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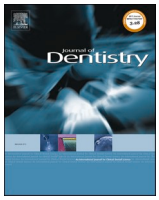

Dimensional changes of the gingival tissues induced by clear aligners and fixed orthodontic appliances

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ABSTRACT

Objective: The aim of this study was to evaluate gingival tissue adaption induced by orthodontic tooth movement, in terms of clinical crown height (*i.e.,* attachment loss), and thickness of the keratinized gingiva at the margin level.

Methods: Pre- and post-treatment intraoral models/scans of 100 orthodontically treated patients (50 treated with clear aligners and 50 treated with fixed appliance) were acquired. Models were digitally scanned. Each couple of pre- and post-treatment scans were superimposed using the Compare© software (Medit, Seoul, South Korea) taking the same reference landmarks in all cases, that were the palatal rugae for the upper arch, and the labial median frenulum for the lower arch. Only teeth that had undergone vestibulo-palatal (or vice versa) movement, greater than 1 mm were included in the analyses. The change from pre-treatment to post-treatment, in the clinical crown height and thickness of the keratinized gingiva at the margin level were digitally measured and compared between the two groups. Statistical analysis included paired t-tests, and unpaired t-tests with significance set at $p<0.05$.

Results: There was a statistically significant change in clinical crown height and gingival thickness in both groups. However, a clinically relevant attachment loss was found only within the fixed appliance group. Whereas, regarding the change in gingival thickness, there was no clinically relevant changes between the two groups.

Conclusions: Orthodontic tooth movement with fixed appliance is associated to a clinically relevant attachment loss. Clear aligners seem to be associated with a more discrete attachment loss than the one observed with fixed appliances.

Clinical relevance: Orthodontists should pay attention and monitoring the clinical crown height (i.e., attachment loss) during orthodontic movement, mostly when using fixed appliances.

1. Introduction

Orthodontics is inextricably linked to periodontal health [1,2]. Good orthodontic treatment can improve the function of the stomatognathic system, and proper tooth alignment can promote oral hygiene and reduce the risk of periodontal disease [1,3]. Before carrying out any orthodontic treatment, it is appropriate to evaluate the supporting tissues of the tooth, to be able to prevent all those problems that could establish during the treatment and lead to a loss of the supporting tissues of the tooth element [4,5].

To date, fixed orthodontic appliance is the conventional choice in adolescent patients, or those with medium to severe malocclusions, although it carries some disadvantages, including the accumulation of bacterial plaque, caused by difficulty in brushing [6–8]. However, this treatment, especially for aesthetic reasons, is less desirable in the adult population [6,9,10]. Therefore, new orthodontic techniques such as clear aligners were introduced to improve patient acceptance of the device and simplify oral hygiene procedures [10–12].

Clear aligners are aesthetically pleasing, comfortable and simple; they work through transparent, vacuum-formed or pressure-molded appliances, which must be worn for at least 20 hours a day [6,10,13]. Aligners also seem to be associated with less bacterial plaque

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accumulation, compared with conventional fixed appliance, thus reducing the risk of periodontal tissue damage [10,13,14].

Several observational studies have been carried out to evaluate the adaption of periodontal tissue to orthodontic tooth movement, particularly that of keratinized gingiva [4,7,15].

Previous studies have, in fact, shown that the entire periodontium, including bone and soft tissue components, reshapes itself because of orthodontic tooth movement [12]. In terms of changes, regarding gingival margin and thickness, two factors should be considered that are, the direction of tooth movement and the initial thickness of the gingiva [5,16,17]. Overall, it has been documented that an orthodontic movement in the lingual direction promote an increase in gingival thickness, while movements in the buccal direction led to its decrease [7,18].

The aim of this study was to evaluate gingival tissue adaptation induced by orthodontic tooth movement, in terms of clinical crown height (i.e., attachment loss), and thickness of the keratinized gingiva at the margin level. Then, a comparison was made between two groups of patients treated with the two most used orthodontic techniques in clinical practice: conventional fixed appliance and clear aligners.

