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Evolution of root length throughout orthodontic treatment in maxillary incisors with previous history of dental trauma: a longitudinal controlled trial

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Abstract

Objectives: To compare changes in root length of maxillary incisors with and without dental trauma throughout orthodontic treatment.

Materials and method: Patients younger than 18 years, with trauma on at least one maxillary incisor, undergoing orthodontic treatment between 2017-2021 were included, using the contralateral side as control without trauma when available. Periapical radiographs were taken pre-treatment and at 6 months intervals and root/crown ratio was calculated. Linear mixed models were used to describe the evolution of root length at the different time points and to compare trauma and control values. Differences between central and lateral incisors and between treatment modalities were additionally explored.

Results: 1768 measurements were performed on 499 teeth (201 with trauma) in 135 patients. Incisor root length significantly decreased during orthodontic treatment in teeth with and without trauma. Lateral incisors with trauma were more susceptible to root resorption than those without trauma and central incisors. No significant decrease in root length was observed with removable appliances, which never exceeded 15 months of treatment. Treatment with fixed appliances led to gradually increasing, significant root length shortening in teeth with and without trauma.

Conclusion: Treatment duration directly correlated with root length shortening both in teeth with and without trauma history. Teeth with trauma showed significantly more root resorption after treatment with fixed appliances while removable appliances had no significant influence on root length.

Clinical relevance: Previous history of dental trauma is no absolute contra-indication to start orthodontic treatment, as long as treatment duration is kept as short as possible.

Keywords

Tooth injuries, dental trauma, root length, orthodontics, fixed appliances, root resorption

Introduction

Dental trauma is highly prevalent. Literature reports that 13.5% of European children experience a traumatic injury to their permanent teeth before becoming 12 years old[1]. Almost 10% of children seeking orthodontic treatment has a history of trauma to one or more permanent incisors[2]. Dental trauma has been linked to pulp necrosis and obliteration, tooth ankylosis and external root resorption[3]. However, its relation with orthodontics, especially regarding root resorption, remains understudied.

Root resorption is a widely recognized phenomenon that consists of progressive loss of dentine and cementum through the continued action of osteoclastic cells[4]. It is a physiological process in primary/mixed dentition but pathological in the permanent dentition, where it can be induced by pulpal or periodontal infection, orthodontic forces, tooth impaction, tumor pressure, ankylosis or trauma[5]. External inflammatory resorption due to trauma can occur when traumatic forces damage the external surface of the root, leading to cementum loss, or if the pulp becomes infected after exposure to bacteria. The traumatic injuries most often linked to root resorption are avulsion, intrusion, lateral luxation and extrusion with crown fracture. Root resorption can occur immediately after trauma or at a later time, often in absence of signs or symptoms[6].

Orthodontically induced external apical root resorption (OIEARR)[7] is a well-documented form of resorption that begins at the root surface as a result of odontoclastic activity in the apical area. It presents a progressive character whose etiology and pathogenesis are not fully known[8]. In most orthodontic patients, root shortening varies from 6-13% or 0.45-1.5 mm, which is considered as minor to moderate[9-12]. OIEARR is a complex and multifactorial condition that can be induced by factors related to individual biologic variability, genetic predisposition and mechanical factors. Orthodontic risk factors have been widely discussed in literature and include treatment duration[13], the magnitude of the applied force, the direction of tooth movement, the amount of apical displacement and the method of force application[9, 13]. Patient-related risk factors include history of root resorption, root length and morphology (short, blunt, apical bend or pipette-shaped roots[14]), systemic factors (including medication), root proximity to the cortical bone, alveolar bone density, endodontic treatment, severity and type of malocclusion, age and sex, among others[9].

Despite the available evidence, the influence of orthodontic treatment on teeth with previous history of dental trauma is not yet understood, especially not in the long-term. Although OIEARR can affect any tooth, the upper incisors are the most often affected and coincidentally also the ones most prone to dental trauma[15]. Since most patients with trauma to the incisors need orthodontic treatment, especially when one or more teeth have bad prognosis, prospective research in this field is essential to determine whether previous dental trauma increases the risk of OIEARR.

This controlled clinical trial aims to investigate the evolution of root length in upper incisors with previous history of trauma throughout orthodontic treatment, by comparing them with a group of teeth without dental trauma.

Materials and methods

Ethical considerations

The protocol of this study was defined prior to the start and was approved by the Medical Ethics Committee of the University Hospitals Leuven with registration number S60097. The study was conducted in accordance to the principles of the Helsinki declaration. Informed consent was obtained from all involved subjects as well as from their parents/guardians if applicable.

Study population and inclusion criteria

All individuals attending the Department of Orthodontics of University Hospitals Leuven between 2017 and 2021 and complying with the following selection criteria were invited to participate in the study: healthy patients with history of dental trauma on at least one definitive upper front tooth (12-11-21-22), younger than 18 years old at the start of orthodontic treatment, receiving treatment at the Department mentioned above. Data of patients who received less than 6 months of active orthodontic treatment were excluded from further examination. Patients were treated by different orthodontists in training, always under supervision of an experienced orthodontist.

Data collection and analysis

Initial orthodontic records included collection of the following data: (1) General Information (date of birth, sex, dental and medical anamnesis), (2) Trauma History (date, circumstances and location of the trauma, involved teeth, type of trauma (hard tissue, pulp or periodontal bone trauma) developmental stage of the roots and dental treatment after trauma), (3) Orthodontic Data (assessment of the facial profile (straight, convex, concave), nasolabial angle, lip relation, molar and canine occlusion, overjet, overbite, skeletal relation and presence of oral habits such as nail biting or tongue thrust).

