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# Piezocorticision-assisted orthodontics: Efficiency, safety, and long-term evaluation of the inflammatory process

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**Objectives:** The aim of this work was to compare the duration of treatment between orthodontic treatment combined with piezocorticision (OT-PC) and conventional orthodontic treatment (COT), as well as to evaluate the safety, inflammatory process, periodontal health, and soft tissue healing in the OT-PC group. **Methods:** Twelve patients were included in each group, and their treatment times were compared for preliminary bracket alignment (PBA) and for overall treatment. In the OT-PC group, the inflammatory process was evaluated by quantifying cytokines in the gingival crevicular fluid. A calibrated examiner measured the probing depth (PD), the distance between the gingival margin and the cementoenamel junction (GM-CEJ), and the clinical attachment level (CAL), before and after OT-PC. The presence of gingival scars was evaluated. Bone and root injuries were assessed with the use of cone-beam computed tomography. **Results:** The treatment time was significantly reduced in the OT-PC group for PBA in both maxilla (45%; $P = 0.001$) and mandible (31%; $P = 0.023$), as well as for overall treatment (52%; $P < 0.0001$). Although not statistically significant, several inflammatory mediators demonstrated peaks at 3-5 and 16 weeks. There were not significant changes in PD and GM-CEJ after OT-PC treatment, unlike CAL (0.09 $\pm$ 0.12 mm; $P = 0.024$); 47.5% of piezocorticisions caused gingival scars. Only one patient showed no scars. Four cortical bones did not heal completely, and 2 roots had piezoelectric injuries. **Conclusion:** OT-PC was effective at reducing the orthodontic treatment time. (Am J Orthod Dentofacial Orthop 2019;155:662-9)

Although the popularity of adult orthodontics has increased in the past 20 years,[1] treatment duration remains one of the main factors for refusal of orthodontic therapy.[2] Currently, the mean treatment time is 20.02 months. This duration might be reduced with the advent of new technologies, but the majority of adult patients expect that their treatment will be less than 1 year.[3] To address this issue, orthodontists, in collaboration with other specialists, have sought to reduce treatment time with the use of novel techniques, both invasive and noninvasive.[4,5] Surgical techniques have been the most studied, and they have evolved and become more popular since the introduction of corticotomies by the Wilcko brothers in 2001.[6] Their work proposed that the acceleration of orthodontic tooth movement observed with corticomy-assisted orthodontic therapy was based on the regional acceleratory phenomenon (RAP), as first described by Frost.[7] Theoretically, this phenomenon increases the bone turnover, decreases the hyalinization process, and creates an osteopenia.[8] However, the cellular mechanisms involved, their duration, and their intensity are still widely debated.[9]

Corticotomies are often considered to be too invasive by both practitioners and patients, so their acceptance remains weak.[10] To overcome this problem, a new minimally invasive surgical approach without flap elevation, called piezocorticision or piezocision, has been developed.[11] However, according to the literature, the clinical benefits and particularly the long-term results of this technique remain unclear.[12,13] The primary aim of the present clinical trial was to compare the duration of orthodontic treatment combined with piezocorticision (OT-PC) versus conventional orthodontic treatment

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(COT). The secondary objectives were to evaluate the safety of the piezocorticision and to assess the inflammatory process, periodontal health, and soft tissue healing during the first 6 months in the OT-PC group.

## MATERIAL AND METHODS

Patients were recruited from the graduate orthodontic clinic of the Université de Montréal. Participants in the OT-PC group were recruited from the adults' candidate list compiled from March to December 2015. The COT group was selected from a database of 292 consecutive patients treated from 2012 to 2015, with the use of buccal brackets and without orthognathic surgery, without impacted canine or agenesis, and who had finished in a Class I canine relationship.[14] The protocol was approved by the Health Research Ethics Committee of the Université de Montréal. Written consents were obtained from all participants after explanation of the potential risks and benefits.

Inclusion of at least 11 subjects in each group was required after sample size calculation to achieve a power of 80% at a 5% significance level, based on a mean treatment time of 18 months for OT-PC and 24 months for COT. To avoid a lack of power due to attrition, it was decided to include 16 consecutive adult patients in the OT-PC group. The COT group was composed of 16 consecutively treated individuals.

