HOW EFFICIENT IS CUSTOMIZED LINGUAL ORTHODONTICS? AN ASSESSMENT OF TREATMENT OUTCOME

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Conflict of interest

There are no conflicts of interest to report.

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Abstract

Objective: To assess the efficacy of lingual orthodontics by comparing setups and post-treatment casts.

Setting and Sample Population: Thirty-two consecutive patients treated with a customized lingual orthodontic appliance were included in this retrospective study.

Materials and Methods: Initial casts, post-treatment casts and setups were scanned, and the digital models produced were analysed in terms of overjet; overbite; molar and canine relationships; intercanine, interpremolar and intermolar distances; upper and lower arch lengths; midline deviation; bucco-lingual angulation of all teeth and mesio-distal angulation of anterior teeth. Comparisons between setups and post-treatment casts were performed via paired *t*-tests. Relationships between the planned and actual correction were studied using regression analysis.

Results: Statistically significant differences in bucco-lingual torque between setups and post-treatment casts were found for all upper teeth, except for central incisors. In the lower jaw, statistically significant differences in bucco-lingual torque were found between setups and post-treatment casts for the lower incisors and molars. No statistically significant differences in mesio-distal angulation of anterior teeth were found between setups and post-treatment casts. Upper and lower arch widths did not vary significantly between setups and final casts, except upper inter-second premolar and intermolar distances.

Conclusion: Customised lingual appliances offer efficient control of mesio-distal angulation of all anterior teeth. Significant differences in torque between setups and post-treatment casts were observed for upper lateral incisors, canines, premolars, and molars, as well as lower incisors and molars. However, the torque difference was clinically significant (over three degrees) for upper second premolars and molars only.

Key words: lingual orthodontics; treatment outcome; setups; torque; angulation

Introduction

Lingual orthodontics is an aesthetic alternative to traditional fixed appliances for patients seeking orthodontic treatment.[1] The use of the lingual technique makes the orthodontic treatment satisfactory from an aesthetic point of view, especially for patients who would probably otherwise refuse traditional orthodontic treatment for social or professional reasons, and may thus be the solution that best meets the needs of patients without risking compromising biomechanical efficiency.[2,3] The lingual technique was developed in the early 1970s in the United States by Craven Kurz, an orthodontist treating mostly adult patients with high aesthetic demands.[1] The method was popularised by the introduction of a customised CAD/CAM system by Dirk Wiechmann in the early 2000s.[4]

The use of lingual appliances is thought to produce clinical outcomes different from those of traditional fixed appliances (hereafter called buccal technique), such as decreased axial inclination of the maxillary incisors and reduced root angulation.[5] Although a belief pertains that treatment results after lingual orthodontics are less predictable and favourable than those achieved using the buccal technique, some studies have shown that the setups created prior to lingual orthodontic treatment gave rise to no significant differences between the desired result and the actual treatment result.[6-10] Fully customised lingual orthodontic appliances were found to be accurate in achieving the goals planned, except for expansion and inclination of the second molars.[6] Furthermore, a systematic review reported achievement of good clinical outcomes with lingual orthodontics, specifically concerning the achievement of individualised treatment goals and the reduction of decalcifications on the bonded surfaces of the teeth.[11]

Three-dimensional (3D) dental models are now widely used in dental-related fields and are known to be as reliable as traditional plaster models.[10] Parallel to the development of systems' standardization, setups are used as a tool for simulating planned treatment results.[12,13]

The studies that have so far assessed the accuracy of tooth positioning after lingual orthodontics consisted in 3D superimposed final casts on the setups.[6-9] Although those studies showed interesting results, superimpositions are relying on the accuracy of the registration process, which depends on the stable structures chosen. For superimpositions of the maxilla, surface-to-surface superimposition on the palatal rugae can be used,[14] but this is not possible for setups, while stable reference structures for the mandible are lacking. Therefore, defining anatomical references and planes in order to precisely measure the differences between setups and final casts for each tooth could offer a more accurate way to compare the outcome of a lingual orthodontic treatment.

Therefore, the aims of this study were to assess the precision of treatment outcome following lingual orthodontics by comparing setups with post-treatment casts and to assess the treatment results with reference to the initial situation.

In the present study, it was hypothesised that the outcome of lingual orthodontic treatment would not be different from the pre-treatment setup.

