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Quantifying Resistance to Sliding in Orthodontics: A Systematic Review

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Authors' contributions

This work was carried out in collaboration between all authors. Authors HT, PT and GW designed the study. Data collection, reviewing of the collected studies and writing the first draft of the manuscript were performed by author HT. Additional reviewing and cross checking of findings were performed by the authors MCLP and GW. Mechanical and material-related aspects were checked by author JPC. All authors read and approved the final manuscript.

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ABSTRACT

Objective: The present article aims to review all the *in vitro* experimental setups available in literature used to evaluate the resistance to sliding (RS) in orthodontics in correlation with other related parameters.
Methods: An electronic search was performed in three different data bases including all articles published until 20th February 2016. Additionally, a manual search through the reference lists of the collected records was performed. Studies that addressed different experimental setups to evaluate RS were selected, reviewed, and grouped per research group. The experimental setups were

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compared and assessed based on their degree of clinical simulation.
Results: A total of 1380 non-duplicate records were primarily selected in the electronic search. After applying the selection criteria, only 189 studies were considered eligible.
Conclusion: The clinical simulation of each setup varied based on the aim of the performed investigation. None of the included experimental setups could achieve a full clinical simulation by studying several variables synergistically in a scenario as similar as possible to the oral environment.
Clinical Relevance: Unfortunately, *in vivo* evaluation of RS is not possible so far. Therefore, reviewing the *in vitro* methods and analyzing them on the light of the clinical situations they represent, would be of a great clinical benefit. Deeper understanding of this multifactorial phenomenon will help improving the current *in vitro* designs with an obvious clinical impact.

Keywords: Experimental design; friction; resistance to sliding; in vitro techniques; orthodontics; systematic review.

1. INTRODUCTION

The lowering of the resistance to sliding (RS) in contemporary orthodontics is a matter of interest when introducing new materials. However, RS is determined by many variables, such as biological parameters (saliva, plaque, pellicle, tissue response, etc.), mechanical characteristics (i.e. angulation, degree of malocclusion, etc.) as well as physical and chemical material properties [1]. Many investigations have been carried out over the past decades to evaluate the friction generated between brackets and archwires in correlation with these variables [2-8]. However, they actually reported RS, which is not interchangeable with the term "friction". So, it is important to differentiate between the two terms. From a mechanical point of view, friction is defined as "the resistance to motion during sliding or rolling that is experienced when one solid body moves tangentially over another with which it is in contact" [9]. RS is a more comprehensive concept than friction as it includes other components that resist sliding such as binding and notching [10].

Evaluation of the influence of each of the parameters involved in RS separately is not feasible *in vivo* since the RS is a multi-factorial process [1,11]. Moreover, a full *in vitro* clinical simulation has not been accomplished so far, presumably because of its technical difficulty. Such capabilities would allow a high standard of basic hypothesis testing, product development, quality control, and product performance evaluation with relative ease [12]. For these reasons, there have been many *in vitro* experimental trials to simulate certain clinical scenarios. The degree of clinical simulation has varied depending upon the purpose of each investigation, i.e. the desired clinical simulation and the available capabilities.

1.1 Objectives

The purpose of this study is to review all the experimental *in vitro* setups reported in literature for the evaluation of RS of orthodontic materials and the investigation of their capabilities and degree of clinical simulation in order to answer the following research question: What is the most ideal or controlled way to quantify resistance to sliding in orthodontics taking into account the various clinical conditions?

2. MATERIALS AND METHODS

2.1 Protocol

A systematic review structure has been followed, whose protocol was developed prior to the start. The reporting of this review follows the PRISMA guidelines (www.prisma-statement.org) [13].

2.2 Information Sources and Search Strategy

An electronic search was performed in three different data bases, namely The MedLine Database (Entrez PubMed, www.ncbi.nim.nih.gov), Web of Science (Inspec Database, apps.webofknowledge.com), and Grey Literature Report of the New York Academy of Medicine (www.greylit.org). The search included all studies published in literature until February the 20th 2016. No language restrictions were taken into account. A search string of keywords was developed based on the terms "friction" and "orthodontics" which are the most commonly used keywords in the studies of interest. Other keywords related to the aim of this review were also included in the search string, such as "*in vitro*", "test" or "technique" (Table 1).

Table 1. Electronic search string details

Data Base	Keywords (search strategy)
Pubmed From inception until 20th of February 2016	(Orthodontic[all fields] OR ("orthodontics"[MeSH Terms] OR "orthodontics"[all fields])) AND (Friction[all fields] OR Frictional[all fields] OR Resistance[all fields]) AND ((In vitro[all fields]) OR (Technique[all fields]) OR (model[all fields]) OR (study[all field]) OR (test[all fields]))
Web of Science (Inspec) From inception until 20th of February 2016	TS=(Orthodontic OR Orthodontics) AND TS=(Friction OR Frictional OR resistance) OR CL=(A0600)
Grey Literature Report From inception until 20th of February 2016	Friction AND/OR Orthodontics

2.3 Eligibility and Study Selection

The inclusion and exclusion criteria listed in Table 2 were established according to the PICO format as follows:

- Problem: RS could not be evaluated *in vivo* so far, and the high number and variability of the *in vitro* studies make it difficult to clearly state how these *in vitro* methods are related to the clinical background in order to fully understand RS.
- Intervention: reviewing all experimental designs published in literature.
- Comparison of the reviewed designs in terms of capabilities, limitations and degree of clinical simulation.
- Outcome: improving the knowledge of the limitations and capabilities of the current designs. Being aware of the shortages of experimental designs helps to develop an improved, more clinically oriented model that could result in a better understanding of RS.

The initial study selection was based on titles and abstracts. Next, the reference lists of the selected studies were additionally checked manually. Then, all the selected studies were read in full text to verify their suitability. Based on the full-text reading, they were grouped per research groups, and checked for the experimental setup used and the testing conditions. From the same research group, only the first paper describing the experimental setup was selected, while the remaining papers were selected only if they described different testing conditions. The collection of data and reviewing of the collected studies were performed by the first author. Additional reviewing and cross checking of findings were performed by the second and the corresponding authors independently.

2.4 Setup Evaluation and Data Collection Process

The studies included in this review were grouped according to the experimental setup used. Different research groups using similar experimental setups were grouped together with the first research group describing that setup, and they were collected under the term "*others*" in Appendices I and II. In case that more than one setup was developed by the same research group, they were marked by Latin numbers in Appendices I and II. After that, every research group was subjected to a developed methodology assessment questionnaire (Table 3). That questionnaire consisted of "Yes" and "No" questions, each of them describes a clinical scenario or a criterion. "Yes" indicated that the criterion could be performed by the setup, while "No" indicated that the criterion could not be performed by the setup or the information was not reported. The scoring of results is as follows: "Yes" = 1 points and "No" = 0 points. Based on the questionnaire, a score was given to each setup which indicated the degree of clinical simulation achieved with that experimental setup (Appendix I). The data of different testing conditions in each research group were extracted and piloted to provide a more comprehensive overview on the different methodologies (Appendix II).

