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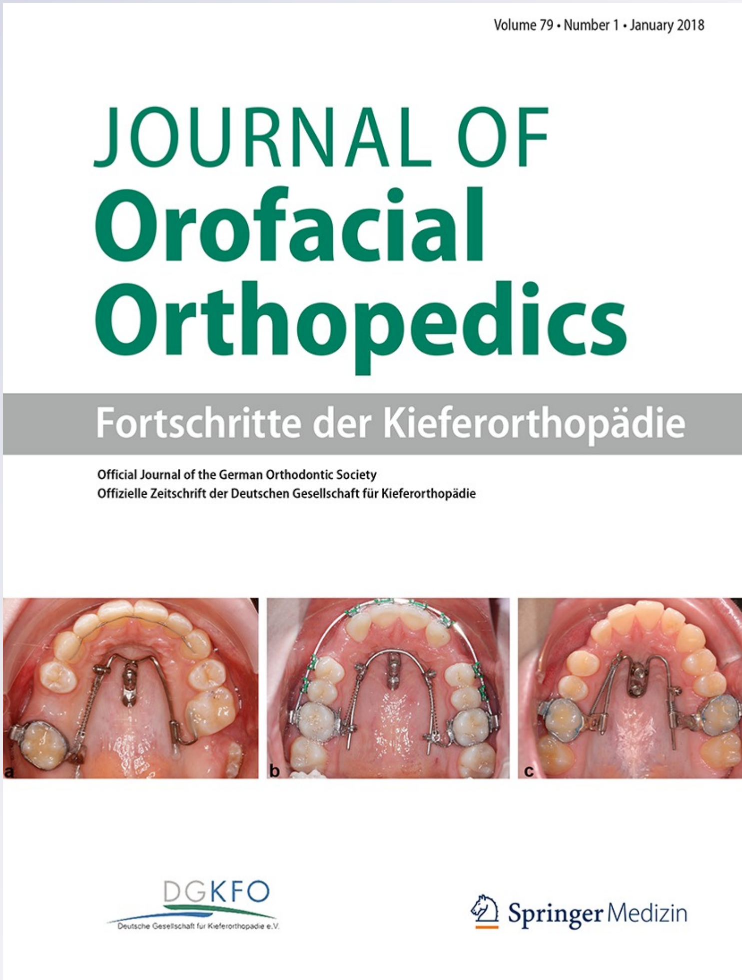

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ORIGINAL ARTICLE

Skeletally anchored mesialization of molars using digitized casts and two surface-matching approaches

Analysis of treatment effects

Skelettal verankerte Molarenmesialisierung mittels digitalisierter Modelle und zweier Oberflächenregistrierungsverfahren

Analyse der Behandlungseffekte

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Abstract
Purpose To (1) quantify the three-dimensional treatment effect of a Mesialslider appliance using superimposed digital models, (2) to evaluate anchorage loss (measured by incisor displacement), and (3) to assess agreement between two different matching approaches, i.e., control point (CP)-based and iterative closest point (ICP) matching.
Methods In a retrospective study, the effects of a skeletally anchored uni- and bilateral mesialization appliance (Mesialslider) as well as simultaneous mesialization and distalization appliance (Mesio-Distalslider) were evaluated in 48 subjects (aged 11–53 years). Pre- and posttreatment casts were digitized and superimposed with two different approaches, i.e., using ten manually selected control points located at the anterior palate and by means of an automated ICP-matching approach using a standardized palatal reference area. The treatment effects were evaluated using control points on the maxillary central incisors and maxillary molar teeth, and the methods were compared through the application of linear regression analyses and computation of alignment errors.
Results Average upper molar mesialization was 6.3 ± 2.6 mm. Anchorage loss, designated as the mean amount of upper incisor displacement, was less than 0.5 mm in all dimensions investigated. Using the measurement method sufficient registration was possible using both approaches and corresponding tooth movements were significantly correlated ($p < 0.01$).
Conclusions Accurate measurements of tooth displacement can be performed using both CP- and ICP-based matching approaches. Within the limits of performing a retrospective study, a premolar width of molar mesialization appeared possible without clinically relevant anchorage loss.