The radiological images taken at this point consisted of a panoramic, cephalometric and periapical radiograph (the latter only from the teeth involved in the trauma and two adjacent teeth).

Dental trauma was classified into 2 categories, namely hard tissue/pulp damage and periodontal/alveolar bone damage. Annex 1 shows an overview of the subdivisions of these two categories (A) as well as a list with the parameters recorded during and after orthodontic treatment, along with their scoring method (B, C).

Quantitative assessment of root resorption

At the beginning and end of orthodontic treatment, as well as approximately every 6 months during treatment, a periapical radiograph of the teeth affected by trauma was taken, including the adjacent upper incisors. On those periapical radiographs, measurements of the root and crown length were performed for all imaged teeth by using Adobe Photoshop CS6 64 bit (San José, California, USA). To avoid bias due to magnification[16], root and crown length of the present teeth (with trauma and adjacent) was measured in pixels. The root/crown ratio was then determined, assuming constant crown length over the observation period. The distance between the mid-incisal point of the crown and the midpoint of the cementoenamel junction was considered as the crown length. The distance between the midpoint of the cementoenamel junction and the most apical point of the root was considered the root length. These measurements were performed according to the protocol described by Brezniak et al[16, 17]. Periapical radiographs with low quality, obvious distortion, or failing to show the complete crown and root were discarded.

The date of each periapical radiograph was used to create a continuous overview over time, instead of the 6 months interval, of the decreasing root/crown ratio. No measurements were performed in case of incomplete root formation.

Comparisons among groups

Root length was compared within the following groups:

1. All central and lateral upper incisors with history of dental trauma were compared to their contralateral teeth without damage, after confirming they were not involved in the trauma. The latter teeth are further designated as controls.
2. Central incisors were compared with lateral incisors, with and without trauma.
3. Incisors were also grouped according to the type of orthodontic treatment received:
    a. Removable appliances: this included functional appliances such as headgear, activator or standard removable appliances. None of the included patients were treated with clear aligners.
        i. Treatment with removable appliances only. This kind of treatment was always finished before 15 months.
        ii. Subjects starting with removable appliances and getting fixed appliances afterwards, these were analyzed separately.
    b. Treatment with fixed appliances only. Fixed appliance treatment was performed with conventional metallic brackets with Roth.018” prescription. The wire sequence used was: alignment and levelling with NiTi wires (0.014 - 0.016 - 0.016x0.016 and 0.016x0.022),

followed by stainless steel (0.016x0.016 or 0.016x0.022) as working wire and finishing with 0.016x0.022 multiloop arches.

Statistical analysis

Linear mixed models were used to describe the evolution of maxillary central and lateral incisor root length. The models contained random intercepts for subject and for tooth (nested within subject). The analysis was performed on log-transformed ratios, since ratio units are not equidistant. Predicted evolutions with 95% confidence intervals were obtained after back transformation to the original scale. Restricted cubic splines (with four knots) were used to allow a nonlinear relation. P-values smaller than 0.05 were considered significant. No corrections for multiple testing were applied.

The intra-observer reliability of the crown and root measurements and of the ratios was visualized using a Bland-Altman plot. The intra-class correlation and within-subject standard deviation derived from a two-way random effects model were reported. Note that the reliability of the ratio was evaluated on the log-scale. The evaluation of the intra-observer reliability was performed on pooled data from the different teeth. Comparison of the measurements was established by having the same examiner take measurements twice on 10 patients (in total 43 radiographs) randomly selected.

In absence of evidence regarding linearity of root resorption, non-linearity was allowed. All analyses were performed using SAS software, version 9.4 of the SAS System for Windows.

Results

In total, 169 patients with previous history of dental trauma were prospectively recruited between 2017 and 2021. From these, 34 were excluded due to several reasons, such as missing appointments, treatment drop out or extraction of the trauma tooth. The final sample consisted of 135 patients who were longitudinally followed up. In total, 1768 measurements were performed on 499 teeth. The demographic data of the included patients can be found in Table 1. In Table 2, an overview of the prevalence of the different types of dental trauma is presented. Intra-class correlation for the repeated measurements of the root/crown length ratio showed a high intra-observer agreement (ICC 0.990 (95%CI: 0.984;0.993)). Annex 2 shows the Bland-Altman plot for root/crown ratio (A), root length (B) and crown length (C). Since a complete lack of evidence was found (Spearman rho=-0.02, P = 0.4912) for a relation between the age at the start of treatment and the (log) ratio, no correction for differences in age was considered.

Root length over time

Figure 1 shows the evolution of root/crown length ratio in incisors with and without trauma, while the group differences in root/crown length ratio over time are presented in Table 3. In Table 4 the mean root/crown length ratios per group at start and after 36 months of treatment are shown.

Incisor root length decreased significantly through orthodontic treatment in both teeth with and without trauma (P < 0.0001, Fig. 1a and 1b). Incisors without previous trauma history seem to start with a slightly longer root than those with trauma, but these baseline differences are non-significant.(Table 3). Root shortening, however, evolves in the same way than in trauma teeth (Fig. 1c).

