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Incisor and profile alterations in extraction cases treated with standard Edgewise and preadjusted appliances: a controlled before-and-after study

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Running title: Post-extraction incisor inclination with standard Edgewise and straightwire appliances

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A B S T R A C T

Background: Even though treatment of Class II malocclusion with premolar extractions and incisor retraction might impact incisor inclination and soft-tissue profile, the effects of bracket prescription on this has not been thoroughly assessed.

Methods: Fifty- patients (mean age: 13.6 years; 34% male) receiving extraction-based treatment with either standard Edgewise or preadjusted appliances were included. Between-group differences in the incisor inclination assessed with lateral cephalograms were analyzed statistically with linear/logistic regression at 5%.

Results: Treatment-induced changes included retroclination of the upper/lower incisors (-3.0° and -2.0°, respectively), retraction of the upper/lower incisors (-3.4mm and -1.5mm, respectively), retraction of the upper/lower lip (-2.1mm and -2.0mm, respectively), and enlargement of the nasolabial angle (+1.6°). Analysis of the data adjusting for confounders indicated that the preadjusted group had after treatment larger inclination of the upper or lower incisors (+3.2° and +4.5°, respectively), more prominent upper incisors relative to the facial plane (+1.3mm), and smaller interincisal angle (-7.3 or -7.7°). Post-treatment upper incisor inclination fell within the cephalometric norm significantly more in the preadjusted than in the standard Edgewise group (odds ratio=4.3; 95% confidence interval=1.1 to 16.6). No differences were found in lower incisor prominence, upper/lower lip prominence, or nasolabial angle.

Conclusions: Preadjusted appliances were associated with increased inclination of the upper and lower incisors, with more prominent upper incisors, and with more acute interincisal angle after retraction compared to standard Edgewise appliances. However, such differences did not translate in greater retraction of the upper/lower lips and greater nasolabial angle.

Keywords Treatment outcome · Incisor inclination · Orthodontic · Fixed appliances · Controlled before-and-after study

Abbreviations

ABO, American Board of Orthodontists

CI, Confidence Interval

MBT, McLaughlin-Bennett-Trevisi

SD, standard deviation

STROBE, Strengthening the Reporting of Observational Studies in Epidemiology

1. Introduction

The effectiveness of orthodontic treatment with fixed appliances in establishing a well-balanced occlusion has been well documented over the last century. In the last years, clinical research has focused on objectively measured treatment outcome quality [1] and its association with long-term outcomes. For example, finishing orthodontic treatment to an ideal occlusal standard, as proposed by the American Board of Orthodontists (ABO) [2], seems to be associated with a more balanced activation of anterior temporalis muscle and improved patient-reported chewing ability compared to worse finished occlusions [3]. Additionally, long-term changes in the occlusion of orthodontically treated patients seem to be more favorable in terms of improved settling and reduced tendency for anterior crowding relapse [4] as the finishing quality of orthodontic treatment increases [5]. Such evidence highlights the importance of a well-finished post-orthodontic occlusion plays and the care with which orthodontists should strive to achieve optimal results.

Orthodontic treatment of malocclusion with skeletal components, large overjet, or moderate to severe arch length discrepancy often includes extraction of permanent teeth, which are usually the first or second premolar. Extraction-based orthodontic treatment has been shown to be associated with better outcomes and improved long-term stability compared to non-extraction treatment of borderline cases [1,6]. At the same time, extraction of premolars and orthodontic retraction of the anterior teeth might affect the patient's soft tissue profile [7] in a manner dependent on the retraction amount [8] and especially if uncontrolled tipping is used. In such cases, one might need to apply additional torque to the retracted incisors to restore their ideal position within the alveolar bone, improve esthetics, enable proper articulation with the lower teeth, and facilitate adequate soft tissue support. However, torque application on upper incisors might prove to be a lengthy [9] and complicated task from the side of biomechanics of fixed appliances [10,11].

The orthodontic fixed appliance has become an integral part of modern orthodontic treatment since its introduction by E.H. Angle and the development of the pre-adjusted appliance by L. Andrews [12]. In the original concept of Andrews, the ideal fixed appliances would provide an advantage during many treatment phases, including post-extraction incisor retraction, since the preadjusted bracket slot should minimize losses in tooth inclination / torque due to uncontrolled tipping. Various prescriptions for orthodontic

appliances have been introduced in their last decades, but existing evidence on their comparative performance still remains limited [13]. A previous comparative study indicated that both standard Edgewise and preadjusted appliances were compatible with similar finishing quality according to the ABO tool, even though preadjusted appliances were associated with reduced treatment duration [14]. However, no evidence currently exists about the incisor inclination post retraction, which might also contribute to the establishment of a harmonious and stable in the long-term dentition [15–17].

Therefore, aim of the present study was to assess the incisor inclination after extraction-based orthodontic treatment with either standard Edgewise or preadjusted fixed appliances. The primary research question is: “Is the inclination of the upper incisors after retraction different with preadjusted appliances compared to standard Edgewise appliances?”.

2. Materials and methods

2.1. Protocol, registration, and ethical approval

This controlled before-and-after study (retrospective collection of data from patients treated/measured prospectively) is based on an a priori protocol registered in ISRCTN (ID 13048456) and openly available in Open Science Framework (https://osf.io/e3j5f/). Ethical approval was sought and acquired from University of …. (BASEC-Nr.: 2018-00631) and University of …. (Regional Committees for Medical and Health Research Ethics; Ref. nr.: 2017/1885). This paper is based on the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [18].