Keywords Mesialization · Skeletal anchorage · Treatment effects · Incisor stability · Surface matching · 3D tooth movement

Zusammenfassung
Ziele (1) Quantifizierung der dreidimensionalen Behandlungseffekte der Mesialslider-Apparatur mithilfe von überlagerten und digitalisierten Modellen, (2) Analyse des Verankerungsverlusts (gemessen als Inzisiven-Bewegung) und (3) Bewertung der Übereinstimmung zweier Oberflächenregistrierungsverfahren, d.h. Registrierung anhand manuell gesetzter Kontrollpunkte (CP) und mittels

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eines automatisierten ICP("iterative closest point")-Verfahren.

Methoden Retrospektiv wurden die Effekte einer ein- und beidseitigen Mesialisierungsapparatur (Mesialslider) sowie einer simultanen Mesialisierungs- und Distalisierungsapparatur (Mesial-Distalslider) bei 48 Patienten (Alter 11–53 Jahre) untersucht. Dazu wurden vor (T0) und nach Mesialisierung (T1) angefertigte Gipsmodelle digitalisiert und mit 2 verschiedenen Registrierungsverfahren überlagert, d.h. mit 10 manuell am anterioren Gaumen gewählten CP und mit einem automatisierten ICP-Verfahren unter Nutzung einer Überlagerungsregion am anterioren Gaumen. Die Zahnbewegungen wurden mittels Referenzpunkten an den oberen mittleren Schneidezähnen und am ersten Molaren berechnet; verglichen wurden die beiden Verfahren per linearer Regressionsanalyse sowie hinsichtlich der jeweiligen Registrierungsfehler.

Ergebnisse Die durchschnittliche Molarenmesialisierung betrug 6,3 ± 2,6 mm. Der Verankerungsverlust, gemessen als die durchschnittliche Inzisivenbewegung, betrug weniger als 0,5 mm pro Richtung. Bei der Bewertung der Methode zeigte sich, dass beide Verfahren eine zuverlässige Registrierung ermöglichten und die korrespondierenden Zahnbewegungen signifikant ($p < 0{,}01$) korreliert waren.

Schlussfolgerung Akkurate Messungen von Zahnbewegungen können mittels CP- und ICP-basierten Registrierungsverfahren durchgeführt werden. Unter Berücksichtigung der Limitationen einer retrospektiven Analyse erschien eine Mesialisierung um eine Prämolarenbreite ohne klinisch relevanten Verankerungsverlust möglich.

Schlussfolgerung Mesialisierung · skelettale Verankerung · Behandlungseffekte · Inzisivenstabilität · Oberflächen-Matching · 3-D-Zahnbewegung

Introduction

Congenital absence of the lateral incisor or second premolar teeth, extremely displaced canines, or severe trauma to the central incisors all refer to clinical situations that may result in a shortened maxillary dental arch. In many cases, mesialization of the posterior dental segment may be a desirable and cost-effective option, since treatment can be completed once the secondary dentition has erupted [28]. The substitution of the absent maxillary lateral incisor by the canine can be readily accomplished with sound aesthetic outcome through tooth reshaping and modification, bleaching, and prosthetic recontouring [23, 27].

Demands for anchorage quality depend on the position of the missing tooth in the dental arch. Space closure in the incisal region requires much more anchorage compared to the premolar region, and unilateral or asymmetric space closure is even more challenging. Thus, predictable anchorage control is very important and preservation of the midline as well as lingual tipping of the maxillary incisor teeth must be prevented during mesialization.

With the goal to achieve reliable anchorage, the use of mini-implants has become popular over the last decade [9, 11]. The Mesialslider appliance, attached to two coupled mini-implants in the anterior palate, permits protraction of the maxillary dentition either unilaterally (Fig. 1a) or bilaterally [26] (Fig. 1b). In cases with a dental midline asymmetry, the Mesial-Distalslider can be used for simultaneous mesialization and distalization [25] (Fig. 1c).

Several recent case reports indicated satisfactory treatment outcomes for the Mesialslider with only minor side effects observed on the maxillary incisor teeth [15, 24]. However, to the best knowledge of the authors, no quantitative analyses of the actual treatment effects with respect to orthodontic tooth movement have been reported.

Three-dimensional imaging allows for assessment of actual three-dimensional tooth movements including the displacement of the incisors, whereas traditional assessment employing lateral cephalograms is limited to two-dimensional comparisons [20]. Given the relatively higher radiation exposure and current health regulations, three-dimensional analyses using cone-beam computed tomography (CBCT) [6] purely for treatment analyses are not ethically justified [10], while registration of digital plaster models or intraoral scans from different time points provide a radiation-free alternative [2, 5, 7, 8, 12, 22].

