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Resistance to sliding in orthodontics: misconception or method error? A systematic review and a proposal of a test protocol

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Resistance to sliding (RS) between the bracket, wire, and ligature has been largely debated in orthodontics. Despite the extensive number of published studies, the lack of discussion of the methods used has led to little understanding of this phenomenon. The aim of this study was to discuss variables affecting RS in orthodontics and to suggest an operative protocol. The search included PubMed©, Medline©, and the Cochrane Library©. References of full-text articles were manually analyzed. English-language articles published between January 2007 and January 2017 that performed an *in vitro* analysis of RS between the bracket, wire, and ligature were included. Study methods were analyzed based on the study design, description of materials, and experimental setup, and a protocol to standardize the testing methods was proposed. From 404 articles identified from the database search and 242 records selected from published references, 101 were eligible for the qualitative analysis, and six for the quantitative synthesis. One or more experimental parameters were incompatible and a meta-analysis was not performed. Major factors regarding the study design, materials, and experimental setup were not clearly described by most studies. The normal force, that is the force perpendicular to the sliding of the wire and one of the most relevant variable in RS, was not considered by most studies. Different variables were introduced, often acting as confounding factors. A protocol was suggested to standardize testing procedures and enhance the understanding of *in vitro* findings.
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INTRODUCTION

Friction (FR) is defined as the resistance to motion when one object moves tangentially against another[1] (Figure 1). Thus, friction is a tangential force parallel to the sliding direction, and proportional to the coefficient of friction (μ) and to the normal force (NF), which is perpendicular to the surface of contact:

$$FR = \mu \times NF \quad (1)$$

Friction, also known as classical friction, can be further divided into ploughing (PL), roughness interlocking (IN), and shearing (SH)[2,3]:

$$FR = PL + IN + SH \quad (2)$$

However, resistance to sliding (RS) is a more comprehensive concept than friction and comprises friction, binding (BI), and notching (NO)[4]:

$$RS = FR + BI + NO \quad (3)$$

Thus:

$$RS = PL + IN + SH + BI + NO \quad (4)$$

Rather than by the mere friction, orthodontic biomechanics is influenced by the RS[5] since applied tangential forces, which are orthodontic forces, must overcome the RS in the opposite direction to allow tooth movement. Thus, a higher RS requires greater orthodontic forces.[6] However, forces of greater magnitude do not imply an increased load on the anchorage teeth,[7] despite the fact that potential anchorage loss was considered one of the disadvantages of high RS.[8] This being said, controlling differential forces is still fundamental in orthodontics and the mechanical basis of RS still require clarifications.

Wire-slot interactions should be controlled in three dimensions, i.e., the first (I),[9] second (II),[3] and third orders (III),[10,11] and the RS can be respectively generated on each plane, apart III since the slot has no surfaces on it:

$$RS = RS_{I} + RS_{II} \quad (5)$$

Lastly, since the components involved in RS during orthodontic movement are the bracket, the wire, and the closing system; each of these factors may have specific characteristics in terms of shapes and chemical and mechanical properties that contribute in different magnitudes to the RS.

Since friction is proportional to the normal force, and binding and notching are also affected by the normal force generated by wire deflexion when the critical contact angle (θ) is exceeded,[3] RS is mainly determined by the normal force applied to each of the above-mentioned orders (Equation 5). With regard to this, ligating methods play a primary role,[12] and changes in the spatial configuration[3] or elastic deformation of the mechanical components[13] may also affect RS. Furthermore, additional variables may influence RS through the coefficient of friction, such as material compositions[4] and lubricants.[14]

Despite the considerable amount of published literature on RS, including reviews analyzing the effects of several related parameters,[15] and because of the apparent disagreement between *in vitro* tests[16] and clinical trials,[17] the contribution of several variables involved in the phenomenon still require clarification.

