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RESEARCH

Do changes of incisal inclination during orthodontic treatment influence the size of the buccal corridors?

A longitudinal study in adolescents

Linda Sangalli[1] · Domenico Dalessandri[2] · Gualtiero Mandelli[2] · Luca Visconti[2] · Stefano Bonetti[2] · Fabio Savoldi[2]

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Abstract

Purpose The buccal so-called corridors are important aspects in smile aesthetics. Changes in the inclination of incisors may influence dental arch display and lip position during smile, with possible consequences on the buccal corridor size. Thus, in this study the effects of changes in the incisal inclination on smile aesthetics after orthodontic treatment were analysed.

Methods A total of 77 patients (44 females and 33 males, mean age 14.4 ± 2.7 years), treated with orthodontic fixed appliance with passive self-ligating brackets were retrospectively selected. Changes in the upper incisors inclination (UII), lower incisors inclination (LII), and various dentoskeletal parameters (SNA, SNB, ANB, SN/AnsPns, AnsPns/GoGn, Fh/GoGn, SN/Occl and IIA) were measured on lateral cephalograms. Smile measurements were normalised by using relative values. Thus, changes in the ratio between the intercanine distance and the intercommissure distance (named "relative intercanine amplitude" [RICaAm]), in the ratio between the dental arch width and the intercommissure distance (named "relative dental arch amplitude" [RDAAm]) and in the ratio between the buccal corridor area and the smile area (named "relative buccal corridor area" [RBCAr]) were measured on smile photographs. Linear regression analysis was used to estimate the effects of ΔUII and ΔLII on ΔRBCAr (by adjusting for age, sex, ANB, FH/GoGn, and ΔRICaAm; significance level $\alpha = 0.05$).

Results The RBCAr showed a significant reduction of 3.2% after treatment ($p < 0.001$), which was independent from changes in UII and LII, but rather influenced by an increased RICaAm ($p = 0.015$), and by the age at the beginning of orthodontic treatment ($p = 0.013$).

Conclusion Beginning orthodontic treatment at younger age and widening the intercanine amplitude may lead to smaller buccal corridors after treatment, while incisal inclination seems to have no important effect on the buccal corridors.

Keywords Esthetics · Smile · Cephalometry · Adolescents · Longitudinal studies

✉ Fabio Savoldi
fabio.savoldi@unibs.it

Linda Sangalli
lsanga@midwestern.edu

Domenico Dalessandri
domenico.dalessandri@unibs.it

Gualtiero Mandelli
gumande@tin.it

Luca Visconti
luca.visconti@unibs.it

Stefano Bonetti
stefano.bonetti1@unibs.it

1 College of Dental Medicine – Illinois, Midwestern University, Downers Grove, United States

2 Dental School, Department of Medical and Surgical Specialties, Radiological Sciences and Public Health, University of Brescia, Brescia, Italy

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Beeinflussen Veränderungen der Inzisiven-Inklination während einer kieferorthopädischen Behandlung die Ausdehnung der bukkalen Korridore?
Eine Längsschnittstudie bei Jugendlichen