Comparison maxillary incisors

Central incisors with and without trauma history showed similar root shortening through the 36 months of orthodontic treatment (P = 0.9531, Fig. 1d). In contrast, lateral incisors with trauma seem to be more susceptible to root resorption than lateral incisors without trauma (P = 0.0318, Fig. 1e). The reaction of central and lateral incisors is further explored in Figure 2. The accompanying P-values are presented in Table 3. No significant differences were found between central and lateral incisors with or without trauma (Fig. 2b, 2c). Only if all incisors were compared, lateral incisors showed more root shortening throughout orthodontic treatment, but the result was just in the significant range (P = 0.0496, Fig. 2a)

Removable versus fixed appliances

The evolution of root/crown length ratio in patients treated with removable appliances (group 3a) compared to patients treated with fixed appliances (group 3b) can be found in Figure 3. Incisors with and without trauma treated with removable appliances do not present a significant decrease in root length during treatment in contrast to incisors treated with fixed appliances. (P < 0.0001, Fig. 3a, 3b). Treatment exclusively with removable appliances never lasted longer than 15 months (group 3ai). Some patients received further treatment with fixed appliances afterwards (group 3aii). Group 3a and 3b are compared in Figure 3c, which shows less root shortening with time in the group starting with removable appliances followed later by fixed appliances, compared to those treated with fixed appliances from the beginning (P = 0.0013). When analyzing teeth with and without trauma separately, significantly more root shortening was found in incisors with trauma in patients treated with fixed appliances compared to removable (P < 0.0001, Fig. 3d). This difference was not seen in teeth without trauma (Fig. 3e).

Treatment duration

Figure 4 represents the evolution of root length in incisors with and without trauma according to the type of orthodontic treatment received (only removable appliances or only fixed appliances) for the first 18 months. Data in the removable appliance group, from the moment fixed appliances are placed, are excluded from this comparison. No significant differences were found when taking all incisors in consideration (Fig. 4a), nor for controls or teeth with trauma separately (Fig. 4b, 4c).

Discussion

This study longitudinally followed up 135 patients with history of dental trauma on one or more permanent maxillary incisors. In these patients, the evolution of root length of maxillary central and lateral incisors throughout orthodontic treatment was investigated and compared between teeth with and without dental trauma, additionally exploring potential differences according to the type of incisor or orthodontic treatment received.

In order to determine root length, both crown and root were measured on periapical radiographs and the root/crown ratio was used for comparison with subsequent time points. A simple subtraction of the root or tooth length on periapical films before and after treatment would be inaccurate, since the angulation on which the image was taken can lead to shortening or elongation[17]. Assessment of the amount of root length loss on buccal and lingual surfaces was not possible on the 2D radiographs; 3D cone beam CT would have been more accurate to measure the changes in root volume over time[10, 16, 17]. However, this technique is not applicable for repeated longitudinal follow up of growing individuals, due to higher radiation doses. Literature shows that periapical radiographs are more advantageous than panoramic or lateral cephalometric radiographs to measure root length, because they do have fine details and less distortion, especially for incisors[18, 19]. In order to establish the root/crown ratio, the midpoint of the cementoenamel junction was used to distinguish crown and root length. This point is a stable one, not normally subjected to distortion[16]. However, the possible effects of bending the upper part of the film against the palate may have had an effect on the measured lengths, which could explain some of the oscillations seen in the results (Fig. 1e).

Root length was observed to significantly decrease throughout orthodontic treatment in almost every maxillary incisor involved in this study, disregarding its history of trauma ($P < 0.0001$), as previously reported by other authors[14, 20, 21]. Orthodontic treatment is therefore an important risk factor for incisor root resorption, as already mentioned in literature[9, 22]. Although not significant, incisors with trauma seem to present slightly shorter roots than controls before treatment but root shortening evolves in the same way throughout treatment in both groups. Also, lateral incisors with trauma history seem to be more susceptible to root resorption than those without, which was not observed for central incisors. In contrast, no difference was found in the reaction of central versus lateral incisors with or without trauma. Only if all incisors are compared, it can be observed that lateral incisors undergo more root resorption throughout orthodontic treatment, although this result was only just in the significant range. To this regard, literature is somewhat contradictory. While Sameshima et al [19] also found more resorption in lateral incisors than in central incisors, Remington et al [23] found the central incisor to undergo more root resorption over time during orthodontic treatment. Upper central incisors are known to be most affected by trauma, especially in patients with retruded position of the lower jaw and/or increased overjet, since these are the most prominent teeth [9]. Most patients with history of dental trauma present a skeletal class II relationship with accompanying distal occlusion [2]. Lateral incisors are less often affected with dental trauma. In our study, only 26 lateral incisors with trauma were included (in contrast to 175 central incisors) and no subdivision into the different kinds of trauma was made. Due to this small sample, the significant results of the lateral incisors with trauma have to be interpreted with caution.

Group 3b (treated with fixed appliances only over a period of 36 months) was compared with group 3aii (starting with removable and followed by fixed appliances). A significant decrease in root length was observed in both groups. However, with the same length of treatment, significantly less root shortening was found in incisors with trauma in patients starting with removable appliances followed by fixed appliances compared to the use of fixed appliances from the beginning. The use of removable appliances often involves functional therapy in order to first correct a sagittal and/or vertical discrepancy, often also meaning a shorter treatment time with fixed appliances. This can guide alveolar growth and eruption in the right direction and reduce the need for orthodontic compensation of skeletal discrepancy, which often results in more incisor displacement. In most cases, treatment with removable appliances does not involve exertion of direct forces on the incisors, in contrast to what happens with fixed appliances[24]. On the other hand, removable appliances exert intermittent forces (the force drops to zero when the appliance is removed)[25] while fixed appliances apply continuous forces, which have been argued to induce more resorption [26, 27].

