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ORIGINAL ARTICLE

Post-treatment changes in permanent retention
Post-therapeutische Veränderungen unter permanenter Retention

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Abstract
Objectives While permanent retention is today the method of choice to stabilize orthodontic treatment outcomes, recent studies have increasingly reported posttreatment changes in tooth position during permanent retention. We conducted this study to analyze changes in the anterior mandible, whether the changes follow an underlying movement pattern, and, aiming for a preventive strategy, whether any risk factors could be identified comparing findings with the pretreatment situations.
Methods We included 30 patients who had worn fixed Twistflex retainers (UK 3–3) extending from canine to canine in the mandible. Casts reflecting the intraoral situations before orthodontic treatment (T0), directly after completion of active therapy (T1), and 6 months later (T2) were scanned and superimposed using Imageware Surfacer software. Posttreatment changes (T2−T1) of tooth position within the retainer block were analyzed on 3D virtual models and were compared to pretreatment (T0) and treatment-related (T1−T0) findings to identify potential risk factors.
Results Almost all analyzed patients revealed three-dimensional changes in tooth position within the retainer block. Comparing these movements, we repeatedly found rotated retainer blocks in labio-oral direction, while the center of rotation was located at the first incisors. This pattern was associated with intercanine expansion and excessive overjet correction during orthodontic treatment. The canines underwent the most pronounced (rotational and translational) movements.
Conclusions In general permanent lingual retainers are safe but in special clinical cases retainers can induce undesired tooth movement. Risk factors seem to be intercanine expansion and excessive overjet correction during orthodontic treatment. In specific cases an additional retention device might be needed.

Keywords Lingual retainer · Orthodontic retention · Twistflex retainer · Tooth movement · Prevention

Zusammenfassung
Zielsetzung Permanente Retention ist häufig das Mittel der Wahl, um ein orthodontisches Behandlungsergebnis zu stabilisieren. In jüngster Zeit werden häufig Fallberichte über Veränderungen unter permanenter Retention publiziert. Ziel der vorliegenden Studie war es, mögliche posttherapeutische Veränderungen unter permanenter Retention in der Unterkieferfront zu analysieren und zu prüfen, ob diesen Veränderungen ein grundsätzliches Bewegungsmuster zugrunde liegt und ob sich durch Korrelation zum prätherapeutischen Anfangsbefund

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Risikofaktoren zur Etablierung einer geeigneten Präventionsstrategie benennen lassen.

Material und Methoden Ausgewählt wurden 30 Patienten, die während der Retentionsphase ausschließlich mit festsitzenden Twistflex-Retainern (UK 3-3) retiniert wurden. Die entsprechenden Unterkiefermodelle direkt nach Abschluss der aktiven Therapie, sowie Kontrollmodelle mindestens 6 Monate später wurden digitalisiert und mit einer Surfacer-Software überlagert. Stellungsveränderungen der Frontzähne unter permanenter Retention wurden in allen drei Raumebenen analysiert und mit dem prätherapeutischen Modellbefund zur Benennung risikorelevanter Faktoren in Beziehung gesetzt.

Ergebnisse Die Daten zeigen in fast allen untersuchten Fällen Veränderungen in allen drei Raumebenen im retinierten Unterkiefersegments. Beim Vergleich der einzelnen Stellungsabweichungen fällt ein wiederkehrendes Bewegungsmuster auf, das sich in Form einer labiooralen Schwenkung des Retainerblocks mit einem Drehzentrum im Bereich der ersten Inzisivi manifestiert. Dies scheint mit einer therapeutischen Expansion der intercaninen Breite und der exzessiven Korrektur des sagittalen Overjets zu korrelieren. Die stärksten Stellungsveränderungen wurden an den Eckzähnen in rotatorischer und translatorischer Bewegung festgestellt.