2.2. Sample

This controlled before-and-after study includes patients having comprehensive fixed appliance treatment with extraction of at least two upper premolars in two university clinics (… and …). Informed consent was acquired from all patients or their parents prior to treatment. Included patients in this study complied to the following patient eligibility criteria: (i) any age, sex, ethnicity, race, or Angle’s molar classification; (ii) full complement of teeth excluding the third molars; (iii) no prior orthodontic therapy; (iv) no dentofacial deformities and clefts; and (v) complete pre- / and post-treatment data. Additionally, they should fulfill the following treatment-related inclusion criteria: (i) comprehensive treatment with labial fixed

appliances in both arches; (ii) bilateral extraction of upper 1st or 2nd premolars (with / without extraction of lower premolars); (iii) retraction during treatment of the upper incisors as seen through superimposition of lateral cephalograms on the nasal line; (iv) no temporary anchorage devices; (v) no orthognathic surgery; (vi) no dental trauma; and (vii) no impacted canines. Patients from the two university clinics were selected randomly from the archives of patients treated by postgraduate orthodontic residents in the last 10 years under the direct supervision of university faculty and presented in the orthodontic specialization boards of each country. Patients from one clinic (University of ….) were treated with standard Edgewise appliances (Mini Twin Diamond, Ormco, Orange, Calif) and patients from the other clinic (University of ….) were treated with preadjusted appliances (MBT Victory, 3M Unitek, Monrovia, Calif) – both systems conventionally ligated and with an 0.018-inch slot. The university clinic in … uses solely preadjusted appliances, while the university clinic in … uses standard Edgewise appliances for almost 95% of each postgraduate's cases and only a handful selected cases are treated with preadjusted appliances (none included in this study). Treatment mechanics (including torque application) were left to the discretion of the clinical instructors supervising treatment in the two clinics, but space closure mostly included closing loops for the standard Edgewise group and sliding mechanics for the preadjusted group —both on slot-filling rectangular wires.

This study is based on patient records (pre-treatment age, pre-treatment sex, extraction plan, treatment duration), dental cast measurements (overjet and overbite), and radiographic measurements from lateral cephalograms. Lateral cephalograms were taken in natural head position and analyzed using a modified Bell-Proffit-White analysis. From each patient's documentation or dental casts the following pre-treatment data were extracted: age, sex, overjet, overbite, and the following cephalometric angles: SNA, SNB, ANB, Wits, and SN-ML (for explanation see Supplement 1). Additionally, treatment duration and the primary / secondary outcomes were extracted before (T1) and after treatment (T2). Finally, it was noted if 4 or less (2 or 3) premolars were extracted for orthodontic treatment and what was the malocclusion according to Angle's molar classification.

2.3. Sample size calculation

A priori sample size calculation for the primary outcome of upper incisor inclination was included in the pre-registered protocol and was based on the previous study [19] with: (i) control mean of 104.06º

degrees, (ii) standard deviation of 5.65º - assumed common between groups, (iii) a clinically meaningful difference in inclination of 5 degrees compared to that of the control mean, (iv) use of an independent-samples Student's t-test, (v) alpha of 5%, and (vi) beta of 20%. With these baseline data and assumptions, a needed sample of 22 patients/group (to a total of 44 patients) was calculated, which was increased to 25 patients/group (total of 50 patients) to allow for adjusted-for-confounding regression analyses.

2.4. Outcomes

The primary outcome of this study was the upper incisor inclination, as measured relative to the nasal line (1s-NL). Secondary outcomes included (i) upper incisor inclination relative to the cranial base (1s-SN), (ii) lower incisor inclination relative to the mandibular plane (1i-ML); (iii) upper incisor position relative to the facial plane (1s-NPg), (iv) lower incisor position relative to the facial plane (1i-NPg), (v) interincisal angle (1s-1i), (vi) upper lip distance from esthetic line (UL-E line), (vii) lower lip distance from the esthetic line (LL-E line), and (viii) nasolabial angle. All measured cephalometric variables are explained in Supplement 1. All outcomes were assessed in terms of average across all patients within each group. Additionally, the primary (upper incisor inclination) and two other selected outcomes (lower incisor inclination and interincisal angle) were also assessed as the proportion of patients having 'acceptable' incisor inclination. This was arbitrarily judged to be the case if a patient's incisor inclination fell within the variable's cephalometric norm [20] ± half a Standard Deviation (SD) (110±6° for 1s-NL, 94±7° for 1i-ML, and 130±6° for 1s-1i). The principal investigator (SNP) and the second author (CC) had prior to the study completed the necessary calibration process with 40 random cases not included in this study. Data were acquired in a blind manner by having all patient identifiers blocked-out by a third person from all radiographs and patient files.

2.5. Statistical analysis

Normality was checked through visual graph inspection and formally with the Shapiro-Wilk test. Descriptive statistics including means and SDs for continuous and absolute/relative frequencies for categorical variables. Differences between groups in baseline characteristics or follow-up measurements were assessed with Student's t-tests for independent samples or chi-squared test. Crude linear regression

modelling or logistic regression modelling was used to assess the effect of appliance on the primary or secondary outcomes with its 95% Confidence Intervals (CIs) using the post-treatment inclination as response and the pre-treatment inclination as covariate. Adjusted analyses controlling for confounders were done using the change-in-estimate method to select potential confounders with a minimum of 10% change set as cut-off [21]. A sample of 20 patients was randomly chosen and measured by both the first (SNP) and the second author (CC), while another random sample of 20 patients was re-measured by the second author (CC) after 2 weeks for repeatability. Repeatability and agreement of the measurements were assessed with the concordance correlation coefficient [22] and the Bland-Altman method [23]. Alpha was set at a two-sided 5%, but efforts were made to use more recent statistical guidelines on interpretation of statistical tests without overly relying on a $P<0.05$ as a sole measure of association [24]. All analyses were done in Stata SE 14.2 (StataCorp., College Station, Texas, USA), and the data set was openly provided [25].

