Original Article

Disentangling the effects of CAD/CAM customized appliances and piezocision in orthodontic treatment: *New evidence*

Carole Charavet[a]; Dorien Van Hede[b]; Nathalie Maes[c]; Adelin Albert[d]; France Lambert[e]

ABSTRACT

Objectives: To discern the effects of computer-aided design (CAD)/computer-aided manufactured (CAM) customized appliances and piezocision on orthodontic treatment (OT).

Materials and Methods: The study combined findings from two previously published randomized controlled trials: (1) standard OT vs piezocision-assisted standard OT, and (2) CAD/CAM OT vs piezocision-assisted CAD/CAM OT. (Piezocision is a minimally invasive corticotomy surgical procedure used to accelerate orthodontic treatment and CAD/CAM refers to CAD/CAM customized brackets and archwires.) The outcomes were the overall treatment time, and the durations of the alignment phase and fine-tuning phase. Clinical and radiological features also were evaluated.

Results: The combined study included 48 patients with similar baseline characteristics. Compared to the standard treatment, CAD/CAM technology alone significantly decreased the overall median OT time from 543 to 394 days ($P < .001$) and from 543 to 254 days ($P < .0001$) when combined with piezocision. Although piezocision significantly reduced the duration of the alignment phase in the mandible and maxilla, CAD/CAM technology considerably shortened the fine-tuning phase. All periodontal and radiographic parameters remained stable from the start to the end of treatment in all groups.

Conclusions: CAD/CAM technology combined with piezocision accelerates the entire OT process, during the alignment phase for piezocision and during the fine-tuning phase for CAD/CAM, with a global reduction of the overall treatment time of more than 50%. (*Angle Orthod.* 0000;00:000–000.)

KEY WORDS: CAD/CAM orthodontic appliance; Orthodontic appliance design; Accelerated orthodontic treatment; Piezocision; Piezosurgery

INTRODUCTION

Acceleration of orthodontic treatment (OT) has received growing attention in recent years, especially in adult patients. Different concepts have been developed to respond to patient demands such as the use of custom-made orthodontic appliances or minimally invasive corticotomies like piezocision (PZ).[1] On one hand, the piezocision procedure is a non-invasive corticotomy surgical technique (without flap) combining buccal incisions and corticotomies (3-mm

[a] Associate Professor, Université Côte d'Azur, Laboratoire Microbiologie orale Immunité Santé MICORALIS (Unité Propre de Recherche 7354), Faculté de Chirurgie Dentaire, Centre Hospitalier Universitaire de Nice, Nice, France; and Researcher, Dental Biomaterials Research Unit (d-BRU), University of Liège, Liège, Belgium.

[b] Postdoctoral Researcher, Dental Biomaterials Research Unit (d-BRU) and Department of Periodontology, Oral Surgery and Implant Surgery, University Hospital of Liège, Liège, Belgium.

[c] Biostatistician, Biostatistics and Medico-Economic Information Department, University Hospital of Liège, Liège, Belgium.

[d] Professor Emeritus, Department of Public Health, University of Liège, Liège, Belgium.

[e] Professor and Head, Department of Periodontology, Oral Surgery and Implant Surgery, University Hospital of Liège; and Co-Director, Dental Biomaterials Research Unit (d-BRU), University of Liège, Liège, Belgium.

Corresponding author: Pr. Dr. Carole Charavet, Université Côte d'Azur, Faculté de Chirurgie-Dentaire, 5 Avenue du 22ième BCA, Nice 06300, France
(e-mail: c.charavet@gmail.com)

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deep and 5-mm long) performed using a piezotome and possibly combined with buccal bone regeneration.[2] This technique is based on the regional acceleratory phenomenon (RAP), a biological phenomenon characterized by an increase of bone turnover and a decrease in the mineral content of the bone,[3] responsible for faster orthodontic tooth displacement. On the other hand, custom-made orthodontic appliances are currently widely used, including clear aligners, and customized labial or lingual systems, all with the objective of improving the overall efficiency and effectiveness of OT. Specifically, computer-aided design and computer-aided manufactured (CAD/CAM) customized brackets and archwires are designed on the basis of a reviewed digital setup, produced by machine milling and then placed using indirect bonding jigs. It has been suggested that this system decreases the overall OT duration, as in the retrospective study of Brown et al.[4]