The objectives of the present review were to identify variables involved in the *in vitro* evaluation of RS in orthodontics in an attempt to clarify the reasons behind the discrepancies among *in vitro* studies and between *in vitro* and clinical findings. The present

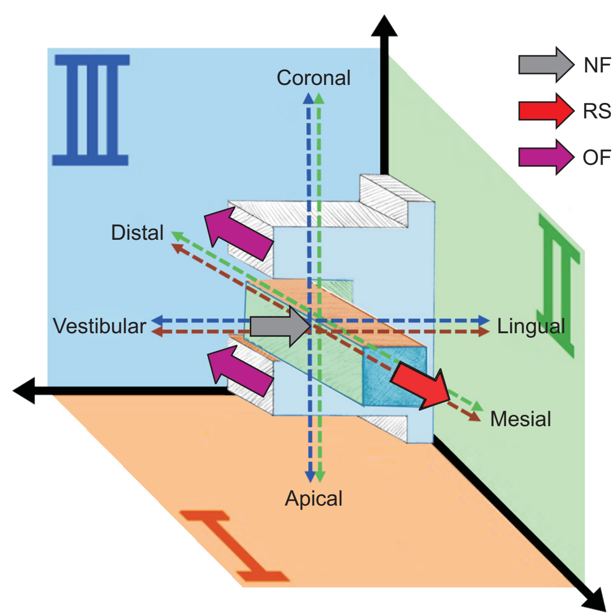

Figure 1. Example of a wire inserted into a bracket slot describing the first order plane (I, brown), second order plane (II, green), third order plane (III, blue), and their respective axes (apico-coronal, linguo-vestibular, and mesio-distal). In the example, a normal force (ligating force) (NF, gray arrow) is applied on the second-order plane of the wire. Because of the orthodontic force (OF, purple arrow), which can be generated either by movement of the bracket or the wire, resistance to the sliding of the wire (RS, red arrow) is created along the mesio-distal axis. In this case, the contact surface responsible for the RS is on the II order (RS_{II}).

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Table 1. Descriptions of the variables relevant to resistance to sliding

Variable	Description
Study design	
Number of tests*	The number of times that the same test has been repeated
Aligning method*	The method used to align the slot of the bracket in a neutral position relatively to the sliding direction
Friction type*	The type of friction evaluated during the test (e.g. static)
Static friction evaluation*	The criteria used to evaluate the static friction (e.g. max force)
Dynamic friction evaluation*	The criteria used to evaluate the dynamic friction (e.g. max force)
Applied normal force (N)	The force applied to the archwire to hold it into the slot (e.g. ligating force of 200 g)
Load cell (N)	The range of the load cell of the mechanical testing machine (e.g. 100 N)
Surface evaluation	The analysis of the surface of the materials (e.g. scanning electron microscopy)
Materials	
Bracket	
Type*	The type of bracket used (e.g. self-ligating)
Slot height (mil)*	The occlusal-gingival dimension of the slot (e.g. 22 mil)
Slot width (mil)	The mesio-distal dimension of the slot (e.g. 120 mil)
Slot depth (mil)	The bucco-lingual dimension of the slot (e.g. 28 mil)
Slot material*	The material in which the slot is made (e.g. stainless steel)
Angulation prescription (°)	The angulation of the bracket slot ("tip") (e.g. +5°)
Inclination prescription (°)	The inclination of the bracket slot ("torque") (e.g. +5°)
In-out prescription (mm)	The bucco-lingual distance of the slot from the base of the bracket (e.g. 0.5 mm)
Archwire	
Size (mil)*	The width of the wire measured on the two sides of its cross-section (e.g. 16 × 22 mil)
Material*	The material in which the wire is made (e.g. stainless steel)
Form	The form of the arch wire used (e.g. ovoid)
Ligature	
Size (mil)	The diameter of the cross-section of the ligature (e.g. 10 mil) (if applicable)
Material*	The material in which the ligature is made (e.g. stainless steel) (if applicable)
Relaxation time (min)	The time waited before testing to allow the relaxation of elastic ligatures (e.g. 5 min) (if applicable)
Experimental setup	
Number of brackets*	The number of brackets used during the test, in which the wire slides during the test (e.g. 5)
Bonding material	The method used to stabilise the bracket (e.g. epoxy resin)
Temperature (°C)	The temperature at which the test is carried (e.g. 25°C)
Sliding velocity (mm/min)*	The velocity of the axial displacement of the wire or of the bracket (e.g. 5 mm/min)
Sliding duration (min)	The duration of the test (e.g. 5 min)
Sliding length (mm)	The amount of displacement (e.g. 5 mm)
Wet/dry conditions	If the experiment is carried in dry or wet conditions (e.g. artificial saliva)
Torque moment (g × mm)	The moment applied on the bracket or arch wire during the test (e.g. 5 g × mm) (if applicable)
Experimental angulation (°)	The angulation ("tip") added experimentally, on top of the prescription of the bracket (e.g. +5°) (if applicable)
Experimental inclination (°)	The inclination ("torque") added experimentally, on top of the prescription of the bracket (e.g. +5°) (if applicable)
Experimental in-out (mm)	The in-out ("rotation") added experimentally, on top of the prescription of the bracket (e.g. +5°) (if applicable)
Vertical misalignment (mm)	The amount of vertical misalignment between two or more bracket (e.g. 5 mm) (if applicable)
Inter-bracket distance (mm)*	The distance between two or more bracket (e.g. 5 mm) (if applicable)