Table 2. Eligibility selection criteria

Inclusion criteria	Exclusion criteria
1-Studies considering and/or quantifying friction in orthodontic tooth movement using bracket/archwire system under different conditions. 2-Studies evaluating aspects possibly affected by friction 3-Studies evaluating material and mechanical properties possibly affecting friction.	1-Editorial letters, opinions, comments and reviews. 2-Studies considering frictional properties not related to orthodontics. 3-Studies related to orthodontics but not related to frictional properties. 4-Studies considering other orthodontic treatment modalities. 5-Studies considering other forces not in the context of RS (e.g. Interdental or occlusal forces). 6-Studies considering biologic effects of materials used in orthodontics.

Table 3. Methodology assessment protocol

Study Title:	1st Author:	Journal:	Year:	Vol:	Page:
1.	Did the setup imitate a clinical situation? ☐Yes ☐ No				
2.	Did the setup permit repeated contact (reciprocal sliding)? ☐Yes ☐ No				
3.	Did the setup permit labiolingual displacement simulation? ☐Yes ☐ No				
4.	Did the setup permit occlusoapical displacement simulation? ☐Yes ☐ No				
5.	Did the setup permit tipping simulation? ☐Yes ☐ No				
6.	Did the setup permit torque simulation? ☐Yes ☐ No				
7.	Did the setup permit evaluation of effects of variable inter-bracket distances (IBD)? ☐Yes ☐ No				
8.	Were the test brackets mounted in a way similar to the dental arch form (convex pattern)? ☐Yes ☐ No				
9.	Was the setup reported to perform in environment simulating oral medium? ☐Yes ☐ No				
10.	Did the setup permit evaluation of variable change in temperature? ☐Yes ☐ No				
11.	Did the setup permit evaluation of different ligature materials (ligature-dependent ligation)? ☐Yes ☐ No				
12.	Did the setup allow machine-controlled normal/ligation force application? ☐Yes ☐ No				
Score:	Comments:				

Yes = 1, No = 0

3. RESULTS

3.1 Study Selection and Study Characteristics

A general overview of the performed electronic search and study selection is shown in a flow diagram following the PRISMA guidelines [13] (www.prisma-statement.org) (Fig. 1). The initial search retrieved 1,416 records from all data bases (1,162 PubMed, 254 Inspec, 0 Grey Literature Report). Once duplicates were removed, 1,380 records were screened. By checking manually the reference lists of the included studies, a total of 15 records was further included. 1,005 records were excluded for not matching the aim of this review. 390 study were read in full, from which 200 study were excluded for not matching the selection criteria listed in Table 2. One additional non-

English study was further excluded for the inability to translate the text (n = 201). We contacted the authors for help but we got no response [14]. A total of 189 studies were considered eligible and finally included in this review.

3.2 Setup Evaluation and Study Characteristics

From the 189 studies, 98 groups were identified, each of them representing a different experimental setup. However, there is no clear cut among the experimental setups. Details of methodological score results of every setup are shown in Appendix I, while the details of different testing conditions are shown in Appendix II. Scoring varied based on the degree of clinical simulation achieved by every setup. The higher the score, the more clinical scenarios could be achieved by a given setup, and the closer it will be to the *in vivo* state. None of the setups included in this review achieved a score higher than 7 out of 12. The highest score was achieved by the setup developed by Kusy research group [5,15-17] (Appendix I). In their setup, a single-pass, straight-line traction was used to slide an archwire relative to a single test bracket between two movable rollers simulating different inter-bracket distances (IBDs) under various amounts of static tipping. Their system allowed either wet or dry interface testing under thermocouple controlled temperature. On the other hand, the lowest score of 1 was given to the setup developed by Major research group [18] (Appendix I), as insufficient information was reported about the full capabilities of that setup. In their setup, a Teflon guide applied a load of 500 g on the test wire which was pulled over either lateral or inter-wing surfaces of the test bracket (single surface contact interface). Their tests were performed under dry conditions and no information was reported on other media simulation and/or temperature control.

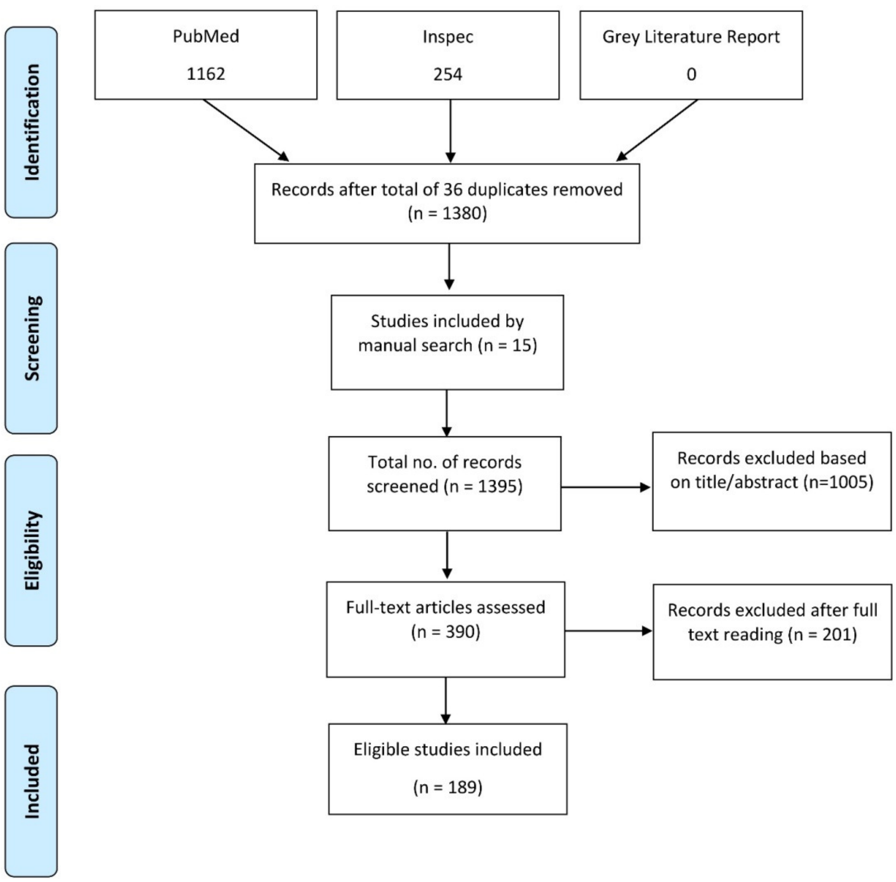

Fig. 1. Illustrative PRISMA diagram flow

None of the reviewed *in vitro* studies was able to fully replicate several clinical conditions at the same time. The testing conditions varied based on the research groups and the desired clinical simulations. The counter-bodies used in the setups were either brackets [19-21], flats [22] or disks [23]. The ligation force was mostly ligature-dependent [24-26], and an average of 200 g force was applied. Tipping ranged from 0° to 13° [5], while other displacements, such as apical or labial, ranged from 0 to 4 mm [27,28]. A range of 50-200 g suspended loads was also used to express tipping (produced tipping moment) by offset suspension of a mass [11]. The inter-bracket distance (IBD) varied from 8 to 18 mm [16]. The simulation of the oral medium was achieved by using either human saliva [29], artificial saliva [30] or by applying different degrees of humidity [6,31].

