round 0.014- and 0.016-in archwires. Henao and Kusy<sup>27</sup> reported that In-Ovation SL brackets produced significantly less friction than the respective conventional brackets when coupled with 0.014-in archwires, but the difference was not significant for the 0.016- × 0.022-in and 0.019- × 0.025-in archwires. Henao and Kusy<sup>26</sup> reported that when coupled with up to 0.020- × 0.020-in archwires, In-Ovation yielded lower friction compared with conventional brackets. For the 0.016- × 0.025-in archwires, In-Ovation produced higher friction compared with conventional brackets.

### Activa Brackets

Shivapuja and Berger<sup>3</sup> and Sims et al<sup>11,22</sup> reported that Activa SL brackets showed lower friction than conventional brackets. Read-Ward et al<sup>28</sup> reported that for zero angulation, Activa SL and Mobil-lok SL brackets demonstrated significantly lower static frictional resistance in comparison with conventional brackets, for the 0.020-in wires. But for the 0.021- × 0.025-in wires,

and the wires used most commonly in sliding mechanics (0.019 × 0.025 in), the differences between the brackets were statistically less significant.

### Edge-lok Brackets

Shivapuja and Berger<sup>3</sup> reported that Edge-lok SL brackets showed lower levels of friction than conventional brackets when tested with 0.018-in archwires.

### Smart-Clip Brackets

Kim et al<sup>36</sup> and Franchi et al<sup>37</sup> reported lower friction for Smart-Clip brackets compared with conventional brackets when coupled with either round (0.014 and 0.016 in) or rectangular (0.019 × 0.025 in) archwires. Yeh et al<sup>33</sup> reported the frictional resistance of Smart-Clip SL brackets to be less than novel (Synergy) brackets when coupled with 0.019- × 0.025-in archwires. However, in the simulated 3° and 6° rotation, Smart-Clip had greater friction than Synergy brackets. No significant difference was observed between Smart-Clip and Synergy for second-order intrusions and third-order angulations. It should be noted that in this study, the elastomeric ligation was tied on the center wings of the Synergy brackets.

### Opal SL Brackets

Franchi et al<sup>37</sup> reported lower friction for Opal-M brackets compared with either steel or ceramic conventional brackets when coupled with 0.019- × 0.025-in archwires. Reicheneder et al<sup>29</sup> reported that Opal SL ceramic brackets had significantly lower friction than conventional ceramic brackets when coupled with either 0.017- × 0.025-in or 0.019- × 0.025-in archwires.

### Oyster Ceramic SL Brackets

Cacciafesta et al<sup>13</sup> reported that the frictional forces of Oyster ceramic SL brackets were similar to conventional steel brackets. Reicheneder et al<sup>29</sup> reported that the friction of Oyster ceramic SL brackets was lower than conventional ceramic brackets when tested with either 0.017- × 0.025-in or 0.019- × 0.025-in archwires.

### Carriere Brackets

Franchi et al<sup>37</sup> reported lower friction for Carriere SL brackets compared with conventional brackets when coupled with 0.019- × 0.025-in archwires.