Variables marked with an asterisk (*) were considered major variables and their reporting was used as inclusion criteria for eligibility in the quantitative synthesis.
1 mil = 1/1,000 inch.

work also suggests a step-by-step protocol to improve standardization of *in vitro* testing procedures.

MATERIALS AND METHODS

Eligibility criteria

Journal articles published between January 2007 and January 2017 in the English language and indexed either on Scopus© or PubMed© were considered. Only *in vitro* studies focusing on the evaluation of RS between the wire, bracket, and ligature were included.

Information sources, search strategy, and study selection

PubMed©, Medline©, and the Cochrane Library© databases were screened. The following search was performed: ("friction" [MeSH Terms] OR "friction" [Title] OR "resistance to sliding" [Title]) AND ("orthodontics" [MeSH Terms] OR "orthodontics" [Title] OR "bracket" [Title] OR "braces" [Title] OR "archwire" [Title] OR "wire" [Title]). Further records were identified from the references of full text-articles. Record identification was performed through title analysis, followed by an exclusion process based on the publication date and duplicate removal. Screening was carried by abstract analysis during the study selection and two authors (AP and JKHT) were assigned to the tasks of identification and assessment for eligibility.

Data items and collection

Data collection was performed by one author (AP), from a full-text analysis, and data were converted into the same units of measurement to enable inter-study comparisons. Variables were categorized into "study design", i.e., contributing to the quality of the data but not directly to the outcome measurements, "materials", i.e., related to the characteristics of the tested materials (further divided into "bracket", "wire", and "ligature" characteristics), and "experimental setup", i.e., related to the experimental procedures (Table 1).

Summary measures and approach to synthesis

Variables of primary importance for RS were identified as "major variables" and were used as inclusion criteria during the eligibility assessment for the quantitative synthesis (Table 1); minor variables were considered in the discussion part. Despite its importance, ligation force was not used as an inclusion criterion and was analyzed in the discussion part. The prevalence (%) of the reporting of major variables among studies was assessed to provide a general picture of the information reported in the methods of published studies. Risk of bias, principal summary measures, and methods of combining the results from studies were not applicable because no study was included in the quantitative synthesis.

RESULTS

Study selection and characteristics

From 404 articles identified from the database search and 242 additional articles collected from references, 101 full-text articles were eligible for qualitative analysis, and six articles were eligible for quantitative synthesis (Figure 2).

Important major factors affecting the quality of the study were not described by most studies, such as the application of methods to initially align the slot and wire relative to each other (50%), and methods used to determine static (54%) or dynamic (68%) friction. None of the included studies calculated the normal force of the ligation method.