Zusammenfassung

Zielsetzung Die sog. bukkalen Korridore sind wichtige Aspekte der Lächeln-Ästhetik. Veränderungen der Neigung der Schneidezähne können die Darstellung des Zahnbogens und die Lippenposition beim Lächeln beeinflussen, was sich möglicherweise auf die Größe des bukkalen Korridors auswirkt. Daher wurden in dieser Studie die Auswirkungen von Veränderungen der Neigung der Schneidezähne auf die Lächeln-Ästhetik nach kieferorthopädischer Behandlung analysiert.
Methoden Insgesamt wurden 77 Patienten (44 Frauen und 33 Männer, Durchschnittsalter 14,4 ± 2,7 Jahre), die mit einer festsitzenden kieferorthopädischen Apparatur mit passiven selbstligierenden Brackets behandelt wurden, retrospektiv ausgewählt. Veränderungen der Neigung der oberen Schneidezähne (UII), der unteren Schneidezähne (LII) sowie verschiedener dentoskelettaler Parameter (SNA, SNB, ANB, SN/AnsPns, AnsPns/GoGn, Fh/GoGn, SN/Occl und IIA) wurden anhand von seitlichen Cephalogrammen gemessen. Die Messungen des Lächelns wurden unter Verwendung relativer Werte normiert. So wurden Veränderungen im Verhältnis zwischen dem Interkanin-Distanz und dem Interkommissur-Abstand (bezeichnet als „relative Interkanin-Amplitude“ [RICaAm]), im Verhältnis zwischen der Zahnbogenbreite und dem Interkommissurabstand (bezeichnet als „relative Zahnbogenamplitude“ [RDAAm]) sowie im Verhältnis zwischen der bukkalen Korridorfläche und der Lächelfläche (bezeichnet als „relative bukkale Korridorfläche“ [RBCAr]) anhand von Lächelfotos gemessen. Mittels linearer Regressionsanalyse wurden die Auswirkungen von ΔUII und ΔLII auf ΔRBCAr geschätzt (unter Berücksichtigung von Alter, Geschlecht, ANB, FH/GoGn und ΔRICaAm; Signifikanzniveau $\alpha = 0{,}05$).
Ergebnisse Der RBCAr zeigte nach der Behandlung eine signifikante Verringerung um 3,2 % ($p < 0{,}001$), die unabhängig von Veränderungen bei UII und LII war, sondern vielmehr durch einen erhöhten RICaAm ($p = 0{,}015$) sowie durch das Alter zu Beginn der kieferorthopädischen Behandlung ($p = 0{,}013$) beeinflusst wurde.
Schlussfolgerung Der Beginn der kieferorthopädischen Behandlung in jüngerem Alter und die Erweiterung der Interkanin-Amplitude können zu schmaleren bukkalen Korridoren nach der Behandlung führen, während die Inzisalneigung offenbar keinen wesentlichen Einfluss auf die bukkalen Korridore hat.

Schlüsselwörter Ästhetik · Lächeln · Kephalometrie · Jugendliche · Longitudinale Studien

Background

The inclination of the central incisors is an important parameter to be considered during the early stages of orthodontic treatment planning [25]. This is of particular relevance in techniques based on preadjusted appliances [27], as the choice of the prescription of brackets will contribute to the clinical outcome of the incisal position, with relevant consequences on smile aesthetics and masticatory function [19, 28]. Incisal inclination plays a significant role in cutting food during mastication, producing sounds during speech and guiding mandibular movements [24]. In particular, during protrusive slide of the mandible, incisal inclination determines teeth disclosure and the respective movement of the mandibular condyles [30]. It is important to consider smile aesthetics to ensure good predictability of orthodontic treatment outcome, including patient satisfaction and the effect of orthodontic treatment on quality of life [13]. An inharmonious smile may impair the appearance of the face and may lead to discomfort in social life, as smiling is used to demonstrate friendship, pleasure and appreciation [23, 25]. As a consequence, orthodontists should be aware of the societal perceptions of beauty, harmony and proportions when planning treatment [16]. Indeed, dentofacial attractiveness is important for psychosocial well-being and people with a normal dental appearance are judged socially more attractive than those with malocclusion [10]. Among the features that contribute to smile aesthetics, the buccal corridor area is one of the most relevant [5]. Buccal corridors are defined as the dark spaces between the maxillary lateral teeth and the corner of the mouth during smiling [3]. Several factors, such as the maxillary arch width, the anteroposterior position of the maxilla and the rotation of the upper molars [5, 26, 38] have been shown to influence the buccal corridor area, which is inversely related to the smile area [37]. Upper incisal exposure, which is in turn influenced by their inclination, influences buccal corridors width with a negative proportion (i.e. a reduced incisal exposure, which is often related to a reduced incisal inclination, may be associated with larger buccal corridors) [37]. However, the cited study evaluated buccal corridors only posttreatment [37]. A further study analysed the influence of incisal inclination on buccal corridors pre- and posttreatment but their analysis was limited to the posterior teeth and the canines [17]. To the best of our knowledge, no previous study has compared changes in buccal corridors with respect to changes in incisal inclination. Notably, buccal corridors and smile are not static concepts, as they depend on the position of lips during smile. Since the inclination of upper and lower incisors may influence lip posture and the tension of the muscles supporting the lips, changes in incisal inclination in the sagittal plane may also affect smile aesthetics in the frontal plane [8]. Other important dental parameters contributing to smile aesthetic are the distance between the canines [37], later identified as "intercanine amplitude", and the width of the dental arch [29], later identified as "dental arch amplitude". Both measurements can be related to the width of the soft tissues while smiling, which is measured as the distance between the labial commissures, later identified as "intercommissure amplitude", in order to achieve better clinical interpretation [37]. All such parameters appear two-dimensional in the frontal view, and they can be quantified using linear or area measurements, while ratios can be used to obtain proportions for better comparison among different individuals [21, 26].