In a previous randomized controlled trial (RCT), it was found that piezocision combined with standard (STD) self-ligating brackets (Damon, Ormco, ~~Brea, CA, USA~~) decreased the overall treatment time by 43% compared to standard OT [5]. In another RCT, it was demonstrated that using a CAD/CAM customized orthodontic appliance (Insignia, Ormco) led to an acceleration of the overall treatment time by 36% when combined with piezocision.[6] In both RCTs, however, the significant reduction of the overall treatment time was observed to occur during the alignment phase. Indeed, the stimulating influence of bone injuries from piezocision is actually limited to the first 4–6 months after surgery,[5,7] as shown by two preclinical studies that highlighted the transient and reversible tissue, and cellular and molecular biological mechanisms of piezocision.[8,9] Unfortunately, the second RCT alone did not offer the possibility of evaluating the specific effect of the custom-made appliance on the timing of OT and, as already stated by some authors,[4] further investigation on CAD/CAM orthodontic appliances is required, including a standardization of the appointment intervals.

Therefore, since both RCTs had the same study design, it was decided to combine them in the style of a meta-analysis to disentangle the respective roles and dynamics of piezocision and CAD/CAM appliances on the acceleration of orthodontic tooth movement.

MATERIALS AND METHODS

Registration

The two RCTs[5,7] received approval from the University Hospital of Liège (Belgium) Ethics Committee and were registered with Clinical Trials (Identifier: NCT02590835 and NCT03406130).

Study Design

This work combined all patients from the two RCTs.[5,7] The patients from the first RCT were named as follows: STD (n = 12) and STD + PZ (n = 12), whereas patients from the second RCT were named as follows: CAD/CAM (n = 12) and CAD/CAM + PZ (n = 12).

To be included in the trials, patients had to fulfill the following criteria: (1) adult requiring OT in both arches; (2) minimal to moderate maxillary and mandibular anterior crowding at baseline (irregularity index $\leq$6);[10] (3) American Society of Anesthesiologists (ASA) stage I or II; and (4) suitable dental and oral health. Exclusion criteria consisted of: (1) previous periodontitis with a loss of alveolar support $>$ 10%; (2) gingival recession $>$ 2 mm; (3) smoking; (4) altered bone metabolism; and (5) pregnancy.

Orthodontic Procedure

For STD and STD + PZ patients, Damon self-ligating brackets (Ormco) were used. The alignment sequence consisted of 0.014-inch, 0.018-inch, 0.014 $\times$ 0.025-inch and 0.018 $\times$ 0.025-inch copper nickel-titanium archwires followed by 0.019 $\times$ 0.025-inch stainless steel archwires for fine-tuning. For CAD/CAM and CAD/CAM + PZ subjects, CAD/CAM self-ligating appliances (Insignia, Ormco) were employed. The sequence of customized archwires for alignment consisted of 0.014-inch, 0.018-inch, 0.014 $\times$ 0.025-inch and 0.018 $\times$ 0.025-inch copper nickel-titanium archwires followed by 0.019 $\times$ 0.025-inch stainless steel archwires for fine-tuning. All patients were recalled every 2 weeks. A third blinded orthodontist confirmed the appliance removal or requested adjustments based on the model, without any group indication.