3. Results

This study included 50 patients treated either with preadjusted (n=25) or with standard Edgewise appliances (n=25), with no statistically significant differences in demographics between groups, except for age (Table 1), where standard Edgewise patients were slightly older than preadjusted patients (14.4 and 12.8 years, respectively). Among the 50 included patients 17 (34%) were male and 41 patients (82%) were treated with extraction of four premolars with an average duration of 27.4 months. Orthodontically, patients at baseline had mean overjet of 4.6 mm, overbite of 2.7 mm, and neutral jaw relationship both sagittaly (average SNA 80.6º, SNB 77.2º, ANB 3.3º, Wits -0.5 mm) and vertically (average SN-ML of 35.3º) (Table 2). Compared to the standard Edgewise group, the preadjusted group had slightly more retrognathic mandibles (SNB of 76.2º and 78.3º, respectively) and more vertical configurations (SN-ML of 37.1º and 33.5º, respectively).

The observed treatment-related effects were summarized on average as upper incisor retroclination (-3.0º), lower incisor retroclination (-2.0º), enlargement of the interincisal angle (+5.6º), upper incisor retraction (-3.4 mm), lower incisor retraction (-1.5 mm), upper lip retraction (-2.1 mm), lower lip retraction (-2.0 mm), and enlargement of the nasolabial angle (+1.6º). Descriptive statistics (Table 3)

indicated that treatment effects on the position of the upper or lower incisors (1s-NPg and 1i-NPg) and the interincisal angle (1s-1i) might differ between the two groups (P values of 0.07, 0.09, and 0.002, respectively).

As far as the primary outcome is concerned, after adjusting for confounders (Supplement 2a) the observed data indicate that upper incisors in the preadjusted group are more proclined after treatment than the standard Edgewise group (average differences of +3.1 or 3.2º; P=0.04). Looking at the secondary outcomes, the data were compatible with the preadjusted group having post space closure (i) an increased upper incisor inclination also taking the cranial base as reference (+3.3º; 95% CI=0.3 to 6.3º; P=0.03), (ii) increased lower incisor inclination (+4.5º; 95% CI=2.0 to 7.0º; P=0.001), (iii) more anterior upper incisor position (+1.3 mm; 95% CI=0.1 to 2.4 mm; P=0.03), and (iv) more acute interincisal angle (with average differences of either -7.3º or -7.7º being most compatible with the data; P<0.001). Analyses of the data indicated that no differences between the two groups were identified for the position of the lower incisors, profile of the upper or lower profile, and the nasolabial angle (P>0.05).

Finally, 52% (n=13) of patients in the preadjusted and 28% (n=7) in the standard Edgewise groups had acceptable inclination of the lower incisors according to the cephalometric norm (± half a SD). The respective results were 44% (n=11) and 36% (n=9) for the lower incisor inclinations or 36% (n=9) and 48% (n=12) for the interincisal angle. Taking into account also potential confounders (Table 2b) the data were compatible with increased odds of having acceptably inclined indicated upper incisors with preadjusted appliances (Table 4c) compared to standard Edgewise appliances (odds ratio=4.3; 95% CI=1.1 to 16.6; P=0.04). No hints for a possible difference for lower incisor inclination or interincisal angle were found (P>0.05).

Interexaminer agreement and repeatability for the primary outcome of upper incisor inclination was almost perfect with a concordance correlation coefficient of 0.95 (95% CI=0.93 to 0.97) and a Bland-Altman average difference of 0.01º (95% limits of agreement=-4.48 to 4.49º). Intraexaminer agreement and repeatability was somewhat worse with a concordance correlation coefficient of 0.91 (95% CI=0.87 to 0.94) and a Bland-Altman average difference of -0.09º (95% limits of agreement=-6.28 to 6.09º). Similar almost perfect agreement was seen for the secondary outcomes of lower incisor inclination and interincisal angle (Supplement 3).

4. Discussion

The current study assessed the incisor inclination of 50 patients treated with incisor retraction after premolar extractions and either preadjusted or standard Edgewise fixed orthodontic appliances. The main finding of this study was that preadjusted appliances were associated with greater upper incisor inclination post-treatment than standard Edgewise appliances (with a difference of +3.2° or +3.1° being most probable according to the data; Table 4a). This might indicate that sliding mechanics along bracket slots that incorporate a prescription might be more effective in retaining at least part of the incisor inclination than commonly used standard Edgewise mechanics like space closure loops. It might be expected that orthodontic extractions and the consequent incisor retraction, even with the use of torqueing auxiliaries, results in retroclination of the upper incisors, which is dependent on the premolar being extracted and the amount of retraction [26]. The greater inclination of the preadjusted group in this study was actually due to the appliance having minimal effect on average on the pre-treatment incisor inclination (-0.6%), while the standard Edgewise group showed loss of inclination (-3.8%; Table 3). This might be explained by the McLaughlin-Bennett-Trevisi (MBT) prescription of the preadjusted appliance used in the University of … and the integrated +17º torque for the upper central incisors that might be retained by a slot-filling wire during retraction. On the contrary, a retrospective study on premolar extraction cases did not agree with the present study and found no significant difference in inclination of the upper and lower incisors or interincisal angle between preadjusted and standard Edgewise appliances [27].