Aim

The present longitudinal retrospective study aimed to assess the changes in smile aesthetics in the frontal plane in relation to the change of incisal inclination in a group of adolescents undergoing fixed orthodontic treatment. The primary hypothesis was that an increase in inclination of the central incisors is correlated with a decrease in the area of the buccal corridors as seen in the frontal plane.

Materials and methods

The study was approved by the Ethics Committee of the University of Brescia (registration number: NP3899, clinical study: ISW01). Participants signed an informed consent prior to participating in the study.

Patient characteristics and treatment

The study retrospectively investigated the orthodontic records of 77 consecutive patients who received nonextraction orthodontic treatment, were characterised by mild crowding at the beginning of treatment and had successfully completed treatment (well aligned dentition and dental class I). Patients with skeletal facial asymmetries, craniofacial syndromes, history of orthognathic surgery, and missing or impacted teeth were excluded. The sample size was based on the minimum number of subjects required for each predictor in a regression analysis, which should be at least 5 and preferably ≥ 8 [12, 34] per up to 9 included independent variables resulting in a sample of 72 patients. All patients were consecutively treated by the same orthodontist with a similar protocol [14], using a fixed multibrackets appliance with passive self-ligating preadjusted brackets with 0.022″ × 0.028″ slot size (Damon Q, Ormco, Brea, CA, USA). During treatment, stage I included the use of 0.014″ copper–nickel–titanium (CuNiTi) archwires, stage II the use of 0.014″ × 0.025″ CuNiTi and 0.018″ × 0.025″ CuNiTi, and stage III the use of 0.019″ × 0.025″ titanium–molybdenum alloy (TMA), 0.016″ × 0.025″ stainless steel (SS) and 0.016″ SS or 0.018″ SS. The treatment was finished with 0.019″ × 0.025″ SS archwires or 0.019″ × 0.025″ TMA. The mean treatment duration was 2.1 years (standard deviation [SD] = 0.5).

Data collection

A standardised protocol was followed during acquisition of the posed smile photographs [1]. Patients were seated in an upright position, with the Frankfurt plane and the interpupillary line parallel to the floor. Patient were asked to look straight ahead to a focal point of reference, the facial midline was aligned to the central vertical line of the grid of the viewfinder of the camera, and an almost constant distance between the camera and the patient was adopted. One photograph was taken at pretreatment (before bracket

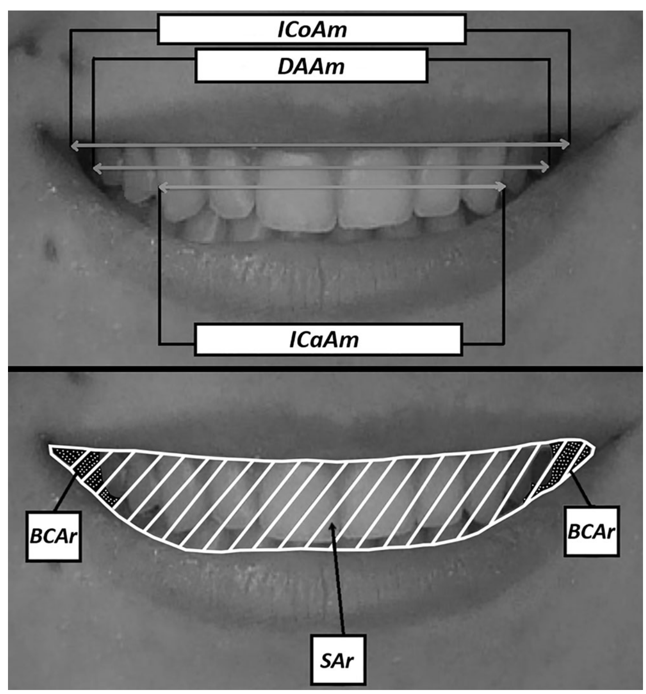

Fig. 1 Length measurements: *ICaAm* intercanine amplitude; *ICoAm* intercommissure amplitude; *DAAm* dental arch amplitude (top). Area measurements: *SAr* smile area; *BCAr* buccal corridor area (bottom)