Schlussfolgerungen Die permanente Retention mittels Lingualretainern stellt eine sichere Retentionsmaßnahme dar, die allerdings in einigen Fällen posttherapeutische Veränderungen auslösen kann. Das Ausmaß der therapeutischen Reduktion der sagittalen Stufe und die Erweiterung der intercaninen Distanz scheinen Risikofaktoren für das Auftreten von posttherapeutischen Veränderungen unter permanenter Retention darzustellen. In ausgewählten Fällen erscheint eine zusätzliche Retention empfehlenswert.

Schlüsselwörter Lingualretainer · kieferorthopädische Retention · Twistflex-Retainer · Zahnbewegung · Prävention

Introduction

Providing long-term stability of treatment outcomes is a particularly challenging task for orthodontists. Much research has gone into this issue, with a continuously increasing trend to use permanent retention systems that are independent of patient compliance. Despite these efforts, no solution has yet been found to prevent post-treatment changes reliably. These may take the form of tooth positions relapsing toward the initial malocclusion, but another issue that is increasingly being discussed concerns changes in tooth position brought about by the retention system itself [4, 9, 29].

Great interest has been devoted to permanent retention of treatment outcomes since the early days of modern orthodontics. Investigations concerning the stability of orthodontic treatment outcomes revealed a marked tendency notably of upper and lower incisors to relapse into their previous positions unless appropriate measures of retention were taken [12, 13]. The concept advocated by Edward Angle to stabilize tooth positions by establishing a neutral occlusal relationship was not adequately effective in preventing posttreatment displacement. Hence Angle's critics suggested various concepts of improving the long-term stability of occlusal relationships. The approach proposed by Tweed sought to prevent relapse due to overexpansion of the dental arch by extracting premolars [3, 29].

However, these concepts do not seem to ensure long-term stability of the tooth positions achieved by orthodontic treatment. Hence recent efforts have focused on appliances worn by patients beyond the stage of active orthodontic treatment. Studies have also increasingly looked into the reasons for orthodontic relapse, aiming to explore whether these insights might hold a prospect for more selective modalities of preventing relapse or, for that matter, any kind of change to which the occlusal relationship may be subjected after completion of treatment. A possible cause of relapse suggested in early reports by Reitan and others [3, 5, 18] was insufficient remodeling of the transgingival fiber apparatus to match the tooth movement, thus, forcing the teeth to move back toward their original displacement after treatment. Accordingly, they suggested severing these fibers by periodontal surgery to prevent relapse. Other measures to ensure posttreatment stability would include overcorrection of the original tooth displacement or gentle modification of the lower intercanine distance (avoiding marked protrusion of the lower incisors) as part of the orthodontic treatment [2, 15, 23, 31].

Numerous retention protocols prove that permanent lingual bonded retainers are currently the most effective and predictable way of stabilizing tooth positions in the anterior mandible. Hence these retention protocols are today's gold standard [6, 9, 22]. However, recent publications report of distinct changes in lower anterior tooth position during and despite the use of permanent lingual retainers, requiring a second orthodontic treatment in severe cases [9, 17]. Interestingly, these changes are unrelated to the pretreatment tooth positions and, thus, should not be discussed in terms of orthodontic relapse. Rather, they must be independently regarded as a tooth movement related to the lingual retainers—and to the orthodontic treatments preceding their insertion—in ways that are currently not understood.

Compared to a growing number of case reports with little scientific evidence, we designed this study to analyze the development of posttreatment changes during the use of permanent fixed lingual retainers. Our first aim was to verify systematically the actual incidence of this phenomenon and whether a consistent movement pattern could be identified. Subsequently these data were used for the next goal, to identify factors related to the preceding treatment regimens by comparing post- and pretreatment casts, thus, verifying the presence of any treatment-related risk factors for future utilization by clinicians in assessing this risk and toward developing a strategy of preventing these posttreatment changes during permanent retention.