Ideally, digital models would be superimposed using the characteristic tooth shapes. However, since teeth are displaced during treatment, they are no reliable reference. Therefore, the rugae area, which appears to be stable under orthodontic therapy [1, 14, 16, 19], has been suggested and employed for model alignments [2, 7, 8, 21]. However, slight changes of the rugae over time, or local alignment optima can both impair alignment accuracy and as a consequence affect the computed tooth displacements. Reliability of the alignments can be validated by comparing computed tooth movements from different registration procedures.

Hence, this study aimed to (1) quantify the three-dimensional molar movement for subjects treated with the Mesialslider appliance (unilateral, bilateral, mesiodistal option), (2) evaluate anchorage loss (measured by incisor displacement), and (3) assess registration accuracy by comparing respective findings for a semimanual control point-based and an automated surface registration approach.

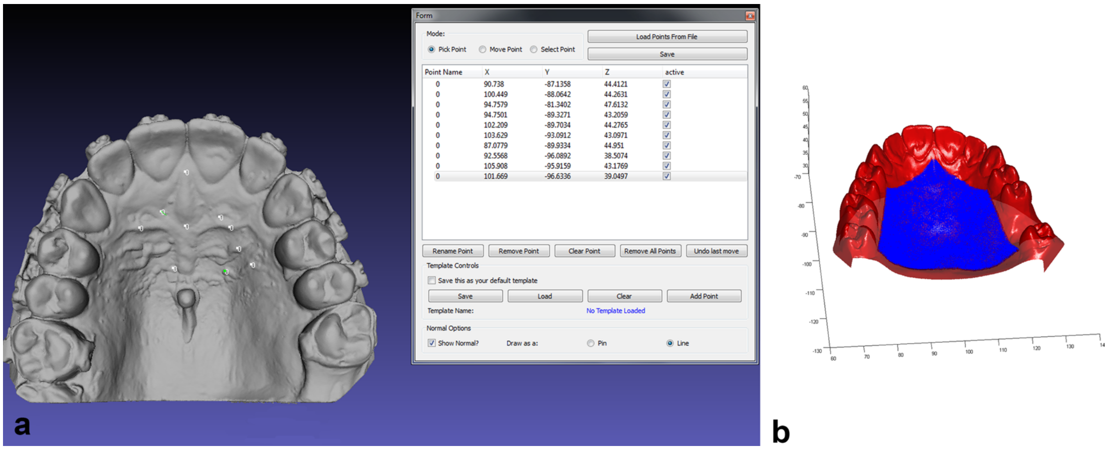

Fig. 1 **a** Illustration of the control point selection procedure with Meshlab. **b** Visualization of the standardized region of interest (ROI) for the iterative closest point (ICP) matching (*blue area*)

Abb. 1 **a** Darstellung des Kontrollpunkt-Selektionsverfahrens mittels Meshlab. **b** Visualisierung der standardisierten Überlagerungsregion (ROI) für das ICP("iterative closest point")-Verfahren (*blauer Bereich*)

Methods

Study design and samples

A retrospective, single-center study was performed with a sample size of 48 subjects (26 females, and 22 males). All subjects presented with an initial indication for upper molar protraction and completed treatment with (1) a unilateral Mesialslider appliance (UM), (2) a bilateral Mesialslider (BM) appliance, or (3) a Mesial-Distalslider (MD) appliance. All appliances were coupled with two mini-implants (PSM, Germany, USA) inserted into the anterior palate, and the orthodontic treatment had to be either fully completed or at least reached the retention phase.

Ethics approval to conduct the study was obtained (IRB no. 5075, Ethical Committee of the Medical Faculty, Düsseldorf University, Germany).

Subjects were excluded from the study on the basis of the following exclusion criteria: (1) existence of craniofacial syndromes, (2) systemic diseases or comorbidities, (3) moderate or severe periodontitis, or (4) pharmacotherapeutic exposure with possible effects on bone metabolism.

Demographic data

The chronological age and gender of each subject were recorded. The baseline status of the dentition (including the need for incisor alignment and the number of missing teeth), the treatment appliance used (unilateral Mesialslider, bilateral Mesialslider, or Mesio-Distalslider), and the treatment duration were recorded.