To further test the effect of treatment duration versus treatment modality on root length of teeth with and without trauma history, incisor root length of patients treated only with removable appliances versus fixed appliances was compared only for the first 18 months, since treatment with removable appliances was generally shorter. Interestingly, no significant differences were found when taking all incisors in consideration, neither for teeth with or without trauma separately, which suggests time (or duration of orthodontic treatment) to influence root shortening more than the trauma history itself, the type of tooth or even the treatment type. After 18 months, root length shortens more with fixed appliances. Despite the fact that most movement of teeth with fixed appliances happens during early phases, when leveling and space closure take place[26], in our sample, resorption did gradually increase further over time. The influence of orthodontic treatment duration on root resorption has been widely discussed in literature. DeShields et al and Linge et al [10, 20] also reported a statistically significant correlation between root resorption and orthodontic treatment length, while Levander and Malmgren [28] found no significant association. Apajalahti et al[29], found a significant correlation between root resorption and fixed appliances as well as influence of treatment duration on root shortening. Nevertheless, most of the available studies measured root length only at the beginning and end of treatment, often on panoramic radiographs[23, 30]. According to Yassir et al, 2021 [9] ‘avoiding heavy, continuous forces and apical displacement over a long treatment is recommended’. This enforces our conclusion regarding treatment duration, even in teeth without trauma. This systematic review, and that of Weltman et al, 2005 [7], also highlight the lack of high quality research regarding root resorption in orthodontically treated teeth with previous trauma. In this sense, we believe our prospective clinical trial to be able to provide more robust evidence than previous retrospective studies in smaller samples.

However, our study design also presents some limitations worth mentioning. First, despite the prospective design and more than 4 years of follow-up, subdivision of the sample into different types of trauma was not possible. This would have potentially allowed for comparison between endodontically treated and non-treated trauma teeth, since research has shown that treated teeth show less resorption[3]. Next, for all teeth, the crown length was assumed to stay unchanged over the observation period, but sometimes a new restoration was done during treatment, which will lead to a slightly different crown length. Also no information was present regarding repeated trauma in the same patient. The particularities of orthodontic treatment were not further explored either. This can have an impact on root length, since literature reports intrusion or space closure after extraction to correlate with more resorption[31-33]. Most of the patients in this study presented with a class II malocclusion which needed sagittal correction. This resulted in 16 cases with premolar extractions in the upper jaw and 39 patients treated with functional appliances for Class II/2. As mentioned before, these therapies can induce more root resorption due to increased tooth movement of the upper incisors. Lastly, the mean age of the patients at start at dental trauma was 9.99 years-old, while literature reports the highest prevalence of dental trauma to be between 11-15 years[2]. However, immature maxillary incisors were excluded because it is impossible to do correct measurements therefore no follow-up is present and the influence of orthodontic treatment on these teeth could not be evaluated.

Conclusion

1. The root length of maxillary incisors with and without trauma decreased significantly during orthodontic treatment.
2. Upper lateral incisors with trauma seem to be more susceptible to orthodontic root resorption than lateral incisors without trauma and central incisors with and without trauma. However, the sample size of upper lateral incisors with trauma was the smallest.
3. Upper incisors with and without trauma treated with both removable and fixed appliances presented a significant decrease in root length along orthodontic treatment. However, significantly more root shortening was seen in incisors with trauma in patients treated with fixed appliances compared to removable ones. This difference was not found in teeth without trauma.

4. Less root shortening with time was observed in patients starting with removable appliances followed by fixed appliances compared to those treated with fixed appliances from the beginning.
5. When comparing patients treated with removable appliances only versus fixed appliances in the first 18 months, no significant differences were found when taking all incisors in consideration, nor for teeth with or without trauma separately, which suggests time (duration of orthodontic treatment) to be the factor influencing root shortening the most, over tooth or treatment type.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Medical Ethics Committee of the University Hospitals Leuven with registration number S60097

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to privacy policies of the University Hospitals Leuven but are available from the corresponding author on reasonable request.

Consent for publication

Not applicable

Competing interest

The authors certify no competing interest with respect to the authorship and/or publication of this article.

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Author contributions

Sofie Fivez, Feline Smeyers, Gertrude Van Gorp, Maria Cadenas de Llano-Pérula, Dominique Declerck, An Verdonck and Guy Willems designed the study protocol. Feline Smeyers and Sofie Fivez collected the patient data. Feline Smeyers performed measurements, analyzed and interpreted the patient data. Steffen Fieuws analyzed and interpreted the patient data. Feline Smeyers wrote the manuscript. Maria Cadenas de Llano-Pérula, Guy Willems, Sofie Fivez, Gertrude Van Gorp, An Verdonck, Giacomo Begnoni, Steffen Fieuws and Dominique Declerck revised all manuscript versions critically for intellectual content. All authors read and approved the final manuscript to be submitted and are in agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work will be appropriately investigated and resolved.

