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ORIGINAL ARTICLE

Comparative Analysis of Stiffness of Lingual Appliances: An *in Vitro* Study

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ABSTRACT

Objective: To analyze and compare the stiffness of different lingual appliances with different archwires. **Material and Methods:** The three-point bending test was used to analyze the stiffness of the lingual archwires for the different lingual systems: eBrace, Harmony, Incognito, and STb. The deflection load curve of each archwire was obtained to evaluate how the section, the material and the manufacturer affect the elasticity and stiffness characteristics of the wires. The comparison of the stiffness between different systems was carried out through a factor variance analysis with three factors (manufacturer, cross-section, and material), followed by the post-hoc Tuckey test. **Results:** An increase in the system's rigidity was reported as the wire section increases, regardless of the manufacturer. The stainless steel archwires have ever higher stiffness values than NiTi and TMA. The STb wires of CuNiTi material, by virtue of the characteristics of the thermal wires, have flatter and lower load-deflection curves than the NiTi wires of other manufacturers. **Conclusion:** Archwires section and material showed a significant influence on the stiffness of the lingual systems. Archwires of the same section and material but different manufacturers show different load-deflection curves of stiffness.

Keywords: Orthodontics; Orthodontic Appliances; Orthodontic Wires; Orthodontic Brackets.

Introduction

Lingual orthodontics appliances became popular in adult patients due to their esthetic appearance. Even if some teeth are missing or implant or prosthesis are present [1,2], or there is no compliance [3], lingual appliance can treat the most common malocclusions in an effective way. However, lingual biomechanics is slightly more complicated concerning the labial one, especially in complex cases (extractions, open bite, impactions) [4] when a perfect 3D control of the teeth is required [5] or a muscular balance is missing [6]. The most important biomechanical difference between labial and lingual approaches regards interbrackets distance and wire stiffness.

Miura et al. [7] used a mathematical formula to experimentally calculate the stress of a superelastic wire, knowing the diameter, the material, the modulus of elasticity, the moment of inertia and the interbracket distance. Recent studies have shown that strength can be up to 7.88 times greater on the lingual side when the interbracket distance is reduced, particularly when brackets with increased mesiodistal dimensions are used [8].

The force exerted by a 0.018x0.025 inch wire is almost double that of a 0.018x0.018 inch archwire [9]. Using a full-thickness square wire in a square slot, it is possible to transmit the same information but exerting much less force. The increased elasticity of a wire also allows for easier insertion and easier clinical management. This concept is even more valid in lingual orthodontics, where the interbracket distances are reduced, it is more difficult to engage the archwires, and it is necessary to exert lighter forces.

The smallest possible archwire-bracket play and the reduced interbracket distance allow lingual systems to excellently transfer the programmed information on the teeth; however, the system's rigidity must not be excessive and decrease the efficiency of orthodontic treatments. For these reasons, the present study aimed to analyze and compare the stiffness of different lingual appliances with different archwires materials to hypothesize that these factors impact the stiffness of the lingual systems.

Material and Methods

Study Design and Data Collection

In this in vitro study, each archwire's deflection load curve was obtained to evaluate how the section, the material, and the manufacturer affect the elasticity and stiffness characteristics of the wires. To perform the comparative analysis between the different lingual systems, the following lingual appliances were selected:

- eBrace (Riton Biomaterial Co. Ltd., Guangzhou International Bio Island, Guangzhou, China);
- Harmony (American Orthodontics Corp., Sheboygan, WI, USA);
- Incognito (TOP-Service für Lingualtechnik GmbH, 3M Unitek Corporation, Bad Essen, Germany);
- STb (Ormco Corp., Orange, CA, USA).

The archwires were selected based on the sequences recommended for each method, trying to opt for the same sequence to compare arches with the same material and section.

The load-deflection test, in collaboration with the Engineering Department of the University of Ferrara, was performed through a modified three-point bending test with an Instron 4467 dynamometer (Instron, Norwood, MA, USA) connected to a 100-N load cell and a metal blade with a curvature range of 1 mm at its extremity fixed to the load cell.

The materials used for the test were resin support with four brackets attached by the four manufacturers (Figure 1).