Relative to the materials description, the majority of the studies did not provide information about the material (48%), width, depth, inclination, or in/out prescription of the bracket slot. Furthermore, the wire form was described in only a few studies and ligature parameters such as the size and relaxation time of elastic ligatures were often omitted as well.

Description of the experimental setup was incomplete in most studies, such as in the case of the inter-bracket distance (38%), testing temperature, and sliding duration or length.

Synthesis of the results

Six studies were eligible for quantitative synthesis. However, one or more experimental parameters were different and data synthesis was not possible (Tables 2–4).

DISCUSSION

Summary of evidence

A considerable number of studies have been published on RS between the bracket, wire, and ligature; its consequences on clinical treatments have been investigated as well.[18] Unfortunately, no uniform methodologies have been followed, leading to disagreement among results and limiting the clinical interpretation of experimental findings. For example, although Saunders and Kusy[19] observed that nickel-titanium (NiTi) wires were related to higher RS than stainless steel (SS) ones, Peterson et al.[20] revealed opposite findings. The ligation method provides additional examples, with some studies reporting that SS-tied brackets showed higher RS than elastomeric-tied ones,[16] and others described an opposite relationship.[21] The reason for such disagreement can be related to the adoption of different criteria in the data acquisition, the use of disparate testing methods, and especially the lack of uniform baselines for variables such as the applied normal force, together with the presence of possible confounding effects. Beside

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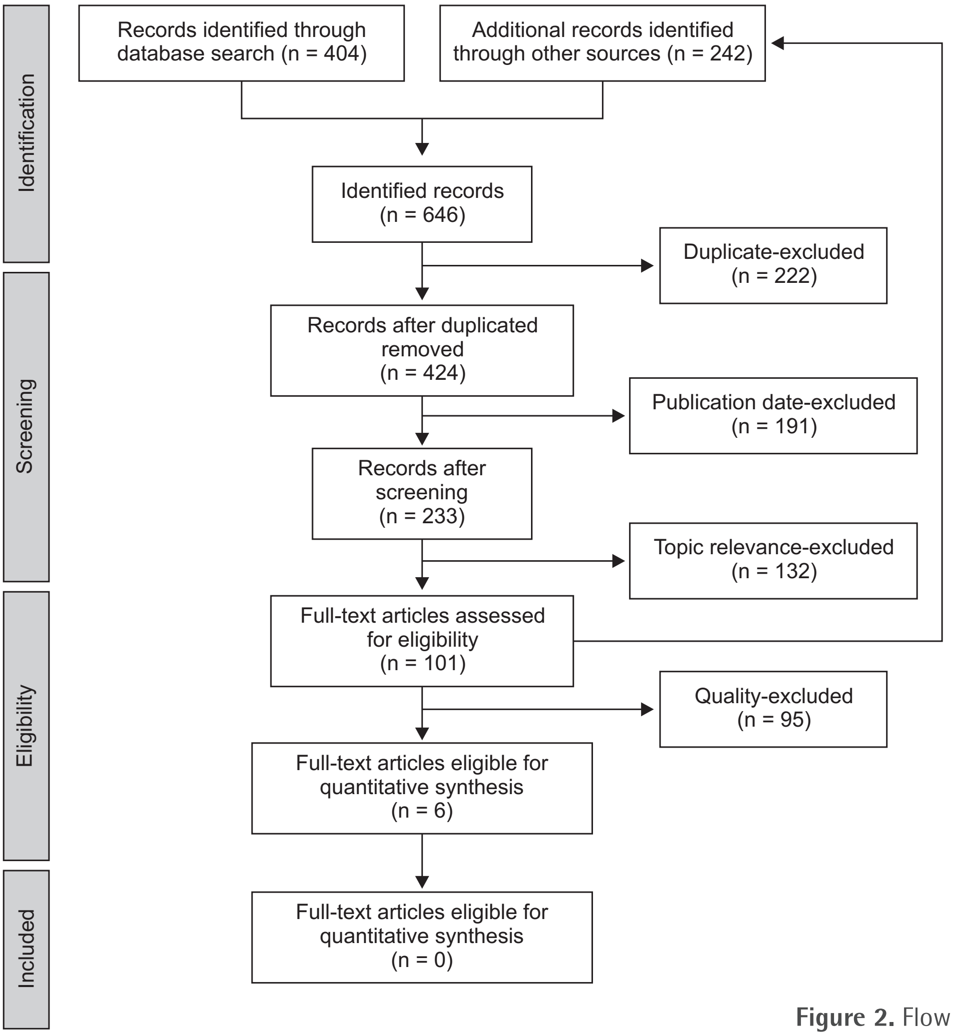

