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Dentoalveolar process remodelling in the anterior mandible after Class III camouflage treatment with lower premolar extractions

Dirk Wiechmann^{1,2*}, Robert Leven¹, Per Rank³, Yann Janssens^{1,4} and Jonas Q. Schmid⁵

Abstract

Background The aim of this investigation was to evaluate if the hard and soft tissue dentoalveolar process of the mandible follows the tooth movements after lower premolar extractions and anterior retraction in Class III camouflage treatment.

Methods This retrospective study included 25 patients in retention (f/m 12,13) who had previously been treated with lower premolar extractions for Class III camouflage with a completely customized lingual appliance (Wits at T0 $-6.7, \pm 2.5$ mm). The periodontal and dental health of the lower 6 anterior teeth was evaluated (T1) by a thermal sensitivity test, probing and visual inspection after a mean retention period of 3.1 years (± 2.5 , min/max 1.0/9.6 years). A novel non-invasive method was used to measure the thickness of the hard and soft tissue dentoalveolar process on the labial and lingual side of the teeth before treatment (T0) and in retention (T1) at 3 different levels using superimposed intraoral scans. A paired t-test with $\alpha=5\%$ was used to evaluate differences between the endpoints.

Results At T1, all 25 patients (mean age 26.8 ± 9.7 years, min/max 16.3/49.5 years) presented uncompromised periodontal and dental situations in the lower anterior segment. The presented digital method for evaluating dimensional changes of the dentoalveolar process had excellent reliability (ICC) with a method error of 0.01 mm. The mean total labio-lingual dimension of the hard and soft tissue dentoalveolar process (min/max 7.89/10.02 mm at T0) was identical at T0 and T1 (mean change of 0.00 ± 0.33 mm, min/max $-0.98/0.8$ mm). At all levels, the teeth moved only 0.12 mm to the lingual side within the dentoalveolar process and therefore, they moved with the dentoalveolar process and not through it.

Conclusion In non-surgical camouflage treatment with lower premolar extractions in moderate to severe Class III malocclusions, the dentoalveolar process can follow the movement of the mandibular incisors and canines during controlled retraction without any adverse effects.

Keywords Lingual orthodontics, Completely customized lingual appliance, Class III camouflage, Dentoalveolar process remodelling, Digital 3-D superimposition

*Correspondence:

Dirk Wiechmann

wiechmann@lingualsystems.de

Full list of author information is available at the end of the article



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Introduction

Dentoalveolar compensation of skeletal discrepancies is one of the most frequently applied orthodontic treatment concepts [1–9]. The indications of this treatment approach and the extent to which it makes sense clinically have been discussed controversially to this day [10, 11]. Consensus has been achieved as to the assessment of how well various orthodontic appliances can perform, with fixed appliances being preferred over removable appliances in terms of controlling the precise, 3-dimensional movement of the teeth [12, 13]. Along with the choice of the orthodontic appliance, the orthodontist's level of qualification has a decisive influence [14]. Orthodontic mechanotherapy is a complex task in which, as in any medical/dental procedure, the quality of how a challenging treatment plan is executed in the patient's mouth reflects the level of training as well as the skill of the orthodontic practitioner to a great extent. In line with this, the discussion of the possibilities associated with the dentoalveolar compensation of skeletal discrepancies, controversial to this day, is shaped by addressing these prerequisites (kind of appliance inserted/therapist's qualification). An orientation for selecting the best treatment plan offered by Proffit and White are the so-called envelopes of possible corrections which define the limits of dentoalveolar compensation in still growing and in adult patients [15]. More recent developments in orthodontic mechanotherapy, such as skeletal anchorage as well as Herbst treatment in adult patients, would even suggest a potentially larger envelope than described by Proffit and White [2, 4, 6–8]. However, the modern shift from multibracket appliances to removable aligners may restrict the range of indications substantially, which immediately raises the subsequent question of the ethical/moral background of this treatment approach, like in other medical disciplines [16, 17]. There is certainly general consensus in medicine/dentistry that no patient should undergo surgery because 1) the orthodontist favours this or that type of approach and dentoalveolar compensation is not possible with the preferred appliance or 2) the orthodontist's limited mechanotherapeutic training and skill requires assistance by a maxillofacial surgeon. Therefore, a clear definition of what is clinically feasible in relation to the relevant skeletal discrepancy in the sagittal, transverse, and vertical planes is essential. In this regard, completely customized lingual appliances (CCLA) have been demonstrated to achieve clinical performance in cases with skeletal discrepancies by numerous studies [2–5, 7–9, 18–23]. In these discrepancies, tooth movements considered unusual to the present state of our knowledge have been achieved in practice with precision,

reliability and efficiency according to the treatment plan.

In a previous study on the inclination control of the lower front teeth in a Class III camouflage treatment with extraction in the mandible, a significant and controlled movement of all front teeth to the lingual side was observed, with a shift of up to more than 7 mm in the area of the centre of resistance [7]. With such a large correction, the question arises as to whether the dentoalveolar process, including its hard and soft tissues, follows the tooth movement or whether the tooth, instead of involving the alveolar process, moves through it. The aim of the present study was therefore to evaluate the condition of the anterior mandibular dentoalveolar process in the identical patient collective after a retention period of at least one year.

Material and methods

This investigation is a follow-up evaluation of the study by Thiem et al. who surveyed 25 adolescent or adult patients presenting a Class III molar relationship on one or both sides [7]. All patients received camouflage treatment with uni- or bilateral lower premolar extraction and were consecutively debonded between 2015 and 2024, after fixed-appliance orthodontic treatment with a CCLA (WIN, DW Lingual Systems, Bad Essen, Germany) in one orthodontic specialist practice (Bad Essen, Germany). Between 2015 and 2024 twelve different orthodontists or postgraduate students have been working in this specialist practice. All cases were supervised by D.W.. The approval for this retrospective cohort study was received from the Ethics Committee of the Hannover Medical School, Hannover, Germany (3151–2016). For Class III camouflage, the lower incisors were retracted “en masse” with precise inclination control (Fig. 1). The mean Wits value before camouflage treatment (T0) was -6.7 mm (± 2.5 , min/max $-10.8/-2.1$) and the lingual displacement of the centre of resistance of the lower incisors was 3.7 mm on average (± 1.3 , min/max $1.4/7.1$ mm) [7].