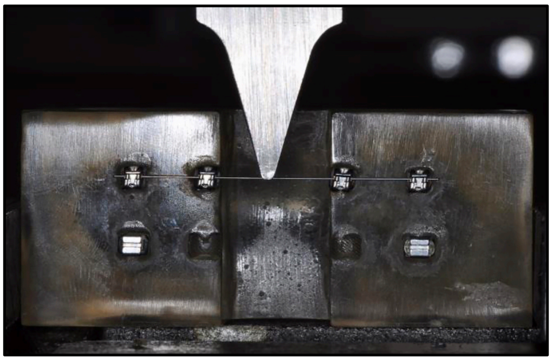

Figure 1. Brackets on the support.

Three segments of at least 55 mm were obtained by cutting the distal parts of the arches without folds or deformations because, in the anterior part, the bends could compromise the validity of the tests. The conventionally ligated brackets were linked to the archwires with elastic ligatures for repeatability reasons, while for the self-ligating ones, their own closure mechanism was used. Three tests were carried out for each type of archwire.

The blade's progression speed is 1 mm / min and the values were measured using a PC connected to the machine and processed with the "Labview 8.5" software. The data obtained were stored in "Excel" sheets in two columns: one relating to the blade's position during loading and unloading and the other relating to the developed force expressed in Newton.

For steel and TMA arches, the force values that the arch exerts at a deflection of 0.5 and 1 mm on the load curve are identified. For the NiTi arches, these values are identified in correspondence with the discharge curve. The mean values and standard deviation of the three tests are calculated for each arc.

This test simulates the behavior of the archwire in the case of a misaligned tooth. In reality, it is a simplification because the test provides that the wire is only placed on the lateral supports, while in the mouth, the presence of the brackets introduces a variable that significantly changes the behavior of the wire. Moreover, the oral cavity's clinical conditions foresee different temperatures and the presence of saliva, while the specific testing conditions were performed at room temperature. However, it is a simple test to perform and provides data that compares arches of different materials and diameters.

The three-point bending test for testing wires is coded by ISO CD 15841 [10]. It provides that an orthodontic arch rests on two supports at a fixed distance of 10 mm. A load cell exerts a deflection directly perpendicular to the center of the archwires (Figure 2).

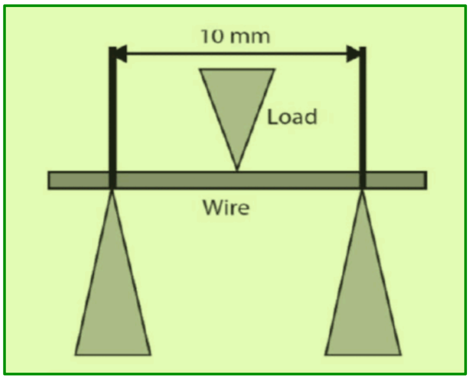

Figure 2. Load deflection test.

Statistical Analysis

The comparison of the stiffness between different systems was carried out through a factor variance analysis with three factors (manufacturer, cross-section, and material), followed by the post-hoc Tuckey test. Data were obtained using SPSS 17.0 statistical software (IBM Corp., Armonk, NY, USA).

Increase in Stiffness as the Section Increases

The variation in stiffness of the wires as the smaller section increases was evaluated by expressing the values as a percentage of the average of the group corresponding to the wire of the smaller section (0.012). It was possible to carry out the analysis only on the wires' data with a round section because those with a rectangular section were all made of NiTi material. The data and graphs were obtained using the Excel program.

The variation in stiffness of the yarns as the material varies was evaluated by expressing the values as a percentage concerning the mean of the group corresponding to the yarn of the SS material. It was possible to carry out this analysis on the wires with section 0.018x0.025 inch, being the only ones to be made of different materials. The data and graphs were obtained using the Excel program.

Results

The results of the three-point bending tests are summarized in Table 1. The average values of force that each archwire exerts when deflected at 1 mm are reported.

With the same material, an increase in the system's rigidity was reported as the wire section increases, regardless of the manufacturer. With the same section, the stainless steel archwires have ever higher stiffness values than NiTi and TMA.