Piezocision Surgical Procedure

The piezocision surgical procedure was carried out as follows: (1) Performed 2 weeks after the placement of the orthodontic appliance;[1] (2) Following local anesthesia (articaine hydrochloride, 7200 mg/1.8 mL, adrenaline, 1800 mg/1.8 mL) in both arches, vertical interproximal micro-incisions (varying between 5 mm and 8 mm) were made below each interdental papilla, then corticotomies (5-mm long and 3-mm deep) were made using a piezoelectric device (Acteon, Merignac, France) (3) Patients were advised to take analgesics (paracetamol/acetaminophen) if needed. Vigilant tooth brushing and the use of a mouthwash (chlorhexidine, 0.2% Perio-Aid, Dentaid, ~~Houten, Netherlands~~) were prescribed for 7 days. Paris, France ?1

Data Collection

~~*Orthodontic data*~~At baseline, space analyses were calculated on study models using digital calipers. Data

Table 1. Baseline Characteristics of the Four Study Groups[a]

Variable	STD	STD + PZ	CAD/CAM	CAD/CAM + PZ	Total	*P* Value
No. of patients	12	12	12	12	*48*	
Demographics						
Age (y)	27 ± 7	34 ± 8	27 ± 7	29 ± 8	*29 ± 8*	.098
Sex (male/female)	4/8	5/7	4/8	5/7	18/30	.95
Space analysis						
Maxilla (mm)	−2.3 ± 1.5	−2.8 ± 1.2	−2.0 ± 1.2	−2.5 ± 1.1	−2.4 ± 1.3	.51
Mandible (mm)	−2.6 ± 1.8	−3.4 ± 1.4	−3.1 ± 1.6	−3.0 ± 1.8	−3.0 ± 1.6	.70
Periodontal data						
Plaque index	0.89 ± 0.37	0.91 ± 0.70	0.67 ± 0.52	0.97 ± 0.73	0.86 ± 0.59	.63
Papilla bleeding index	1.5 ± 0.73	1.5 ± 0.69	1.0 ± 0.58	1.5 ± 0.59	1.4 ± 0.67	.18
Root resorption score	0.46 ± 0.93	0.91 ± 1.0	0.42 ± 1.2	0.42 ± 1.2	0.54 ± 1.0	.62
Pocket depth score	0.33 ± 0.65	0.50 ± 0.52	0.14 ± 0.31	0.40 ± 0.42	0.34 ± 0.50	.34

[a] STD indicates standard orthodontic treatment; PZ, piezocision; and CAD/CAM, computer-aided design and computer-aided manufacturing.
* $P < .05$.

recorded included (1) Total treatment duration (days); (2) Time (days) between each archwire change; (3) Cumulative time (days) from placement of the orthodontic appliance to each archwire change; and (4) Time (days) of the fine-tuning phase.

~~*Periodontal data*~~Periodontal data were measured at baseline and after OT as follows: (1) Recession depth expressed as a summation score; (2) Pocket depth expressed as a score per sextant; (3) Plaque index; (4) Papilla bleeding index. Full periodontal charting (probing at four sites per tooth) was scored per sextant.

~~*Radiographic data*~~All patients underwent baseline and post-treatment computed tomography (CT) scans (Somaton Emotion; Siemens, Malvern, ~~PA, USA~~) and cone-beam computed tomography (CBCT) imaging (Planmeca, Helsinki, Finland). The following data were collected: (1) Root resorption according to the Malmgren classification,[11] excluding the score of 1; and (2) Dehiscence and fenestration scores using specific software (Nobel Clinician, Nobel Biocare, Göteborg, Sweden). Four patients (one in each group) failed to attend the post-treatment scans.

~~*Power calculation*~~A power calculation performed for each RCT revealed that, with a sample size of at least 10 to 11 subjects in each group (without and with piezocision), a reduction of 20% in the total treatment duration could be observed with a power of 80% at the 5% significance level.

Statistical Analysis

Results were expressed as mean and standard deviation (SD) or as frequency (percent). For time durations, the median and interquartile range (IQR) was also calculated and time distributions were displayed as Kaplan-Meier survival curves. Groups were compared using the Kruskal-Wallis test for quantitative variables and the chi-square test was used for proportions. To discern the relative effects of custom-made orthodontic appliances and piezocision on the overall treatment time, alignment phase, and fine-tuning phase times, median values were also compared using the Kruskal-Wallis non-parametric analysis of variance test. All tests were two-sided and the critical significance level was set at 5% ($P < .05$). Statistical calculations were performed using SAS software version 9.4 (SAS Institute, Cary, ~~NC, USA~~) and graphs were obtained with R version 3.6.1.