4. DISCUSSION

4.1 Setup Evaluation Protocol

As previously mentioned, the aim of this systematic review was to examine and compare the experimental designs used to quantify RS. Up to our knowledge, a similar work was never undertaken before. It is widely accepted that RS clinically affects treatment time in orthodontics [32]. Many variables have been described as influencing RS, such as material surface conditions [15] and material elasticity [27]. However, it is also acknowledged that RS is difficult to be evaluated *in vivo*. For this reason most of the studies follow *in vitro* models. There is a huge amount of very important information derived from those *in vitro* studies, including the possibility to design a more accurate, controlled method to evaluate RS. However, unfortunately, none of the validated tools for assessing risk of bias of the included studies can be used in this case. Even so, we find it worthwhile to analyze the existing information, and for that we designed a specific evaluation protocol that contains different studied clinical situations to assess the experimental designs as discussed later. Even with the obvious disadvantages, this is a standard procedure as performed in other studies [33].

The items selected in this evaluation protocol, based on the idea of full *in vitro* simulation of the *in vivo* conditions, represent different clinical situations that have been previously studied and reported in literature. All clinical scenarios reported in literature were included in this protocol except sliding velocity and occlusal forces (Table 3). Because of the complexity of achieving a speed comparable to the rate of orthodontic tooth movement (OTM) *in vitro* due to time limitations and mechanical considerations, the sliding velocity was not selected as a criterion in the established methodology assessment protocol. *In vitro* studies of orthodontic RS typically report values of either static (occurring instantaneously up to the initiation of sliding) or kinetic (occurring after the onset of sliding) frictional resistance as distinctly separated phases [34]. However, *in vitro*, this can be arbitrary and potentially misleading because at such low velocity, static and kinetic frictional resistances are dynamically related [34]. As the force required to initiate sliding by overcoming static friction is usually higher than kinetic friction [10], clinicians should be alert to the amount of force expected to be lost on overcoming static friction [35]. That is why laboratory tests were performed under relatively high velocities to distinguish between both. At the same time, occlusal forces were not included because their simulation is technically difficult, as they are not constant inter or intra individually, and they depend on other factors such as the facial or muscular pattern [36].

4.2 Clinical Significance

The established evaluation protocol contains all those parameters with evidence in literature of having a clinical influence in RS. It is not possible to decide what the most ideal way to evaluate RS is, but in our opinion, the more clinical scenarios replicated in a controlled way by a setup, the closer it would be to the real clinical conditions, and therefore better materials can be designed for most optimal use in those same clinical conditions. Our assessment does not aim to state that a particular setup is not adequate for the evaluation of the specific parameter for which it was designed, but to merely confirm that it is only evaluating that specific parameter. However, findings cannot be extrapolated to the clinical environment because both the experimental conditions and the *in vivo* conditions are not comparable. Although the specific setup may deliver reliable and accurate results, in the clinical environment these findings may be irrelevant or less prevalent because of the more complex *in vivo* interactions [32]. By including as many parameters as possible in a systematic and controllable way in one model, several variables could be evaluated either separately or synergistically, and because RS is a multifactorial event [37], a better understanding to this phenomenon could be achieved, which can certainly be of a great clinical benefit.

4.3 The Evaluation Protocol

The items used to compare the various experimental setups included the following studied clinical scenarios:

4.3.1 Clinical simulation

This was considered suitable when the design used a bracket/archwire interface to evaluate RS. Other interfaces such as flats, surfaces or disks were not considered as suitable alternatives because of differences in contact geometry between interfaces, and because they limit the investigation to the impact of materials only [22,38]. Moreover, using flats as counter-body instead of brackets would not be associated with archwire flexure against the bracket slot, which is involved in the resultant normal force as discussed later [12].

4.3.2 Reciprocal sliding

The majority of experimental setups used single-pass sliding (Appendix II). Reciprocal sliding is of great importance to simulate the actual OTM, because it is a discontinuous, dynamic motion instead of a continuous, linear one [6]. Also, using reciprocal, oscillating sliding instead of single-pass, linear sliding was reported to affect the results of RS evaluation differently [6].

4.3.3 Displacements and angulations

Clinically, a situation where there is no initial angulation or misalignment between bracket and archwire does not exist. Furthermore, binding and bracket/archwire angulation have an influence on RS [5]. So, it is very important to simulate at least some different tooth positions in a 3D space. Similarly, setting test brackets in arch-form is closer to the real clinical conditions than using single test brackets or aligning several brackets parallel to the wire, which was also reported to affect RS [39]. However, the assumed zero-angulation state was used in many designs to evaluate other variables except displacements, such as ligation technique [40] or archwire size [30,41].

4.3.4 Variability of the inter-bracket distance (IBD)

The IBD varies depending upon the anatomical tooth position in the arch and the degree of malocclusion [29]. Therefore, it was found to be an important criterion that should exist in a setup for better clinical simulation.

4.3.5 Oral atmosphere and temperature changes

Designs suitable for performing tests under wet [42] or humid conditions [6] were considered to have an adequate environmental simulation, as sliding occurs actually under such conditions.

4.3.6 Ligature and ligation force application

Regarding ligation force application, the setups could be classified into three different categories: 1- Ligation force applied by the operators. This enables them to evaluate the influence of different ligature materials on RS [43-45], but it presents a risk of bias because of two factors: first, when metal ligatures are used, the ligation force may differ from one operator to another or even within the same operator. Second, when elastic ligatures are used, the force applied may decay over time [46]. 2- Studies where the ligation force was applied directly by the testing machine [5,18,47]. In such setups, a full control on the applied ligation force was achieved, although the influence of different ligature materials on RS could not be investigated. 3- Studies combining both ligation systems, where a known weight was applied directly to the ligatures [48]. In this case, both the amount of ligation force and the effect of ligature material could be investigated.

4.4 Relationship between Clinical Simulation and Evaluation of RS

The experimental setups included in this review and their simulated clinical scenarios can be generally grouped into two main categories (Table 4):

4.4.1 Archwire/bracket combination

In this category test brackets were used as counter-bodies. This is more clinically relevant than other types of counter-bodies, and allows the investigation of the influence of bracket materials, design, and dimensions on RS. Based on sliding conditions, this category can be divided into two groups:

4.4.1.1 Single-pass sliding

This group can be further divided into two subdivisions based on angulation:

4.4.1.1.1 No angulation

Archwires straight-line sliding through brackets parallel to brackets' slots. These setups, where second and third-order bracket angulations were kept at zero degrees, have been used to assess the influence of material, bracket design, bracket and wire dimensions, impact of saliva and different types of ligation [42,49,50]. The basic clinical scenario simulated was canine retraction or space closure with sliding mechanics [42,49,50]. However, the assumption that there is no angulation among the teeth is inaccurate, and OTM is not an entirely linear motion.

4.4.1.1.2 Associated with 1st, 2nd and/or 3rd order of angulation

Archwires sliding through brackets with various static amounts of 1st, 2nd or 3rd order of angulation (mostly evaluated separately). Studies of this group assess the contribution of bracket, archwire, and ligation types to RS while fixing orders of angulation at quantified increments, allowing the investigation of the influence of various amounts of angulation and displacement on RS [16,51-54]. Sliding mechanics during deflection, misalignment or malocclusion were the basic clinical concepts simulated in this group besides the tipping generated after the alignment phase. Archwire guided bodily OTM undergoes a force in the opposite direction of movement generated by tissue surrounding the root, leading to a tooth rotation around its center of resistance (tipping) [3]. Eventually, this will increase the load at the contact points between wire and bracket, and elastic deformity of archwire, producing anti-tip and anti-rotational movements of the teeth [3,11]. In some designs, approximated dental centers of resistance have been simulated to indirectly quantify second-order angulation effects of a stationary bracket relative to a linear archwire traction [11,55,56]. A quantified moment is generated to create a proportional second-order angulation which is –in this case- not directly quantified but rather indirectly described in terms of the induced second-order moment. Again, an accurate simulation of OTM during the alignment phase is technically difficult because the displaced tooth does not remain in its position during alignment, and tooth movement is 3D in space. Due to this, tooth displacements and angulations are expressed apart *in vitro*. In the case of a static fixed amount of tipping, the anti-tip (uprighting) moment created *in vivo* by the elastic deformation at the bracket/archwire interface is overpowered, leading to a permanent deformation of the archwire and a greatly increased RS [57].