Materials and methods

Patients

We retrospectively analyzed data of 30 consecutive patients treated at our institution (Department of Orthodontics, University of Bonn) in the period 2012−2015. Patients were included who underwent ≥1 year of active treatment with fixed appliances, followed by permanent retention in the anterior mandible, with no other appliance in the mandible and no extracted or congenitally missing anterior teeth. Retention was provided as described by Zachrisson et al. [31], using a twistflex retainer (Dentaurum; Dentaflex 0.45 mm three-strand twisted steel wire) bonded to six lingual sites from canine to canine. All retainers were fabricated based on impressions in the laboratory of our department, and a silicone positioner was used for passive intraoral insertion. The preceding orthodontic therapies had been performed after conventional planning and included cases of both non-extraction and extraction of premolars. At the end of active treatment, the 30 (17 female and 13 male) patients were 24.52 ± 4.36 years old.

Digital visualization of tooth positions

For each patient, pairs of casts reflecting the pretreatment situation (T0) and the situation immediately upon completion of active treatment (T1) were available, plus a lower-jaw cast obtained after ≥6 months of retention (T2). Following digitization of the T1 and T2 casts with a laser scanner (Micromeasure70®; Microdenta Sensorik, Linden, Germany), 3D graphics software (Surfacer, v. 10.5; Imageware/Siemens PLM Software, Plano, TX, USA) was used to display the teeth and mucosal tissues as a 3D point cloud. Removing the gingiva—which is subject to dimensional changes [25, 26]—along with the retainer and the bonding sites reduced this display to the tooth surfaces required for tooth-position analysis.

Superposition of the virtual 3D models

To track the posttreatment movement of each anterior tooth during the period of retention, we superposed T1 and T2 models. As the mandible features no anatomical structure that would be both unchangeable by orthodontic therapy and recordable by dental impression-taking [16], we based this superposition on the well-established method of best surface matches [14, 19]. In brief, the point clouds of the same molars scanned from T1 and T2 casts were projected onto each other using a surface–surface matching algorithm that works toward minimizing the distances between the two clouds. These distances were described by a predefined function, the individual parameters of which were varied until the distance was effectively minimized for ideal congruence between the two areas [10].

Measurement of tooth movements

To measure the actual changes in tooth position during permanent retention, teeth 33 to 43 of both superposed modes (T1 and T2) were segmented, then calculating the rotational and translational movement of each tooth at T2 as compared to T1 in all three dimensions by applying the surface–surface matching algorithm (see above) [10]. The coordinate system was defined such that the rotational components of tooth movement (°) were mesiodistal around the x axis, orovestibular around the y axis, and longitudinal around the z axis (=tooth axis); and that the translational components (mm) were orovestibular along the x axis, mesiodistal along the y axis, and apicocoronal (intrusion/extrusion) along the z axis (Fig. 4a) [10]. The mean method error involved was determined by applying the measuring process 10 times to an object based on 1° of rotation and 0.1 mm of translation.

Severity groups of posttreatment change

Based on the clinical appearance of the lower dental arches at T2, the patients were divided into three severity groups. Grade 1 indicated mild or no change which did not require treatment, grade 2 moderate change which also did not require treatment but was documented and monitored, and grade 3 severe change noted by the orthodontist during the retention period which did require another course of active treatment. In addition, a metric grading system was derived from the maximum values of rotational tipping measured for the various teeth. Alterations of tooth position were considered stable if <5°, moderate if ≥ 5° to ≤9°, and severe if >9° irrespective of their directions.

Determination of treatment-related risk factors

To relate the outcomes to the initial situations prior to orthodontic treatment, manual measurements were performed on the T1 and T0 casts, including intercanine distance [1, 7, 8, 11] and overjet [7, 24]. The treatment-related changes of these parameters were obtained by calculating the difference between T0 and T1. Furthermore, the pretreatment space requirement diagnosed for each patient was measured and documented based on the T0 cast.

Statistical analysis

The results of the various measurements were entered and sorted in spreadsheet software (Excel; Microsoft Corporation, Redmond, WA, USA). Any statistically significant differences between results were identified by applying a *t* test for independent samples, using statistical software (Graph Pad Prism 5; GraphPad Software, La Jolla, CA, USA). Differences were considered significant at $p \leq 0.05$.