Material and Methods

This study was approved by the Ethical Committee of canton Geneva, Switzerland (Commission cantonale d’éthique de la recherche de Genève, number 15-111).

A sample size calculation was performed using the program ClinCalc© (ClinCalc LLC 2021), based on a mean difference in bucco-lingual torque of 3° between the setups and the post-treatment casts. Following Lossdörfer et al, the standard deviation of the torque was set as 5.4°.[9] Hence, a sample of 25 subjects was needed to reject the null hypothesis that the means of setups and post-treatment casts were equal (α=0.05 and 1-β=0.8).

In order to account for some potentially damaged casts, thirty-two consecutive patients (mean age: 28.4 years ± 9.2) treated at the University of Geneva with a customised lingual orthodontic appliance (Incognito™, 3M Unitek, Monrovia, CA, USA) were included in this retrospective study. All patients had complete orthodontic records. The inclusion criteria were: full arch Incognito™ appliance manufactured based on a plaster setup. The exclusion criterion was: partial arch Incognito™ appliance (Incognito™ Lite).

All patients were treated by postgraduate students under the close supervision of one single certified orthodontist experienced in the lingual orthodontic technique (MAC). All cases were bonded with opaque silicon transfer keys (provided by Incognito™) and a chemical cure sealant system with fluoride Maximum Cure® (Reliance, Itasca, IL, USA). The following archwires delivered by Incognito™ were used: .014 superelastic nickel-titanium (SE NiTi), .016x.022 SE NiTi, .018x.025 SE NiTi, .016x.024 Stainless Steel and .0182x.0182 Beta Titanium. No finishing bends or any other changes on the wires were requested to the lingual system company. Ligation was performed according to the Incognito™ protocol, namely, conventional o-rings for regular alignment, elastic lassos for derotations, conventional metallic ligatures for later treatment stages, overties for better angulation and torque control in the anterior segment, German overties for maximum seating of the wire, German overties with steel ligature during retraction. Interproximal enamel reduction was performed in case of mild-to-moderate crowding. Intermaxillary elastics were used in order to achieve good relationships between upper and lower arches.

Dates of birth, initial records, bonding, debonding, final records, treatment duration, as well as number of arches treated with the lingual technique were extracted from the patients' files. All data were anonymised.

Initial plaster casts, post-treatment plaster casts and plaster setups were scanned using the 3D scanner Ortho Insight 3D (Motion View Software, LLC, Chattanooga, TN, USA). Upper and lower casts were scanned separately first, then in occlusion, and were saved in the STL file format. The digital models produced (initial, post-treatment and setup) were analysed with Mimics 18 software (Materialise, Leuven, Belgium) by a single operator (CF), after calibration with an expert user (PMC). The following measurements were assessed (Table I): overjet; overbite; molar and canine relationships; intercanine, interpremolar and intermolar distances; upper and lower arch lengths; midline deviation; bucco-lingual angulation of all teeth; mesio-distal angulation of anterior teeth. In order to perform the measurements, 99 anatomical points and 50 planes were defined for each model. The first plane defined was the occlusal plane (represented in red, in Figure 1), which then served as a reference plane for the measurement of the bucco-lingual torque of all teeth and the mesio-distal angulation of the anterior teeth. The occlusal plane was defined by three points: the disto-buccal cusps of the upper right and left first molars and an interpolation of the two mesial tips of the incisal edges of the two upper central incisors. Bucco-lingual torque (plane represented in blue, in Figure 1) and mesio-distal angulation (plane represented in green, in Figure 1) were determined by measurements between planes, defined by specific anatomical points (Table I, Figure 1).

In order to assess intra-observer reliability, all measurements for ten randomly selected initial models, ten randomly selected setups, and ten randomly selected post-treatment models were repeated after five weeks.

Statistics

Statistical analyses included descriptive statistics and normality tests. Since normality was confirmed, paired *t*-tests were used to compare measurements performed on the post-treatment models and the setups. Regression analyses were performed to estimate the significance of the mean change between the planned (initial-setup) and achieved treatment results (initial-final). These analyses were conducted for measurements of bucco-lingual torque of all teeth and mesio-lingual angulation of anterior teeth. For estimation of the random error, the Dahlberg formula was used ($s = \sqrt{(\Sigma d^2/2n)}$).[15,16] All analyses were performed using IBM SPSS Statistics 23 (IBM Corporation, New York, NY, USA). Significance was set to $p < 0.05$.