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Tables

Table 1. Characteristics of the included patients and teeth

Variable (unit)	N (%)	SD	Range
Total patients	135		
Active treatment	63		
Finished	72		
Female	63		
Male	72		
Trauma central incisor	129		
Trauma lateral incisor	24		
Number of patients according to treatment			
Only removable appliances	15		
Of which functional appliances	11		
Removable + fixed appliances	78		
Of which functional appliances	67		
Of which first upper premolar extraction	1		
Only fixed appliances	57		
Of which first upper premolar extraction	15		
Mean age (years)			
Dental trauma	9.99	2.5	
Start orthodontic treatment	12.89	1.6	
End orthodontic treatment	15.14	1.9	
Treatment duration (months)	28.79	9.6	
Removable + fixed appliances	29.02	10.7	
Only fixed appliances	28.28	7.2	
Skeletal relation			
Class I	41 (30.4%)		
Class II	90 (66.7%)		
Class III	3 (2.2%)		
Not registered	1 (0.7%)		
Occlusion (mm)			
Overbite	3.93	1.9	-2 – 9
Overjet	5.21	2.5	1 – 12
Total teeth			
Included	499		
Extracted with trauma	64		
Removable + fixed appliances	299		
- *With trauma*	171		
Only fixed appliances	200		
- *With trauma*	135		

Table 2. Frequency distribution of the different types of dental trauma

	Hard tissue/pulp			Periodontal/alveolar bone			Teeth		
	Total patients	*Uncomplicated*	*Complicated*	*Total patients*	*Minor*	*Major*	*Total*	*Trauma*	*Control*
Central	108 (78.83%)	88	20	71 (51.83%)	35	36	244	175	69
11	73 (53.67%)	63	10	56 (40.88%)	29	27			
21	79 (57.67%)	64	15	57 (41.61%)	32	25			
Lateral	13 (9.56%)	12	1	18 (13.24%)	9	9	255	26	253
12	10 (7.36%)	9	1	15 (11.03%)	6	9			
22	5 (3.68%)	5	0	11 (8.09%)	7	4			
Teeth	153	131	22	108	72	36	499	201	298

Note: Uncomplicated dental trauma: involving enamel or enamel and dentin. Complicated dental trauma: involving also the dental pulp

Table 3. Group differences in root/crown length ratio over time.

	P- value	**P-value intercept**	**P-value evolution**	**Corresponding Figure**
Trauma vs no trauma				
All teeth	0.1901	0.2366	0.3911	Fig 1 C
Central incisor	0.9531	0.9769	0.8888	Fig 1 D
Lateral incisor	0.0318*	0.2660	0.0606	Fig 1 E
Central vs lateral incisor				
All teeth	0.0496*	0.1343	0.1259	Fig 2 A
Control	0.1963	0.2602	0.2387	Fig 2 B
With trauma	0.1050	0.6431	0.0740	Fig 2 C
Fixed vs removable				
All teeth	0.0013*	0.3239	0.0029*	Fig 3 C
Control	0.3433	0.1379	0.8001	Fig 3 E
With trauma	<0.0001*	0.8923	<0.0001*	Fig 3 D
Fixed vs removable first 18 months				
All teeth	0.4620	0.5897	0.3233	Fig 4 A
Control	0.4884	0.2410	0.4012	Fig 4 C
With trauma	0.5025	0.8847	0.3455	Fig 4 B

Note: “P-value” refers to the test for any difference (intercept and/or evolution), “P-value intercept” reflects whether there is any difference in ratio at the start of treatment, “P-value evolution” indicates if there is a difference in the evolution of the ratio over time. Values of $P < 0.05$ are marked with an asterisk (*)

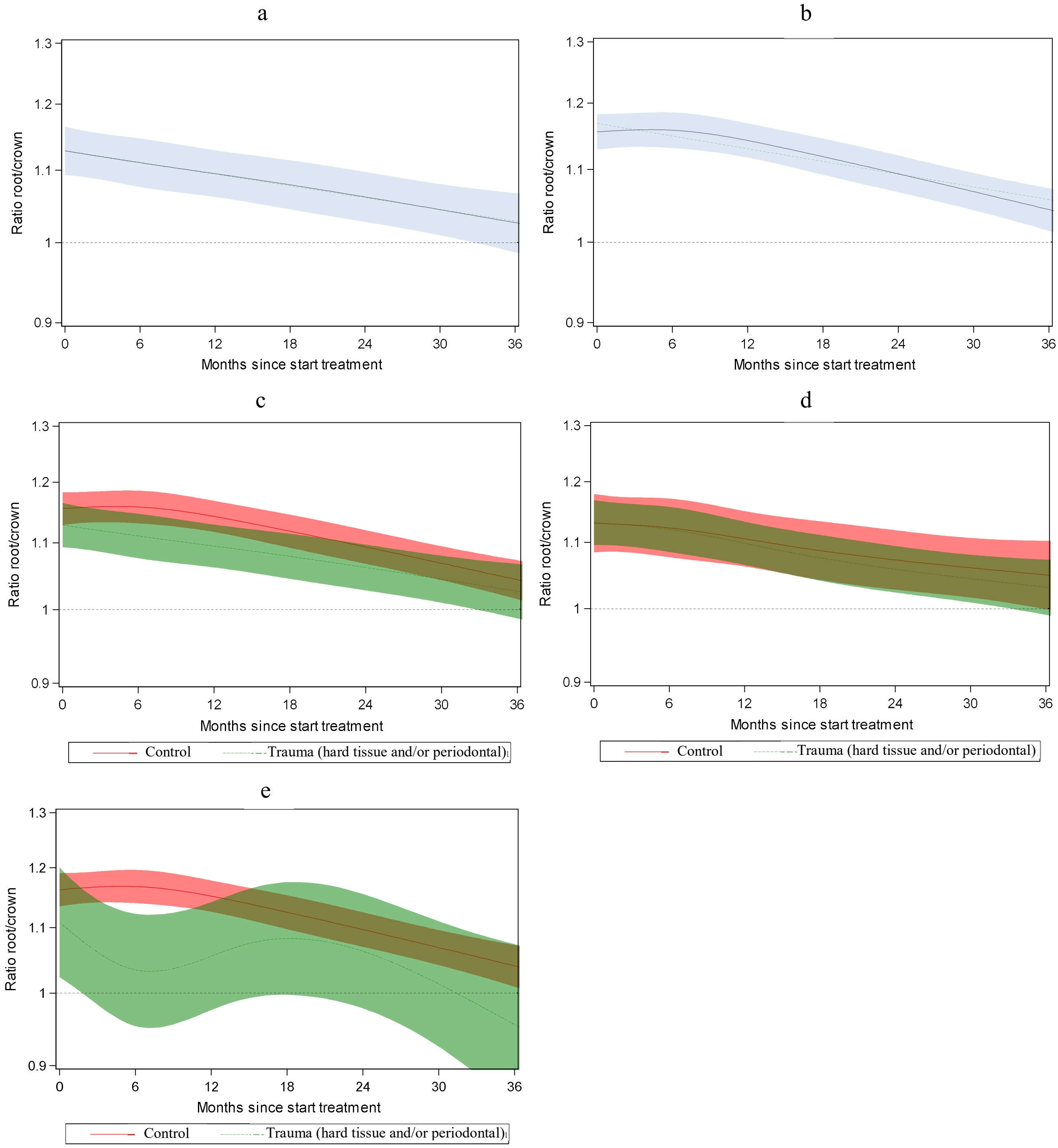
Table 4. Mean root/crown ratio of the different groups at start and after 36 months of treatment.