This reduced retroclination of the upper incisors with preadjusted appliances was accompanied with reduced retraction of the upper incisors' tip compared to the standard Edgewise appliances (with a difference of +1.3 mm being most probable; Table 4a). As all patients were treated to fully closed spaces and to similar finishing quality according to the ABO tool [14], this indicates that the upper incisor tip in the standard Edgewise group was more posterior due to the incisors standing steeper post-treatment.

The data of the present study supported the notion that patients in the preadjusted groups had more often upper incisors acceptably proclined (according to the cephalometric norm) compared to the standard Edgewise group (odds ratio=4.3; Table 4c). This agrees with a previous study having some overlap of patients with the current one [14] that indicated that both appliances lead to similar finishing

quality in terms of the ABO's objective grading tool. Small differences existed between appliances in some ABO criteria and standard Edgewise appliances fared worse in the ABO's 'overjet' criterion than preadjusted appliances (5.4 versus 3.9 penalty points, respectively), which might be influenced by the post-treatment inclination of the upper incisors. However, such differences were in any case small, which indicates that the clinician's experience might play a greater role for the final outcome of treatment than the prescription of the fixed appliance. This is corroborated by another study comparing preadjusted Roth appliances to standard Edgewise appliances in terms of ideal tooth relationships [28]. That study indicated that Roth appliances were associated with better outcomes for some angulation and inclination outcomes compared to standard Edgewise appliances, but other outcomes were heavily dependent on the practitioner with some producing better results with standard Edgewise and other with preadjusted appliances.

Considerable inclination differences were further found, with patients in the preadjusted group having higher lower incisor inclination (+4.5°) and more acute interincisal angle post-treatment (-7.3° to -7.7°) compared to the standard Edgewise group. The increased lower incisor inclination was similarly due to different retroclination during treatment in the preadjusted and standard Edgewise groups (-0.8% and -3.3%, respectively) and differential opening of the interincisal angle (+3.6% and +7.2%, respectively). However, it must also be noted that the lower incisors were on average less retracted in this study than the upper incisors (-1.5 mm versus -3.4 mm, respectively), which might account for different effects in the inclination of these teeth.

Overall, even though differential effects were found for incisor position and inclination between the two appliances, this was not the case for the prominence of the lips or the nasolabial angle. Therefore, some small differences in tooth positioning might be of little clinical relevance to the patient from an esthetic standpoint.

This controlled before-and-after study presents several strengths, which include its pre-registered protocol [29] and the transparent provision of its dataset [30]. The a priori sample size estimation contributes to this study being adequately powered to identify any clinically important effects on upper incisor inclination, while blind outcomes assessment reduces the risk for bias. However, limitations also exist for the present study, like its retrospective nature for data collection, which is associated with inflated effects compared to randomized clinical trials [31]. Furthermore, not all treating orthodontists were equally

proficient and used both standard Edgewise and preadjusted appliance, it was not possible to administer both appliances in a single clinic to better account for individual proficiency variation. Additionally, retraction mechanics were not pre-determined and were left to the discretion of the clinical instructors overseeing treatment in each university clinic. The possibility that proficiency bias might exist cannot be ruled out, even though all patients were treated under the direct supervision of long-term clinical instructors with decades of experience. Lip prominence was checked with the E-line as reference, which might be affected by the growth changes of the nose [32], although patients were of relatively similar age and had similar treatment duration of slightly over 2 years. Finally, important adverse effects like root resorption, vestibular / palatal gingival recessions, tooth elongation, and anchorage loss were not assessed in this study, even though these are often taken into consideration during clinical decision-making regarding implemented appliances and techniques.

5. Conclusions

Within the limitations of the present controlled before-and-after study, it can be concluded that extraction treatment with preadjusted appliances might be associated with increased inclination of the upper and lower incisor, with more prominent upper incisor position, and with more acute interincisal angle than standard Edgewise appliances. However, such differences might not have a meaningful impact on lip prominence or nasolabial angle.

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TABLES

Table 1
Demographics of included patients

Variable	Category	Standard Edgewise	Preadjusted	P
Sex	Female – n (%)	18 (72%)	15 (60%)	0.37*
	Male – n (%)	7 (28%)	10 (40%)	
Age (years)	Mean (SD)	14.4 (2.5)	12.8 (1.0)	0.004†
Molar relationship	Class I – n (%)	14 (56%)	16 (64%)	0.29*
	Class II – n (%)	5 (20%)	7 (28%)	
	Class III – n (%)	6 (24%)	2 (8%)	
Extracted premolars	4 – n (%)	23 (92%)	18 (72%)	0.07*
	2-3 – n (%)	2 (8%)	7 (28%)	
Treatment duration (months)	Mean (SD)	27.8 (5.9)	27.0 (4.8)	0.62†

SD, standard deviation
* chi-squared test
† t-test for independent samples

Table 2

Baseline dental / skeletal characteristics of included patients, given as mean (SD)

Variable	Standard Edgewise (n=25)	Preadjusted (n=25)	P*
Overjet (mm)	4.3 (1.7)	4.9 (2.7)	0.36
Overbite (mm)	3.2 (1.5)	2.2 (2.8)	0.11
SNA (°)	81.0 (5.0)	80.1 (4.4)	0.51
SNB (°)	78.3 (3.1)	76.2 (3.5)	0.04
ANB (°)	2.8 (2.8)	3.9 (2.9)	0.16
Wits (mm)	-1.3 (2.2)	0.2 (3.3)	0.08
SN-ML (°)	33.5 (5.9)	37.1 (6.6)	0.04
1s-SN (°)	107.3 (7.9)	105.5 (9.5)	0.47
1s-NL (°)	113.4 (8.0)	112.1 (8.2)	0.56
1i-ML (°)	95.1 (5.5)	94.2 (6.9)	0.64
1s-NPg (mm)	9.5 (2.8)	9.9 (5.5)	0.73
1i-NPg (mm)	4.8 (3.1)	4.9 (4.6)	0.95
1s-1i (°)	124.2 (9.1)	123.1 (14.3)	0.76
UL-E line (mm)	-1.2 (2.5)	-1.0 (2.9)	0.81
LL-E line (mm)	1.2 (2.4)	1.1 (3.6)	0.87
Nasolabial angle (°)	104.2 (11.4)	107.0 (9.9)	0.36