2. Materials and methods

2.1. Study Protocol

This observational retrospective historical cohort study was approved by the Ethic Committee of the San Raffaele University (38/INT//2023 of 12/7/2023).

Pre- and post-treatment intraoral models/scans of 100 orthodontically treated patients in the time range from 2017 to 2022 were acquired: 50 subjects (average 24.8 $\pm$ 8.6 years) were treated with clear aligners (treated with comprehensive/full-package Invisalign aligners, with planned stripping always being less than 4 mm and performed in both the anterior and posterior sectors) and 50 (average 24 $\pm$ 9.4 years) were treated with fixed orthodontic appliance (all cases underwent treatment with straight wire mechanotherapy, following MBT prescription, without extractions). Patients were selected according to the following inclusion criteria: horizontal displacement of teeth $\geq$ 1mm; patient age $>$ 12 years; periodontal health; full permanent dentition; patients undergoing orthodontic treatment on both arches. While the exclusion criteria considered were: inadequate oral hygiene before treatment, reported in the medical record; history of periodontitis; patients with diseases affecting periodontal health (gingivitis and periodontal disease); pregnancy; presence of gingivitis before treatment and at recall.

According to data extracted from the clinicians' clinical database, all subjects underwent therapy lasting between 1.5 to 2.4 years; none of the patients had tooth extractions during treatment; and, at the end of treatment, all received two removable retainers for the upper and lower arches to be worn every night.

For both therapies, the landmarks utilized to determine the degree of proclination and arch expansion included: the degree of lower incisor proclination observed via cephalometry and the extent of the WALA (Width of the Anterior Loop of the Alveolar Process) ridge available for vestibular arch expansion. Based on these parameters and the patient's original arch form, suitable orthodontic wires were selected for fixed multibracket therapy, while an appropriate arch form and anterior dental limit were established using the ClinCheck software for clear aligner therapy.

It is important to highlight that none of patients experienced any major dental problems during orthodontic treatment. According to the initial models, all cases exhibited average crowding and contracted arches with the potential for dentoalveolar expansion.

2.2. Sample size justification

Regarding fixed appliance, in the literature, the reduction (DELTA) of width of keratinized gingiva ranges from 4.11+/−1.15 mm to 3.99+/−0.15 mm [19]. Assuming a standard deviation of DELTA of 2 mm and considering that the difference between DELTA of the two groups is clinically significant if it is greater than and/or equal to 1 mm, the numerosity required to show this difference, with a power of 80% and an alpha error about 0.05, was 50 subjects per group.

2.3. Procedures

All examinations, diagnostic procedures, and orthodontic treatments were performed in the selected patients according to the standard of care. For the present study, pre- and post-treatment Standard Tessellation Language (STL) models were extracted by clinical database of the clinicians and were compared and superimposed on each other using the software Compare© (Medit, Seoul, Republic of Korea) to determine changes in gingival characteristics before and after the orthodontic movement. Firstly, the overlay of pre- and post-treatment models was created using the Medit Design tool, matching the two images with palatal rugae for the upper arch, and median frenulum for the lower arch as references. For the standardization of measurements, this repeatable technique was adopted for each element (e.g. Fig. 1a, b).

Then, the tooth displacement value was calculated (in mm) and compared with the tooth soft tissue displacement value (in mm) for each tooth examined. For this purpose, the following procedure was adopted.

Firstly, a section line was drawn for each tooth, passing through the facial axis of the clinical crown (F.A.C.C.) (Fig. 2).

Then, the displacement in mm of the tooth was calculated on the sagittal section of the tooth, correspondent to the F.A.C.C., by using a millimeter grid, and measuring pre-post-treatment cusp displacement (Fig. 3). Only those elements where this displacement was $\geq$ 1mm were included in the analyses.

Then, the clinical crown height was measured on pre- and post-treatment models, as the distance (in mm) between the cusp of the tooth and the gingival margin. After which, the change in clinical crown height (attachment loss) was calculated by subtracting the post-treatment value from the pre-treatment value (Fig. 4).

