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ORIGINAL ARTICLE

Effectiveness of Fully Customized Lingual Orthodontic Treatment: A Retrospective Pilot Study

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ABSTRACT

Objective: To investigate the effectiveness of Suresmile® lingual therapy on torque, tip, and rotations measures through digital evaluation of planning and post-treatment digital models. **Material and Methods:** A sample of 12 Caucasian adult patients (4 men; mean age 30.6 years ± 3.9 and 8 women; mean age 31.4 years ± 4.5) treated with the Suresmile® lingual orthodontic technique was retrospectively selected, regardless of the type of malocclusion. Digital planning was performed with Suresmile® software, while lingual therapy was accomplished with interactive self-ligating lingual brackets and customized Suresmile® arches. First, digital models of planning and post-treatment digital models were compared using VAM software (and the discrepancies were analyzed through MANOVA and four multivariate. Then, Tukey and Bonferroni's post-hoc tests are performed. **Results:** The accuracy average values are 60.11 ± 27.67% for torque, 53.52 ± 27.37% for tip and 59.19 ± 26.42% for rotation, while for inaccuracy values are 2.72° ± 2.23° for torque, 2.98° ± 2.16° for tip and 3.58° ± 3.29° for rotation. No significant differences have been recorded evaluating different sectors of both arches. **Conclusion:** This retrospective preliminary study highlight how overcorrections, especially in the Suresmile lingual technique, should be performed during orthodontic planning. Moreover, the study gets bases for further, more structured future studies that should involve larger and more homogeneous samples.

Keywords: Dental Occlusion; Orthodontic Brackets; Orthodontic Appliances, Fixed; Esthetics, Dental.

Introduction

Since its advent, the lingual technique had been characterized by some procedural and clinical difficulties [1-4]. The orthodontic approach from the lingual side is more difficult. It requires complete customization of the lingual appliances [5,6] due to the considerable heterogeneity of the lingual surfaces of the teeth concerning vestibular surfaces, whose homogeneity allowed the development of the straightwire appliances [7,8].

Fujita [9] faced this problem with the use of mushroom lingual archwires. Despite this, easy arch coordination was often difficult to accomplish due to presence of vertical and horizontal folds between canines and first premolars and this difficulty [10], and the impossibility to produce miniaturizing brackets and to exert light forces at time, leads to a reduction of is used worldwide [11]. Thus, the improvement of this technique has essentially seen two evolutionary paths.

Scuzzo et al. [12] elaborated the lingual straightwire concept through the use of lingual miniaturized lingual brackets and the identification of the Lingual Straightwire Plane (LPS), where the in-out differences are deleted [13]. On the other hand, the use of lingual straightwire arches allowed an easier archwire coordination, the use of sliding mechanics and greater comfort for the absence of in-out bends [1,13-15].

Additionally, technological improvements made it possible to develop robotic bending NiTi archwires, leading to fully customized CAD/CAM lingual appliances [16-18]. Wiechmann [17,18] was the first to introduce a completely customized CAD/CAM lingual appliance using robotic bending (Incognito, 3M Unitek, Bad Essen, Germany) in 2002.

More recently, Sachdeva [19] has developed a further orthodontics approach which allowed not only the full customization of the appliances (both vestibular and lingual) but the birth of a new philosophy of planning which starts from the matching of digital models and 3d tomographic investigations (Cone Beam Computed Tomography - CBCT) to obtain a three-dimensional diagnostic model of the patient.

The term "Biodigital Orthodontics" has been introduced to indicate a fully individualized and patient-centered orthodontic therapy, thanks to the use of modern technologies. According to the author, a "reactive model" was routinely used by clinicians in the past, where they spent a lot of time to correct side effects of the previous orthodontic activations such as loss of anchorage, unwanted space openings and premature contacts [20], with a reduced efficiency and an increased overall treatment time [21].