RESULTS

Patient Characteristics

Patient characteristics are presented in Table 1; the four patient groups were considered as homogenous.

Total Orthodontic Treatment Duration

To summarize, in comparison to STD treatment, the median treatment duration was reduced by 27% (1.4 times faster) with CAD/CAM, by 43% (1.7 times faster) with STD + PZ, and by 53% (2.1 times faster) with CAD/CAM + PZ (Figure 1).

Alignment and Fine-tuning Phase Durations

As orthodontic treatment is generally divided into two phases, the alignment phase and the fine-tuning phase, the relative effects of CAD/CAM and piezocision on the duration of each phase were investigated in the maxilla and mandible. Regarding the alignment phase, piezocision significantly reduced its duration. In the maxilla (Figure 2a), the median (IQR) duration was 112 days for STD + PZ vs 226 days for STD alone ($P = .0002$) and 146 days for CAD/CAM + PZ vs 253 days for CAD/CAM alone ($P < .0001$). No difference was found between STD and CAD/CAM ($P = .33$). In the mandible (Figure 2b), the median (IQR) duration was 125 days for STD + PZ vs 244 (176–266) days for STD alone ($P = .0002$) and 164 days for CAD/CAM + PZ vs 261 days for CAD/CAM alone ($P = .0001$). As in the

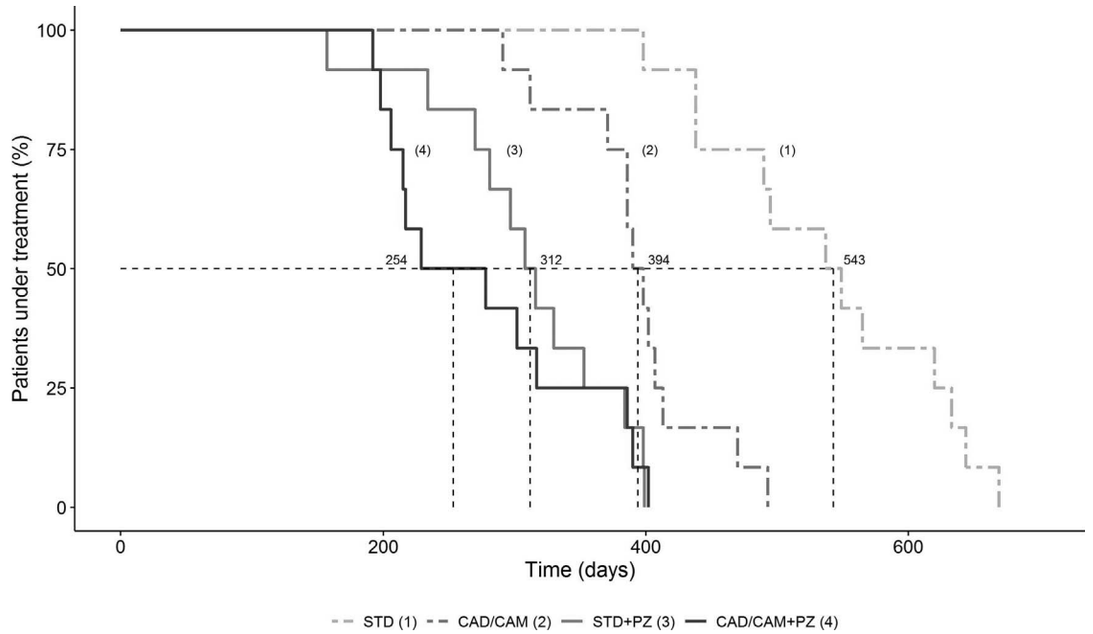

Figure 1. Total treatment duration in the four study groups.

maxilla, no difference was found between STD and CAD/CAM in the mandible ($P = .34$).