After a minimum retention phase of at least 1 year (mean: 3.1 years, $SD \pm 2.5$, min/max 1.0/9.2 years), all 25 patients (f/m 12/13) were called in for a clinical re-evaluation (T1) of the achieved treatment result with particular attention to the periodontal situation in the lower anterior segment. To get an impression of the tooth movement achieved during camouflage, superimpositions of the mandible before and directly after treatment were traced by an orthodontist with comprehensive expertise in this field (P.R.). The profile x-rays before and after treatment were checked and corrected for enlargement differences and traced with Adobe Illustrator 9.0 (Adobe Inc. San José, USA) [24]. The tracings were superimposed on the stable anatomical structures



Fig. 1 Adult patient with Class III malocclusion (same patient as Fig. 6 b). Camouflage treatment with lower premolar extractions and lower incisor inclination control

in the mandible according to Björk [25], Björk and Skiel-ler [26] and Springate [27]. All 25 patients showed up and the actual clinical situation could be re-evaluated: 1) A thermal tooth sensitivity test with a refrigerant spray was performed on the lower incisors and canines. 2) On the

same teeth, the probing depth was measured on the lingual side with a periodontal probe (PCP11, Aesculap AG, Tuttlingen, Germany) at the deepest point of the gingival margin. 3) To document potential lingual recessions in this segment, high-resolution, digital, intraoral photographs (Camera D200, with Nikkor 105 mm, Nikon, Tokyo, Japan) were taken with the help of an intraoral mirror (Filtrop AG, Balzers, Liechtenstein). Similar to the methodology of Renkema et al., a lingual recession was scored if the lingual root surface was clearly exposed [28]. 4) An intraoral scan of the mandible with the Trios 3 (3shape, Copenhagen, Denmark) was performed with particular attention to the anterior dentoalveolar process.

Hard and soft tissue dentoalveolar process evaluation

This scan was compared to the initial Trios 3 scan before treatment (T0) with the help of the software GOM 2021 (2021 Hotfix 8, Rev. 152,091, GOM Braunschweig, Germany). As measurements of the thickness of the alveolar process or its bone morphology may lead to wrong results when rotated teeth are measured before and after derotation, teeth rotated by 6° or more at T0 were excluded (Figs. 2 and 3). A customized best-fit algorithm was used to standardize and facilitate the matching process of every single anterior tooth (lower canine to canine) and define and cut a reproducible plane in the labio-lingual tooth axis (Beyer 3D Scan und Messtechnik GmbH, Ahaus, Germany). Any change in thickness of the alveolar process between the two timepoints was recorded as the difference (T1-T0) of the distance between its outer soft tissue borders/margins on the labial and lingual sides at the relevant tooth measured at both T0 and T1 on three different levels, 1, 2 and 3 mm

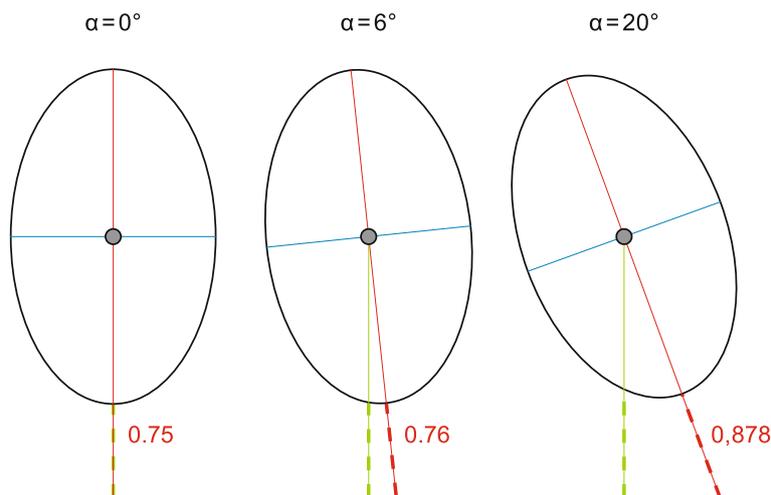


Fig. 2 The measurement of dentoalveolar process dimensions on the labial or on the lingual side of the root leads to wrong results if teeth are rotated. With $\alpha < 6^\circ$ of rotation the error amounted to under 0.01 mm, which seemed acceptable for this study (left and middle image). With more severe rotations, the results would be misleading (right image)