The inclusion criteria for the OT-PC group were as follows: (1) age 18-40 years, (2) complete permanent dentition; (3) patient in good health desiring orthodontic treatment with a shorter duration; (4) minor skeletal disharmonies; (5) malocclusion not requiring extraction or orthognathic surgery; (6) good oral hygiene; and (7) absence of oral infection or periodontitis. The exclusion criteria were as follows: (1) regular intake of analgesics or antidepressants; (2) alcohol or drug abuse; (3) smoking more than 10 cigarettes a day; (4) pregnancy; (5) local or systemic immunodeficiency or uncontrolled systemic disease; (6) coagulation disorders or anticoagulant therapy; (7) oral bisphosphonate intake for more than 4 years or intravenous administration of bisphosphonates; (8) premature debonding due to treatment cessation as requested by the patient; and (9) noncompliant patients who missed more than 3 appointments or with bracket failure of 5 units or more. The same inclusion and exclusion criteria were used in the COT group, except for the age of inclusion, which was 16-40 years.

Complete extra- and intraoral examinations were performed on all individuals, including extra- and intraoral photographs, dental cast models, panoramic radiographs, and lateral cephalographs. For the experimental group, a full periodontal examination was carried out. Initial difficulty of the cases was rated by a calibrated examiner with the use of the discrepancy index (DI).[15]

The surgical and radiologic planning procedures were carried out based on the method previously described by Strippoli et al.[16] Briefly, a radiologic guide was used to estimate the safest location of bone incisions with the use of cone-beam computed tomographic (CBCT; Cone Beam CT 5G; Newtom, Verona, Italy) exploration. It was then converted into a surgical guide by creating cuts on a clear retainer with a thin carbide disc mounted on a straight handpiece. The acquisition parameters for the CBCT images were 110 kVp and field of view (FOV) 12 $\times$ 8 cm. The total exposure (mAs) was set automatically by the scanner based on scout images. A high-resolution scan mode was systematically used with 486 views and a voxel size of 0.15 mm. These parameters were chosen because image resolution with a voxel size smaller than 0.2 mm demonstrates good precision and accuracy for measuring the bone crest level and thickness of the buccal and lingual cortical bone plates.[17]

Participants were asked to rinse with a 0.12% chlorhexidine gluconate mouth rinse (Peridex; 3M, St Paul, Minn) for 1 minute before the surgery. Regional and local anesthesia were performed with the use of 0.5% bupivacaine HCl with 1:200,000 epinephrine (Vivacaine; Septodont, Saint-Maur-des-Fossés, France). The surgical guides were placed on their respective arches and 5-mm-long mucoperiosteal incisions were performed using a #15 surgical blade through the cut lines. The surgical guide was removed and the gingival thickness were determined with the use of a periodontal probe. To guide the piezoelectric insert depth, this measurement was added to the initial bone depth determined from the CBCT analysis. Bone incisions were performed with the use of a 3-mm-long and 0.35-mm-thick piezoelectric insert (OT7S-3 Piezosurgery; Mectron, Columbus, Ohio). The piezocorticisions were carried out from the mesial of the second molar to the contralateral tooth in both arches. Mean depths of the piezocorticisions on alveolar bone were $\sim$2 mm in the anterior and $\sim$3 mm in the posterior sextants, depending on alveolar bone and tooth anatomy, with a length of the incision of 5 mm. Neither gingival sutures nor bone and soft tissue grafts were used. Patients were prescribed 500 mg acetaminophen to be taken immediately after the surgery, then every 4 hours for the next 48 hours and as needed thereafter. Patients were prescribed a 0.12% chlorhexidine gluconate mouth rinse to use for 1 minute twice daily for 7 days.

All patients were treated with Speed brackets (Strite Industries, Cambridge, Ontario, Canada). In the OT-PC group, indirect orthodontic bonding was performed 30 minutes after the surgery. A 0.018″ coaxial nickel titanium (NiTi; Supercable; Strite Industries) was used for 3 weeks from the first molar to the contralateral tooth in both arches. Oral hygiene and postoperative instructions were reviewed with the patient. During follow-up appointments, the archwire sequence was adapted for each patient as a function of the biomechanics required. Patients were followed every 2-3 weeks in the OT-PC group and approximately every 6 weeks in COT group.