Results

Posttreatment changes observed clinically and on virtual models

Comparing T1 and T2, some patients reveal a change in tooth position within the retainer segment (Fig. 1). Notably the canines had moved relative to the first premolars by T2. This was confirmed after digitization of the T1 and T2 casts and superposition of the virtual models, which revealed that the retention-related posttreatment change was often characterized by the canines showing the greatest and the central incisors the smallest movement by T2. In the majority of cases, this movement exhibited a rotation-style pattern with the center of rotation in the area of the central incisors (Fig. 2).

Incidence of posttreatment changes during permanent retention

Qualitative and quantitative evaluation of severity of posttreatment changes (see "Materials and methods" section) allowed to classify patients having undergone stable, moderate, or severe post treatment changes in tooth position during retention (Fig. 3). The permanent lingual retainers ensured stability of the tooth positions in 55.68 % of cases. Moderate changes were observed in 30 % and severe changes rising the question for lower jaw treatment in 13.32 % of cases.

Involvement of tooth types in the posttreatment changes

Superposition of each digitized and segmented tooth allowed to determine the nature of the movement to which each lower anterior tooth had been subjected. Both the rotational and the translational components were analyzed in all three dimensions. Analysis of movement revealed that the canines underwent the most pronounced rotation and translation.

Findings of rotational (tipping) movement

Figure 4a illustrates the coordinate system, which defined rotational tooth movements around the *x*-, *y*-, and *z*-axes. Figure 4b illustrates the mean rotational movements during retention, which were found to be most pronounced for the canines in the group of patients with severe posttreatment changes. These movements were clearly more pronounced in the mesiodistal (x: 6.96° ± 3.95°) and orovestibular (y: 5.13° ± 2.94°) planes than longitudinally (z:

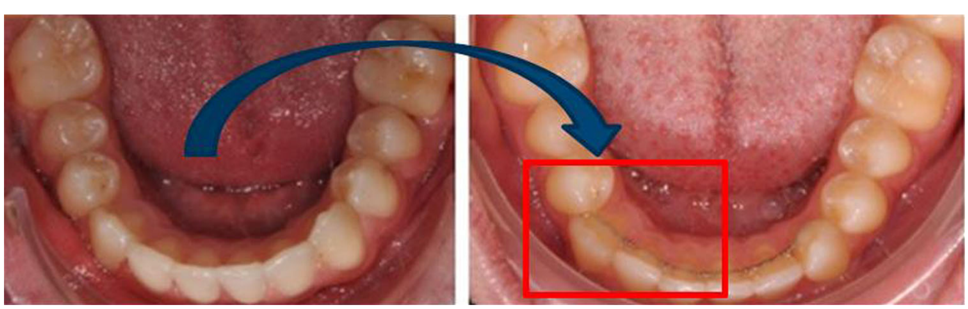

Fig. 1 Intraoral photos of a patient whose tooth positions changed in the posttreatment period despite of wearing a permanent fixed lingual retainer. Compared to the *left* photograph taken at the end of active treatment (*T1*), moderate movement of the canines relative to the first premolars was observed following 6 months of retention (*T2*).

Abb. 1 Intraorale Aufnahmen eines Patienten mit Veränderungten der Zahnstellung während der posttherapeutischen Phase trotz eines festsitzenden Lingualretainers. Im Vergleich zur Aufnahme *links* bei Beendigung der aktiven Behandlung (*T1*) war nach 6 Monaten Retention (*T2*) eine Bewegung der Eckzähne zu beobachten