Results

The average error of the method (Dahlberg's formula) was 1.23 degrees for the bucco-lingual torque measurements, 1.27 degrees for the mesio-distal angulation measurements and 0.30 mm for the linear measurements. All values are presented in Supplementary Table I.

The mean treatment duration was 2.2 ± 0.9 years. The sample included 21 non-extraction cases with mild-to-moderate crowding and 11 extraction cases with severe crowding (one lower incisor (6); one premolar (3); two premolars (1) and 4 premolars (1)). The sample consisted in 12 cases of Class I malocclusion; 18 cases of Class II malocclusion and 2 cases of Class III malocclusion.

Statistically significant differences in bucco-lingual torque were found for all upper teeth between the setups and post-treatment casts (ranging from 2.4 ± 3.3º: canines, to 6.1 ± 5.7º: second premolars), except for the central incisors (Table II). In the lower arch, statistically significant differences in bucco-lingual torque were found between the setups and post-treatment casts for the incisors and molars (ranging from -2.6 ± 6.3º: first molars, to 3.0 ± 5.5º: central incisors), but not for the canines and premolars.

Regarding the mesio-distal angulation of anterior teeth, no statistically significant differences were found between setups and post-treatment casts in either the upper or the lower arches (Table III).

The mean upper intercanine and inter-first premolar distances did not vary significantly between the setups and the final casts. The mean upper inter-second premolar and intermolar distances were significantly larger on the setups than on the post-treatment casts (Table IV: 0.5 ± 1.2 mm for second premolars and 1.1 ± 1.8 mm for molars). The lower intercanine, interpremolar and intermolar distances did not vary significantly between the setups and the final casts (Table IV). Both upper and lower arch lengths were significantly larger on the final casts than on the setups. No statistically significant differences in overjet and overbite were found between the setups and the post-treatment casts (Table IV). The post-treatment molar relationship was as predicted on the setups, except in four cases where there was a unilateral difference of a quarter cusp (three cases) or half a cusp (one case). The post-treatment canine relationship was as predicted on the setup in 18 cases. There was a unilateral difference of a quarter cusp in 11 cases, a bilateral difference of a quarter cusp in two cases, and a bilateral difference of a quarter cusp on one side and of a half a cusp on the other side in one case. The midline was corrected in 24 cases, whereas a deviation of more than 1 mm was still present after treatment in the remainder eight cases.

The regression analyses showed a statistically significant positive relationship between the planned and achieved torque and angulation of all teeth, except for the torque of the upper first premolars (Table V).

Considering those results, the null hypothesis was rejected in terms of bucco-lingual inclination, as well as arch width and length, since the outcome of lingual orthodontic treatments was significantly different from the pre-treatment setups. However, with regards to the angulation of anterior teeth, overbite and overjet, the null hypothesis could not be rejected.

Discussion

Invisible orthodontics will play a major role in the future as patients become more concerned with aesthetics, with lingual treatment becoming highly requested, especially by adult patients.[2] Therefore, it is crucial to be able to propose such treatment without compromising the treatment results. Orthodontic treatment results achieved when using the lingual technique are believed to be less predictable than those achieved by conventional buccal techniques. On the other hand, some authors have stated that customised brackets and arch wires for lingual orthodontics represented a considerable advantage challenging finishing processes and patient discomfort.[7,17] Because of this apparent contradiction in views, the present study aimed to retrospectively assess treatment outcome after lingual orthodontics by comparing setups with the post-treatment results.

Previous studies have compared buccal and lingual orthodontic treatment.[5,10,11,18-24] Advantages and disadvantages have been reported for both alternatives: patients undergoing lingual orthodontic treatment were shown to have impaired speech articulation compared with patients having buccal orthodontic treatment.[19-22,25] Moreover, a systematic review has reported that lingual appliances are related to overall oral discomfort and increased eating difficulty.[21] On the other hand, one study described a reduced risk of caries development as an advantage of lingual orthodontics.[11,26,27] Concerning bond failure rates, one study has compared both buccal and lingual techniques, finding no difference between the two techniques within the first year after bonding.[23] Similarly, treatment duration was shown to be similar for both lingual and buccal orthodontic techniques,[10] thus disproving the belief among clinicians that lingual orthodontic treatments last longer.