Abb. 1 Längenmaße: *ICaAm* Interkanin-Amplitude; *ICoAm* Interkommissural-Amplitude; *DAAm* Zahnbogenamplitude (oben). Flächenmaße: *SAr* Bereich des Lächelns; *BCAr* Bereich des bukkalen Korridors (unten)

Table 1 Cephalometric variables used for the craniofacial assessment
Tab. 1 Für das kraniofaziale Assessment verwendete kephalometrische Variablen

Cephalometric parameter	Nomenclature	Description
SNA (°)	Sella–Nasion–A point	Angle between A point (the deepest concavity anteriorly on the maxilla) and the anterior cranial base (the line connecting Sella and Nasion)
SNB (°)	Sella–Nasion–B point	Angle between B point (the deepest concavity anteriorly on the mandibular symphysis) and the anterior cranial base
ANB (°)	A point–Nasion–B point	Angle between A point, Nasion, and B point
SN/ANS-PNS (°)	Sella–Nasion/Anterior Nasal Spine–Posterior Nasal Spine	Angle between the anterior cranial base and the maxillary complex (the line connecting ANS and PNS)
ANS-PNS/GoGn (°)	Anterior Nasal Spine–Posterior Nasal Spine/Gonion–Gnathion	Angle between the maxillary complex and the inferior border of the mandible (the line connecting Gonion and Gnathion)
SN/GoGn (°)	Sella–Nasion/Gonion–Gnathion	Angle between the anterior cranial base and the inferior border of the mandible
Fh/GoGn (°)	Frankfurt horizontal/Gonion–Gnathion	Angle between the Frankfurt horizontal (the line connecting the most inferior point of the orbital margin and the upper margin of the external auditory meatus) and the inferior border of the mandible
SN/Occl (°)	Sella–Nasion/Occlusal plane	Angle between the anterior cranial base and the occlusal plane
UII (°)	Upper Incisal Inclination	Angle between the upper central incisor (the line passing through its long axis) and the maxillary complex (measured anteriorly)
LII (°)	Lower Incisal Inclination	Angle between the lower central incisor (the line passing through its long axis) and the inferior border of the mandible (measured anteriorly)
IIA (°)	Interincisal Angle	Angle between the upper and lower central incisors

bonding) and one at posttreatment (after bracket debonding) by using a digital camera (D7000, Nikon, Tokyo, Japan). Images were uploaded into graphical software (Adobe Photoshop 7.0, Adobe Systems, San Jose, CA, USA) and three linear measurements (linear measuring tool) and two area measurements (polygonal lasso tool) were taken for each image (Fig. 1). The linear measurements included the following: maxillary intercanine amplitude (ICaAm), measured as the distance between the right and left lateral margins of the canine; the intercommissure amplitude (ICoAm), measured the distance between the internal commissures of the lips; and the maxillary dental arch amplitude (DAAm), measured as the distance between the lateral margins of the most lateral teeth exposed when smiling. The area measurements included the smile area (SAr), measured as the area within the upper edge of the inferior lip and the lower edge of the superior lip; and the buccal corridor area (BCAr), measured as the area within the internal labial commissure and the buccal margin of the most lateral tooth that was visible (the sum between right and left sides was recorded). Lateral cephalometric radiographs were taken with the patients in natural head position at pre- and posttreatment, and cephalometric analysis was performed using a computer software (Nemoceph, Nemotec, Madrid, Spain) by including upper incisal inclination (UII, the angle between the line passing through the long axis of the upper central incisor and the maxillary complex), lower incisal inclination (LII, the angle between the line passing through the long axis of the lower central incisor and the inferior border of the mandible), and additional craniofacial parameters including maxillary prognathism (SNA), mandibular prognathism (SNB), sagittal maxillomandibular discrepancy (ANB), maxillary inclination (SN/AnsPns), maxillomandibular angle (AnsPns/GoGn), mandibular inclination (Fh/GoGn), occlusal plane inclination (SN/Occl), and interincisal angle (IIA) (Table 1).