Dental casts

The dental casts of this study were made of plaster (Bon-Dur M, Wiegelmann Dental GmbH, Germany) and reflected the treatment situation prior to mesialization (T0) and after mesialization (T1), respectively.

Digitization of the dental casts

The casts were digitized using an optical laser scanner (Dentaurum Smart Optics Activity, Germany) and the software program Activity Orthodontics V2.7.04 (Dentaurum, Germany). After each scan, the option "hole filling" was enabled. Following this procedure, the resulting surface meshes were exported to the stereolithography (STL) file format.

Control point selection

Control points (CP) selection was performed manually using the "pick points" tool of the open source software program Meshlab (3D-CoForm project): ten CPs were selected on the palatal rugae and used for CP-based matching (Fig. 1a). Five landmark points bordered the standardized region of interest (ROI) for iterative closest point (ICP) matching (Fig. 1b). These points were located at the (1) incisal papilla, (2) gingival margin at the third rugae, and (3) gingival margin at the posterior margin of the hard palate.

In order to assess the tooth movements and incisor stability three-dimensionally, the papilla reference point was aligned with the coordinate origin, and an additional CP at the suture as well as the four reference points at the gingival margins were used to compute an optimal symmetric alignment of the models to the *x*, *y*-plane.

CPs at the molars of interest as well as on the mesial and distal aspects of the two central incisors served as dental reference points.

Fig. 2 Clinical photos of a Mesialslider anchored by two mini-implants: **a** unilateral Mesialslider, **b** bilateral Mesialslider, **c** Mesial-Distalslider

Abb. 2 Klinische Aufnahmen eines mit 2 Minimplantaten skelettal am anterioren Gaumen verankerten Minislider: **a** einseitiger Mesialslider, **b** beidseitiger Mesialslider, **c** Mesial-Distalslider

Image processing and registration

The image processing and surface registration was conducted using an in-house developed script in the mathematical computing environment Matlab (R2014a, The Mathworks, Natick, MA, USA). The T0 and T1 STL meshes were reduced to 40,000 faces in order to assure acceptable computing times and to have comparable resolution.

The digital models were aligned to the axes of the Cartesian coordinate system as described above by translating the papilla reference point to the origin and by performing a principal component analysis to assess the optimal rotation. Symmetric alignment to the *y*-axis was achieved using an additional reference point on the suture.

CP-based matching was performed using the approach described by Besl and McKay [4] and as implemented by Nghia Ho [13].

To achieve surface matching, vertices within the ROI were identified and a rigid kd-tree based ICP algorithm was applied (Matlab implementation by Kjer and Wilm [17]). After completion of the CP- and the ICP-based matching, the respective root mean squared (RMS) errors were calculated.

Computation of the orthodontic tooth movements

Following registration, distances between the T1 and T0 dental reference points yielded the respective 3D orthodontic tooth movement (OTM). The absolute OTMs were assessed by computing the Euclidean distances.

Statistical analysis

The statistical analysis was performed using the open-source software program R (Development Core Team). Simple descriptive statistics (mean, standard deviation, and frequency distributions) were used to summarize data. Initial tests for normality (assessment for skewness, kurtosis and Shapiro–Wilk) were performed to apply, where appropriate, parametric and nonparametric univariate analysis testing for the continuous variables. The linear association of corresponding tooth movements among the two matching approaches was tested using linear regression models (normality of the residuals and homogeneity of variance were tested in advance). All statistical tests were two-sided and a p value of ≤ 0.05 was considered to be statistically significant.

Results

Demographic and treatment characteristics

At the commencement of treatment, the chronological age of the subjects ranged from 11–53 years. Nine subjects were treated with a unilateral Mesialslider (UM) appliance (Fig. 2a), 28 subjects were treated with a bilateral Mesialslider (BM) appliance (Fig. 2b), and 11 subjects were treated with a Mesial-Distalslider (MD) appliance (Fig. 2c). The mean duration of slider treatment was 11.65 ± 7.55 months (UM: 9.33 ± 5.71 months, BM: 12.41 ± 7.92 months, MD: 10.72 ± 6.95 months).