Sachdeva advocated the use of a "proactive model," aiming to avoid these side effects and reduce the errors to optimize the treatment and respect at the same time patient's biology [22]. This "proactive approach" needs almost complete digitization of clinical practice that relies on the use of an intraoral scanner, of digital set-up, of the use of robotic bending archwires [23] and the use of CBCT machines.

Suresmile® technique (OraMetrix, Inc., Richardson, TX, USA) was introduced in 2001 by Sachdeva. It seems to be an effective and efficient technique concerning conventional ones. Still, these considerations have been claimed by some opinion leaders with clear conflicts of interest and, therefore, their scientific value could be considered low [24-27].

There are four retrospective studies in literature that investigate Suresmile technique, three of which have a control group. These studies state that Suresmile® treatment is more effective and efficient than conventional therapy, although these studies suffer from some methodological bias such as poor calibration, inhomogeneity of pre-treatment groups and no clear selection criteria [27].

Moreover, Larson et al. [28] report a good result with Suresmile® technique, although they recorded a discrepancy between the planning and the post-treatment results that are slightly beyond the threshold values of clinical tolerance for angular (except for lower second premolars for torque values and lower second premolars and first molars for tip) and linear values. The authors state that some overcorrections should be added during digital planning. The above-mentioned studies were conducted with vestibular Suresmile® technique, while to date findings of lingual Suresmile® technique lack.

Therefore, the purpose of this preliminary retrospective study is to evaluate the effectiveness of the Suresmile® lingual technique, comparing the programmed digital level with the result obtained at the clinical level.

Material and Methods

Ethical Approval

The study protocol was designed and accepted by the ethics committee of the Post-graduate School in Orthodontics of the University of Ferrara, with protocol number 5/2016.

Study Design and Sample

A sample of 12 Caucasian adult patients (4 men; mean age 30.6 years ± 3.9 and 8 women; mean age 31.4 years ±4.5) was treated with the Suresmile® lingual orthodontic technique and retrospectively selected.

The patients investigated meet the following inclusion criteria: the presence of a complete dentition or a partial edentulous condition (that does not exceed the absence of 4 teeth excluding the third molars); no extractive therapy; the absence of supernumerary elements and anomalies in the shape of the teeth; the absence of rotations of this magnitude that would have allowed easy lingual positioning of the brackets; the absence of systemic bone pathologies and pharmacological treatments, which would affect tooth movement, and of active periodontal disease.

Malocclusion composition of the sample is quite heterogeneous with the presence of: 2 subjects affected by Class III malocclusion, 1 by Class I malocclusion with the presence of diastemas on both arches, 1 by Class II malocclusion with open anterior bite, 4 by Class I and 4 by Class II, with crowding in the anterior sector of the mandible respectively. Details of skeletal, dental and facial characteristics are listed in Table 1.

Table 1. Summary of skeletal, dental and facial characteristics of each subject belonging to sample.

Patient No.	Gender	Measurements			
		Skeletal		Dental Features	Facial Profile
		Sagittal	Features		
1	Male	Class I	Hypodivergent	Anterior Mandibular Crowding	Straight
2	Female	Class II	Hyperdivergent	Anterior Mandibular Crowding	Convex
3	Female	Class III	Hypodivergent	Minimal Crowding on Both Arches	Concave
4	Female	Class II	Mesodivergent	Anterior Mandibular Crowding	Slight Convex
5	Male	Class I	Mesodivergent	Diastemas on Both Arches	Straight
6	Female	Class III	Mesodivergent	Minimal Crowding on Both Arches	Concave
7	Female	Class I	Mesodivergent	Anterior Mandibular Crowding	Slight Convex
8	Male	Class I	Hypodivergent	Anterior Mandibular Crowding	Slight Concave
9	Female	Class II	Mesodivergent	Anterior Mandibular Crowding	Convex
10	Male	Class II	Hyperdivergent	Anterior Open-Bite	Convex
11	Female	Class I	Mesodivergent	Anterior Mandibular Crowding	Straight
12	Female	Class II	Hypodivergent	Anterior Mandibular Crowding	Straight

Skeletal Sagittal (ANB°): Class I: 0°-4°, Class II>4°, Class III<0°; Skeletal Vertical (FMA°): Hypodivergent<22°, Mesodivergent: 22°-25°, Hyperdivergent >28°. Anterior mandibular crowding: Little index≥4mm. Minimal crowding <3mm. Anterior open-bite = Overbite <0mm.