Figure 2. Flow diagram of the study selection.

previous reviews has discussed several of these variables comparing the results of published studies,[15] the present work has focused on their methodologies in terms of study design, materials, and experimental setup adopted.

Study design

The aligning method utilized to establish an angular reference position, i.e., a completely passive interaction of the wire with respect to the bracket slot, is of particular importance when different types of brackets are tested[16,21-29] to avoid the bracket prescription acting as a confounding variable. In this regard, an alignment jig should be used during bonding of the bracket, and preliminary tests without the application of normal forces should be performed to verify the absence of RS during translational displacement in the angular reference position. Furthermore, it should be considered that RS can be both of the static and dynamic types and respective evaluation methods based on peak forces[22,30] or displacements[22,30] should be used to discriminate between the two. Simple averages of the data as performed in some studies[31-34] or unclear attribution of the values to either static or dynamic friction[16,21,25,28,35-44] may lead to oversimplifications.

Lastly, since RS in orthodontics ranges between forces of relatively low magnitudes, e.g., between 1 N[45] and 100 N,[22] the sensitivity of the testing apparatus should be able to detect small force variations. Thus, the load cell of the testing machine, i.e., its operative load range, should have an upper limit similar to the expected maximum RS and should not be as high as 500 N[41] or 10,000 N.[32]

Materials

Although RS may be affected by the bracket type, the classification of brackets into standard (STD), self-ligating (SL), active self-ligating (ASL), interactive self-ligating (IASL), and passive self-ligating (PSL) categories does not identify dimensions, materials, or normal forces applied by their respective closure systems to

Table 2. Summary of the study design characteristics of the studies eligible for quantitative synthesis

Study	Study design							
	Number of tests*	Aligning method*	Friction type*	Static friction evaluation*	Dynamic friction evaluation*	Applied normal force (N)	Load cell (N)	Surface evaluation
Yeh et al. (2007)[9]	10	SS 21.5 × 28 mil	Static/dynamic	Mean of max forces	Mean of max forces	ND	490	SEM
Cordasco et al. (2009)[71]	12	SS 21 × 25 mil	Dynamic	(No static)	Mean of max forces	ND	ND	ND
Doshi and Bhad-Patil (2011)[72]	10	SS 21 × 28 mil	Static/dynamic	Max forces	Mean forces	ND	10	SEM
Pacheco et al. (2011)[70]	5	U-shape SS 21 × 25 mil	Static	Mean force	(No dynamic)	ND	5	ND
Uribe et al. (2012)[41]	9	SS 21 × 25 mil	Dynamic	(No static)	Mean of max forces	ND	500	ND
de Lima Mendonça et al. (2014)[54]	21	SS 21.5 × 28 mil	Static	Mean of max forces	(No dynamic)	ND	10	ND

SS, Stainless steel; ND, not detected; SEM, scanning electron microscopy.
1 mil = 1/1,000 inch.
*Counted for inclusion in the quantitative synthesis.

the wire. Although most studies described the bracket type (84%), the parameters necessary to understand its influence on RS were often not reported, such as the material (48%), slot width or depth, and the inclination or the in/out prescription. Furthermore, even if this information was declared, the data source was often the product manufacturer, and very few studies provided direct measurements of these parameters[9,46] to find discrepancies between the declared data and actual measurements. Moreover, although positional details of the slot were reported by some authors, their relevance was lost if the previously described reference position was not determined.[16,21-28,31,34,35,37,38,45,47,48] Despite the slot height being commonly reported (88%), a single parameter cannot represent the complex three-dimensional (3D) interaction between the bracket and wire.[21] In fact, not only the slot height but also the slot width and depth determine the onset of the critical contact angles in the respective planes.[3] Beyond this, the bracket width also influences the inter-bracket distance and wire elasticity,[49] which have obvious consequences on RS.