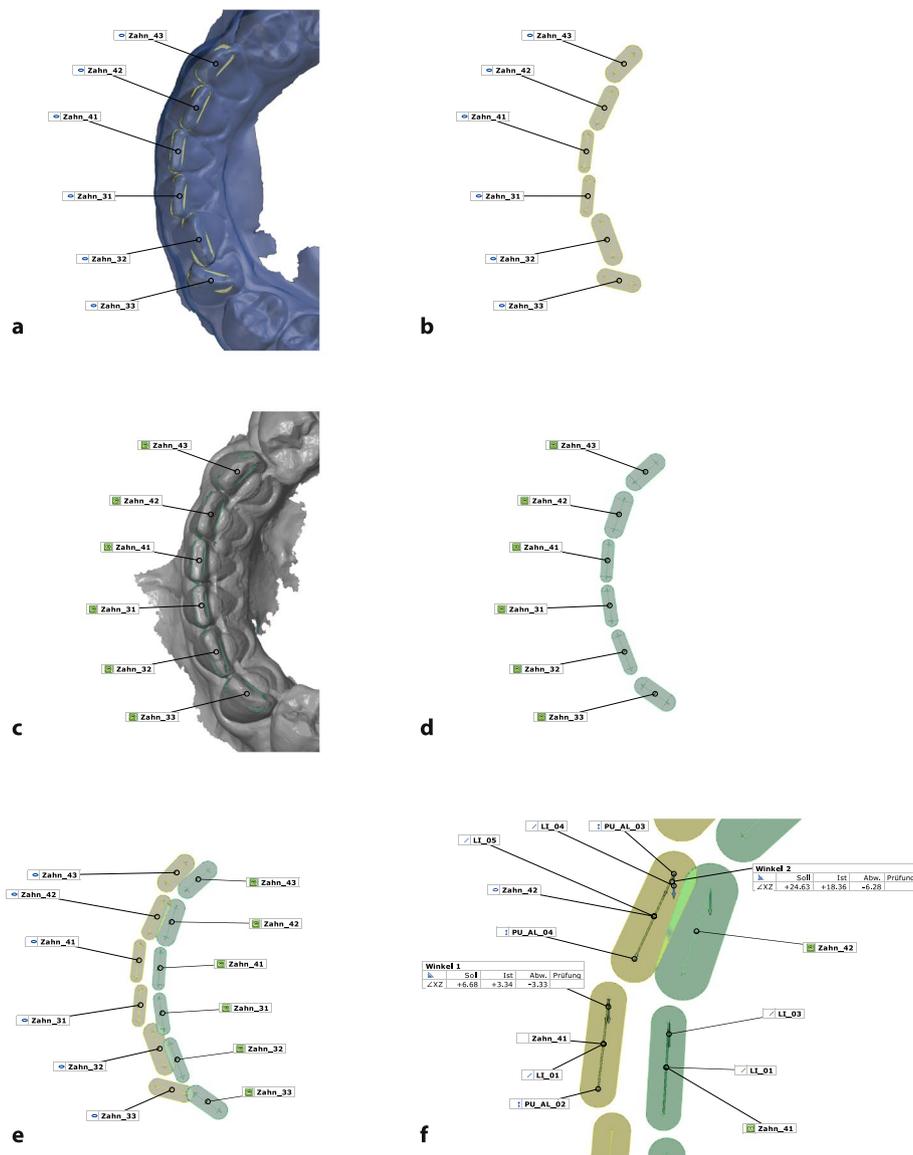


Fig. 3 Customized GOM software for rotation measurements. Individual markers on the incisor edges of the malocclusion model from canine to canine (a, b). Transfer of the individual markers to the final model after debonding (c, d). Measurement of the angle of rotation correction during treatment after matching (e, f)

apical from the gingival margin as found at T1 (Figs. 4 and 5). Also, the overall dimension of the alveolar process on these three different levels was recorded in millimetres at both timepoints.

Statistical analysis

Intrarater reliability was evaluated using intraclass correlation coefficients (ICC). For this purpose, 10% of the sample was randomly selected and remeasured after at least 2 weeks by the main investigator (R.L.). ICC

estimates and their 95% confidence intervals were calculated based on a single-measurement, absolute-agreement, 2-way mixed effects model. Interpretation of the correlation coefficients followed the cut-off limits of Koo and Li 2016 [29]. The error of measurement was determined using Dahlberg’s formula [30]. All data were summarized descriptively for each endpoint using mean, ± standard deviation (SD), min, max. The difference between T0 and T1 at the different levels and for the different kinds of teeth were analysed using a paired t-test. A *p*-value *p* < 0.05 was considered as statistically significant.

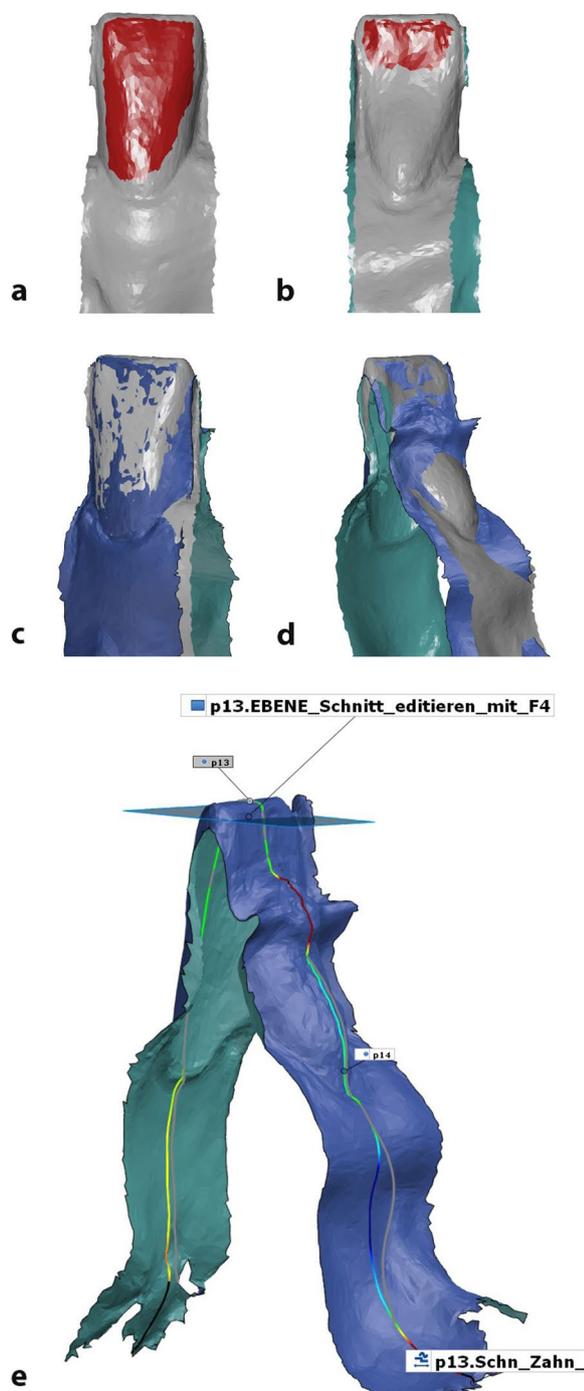


Fig. 4 Method for measuring the change of hard and soft tissue dentoalveolar process thickness on the labial and the lingual side and its total labio-lingual dimension at 3 different levels. Definition of areas for matching (red) after isolating each single tooth together with its periodontal process (a, b). The incisor edge should not be used for the matching process because it is frequently abraded, particularly in Class III patients. Matched central incisor at T0 and T1 (c, d). Customized software-assisted sagittal cut of the incisor and its surrounding hard and soft tissue dentoalveolar process (e)