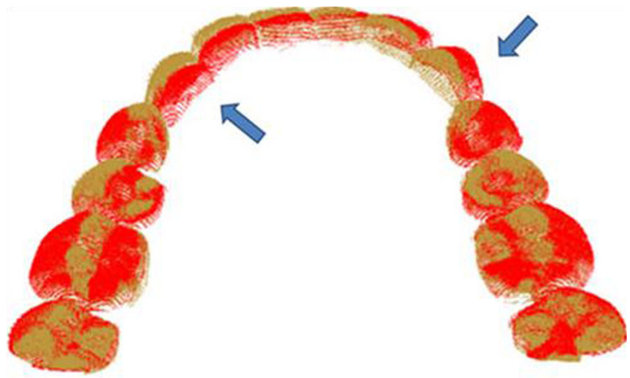

Fig. 2 Superposition of two virtual 3D models reflecting the situations in the same mandible at the end of active treatment (*T1*; *brown areas*) and after 6 months of fixed lingual retention (*T2*; *red areas*). Movement of the area spanned by the retainer had been noticed clinically. Its rotational pattern is representative of the results of the present study, given a center of rotation in the area of the central incisors with resultant "swerving" of the canines.
Abb. 2 Digitale Überlagerung des Frontblocks eines Patienten zum Ende der aktiven Therapie und nach 6-monatiger Retentionsphase. Es kann eine bereits klinisch beobachtete Stellungsveränderung im Bereich des mit dem Lingualretainer fixierten Zahnsegments anhand der 3D Überlagerung visualisiert werden. In Anbetracht der vorliegenden Daten kann hier ein wiederholt auftretendes Rotationsmuster mit Rotationspunkt im Bereich der mittleren Inzisivi sowie ein „Ausscheren" der Eckzähne beobachtet werden (braun = Abschluss aktive Therapie, rot = Kontrollmodell).

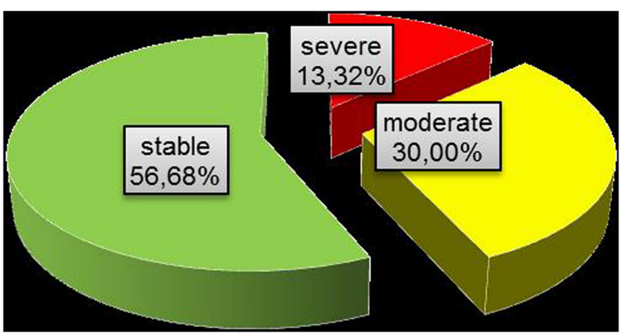

Fig. 3 The Graph shows the distribution of the severity of posttreatment changes in the patient groups. Stable posttreatment results (rotational change <5°) accounted for 56.68 %, moderate changes (≥5° to ≤9°) for 30 %, and severe changes (>9°) for 13.32 % of cases.
Abb. 3 Grafische Darstellung der Verteilung der Schweregrade posttherapeutischer Veränderungen in den Patientengruppen. Stabile Behandlungsergebnisse (rotatorische Veränderung <5°) zeigten sich bei 56,68 %, mäßige (≥5° to ≤9°) bei 30 % und erhebliche Veränderungen bei (>9°) 13,32 % der Fälle.

3.3° ± 3.12°). In the group with severe changes, the mesiodistal (*x*) and orovestibular (*y*) rotational changes were significantly greater than in the group with moderate changes and in the stable group. No significant differences in longitudinal tooth rotation were noted (*z*).

Findings of translational (bodily) movement

The coordinate system (Fig. 4a) expressed translational movements as orovestibular along the *x* axis, mesiodistal along the *y* axis, and apicocoronal (i.e., reflecting intrusion or extrusion) along the *z* axis. Figure 4c illustrates the mean translational movements observed during retention. The greatest changes in tooth position were observed for the canines in the patient group showing severe posttreatment changes. These movements were most pronounced in the orovestibular (*x*: 0.81 ± 0.59 mm) and mesiodistal (*y*: 0.95 ± 0.43 mm) planes. The results in the vertical axis revealed extrusion of the canines (*z*: 0.52 ± 0.35 mm). Again, the differences between the severe and the stable group were statistically significant in all three planes, and the lateral and central incisors had moved far less than the canines.

Association of posttreatment changes with treatment-related factors

Casts obtained for all patients directly after (T1) and before (T0) orthodontic treatment revealed significantly larger amounts of intercanine expansion (Fig. 5a) and overjet reduction (Fig. 5b) in the group showing severe posttreatment changes. Thus, the present data defines patients with marked findings of intercanine expansion and/or overjet reduction during orthodontic treatment to have a significantly higher risk for posttreatment changes in tooth position even though a fixed lingual retainer is placed. No differences between the three groups of posttreatment changes were found based on the patients' pretreatment space requirements in the mandible (Fig 5c) or based on treatments that included extraction of premolars (Fig. 5d).