The NiTi wires show a superelastic behavior producing a deflection load curve with a characteristic flag shape, with a non-linear trend. The relief curve is evaluated for the force exerted on the tooth elements.

The STb wires of CuNiTi material, by virtue of the characteristics of the thermal wires, have flatter and lower load-deflection curves than the NiTi wires of other manufacturers. The 0.016 inch Copper NiTi STb wires exert lighter forces than the manufacturers, Incognito, Harmony and eBrace. This is also valid for rectangular section wires (0.016x0.022 CuNiTi). The 0.017x0.017 inch NiTi square section wires demonstrate increased rigidity for STb System compared to the same wire from the Harmony manufacturer.

Table 1. Three-point bending test: force (g) that each archwire exerts when subjected to a deflection of 1 mm.

Archwire	eBrace	Harmony	Incognito	STb
0.012 NiTi	50.1	---	54.56	65.5
0.014 NiTi	108.6	125.2	122.3	122.6
0.016 NiTi	230	213.7	219.9	160.3
0.016x0.022 NiTi	277	410.1	655.5	284
0.017x0.017 NiTi	---	346	---	376.1
0.018x0.025 TMA	752	1018	778.9	---
0.018x0.025 SS	1810	1845	1810	---
0.018x0.018 SS	---	---	---	1432

Figure 3 showed the percentage increases in stiffness at the transition from 0.012 to 0.014 inch NiTi and from 0.012 to 0.016 inch NiTi with the same manufacturer.

The percentage values of the decrease in stiffness between SS steel wires and TMA wires. With the same section, the 0.018x0.025 inch wires in TMA are approximately 50% less rigid than steels (SS) (Figure 4).

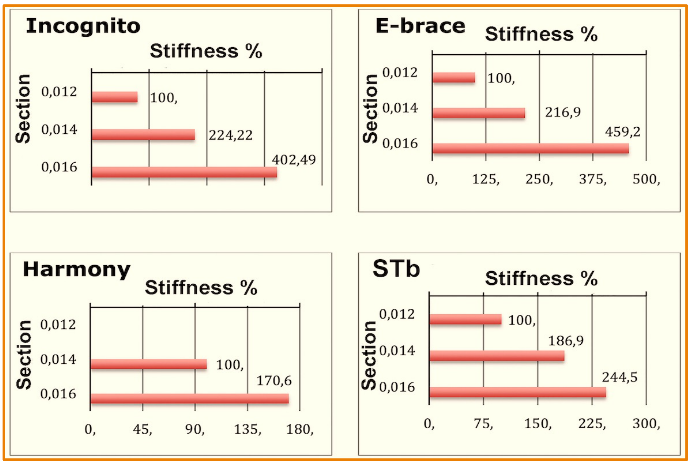

Figure 3. Percentage increase of thickness.

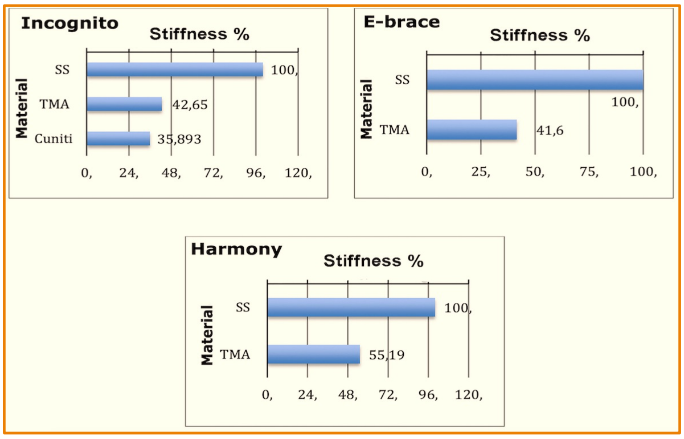

Figure 4. Percentage decrease of thickness.

The three-factor analysis of variance highlighted significance in the primary effects of the factors evaluated. Therefore, the Tuckey post-hoc test for the required comparisons (manufacturer factor) was performed. The highly significant difference between the STb System manufacturer and the other three (Incognito, E-brace and Harmony) is evident from Figure 5.