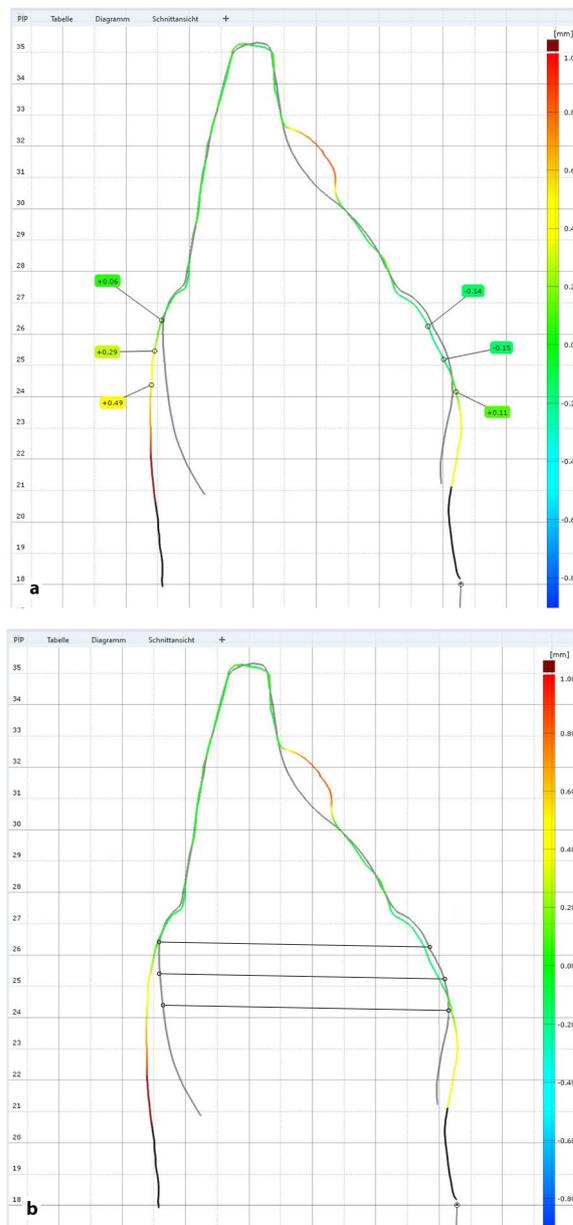


Fig. 5 Measurements of the changes in the labial and lingual dentoalveolar process thickness after superimposition (T0 grey/ T1 colored) 1, 2, and 3 mm apical from the gingival margin at T1 (a). Measurements of the total labio-lingual dimension of the dentoalveolar process at T0 (grey) on the same levels (b)

Results

The baseline characteristics are summarized in Table 1. The amount of anterior tooth movements in each patient during Class III camouflage treatment with lingual appliances and the corresponding clinical lingual view of the lower front teeth in retention (T1) is shown in Fig. 6. Overall, a clinically uncompromised periodontal and dental situation was evident at T1: All ($n=150$) lower

Table 1 Baseline Characteristics

Number of included patients	25
Male/Female	13/12
Evaluated teeth	150
Age at T1 (years) Mean, \pm SD, Min/Max	26.8, \pm 9.7, 16.3/49.5
Time in retention at T1 (years) Mean, \pm SD, Min/Max	3.1, \pm 2.5, 1.0/9.6
Wits Male at T0 (mm) Mean, \pm SD, Min/Max	-7.1, \pm 2.5, -10.7/-2.1
Wits Female at T0 (mm) Mean, \pm SD, Min/Max	-6.3, \pm 2.5, -10.8/-3.4
Lower 1 Cr displacement (mm) Mean, \pm SD, Min/Max	3.7, \pm 1.3, 1.4/7.1

anterior teeth responded positively to the thermal tooth sensitivity testing. The mean probing depth on the lingual side of the lower incisors and canines was 1.27 mm (\pm 0.45, min/max 1/2 mm). Four patients showed 6 recessions in total on the lingual side, all less than 1 mm, which became visible after the removal of calculus around the fixed retainer. All fixed retainers were intact at T1.

Alveolar process remodelling

Measurements of the tooth rotation achieved during active treatment led to the exclusion of 82 teeth as they were rotated by 6° or more at T0 compared to their position at T1 (Figs. 2 and 3). The thickness of the dentoalveolar process, including hard and overlaying soft tissue, of 26 central incisors, 21 lateral incisors and 21 canines could be evaluated in the end. Intrarater reliability was excellent for changes in alveolar process thickness on the labial and on the lingual side of the matched teeth (ICC 0.998, 95% CI 0.996–0.999) and for labio-lingual total alveolar process dimension (ICC 0.990, 95% CI 0.970–0.996). According to Dahlberg's formula, a measurement error of 0.01 mm and 0.06 mm must be assumed, accordingly, for this study (Table 2). The descriptive statistics for all included teeth and the results of the corresponding t-tests are shown in Tables 3, 4 and 5. Looking at all included teeth, there was no change of mean total dentoalveolar process dimension at all 3 levels together (mean: 0.00 mm, \pm 0.33 mm, min/max -0.98/0.8 mm, CI95% -0.08, 0.08, Table 3). Overall, there was a mean augmentation of the thickness on the labial side of 0.12 mm (\pm 0.25 mm, min/max -0.71/0.82 mm) and a mean reduction of the thickness on the lingual side of -0.11 mm (\pm 0.24 mm, min/max -0.7/0.46 mm, Table 3). Furthermore, in none of the 3 different tooth groups a significant change in alveolar process thickness was found when evaluating the three different levels together (Table 4). Looking at the different levels of the different tooth groups, a statistically significant, but

clinically irrelevant mean change of 0.19 mm for the first level of the canines (\pm 0.36, min/max -0.61/1.05 mm) and -0.13 mm for the second level of the lateral incisors (\pm 0.28, min/max -0.9/0.18 mm) was found (Table 4). Looking at the different levels separately, no statistically significant dimension change could be seen. The mean total labio-lingual dimension changes on the different levels were all less than 2% compared to their dimension at T0 (Table 4). Although the mean total thickness of the alveolar process did not change, the position of the central and lateral incisors within the process appeared to be a bit more (-0.15/-0.17 mm) towards the lingual side (Table 5).