Regarding the fine-tuning phase, the reduction effect was due to CAD/CAM and not to piezocision. In the maxilla (Figure 3a), the median (IQR) duration was 154 days for CAD/CAM alone vs 308 days for STD alone ($P = .0033$) and 83 days for CAD/CAM + PZ vs 191 days for STD + PZ ($P = .021$). No difference was found between CAD/CAM and CAD/CAM + PZ ($P = .44$) but STD and STD + PZ differed markedly ($P = .0066$). In the mandible (Figure 3b), results were comparable to the maxilla. The median (IQR) duration was 122 days for CAD/CAM alone vs 297 days for STD alone ($P = .0001$) and 59 days for CAD/CAM + PZ vs 174 days for STD + PZ ($P = .033$). No difference was found between CAD/CAM and CAD/CAM + PZ ($P = .19$) but STD and STD + PZ differed significantly ($P = .0013$).

Periodontal and Radiographic Outcomes

Recession scores and mean probing depth did not change from baseline to end of treatment in any of the groups. No increase in dehiscence or fenestration was observed and root resorption remained unchanged after each treatment (Table 2).

DISCUSSION

This study was the first to highlight the impact of CAD/CAM customized orthodontic appliances and piezo-assisted decortication on the overall duration of OT, with particular attention paid to the alignment and fine-tuning phases. Both technologies, CAD/CAM and piezocision, significantly reduced the overall OT time with a phase-specific effect. Indeed, piezocision generated a strong accelerating action on the alignment phase. In contrast, CAD/CAM appliances significantly reduced the duration of the fine-tuning phase, and markedly more than in the case of piezocision. This study showed that the CAD/CAM system assisted by the piezocision procedure offered the most rapid OT time.

Effect of Piezocision Surgical Procedure

The piezocision technique significantly accelerated the alignment phase compared to the fine-tuning phase. Indeed, according to several clinical studies,[12–15] piezocision was effective in accelerating orthodontic tooth movement in different clinical conditions. However, the efficacy seems to be limited to within 4 to 6 months after the surgery.[5,7,16,12,17] This acceleration could be related to RAP, which is a biological response after a bone injury, initially described by Frost[18,19] and validated recently in rat[3] and dog[20–22] studies. The RAP is transient, with an initiation and expiration period, as found in animal studies.[8,22,23] Specifically, the biological response following the piezocision procedure was recently highlighted in a rat study,[9] in which the authors also found transient and reversible biological effects at the tissue, cellular, and molecular levels. Thus, the temporary RAP cascade response after a bone injury could also explain the transient effect of the acceleration found after the piezocision procedure. To extend the acceleration of