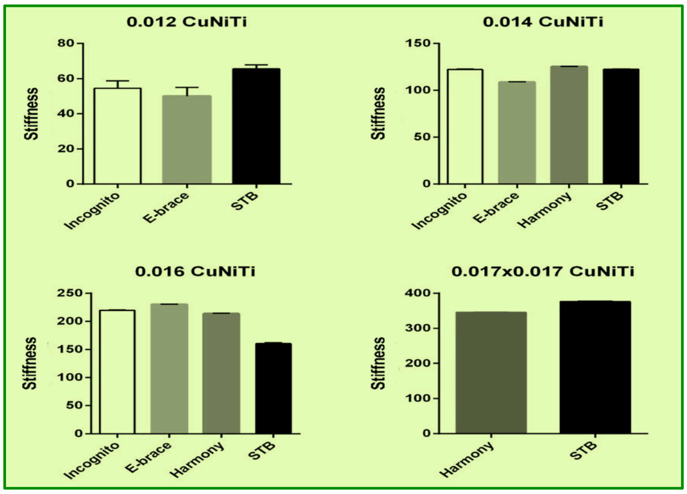

Figure 5. Different stiffness for different manufacturers.

Discussion

Knowing orthodontic appliances' features allows an appropriate clinical practice use only if this knowledge is integrated with the fundamental aspects of biomechanics. It is not possible to simply transfer the mechanics applied to traditional vestibular orthodontics to the lingual side.

The distance between the point of application of the force and the center of resistance of the tooth is different in vestibular and lingual orthodontics and this affects the magnitude of the moment that is created and the consequent movement of the tooth [11,12].

The choice of the type (material) of wire and folds' presence on the arch affects its characteristics of rigidity and elasticity. The modified three-point bending test, used in the past by several authors, allowed evaluating and comparing the deflection load curve of arches of different sizes and materials. The test results we performed on wires of the same material are in line with what emerged from the literature [13,14].

As the wire cross-section increases, the resistance to deflection always increases. SS steel arches always express greater forces than TMA and NiTi wires [15-19]. Even with the same cross-section, SS and TMA arches have different behaviors; this is due to the different Yung modulus or Elasticity modulus; in fact, the steel proves to be more rigid than the TMA. The modulus of steel elasticity is on average double that of TMA, which justifies our results.

The superelastic 0.014 inches NiTi eBrace yarns exert lighter forces than the yarns of the same cross-section and material of the other manufacturers. The 0.016 inch CuNiTi STb wires exert less force than the superelastic 0.016 NiTi wires from the Incognito, Harmony and eBrace manufacturers. This in accordance with the characteristics of thermal NiTi yarns compared to traditional NiTi and NiTi Superelastic yarns. This is also valid for wires with a rectangular section (0.016x0.022 inch CuNiTi).

If we compare the characteristics of the superelastic wires in NiTi and NiTi Termico with the characteristics of the steel wires, we will notice a significant reduction in terms of stiffness of the former. These differences are due both to the modulus of elasticity of the NiTi conditioned by the percentages of the components of this alloy which is about 5 times lower than the E modulus of steel, 8 times lower for the CuNiTi; and to the lower resistance to deflection of the alloy in the discharge phase.

If we focus on the data obtained, we will notice no statistically significant difference in the resistance to deflection of the archwires 0.012 and 0.014 inch NiTi of the four different systems. We note a greater elasticity of the NiTi thermal wires of the STb system (0.016 and 0.016x0.022 inches) compared to the wires of the same section of the other systems. TMA wires with the same section have a double elasticity compared to steel wires; this is true in all systems considered.

Compared to the similar rectangular one (0.018x0.018 instead of 0.018x0.025 inch), the use of a square wire reduces the force transmitted to the dental elements while not greatly varying its ability to express information given the reduced variation in the degrees of play wire-slot between a square and rectangular arch.