Regarding the differences between setups and treatment outcome, the present study showed that the post-treatment molar and canine relationships were as planned in the majority of cases. Few cases showed a discrepancy of a quarter cusp, which can be clinically accepted and is probably similar to what may be expected with buccal appliances. Inter-arch relationships have not been assessed previously for lingual orthodontic treatment, which is one of the strengths of the present study. In adults, obtaining class I relationships depends mostly on compliance with elastics, which is generally considered to be good in adult patients. This may suggest that although lingual patients have high aesthetic standards, their compliance with elastics is good provided that they are well informed when treatment is initiated. Obtaining class I relationships also depends on anchorage control. Some authors suggest that posterior anchorage is easier to achieve with lingual than with labial orthodontics;[2] as most cases start with class II relationships, this might be a help for achieving class I.

Previous studies have indicated that vertical forces applied to buccal and lingual appliances produce different clinical effects with respect to tooth movement.[2,28] This difference arises because of the distance between the centre of resistance and the point of force application, which differs between lingual and buccal techniques, thus influencing the magnitude of the moments of the forces. For this reason, torque has been reported as more difficult to control with lingual orthodontics.[28] On the other hand, one *in vitro* study has assessed torque play with different lingual bracket systems and showed that a low torque play is present; the authors therefore concluded that these appliances can precisely perform the planned tooth movements.[29] Other *in vitro* studies performed on typodonts have previously shown that given the high precision of the bracket slot-arch wire combination for lingual appliances, an effective torque control could be achieved clinically.[30,31] It has also been shown *in-vitro* that the efficiency of the ligature-archwire-slot system in torque control with a customised lingual appliance does not depend on the ligature type and geometry, except when using a 0.016″ × 0.022″ NiTi wire.[32] Clinical studies have confirmed that a good and effective torque control can be achieved with lingual orthodontic treatments.[4,33] However, the results of the present study have shown significant differences in bucco-lingual torque between the setups and post-treatment casts for all teeth, except for the upper central incisors, the lower canines and the lower premolars. These results are not in agreement with the results reported in previous performed *in vitro* studies.[31,34] Yet, although statistically significant bucco-lingual torque differences were observed between the setups and the post-treatment casts, the question whether these differences are clinically relevant can be raised. Indeed, with labial brackets, the smallest torque play values reported in the literature with a full size arch wire are in the range of 4 degrees,[35] while for lingual brackets the smallest torque play values reported are in the range of 2 degrees.[36] Therefore, when setting as threshold for clinical significance an average value of 3 degrees, in the present study the differences between the final results and the setups would be relevant only for the upper second premolars and first molars.

Interestingly, by comparing setups with post-treatment casts, we found that all teeth except lower second premolars and first molars showed a more positive torque on the post-treatment casts than on the setups, suggesting that lingual orthodontics does not end up in overly retroclined teeth because of the more lingual position of the brackets in relation to the centre of resistance of the teeth. Regression analysis showed that there was a positive correlation between the planned and achieved torque for all teeth, except for the upper first premolars.

Regarding the mesio-distal angulation of anterior teeth, the present study found no differences between setups and post-treatment casts, although the slots had a vertical insertion in the anterior segment, which might compromise angulation control. The regression analysis showed that there was a positive correlation between the mesio-distal angulation planned and achieved, for all anterior teeth. These results are in agreement with previous research.[6,7]

Khattab *et al*. have previously reported that during space closure, lingual orthodontic treatments result in a decreased intermolar width, an increased intercanine width and significantly decreased anchorage loss of the maxillary first molar.[34] This was not seen in the present study: though the upper inter-second premolar and intermolar distances were significantly larger on setups than on post-treatment casts, this difference was not clinically relevant (second premolars: 0.5 mm ± 1.2; molars: 1.1 mm ± 1.8). No differences between setup and post-treatment outcomes were observed with respect to upper intercanine distance, and this is in agreement with previous reports.[7,8] In the present study, the post-treatment upper and lower arch lengths significantly differed from the setup, however these differences were not clinically significant (upper arch length: -0.8 mm ± 0.7; lower arch length: -0.6 mm ± 0.9). There were no significant differences between setups and post-treatment casts for overjet and overbite, which supports previously published reports.[6,7,11]

Knosel *et al.* compared the duration of orthodontic treatments with two different customised lingual orthodontic systems (Incognito™ and WIN lingual system), showing that the treatment duration with the WIN appliance was shorter.[37] The treatment duration in the present study (26 months) was similar to the treatment duration with the Incognito™ appliance in the above-mentioned study.[37]

The present study offers a detailed assessment of specific measurements such as angulation and torque in order to precisely evaluate the efficiency of lingual orthodontics. Previously, only two studies have measured several clinical variables independently,[6,7] by superimposing 3D models. Grauer and Proffit[6] did not assess torque and angulation, whereas Pauls'[7] methodological reproducibility may be questionable.