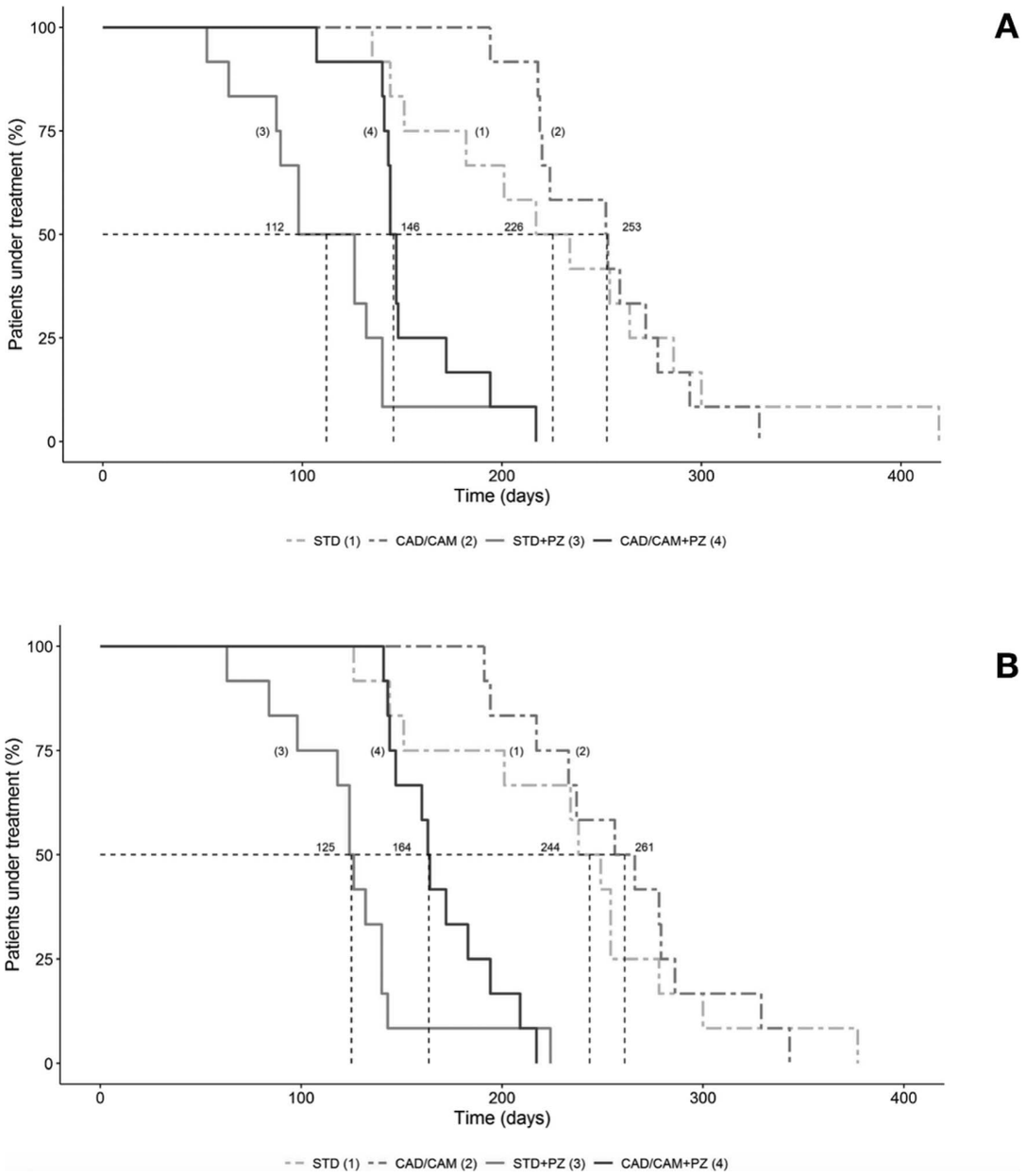

Figure 2. (a) Duration of the alignment phase in the maxilla in the four study groups. (b) Duration of the alignment phase in the mandible in the four study groups.

the tooth movement up to the fine-tuning phase, it has been suggested that a second piezocision should be performed,[5] but this has not yet been investigated and the potential additional morbidity with patient-reported outcome measurements (PROMs) also should be explored. Alternatively, the present results demonstrated that combining the piezocision procedure with a CAD/CAM appliance was an efficient treatment approach that accelerated tooth movement during the overall orthodontic treatment.

Effect of CAD/CAM Customized Orthodontic System

The CAD/CAM system significantly accelerated the fine-tuning phase compared to the piezocision procedure. Even if the available literature on this topic remains limited and has not investigated and deciphered action on the alignment and fine-tuning phases, some authors have agreed with the acceleration provided by CAD/CAM orthodontic systems. Brown et al.[4] demonstrated a significantly shorter overall treat-