Finally, the gingival thickness was deduced from the tooth section, through a digital geometric artifice: as a first step, the gingival margin migration of the tooth from pre-to post- was measured, as described in Fig 5a; this value was considered as the initial gingival thickness. Then, in both the pre- and post-treatment section, a point 1 mm away from the gingival margin was geometrically deducted (Fig. 5b); finally, the distance between these two geometrical points was measured (Fig. 5c) and considered as the final gingival thickness. By subtracting the final value from the initial one, the change in gingival thickness was obtained.

All the measurements were performed by the same operator and double checked by another operator.

2.4. Data handling and statistical analyses

The tooth displacement, the change in clinical crown height, and the change in gingival thickness were expressed as mean and standard deviation for each group at pre- and post-treatment time. Kolmogorov-Smirnov test and visual assessment of data were used to confirm the homogeneity and normality of the distribution of data. Within-group differences were evaluated by *t*-test for paired samples. Comparisons between the two groups were evaluated by *t*-test for unpaired samples. Stat Plus© software (Alexandria, Virginia, USA) was used for all the analyses, applying a significance level of $p<0.05$.

The measurement error was also calculated by doing repeated measurements on a sample of 15 teeth and applying the Dahlberg's Formula it resulted to be equal to 0.04 mm, the 4% of the clinical significance threshold of 1mm, so it can be considered negligible.

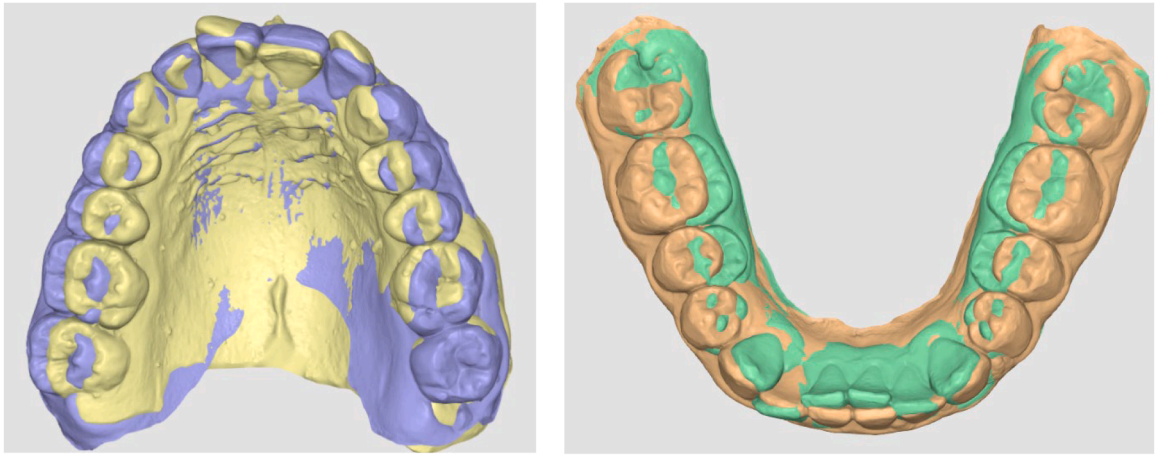

Fig. 1. (a, b) Occlusal view of the overlay of the pre- and post-treatment models. The colors yellow (for upper arch) and green (for lower arch) represent the initial model. Purple (for upper arch) and orange (for lower arch) colors represent the final model.