A limitation of the present study was the use of post-treatment casts, which do not always reflect the performance of the final arch wires. Indeed, in our sample, clinicians performed finishing wire bendings to meet patient-specific treatment goals, especially for the anterior teeth, in order to achieve correct mesio-distal tip or bucco-lingual torque. Obviously, the retrospective design of the present study does not allow us to establish which finishing wire bends were performed. With the development and growing reliability of intra-oral scanning technology[38], this limitation could be overcome by obtaining intra-oral scans after placement of finishing arch wires to assess precisely the efficiency of the wire and bracket combination, without influence of finishing wire bends.

The use of the occlusal plane as a reference plane for torque and angulation measurements can also be seen as a limitation, as the occlusal plane can change from the pre- to the post-treatment situation, especially when using class II elastics. However, it is important to mention that none of the subjects in the present study had massive class II mechanics, since severe class IIs were corrected with distalization or extractions.

Finally, another limitation of the present study is the fact that the sample jointly analysed both extraction and non-extraction cases. This could be considered a bias, since extractions of teeth can generate torque and angulation issues. However, as it was not the absolute effects of treatment that were assessed, but specifically the differences between what was planned against what was achieved with the actual treatment. In addition, since daily practice consists of both extraction and non-extraction cases, we wanted to assess a sample that was as close as possible to the clinical setting in terms of case diversity, and thus both types of cases were included.

Further research may investigate the fully digital workflow now proposed by Incognito™, which is based on a printed bonding tray, and compare this with the combined plaster setup – CAD/CAM-produced bracket and wire system investigated in the present study. The fact that the brackets are placed manually on the malocclusion casts in order to fabricate the transfer trays may produce some errors and reduce the precision of the system.

Conclusions

Orthodontic treatment using a customised lingual appliance is very efficient in terms of control of mesio-distal angulation of all anterior teeth, intercanine distances, molar relationship, overjet and overbite. Significant differences in bucco-lingual torque between setups and post-treatment casts were observed for upper lateral incisors, canines, premolars, and molars, as well as lower incisors and molars. However, if a 3-degree threshold were considered clinically significant, the lack of torque control would be relevant only for the upper second premolars and first molars.

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Figure legends

Figure 1. Measurement of bucco-lingual torque and mesio-distal angulation. The blue plane represents the bucco-lingual torque of the upper left canine, which is measured in relation to the occlusal plane, in red. The green plane represents the mesio-distal angulation of the same tooth, which is also measured in relation to the occlusal plane.

Data availability statement

The data that support the findings of this study are not openly available due to ethical reasons and are available from the corresponding author upon reasonable request.

Table I. Measurements

Angular Measurements (degrees): measured between *occlusal plane* and *torque and angulation planes* defined for each tooth		
Measurements	Teeth	Points used to define *torque and angulation planes* for each tooth
Bucco-lingual torque	Upper central incisors	Palatal and buccal gingival points; mesial and distal tips of the incisal edges; midpoint between the mesial and distal tips of the incisal edges; midpoint between the palatal and buccal gingival points
	Upper lateral incisors	
	Upper canines	Palatal and buccal gingival points; point on the cusp; mesial and distal tips of the edges; midpoint between the palatal and buccal gingival points
	Upper first premolars	Palatal and buccal gingival points; mesial and distal contact points; tip of the buccal cuspid; fissure point
	Upper second premolars	
	Upper first molars	Palatal groove and buccal gingival points; mesial and distal tips of the buccal cusps; fissure point; mesial contact point
	Lower central incisors	Lingual and buccal gingival points; mesial and distal tips of the incisal edges; midpoint between the mesial and distal tips of the incisal edges; midpoint between the lingual and buccal gingival points
	Lower lateral incisors	
	Lower canines	Lingual and buccal gingival points; point on the cusp; mesial and distal tips of the edges; midpoint between the lingual and buccal gingival points
	Lower first premolars	Lingual and buccal gingival points; mesial and distal contact points; tip of the buccal cuspid; fissure point
	Lower second premolars	
	Lower first molars	Palatal groove and buccal gingival points; mesial and distal tips of the buccal cusps; fissure point; mesial contact point
Mesio-distal angulation	Upper central incisors	Palatal and buccal gingival points; mesial and distal tips of the incisal edges; midpoint between the mesial and distal tips of the incisal edges; midpoint between the palatal and buccal gingival points
	Upper lateral incisors	
	Upper canines	Palatal and buccal gingival points; point on the cusp; mesial and distal tips of the edges; midpoint between the palatal and buccal gingival points
	Lower central incisors	Lingual and buccal gingival points; mesial and distal tips of the incisal edges; midpoint between the mesial and distal tips of the incisal edges; midpoint