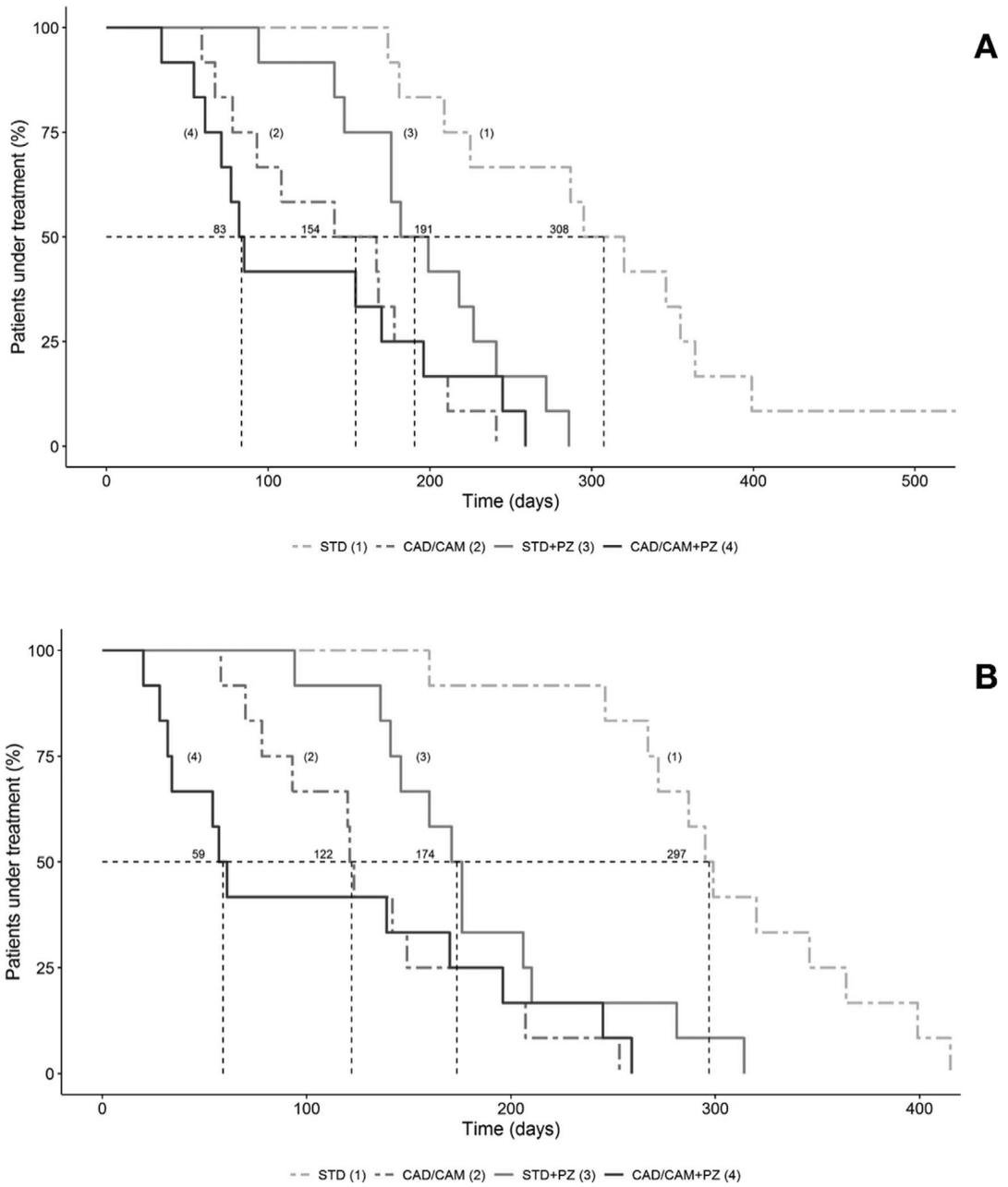

Figure 3. (a) Duration of the fine-tuning phase in the maxilla in the four study groups. (b) Duration of the fine-tuning phase in the mandible in the four study groups.

ment time in the CAD/CAM group compared to direct and indirect bonding groups, under the conditions of non-standardized appointment intervals between the different treatment groups. Additionally, Weber et al.[24] showed a reduction of the number of appointments and a shorter overall treatment time in the customized appliance group vs traditional twin appliances. Looking at the characteristics of the CAD/CAM orthodontic system, some theories could explain the acceleration found in the fine-tuning phase. First, the treatment plan is based on a virtual treatment schedule provided by software able to improve the definition of treatment objectives and visualization of the outcome. Second, it gives the user the possibility of evaluating different treatment options (localization and quantity of stripping . . . etc.) and also enabling the achievement of a perfect scenario and fine-tuning phase. Third, the workflow related to custom-made orthodontic appliances permits

Table 2. Change of Periodontal Parameters From Baseline to End of Treatment in the Four Groups[a]