Common indications for mesialization, or protraction of the dentition, was to close residual space to address the congenital absence of teeth or following the extraction of one or more teeth (42 subjects). The most frequently missing teeth were premolars (16 subjects), followed by incisors (14 subjects) and molars (12 subjects). In 6 subjects, mesialization was indicated due to multiple spacing or a need for dentoalveolar compensation of a Class III skeletal malocclusion.

Prior to the commencement of mesialization treatment, 20 subjects did not require preliminary incisor alignment (UM: 7, BM: 11, MD: 2) to be performed. The remaining 28 subjects needed comprehensive orthodontic treatment including preliminary incisor alignment. Since incisors of these patients were subject to orthodontic treatment during

Tab. 1 Descriptive statistics for the mesial movements of the first upper molars with the unilateral Mesialslider (**a**), the bilateral Mesialslider (**b** right molar, **c** left molar) and the Mesial-Distalslider (**d**) in transverse (T), anteroposterior (A), and vertical (V) direction. The total movements present the respective Euclidean distances. Sign convention: Anterior (+), posterior (−), palatal (+), buccal (−), extrusion (+), intrusion (−)

Tab. 1 Deskriptive Statistiken für die Mesialbewegung der ersten oberen Molaren mithilfe eines einseitigen Mesialsliders (**a**), eines beidseitigen Mesialsliders (**b** rechter, **c** linker Molar) und eines Mesial-Distalsliders (**d**) in transversaler (T), anteroposteriorer (A) und vertikaler (V) Richtung. Die absoluten Zahnbewegungen wurden mittels euklidischer Distanz berechnet. Vorzeichenkonvention: anterior (+), posterior (−), palatinal (+), Bukkal (−), Extrusion (+), Intrusion (−)

	T	*A*	*V*	Total
(a)				
Mean	0.06	4.88	1.12	6.03
Standard deviation	2.19	2.39	2.48	2.01
25th percentile	−0.29	4.24	−0.90	5.35
Median	−0.02	4.65	0.98	6.01
75th percentile	1.75	5.60	2.40	6.72
(b)				
Mean	0.61	5.57	−0.26	6.32
Standard deviation	2.52	2.43	1.58	2.43
25th percentile	−1.02	3.35	−0.92	4.34
Median	1.40	6.01	−0.13	6.36
75th percentile	2.59	7.58	0.50	8.12
(c)				
Mean	−0.65	5.62	0.25	6.60
Standard deviation	2.39	3.15	2.17	2.90
25th percentile	−2.32	3.50	−0.95	4.42
Median	−0.99	5.29	−0.06	6.28
75th percentile	1.19	7.47	1.29	8.40
(d)				
Mean	0.50	5.44	−0.67	5.93
Standard deviation	2.22	3.01	1.17	3.16
25th percentile	−0.26	2.81	−0.99	2.89
Median	0.48	6.42	−0.60	6.92
75th percentile	1.40	7.50	0.06	8.29

mesialization, only molar displacements were assessed for these patients.

Orthodontic tooth movements

Total molar movements were 6.3 ± 2.6 mm (anteroposterior: 5.5 ± 2.7 mm, vertical: 0.0 ± 1.9 mm, transverse 0.1 ± 2.7 mm). The total molar movements were comparable among all groups (Table 1). Among the 20 subjects with satisfactory incisor position prior to treatment, incisor displacement was below 0.5 mm in the transverse, anteroposterior, and vertical directions (Table 2).

Tab. 2 Pooled descriptive statistics for the movements of the first upper (**a**) right and (**b**) left incisors in transverse (T), vertical (V), and anteroposterior (A) direction. The total distances denote the respective Euclidean distances

Tab. 2 Gepoolte deskriptive Statistiken für die Bewegungen der ersten oberen rechten (**a**) und linken (**b**) Inzisiven in transversaler (T), vertikaler (V) und anteroposteriorer (A) Richtung. Die absoluten Zahnbewegungen wurden mittels Euklidischer Distanz berechnet

	T	*A*	*V*	Total
(a)				
Mean	0.1	0.5	−0.1	1.9
Standard deviation	0.9	1.3	1.5	1.0
25th percentile	−0.6	−0.4	−0.9	1.1
Median	−0.1	0.4	0.1	1.7
75th percentile	0.5	1.1	1.0	2.5
(b)				
Mean	−0.1	0.4	−0.2	1.9
Standard deviation	0.9	1.2	1.5	0.9
25th percentile	−0.7	−0.4	−1.0	1.3
Median	−0.3	0.5	−0.1	1.8
75th percentile	0.3	1.3	0.8	2.3