A subdivision of this group used a test bracket mounted with rotation freedom on a rotating disc. This subgroup differs in its passivity of second-order angulation or tipping. The evaluation was performed under conditions of zero torque, but with passive self-centering tip [1,58], allowing the bracket to passively rotate through 360° of 2nd order angulation, and attempting to eliminate 2nd order binding as a potential confounding variable [12].

Another subdivision of this group used a test bracket fixed on a tooth simulation or a dentoalveolar model. Biologic tooth movement was simulated through the application of a retarding force applied to the carriage-mounted housing, or through the viscosity of a polymer [3,57]. One of the most important features of this experimental design is the full 3D mobility of the simulated tooth although it was not fully controlled by force transducers in all planes of movement [3,57]. That makes it theoretically possible to simulate repeated tipping and uprighting cycles.

4.4.1.2 Reciprocating sliding

This group can be further grouped into two subdivisions based on angulation:

4.4.1.2.1 No angulation

Archwires straight-line sliding through brackets parallel to bracket slots (2nd and 3rd orders of angulation were kept at zero degrees) allow the investigation of the influence of bracket/archwire materials, design, and dimensions in addition to the impact of environmental medium and different amounts of ligation force, as well as the relationship between RS and wear, and the tribological behavior of materials [6,47]. Reciprocating motion with small repetitive displacements (back-and-forth movements) was used in this group. It approximates more to the real clinical scenario than linear single-pass regime because OTM is a dynamic and discontinuous motion with repetitive cycles of movement until the desired position is reached [59]. Reciprocating motion takes into consideration the resultant adhesive wear on interacting vibrating contacts which has an impact on RS [6].

4.4.1.2.2 Tipping

In this group, a rotational reciprocal motion was used (similar to pin-on-disk friction tester but with test bracket as a counter-body) allowing the investigation of RS and the degree of wear in addition to the impact of different bracket materials and design on RS [60]. This system can measure circular or reciprocating movements with various angular speeds. The used design allowed a gradual, continuous angular change in tipping [60].

4.4.2 Archwire/flats or disks

In this category, contact flats or disks were used as counter-bodies made of materials similar to brackets. Based on the sliding conditions, this category can be divided into two groups:

4.4.2.1 Single-pass sliding

Archwires straight-line sliding or traction through contact flats under variable amounts of ligation force and under different environmental settings [22,38]. It was assumed that an experimental setup must maintain a constant area of contact between sliding materials while ligation force is applied in order to measure the coefficient of friction [22]. However, the normal force on an archwire is clinically affected by either ligation force or wire flexure against the bracket slot [12], and such effects cannot be seen using contact flats, as wires do not show flexure under the pressure of the flats.

4.4.2.2 Reciprocating sliding

Pin-on-disk type friction tester, where the wire was pressed against a disk in a rotational reciprocating motion, allows the investigation of RS and the degree of wear between two materials [23,61]. Movements such as circular or reciprocating can be measured with various angular speeds.

So far, none of the setups published in literature permits a full, controlled 3D movement between bracket and archwire. The use of dental replicas can give an overall idea about the position of teeth in 3D space and its relation to RS, but a separate evaluation of each order of angulation can still not be achieved [29].

4.5 Testing Conditions

Different counter-bodies were used in setups, such as brackets [62], flats [38] or disks [61] (Appendix II). The setup capability is affected by the type of counter-body used as previously mentioned. The ligation force was mostly achieved through ligatures, which is close to clinical situation. A ligation force average of 200 g was applied because it is comparable to the force applied by elastic ligatures [6]. It is very important to decide how to simulate the oral atmosphere in a setup. Human saliva or artificial saliva were mostly used as wet testing media. Human saliva has the advantage of being similar to clinical situations, although differences in viscosity among operators or degree of salivary stimulation may lead to different findings. However, non-significant differences on using human saliva of different viscosities were reported [63]. The period of exposure to saliva or wet medium may have an effect on the elastomeric ligature degradation in a way affecting RS [64]. No common trend of testing distance or testing time is noticed, however, many setups used a range of 8-18 mm sliding as it represents the distance of canine retraction into the extracted first premolar space [1,3,30]. Similarly, no common trend is applied to sliding velocities, which were relatively high as previously mentioned. The environmental temperature during testing, which was reported to influence RS [52], was usually room temperature under dry test conditions or around 37°C under wet test conditions to simulate body temperature.

4.6 RS Evaluation in a Controlled Method and Its Technical Complexity: A Proposal

Researchers have been aiming to provide improved, simple and repeatable designs in order to evaluate RS in a controlled manner. It is a fact that the current setups evaluate RS under one or two controlled parameters while others are isolated depending on the aim of the intended investigations. To fully understand RS and the *in vivo* interactions that take place, we should ideally think about evaluating RS involving interaction with more parameters. It is technically difficult to control many parameters at the same time, as well as it may increase the source of error. However, in our opinion, efforts should be directed toward achieving a clinical simulation as complete as possible by technical and practical improvement.

It could be concluded that single-pass motion together with a straight line traction are not the best way to simulate OTM. For *in vivo* simulation,

Table 4. Classification of experimental designs and their limitations

Combination type	Sliding direction	Angulation	Limitations
1-Archwire/Bracket	a- Single-pass	i- No angulation	-No angulations or displacements. -Reciprocal sliding was not used.
		ii- 1st, 2nd or 3rd order	-Static, fixed amounts of angulations were mostly used instead of passive ones. -Displacement types could not be evaluated together. -Reciprocal sliding was not used.
	b- Reciprocal	i- No angulation	-No angulations or displacements. -Only single test brackets were used.
		ii- Tipping	-Only single test brackets were used. -Other types of displacements could not be evaluated.
2-Archwire/Flats, surfaces or disks	a- Single-pass	No angulation	-Studies were limited to material surfaces only. -Different contact geometry. -Reciprocal sliding was not used.
	b- Reciprocal	No angulation	-Studies were limited to material surfaces only. -Different contact geometry.

a design should be able to evaluate RS with integrated angular, linear and reciprocating movements as a function of time. The possibility of adding more axes of rotation to test brackets (or even wires) can be used to evaluate more orders of angulation to accurately assess RS in a 3D relationship, although it can be technically complicated. Setting multiple, movable test brackets on an arch will combine variable IBDs and curvatures of the arch on RS, and this, with different orders of angulation, will be a valuable tool to achieve different situations of malocclusion *in vitro*, linking that to RS. Also, combining ligation force application by a specified load with different ligature materials, will provide more reliable data regarding the influence of ligation on RS. Mounting test brackets to their corresponding archwires should be standardized, and be independent of bracket design. Additionally, an experimental device should be flexible to accommodate user-specificity. In order to reproduce oral atmosphere experimental settings, it would be desirable to obtain an environmental chamber that allows full control on temperature, humidity and medium of testing. However, the possibility to immerse test materials in a wet test solution could be advantageous to further investigate the influence of corrosion on RS.