	Start (95% CI)	36 months (95% CI)
All incisors	1.14 (1.12-1.17)	1.03 (1.00-1.06)
Central	1.13 (1.10-1.16)	1.03 (1.00-1.07)
Lateral	1.16 1.13-1.19)	1.04 (1.00-1.07)
With trauma	1.13 (1.09-1.17)	1.03 (0.99-1.07)
Central	1.13 (1.10-1.17)	1.03 (0.99-1.07)
Lateral	1.11 (1.02-1.20)	0.96 (0.85-1.07)
Without trauma	1.16 (1.13-1.18)	1.04 (1.02-1.07)
Central	1.13 (1.08-1.18)	1.05 (1.00-1.10)
Lateral	1.16 (1.36-1.19)	1.04 (1.01-1.07)
Type of appliance		
Only removable	1.15 (1.12-1.19)	1.11 (15 months) (1.06-1.17)
Only fixed	1.13 (1.08-1.17)	0.98 (0.93-1.03)
Removable + fixed	1.16 (1.14-1.21)	1.06 (1.03-1.10)

Note: Means (95% confidence intervals) are derived from the linear mixed model for longitudinal measurements

Figures

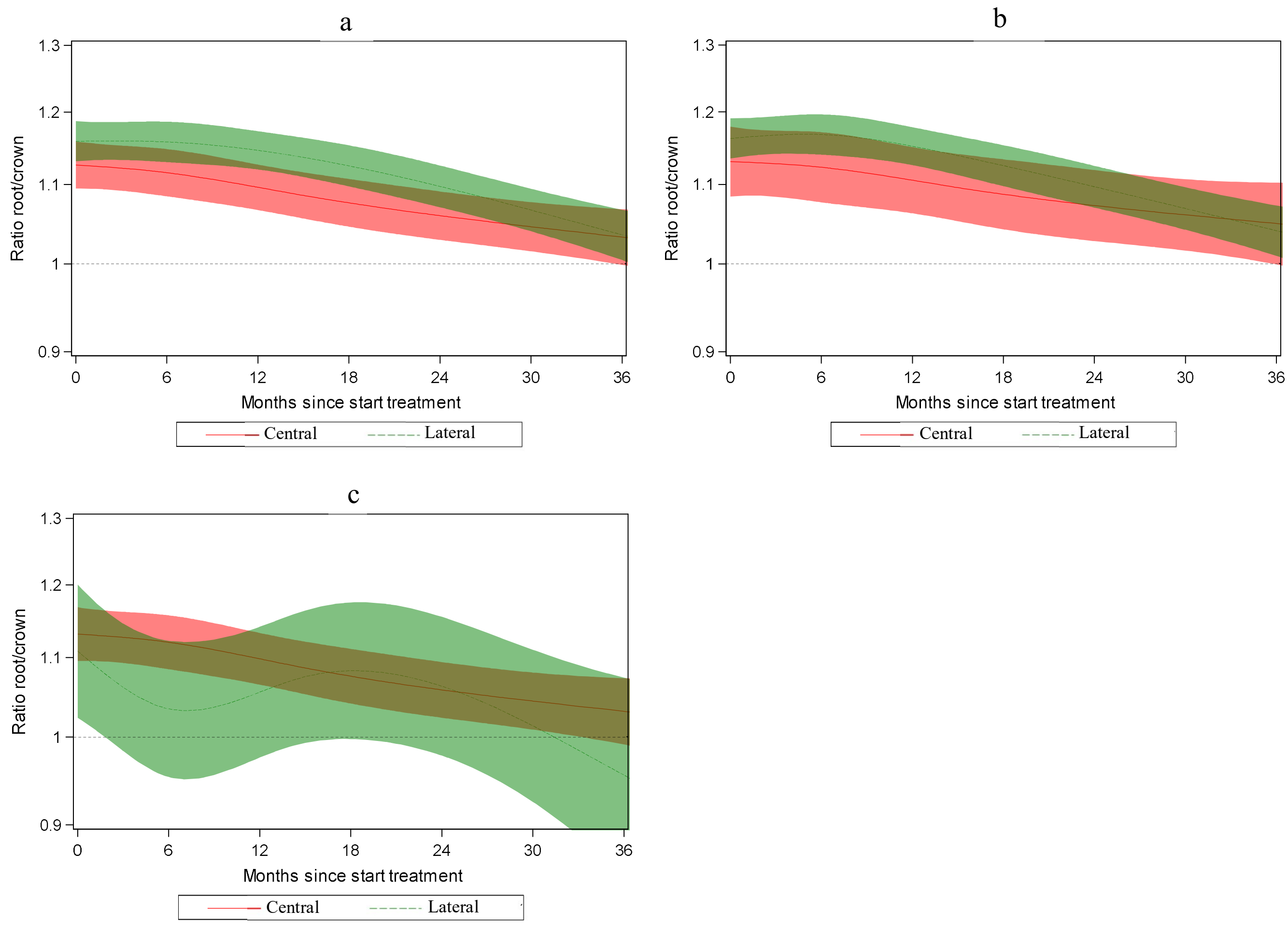
Fig. 1 Evolution of root/crown length ratio in incisors with and without trauma