Method error

The primary and the secondary assessors were two trained orthodontists. The primary assessor repeated all the measurements after a wash-out period of about one month. The intra-assessor and inter-assessor agreement were calculated with the intraclass correlation coefficient (ICC). The ICC was rated as "poor" (<0.5), "fair" (0.5–0.7), "good" (0.7–0.8), "excellent" (>0.8), and "perfect" ($= 1.0$) [32].

Statistical analysis

The average between the repeated measurements of the primary assessor was used for statistical analysis, to improve the quality of the assessment. Normality of the data distribution was assessed using Shapiro–Wilk test. Parameters that were measured in pixel units were normalised by using ratios, in order to optimise the intra- and interpatient comparability and to allow meaningful clinical interpretation. Hence, the relative maxillary dental arch amplitude (RDAAm) was obtained as the ratio between DAAm and

Table 2 Pre- and posttreatment values of the photographic parameters, their difference and the respective statistical comparison

Tab. 2 Werte der Bildparameter vor und nach der Behandlung, deren Differenz und der jeweilige statistische Vergleich

	Pretreatment		Posttreatment		Difference		
	Mean	SD	Mean	SD	Mean	CI	*p*-value[a]
RDAAm (%)	82.2	4.6	86.4	4.5	–4.2	–5.5 to –2.9	**<0.001**
RICaAm (%)	69.1	6.7	69.0	5.1	0.1	–1.3 to 1.4	0.933
RBCAr (%)	7.7	3.3	4.5	2.1	3.2	2.5 to 3.9	**<0.001**

SD standard deviation, *CI* 95% confidence interval of the difference between pre- and posttreatment values, *RDAAm* relative dental arch amplitude, *RICaAm* relative intercanine amplitude, *RBCA* relative buccal corridor area

[a]Statistically significant *p*-values ($p<0.05$) are indicated in bold. Adjusted *p*-values following application of Benjamini–Hochberg method = **0.004**; 0.933; **0.004** (from top to bottom, respectively)

ICoAm, the relative intercanine amplitude (RICaAm) as the ratio between ICaAm and ICoAm, and the relative buccal corridor area (RBCAr) as the ratio between BCAr and SAr. Pre- vs. posttreatment differences in cephalometric and photographic parameters were analysed with the Wilcoxon signed-rank test for paired values to check whether any significant change was present before performing the linear regression analysis. Linear regression analysis (ENTER mode) was used to estimate the effect of ΔUII and ΔLII (independent variables) on ΔRBCAr (dependent variables), by adjusting the model for age, sex, ANB, FH/GoGn and ΔRICaAm (possible confounders). Age and sex were included to account for demographic and growth variations, ANB was included for differences in skeletal class, FH/GoGn for differences in skeletal divergence, and ΔRICaAm for the effect of transverse dental changes on the buccal corridors area. ΔRDAAm was excluded from the model due to high collinearity with ΔRICaAm, ΔIIA was excluded due to high collinearity with ΔUII and ΔLII, and SNA was excluded due to high collinearity with ANB [35], while the other cephalometric parameters were excluded because they showed no statistically significant changes after treatment. Due to possible inflation of family-wise type I error (in presence of multiple hypothesis testing), False Discovery Rate control (Benjamini–Hochberg procedure) was applied. Data analysis was carried out with statistical software (SPSS v. 27, IBM, Armonk, NY, USA); statistical significance was set at a level $\alpha = 0.05$. Clinically relevant changes were regarded as >2.0% or >2.0°, as a commonly adopted empirical threshold for providing a more uniform discussion of the clinical implications of the presented findings (aimed at representing a change that would be noticed by the orthodontist or that would make a significant difference in dentoskeletal diagnosis) [4].