After Class III camouflage treatment with lower premolar extractions and precise inclination control of the lower anterior teeth during dentoalveolar compensation, the hard and soft tissue dentoalveolar process had followed the bodily lingual movement of the teeth, even in severe cases, after a mean retention period of 3.1 years. Although the teeth moved towards lingual perpendicular to the alveolar process up to >7 mm, the tooth movement expressed involved the surrounding hard and soft tissues (Fig. 7).

Discussion

This is the first study that evaluates the periodontal and dental health of the lower anterior teeth that have been in retention for at least 12 months after Class III camouflage treatment with lower premolar extractions. Previously, Thiem et al. showed a dentoalveolar compensation in these cases, introducing unusual, but favourable tooth movements [7]. In particular, the authors could show superior control of the incisor inclination during retraction due to the 3-dimensional torque control of the appliance used. In some cases, the lower incisors were bodily retracted for more than 7 mm as demonstrated on the lateral cephalograms before and after lingual orthodontic treatment (Fig. 6b). On the lateral cephalograms taken directly after debonding, it was difficult to define if the alveolar process, including its hard and soft tissues, had followed the tooth movements or the incisor roots in the end had passed beyond the limits of the envelope of possible corrections described by Proffit and White [15]. Looking only at the hard tissues, several studies based on CBCT analysis reported that after the retraction of maxillary and mandibular incisors, the alveolar process did not follow entirely [31–33]. In a systematic review, Guo et al. reported a reduction of bone thickness of 0.57 mm on the lingual side of mandibular incisors in the finishing stage of treatment after anterior retraction in protrusive cases measured 3 mm apical of the cemento-enamel junction [31]. In contrast, Kobylansky et al. did not find any reduction of the lingual bone thickness after

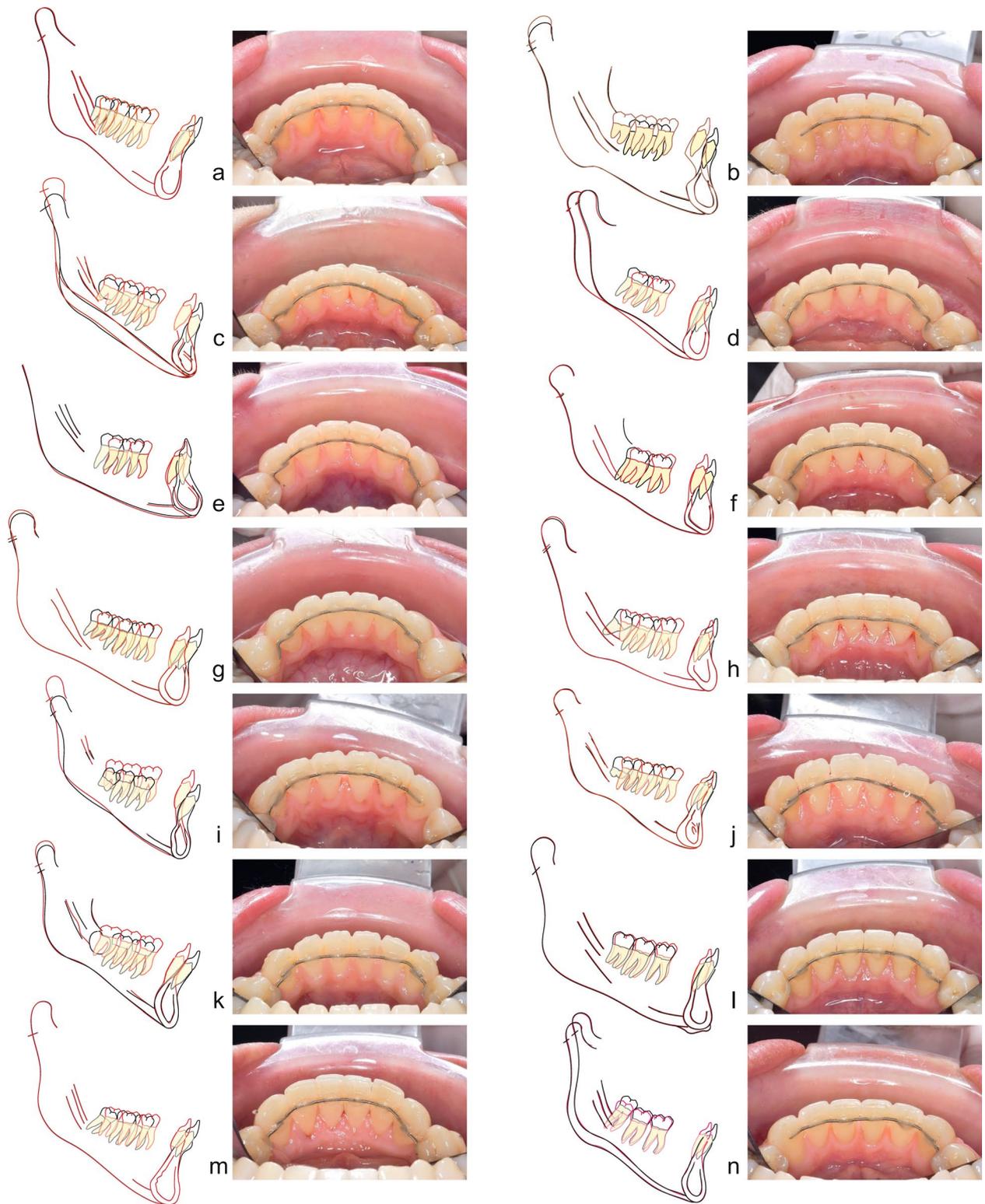


Fig. 6 Structural superimpositions of the mandible of the 25 included patients before and after Class III camouflage treatment with lower premolar extractions and the corresponding clinical situation at recall (T1)