Discussion

Changes in tooth position occurring even the patient is wearing a permanent fixed lingual retainer after orthodontic treatment is of high clinical relevance. This is the first study which systematically evaluates this phenomenon and provides data explaining recent observations and case reports [9, 20, 21]. A permanent fixed lingual retainer in the lower anterior segment is one of the most effective and used technics to stabilize orthodontic treatment outcomes [22, 28, 30]. As our study demonstrates, however, tooth movement may occur even with such a retainer in place. Exactly how these changes occur is not currently understood.

Our findings are consistent with previous case reports pointing to the phenomenon of posttreatment movement of anterior teeth is unrelated to the original malocclusion.

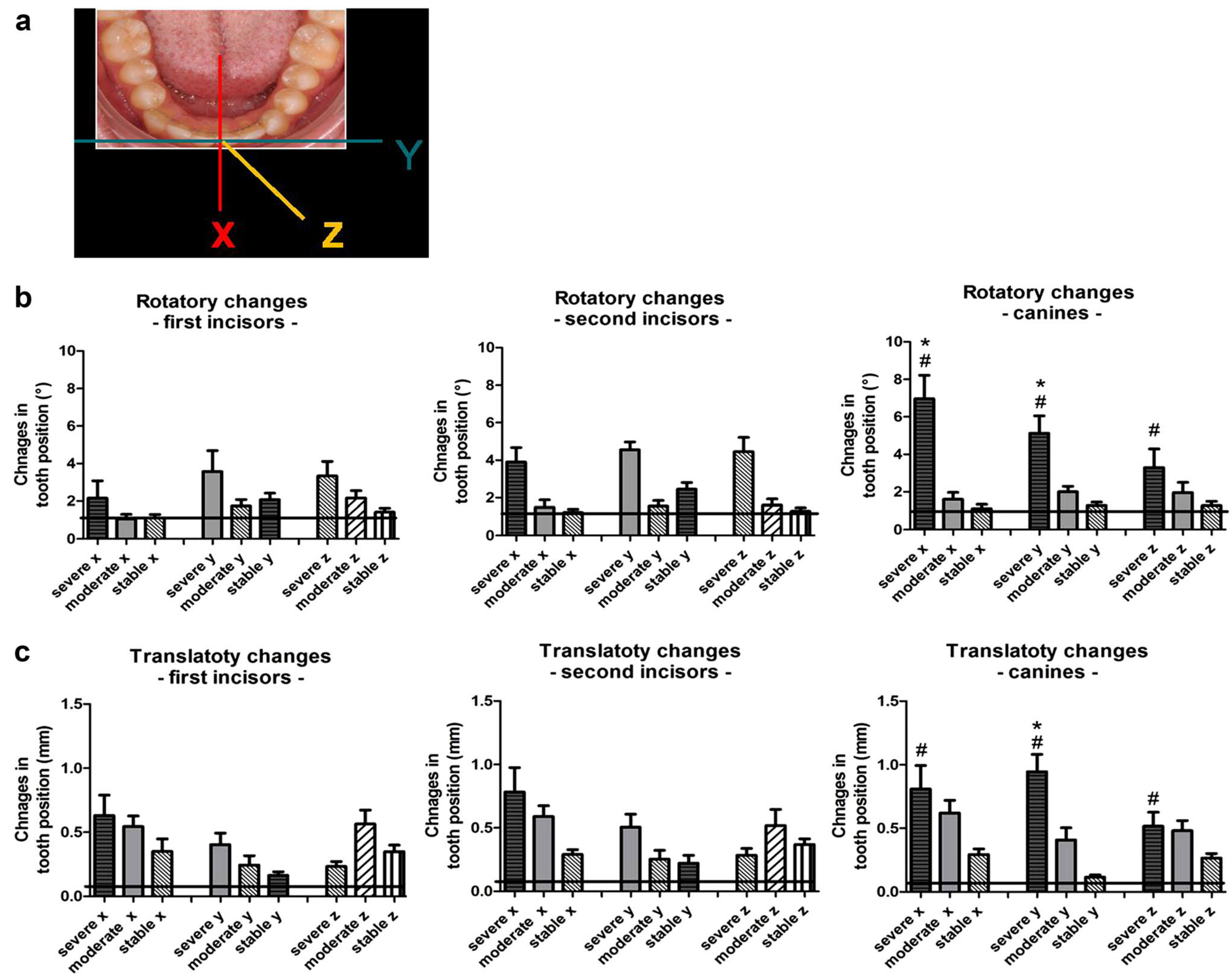

Fig. 4 **a** The coordinate system was defined such that rotational tooth movements were mesiodistal (*x*), orovestibular (*y*), and longitudinal (*z*). Translational movements were orovestibular (*x*), mesiodistal (*y*), or vertical (i.e., reflecting intrusion or extrusion) along (*z*). The graphs illustrates the results for **b** rotational and **c** translational posttreatment tooth movements after 6 months of retention. *Black horizontal lines* crossing the *bars* indicate the method error. * significant ($p < 0.05$) for the patient group with severe posttreatment changes versus both the moderate and the stable groups. # significant values ($p < 0.05$) for the severe group versus the stable group.