Results

The analysis was performed on a total of 77 patients (43% males, 57% females), with a mean age of 14.4 years (SD = 2.7) at the beginning of the treatment and a mean age of 16.6 years (SD = 2.6) at the end of the treatment. A total of 48 patients were skeletal class I (62.3%), 23 were skeletal class II (29.9%) and 6 were skeletal class III (7.8%), where class I was defined as ANB between 0 and 4°, class II as ANB >4° and class III as ANB <0°. A total of 51 patients were normodivergent (66.2%), 20 were hypodivergent (26.0%) and 6 were hyperdivergent (7.8%), where normodivergence was defined as Fh/GoGn between 20 and 30°, hypodivergence as Fh/GoGn <20° and hyperdivergence as Fh/GoGn >30°. For the smile parameters, the intra- and inter-assessor agreement were 0.994 and 0.995 for RDAAm, 0.974 and 0.990 for RICaAm, and 0.832 and 0.866 for RBCAr, respectively. The parameters representing smile changes between pre- and posttreatment are reported in Table 2. The average RDAAm was 82.2% pretreatment and 86.4% posttreatment, showing a 4.2% significant increase ($p<0.001$), which was also clinically relevant. The average RICaAm was 69.1% pretreatment and 69.0% posttreatment, showing a 0.1% nonsignificant decrease ($p=0.933$). The average RBCAr was 7.7% pretreatment and 4.5% posttreatment, showing a 3.2% significant decrease ($p<0.001$), which was also clinically relevant. Cephalometric changes between pre- and posttreatment are reported in Table 3. The average UIP was 111.7° pretreatment and 113.0° posttreatment, showing a 1.3° nonsignificant increase ($p=0.093$). The average LII was 92.7° pretreatment and 94.7° posttreatment, showing a 2.0° significant increase ($p=0.001$), which was also clinically relevant. The average IIA was 130.2° pretreatment and 127.1° posttreatment, showing a 3.1° significant decrease ($p=0.001$), which was also clinically relevant. Further skeletal changes were present for ANB (0.6°, $p<0.001$), FH/GoGn (0.7°, $p=0.016$) and SNA (0.4°, $p=0.045$), although none of these changes were clinically relevant. The results of the linear regression models are reported in Table 4. Neither ΔUII nor ΔLII were significant predictors of ΔRBCAr. Conversely, ΔRICaAm ($\beta=-0.291$, $p=0.015$) and age ($\beta=0.299$, $p=0.013$) were independent significant predictors of ΔRBCAr.

Table 3 Pre- and posttreatment values of the cephalometric parameters and respective statistical comparison
Tab. 3 Werte der kephalometrischen Parameter vor und nach der Behandlung sowie der entsprechende statistische Vergleich

	Pretreatment		Posttreatment		Difference		
	Mean	SD	Mean	SD	Mean	CI	*p*-value[a]
SNA (°)	80.2	3.3	79.8	3.4	–0.4	–0.1 to 0.0	**0.045**
SNB (°)	77.5	3.3	77.7	3.4	0.3	–0.6 to 0.6	0.112
ANB (°)	2.7	2.1	2.1	1.8	–0.6	–0.9 to –0.4	**<0.001**
SN/ANS-PNS (°)	7.8	3.0	7.9	2.9	0.1	0.2 to 0.4	0.346
ANS-PNS/GoGn (°)	25.3	5.6	25.1	6.2	–0.2	–0.7 to 0.2	0.294
SN/GoGn (°)	33.1	5.2	33.0	6.0	–01	–0.6 to 0.4	0.665
Fh/GoGn (°)	23.3	4.8	22.7	5.6	–0.7	–1.2 to –0.1	**0.016**
SN/Occl (°)	17.3	3.9	17.6	4.0	0.3	–0.3 to 0.9	0.345
UII (°)	111.7	8.0	113.0	5.7	1.3	–0.2 to 2.9	0.093
LII (°)	92.7	6.4	94.7	6.8	2.0	0.8 to 3.2	**0.001**
IIA (°)	130.2	11.0	127.1	6.9	–3.1	–5.4 to –0.8	**0.010**

SD standard deviation, *CI* 95% confidence interval of the difference between pre- and posttreatment values
[a]Statistically significant *p*-values ($p < 0.05$) are indicated in bold. Adjusted *p*-values following application of Benjamini–Hochberg method = 0.090; 0.174; **0.004**; 0.404; 0.404; 0.716; **0.037**; 0.404; 0.163; **0.004**; **0.028** (from top to bottom, respectively)