SD, standard deviation

* t-test for independent samples

Table 3
Baseline dental / skeletal characteristics of included patients (n=25 in each group), given as mean (SD)

		T1	T2	T2-T1	T2-T1 %	
Variable	**Group**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean**	**P***
1s-SN (°)	Standard Edgewise	107.3 (7.9)	102.5 (5.3)	-4.8 (8.3)	-4.1%	0.33
	Preadjusted	105.5 (9.5)	103.9 (6.4)	-1.6 (10.9)	-0.7%	
1s-NL (°)	Standard Edgewise	113.4 (8.0)	108.7 (5.1)	-4.7 (8.3)	-3.8%	0.18
	Preadjusted	112.1 (8.2)	110.8 (5.7)	-1.3 (10.4)	-0.6%	
1i-ML (°)	Standard Edgewise	95.1 (5.5)	91.9 (6.7)	-3.2 (5.3)	-3.3%	0.16
	Preadjusted	94.2 (6.9)	93.4 (8.5)	-0.8 (6.0)	-0.8%	
1s-NPg (mm)	Standard Edgewise	9.5 (2.8)	5.6 (2.7)	-3.9 (1.9)	-42.9%	**0.07**
	Preadjusted	9.9 (5.5)	6.9 (3.7)	-3.0 (3.4)	-44.1%	
1i-NPg (mm)	Standard Edgewise	4.8 (3.1)	2.9 (2.5)	-1.9 (1.6)	-1.6%	**0.09**
	Preadjusted	4.9 (4.6)	3.8 (3.5)	-1.0 (2.6)	-2.3%	
1s-1i (°)	Standard Edgewise	124.2 (9.1)	132.4 (6.2)	8.3 (10.2)	+7.2%	**0.002**
	Preadjusted	123.1 (14.3)	126.0 (7.0)	2.9 (15.4)	+3.6%	
UL-E line (mm)	Standard Edgewise	-1.2 (2.5)	-3.2 (2.5)	-2.0 (1.0)	+37.9%	0.89
	Preadjusted	-1.0 (2.9)	-3.1 (3.0)	-2.1 (1.3)	-3152.4%	
LL-E line (mm)	Standard Edgewise	1.2 (2.4)	-1.1 (2.6)	-2.3 (1.3)	-162.9%	0.18
	Preadjusted	1.1 (3.6)	-0.7 (3.7)	-1.8 (1.6)	+142.1%	
Nasolabial angle (°)	Standard Edgewise	104.2 (11.4)	106.0 (11.5)	1.8 (6.7)	+2.0%	0.98
	Preadjusted	107.0 (9.9)	108.3 (10.6)	1.3 (8.1)	+1.4%	

SD, standard deviation; T1, before treatment with fixed appliances; T2, after treatment with fixed appliances.
* from linear regression on the absolute post-treatment value as dependent variable, appliance group as independent variable, and pre-treatment absolute value as covariate.

Table 4a

Unadjusted (crude) and adjusted for confounders linear regression modelling for the effect of appliance type on the primary and secondary outcomes. Effect estimates are given using standard Edgewise appliances as reference and preadjusted appliances as experimental

	1s-SN (°)		**1s-NL (°)**		**1i-ML (°)**		**1s-NPg (mm)**		**1i-NPg (mm)**	
Adjusting for	**b (95% CI)**	**P**	**b (95% CI)**	**P**	**b (95% CI)**	**P**	**b (95% CI)**	**P**	**b (95% CI)**	**P**
Nothing (crude)	1.63 (-1.71, 4.97)	0.33	2.10 (-1.00, 5.21)	0.18	2.28 (-0.92, 5.47)	0.16	**1.10 (-0.07, 2.28)**	**0.07**	0.85 (-0.12, 1.81)	0.09
Sex	1.37 (-1.96, 4.70)	0.41	-	-	-	-	-	-	-	-
Age at T1	1.24 (-2.44, 4.92)	0.50	2.44 (-0.98, 5.85)	0.16	**3.16 (-0.32, 6.64)**	**0.07**	0.89 (-0.39, 2.18)	0.17	0.60 (-0.46, 1.66)	0.26
Tx duration	1.81 (-1.44, 5.06)	0.27	-	-	-	-	-	-	-	-
Molar relationship at T1	-	-	-	-	2.64 (-0.59, 5.87)	0.11	1.21 (0.02, 2.39)	0.05	0.97 (0.01, 1.93)	0.05
4-PM extraction	-	-	-	-	1.34 (-1.82, 4.51)	0.40	-	-	0.66 (-0.34, 1.66)	0.19
SNA at T1	1.97 (-1.26, 5.19)	0.23	-	-	-	-	**1.26 (0.14, 2.39)**	**0.03**	0.95 (0.01, 1.89)	0.04
SNB at T1	**3.30 (0.26, 6.34)**	**0.03**	**3.24 (0.17, 6.31)**	**0.04**	-	-	**1.31 (0.09, 2.54)**	**0.04**	-	-
ANB at T1	-	-	-	-	2.70 (-0.63, 6.03)	0.11	0.77 (-0.35, 1.88)	0.17	0.51 (-0.41, 1.42)	0.27
Wits at T1	2.67 (-0.57, 5.90)	0.10	**2.99 (-0.07, 6.05)**	**0.06**	1.74 (-1.66, 5.14)	0.31	-	-	0.65 (-0.33, 1.63)	0.19
SNML at T1	2.56 (-0.86, 5.98)	0.14	**2.89 (-0.32, 6.09)**	**0.08**	**4.49 (1.98, 6.99)**	**0.001**	-	-	-	-
Overjet at T1	2.15 (-1.17, 5.47)	0.20	**2.62 (-0.45, 5.69)**	**0.09**	-	-	1.25 (0.11, 2.39)	0.03	-	-
Overbite at T1	**2.86 (-0.39, 6.10)**	**0.08**	**3.11 (0.04, 6.19)**	**0.04**	**3.66 (0.91, 6.40)**	**0.01**	-	-	-	-
1s-NPg1 at T1	1.82 (-1.54, 5.18)	0.28	2.39 (-0.66, 5.44)	0.12	**2.51 (0.03, 5.00)**	**0.04**	-	-	-	-
Δ1s-NPg T2-T1	1.03 (-2.07, 4.12)	0.51	1.26 (-1.37, 3.89)	0.34	0.96 (-1.46, 3.38)	0.43	-	-	-	-
1i-NPg1 at T1	-	-	-	-	-	-	-	-	-	-
Δ1i-NPg T2-T1	-	-	-	-			-	-	-	-