Data Collection

After the pre-treatment records acquisition, pre-treatment diagnostic records of each subject were entered into the Suresmile® software platform through the IDO account (Institute of Digital Orthodontics SRL; Catanzaro, Italy) and, subsequently, a work set-up was performed on the therapeutic model.

After the completion of the set-up, the following step was to identify the most appropriate placement of interactive self-ligating lingual brackets (In-Ovation L, GC Orthodontics Europe GmbH, Breckerfeld, Germany) to avoid excessive bends on future robotic bending archwires (customized Suresmile® archwires) (Figure 1).

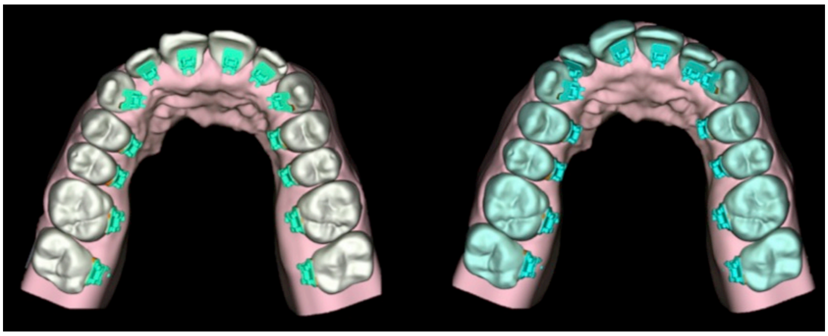

Figure 1. Positioning of lingual brackets during planning phase.

Subsequently, the lingual brackets were placed with indirect bonding using a soft and transparent transfer tray (Memosil2, Kulzer GmbH, Wasserburg, Bodensee, Germany), built on the prototyped model of the malocclusion with the lingual brackets in situ.

After the phase of bonding, a preliminary alignment was performed with pre-formed rounded lingual thermal NiTi archwires (Ormco Corp., Glendora, CA, USA) of different sizes (0.012 NiTi or 0.014 NiTi) according to the entity of the initial crowding, since Suresmile® arch-bending robots are not able to perform bends on very thin initial NiTi wires.

After about 4-5 months, a second scan of the dental arches was performed in order to record the real position of both the brackets on each dental element and teeth after initial alignment [24]. On this new therapeutic model, the final work set-up was prepared, on which the Suresmile® customized lingual archwires were programmed.

The archwire sequence was: 0.016 NiTi, 0.016X0.016 NiTi, 0.016x0.022 NiTi and 0.017x0.025 NiTi. After the alignment and leveling phase, the final steps are conducted with 0.017x0.025 TMA or 0.016x0.022 SS.

Eight maxillary and twelve mandibular digital models were obtained through an intraoral scanner (Trios, 3Shape, Copenhagen, Denmark) before treatment (T0) to plan working set-up and immediately after treatment (T1) reaching a total of 40 digital arches and of 308 teeth investigated.

After this process, both Suresmile® planning and post-treatment digital models were exported in .STL file and associated with a reference number to protect their identity and blind them to the operator who performed measures.

A total of 100 anatomical reference points per model were identified by a single expert operator (PA), including second molars, using VAM software (Vectra; Canfield Scientific, Fairfield, NJ) according to the method proposed and validated by Huanca Ghislanzoni (Figure 2).