Variable	STD (n = 12)	STD + PZ (n = 12)	CAD/CAM (n = 12)	CAD/CAM + PZ (n = 12)	*P* Value
Plaque index					
Baseline	0.89 ± 0.37	0.91 ± 0.70	0.67 ± 0.52	0.97 ± 0.73	
After treatment	0.83 ± 0.35	0.66 ± 0.30	0.35 ± 0.58	0.65 ± 0.57	
Difference	−0.058 ± 0.30	−0.25 ± 0.51	−0.32 ± 0.89	−0.32 ± 0.42	.66
Papilla bleeding index					
Baseline	1.5 ± 0.73	1.5 ± 0.69	1.0 ± 0.58	1.5 ± 0.59	
After treatment	1.2 ± 0.86	1.2 ± 0.41	0.54 ± 0.55	0.85 ± 0.59	
Difference	−0.23 ± 0.51	−0.33 ± 0.56	−0.48 ± 0.92	−0.68 ± 0.62	.40
Root resorption score					
Baseline	0.46 ± 0.93	0.91 ± 1.0	0.42 ± 1.2	0.97 ± 0.73	
After treatment	1.5 ± 0.73	1.5 ± 0.69	1.0 ± 0.58	1.5 ± 0.59	
Difference	0.46 ± 0.93	0.91 ± 1.0	0.42 ± 1.2	0.42 ± 1.2	.24
Pocket depth score					
Baseline	0.33 ± 0.65	0.50 ± 0.52	0.14 ± 0.31	0.40 ± 0.42	
After treatment	0.33 ± 0.65	0.58 ± 0.52	0.14 ± 0.31	0.38 ± 0.46	
Difference	0.0 ± 0.43	0.083 ± 0.52	0.0 ± 0.0	−0.02 ± 0.39	.92

[a] STD indicates standard orthodontic treatment; PZ, piezocision; CAD/CAM, computer-aided design and computer-aided manufacturing. * $P < .05$.

the production of a digital setup and details such as 3D tooth position. Finally, the intensity of the contact point or the arch form can be determined prior to treatment.[25] The manufacturing of CAD-CAM brackets allows custom-made torque and archwires that most likely contribute to an accurate and straightforward fine-tuning phase. In addition, the accuracy of the bonding bases of the brackets provides an almost perfect fit on the buccal tooth surfaces. The machine-milled indirect bonding jig contributes to a reduction in human error when bonding brackets. All these factors, therefore, can lead to an enhanced and precise prediction of the fine-tuning phase. Finally, a realistic expectation of the outcomes may be visualized allowing for better communication with the patient.[26]

Without taking the piezocision procedure into account, the CAD/CAM system can lead to more rapid OT compared to a standard approach, according to the hypothesis stated already. However, standard orthodontic treatment assisted by the piezocision procedure remained more rapid than the custom-made approach. Indeed, the acceleration provided by the CAD/CAM system during the fine-tuning phase did not reach the acceleration obtained by the piezocision procedure. For these reasons, the combined approach (CAD/CAM + piezocision) permitted OT that was twice as fast as a conventional approach, and might therefore be a relevant option in patients requesting an OT time as short as possible. In conditions of moderate crowding, the tooth movement acceleration provided by these two technologies did not impair periodontal parameters, including recession and root resorption. However, it is important to emphasize that the piezocision procedures were carefully planned and based on the preoperative CBCT imaging.

Limitations

This study was not in itself a four-arm RCT. The RCTs were performed at different time periods but under identical working conditions and the four patient groups were perfectly homogeneous. Study findings strictly apply to patients with mild-to-moderate crowding; therefore, it would be interesting to investigate treatment effects in subjects with a larger range of abnormalities. Finally, in view of these encouraging findings, further trials should be designed and carried out to test different CAD/CAM systems using various software and systems.

CONCLUSIONS

- The present study showed that both CAD/CAM customized orthodontic appliances and the use of piezocision markedly reduce the overall orthodontic treatment time.
- Although piezocision has an accelerating impact during the alignment phase, CAD/CAM customized orthodontic appliances significantly reduce the duration of the fine-tuning phase. The combination of the two techniques provides the highest treatment acceleration, with an overall treatment time that is twice as fast.

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