Although the wire size (95%) and material (95%) were often described, the form of the wire was reported less frequently. Therefore, especially when super-elastic NiTi wires were tested, it was not clear whether wire curvature, e.g., the pre-formed U-shape, was taken into consideration.[16,22-25,28,30,31,34,39,43,47,50-54] Moreover, the wire form has obvious consequences on RS, including changes in the normal force and critical contact angles, especially in the first order[3,48] (Figure 1).

In most studies, the ligature size was not measured, and when elastic ligatures were tested, only a few authors reported the relaxation time. Surprisingly, although major attention should be focused on the ligating method because of its influence on the normal force,[16,21,25,53] this aspect received far less attention than the geometry of the wire and bracket.

Experimental setup

The number of consecutive brackets affects wire elasticity, which is proportional to the inter-bracket distance, and is also related to RS.[49] However, only 38% of the studies testing a multi-bracket system reported this variable. Despite the use of multiple brackets on a two-dimensional surface[55-60] or even in a 3D configuration[9,61-65] may allow the development of more accurate simulations of the clinical situation compared to that from a single bracket, it also creates challenges in understanding causal relationships between experimental variables and RS. Additionally, environmental factors such as temperature[66] and the presence of dry or wet conditions[14] can influence RS. For example, saliva may promote adhesive and

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Table 3. Summary of the material characteristics of the studies eligible for quantitative synthesis

Study	Materials													
	Bracket								Archwire			Ligature		
	Type*	Slot height (mil)	Slot width (mil)	Slot depth (mil)	Slot material*	Angulation prescription (°)	Inclination prescription (°)	In/out prescription	Size* (mil)	Material*[†]	Form	Size (mil)	Material*	Relaxation time (min)
Yeh et al. (2007)[9]	PSL	22	ND	ND	SS	ND	ND	ND	14 16 × 22 19 × 25	NiTi	ND	ND	EL	3
Cordasco et al. (2009)[71]	PSL STD	22	ND	28	SS	+2	−7	ND	21 × 25	SS	Straight	10 (SS)	EL SS	ND
Doshi and Bhad-Patil (2011)[72]	STD	22	78	ND	AuPd SS	MBT	MBT	MBT	19 × 25	SS NiTi TMA	ND	ND	EL	ND
Pacheco et al. (2011)[70]	STD ASL PSL	22	ND	28	SS	+4 +5	+12 +17	ND	18 17 × 25	SS	Straight	ND	EL	ND
Uribe et al. (2012)[41]	STD SL	22	ND	28	SS	ND	ND	ND	19 × 25	SS	Straight	ND	EL	ND
de Lima Mendonça et al. (2014)[54]	STD	22	ND	ND	SS	ND	ND	ND	14	NiTi	Straight	ND	EL	ND

mil, 1/1,000 inch; STD, Standard; SL, self-ligating; ASL, active SL; IASL, interactive SL; PSL, passive SL; ND, not declared; NiTi, nickel-titanium; EL, elastic ligature; SS, stainless steel; AuPd, gold-palladium; MBT, McLaughlin-Bennett-Trevisi; TMA, titanium-molybdenum alloy.
1 mil = 1/1,000 inch.
*Counted for inclusion in the quantitative synthesis; †coating or surface treatments may be present.