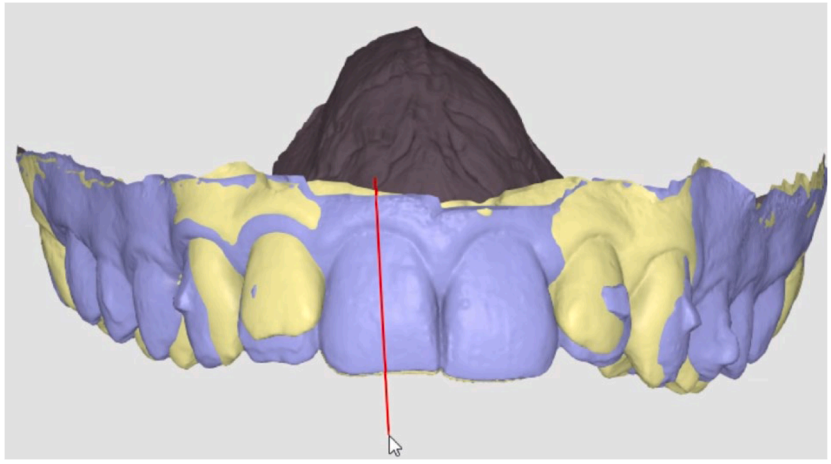

Fig. 2. Creation of the section line, passing through F.A.C.C.

Fig. 3. Calculation of tooth displacement, through millimetre grid, taking pre- (yellow) and post-treatment (purple) vestibular cusps as reference. In this case, the tooth displacement, following orthodontic therapy, was 2.7mm.

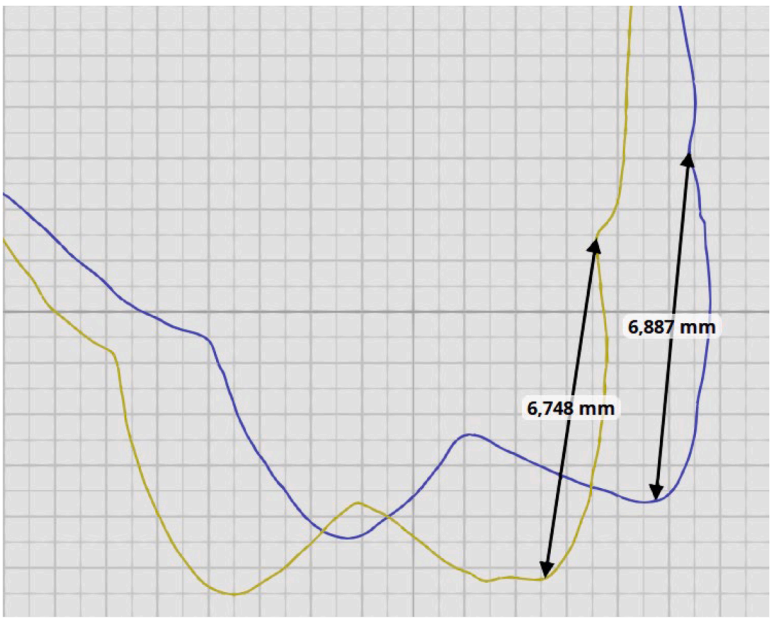

Fig. 4. Calculation of initial (yellow) and final (purple) clinical crown height. In this case the change in clinical crown height (attachment loss) was −0,139 mm.