a. Incisors with trauma ($P < 0.0001$*)
b. Incisors without trauma (control group) ($P < 0.0001$*)
c. Comparison ratio between all incisors ($P = 0.1901$)
d. Comparison ratio between central incisors ($P = 0.9531$)
e. Comparison ratio between lateral incisors ($P = 0.0318$*)

Note: The shaded area in the plots refers to the 95% pointwise confidence interval, the dashed green line refers to a model assuming linearity; the continuous black line refers to the model allowing non-linearity (in a and b)

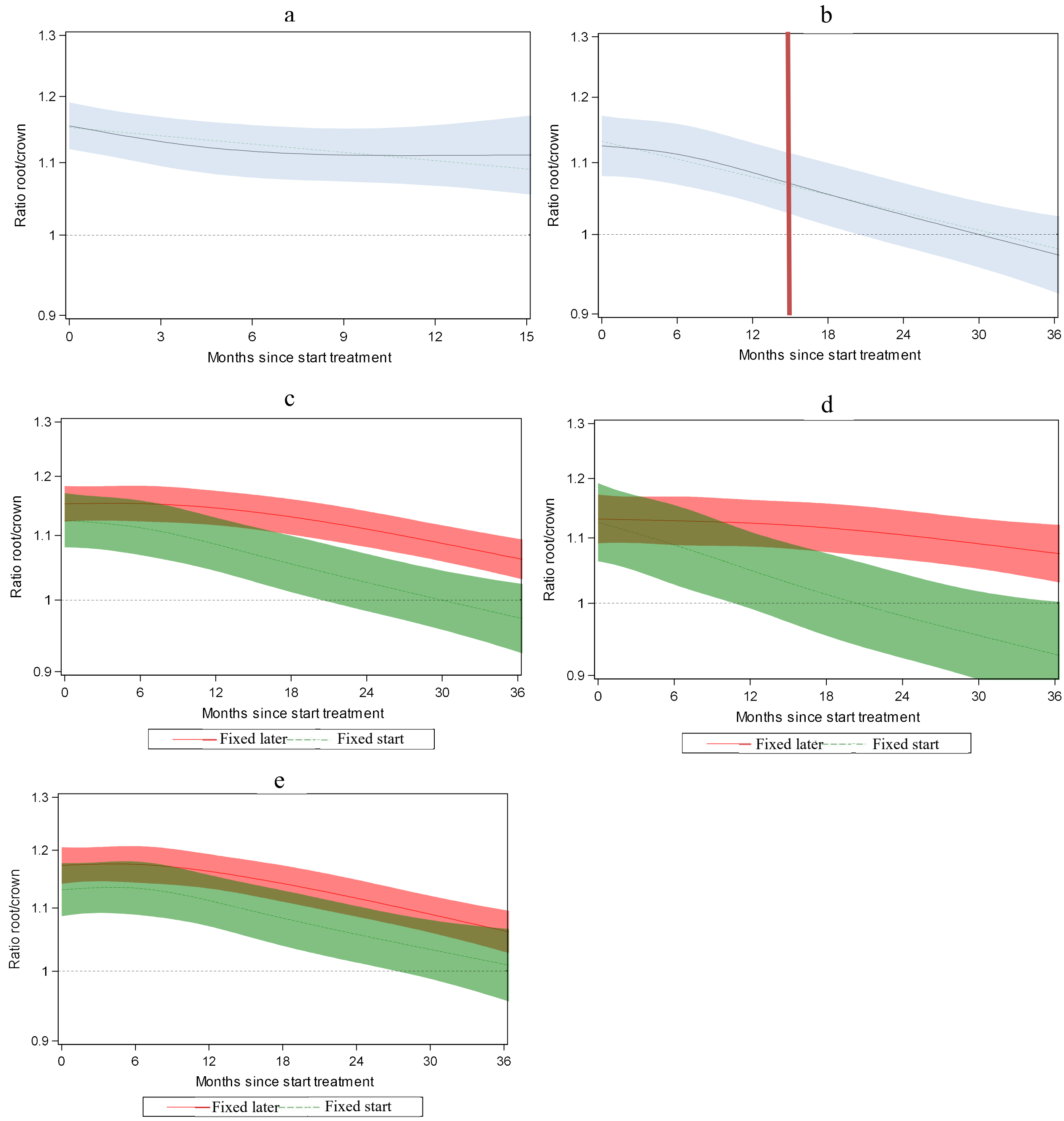
Fig. 2 Evolution of root/crown length ratio in central versus lateral incisors



a. Comparison ratio all central and lateral incisors (P = 0.0496*)
b. Comparison incisors without trauma (P = 0.1963)
c. Comparison incisors with trauma (P = 0.1050)