According to the study carried out by Lombardo et al. [14], there is an increase of about 50% in the stiffness of the wires in increments of 0.02 inches for the same material (NiTi) and increases of 160% for increments of 0.04 inches, in the passage from wires of diameter 0.012 to 0.016 inch NiTi. In accordance with this study, we also found an increase in the stiffness of the wires at the transition from 0.014 to 0.016 inches of approximately 65%, except for STb wires where there is an increase of approximately 30%.

The 0.017x0.017 inch square section wires have increased stiffness compared to the 0.016x0.022 inch rectangular wires. However, we must consider two fundamental factors in lingual orthodontics: the type of technique used and the interbracket distance.

The STb system always uses a straight wire method; the Harmony system leaves the clinician to choose the type of arch to use, straight, folds characteristic of the mushroom arch, or folds customized for that type of malocclusion. The Incognito and eBrace systematics provide for the use of arches with individualized folds. The presence of folds in the arch increases the arch's total length and, consequently, its elasticity. This significantly affects its resistance to deflection and the force transmitted to the dental elements will be reduced compared to that transmitted by a straight arch with the same material, section, and interbracket distance.

By virtue of these considerations, we can say that the eBrace system has the wires with the least resistance to deflection and, considering the presence of folds in the arches, there is a further increase in the elasticity of this system.

The three-point bending test results on the STb system's wires show reduced stiffness values, but since it is a straight wire system, the absence of bends in the arch does not reduce this elasticity. So we can say that this system transmits light forces on the dental elements but, on the other hand, we cannot say that these forces are less than the forces expressed in the other systems that add up the elastic properties of the wires to the addition of folds in the arch.

During the work phases, to obtain the dental arches' leveling, the closure of spaces, and to counteract the bowing effect, it is important to use wires that are characterized by adequate rigidity. It is interesting to note that the 0.018x0.018 inch square section wires have a reduced stiffness compared to the 0.018x0.025 inch rectangular full-thickness wires.

Clinically, this data has a very important implication since a square arch while generating slightly reduced forces is easier to use as it is easier to engage, especially on the lingual side than a rectangular wire of the same height. However, this is an *in-vitro* study and the clinical possibility to use palatal skeletal anchorage was not considered [20].

Straight wire samples were used to perform the three-point bending tests. In the eBrace, Harmony and Incognito systems, unlike the STb system, the wires have numerous folds, individualized for each patient and not compatible with the protocol used in our test. The presence of folds in an arch, increasing its length, increases its elasticity. For this reason, the strength that the archwires of the three systematics (eBrace, Harmony and Incognito) exert clinically is less than that found experimentally in our test. However, our study aimed not to find absolute numerical values but to study the behavior of wires of different sizes and materials when subjected to deflection.

Statistically, the imperfect independence between the independent variables and the low number of specimens is a limitation of this study; therefore, new tests' execution may provide important data for future research.

Conclusion

Given the same section, the stainless steel archwires have more stiffness than the Nickel-Titanium and TMA archwires for each manufacturer archwire. Given the same material, rectangular arches are more rigid than square arches for each manufacturer archwire. Archwires of the same section and material but different manufacturers show different load-deflection curves of stiffness.

Authors' Contributions

AP	https://orcid.org/0000-0002-4020-5065	Conceptualization, Methodology, Formal Analysis, Investigation, Writing - Original Draft and Writing - Review and Editing.
FC	https://orcid.org/0000-0002-4641-2196	Conceptualization and Writing - Review and Editing.
MP	https://orcid.org/0000-0001-6198-3053	Writing - Review and Editing.
All authors declare that they contributed to critical review of intellectual content and approval of the final version to be published.		