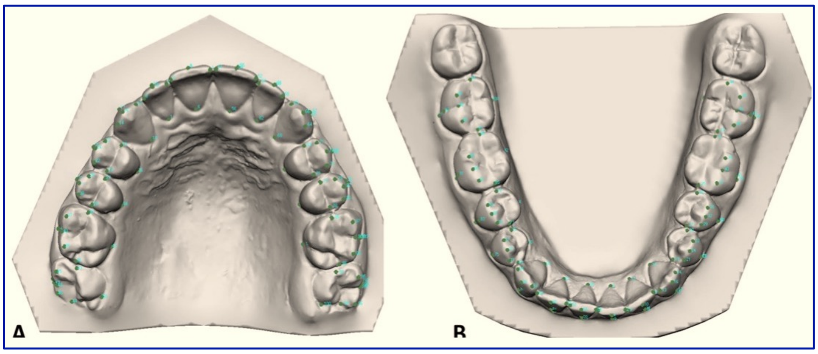

Figure 2. 3D view of occlusal plane used as a reference for all measurements.

Therefore, their three-dimensional coordinates were exported into specific .txt files (Microsoft Excel, Microsoft, Redmond, WA, USA). This enabled extrapolation through a complex algorithm of the tip, torque and rotation values of each tooth with respect to an occlusal reference plane passing through the following points:

• The mesiovestibular cusp on the right first molar (Point A)

• The mesiovestibular cusp on the left first molar (Point B)

• The centroid of all the most occlusal points on the FACC line (the facial axial of the clinical crown) of the all teeth, excluding the cusp of the canines and the second molar (Figure 3). Thus, six points were assigned to the incisors and canines, respectively, and eight points were assigned to each of the premolars and molars.

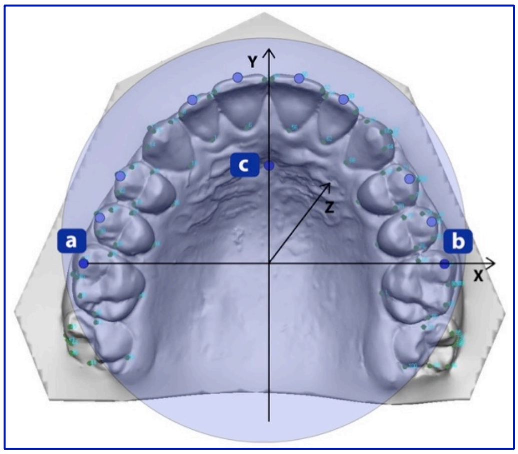

Figure 3. Graphical representation of occlusal reference plane constructed on maxillary arch.

After six weeks, measurements on 18 randomized arches were repeated by the same operator (PA), and the method error (ME) was calculated according to Dahlberg's formula ($S2 = \sum d2 / 2n$). Dahlberg values ranged between 0.11° and 26.50° for angular values and between 0.064 mm and 3.19 mm for linear measurements. The systematic error was calculated via the dependent Student's t-test, with a p-value of <0.05 being considered as significant. The mean p-value was 0.462 and no statistically significant differences were found in any case.

Statistical Analysis

Statistical analysis was carried out using SAS (Statistical Analysis System) software [29]. The accuracy of the movement obtained (real) on what was programmed (ideal) was measured according to the following formula:

$$\text{movement accuracy} = \frac{\text{real posttreatment} - \text{initial pretreatment}}{\text{ideal posttreatment} - \text{initial pretreatment}} \times 100$$

The ideal is given by the difference between ideal post-treatment and initial pre-treatment values, while the real is given by the difference of initial pre-treatment and real post-treatment. Their ratio reports the accuracy in a percentage value (%). Also, the inaccuracy (°) has been reported as the difference between which planned (ideal) and which obtained (real).

To make clearer the results and to take into account the different bone density of different regions, each arch has been divided into anterior (incisors and canine) and posterior regions (premolars and molars), getting four different regions in total: Maxillary anterior region (MxAR), Maxillary posterior region (MxPr), Mandibular anterior region (MnAr) and Mandibular posterior region (MnPr).