5. CONCLUSION

Several *in vitro* designs were developed to isolate different variables influencing RS for specific purposes depending on the aims of the investigators. Generally, they used different techniques to quantify and to compare the mechanical efficiency of several bracket, archwire, and ligation combinations under different test conditions.

The so called “ideal experimental setup” or “the best way to evaluate RS” does not exist so far. However, the more clinical scenarios can be replicated by an experimental setup in a controlled way, the closer it would be to the clinical conditions. As RS is multifactorial, a design achieving various clinical scenarios and different setup combinations under full control would be desirable to investigate the influence of different related parameters in RS, either separately or synergistically, although it is indeed technically difficult.

Finally, operators should be aware of the testing conditions, and the fact that changes in these conditions will influence the outcome and degree of clinical simulation.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Appendix I. Methodological score results of research groups' setups

Research Group (RG)	Clinical Imitation?	Reciprocal Sliding?	Labio-lingual?	Occluso-apical?	Tipping?	Torque?	Variable IBD?	Arch form set?	Oral atmo-sphere?	Variable tempera-ture?	Ligature materials?	Ligation force applied?	Score
I-Major RG [18]	×	×	×	×	×	×	×	×	×	×	×	✓	1
Chang RG [65]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Freer RG & others [66,67]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Hooshmand RG [24]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Hsu RG & others [21,68-70]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
I-Franchi RG [71]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
II-Franchi RG & others [72,73]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
II-Lin RG [74]	✓	×	×	×	×	×	×	×	×	×	×	✓	2
I-Nanda RG& others [58,75,76]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
I-Oliveira RG [77,78]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Ireland RG [44]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Kahlon RG & others [45,79-83]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Kailasam RG [84]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Kapila RG [1]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Kim RG [85-87]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Lombardo RG [88]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Mendes [43]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Taylor RG [41,89,90]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Voudouris [91]	✓	×	×	×	×	×	×	×	×	×	✓	×	2
Basting RG & others [40,92,93]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Berger RG [94,95]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Braun RG[96]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Dhopatkar RG & others [49,97-99]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Khalaf RG [100]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Khambay RG [101]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Pliska RG [56]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Pratten RG [102]	✓	×	×	×	×	×	×	×	✓	×	×	✓	3
Stannard RG & others [22,38]	×	×	×	×	×	×	×	×	✓	✓	×	✓	3
Suwa & Watari RG [103]	✓	×	×	×	×	×	×	×	✓	×	×	✓	3
Tecco,Baker &others [42,50,104-107]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Wichelhaus RG [108]	✓	×	×	×	×	✓	×	×	×	×	✓	×	3
II-Gil RG [109]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3

Appendix I. Methodological score results of research groups' setups (Cont.)

Research Group (RG)	Clinical Imitation?	Reciprocal Sliding?	Labio-lingual?	Occluso-apical?	Tipping?	Torque?	Variable IBD?	Arch form set?	Oral atmo-sphere?	Variable tempera-ture?	Ligature materials?	Ligation force applied?	Score
Almeida RG [110]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Baccetti RG&others [7,111]	✓	×	×	✓	×	×	×	×	×	×	✓	×	3
Bandeira RG [112]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Bednar RG [55]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Bolognese RG & others [113,114]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Brauchli RG [115]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Cacciafesta RG [116]	✓	×	×	×	×	×	✓	×	×	×	✓	×	3
Camporesi RG [117]	✓	×	×	✓	×	×	×	×	×	×	✓	×	3
De Franco RG [118]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Dowling RG [119]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Drescher RG & others [3,57,120]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Edwards RG [48]	✓	×	×	×	×	×	×	×	×	×	✓	✓	3
Gandedkar RG [121]	✓	✓	×	×	×	×	×	×	×	×	✓	×	3
Garner RG [30]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Il-Major RG [122]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Il-Oliveira RG [123]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Il-Redlich RG [124]	✓	×	✓	×	×	×	×	×	×	×	✓	×	3
Ioi RG [125,126]	✓	×	×	✓	×	×	×	×	×	×	✓	×	3
Iwasaki RG [127]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Jordan RG [128]	✓	×	×	✓	×	×	×	×	×	×	✓	×	3
Kuroe RG [31]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Monteiro RG [129]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Moore RG & others [130,131]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Namura RG [51]	✓	×	✓	×	×	×	×	×	×	×	✓	×	3
Nicolls [2]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
O'Reilly RG [132]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Oliver RG [53]	✓	×	×	×	×	✓	×	×	×	×	✓	×	3
Ortan RG [133]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Schumacher RG [134]	✓	×	×	×	×	×	×	✓	×	×	✓	×	3
Tanne RG [135]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Wilmes RG [136]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Yamaguchi RG [137]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3

Appendix I. Methodological score results of research groups' setups (Cont.)

Research Group (RG)	Clinical Imitation?	Reciprocal Sliding?	Labio-lingual?	Occluso-apical?	Tipping?	Torque?	Variable IBD?	Arch form set?	Oral atmo-sphere?	Variable tempera-ture?	Ligature materials?	Ligation force applied?	Score
I-Lin RG [138,139]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Pattan RG [140]	✓	×	×	×	×	×	×	×	✓	×	✓	×	3
Reicheneder RG [141]	✓	×	×	×	✓	×	×	×	×	×	✓	×	3
Sukh RG [25]	✓	×	×	×	×	×	×	✓	×	×	✓	×	3
Bagby RG [142]	✓	×	×	×	×	×	×	✓	✓	×	✓	×	4
Boccaccio RG [28]	✓	×	✓	✓	×	×	×	×	×	×	✓	×	4
Downing RG [143,144]	✓	×	×	×	×	×	×	×	✓	✓	✓	×	4
II-Kusy RG [29]	✓	×	×	×	×	×	×	✓	✓	×	✓	×	4
II-Nanda RG & others [4,145]	✓	×	✓	✓	×	×	×	×	×	×	✓	×	4
II-Rock RG [64,146]	✓	×	×	×	✓	✓	×	×	×	×	✓	×	4
I-Rock RG [147]	✓	×	×	×	✓	✓	×	×	×	×	✓	×	4
Lee RG [27]	✓	×	×	✓	×	×	✓	×	×	×	✓	×	4
Normando RG & others [148-150]	✓	×	×	×	✓	×	×	×	✓	×	✓	×	4
Ozcan RG [39]	✓	×	×	×	×	×	×	✓	✓	×	✓	×	4
Rached RG & others [151-153]	✓	×	×	×	✓	×	×	×	✓	×	✓	×	4
Shao RG [154]	✓	×	×	×	✓	×	×	×	✓	×	✓	×	4
Thiry RG [155]	✓	✓	×	×	×	×	×	×	✓	×	✓	×	4
Tidy RG & others [11,19,26,156-165]	✓	×	×	×	✓	×	×	×	✓	×	✓	×	4
West RG & others [166,167]	✓	×	×	×	✓	×	×	×	✓	×	✓	×	4
Andreasen RG [168]	✓	×	×	×	✓	×	✓	×	✓	×	✓	×	5
Artun RG [169]	✓	×	✓	×	✓	×	×	×	✓	×	✓	×	5
Farronato RG [170,171]	✓	×	✓	✓	×	✓	×	×	×	×	✓	×	5
Frank & Nikolai [35]	✓	×	×	×	✓	×	✓	×	×	×	✓	✓	5
I-Gil RG & others [23,60,61]	✓	✓	×	×	✓	×	×	×	✓	×	×	✓	5
I-Redlich RG&others [20,54,172-176]	✓	×	×	×	✓	✓	×	×	✓	×	✓	×	5
Jones RG&others [62,177-180]	✓	×	×	×	✓	×	×	×	✓	×	✓	✓	5
Keith,Jones &others [46,181-183]	✓	×	×	×	✓	×	×	×	✓	×	✓	✓	5
Kusnoto RG &others [184,185]	✓	×	✓	✓	×	✓	×	×	×	×	✓	×	5
Liu RG [52]	✓	×	×	✓	×	×	×	×	✓	✓	✓	×	5
Nucera RG [186-188]	✓	×	✓	✓	✓	×	×	×	×	×	✓	×	5
Sims RG& others [189-194]	✓	×	×	×	✓	✓	×	×	✓	×	✓	×	5
Willems RG & others [6,47,195-199]	✓	✓	×	×	×	×	×	×	✓	✓	×	✓	5
Baek RG [8,200]	✓	×	✓	✓	×	×	×	✓	✓	×	✓	×	6
I-Kusy RG & others [5,15-17,63]	✓	×	×	×	✓	×	✓	×	✓	✓	✓	✓	7