	Lower lateral incisors	between the lingual and buccal gingival points
	Lower canines	Lingual and buccal gingival points; point on the cusp; mesial and distal tips of the edges; midpoint between the lingual and buccal gingival points
Linear measurements (mm)		
Upper intercanine distance		Distance between the points on the cusps of each canine
Upper inter-first premolar distance		Distance between the tips of the buccal cusps of each premolar
Upper inter-second premolar distance		
Upper intermolar distance		Distance between the tips of the disto-buccal cusps of each molar
Lower intercanine distance		Distance between the points on the cusps of each canine
Lower inter-first premolar distance		Distance between the tips of the buccal cusps of each premolar
Lower inter-second premolar distance		
Lower intermolar distance		Distance between the central fossa of each molar
Upper arch length		Measured by defining upper molar vertical plane: perpendicular to occlusal plane and passing through the anterior contact points of the first upper molars. Distance between upper molar vertical plane and the midpoints of the two mesial tips of the incisal edges of the two central incisors
Lower arch length		Measured by defining lower molar vertical plane: perpendicular to occlusal plane and passing through the anterior contact points of the first lower molars. Distance between lower molar vertical plane and the midpoints of the two mesial tips of the incisal edges of the two central incisors
Overjet		Distance between the midpoint of the mesial and distal tip of the incisal edge of the most protruded upper central incisor and buccal surface of its antagonist tooth
Overbite		Distance between the midpoint of the mesial and distal tips of the incisal edge of the lower incisor and incisal edge of its antagonist (the upper incisor that would be in the lowest position)
Midline deviation		Measured by defining two planes: the first one perpendicular to both the occlusal and the upper molar vertical planes and passing through the midpoint of the upper central incisors; the second plane was constructed using the same approach but using the lower central incisors' midpoint. Distance between these planes.

Table II. Differences in bucco-lingual torque between setups and post-treatment casts.

Group of teeth (average of right and left sides)	N	Mean difference (degrees)	SD	95% Confidence Interval		*p* value
				Lower	Upper	
Upper Central Incisors	32	0.7	4.9	-1.0	2.5	0.406
Upper Lateral Incisors	32	2.6	5.6	0.6	4.6	0.013*
Upper Canines	31[1]	2.4	3.3	1.2	3.6	0.000***
Upper First Premolars	26	2.9	6.7	0.2	5.6	0.035*
Upper Second Premolars	32	6.1	5.7	4.0	8.1	0.000***
Upper First Molars	32	4.9	5.8	2.8	6.9	0.000***
Lower Central Incisors	27[3]	3.0	5.5	0.8	5.1	0.009**
Lower Lateral Incisors	27[3]	2.5	5.0	0.5	4.4	0.017*
Lower Canines	27[3]	0.8	4.7	-1.1	2.6	0.396
Lower First Premolars	26	0.4	6.0	-2.0	2.9	0.703
Lower Second Premolars	28[2]	-0.7	5.7	-2.9	1.6	0.511
Lower First Molars	28[2]	-2.6	6.3	-5.0	-0.1	0.041*

[1]The sample included one case with an impacted canine: this tooth was absent from the setup, therefore the bucco-lingual torque was not assessed for this patient.

[2]Four cases had lingual appliances in the upper jaw only.

[3]One plaster setup was broken at the level of teeth 31, 41, 42 and 43, therefore the bucco-lingual torque of these teeth were not assessed for this patient.

Levels of significance: ***p<0.001; **p<0.01; *p<0.05

Table III. Differences in mesio-distal angulation between setups and post-treatment casts.