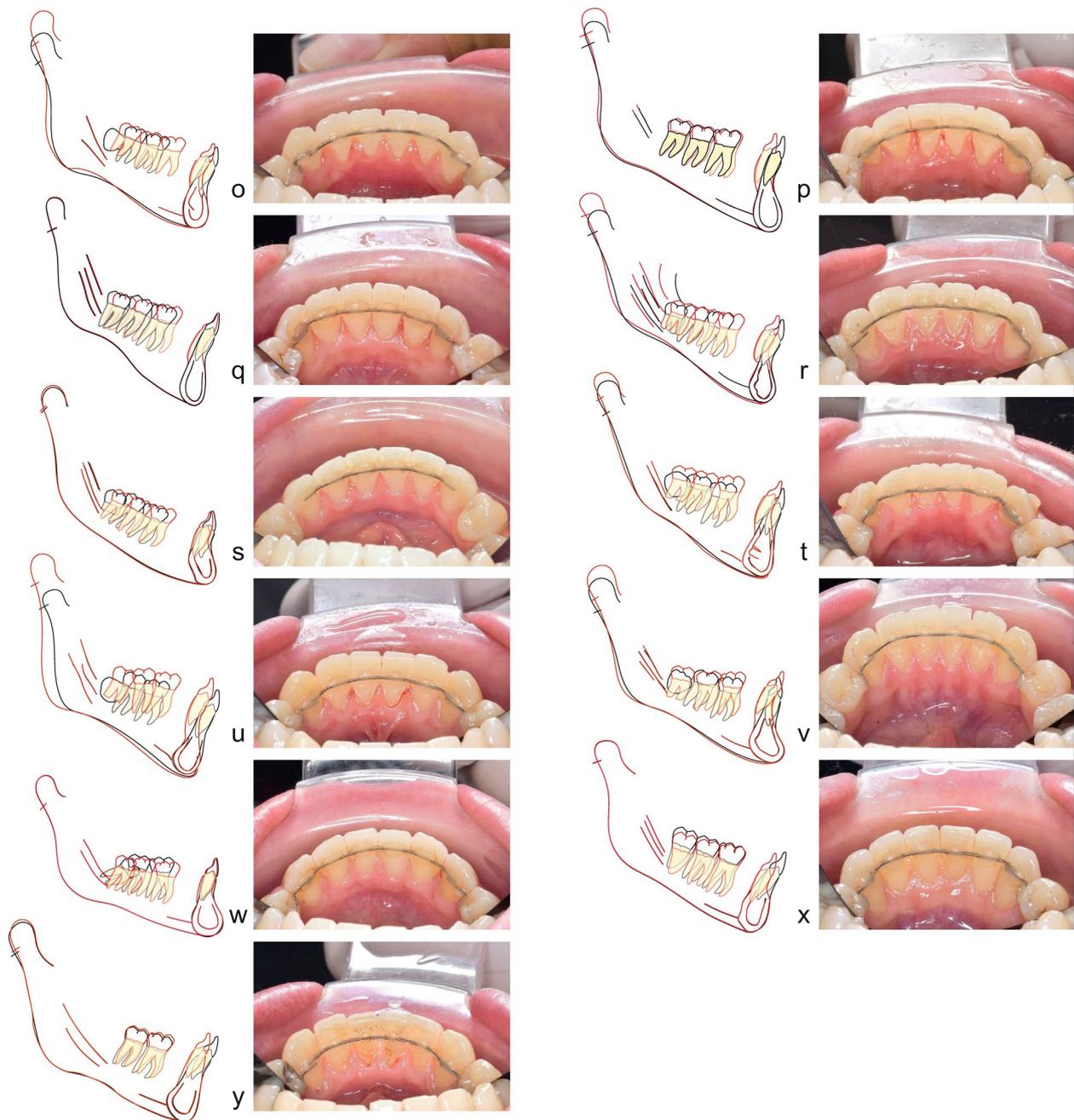


Fig. 6 continued

Table 2 Intrarater correlation coefficient and method error

Measurement	Description	ICC (95%CI)	Method error
Change in dentoalveolar process thickness on labial and lingual side on 3 different levels	Distance between the superposed labial and lingual borders of the hard and soft tissue alveolar process at T0 and T1	0.998 (0.996–0.999)	0.01 mm
labio-lingual dentoalveolar process dimension on 3 different levels	Thickness of the total hard and soft tissue alveolar process perpendicular to the incisor edge	0.990 (0.970–0.996)	0.06 mm

ICC < 0.5: poor reliability; 0.5 ≤ ICC < 0.75: moderate reliability; 0.75 ≤ ICC < 0.9: good reliability; ICC ≥ 0.9: excellent reliability

Table 3 Change of the thickness of the hard and soft tissue dentoalveolar process on labial and lingual side of the teeth and difference in total dimension in different levels in millimeters. Paired t-Test over all teeth (Post – Pre treatment) H0: difference = 0

All teeth	N	Mean	SD	95% Confidence Intervall	Min	Max	p-value
Labial level 1	68	0.09	0.24	(0.03, 0.15)	-0.9	0.8	0.0045
Labial level 2	68	0.12	0.26	(0.06, 0.18)	-0.72	0.86	0.0002
Labial level 3	68	0.14	0.31	(0.06, 0.21)	-0.71	0.8	0.0004
Lingual level 1	68	-0.07	0.26	(-0.13, 0)	-0.55	0.66	0.0383
Lingual level 2	68	-0.11	0.26	(-0.18, -0.05)	-0.76	0.49	0.0004
Lingual level 3	68	-0.16	0.3	(-0.23, -0.09)	-0.85	0.55	< 0.0001
All labial levels	204	0.12	0.25	(0.06, 0.18)	-0.71	0.82	0.0003
All lingual levels	204	-0.11	0.24	(-0.17, -0.05)	-0.7	0.46	0.0003
Total dimension difference level 1	68	0.02	0.36	(-0.07, 0.11)	-1.14	1.05	0.6275
Total dimension difference level 2	68	0.01	0.32	(-0.07, 0.08)	-0.9	0.94	0.8474
Total dimension difference level 3	68	-0.02	0.38	(-0.11, 0.07)	-0.89	0.91	0.6792
Total dimension difference all levels	204	0	0.33	(-0.08, 0.08)	-0.98	0.8	0.9343

Table 4 Hard and soft tissue dentoalveolar process total dimension on different levels by tooth group in millimeters and change in total dimension. Paired t-Test of the change in total dimension (Post – Pre treatment) H0: difference = 0