The XlStat and the SAS software have been used to give a summary and more analytical statistics for accuracy (%) and inaccuracy (°) for torque, tip and rotation values per each region investigated.

MANOVA (Multivariate Analysis of Variance) test has been performed using SAS software, with a significance threshold of α=0.05 (5%). One of the objectives of the MANOVA was the analysis of the homogeneity for each measure (torque, tip and rotation), assuming their multivariate normal distribution, considering this test more appropriate in a condition of small size group when a normality data distribution was not assumed. After, four multivariate tests were performed (Wilks Lambda, Pillai's trace, Hotelling-Lawley trace, and Roy's greatest root) to confirm if there is an influence between regions and three dependent variables (torque, tip and rotation). Post-hoc Tukey and Bonferroni tests have subsequently been performed to detect any significant statistical differences between ideal and real values for all three variables in each region, considering p-value <0.05 as significant.

Results

Data about accuracy (%) and inaccuracy (°) are reported in Table 2 and Table 3, respectively. The accuracy average values and standard deviations are 60.11 ± 27.67% for torque, 53.52 ± 27.37% for tip and 59.19 ± 26.42% for rotation. In detail, accuracy values and standard deviations range from 67.18 ± 27.09% for torque in anterior region of the mandible to 49.33 ± 32.18% for tip in the posterior sector of the mandible.

Table 2. Mean value and SD accuracy of torque, tip and rotation expressed as a percentage (%) for each region and for the total.

Region		Accuracy (%)								
		Torque (%)			Tip (%)			Rotation (%)		
		N	Mean (%)	SD (%)	N	Mean (%)	SD (%)	N	Mean (%)	SD (%)
Maxilla	Anterior	29	53.72	28.39	29	55.23	25.44	29	66.78	24.32
	Posterior	37	59.97	26.78	45	49.33	32.18	37	57.14	27.27
Mandible	Anterior	40	67.18	27.09	40	58.98	28.67	40	54.06	25.62
	Posterior	45	59.61	28.44	37	50.55	23.23	45	58.78	28.51
Total		151	60.11%	27.67	151	53.52%	27.37	151	59.19%	26.42

The best accuracy value for rotation is recorded in the anterior region of maxilla (66.78 ± 24.32%) (Table 2). Regarding inaccuracy, mean average values and standard deviations are 2.72° ± 2.23° for torque, 2.98° ± 2.16° for tip and 3.58° ± 3.29° for rotation. In detail, accuracy values and standard deviation range from 2.44° ± 1.61° for tip of anterior region of the maxilla and 4.01° ± 3.87° for rotation in the posterior sector of the mandible (Table 3).

Table 3. Mean value and SD inaccuracy of torque, tip and rotation expressed as difference (°) for each region and for the total.

Region		Inaccuracy (°)								
		Torque			Tip			Rotation		
		N	Mean (°)	SD (°)	N	Mean (°)	SD (°)	N	Mean (°)	SD (°)
Maxilla	Anterior	29	2.84	2.086	29	2.438	1.609	29	3.421	3.34
	Posterior	37	2.27	1.855	45	3.871	2.643	37	3.208	2.336
Mandible	Anterior	40	2.52	1.993	40	2.528	2.021	40	3.72	3.676
	Posterior	45	3.28	3.013	37	3.384	2.402	45	4.013	3.871
Total		151	2.72°	2.23	151	2.98°	2.16	151	3.58°	3.29

MANOVA analysis and the four multivariate tests confirmed the absence of significant correlation between the four regions analyzed for torque, tip and rotation with Pr > F values major than 0.05. It has also been shown that two of the three movements are interdependent (Torque and Tip Values), so they influence each other, while neither of these are influenced by rotations. Post-hoc Tukey and Bonferroni test highlight that differences between different regions do not reach a statistical significance for each measure investigated ($p<0.05$ considered as significant) (Table 4).