Tab. 3 Descriptive statistics for the root mean squared (RMS) errors for control point (CP)-based registration and for iterative closest point (ICP) matching

Tab. 3 Deskriptive Statistiken für die RMS(mittleren quadratischen)-Gesamtfehler für das CP(Kontrollpunkt)- und das ICP("iterative closest point")-Verfahren

	Control points	ICP
Mean	0.8	0.8
Standard deviation	0.4	0.3
25th percentile	0.6	0.6
Median	0.8	0.7
75th percentile	1.0	1.0

Alignments of the models

Consistent alignment of the digital models taken prior to commencement of mesialization to the Cartesian *x*, *y*-plane and coordinate origin was completed successfully for all models. Subsequent rotation of the models such that the palatal suture coincided with the negative aspect of the Cartesian *y*-axis enabled a three-dimensional evaluation of orthodontic tooth movements.

Registration results

The registration approaches showed comparable root mean square (RMS) errors in the range of 0.6–1.0 mm, and a slight median reduction by 0.1 mm was observed following the automated surface matching (Table 3). Visual

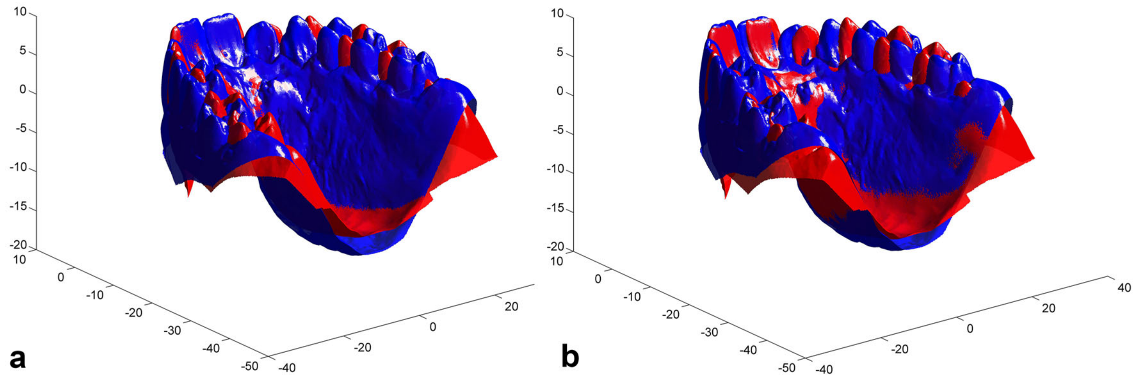

Fig. 3 Exemplary visualization for comparable registration outcomes using **a** the control point (CP)-based approach and **b** an iterative closest point (ICP) matching (color convention: T0 casts *red*, T1 casts *blue*)

Abb. 3 Beispielhafte Visualisierung für vergleichbare Überlagerungsresultate mithilfe einer **a** CP(Kontrollpunkt)-basierten Registrierung und **b** einem ICP("iterative closest point")-Verfahren (Farbkonvention: T0-Modelle *rot*, T1-Modelle *blau*)

examination corroborated comparable registration for most of the models, or slight improvement of the registration outcome (Fig. 3). Visual impairment of registration accuracy following ICP was observed for one patient with major molar intrusion (Fig. 4). When correlating congruent tooth movements, significant linear association was noted between the two registration approaches (Fig. 5). However, regression coefficients were not equal to one. Hence, registration outcomes were not perfectly identical despite the comparable RMS errors.

Discussion

The present study aimed to assess the three-dimensional molar movements and stability of incisors for subjects treated with a skeletally anchored mesialization appliance using superimposed digital models. Furthermore, it aimed to evaluate agreement between two different matching approaches, i.e., a semimanual CP-based registration and an automated surface registration through ICP matching. Therefore, the RMS errors were compared and tests for linear association of the corresponding orthodontic tooth movements (OTM) were performed.

When assessing the molar movements, the greatest tooth movement occurred in anteroposterior direction, and only minor vertical movements were found. This finding is consistent with another study comparing mini-implant anchored mesialization with mini-plate and headgear anchored protraction of the posterior segment, which found slight bodily intrusion for mini-implant anchorage, slight mesial tipping and intrusion for the headgear group, and significantly higher intrusion for mini-plate anchorage [18].