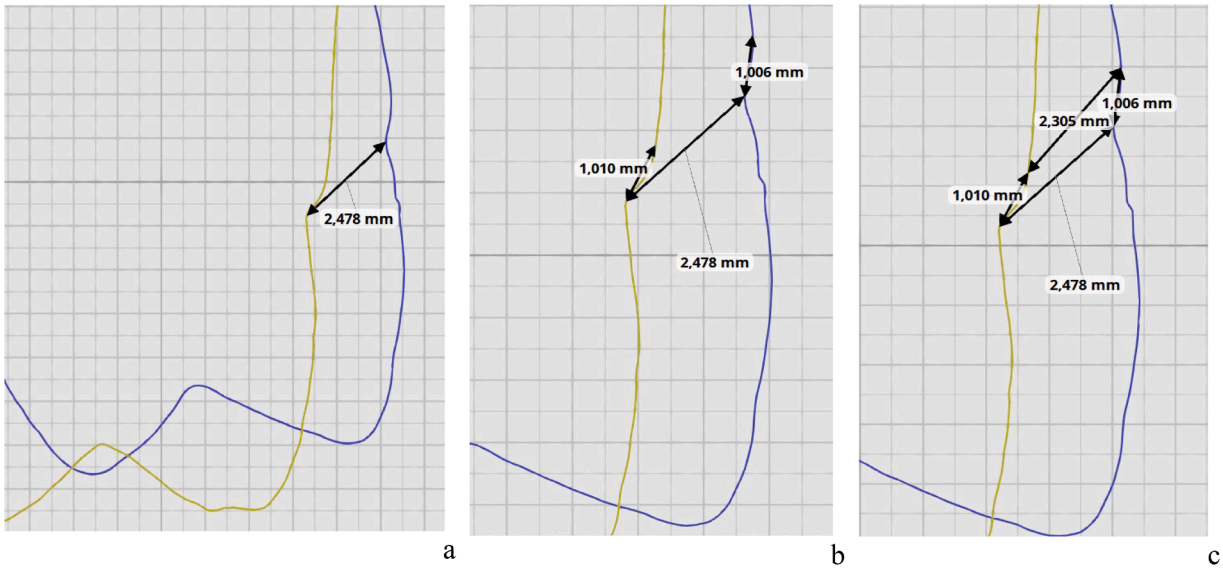

Fig. 5. (a) The gingival margin displacement of the tooth from pre- (yellow) and post- (purple) was measured and considered as initial gingival thickness, which in this case was about 2.478 mm. (b) A point distant 1mm from the gingival margin, both in the pre-treatment tooth (yellow) and post-treatment tooth (purple) was geometrically measured. (c) By joining the points 1 mm away from the gingival margin, the final gingival thickness was deduced, which in this case was about 2.305 mm.

3. Results

In the group of patients treated with clear aligners, from 1349 initially examined teeth, 623 elements were finally included in the analyses, according to the inclusion criteria. These were: 28 upper incisors, 51 lower incisors, 38 upper canines, 33 lower canines, 164 upper premolars, 135 lower premolars, 92 upper molars and 82 lower molars. In the group of patients treated with fixed orthodontic therapy from 1251 teeth, a total of 506 elements were finally included in the analyses, that were: 78 upper incisors, 95 lower incisors, 29 upper canines, 28 lower canines, 107 upper premolars, 89 lower premolars, 43 upper molars and 37 lower molars. There is no homogeneity of initial malocclusion types, and this may increase the presence of confounding factors.

The changes in clinical crown height, thickness of the keratinized gingiva at the margin level, and tooth displacement were expressed in millimeters as mean and SD for both the two groups in Table 1 for the upper teeth and Table 2 for the lower teeth, with the evidence of statistically significant differences between the two groups.

3.1. Clinical crown heigh (attachment loss)

A change in the clinical crown height between pre-treatment and post-treatment was observed in both groups for all teeth, except for - but only in the aligners group –the lower molars, where it was 0.0 ± 0.5 at mean.

Generally, these changes were all with poor clinical relevance, in both groups, as in most cases were < 1 mm. Statically and clinically relevant changes ($p<0.05$ with amount higher than the clinical

Table 1
Changes in clinical crown height (attachment loss), thickness of the keratinized gingiva at the margin level, and tooth displacement in the upper teeth expressed in millimeters for both the two groups, with the evidence of statistically significant differences between the two groups ($p<0.05$).

		Clear aligners Mean ± SD	Fixed appliance Mean ± SD	p-value (between groups differences)
Incisors	Attachment loss	−0.3 ± 0.5	−0.6 ± 0.9	**0.047**
	Gingival thickness	0.1 ± 0.2	0.0 ± 0.2	0.078
	Tooth displacement	**1.3 ± 0.9**	**1.9 ± 1.1**	**0.001**
Canines	Attachment loss	−0.3 ± 0.7	**−1.0 ± 1.2**	**0.007**
	Gingival thickness	−0.2 ± 1.5	0.0 ± 0.1	0.335
	Tooth displacement	1.6 ± 0.5	1.6 ± 0.6	0.869
Premolars	Attachment loss	−0.3 ± 0.7	**−0.8 ± 0.9**	**0.000**
	Gingival thickness	−0.1 ± 0.1	0.0 ± 0.2	**0.017**
	Tooth displacement	1.9 ± 0.8	2.0 ± 1.1	0.270
Molars	Attachment loss	−0.3 ± 0.6	−0.6 ± 1.0	0.064
	Gingival thickness	0.0 ± 0.2	0.0 ± 0.2	0.830
	Tooth displacement	1.6 ± 0.8	2.3 ± 1.4	**0.005**