Table 4. Statistical comparisons performed by Tukey and Bonferroni post-hoc tests (among different regions investigated and for each measure obtained (torque, tip and rotation).

Test	Measures	Contrast	Diff	Pr > Diff	Statistical Significance
Tukey post hoc	Tip	MnAr *vs.* MxPr	9.65	0.417	Not
		MnAr *vs.* MnPr	8.43	0.495	Not
		MnAr *vs.* MxAr	3.75	0.944	Not
		MxAr *vs.* MxPr	5.90	0.823	Not
		MxAr *vs.* MnPr	4.68	0.891	Not
		MnPr *vs.* MxPr	1.22	0.997	Not
	Torque	MnAr *vs.* MxAr	13.46	0.195	Not
		MnAr *vs.* MnPr	7.57	0.59	Not
		MnAr *vs.* MxPr	7.21	0.664	Not
		MxPr *vs.* MxAr	6.25	0.799	Not
		MxPr *vs.* MnPr	0.36	1	Not
		MnPr *vs.* MxAr	5.89	0.808	Not
	Rotation	MxAr *vs.* MnAr	12.72	0.21	Not
		MxAr *vs.* MxPr	9.64	0.466	Not
		MxAr *vs.* MnPr	8.00	0.59	Not
		MnPr *vs.* MnAr	4.72	0.848	Not
		MnPr *vs.* MxPr	1.64	0.993	Not
		MxPr *vs.* MnAr	3.08	0.958	Not
Bonferroni post-hoc	Tip	MnAr *vs.* MxPr	9.65	0.13	Not
		MnAr *vs.* MnPr	8.43	0.16	Not
		MnAr *vs.* MxAr	3.75	0.58	Not
		MxAr *vs.* MxPr	5.90	0.39	Not
		MxAr *vs.* MnPr	4.68	0.48	Not
		MnPr *vs.* MxPr	1.22	0.84	Not
		MnAr *vs.* MxAr	13.46	0.05	Not
	Torque	MnAr *vs.* MnPr	7.57	0.21	Not

	MnAr *vs.* MxPr	7.21	0.26	Not
	MxPr *vs.* MxAr	6.25	0.36	Not
	MxPr *vs.* MnPr	0.36	0.95	Not
	MnPr *vs.* MxAr	5.89	0.37	Not
Rotation	MxAr *vs.* MnAr	13.46	0.05	Not
	MxAr *vs.* MxPr	7.57	0.21	Not
	MxAr *vs.* MnPr	7.21	0.26	Not
	MnPr *vs.* MnAr	6.25	0.36	Not
	MnPr *vs.* MxPr	0.36	0.95	Not
	MxPr *vs.* MnAr	5.89	0.37	Not

p-value < Diff is considered as statistically significant.

Discussion

Constant improvements in digital orthodontics allowed the use of fully customized CAD/CAM appliances [19], especially in multidisciplinary patients [30-32]. On the other hand, also lingual orthodontic technique benefits from such improvements.

Suresmile technique was introduced in 2002, with a new philosophy of a proactive model, starting from a full diagnostic digital workflow (CBCT, digital models, previsualization with working set-up) to guarantee a personalized and full customized orthodontic treatment for each patient [19].

This retrospective pilot study aims to investigate the effectiveness of Suresmile® lingual treatment with the use of Suresmile® customized archwires, since such findings are not reported in the literature to date. Our study shows how accuracy for torque, tip and rotation values is not optimal, with a mean percentage of about 60% [8]. Furthermore, angular measures of inaccuracy always exceed the 2°, which is considered a threshold value for a general clinical acceptance [33]. However, despite these findings, angular differences between planned and obtained never exceed 4° except for rotation values of mandibular posterior regions.