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Table 4. Summary of the experimental setup characteristics of the studies eligible for quantitative synthesis

Study	Experimental setup												
	Number of bracket (s)*	Bonding material	T (C°)	Sliding velocity* (mm/min)	Sliding duration (min)	Sliding length (mm)	Wet / dry condition	Torque moment (g × mm)	Experiment angulation (°)	Experiment inclination (°)	Experiment in/out (mm)	Vertical misalignment (mm)	Inter-bracket distance* (mm)
Yeh et al. (2007)[9]	3	Cyanoacrylate	(Room)	0.5	12	6	Dry	ND	0 +3	0 +3 +6	0 +0.5 +1	0 +0.5	4.5 5
Cordasco et al. (2009)[71]	3	Composite resin	37	5	ND	ND	Dry	ND	ND	ND	ND	1	11
Doshi and Bhad-Patil (2011)[72]	1	Epoxy resin	25	0.5	ND	4	Dry	ND	ND	ND	ND	ND	Single bracket
Pacheco et al. (2011)[70]	1	Cyanoacrylate	ND	1	ND	ND	Dry	ND	ND	ND	ND	ND	Single bracket
Uribe et al. (2012)[41]	2	ND	20	5	ND	8	Dry	ND	ND	ND	ND	ND	8
de Lima Mendonça et al. (2014)[54]	5	Composite resin	25	6	ND	ND	Dry	ND	ND	ND	ND	ND	6

ND, Not declared.
*Counted for inclusion in the quantitative synthesis.

lubricious behavior[14] and temperature may influence the mechanical properties of wires.[66] Nevertheless, the testing temperature was reported by only a few studies. Furthermore, although the sliding velocity was usually mentioned (89%), previous studies showed variations in RS at different velocities[35,36,67] and it is noteworthy that the values reported, e.g., up to 20 mm/min,[36,68] were far from clinical orthodontic movements by several orders of magnitude. This being said, the bonding material was not considered even though resin composite luting cement,[69] cyanoacrylate cement,[9,70] and epoxy resin[32] may exhibit different elasticities that influence bracket movement.

Quantitative synthesis

Six studies[9,41,54,70-72] were eligible for quantitative synthesis. Nevertheless, parameters were different in terms of the bracket type (STD, ASL, PSL), sliding velocity (from 0.5 to 6 mm/min), inter-bracket distance (from 4.5 to 11 mm), number of brackets tested (from 1 to 5), wire material (SS, titanium-molybdenum, or NiTi), wire size (0.014″, 0.018″, 0.016″ × 0.022″, 0.017″ × 0.025″, 0.019″ × 0.025″, or 0.021″ × 0.025″), and thus a quantitative synthesis was not possible (Tables 2–4). Besides these discrepancies, it would have been difficult to attribute the differences in RS to any of the reported variables because of the scarce information on the applied normal force.

Suggested protocol

A 23-step operative protocol (Table 5) was suggested to standardize and improve the quality of future studies. Unfortunately, the standardization of some parameters, such as the tying force of the metallic ligatures, is far from being practical, making it controversial to control the applied normal forces.[73] In fact, only a few studies attempted to quantify the ligation force in standard brackets.[74] Regarding SL brackets, although in ASL and IASL brackets the force of the closure system can be measured through the constant of elasticity of the clip,[67] comparisons between different types of brackets are still challenging. Lastly, in agreement with their definition, PSL brackets have no active component and thus no normal force is generated by the ligating system of the bracket. In this case, it is the wire (through its elastic deformation) that generates the normal force by contacting the walls of the slot. Although this also happens on the surface of the slot of standard brackets, the contact of a wire against a rigid closure clip is a particular characteristic of PSL brackets.[10] Whereas in PSL brackets normal forces are determined only by the wire, they may result from the elastic deformation of both the wire and ligating system in other bracket types.