b, unstandardized regression coefficient; CI, confidence interval; PM, premolar; T1, before treatment; T2, after debond; Tx, treatment

Table 4b

Unadjusted (crude) and adjusted for confounders linear regression modelling for the effect of appliance type on the primary and secondary outcomes. Effect estimates are given using standard Edgewise appliances as reference and preadjusted appliances as experimental (continued)

	1s-1i (°)		**Upper lip-E line**		**Lower lip-E line**		**Nasolabial angle (°)**	
Adjusting for	**b (95% CI)**	**P**	**b (95% CI)**	**P**	**b (95% CI)**	**P**	**b (95% CI)**	**P**
Nothing (crude)	**-6.33 (-10.12, -2.54)**	**0.002**	-0.05 (-0.73, 0.63)	0.89	0.55 (-0.27, 1.38)	0.18	0.05 (-4.07, 4.16)	0.98
Sex	-	-	-0.02 (-0.71, 0.67)	0.96	0.49 (-0.34, 1.32)	0.24	0.44 (-3.53, 4.42)	0.82
Age at T1	-	-	0.18 (-0.57, 0.92)	0.64	-	-	-0.45 (-4.98, 4.08)	0.84
Tx duration	-	-	-0.09 (-0.76, 0.59)	0.80	-	-	-0.12 (-4.27, 4.03)	0.96
Molar relationship at T1	-	-	-	-	0.73 (-0.06, 1.52)	0.07	-0.31 (-4.54, 3.91)	0.88
4-PM extraction	-	-	0.04 (-0.68, 0.75)	0.92	-	-	0.82 (-3.33, 4.97)	0.69
SNA at T1	-	-	-0.10 (-0.78, 0.58)	0.77	-	-	0.15 (-4.02, 4.33)	0.94
SNB at T1	**-7.10 (-11.04, -3.16)**	**0.001**	-0.17 (-0.88, 0.54)	0.64	-	-	0.20 (-4.14, 4.54)	0.93
ANB at T1	-	-	0.01 (-0.69, 0.71)	0.98	0.40 (-0.44, 1.23)	0.34	-0.15 (-4.36, 4.06)	0.94
Wits at T1	-	-	0.05 (-0.65, 0.75	0.89	-	-	-0.59 (-4.79, 3.61)	0.78
SNML at T1	**-7.27 (-11.17, -3.37)**	**<0.001**	-0.25 (-0.94, 0.45)	0.48	0.36 (-0.52, 1.24)	0.41	1.12 (-3.13, 5.38)	0.60
Overjet at T1	-	-	-	-	-	-	0.18 (-4.02, 4.38)	0.93
Overbite at T1	**-7.68 (-11.22, -4.13)**	**<0.001**	-0.22 (-0.89, 0.44)	0.50	0.46 (-0.39, 1.32)	0.28	0.05 (-4.25, 4.35)	0.98
1s-NPg1 at T1	-	-	-	-	-	-	0.15 (-4.00, 4.31)	0.94
Δ1s-NPg T2-T1	**-4.59 (-8.06, -1.12)**	**0.01**	-0.15 (-0.83, 0.53)	0.65	0.42 (-0.39, 1.24)	0.30	-0.25 (-4.39, 3.89)	0.90
1i-NPg1 at T1	-	-	-	-	-	-	0.07 (-4.07, 4.22)	0.97
Δ1i-NPg T2-T1	-	-	-0.10 (-0.80, 0.60)	0.77	0.42 (-0.41, 1.24)	0.32	-0.40 (-4.54, 3.75)	0.85

b, unstandardized regression coefficient; CI, confidence interval; PM, premolar; T1, before treatment; T2, after debond; Tx, treatment.

Table 4c

Unadjusted (crude) and adjusted for confounders logistic regression modelling for the effect of appliance type on the correct incisor inclination after treatment. Effect estimates are given using standard Edgewise appliances as reference and preadjusted appliances as experimental.