Table 2
Changes in clinical crown height (attachment loss), thickness of the keratinized gingiva at the margin level, and tooth displacement in the lower teeth expressed in millimeters for both the two groups, with the evidence of statistically significant differences between the two groups ($p<0.05$).

		Clear aligners Mean ± SD	Fixed appliance Mean ± SD	p-value * (between groups differences)
Incisors	Attachment loss	−0.4 ± 0.6	−0.2 ± 0.7	0.052
	Gingival thickness	0.0 ± 0.1	0.0 ± 0.2	0.777
	Tooth displacement	1.7 ± 0.7	1.8 ± 0.8	0.652
Canines	Attachment loss	−0.2 ± 0.4	−0.3 ± 1.1	0.593
	Gingival thickness	0.0 ± 0.2	0.1 ± 0.3	**0.011**
	Tooth displacement	1.6 ± 0.8	1.9 ± 0.8	0.231
Premolars	Attachment loss	−0.3 ± 0.5	−0.6 ± 0.9	**0.003**
	Gingival thickness	−0.1 ± 0.1	0.0 ± 0.2	0.560
	Tooth displacement	1.9 ± 2.0	1.5 ± 0.6	0.074
Molars	Attachment loss	0.0 ± 0.5	−0.4 ± 0.8	**0.003**
	Gingival thickness	−0.1 ± 0.1	0.0 ± 0.1	**0.001**
	Tooth displacement	1.5 ± 0.6	1.6 ± 0.7	0.659

* Student's t test for independent samples.

relevance threshold) were observed in the fixed appliance group for the upper premolars and the upper canines (where they reached values of about −0.8/−1 mm respectively, with a statistically significant difference respect to the clear aligner group ($p=0.007$ and $p=0.001$, respectively) as evidenced in Table 1.

3.2. Thickness of the keratinized gingiva at the margin level

Within the aligners group, a statistically significant change was recorded for upper incisors, upper and lower premolars, and lower molars. While within the fixed appliance group, statistically significant changes were recorded only in the lower arch (lower canines and lower premolars).

However, all the observed changes were not clinically relevant, because they were less than 1 mm.

Comparison between the two groups (reported in Tables 1-2) evidenced statistically significant differences for the upper premolars, lower canine, and lower molars, but all the differences were not clinically relevant.

3.3. Tooth displacement

The analyses show that the differences between the two groups regarding tooth displacement was not statistically significant for any tooth element, except for upper incisors and upper molars (Table 1).

A clinically relevant difference between the two group is observed for the upper incisors ($p=0.001$), as an average of 1.3 mm of displacement was recorded in the aligners group, and an average of 2 mm displacement in the fixed appliance group (i.e., twice as much).

4. Discussion

This study evaluated gingival tissue adaption induced by orthodontic tooth movement, in terms of clinical crown height (*i.e.,* attachment loss), and thickness of the keratinized gingiva at the margin level in patients treated with clear aligners or fixed appliance.

From the data analyzed, it was found that for the lower teeth the differences between the two groups were not clinically relevant. Some differences were recorded for the maxillary teeth, where treatment with clear aligners was less traumatic for the gingival tissues, particularly the canines and premolars, than treatment with fixed appliance, which was associated with a significantly higher and clinically relevant attachment loss (change in clinical crown height) and a greater reduction in the thickness of keratinized gingiva (significantly higher for the premolars).

A previous study had already evaluated the periodontal status of patients treated with the same methods and showed significantly better periodontal indices in patients who had undergone orthodontic treatment with clear aligners [11,12,14].