Abb. 4 **a** Im Koordinatensystem waren rotatorische Zahnbewegungen mesiodistal (x), orovestibulär (y) und longitudinal (z), translatorische orovestibulär (x), mesiodistal (y) oder vertikal (d. h. je nach In- bzw. Extrusion) entlang der z-Achse definiert. Die Graphen zeigen die Ergebnisse für **b** rotatorische und **c** translationale posttherapeutische Zahnbewegungen 6 Monate nach Retention. *Schwarze horizontale Linien* Methodenfehler. *Statistisch signifikante (p < 0,05) Werte für die Gruppe mit gravierenden posttherapeutischen Veränderungen im Vergleich mit den Gruppen mit mäßigen Veränderungen bzw. stabil gebliebenen Ergebnissen; #signifikante Werte (p < 0,05) für die Gruppe mit gravierenden Veränderungen im Vergleich zur Gruppe mit stabilen Resultaten

Hence, these changes should not be discussed in terms of relapse but should be regarded as a new development associated with the presence of the fixed lingual retainer. Due to mechanisms that remain inadequately documented, lingual retainers seem capable of inducing movement, which may result in a new malocclusion requiring retreatment. More studies are needed to identify risk factors which are concerned with posttreatment changes in tooth position even though a fixed lingual retainer was placed.

The present analysis disclosed a rotational movement pattern of the six anterior teeth induced by the retainer, while the center of rotation was located at the central incisors. For reasons not currently fully understood, the retention protocol described here seems to result in forces capable of rotating the entire block of teeth interconnected by the retainer, with one end of the block drifting in a lingual and the other end in a vestibular direction (see Fig. 1). Possible explanation for this phenomenon could be a posttreatment transverse relapse, with a resulting force of jaw-narrowing being vented in the anterior mandible and causing rotation of the entire (rigidly interconnected) retainer block.