	1s-NL (°)		**1i-ML (°)**		**1s-1i (°)**	
Adjusting for	**OR (95% CI)**	**P**	**OR (95% CI)**	**P**	**OR (95% CI)**	**P**
Nothing (crude)	2.79 (0.86, 9.01)	0.09	1.40 (0.45, 4.35)	0.56	0.61 (0.20, 1.89)	0.39
Sex	-	-	1.28 (0.40, 4.09)	0.68	0.54 (0.17, 1.75)	0.31
Age at T1	**4.26 (1.09, 16.63)**	**0.04**	1.30 (0.38, 4.50)	0.68	0.43 (0.12, 1.53)	0.19
Tx duration	-	-	-	-	-	-
Molar relationship at T1	3.16 (0.93, 10.76)	0.07	-	-	0.67 (0.21, 2.13)	0.50
4-PM extraction	-	-	-	-	0.65 (0.20, 2.08)	0.46
SNA at T1	-	-	1.60 (0.49, 5.23)	0.44	-	-
SNB at T1	2.27 (0.67, 7.72)	0.19	2.05 (0.59, 7.15)	0.26	0.55 (0.17, 1.81)	0.32
ANB at T1	**3.49 (0.99, 12.34)**	**0.05**	1.30 (0.41, 4.16)	0.66	-	-
Wits at T1	**3.27 (0.95, 11.26)**	**0.06**	1.45 (0.45, 4.68)	0.54	-	-
SNML at T1	2.29 (0.68, 7.76)	0.18	1.65 (0.50, 5.50)	0.41	0.56 (0.17, 1.85)	0.35
Overjet at T1	-	-	1.53 (0.48, 4.87)	0.48	-	-
Overbite at T1	2.48 (0.75, 8.27)	0.14	1.30 (0.40, 4.19)	0.66	0.54 (0.17, 1.77)	0.31
1s-NPg1 at T1	-	-	-	-	-	-
Δ1s-NPg T2-T1	-	-	-	-	-	-
1i-NPg1 at T1	-	-	-	-	-	-
Δ1i-NPg T2-T1	-	-	1.64 (0.50, 5.38)	0.41	-	-
Acceptable inclination at T1	-	-	-	-	-	-

b, unstandardized regression coefficient; CI, confidence interval; PM, premolar; T1, before treatment; T2, after debond; Tx, treatment

SUPPLEMENTS

Supplement 1
Description of cephalometric measurements used in this study

Variable	Description	Construction
SNA (°)	Anteroposterior maxilla position relative to the cranial base	Sella point – Nasion point – A point
SNB (°)	Anteroposterior mandible position relative to the cranial base	Sella point – Nasion point – B point
ANB (°)	Anteroposterior maxilla-mandible relation relative to the cranial base	A point – Nasion point – B point
Wits (mm)	Anteroposterior sagittal maxilla-mandible discrepancy relative to the occlusal plane	Projection of A point and B point on the occlusal plane
SN-ML (°)	Mandible inclination relative to cranial base	(Sella point and Nasion point) – (Menton to Gonion tangent)
1s-SN (°)	Upper incisor inclination relative to the cranial base	(Upper incisor tip and apex) – (Sella point and Nasion point)
1s-NL (°)	Upper incisor inclination relative to maxilla	(Upper incisor tip and apex) – (Anterior and Posterior Nasal Spine)
1i-ML (°)	Lower incisor inclination relative to mandible	(Lower incisor tip and apex)– (Menton to Gonion tangent)
1s-NPg (mm)	Upper incisor distance from the facial plane	(Upper incisor tip and apex) – (Nasion point and Pogonion point)
1i-NPg (mm)	Lower incisor distance from the facial plane	(Lower incisor tip and apex) – (Nasion point and Pogonion point)
1s-1i (°)	Interincisal angle	(Upper incisor tip and apex) – (lower incisor tip and apex)
UL-EL (mm)	Upper lip distance from the esthetic line	Labrare superius – (Pronasale and Soft-tissue Pogonion)
LL-EL (mm)	Lower lip distance from the esthetic line	Labrare inferius – (Pronasale and Soft-tissue Pogonion)
Nasolabial angle	Nasolabial angle	(Subnasale tangent to the nose) – (Subnasale tangent to the upper lip)

Supplement 2a

Selection of variables to be used as covariates in the adjusted-for-confounders regression analyses. Confounders selected to adjust for are given with green highlight