Tooth-type	N (teeth)	Labio-lingual dimension at T0 in mm	Treatment effect in mm (%)	SD	95% Confidence Intervall	Min	Max	p-value
Central incisor level 1	26	7.89	-0.02 (-0.25)	0.34	(-0.16, 0.11)	-0.85	0.73	0.7317
Central incisor level 2	26	8.31	0.03 (-0.36)	0.36	(-0.11, 0.18)	-0.88	0.94	0.6654
Central incisor level 3	26	8.42	0 (0)	0.45	(-0.18, 0.18)	-0.87	0.91	0.9863
Central incisor all	78	8.20	0 (0)	0.36	(-0.14, 0.15)	-0.87	0.8	0.9771
Lateral incisor level 1	21	8.29	-0.09 (-1.09)	0.35	(-0.25, 0.06)	-1.14	0.46	0.2339
Lateral incisor level 2	21	8.62	-0.13 (-1.51)	0.28	(-0.25, 0)	-0.9	0.18	0.0459
Lateral incisor level 3	21	8.69	-0.07 (-0.81)	0.36	(-0.23, 0.09)	-0.89	0.51	0.374
Lateral incisor all	63	8.53	-0.1 (-1.17)	0.3	(-0.23, 0.04)	-0.98	0.22	0.1535
Canine level 1	21	9.79	0.19 (1.94)	0.36	(0.03, 0.36)	-0.61	1.05	0.0254
Canine Level 2	21	9.98	0.11 (1.10)	0.27	(-0.01, 0.24)	-0.31	0.59	0.067
Canine level 3	21	10.02	0.01 (0.10)	0.31	(-0.13, 0.15)	-0.43	0.67	0.8786
Canine all	63	9.93	0.11 (1.11)	0.29	(-0.03, 0.24)	-0.38	0.65	0.1126

the alignment phase in which the anterior teeth were reclined [34]. Recently, several authors found significant remodelling and increasing alveolar bone thickness after orthodontic retraction on the lingual side of the anterior teeth in the retention phase [35–39]. Similar findings have been reported for retracted maxillary incisors after up to 9 years in retention [35, 37–40]. This leads to the hypothesis that the envelope of possible corrections in adult Class III patients with orthodontic tooth movement only is possibly larger than what Proffit and White had in mind [15]. The results of our study support these

findings, even for more severe Class III corrections with exceptional root control and, therefore, substantial root movement of lower anterior teeth to the lingual side.

Tooth related 3-dimensional superimposition of the alveolar process

A novel method of digital 3-dimensional superimposition of the dentoalveolar process comprising its hard and soft tissues is introduced in this study. Digital models have been used to evaluate dimensional changes on the labial and lingual side of the teeth and its total dimension in

Table 5 Change of the thickness of the hard and soft tissue dentoalveolar process on labial and lingual side in 3 different levels by tooth group and paired t-test for the difference (Post – Pre treatment) H0: difference = 0

Tooth-Type	Variable	N	Mean	SD	95% Confidence Interval	Min	Max	p-value
Central Incisor	Labial level 1	26	0.11	0.25	(0.01, 0.21)	-0.7	0.8	0.0301
	Labial level 2	26	0.16	0.28	(0.05, 0.27)	-0.72	0.86	0.008
	Labial level 3	26	0.18	0.34	(0.04, 0.32)	-0.71	0.8	0.0124
	Lingual level 1	26	-0.13	0.19	(-0.21, -0.06)	-0.5	0.23	0.0016
	Lingual level 2	26	-0.13	0.2	(-0.21, -0.05)	-0.51	0.25	0.0033
	Lingual level 3	26	-0.18	0.27	(-0.29, -0.07)	-0.85	0.33	0.0021
	Labial all levels	78	0.15	0.28	(0.04, 0.26)	-0.71	0.82	0.0103
	Lingual all levels	78	-0.15	0.19	(-0.22, -0.07)	-0.5	0.23	0.0004
Lateral Incisor	Labial level 1	21	0.02	0.27	(-0.1, 0.14)	-0.9	0.38	0.7724
	Labial level 2	21	0.08	0.27	(-0.05, 0.2)	-0.53	0.53	0.2139
	Labial level 3	21	0.13	0.33	(-0.02, 0.29)	-0.46	0.53	0.0763
	Lingual level 1	21	-0.11	0.27	(-0.23, 0.01)	-0.55	0.35	0.0786
	Lingual level 2	21	-0.21	0.32	(-0.35, -0.06)	-0.76	0.49	0.0084
	Lingual level 3	21	-0.21	0.39	(-0.38, -0.03)	-0.8	0.55	0.0261
	Labial all levels	63	0.08	0.27	(-0.05, 0.2)	-0.62	0.46	0.2158
	Lingual all levels	63	-0.17	0.31	(-0.31, -0.03)	-0.7	0.46	0.0184
Canine	Labial level 1	21	0.13	0.21	(0.03, 0.22)	-0.17	0.6	0.0121
	Labial level 2	21	0.12	0.21	(0.03, 0.22)	-0.29	0.55	0.0129
	Labial level 3	21	0.09	0.23	(-0.01, 0.19)	-0.34	0.6	0.0846
	Lingual level 1	21	0.06	0.27	(-0.06, 0.19)	-0.48	0.66	0.285
	Lingual level 2	21	-0.01	0.21	(-0.1, 0.09)	-0.33	0.43	0.8621
	Lingual level 3	21	-0.08	0.21	(-0.17, 0.01)	-0.51	0.28	0.092
	Labial all levels	63	0.11	0.19	(0.03, 0.2)	-0.27	0.55	0.0142
	Lingual all levels	63	-0.01	0.21	(-0.1, 0.09)	-0.35	0.4	0.8671