Note: The shaded area in the plots refers to the 95% pointwise confidence interval

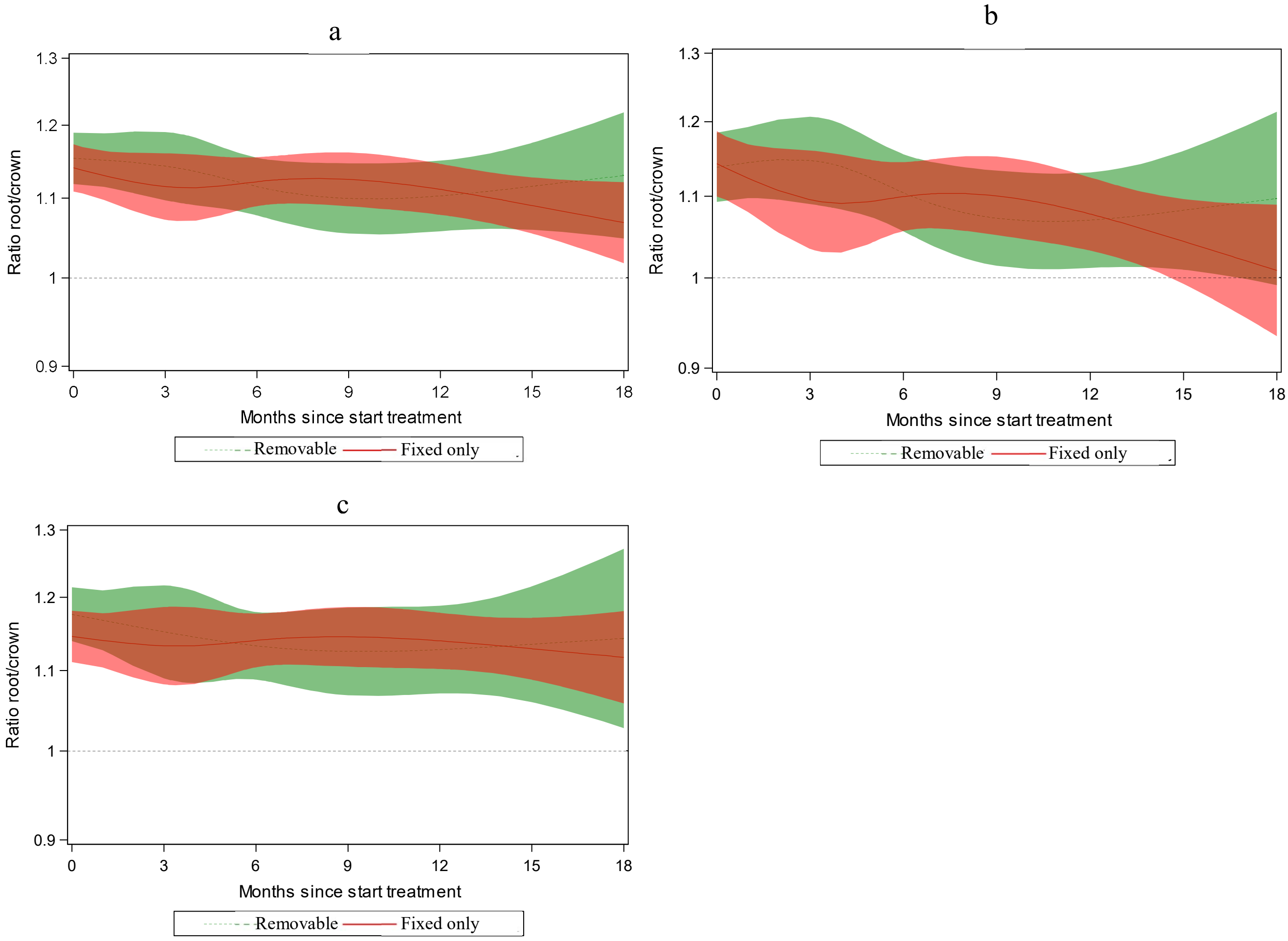
Fig. 3 Evolution of root/crown length ratio according to the type of orthodontic treatment received (only removable appliances or fixed appliances)



a. Removable appliances, all incisors (P < 0.0001*). In these cases, treatment was never longer than 15 months.
b. Fixed appliances, all incisors. The red line represents 15 months in treatment. (P < 0.0001*)
c. Comparison ratio in all incisors between removable and fixed appliances. The cases with removable appliances are gradually getting fixed appliances, all before 18 months of treatment. So before this time, the red group is mixed with removable and fixed appliances. (P = 0.0013*, P evolution = 0.0029*)
d. Comparison ratio in all incisors with trauma (P < 0.0001*, P evolution < 0.0001*)
e. Comparison ratio in all incisors without trauma (P = 0.3433)

Note: The shaded area in the plots refers to the 95% pointwise confidence interval, the dashed green line refers to a model assuming linearity; the continuous black line refers to the model allowing non-linearity (in A and B)

Fig. 4 Evolution of incisor root/crown length ratio according to the type of orthodontic treatment received (only removable appliances or fixed appliances) during the first 18 months



a. Comparison ratio in all incisors (P = 0.4620)
b. Comparison ratio in incisors without trauma (P = 0.4884)
c. Comparison ratio in incisors with trauma (P = 0.5025)

Note: The shaded area in the plots refers to the 95% pointwise confidence interval