	1s-SN		1s-NL		1i-ML		1s-NPg		1i-NPg		1s-1i		UL-E line		LL-E line		Nasolabial angle	
Controlling for	**b**	**Δ (%)**	**b**	**Δ (%)**	**b**	**Δ (%)**	**b**	**Δ (%)**	**b**	**Δ (%)**	**b**	**Δ (%)**	**b**	**Δ (%)**	**b**	**Δ (%)**	**b**	**Δ (%)**
Nothing (crude)	1.6303	-	2.1026	-	2.2753	-	1.1017	-	0.8454	-	-6.3285	-	-0.0478	-	0.5550	-	0.0451	-
Sex	1.3714	-16%	1.9724	-6%	2.3043	1%	1.1341	3%	0.8659	2%	-6.2219	-2%	-0.0171	-64%	0.4933	-11%	0.4447	886%
Age	1.2406	-24%	2.4371	16%	3.1590	39%	0.8919	-19%	0.6021	-29%	-5.9808	-5%	0.1757	-468%	0.5003	-10%	-0.4462	-1089%
Tx duration	1.8106	11%	2.2036	5%	2.2570	-1%	1.0577	-4%	0.8026	-5%	-6.4537	2%	-0.0856	79%	0.5113	-8%	-0.1172	-360%
Molar relationship at T1	1.7703	9%	2.1645	-3%	2.6396	-16%	1.2091	10%	0.9733	15%	-6.3996	-1%	-0.0062	4%	0.7292	31%	-0.3139	-796%
4-PM extraction	1.7048	5%	2.1852	4%	1.3410	-41%	1.0360	-6%	0.6615	-22%	-6.3560	0%	0.0369	-177%	0.5562	0%	0.8167	1711%
SNA at T1	1.9662	21%	2.3220	10%	2.2302	-2%	1.2609	14%	0.9511	13%	-6.6665	5%	-0.0997	109%	0.5889	6%	0.1548	243%
SNB at T1	3.3004	102%	3.2400	54%	2.3555	4%	1.3106	19%	0.9259	10%	-7.0981	12%	-0.1692	254%	0.5488	-1%	0.2009	346%
ANB at T1	1.7618	8%	2.2421	7%	2.7025	19%	0.7685	-30%	0.5051	-40%	-5.7547	-9%	0.0077	-116%	0.3980	-28%	-0.1467	-425%
Wits at T1	2.6681	64%	2.9878	42%	1.7399	-24%	1.1544	5%	0.6517	-23%	-6.2170	-2%	0.0488	-202%	0.4968	-10%	-0.5897	-1408%
SNML at T1	2.5555	57%	2.8858	37%	4.4862	97%	1.0946	-1%	0.8906	5%	-7.2701	15%	-0.2467	416%	0.3601	-35%	1.1247	2394%
Overjet at T1	2.1497	32%	2.6192	25%	2.2149	-3%	1.2487	13%	0.8087	-4%	-6.2115	-2%	-0.0449	-6%	0.5110	-8%	0.1820	303%
Overbite at T1	2.8558	75%	3.1118	48%	3.6561	61%	1.1991	9%	0.9184	9%	-7.6769	21%	-0.2242	369%	0.4648	-16%	0.0502	11%
1s-NPg at T1	1.8191	12%	2.3917	14%		-	-	-	-	-	-6.2739	-1%	-0.0444	-7%	0.5061	-9%	0.1539	241%
Δ1s-NPg T2-T1	1.0268	-37%	1.2639	-40%		-	0.0148	-99%	-	-	-4.5896	-27%	-0.1541	222%	0.4218	-24%	-0.2540	-663%
1i-NPg1 at T1	-	-	-	-	2.5121	10%	-	-	-	-	-	-	-0.0478	0%	0.5349	-4%	0.0748	66%
Δ1i-NPg T2-T1	-	-	-	-	0.9620	-58%	-	-	0.0071	-99%	-	-	-0.1019	113%	0.4165	-25%	-0.3950	-976%

Δ, change; b, unstandardized regression coefficient; NT, not tested; PM, premolar; T1, before treatment; T2, after fixed appliance treatment; Tx, treatment.

Supplement 2b
Selection of variables to be used as covariates in the adjusted-for-confounders regression analyses. Confounders selected to adjust for are given with green highlight

	Acceptable 1s-NL		Acceptable 1i-ML		Acceptable 1s-1i	
Controlling for	**logOR**	**Δ (%)**	**logOR**	**Δ (%)**	**logOR**	**Δ (%)**
Nothing (crude)	1.0245	-	0.3342	-	-0.4953	-
Sex	0.9636	-6%	0.2479	-26%	-0.6082	23%
Age	1.4482	41%	0.2634	-21%	-0.8463	71%
Tx duration	1.0326	1%	0.3466	4%	-0.4557	-8%
Molar relationship at T1	1.1519	12%	0.3357	0%	-0.4008	19%
4-PM extraction	0.9325	-9%	0.3103	-7%	-0.4374	-12%
SNA at T1	0.9992	-2%	0.4671	40%	-0.5203	5%
SNB at T1	0.8192	-20%	0.7177	115%	-0.6035	22%
ANB at T1	1.2512	22%	0.2634	-21%	-0.4926	-1%
Wits at T1	1.1849	16%	0.3709	11%	-0.5404	9%
SNML at T1	0.8289	-19%	0.5024	50%	-0.5742	16%
Overjet at T1	1.0581	3%	0.4233	27%	-0.5036	2%
Overbite at T1	0.9096	-11%	0.2642	-21%	-0.6079	23%
1s-NPg at T1	1.0382	1%	-	-	-0.5195	5%
Δ1s-NPg T2-T1	1.0478	2%	-	-	-0.4618	-7%
1i-NPg1 at T1	-	-	0.3318	-1%	-0.5124	3%
Δ1i-NPg T2-T1	-	-	0.4957	48%	-0.4537	-8%
Acceptable inclination at T1	1.0381	1%	0.4866	-	-0.4868	-2%

Δ, change; b, unstandardized regression coefficient; NT, not tested; PM, premolar; T1, before treatment; T2, after fixed appliance treatment; Tx, treatment.

Supplement 3

Inter-examiner and intra-examiner agreement of repeated measurements

Agreement	**Measure**	**1s-NL**	**1i-ML**	**1s-1i**
Inter-examiner	CCC (95% CI)	0.95 (0.93, 0.97)	0.96 (0.94, 0.97)	0.86 (0.80, 0.90)
	Average difference (95% LoA)	0.01 (-4.48, 4.49)	0.11 (-4.02, 4.24)	0.18 (-10.98, 11.34)
Intra-examiner	CCC (95% CI)	0.91 (0.87, 0.94)	0.92 (0.88, 0.94)	0.75 (0.66, 0.83)
	Average difference (95% LoA)	-0.09 (-6.28, 6.09)	0.14 (-5.71, 5.98)	-0.02 (-15.24, 15.20)

CCC, concordance correlation coefficient; CI, confidence interval; LoA, limits of agreement.