Table 5. Step-by-step protocol

Category	Step	Item	Description	Suggested standard
Materials	1	Bracket	Define bracket type, width/height/depth of the slot, its angulation/inclination/in-out prescription, and its material. Surface evaluation is suggested.	
	2	Archwire	Define wire size, material, and form. Surface evaluation is suggested.	
	3	Ligature	Define ligature size, material, and relaxation time (if elastic). Surface evaluation is suggested.	
Experimental setup	4	Hypothesis	Set the null hypothesis selecting the independent and dependent variables, with particular attention to confounding variables.	
	5	Measurements	Define friction type and respective methods to calculate static and dynamic friction. Measure the force utilizing load cell proportioned to the expected range of values.	Load cell 30% > experimental max force
	6	Randomisation	If different materials are tested, test them in random order.	
	7	Data recording	Check that the data recording setup is compatible with the experimental requirements (expected range of values, sampling rate, background noise).	Sampling rate >10 Hz
	8	Material quality	Use material from closed packages, and that they are not altered. Better if chosen from different production lots. Verify data declared by the manufacturer with direct measurements.	
	9	Holding system	Verify the stability of the device by applying forces to the components supposed to be static (e.g. the bracket). Perform mechanical testing at forces ≥ to the experimental forces.	Mobility ≤ 100 μm
	10	Bracket alignment	The bracket slot shall be aligned in a standardized null (reference) position. Use a full size archwire for each specific slot size.	21.5 × 28 mil archwire in 22 × 28 mil slot
	11	Bracket fixation	Bond the bracket using the aligning wire. Methods which may alter materials properties (e.g. welding) or introduce stress (e.g. bending) shall be avoided.	Light curing composite resin
	12	Bracket mobility	Test bracket mobility on the axis of the experimental force.	No mobility at force 30% > experimental max force
	13	Archwire alignment	Test wire alignment respect to bracket slot during sliding in absence of ligatures. The absence of applied normal forces should result in the absence of frictional forces.	
	14	Archwire fixation	Fix the wires to the machine with clamps. Fixing methods which may alter materials properties (e.g. welding, soldering) or introduce stress (e.g. bending) shall be avoided.	Clamping
	15	Archwire mobility	Test wire mobility on the axis of the experimental force.	No mobility at force 30% > experimental max force
	16	Material cleaning	Cleaning materials and use gloves to prevent hand oil to act as a lubricant, and to remove possible residual substances from manufacturing process.	99% ethanol
	17	Number of tests/ statistics	Repeat all tests 10 times. Tests and statistical analysis shall be performed by a blinded operator.	

Table 5. Continued

	Step	Item	Description	Suggested standard
Variables	18	Velocity	A velocity compatible with the experimental setup is suggested.	1 mm/min*
	19	Duration/ displacement	A displacement similar to a monthly orthodontic tooth movement (or a respective duration to achieve a similar displacement) is suggested.	5 mm or a respective duration to achieve 5 mm*
	20	Environment	Record the room or chamber temperature. Choose either wet or dry conditions.	Room temperature 20–25°C or mouth temperature 37°C*
	21	Elastic ligature relaxation	In case elastic ligatures are used.	5 min*
	22	Ligating force	Preliminary tests should be carried to measure the ligating force (e.g. generating a minimum displacement of a ligated archwire on a direction perpendicular to the base of the bracket). If metallic ligatures are used, decide a fixed number of turns to be performed clamping the ligature at a fixed distance from the slot.	5 turns from 10 mm*
	23	Setup	Number of brackets tested simultaneously. If any: torque moment, experimental angulation/inclination/in-out, vertical misalignment, inter-bracket distance.	

1 mil = 1/1,000 inch.
*Applicable if the item is not the outcome variable.

CONCLUSION

Because of the numerous variables involved and lack of measurement of the applied normal forces, the contributions of the bracket, wire, ligature, and environmental factors to RS still require further analysis. Despite the legitimate aim to investigate complex clinical questions, the objectives of mechanical *in vitro* studies should be in proportion to their technical intrinsic limitations. Accordingly, the hypothesis should be specific enough to allow clear identification of the causal effects of experimental variables on RS. A protocol was suggested to achieve more objective evaluations and more relevant applications of *in vitro* findings to clinical treatments.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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