This finding could be due to better maintenance of oral hygiene of clear aligners, instead of fixed appliance (that could promote the occurrence of marginal gingivitis, leading to possible tissue damage) [6, 10,11,12,14].

In the present study, the differences between the two groups were clinically relevant mainly as a variation of clinical crown height in the upper canines and upper premolars, observed in the inter-group evaluation.

From a clinical point of view, this finding seems to suggest that arch expansion, and thus orthodontic tooth movement in the vestibular direction, could result in loss of attachment and possible increasing of clinical crown height (gingival recession) [12,20], particularly when the expansion concerns the canine-premolar sector of the arch. Overall, the main data was about the clinical crown height, whose change resulted significantly greater in the fixed appliance group than in the clear aligner group.

Comparing the changes in gingival thickness between the two groups, this study shows statistically significant differences in the lower

arch (for canines, premolars, and molars) and less in the upper arch (with premolars) with significantly greater variations for the fixed appliance group. However, none of these differences can be considered clinically relevant, as they all averaged about 0.1 mm.

Finally, in this study, the upper incisors showed an orthodontic movement that was found to be greater about 2 times in the fixed appliance group, respect to clear aligners group. In the same teeth, the change in the clinical crown height resulted significantly greater in subjects treated with brackets, compared with those treated with aligners (mean attachment loss of −0.6 mm for cases treated with brackets, and −0.3 mm for aligners; $p<0.05$), although the difference was not clinically relevant (< 1 mm). These observations seem to suggest that the use of clear aligners, due to the possibility to program each orthodontic movement, gave better control of tooth displacement and supporting tissue.

To the author's knowledge, this study is the first one in the literature in this field, and therefore there are no other data to compare the present results. Some limits of this research protocol are:

- As this was a retrospective study, there was no opportunity to follow therapy and patients over time, but only pre- and post-treatment patterns were analyzed, so the oral hygiene maintenance is unknown.
- Despite malocclusion type and mechanotherapy of patient cases was quite similar in all cases included in the sample, there was no certain homogeneity of initial malocclusion types, and this may increase the presence of confounding factors.
- Gingival thickness was deduced through a digital geometric artifice, so it is not as accurate as the measurement made through a periodontal probe.
- The age range of the selected patients was quite wide. Considering that tooth movement progresses at a faster rate in adolescent patients compared to adults [11], due to the increase in bone density and the decrease in osteoclastic activity with advancing age, the difference in age between subjects may have influenced the results, even though the average age of the two samples remained homogeneous.

Therefore, from a clinical perspective, it seems crucial to conduct a thorough evaluation of gingival tissues before undertaking any kind of orthodontic treatment, with a preference for clear aligners in case of criticality.

5. Conclusions

Within the limits of this study, it can be concluded that:

- While we observed statistically significant changes in the considered periodontal variables in both groups, patients treated with clear aligners seem not to exhibit clinically relevant changes. So clear aligners seem to be associated with a more discrete attachment loss than the one observed with fixed appliances.
- In the fixed appliance group, clinically relevant changes in the clinical crown height were observed for upper canines and upper premolars, measuring approximately 1 mm. These changes were significantly greater than those observed in the clear aligners group.
- The results suggest that clear aligners, facilitated by digital planning, seem to allow a better control of the final upper incisors position achieving less proinclination.
- Further studies are needed to better investigate the differences between clear aligners and fixed appliances in terms of upper incisor control and impact on periodontal tissues.

Clinical relevance

Although we found statistically significant changes in the periodontal variables considered in both groups, patients treated with clear aligners seem not to show clinically relevant changes. In the fixed appliance group, clinically relevant changes in clinical crown height were observed for upper canines and upper premolars of about 1 mm, significantly greater than in the aligner-treated group.

CRediT authorship contribution statement

Miryam Romito: Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alessandro Nota:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Francesco Ferrini:** Resources, Methodology, Investigation, Conceptualization. **Giacomo Dal Porto:** Resources. **Francesco Guido Mangano:** Visualization, Supervision, Supervision, Methodology, Investigation, Conceptualization. **Simona Tecco:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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