Appendix II. Different testing conditions of research groups' setups

Research Group (RG)	Counter Body	Sliding	Distance &/or Time	Ligation Force	Inter Bracket Distance		Temperature	Medium	Sliding Velocity	Angulation
					IBD	Variability				
Andreasen RG [168]	Bracket	Single-pass	Until sliding	Spring (600g)	7 mm	Variable	N/A	Dry/Saliva	N/A	0°-15° (Tipping)
Bagby RG [142]	Bracket	Single-pass	Until Sliding	By means of ligation	N/A	Fixed	37℃	Artificial Saliva	2 mm/min	No angulation
Bednar RG [55]	Bracket	Single-pass	6.35 mm	By means of ligation	Single Bracket	/	N/A	Dry	12.7 mm/min	100 g (Tip)
Berger RG [94,95]	Bracket	Single-pass	25.4 mm	By means of ligation	Single Bracket	/	N/A	Saline	0.025 - 0.5 mm/min	No angulation
Braun RG [96]	Bracket	Single-pass	N/A	By means of ligation	Single Bracket	/	N/A	Dry	0.1 mm/min	0 – 25.5° (Tipping)
De Franco RG [118]	Bracket	Single-pass	3 mm	By means of ligation	Single Bracket	/	N/A	Dry	0.625 mm/min	0°-15° (Tipping)
Dowling RG [119]	Bracket	Single-pass	10 sec after sliding	By means of ligation	Single Bracket	/	37℃	Wet	1 mm/min	No angulation
Drescher RG &others [3,57,120]	Bracket	Single-pass	10-12 mm	Spring (1 N) or by ligature	Single Bracket	/	N/A	Dry	2 mm/sec or 1 mm/sec	0 - 3 N (Tip)
Freer RG & others [66,67]	Bracket	Single-pass	N/A	By means of ligation	Single Bracket or 3, IBD=7 mm	Fixed	N/A	N/A	0.01 g weight	No angulation
Garner RG [30]	Bracket	Single-pass	10 mm	By means of ligation	Single Bracket	/	N/A	Artificial Saliva	2 mm/min	No angulation
II-Kusy RG [29]	Bracket	Single-pass	2 mm	By means of ligation	N/A	Fixed	34℃	Dry/Saliva	0.5 mm/min	N/A
II-Nanda RG & others [4,145]	Bracket	Single-pass	2 min or 1 mm	By means of ligation	N/A	Fixed	N/A	Dry	0.02 inch/min or 0.5 mm/min	Horizontal/ vertical up to 1 mm
I-Kusy RG & others [5,15-17,63]	Bracket	Single-pass	10-20 mm	0.05 – 1 Kg or by ligature	8 - 18 mm	Variable	34℃	Dry/Saliva (different viscosities)	10 mm/min	0°-13° (Tipping)
I-Nanda RG& others [58,75,76]	Bracket	Single-pass	2 min or 1 mm	By means of ligation	Single Bracket	/	22℃	Dry	0.02 inch/min or 12.7 mm/min	Self-centering tip
Jones RG&others [62,177-180]	Bracket	Single-pass	0.2-8 mm or 2-4 min	100-200 g or ligature	Single Bracket	/	22℃	Dry/Saliva or ArtSaliva	0.5-10 mm/min	0°-12° (Tipping)

Appendix II. Different testing conditions of research groups' setups (cont.)

Research Group (RG)	Counter Body	Sliding	Distance &/or Time	Ligation Force	Inter Bracket Distance		Temperature	Medium	Sliding Velocity	Angulation
					IBD	Variability				
Kapila RG [1]	Bracket	Single-pass	2 min	By means of ligation	Single Bracket	/	N/A	Dry	5.1 mm/min	Self-centering tip
Keith,Jones & others [46,181-183]	Bracket	Single-pass	2 mm or 2 min	50-500 g or by ligatures	Single Bracket	/	N/A	Dry/Water	0.05,3 or 5 mm/min	0°-10° (Tipping)
Moore RG & others [130,131]	Bracket	Single-pass	Until Sliding	By means of ligation	Single Bracket	/	N/A	N/A	10 mm/min	50-150 g (Tip)
O'Reilly RG [132]	Bracket	Single-pass	1 min	No	N/A	Fixed	N/A	N/A	0.5 mm/min	100 g (Tip)
Pratten RG [102]	Bracket	Single-pass	Until sliding	300 g	10 mm	Fixed	N/A	Dry/ArtSaliva	N/A	No angulation
Schumacher RG [134]	Bracket	Single-pass	5 mm	By means of ligation	5-8 mm	Fixed	N/A	N/A	Spring 1 N	No angulation
Sims RG& others [189-194]	Bracket	Single-pass	2-10 min or 5-10 mm	By means of ligation	Single Bracket or 3, IBD= 5 mm	Fixed	24°-37°C	Dry/Wet	0.5-5 mm/min	0°-6° (Tip), 0°-25° (Torque)
Stannard RG & others [22,38]	Contact Flats	Single-pass	11 mm	0.2 – 10 Kg	/	/	34°C	Dry/ArtSaliva	$5x10^{-4}$ – 10 mm/min	/
Tanne RG [135]	Bracket	Single-pass	85 sec	No	Single Bracket	/	N/A	Dry	0.1 mm/sec	N/A
Taylor RG [41,89,90]	Bracket	Single-pass	10 mm	By means of ligation	5 mm	N/A	22°C	N/A	5-10 mm/min	No angulation
Tidy RG & others [11,19,26,156-165]	Bracket	Single-pass	2-10 mm	By means of ligation	8 mm	Fixed	N/A	Dry/ArtSaliva	5-10 mm/min	0 – 200 g (Tip)
Voudouris [91]	Bracket	Single-pass	8 mm	By means of ligation	Single Bracket	/	N/A	Dry	10 mm/min	No angulation
Willems RG & others [6,47,195-199]	Bracket	Reciprocal	100 - 200 µm (20 cycles), 4 mm (1200 cycle) or 0.694 µm/min	1-5 N	Single Bracket	/	20°-37°C	Humid air/ArtSaliva/ aq.solutions	0.5-5 Hz or 1 mm/min	No angulation
Baek RG [8,200]	Bracket	Single-pass	2.5 mm	By means of ligation	N/A	Fixed	N/A	Dry/ArtSaliva	0.5 mm/min	0 – 3 mm (vertical/lingual)
Basting RG & others [40,92,93]	Bracket	Single-pass	1-10 mm or 40 sec	By means of ligation	Single Bracket	/	N/A	Saliva/aq solutions	3-5 mm/min	No angulation
Boccaccio RG [28]	Bracket	Single-pass	Until Sliding	By means of ligation	8.5 mm	Fixed	20°C	Dry	N/A	0-4.5 mm (Apical & Lab.)