Group of teeth (average of right and left sides)	N	Mean difference (degrees)	SD	95% Confidence Interval		*p* value
				Lower	Upper	
Upper Central Incisors	32	0.4	1.6	-0.2	0.9	0.233
Upper Lateral Incisors	32	-0.1	3.1	-1.2	1.0	0.835
Upper Canines	31[1]	-0.5	3.7	-1.9	0.8	0.425
Lower Central Incisors	27[2]	0.2	1.6	-0.4	0.8	0.571
Lower Lateral Incisors	27[2]	0.6	3.0	-0.6	1.8	0.282
Lower Canines	27[2]	0.4	4.3	-1.3	2.1	0.648

[1]The sample included one case with an impacted canine: this tooth was absent from the setup, therefore the mesio-distal angulation was not assessed for this patient.

[2]Four cases had lingual appliances in the upper jaw only. One plaster setup was broken at the level of teeth 31, 41, 42 and 43, therefore the mesio-distal angulation of these teeth were not assessed for this patient.

Levels of significance: ***p<0.001; **p<0.01; *p<0.05

Table IV. Differences in arch widths and lengths, overjet and overbite, between setups and post-treatment casts.

Distance measured	N	Mean difference (mm)	SD	95% Confidence Interval		*p* value
				Lower	Upper	
Upper intercanine distance	31[1]	0.0	0.6	-0.2	0.2	0.925
Upper inter-first premolar distance	26	0.1	0.8	-0.2	0.4	0.569

Upper inter-second premolar distance	32	0.5	1.2	0.0	0.9	0.036*
Upper intermolar distance	32[3]	1.1	1.8	0.4	1.7	0.002**
Lower intercanine distance	27	-0.4	1.0	-0.8	0.0	0.063
Lower inter-first premolar distance	26	0.2	1.1	-0.3	0.6	0.479
Lower inter-second premolar distance	28[2]	0.3	1.2	-0.2	0.7	0.252
Lower intermolar distance	28[3]	0.4	1.4	-0.2	0.9	0.189
Upper arch length	32[3]	-0.8	0.7	-1.0	-0.5	0.000***
Lower arch length	28[3]	-0.6	0.9	-0.9	-0.2	0.002**
Overjet	32	-0.3	0.9	-0.6	0.0	0.071
Overbite	32	0.1	0.6	-0.1	0.4	0.268

[1]The sample included one case with an impacted canine: this tooth was absent from the setup.

[2]Four cases had lingual appliances in the upper jaw only.

[3]Two cases had one missing permanent molar (one upper and one lower) and space closure was planned. Therefore, the second molar replacing the missing first molar was taken into account (in the setup and posttreatment casts).