Anchorage control was evaluated by assessing the amount of maxillary incisor displacement following Mesialslider appliance treatment. In all directions investigated, incisor displacement was below 0.5 mm. This outcome points at a very minimal degree of displacement and, thus, clinically stable anchorage.

When quantifying computed tooth movements from digitally registered digital models, accurate and consistent alignment of the digital casts to the Cartesian coordinate system is indispensable. An accurate alignment of digital models to the Cartesian origin and the unit vectors by means of a principal component analysis has been described by Ashmore et al. [2]. Whereas this procedure appeared promising and was successfully repeated in the present study, one modification was necessary. The occlusal plane might not be stable during molar protraction. Hence, reference points at the gingival margin were used instead to achieve alignment with the Cartesian *x*, *y*-plane.

If tooth movements are computed following registration of digital models, it has to be noted that these results can be directly affected by the errors of the alignments. Alignment errors, in turn, may result from anatomical changes over time, or because the matching algorithm gets stuck in local optima.

Since teeth are displaced during orthodontic treatment, their characteristic shape cannot be employed for registration purposes. Hence, the soft-tissue coverage of the palate is the only structure available to achieve alignment. Whereas manual reference point selection usually considers recognizable aspects of the rugae, surface-matching approaches would rather concentrate on curvatures of the palate and the overall rugae shape.

Both approaches have been applied in previous studies: Choi et al. [7] simulated tooth movements and registered identical models based on the palatal rugae area using an automated surface-matching approach. Later, the same procedure was replicated for digital models from patients treated with maxillary expansion (RME) and maxillary protraction headgear. Outcomes were compared to congruent findings assessed from superimposed lateral

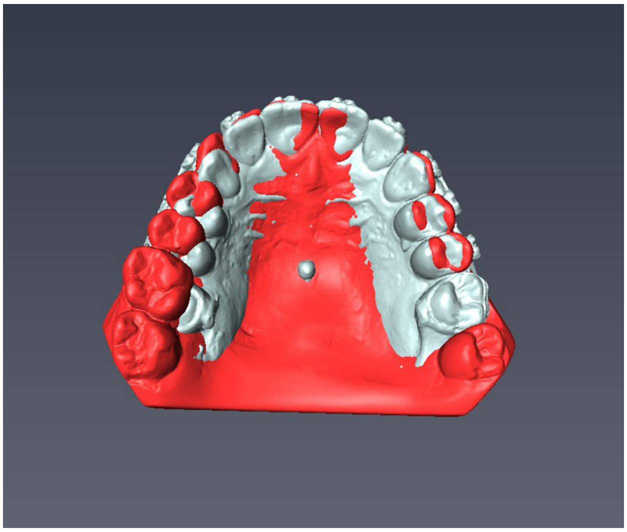

Fig. 4 Registration result (control point [CP]-based registration) for a patient treated with a bilateral mesial slider and simultaneous molar intrusion (color convention: T0 cast *red*, T1 cast *grey*), which was visualized with Amira (v6.1). Unilateral mesialization by a molar width was possible without anchorage loss (stable incisor positions)
Abb. 4 Registrierungsergebnis (CP[Kontrollpunkt]-basierte Registrierung) für einen mit einem beidseitigen Mesialslider und simultaner Molarenintrusion behandelten Patienten (Farbkonvention: T0-Modelle *rot*, T1-Modelle *blau*), die Visualisierung erfolgte mittels Amira (v6.1). Eine ausschließliche Mesialisierung um eine Prämolarenbreite im zweiten Quadranten war ohne Verankerungsverlust möglich (stabile Inzisivenpositionen)

cephalograms [8]. Whereas a high correlation was reported for anteroposterior tooth movements, changes of the palatal slope during RME appeared to be problematic. Another study performed manual selection of reference points on the palatal rugae to achieve alignment and reported errors for manual rugae point selection among corresponding models to be in the range of 0.25–0.56 mm [2]. Based on this finding, the present study considered 10 reference points necessary to average out reference point selection errors. Prior to the start of the present study, our group added different amounts of random noise to the T0 models and noticed convergence of the registration error with 10 CP [3].