Financial Support

None.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

References

[1] Lopez MA, Andreasi Bassi M, Confalone L, Gaudio RM, Lombardo L, Lauritano D. Retrospective study on bone-level and soft-tissue-level cylindrical implants. J Biol Regul Homeost Agents 2016; 30(2 Suppl 1):43-8.
[2] Lopez MA, Andreasi Bassi M, Confalone L, Gaudio RM, Lombardo L, Lauritano D. Clinical outcome of 215 transmucosal implants with a conical connection: a retrospective study after 5-year follow-up. J Biol Regul Homeost Agents 2016; 30(2 Suppl 1):55-60.
[3] Arreghini A, Trigila S, Lombardo L, Siciliani G. Objective assessment of compliance with intra- and extraoral removable appliances. Angle Orthod 2017; 87(1):88-95. https://doi.org/10.2319/020616-104.1
[4] Pisani L, Bonaccorso L, Fastuca R, Spena R, Lombardo L, Caprioglio A. Systematic review for orthodontic and orthopedic treatments for anterior open bite in the mixed dentition. Prog Orthod 2016; 17(1):28. https://doi.org/10.1186/s40510-016-0142-0
[5] Arreghini A, Lombardo L, Mollica F, Siciliani G. Torque expression capacity of 0.018 and 0.022 bracket slots by changing archwire material and cross section. Prog Orthod 2014; 15(1):53. https://doi.org/10.1186/s40510-014-0053-x
[6] Di Fazio D, Lombardo L, Gracco A, D'Amico P, Siciliani G. Lip pressure at rest and during function in 2 groups of patients with different occlusions. Am J Orthod Dentofacial Orthop 2011; 139(1):e1-6. https://doi.org/10.1016/j.ajodo.2010.02.030
[7] Miura F, Mogi M, Ohura Y, Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. Am J Orthod Dentofacial Orthop 1986; 90(1):1-10. https://doi.org/10.1016/0889-5406(86)90021-1
[8] Demling A, Dittmer MP, Schwestka-Polly R. Comparative analysis of slot dimension in lingual bracket systems. Head Face Med 2009; 5:27. https://doi.org/10.1186/1746-160X-5-27
[9] Graber LW, Vanarsdall RL, Vig KWL. Orthodontics: Current Principles and Techniques. 5th. ed. St. Louis: Mosby; 2011.
[10] Raphael E, Sandrik JL, Klapper L. Rotation of rectangular wire in rectangular molar tubes. Part I. Am J Orthod 1981; 80(2):136-44. https://doi.org/10.1016/0002-9416(81)90214-1
[11] Siciliani G, Terranova S. Ortodonzia Linguale. Milan: Masson, 2001. [In Italian].
[12] Scuzzo G, Takemoto K. Lingual Orthodontics: A New Approach Using Stb Light Lingual System & Lingual Straight Wire. Hanover Park, IL: Quintessence Publishing Co.; 2010. 256p.
[13] Lombardo L, Arreghini A, Al Ardha K, Scuzzo G, Takemoto K, Siciliani G. Wire load-deflection characteristics relative to different types of brackets. Int Orthod 2011; 9(1):120-39. https://doi.org/10.1016/j.ortho.2010.12.011
[14] Lombardo L, Stefanoni F, Mollica F, Laura A, Scuzzo G, Siciliani G. Three-dimensional finite-element analysis of a central lower incisor under labial and lingual loads. Prog Orthod 2012; 13(2):154-63. https://doi.org/10.1016/j.pio.2011.10.005
[15] Burstone CJ, Qin B, Morton JY. Chinese NiTi wire - a new orthodontic alloy. Am J Orthod 1985; 87(6):445-52. https://doi.org/10.1016/0002-9416(85)90083-1
[16] Miura F, Mogi M, Ohura Y, Hamanaka H. The super-elastic property of the Japanese NiTi alloy wire for use in orthodontics. Am J Orthod Dentofacial Orthop 1986; 90(1):1-10. https://doi.org/10.1016/0889-5406(86)90021-1
[17] Kusy RP. A review of contemporary archwires: their properties and characteristics. Angle Orthod 1997; 67(3):197-207.
[18] Johnson E. Relative stiffness of beta titanium archwires. Angle Orthod 2003; 73(3):259-69.
[19] Gurgel JA, Pinzan-Vercelino CR, Powers JM. Mechanical properties of beta-titanium wires. Angle Orthod 2011; 81(3):478-83. https://doi.org/10.2319/070510-379.1
[20] Lombardo L, Gracco A, Zampini F, Stefanoni F, Mollica F. Optimal palatal configuration for miniscrew applications. Angle Orthod 2010; 80(1):145-52. https://doi.org/10.2319/122908-662.1