Our findings agree with Larson et al. [28], who found that angular discrepancies recorded are generally over threshold value of 2°, although they investigated Suresmile® vestibular technique and it is well-know how lingual orthodontics is less effective to control rotational and tip movement due to fact that lingual bracket are generally narrower [34]. This could partially explain our higher values with respect to above-mentioned study. Also, Müller-Hartwich et al. [35] experienced better angular values, although they recorded rotation discrepancies over 2° threshold values for all groups of teeth investigated.

In our study, the inaccuracy for torque measures in the anterior regions for both arches and tip and rotations recorded in posterior regions could be partially explained by the use of interarch mechanics, like Class III and Class II elastics [36]. Moreover, both mandibular and maxillary molars are more mesio-rotated respected to planning. This is probably due to the use of elastic chain in the lingual side to close diastema and remaining spaces [37].

In all dimensions investigated, the second molars for both arches showed more frequent and larger positional discrepancies. This is in agreement with ABO research, which suggests that second molar alignment can be problematic and, therefore, it could be the most common deviation from an ideal position [38,39]. Therefore, all the discrepancies we recorded could not be attributable completely to the technique or the software Suresmile®, but also to intra and inter-arch mechanics that could be difficult to manage, especially in lingual orthodontics where "bowing effect" of lingual archwires are more likely to occur [1].

Finally, considering both archwire-slot play and the size of the late working archwire, overcorrections during the planning phase should be performed. Different regions investigated show no differences between anterior and posterior regions, although differences between teeth are observed.

Although some clinical information about the accuracy of this technique could be acquired, these results should be considered preliminary. However, they get the base for further, more structured studies in the future to provide more robust information about the efficiency of SureSmile® lingual technique according to a different type of malocclusion and biomechanics used.

This study shows some methodological limitations. First of all, the small sample size, composed of only 12 patients, and its within-group inhomogeneity, considering different malocclusions included in this study, which must be necessarily treated with different mechanics, are the major source of possible bias. About the latter aspect, some authors stated that severity malocclusion and the need for more complex and time-consuming biomechanics could worsen the accuracy of treatments results regarding what was planned [36,37], with a worse occlusal index [40]. Therefore, over-engineering and overcorrections should be included during digital treatment planning to counteract the undesired effects of intra and inter-arch mechanics, especially if undersized working archwires have been used, like in this occasion. Moreover, these should take into account also the type and direction of forces used. Finally, it should be considered that these are the first cases treated with lingual Suresmile® technique and its overall accuracy could be underestimated by the lack of clinical experience on its use.

Another limitation is that authors performed a statistical analysis comparing only different regions of both arches with no statistical differences recorded between them; despite this, significant statistical differences comparing each tooth with each other could not be excluded. Therefore, a more robust statistical analysis and a larger and homogenous sample for future studies should be considered. In addition, increasing sample size could eliminate the operator bias, considering that a clinician's skill and planning abilities with Suresmile® lingual technique rise up with time.

Conclusion

This retrospective pilot study shows that the Suresmile® system in lingual orthodontics could be effective in treating several malocclusions, although it registers some angular inaccuracies concerning what was planned. The discrepancies recorded highlight how overcorrections, especially in lingual orthodontics, should be performed and considered during the planning phase, especially if there is a large sagittal discrepancy which that must be solved through the continuative use of inter and intra-arch mechanics such as Class II or Class III elastics. No differences are detected when different regions are compared by each other. This study is the first to evaluate the effectiveness of lingual Suresmile® treatment, although further studies should be accomplished to get more evidence and supported findings.

Authors' Contributions

MP	https://orcid.org/0000-0001-6198-3053	Conceptualization, Methodology, Formal Analysis, Investigation, Writing - Original Draft and Writing - Review and Editing.
MS	---	Writing - Review and Editing.
PA	https://orcid.org/0000-0002-4020-5065	Writing - Review and Editing.
MAL	---	Writing - Review and Editing.
RS	https://orcid.org/0000-0001-6874-4020	Writing - Review and Editing.
FC	https://orcid.org/0000-0002-4641-2196	Conceptualization and 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.

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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.

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