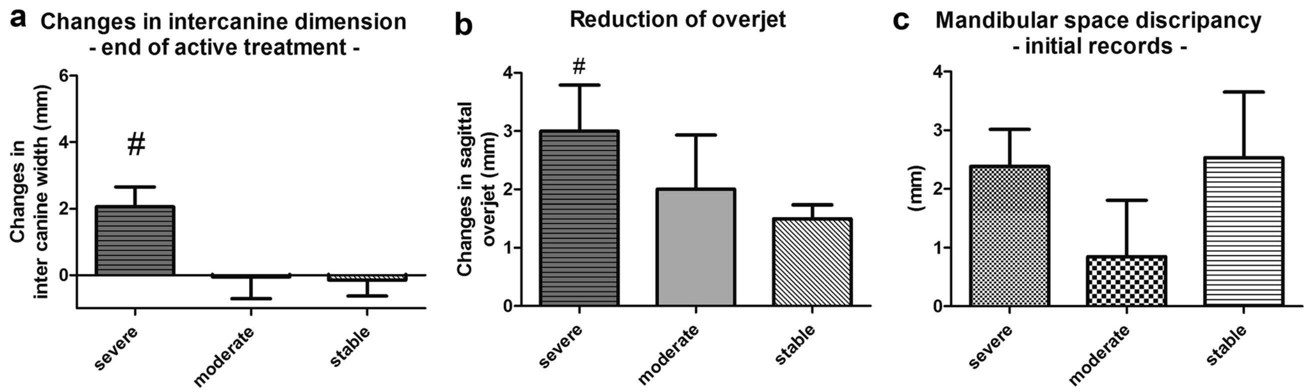

Fig. 5 Potential role of treatment-related factors (as reflected by T1−T0 differences) in the development of posttreatment tooth movement (as reflected by T2−T1 differences) associated with the use of a permanent fixed lingual retainer in the lower anterior segment.

Abb. 5 Möglicher Einfluss behandlungsbezogener Faktoren (reflektiert in den T1−T0-Unterschieden) bei der Entwicklung posttherapeutischer Zahnbewegungen (Unterschiede zwischen T2 und T1), die bei der Verwendung festsitzender Lingualretainer im unteren Frontzahnsegment Zahnbogen auftreten.

Authors of a similar investigation have suggested that age-related anterior development of the mandible may be responsible to induce anterior crowding and uprighting the frontal lower incisors with increasing patients age [4]. According to this theory, an active force would emerge in the dental arch which might be able to deform the lower jaw including the retainer segment. Another potential cause that has been discussed would be an iatrogenic activation of the retainer during bonding, resulting in an active permanent wire that might induce movement of the teeth within the retainer segment [27].

Our results allowed to identify the amounts of intercanine expansion and overjet reduction as potential risk factors for posttreatment changes during permanent retention. Documented findings and considerations suggest that, in some cases, a removable appliance should be used in addition to the fixed retainer to ensure proper stabilization of the treatment outcome. It is reasonable to assume from the available findings, at least while scientific data to prove the contrary are not available, that the same factors on record as modifying the stability of orthodontic treatment outcomes will remain relevant even after a fixed lingual retainer has been inserted. Therefore, repeatedly documented risk factors like mandibular anterior protrusion, mandibular intercanine expansion, or pronounced space requirements should not be ignored even in patients with permanent fixed lingual retainers [3, 5, 18].

Given the similarity of the tooth movements reported here to a rotational pattern, the retainer material itself might also be a causative factor. Rotation of the entire block of teeth interconnected by the retainer might be favored by de-twisting of the retainer wire. At this point, we cannot conclusively conclude whether, and to what extent, such de-twisting might occur in the intraoral environment and whether the resultant forces/moments would be capable of generating such movements. The question of whether the retainer material poses a risk will require future biomechanical and clinical investigations.

Despite the present data about the incidence of posttreatment tooth movement among lingual retainers, bonded retainers may still be considered as an effective and safe method to stabilize outcomes of orthodontic treatment. The fact that, in some cases, retainers can induce tooth movement in their own turn should be noticed. How this happens exactly remains to be scientifically elucidated in future studies. Based on the results of the present study, we recommend a removable retention appliance in addition to a lingual retainer in cases exhibiting transverse expansion of the mandible and pronounced overjet correction during orthodontic treatment.

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Compliance with ethical guidelines This article does not contain any studies with human participants or animals performed by any of the authors. All presented findings belong to retrospective data.

Conflict of interest M. Wolf, U. Schulte, K. Küpper, C. Bourauel, L. Keilig, S.N.Papageorgiou, C. Dirk, C. Kirschneck, N. Daratsianos, A. Jäger state that they have no conflicts of interest.

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