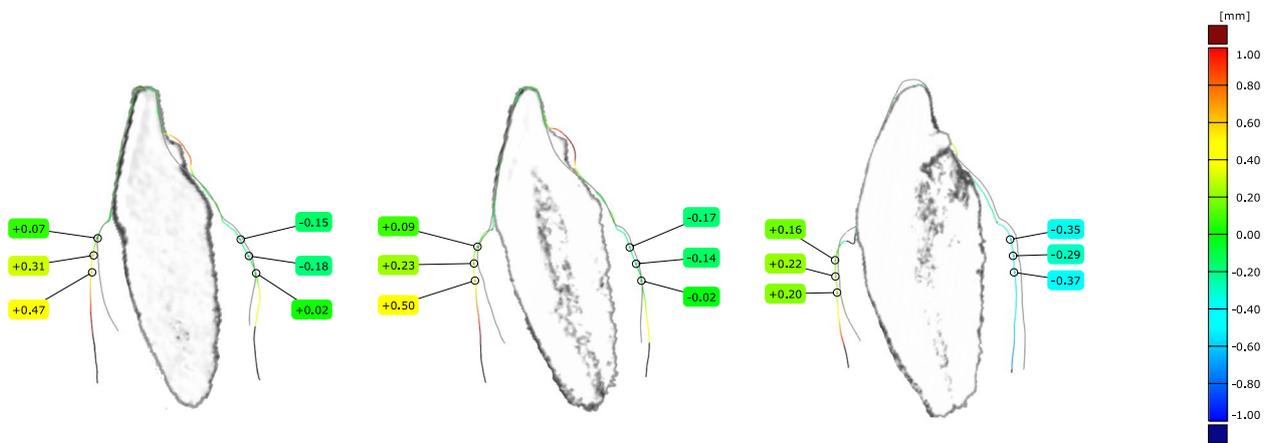


Fig. 7 One included patient had a CBCT scan in retention because of a surgical indication. The matching of the central incisor (left image), lateral incisor (middle image), and canine (right image) in the CBCT scan and the intraoral scan highlight the size and the position of the roots within the alveolar process

three different levels. Earlier studies on this aspect have been based almost exclusively on data acquisition with CBCT scans [31–33]. Upon closer examination of these

studies, the section on limitations in these studies often highlights the recurring issue of an undeniably coarse voxel resolution, which makes an accurate assessment of

structures smaller than 0.5 mm impossible. Particularly in the region of the mandibular anterior teeth, the labial and lingual bony coverage of the roots is often physiologically thinner than 0.5 mm [41, 42]. Moreover, in all European countries, CBCT imaging is not considered part of standard orthodontic diagnostics due to its high radiation exposure deemed disproportionate to its clinical benefit [43]. Therefore, in addition to the simplicity of clinical application in nearly every orthodontic practice, the evaluation using intraoral scans is also advantageous from the perspective of medical ethics. Not only the teeth, but also the dentoalveolar process should be captured as comprehensively as possible, which, in the present study, was achieved through data collection before treatment (T0) and in retention (T1) on all three levels. Since intraoral scanning, which is required as a basis for the 3D superimposition presented here, can be exceedingly challenging when aiming to capture not only the teeth, but also the upper portion of the alveolar process, a perfectly digitized plaster model taken from an alginate or even a silicone impression could alternatively be used for the described evaluation.

Evaluation of the thickness of the dentoalveolar process dimensions around rotated teeth

In this study the thickness of the alveolar process was evaluated exclusively on teeth which were not visibly rotated ($<6^\circ$) at the onset of orthodontic treatment. As displayed in Fig. 2, the changes in thickness of the alveolar process should not be measured on rotated teeth, as the initial thickness, which is always the baseline, may be overestimated, just as in almost all studies on CBCT scans [31–40].

Strengths and limitations

The present study is a continuation of the investigations by Thiem et al. on Class III camouflage treatment. A patient group treated with a comparable treatment concept does not exist. Therefore, this study allows, for the first time, an assessment of the periodontal and dental situation after an average retention period of more than three years following the completion of active camouflage therapy with premolar extractions exclusively in the mandible. The results provide initial indications of a potentially necessary update of the definition of the envelopes of possible corrections according to Proffit and White [15].

The measurement of changes in the thickness of the alveolar process without any radiation exposure, due to the limitations of intraoral scanning, allows an assessment of its upper portion only. However, the measurement 3 mm apical from the gingival margin results in

good comparability with studies based on CBCT imaging. As the measurements reflect the dimensions of the entire dentoalveolar process, including hard and soft tissues, an evaluation of dimensional changes of hard and soft tissues separately is not possible with this method. Thanks to a purpose-developed, major customization of the GOM software, the intrarater reliability (ICC) as well as the error of measurement (Dahlberg) showed excellent values.

A minimum retention period of one year after debonding is not extensive; however, no clinical differences in periodontal or dental health were observed even after more than nine years of retention.

Conclusions

In non-surgical camouflage treatment with lower premolar extractions in moderate to severe Class III malocclusions, the dentoalveolar process can follow the movement of the mandibular incisors and canines during controlled retraction without any adverse effects.

Discussing a redefinition of some of Proffit and White's definitions of the envelope of possible corrections by orthodontic tooth movements only could make sense.

The novel method of measuring dimensional changes of the periodontal process relative to the teeth is reproducible, precise, and non-invasive.

Authors' contributions

D.W. initiated the investigation and wrote the main manuscript. D.W., J.Q.S. and Y.J. defined the conception of the method. D.W. and R.L. treated the patients and prepared the documents for the measurements. P.R. made all the superimpositions. R.L. made the measurements. J.Q.S. (lead) and Y.J. provided the statistical evaluation. All authors reviewed the manuscript.

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Data availability

The data underlying this study can be shared upon reasonable request to the corresponding author.

Declarations

Ethics approval and consent to participate

The approval for this retrospective cohort study was received from the Ethics Committee of the Hannover Medical School, Hannover, Germany (3151–2016).

Consent for publication

All patients signed a written consent form.

Competing interests

D. Wiechmann is the inventor of the WIN system. All other authors have no competing interest.

Author details

¹Private Practice, Lindenstr. 44, 49152, Bad Essen, Germany. ²Department of Orthodontics, Hannover Medical School, Hannover, Germany. ³Private Practice, Svendborg, Denmark. ⁴Department of Orthodontics, Université Paris Cité, Paris, France. ⁵Department of Orthodontics, University of Münster, Münster, Germany.

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