Despite these principal findings, none of the previous studies detailed the actual registration errors. To interpret outcome validity, knowing the respective errors appears indispensable. The present study identified comparable median registration errors of 0.7–0.8 mm for the semi-manual CP-based and automated surface-matching approach, with a slight median improvement when using the latter approach. The errors might be caused by anatomical changes over time and may not correspond exactly to the imprecision of the computed tooth movements. However, the registration errors indicate an accuracy limit for the registration of digital models. Although significant correlation was found for the respective tooth movements, the correlation coefficients did not equal one.

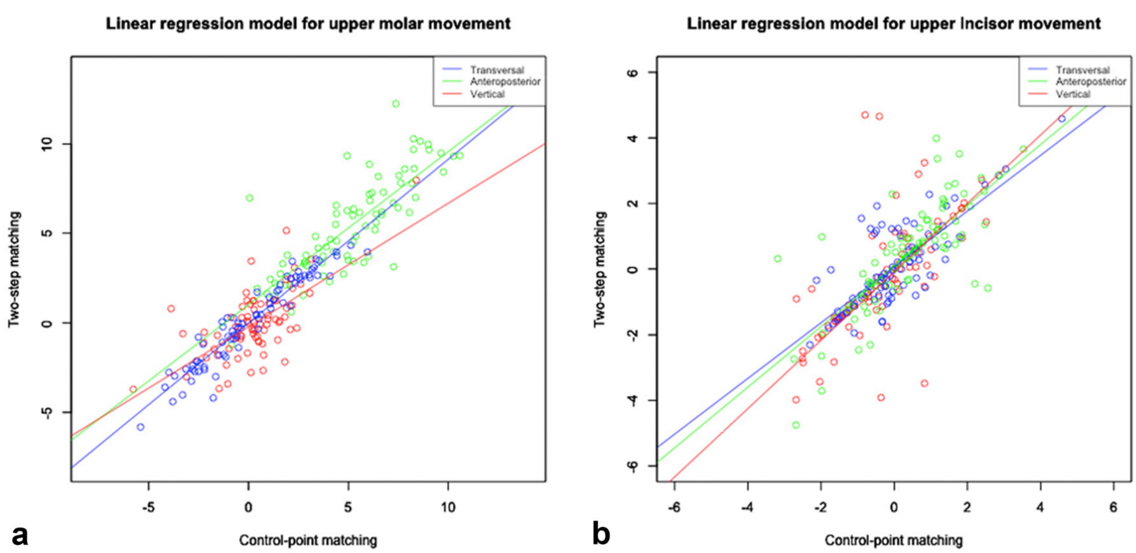

Fig. 5 Linear regression analysis was used to assess agreement of orthodontic tooth movements (OTM) for first upper molars (**a**) and incisors (**b**) computed with an iterative closest point (ICP) matching. Molar ($R_{transverse} = 0.91$, $R_{anteroposterior} = 0.85$, $R_{vertical} = 0.69$) and incisor ($R_{transverse} = 0.85$, $R_{anteroposterior} = 0.92$, $R_{vertical} = 1.04$) movements were significantly correlated in all three directions ($p < 0.01$)
Abb. 5 Eine lineare Regressionsanalyse wurde verwendet, um die Übereinstimmung der mit beiden Registrierungsverfahren ermittelten Zahnbewegungen für die ersten oberen Molaren (**a**) und die mittleren Inzisiven (**b**) zu prüfen. Für die Molaren- ($R_{transversal} = 0{,}1$, $R_{anteroposterior} = 0{,}85$, $R_{vertikal} = 0{,}69$) und die Inzisivenbewegungen ($R_{transversal} = 0{,}85$, $R_{anteroposterior} = 0{,}92$, $R_{vertikal} = 1{,}04$) zeigte sich eine signifikante Korrelation ($p < 0.01$) in jeder untersuchten Raumrichtung

This points at a not perfectly identical registration for the two algorithms, even though the actual final registration errors were likewise.

Conclusion

Our study demonstrated that a 10 CP-based and an automated surface-matching approach both allow for comparable registration and measurement of tooth movements. However, potential registration errors should be considered when interpreting the outcomes. The Mesialslider appliance proved to be a suitable approach to achieve maxillary molar protraction without clinically relevant maxillary incisor displacement.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests related to this study.

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