Appendix II. Different testing conditions of research groups' setups (cont.)

Research Group (RG)	Counter Body	Sliding	Distance &/or Time	Ligation Force	Inter Bracket Distance		Temperature	Medium	Sliding Velocity	Angulation
					IBD	Variability				
Brauchli RG [115]	Bracket	Single-pass	8 mm	By means of ligation	Single Bracket	/	36℃	Dry	10 mm/min	0 – 10 N mm (Tip)
Cacciafesta RG [116]	Bracket	Single-pass	2 min	By means of ligation	20 mm	Variable	N/A	Dry	2.5 mm/min	No angulation
Chang RG [65]	Bracket	Single-pass	1 min	By means of ligation	Single Bracket	/	N/A	Artificial Saliva	5 mm/min	No angulation
Dhopatkar RG & others [49,97-99]	Bracket	Single-pass	5 or 8 mm	By means of ligation	Single Bracket	/	N/A	Dry/ Saliva/ APF	10 or 20 mm/min	No angulation
Hooshmand RG [24]	Bracket	Single-pass	5 mm	By means of ligation	Single Bracket	/	N/A	Dry	10 mm/min	No angulation
II-Gil RG [109]	Bracket	Single-pass	N/A	By means of ligation	Single Bracket	/	37℃	Artificial Saliva	1 mm/min	No angulation
II-Redlich RG [124]	Bracket	Single-pass	1 min	By means of ligation	4.7 mm	Fixed	N/A	N/A	5 mm/min	2°-5° (Labial)
II-Rock RG [64,146]	Bracket	Single-pass	7 - 11 mm	By means of ligation	Single Bracket	/	N/A	Dry	10 mm/min	0°- 12° (Tip & Torque)
I-Redlich RG&others [20,54,172-176]	Bracket	Single-pass	5-10 mm or 25 sec	By means of ligation	Single Bracket	/	34℃	Dry/Distilled Water	5-20 mm/min or 0.5 mm/sec	0°-15° (Tipping), 0°-30° (Torque)
Ireland RG [44]	Bracket	Single-pass	2 min	By means of ligation	N/A	Fixed	37℃	Dry/Water	5 mm/min	No angulation
I-Rock RG [147]	Bracket	Single-pass	8 mm	By means of ligation	Single Bracket	/	24℃	N/A	20 mm/min	1°-3° (Tip) 2°-6° (Torque)
Iwasaki RG [127]	Bracket	Single-pass	10 – 2 mm	By means of ligation	Single Bracket	/	37℃	N/A	Spring (146 N)	14.6 N mm (Tip)
Kailasam RG [84]	Bracket	Single-pass	20 mm	By means of ligation	Single Bracket	/	N/A	Dry	10 mm/min	No angulation
Khambay RG [101]	Bracket	Single-pass	4 min	By means of ligation	Single Bracket	/	N/A	Saliva	5 mm/min	No angulation
Kim RG [85-87]	Bracket	Single-pass	4-7 mm	By means of ligation	Single Bracket	/	N/A	N/A	10-12 mm/min	No angulation

Appendix II. Different testing conditions of research groups' setups (cont.)

Research Group (RG)	Counter Body	Sliding	Distance &/or Time	Ligation Force	Inter Bracket Distance		Temperature	Medium	Sliding Velocity	Angulation
					IBD	Variability				
Lee RG [27]	Bracket	Single-pass	0.5 mm	No	19 mm	Variable	35℃	Dry	0.05 mm/min	0 – 4 mm (Apical)
Lombardo RG [88]	Bracket	Single-pass	N/A	By means of ligation	N/A	Fixed	N/A	Dry	1 mm/min	No angulation
Normando RG & others [148-150]	Bracket	Single-pass	5 mm	By means of ligation	4-7 mm	Fixed	N/A	Dry/Artificial Saliva	0.5-5 mm/min	0°-10° (Tip)
Nucera RG [186-188]	Bracket	Single-pass	5 mm	By means of ligation	8-14.5 mm	Fixed	35℃	Dry	4-5 mm/min	1 - 2 mm (apical), 1 mm (labial), 0°-13° (Tipping)
Ozcan RG [39]	Bracket	Single-pass	5 mm	By means of ligation	6 mm	Fixed	20℃	Artificial Saliva	20 mm/min	No angulation
Pliska RG [56]	Bracket	Single-pass	N/A	By means of ligation	10 mm	Fixed	N/A	N/A	5 mm/min	2000 – 4000 gmm (Tip)
Rached RG & others [151-153]	Bracket	Single-pass	2 min	By means of ligation	Single Bracket	/	25℃	Dry/Artificial Saliva	1-10 mm/min	0°-10° (Tipping)
Reicheneder RG [141]	Bracket	Single-pass	10 mm	By means of ligation	Single Bracket	/	N/A	Saliva then Dry	12.7 mm/min	250 g (Tip)
Suwa & Watari RG [103]	Bracket	Single-pass	Until Sliding	1.26 – 4.35 N	Single Bracket	/	N/A	Dry/Water	2 mm/min	No angulation
Tecco,Baker & others [42,50,104-107]	Bracket	Single-pass	2-10 mm	By means of ligation	5 mm	Fixed	25-34℃	Dry/ ArtSaliva/ Glycerine	0.5-10 mm/min	No angulation
Wichelhaus RG [108]	Bracket	Single-pass	N/A	By means of ligation	Single Bracket	/	N/A	N/A	20 mm/min	5 N mm (Torque)
Artun RG [169]	Bracket	Single-pass	4 min	By means of ligation	Single Bracket	/	N/A	Artificial Saliva	0.5 mm/min	No angulation
Baccetti RG & others [7,111]	Bracket	Single-pass	15 mm	By means of ligation	19 mm	Fixed	20℃	Dry	6-15 mm/min	0 - 6 mm (Apical)
Bandeira RG [112]	Bracket	Single-pass	1 min	By means of ligation	Single Bracket	/	N/A	Artificial Saliva	3 mm/min	No angulation

Appendix II. Different testing conditions of research groups' setups (cont.)