Table 4 Linear regression analysis to estimate the effect of changes in incisal inclination on the changes in the area of the buccal corridors, adjusting for demographic and dentoskeletal variables
Tab. 4 Lineare Regressionsanalyse zur Abschätzung des Einflusses von Veränderungen der Schneidezahnneigung auf die Veränderungen der Fläche der bukkalen Korridore unter Berücksichtigung demografischer und dentoskelettaler Variablen

	Unstandardized β	Coefficients Std. Error	β	t	*p*-value[a]
(Constant)	–8.092	2.621	–	–3.088	0.003
ΔUII	0.015	0.059	0.032	0.250	0.804
ΔLII	–0.084	0.078	–0.137	–1.077	0.285
Sex	–0.019	0.709	–0.003	–0.026	0.979
Age	0.347	0.137	0.299	2.542	**0.013**
ANB	0.124	0.188	0.083	0.661	0.511
Fh/Go-Gn	–0.012	0.079	–0.018	–0.155	0.878
ΔRICaAm	–0.151	0.061	–0.291	–2.488	**0.015**

RICaAm relative intercanine amplitude, Δ difference between pre- and posttreatment, *ANB* sagittal maxillo-mandibular discrepancy, *Fh/Go-Gn* mandibular inclination, *Std. Error* standard error
[a]Statistically significant *p*-values ($p < 0.05$) are indicated in bold. Adjusted *p*-values following application of Benjamini–Hochberg method = 0.979; 0.665; 0.979; 0.052; 0.894; 0.979; 0.052 (from top to bottom, respectively)

Discussion

The present study focused on parameters suitable for the evaluation on frontal photographs, which are usually included in standard patient records and can be of clinical interest thanks to their routine assessment. The goal of any orthodontic treatment is to improve smile aesthetics in harmony with the rest of the face [18]. Aesthetic improvement may involve a large number of variables and there are no standard changes that can be applied to every patient. In fact, reduction of the buccal corridors or smile area [11] may or may not increase the perception of beauty of a smile [17, 20, 22]. For these reasons, the present study refrained from assessing whether changes improved the personal perception of beauty of the smile of a patient. However, understanding the effects of any treatment is necessary for achieving desired aesthetic goals.

This said, direct length measurements on photographs are not accurate because of the changes of the reference scale due to possible variations between the patient and the camera. In fact, all measurements taken in pixels do not have a scale to convert them to millimetres, compared to lateral cephalometry that provides a reference bar. Furthermore, the smile has an interpatient variability that makes worthless a comparison in terms of absolute values [9, 36]. As a consequence, pixel unit measurements were carried on the digital format, followed by the comparison of relative values expressed in percent. The present study focused on changes of incisal position and their effects on smile changes, particularly on buccal corridors changes. The buccal corridors should be calculated relative to the smile area, which adjusts for differences in pixel size between one photograph and another. In addition, when patients smile less, they expose less of the buccal corridors which leads to an apparent reduction. However, when patients smile less, their smile area is also smaller, and measuring the buccal corridors as a percentage of the smile area allows mitigation of variations in patients smiling behaviour between photos

[7, 39]. Conversely, the absolute value of the smile area is more susceptible to bias, as a patient merely smiling more can widen it. This widening has no relation to the incisal inclination and poses a challenge to accurately quantify the effect of dental changes. It is noteworthy that it is difficult to interpret the clinical significance of treatment effects expressed in pixels, in particular in terms of whether they are of any relevance for smile aesthetics. On the other hand, data expressed in percent allow estimation of whether the change was minimal (e.g. a 2% change in the buccal corridor area) or substantial (e.g. a 15% change). This said, the buccal corridors are certainly influenced by the transverse widening or narrowing of the dental arch, which is well-represented by changes in the intercanine amplitude. Hence, it is evident that a wider intercanine amplitude results in reduced buccal corridors, regardless of the changes in incisal inclination. Thus, the intercanine amplitude should be considered as a possible confounder when the independent effect of incisal inclination on buccal corridors is investigated.