Levels of significance: ***p<0.001; **p<0.01; *p<0.05

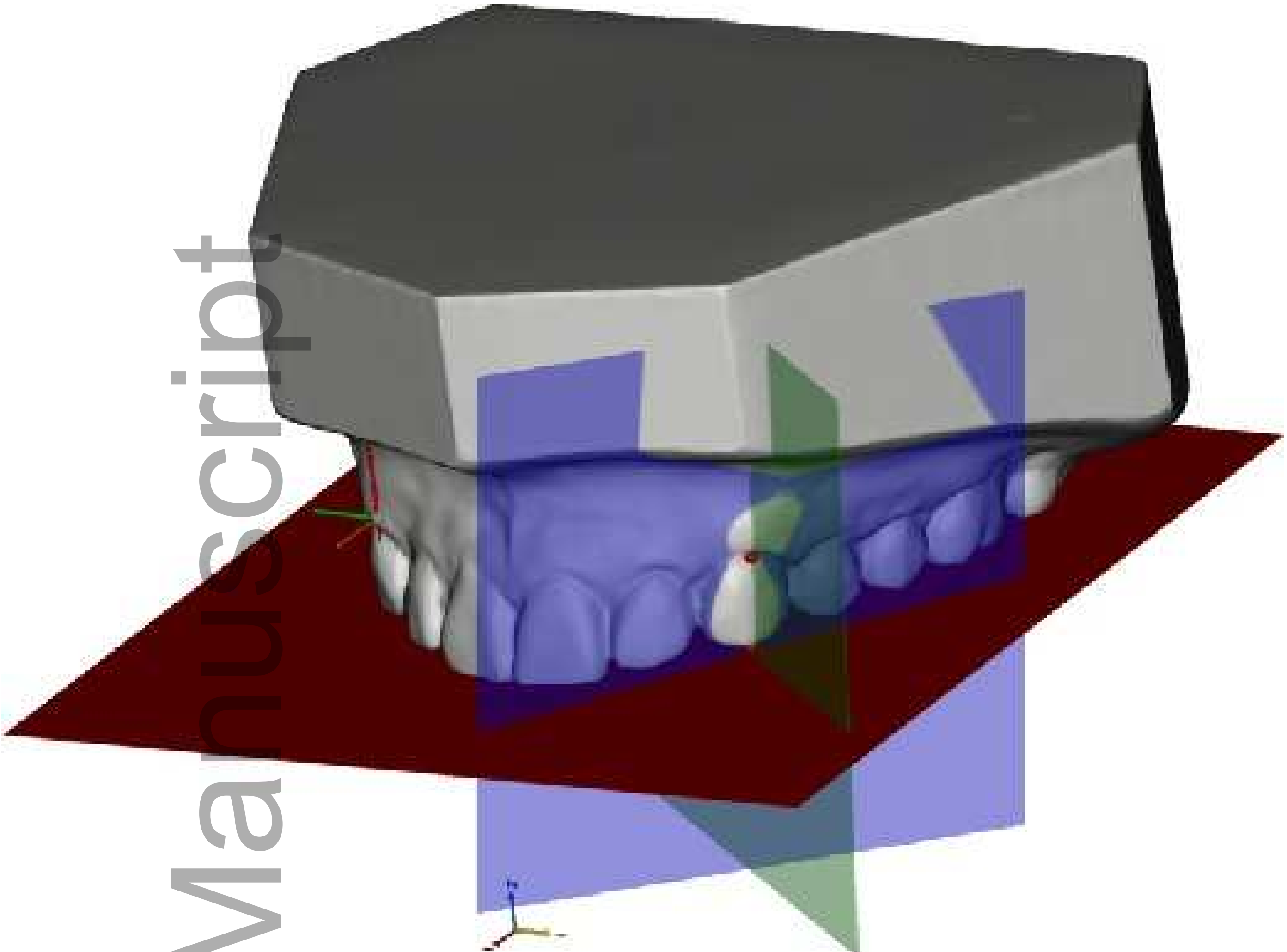
Table V. Bucco-lingual torque and mesio-distal angulation: Regression analysis comparing planned (initial-setup) to achieved treatment results (initial-final).

The more significant the relationship between planned treatment and achieved treatment result, the closer to the setup was to the outcome.

	Group of teeth	Mean change planned treatment	Mean change achieved	Regression coefficient	Confidence Interval (95%)		*p* value
					Lower	Upper	

		(initial-setup) (degrees)	treatment (initial-final) (degrees)	(*β*)			
Bucco-lingual torque	Upper central incisors	-1.7	-2.4	.869	0.5	0.8	0.000***
	Upper lateral incisors	-1.7	-4.4	.760	0.4	0.8	0.000***
	Upper canines	4.4	2.0	.729	0.5	1.1	0.000***
	Upper first premolars	-0.7	-3.6	.090	-0.2	0.3	0.663
	Upper second premolars	-6.1	-4.1	.561	0.2	0.6	0.001**
	Upper first molars	4.3	-0.6	.476	0.1	0.8	0.006**
	Lower central incisors	-15.5	-18.4	.561	0.2	1.0	0.002**
	Lower lateral incisors	-0.9	-3.4	.800	0.6	1.1	0.000***
	Lower canines	5.2	4.4	.758	0.3	0.7	0.000***
	Lower first premolars	-0.8	-1.2	.469	0.1	0.9	0.016*
	Lower second premolars	-1.8	-1.1	.485	0.2	1.0	0.009**
	Lower first molars	-1.6	0.9	.408	0.0	0.8	0.031*
Mesio-distal angulation	Upper central incisors	2.5	2.1	.809	0.5	0.9	0.000***
	Upper lateral incisors	2.6	2.7	.625	0.4	1.0	0.000***
	Upper canines	-0.1	0.5	.769	0.4	0.9	0.000***
	Lower central incisors	2.0	1.8	.908	0.7	1.0	0.000***
	Lower lateral incisors	2.2	1.6	.452	0.1	0.8	0.018*
	Lower canines	5.3	4.9	.646	0.3	0.9	0.000***

Levels of significance: ***p<0.001; **p<0.01; *p<0.05



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