Research Group (RG)	Counter Body	Sliding	Distance &/or Time	Ligation Force	Inter Bracket Distance		Temperature	Medium	Sliding Velocity	Angulation
					IBD	Variability				
Bolognese RG & others [113,114]	Bracket	Single-pass	5 - 8 mm	By means of ligation	Single Bracket	/	37℃	Dry/ArtSaliva	0.5 - 20 mm/min	No angulation
Camporesi RG [117]	Bracket	Unclear	Until Full displacement	By means of ligation	8.5 mm	Fixed	20℃	Dry	N/A	0-6 mm (Apical)
Downing RG [143,144]	Bracket	Single-pass	2 min	By means of ligation	Single Bracket	/	34℃	Dry/ArtSaliva	5 mm/min	No angulation
Edwards RG [48]	Bracket	Single-pass	1 mm	100-1000 g	Single Bracket	/	N/A	Dry/Saliva	0.5 mm/min	No angulation
Farronato RG [170,171]	Bracket	Single-pass	2 min	By means of ligation	8.5 mm	Fixed	N/A	N/A	1-10 mm/min	0-2 mm (Apical), 0-1 mm (Ling.), 0°-10° (Torque)
Frank & Nikolai [35]	Bracket	Single-pass	Until Sliding	By means of ligation	7-13 mm	Variable	N/A	N/A	N/A	0° - 10° (Tipping)
Gandedkar RG [121]	Bracket	Reciprocal	1 mm (10 cycles)	By means of ligation	Single Bracket	/	N/A	N/A	0.5 mm/min	No angulation
Hsu RG & others [21,68-70]	Bracket	Single-pass	6-10 mm or 1-2 min	By means of ligation	Single Bracket	/	30℃	Dry	0.5-12 mm/min	No angulation
I-Franchi RG [71]	Bracket	Single-pass	12 mm	By means of ligation	Single Bracket	/	20℃	Dry	6 mm/min	No angulation
I-Gil RG & others [23,60,61]	Disk or Bracket	Rotational	90 sec	1-10 N	Single Bracket or Disk	/	37℃	Dry/Artificial Saliva	0.5236 rad/sec or 18.8 mm/min	0°-5° (Tipping)
II-Franchi RG & others [72,73]	Bracket	Single-pass	2 min or 5 mm	By means of ligation	9 mm	Fixed	20 or 34℃	Dry	1-20 mm/min	No angulation
II-Lin RG [74]	Bracket	Single-pass	1 mm	1.47 N	Single Bracket	/	25℃	Dry	6 mm/min	No angulation
II-Oliveira RG [123]	Bracket	Single-pass	Until Sliding	By means of ligation	8 mm	Fixed	N/A	N/A	1 mm/min	0° - 10° (Tipping)
I-Lin RG [138,139]	Bracket	Single-pass	1 min	By means of ligation	12 mm	Fixed	23℃	Dry	83 µm/sec	0° - 23° (Tipping)
I-Major RG [18]	Inter-wing or lateral surface of bracket	Single-pass	10 mm	500 g	Single Bracket	/	N/A	Dry	23 mm/min	No angulation

Appendix II. Different testing conditions of research groups' setups (cont.)

Research Group (RG)	Counter Body	Sliding	Distance &/or Time	Ligation Force	Inter Bracket Distance		Temperature	Medium	Sliding Velocity	Angulation
					IBD	Variability				
Ioi RG [125,126]	Bracket	Single-pass	1.5-3 mm	By means of ligation	4.5 mm	Fixed	24℃	Dry	1×10^{-5} – 1×10^{-1} mm/sec	0-2 mm (Apical)
Khalaf RG [100]	Bracket	Single-pass	Until Sliding	By means of ligation	N/A	Fixed	N/A	N/A	0.5 mm/min	0° - 7° (Tipping)
Kusnoto RG &others [184,185]	Bracket	Single-pass	6 mm	By means of ligation	N/A	Fixed	N/A	Dry	0.5-8 mm/min	3°-6° (DistoPalatal), 0.5-1 mm (intrusion), 3° (Torque)
Namura RG [51]	Bracket	Single-pass	Until Sliding	By means of ligation	N/A	Fixed	N/A	Dry	0.5 mm/min	0.5-3 mm (Lingual)
Nicolls [2]	Bracket	Single-pass	Until Sliding	By means of ligation	Single Bracket	/	N/A	N/A	N/A	0° - 35° (Tipping)
Oliver RG [53]	Bracket	Single-pass	1.5 mm	By means of ligation	N/A	Fixed	20℃	Dry	1 mm/min	0°- 15° (Torque)
Ortan RG [133]	Bracket	Single-pass	2 mm	By means of ligation	Single Bracket	/	20℃	Dry	1 mm/min	0°-10° (Tipping)
Shao RG [154]	Bracket	Single-pass	6 mm	By means of ligation	Single Bracket	/	N/A	Dry/ArtSaliva	0.1 mm/sec	0° - 15° (Tipping)
Thiry RG [155]	Bracket	Single-pass & Reciprocal	3-5 cm	By means of ligation	Single Bracket	/	N/A	Artificial Saliva	0.1 mm/min	No angulation
West RG & others [166,167]	Bracket	Single-pass	2-4 mm	By means of ligation	Single Bracket	/	N/A	Dry/ArtSaliva	10 mm/min	0° - 20° (Tipping)

Appendix II. Different testing conditions of research groups' setups (cont.)

Research Group (RG)	Counter Body	Sliding	Distance &/or Time	Ligation Force	Inter Bracket Distance		Temperature	Medium	Sliding Velocity	Angulation
					IBD	Variability				
Almeida RG [110]	Bracket	Single-pass	10 mm	By means of ligation	Single Bracket	/	N/A	N/A	5 mm/min	0° - 5° (Tipping)
Il-Major RG [122]	Bracket	Single-pass	0.2 mm	By means of ligation	Single Bracket	/	N/A	N/A	0.05 mm/sec	0° - 6° (Tipping)
I-Oliveira RG [77,78]	Bracket	Single-pass	9 mm	By means of ligation	N/A	Fixed	20℃	Dry	0.075 mm/seg	No angulation
Jordan RG [128]	Bracket	Single-pass	4 mm	By means of ligation	6 mm	Fixed	24℃	Dry	2 mm/min	0° - 12° (Apical)
Kahlon RG & others [45,79-83]	Bracket	Single-pass	1 min or 10 mm	By means of ligation	5,7.5 or 10 mm	Fixed	20℃	Dry	0.5-6 mm/min or 2 mm/sec	No angulation
Kuroe RG [31]	Bracket	Single-pass	Until Sliding	By means of ligation	Single Bracket	/	15℃	Humid Air	6 mm/min	No angulation
Liu RG [52]	Bracket	Single-pass	3 mm	By means of ligation	N/A	Fixed	20°-55℃	Artificial Saliva	0.5 mm/min	0-3 mm (Apical)
Mendes [43]	Bracket	Single-pass	9 mm	By means of ligation	Single Bracket	/	N/A	Dry	5 mm/min	No angulation
Monteiro RG [129]	Bracket	Single-pass	2 mm	By means of ligation	Single Bracket	/	20℃	Dry	3 mm/min	0° - 10° (Tipping)
Pattan RG [140]	Bracket	Single-pass	20 mm after peak	By means of ligation	Single Bracket	/	N/A	Saliva	5 mm/min	No angulation
Sukh RG [25]	Bracket	Single-pass	7.5 mm	By means of ligation	N/A	Fixed	N/A	Dry	0.5 mm/min	No angulation
Yamaguchi RG [137]	Bracket	Single-pass	2 mm	By means of ligation	Single Bracket	/	N/A	N/A	0.1 mm/sec	100 – 400 g (Tip)
Wilmes RG [136]	Bracket	Single-pass	70 mm	By means of ligation	Single Bracket	/	N/A	N/A	1 mm/sec	10 N mm (Tip)

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