The present study revealed a significant 3.2% reduction of the average area of the buccal corridors at the end of orthodontic treatment. This is consistent with a former study that observed a reduction by 1.8% in the buccal corridor area among nonextraction orthodontic cases [17]. After treatment, the average dental arch amplitude exposed on the frontal photograph exhibited a significant and clinically relevant increase by 4.2%, which was associated with the change in the buccal corridors. This finding was expected as the dental arch amplitude was measured up to the beginning of the dark area constituting the buccal corridors. However, comparing the average measures at pre- and posttreatment may be subject to bias, and the reciprocal effect of multiple variables should be considered to understand the independent effect of each parameter. In fact, the regression model showed that the intercanine amplitude was inversely correlated to the size of the buccal corridors. This is in agreement with other studies in the literature, which indicated that changes in buccal corridor area were associated with the intercanine width but not to the intermolar width [31, 33]. Additional posttreatment changes in dental parameters included proclination of the lower incisors by 2.0° and a reduction of the interincisal angle by 3.1°, which were also clinically relevant. In this regard, clinicians should ensure that aesthetic requirements are compatible with establishing correct mastication and incisal guidance for maintaining physiological function of the temporomandibular joint [30]. However, these changes were not related to a significant effect on the buccal corridors area when included in the regression model. Significant differences were also found in skeletal parameters after treatment. Specifically, the ANB and SNA values decreased by 0.6° and 0.4°, respectively. Additionally, the FH/GoGn was reduced by 0.7°, contributing to a decrease in divergence. Nevertheless, despite being statistically significant, these changes were not clinically relevant and they also showed no significant contribution in the regression model. Hence, posttreatment variations in the smile aesthetic were primarily attributed to the dental component rather than to changes in the skeletal parameters [15].

As previous studies comparing extraction versus nonextraction cases included small groups, the current study focused on a larger sample of nonextraction patients to develop a linear regression model. Overall, the regression model showed that an increase in intercanine amplitude and a younger age significantly predicted the reduction in buccal corridor area. The observation that a larger intercanine width is predictive of a smaller buccal corridor area is intuitive and has been clinically validated by this study. A negative correlation between intercanine width and buccal corridor area has also been documented in similar studies utilizing conventional and self-ligating bracket systems [31]. Additionally, the age at the start of treatment was also found to significantly influence changes in buccal corridor area. Age-related changes in dental and facial structures may contribute to alterations in smile dynamics, leading to a transversely wider and vertically narrower smile area delimited by the soft tissues, and increased buccal corridors [6]. Conversely, neither changes in the inclination of the upper nor the lower incisors significantly predicted the change in buccal corridor area. As such, the null hypothesis that sagittal change of incisal inclination may influence transverse smile parameters, particularly changes in buccal corridor area, has to be rejected.

Limitations

The reported values of incisal inclination measured on lateral cephalometry (i.e. based on the inclination of the long axis of the tooth with respect to the skeletal base) do not correspond to the conventional reference values used for bracket prescription (i.e. based on the inclination of the facial axis of the crown with respect to the occlusal plane, as proposed by Andrews [2]). Moreover, because the patients' median age was 14 years, the observed clinical changes may have been influenced by growth and cannot be considered solely to be the result of orthodontic treatment. Lastly, after the statistical adjustment aimed at controlling for false positives, results remained substantially similar beside the posttreatment change of the SNA angle (which lost statistical significance), and the effect of intercanine amplitude and age on buccal corridors (where statistical significance was borderline). Therefore, the results of the linear regression analysis should be interpreted with caution, and larger samples may be needed for strengthening the evidence of the presented findings.

Conclusion

- An increase in the intercanine amplitude and a younger age at the beginning of treatment were related to a decrease in the area of the buccal corridors, independently from sex, dentoskeletal parameters and other smile parameters.
- Clinicians should consider that beginning the orthodontic treatment earlier and widening the intercanine amplitude may lead to smaller buccal corridors. Conversely, incisal inclination did not affect buccal corridors and should be planned focusing on incisal aesthetics and function.
- However, due to variable growth patterns and individual response to orthodontic biomechanics, clinicians should not exclude possible effects of changes in incisal inclination on the dental arch width and intercanine width, which may influence the size of the buccal corridors.

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Data Availability All data is provided within the manuscript.

Declarations

Competing interests The authors declare no competing interests.

Ethical standards The study was approved by the Ethics Committee of the University of Brescia (registration number: NP3899, clinical study: ISW01). Participants signed an informed consent prior to participating in the study.

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