After bonding the teeth, preliminary bracket alignment (PBA) was considered to be complete at the appointment where the first stainless steel wire was used or after 3 appointments with the same NiTi wire. The overall treatment time was calculated from the first bonding appointment to the debonding appointment of the brackets. All data were expressed in days.

All cases were rated with the use of the American Board of Orthodontics grading system (ABO-GS)[18] by a masked and calibrated examiner on digital models (OrthoCAD; Computer-Aided Dentistry, Fairview, NJ). To keep the blinding, cases were not evaluated for root angulation, because the OT-PC group had final panoramic radiographs reconstructed from the CBCT and the COT group had conventional panoramic radiographs.

At the end of the study, subjects in the OT-PC group were invited to answer whether they would undergo piezocorticision surgery again. If they were not willing to repeat the procedure, they were asked to explain the reasons why.

In the experimental group, a calibrated examiner performed a complete periodontal examination a month before and 2 months after the active orthodontic treatment. The probing depth (PD) and the distance between the gingival margin and the cementoenamel junction (GM-CEJ) were measured on the mesiobuccal, buccal, distobuccal, distolingual, lingual, and mesiolingual aspects of all teeth. The clinical attachment level (CAL) was determined by subtracting the GM-CEJ distance from the PD. For the PD and the CAL, the mean of the buccal and lingual measures were calculated, and for the GM-CEJ only the mean of the buccal data was used to assess the presence or absence of gingival buccal recessions (BRs). During the posttreatment probing, the examiner also noted if scars on the gingiva and mucosa were present.

To investigate the inflammatory process, a variant of the technique described by Uematsu et al[19] was used to collect the gingival crevicular fluid (GCF) on the upper left lateral incisor. The supragingival plaque was cautiously removed without touching the gingival margin to reduce the risk of bacterial contamination. The tooth was isolated with a cotton roll to reduce the risk of saliva contamination and was lightly dried with the use of an air-water syringe. A sterile periodontal paper strip (Periopaper Strips; Oraflow, Hewlett, NY) was used for each sample and the procedure was repeated 3 times. The strip was gently inserted 1 mm deep into the gingival sulcus and was not removed before at least a fourth of the periodontal paper was soaked. The strips were then placed in a vial and stored at $-80^{\circ}$C. The biomarkers were detected by means of the Luminex multianalytical technique (Merck KGaA, Darmstadt, Germany). Each sample was analyzed twice according to total quantification of the proteins. The samples were taken just before surgery to serve as a baseline, then 3, 5, 8, 16, and 24 weeks after surgery. The biomarkers analyzed were interleukin (IL) 1$\beta$, IL-2, IL-6, IL-8, IL-10, interferon (IFN) $\gamma$, tumor necrosis factor (TNF) $\alpha$; receptor activator of nuclear factor kappa-B ligand (RANKL), osteoprotegerin (OPG), granulocyte-macrophage colony-stimulating factor (GM-CSF), macrophage inflammatory protein (MIP) 1$\alpha$, and MIP-$\beta$.

Potential root injuries and cortical bone healing were investigated on axial CBCT slices. Images were oriented along the occlusal plane. All slices were analyzed from the apex of the maxillary teeth to the apex of the mandibular teeth.

### Statistical analysis

The intra- and interexaminer reliability were determined with the use of intraclass (IaCC) and interclass (IeCC) correlation coefficients. IaCC and IeCC from 0.70 to 0.90 were considered to be good, and $>$0.90 as excellent.

A Fisher exact test was used to compare the sex ratio between groups. The Shapiro-Wilk test was used to evaluate the normality of distribution. For variables following the normality law, a 2-sample $t$ test was used with the mean and SD. Otherwise, a Mann-Whitney $U$ test was performed with the median and interquartile range (IQR). Multivariable linear regression analysis was conducted (analysis of covariance) if a significant difference between groups was observed for patient and treatment characteristics. Results were adjusted for the following potential confounding factors on overall treatment time: age, sex, DI, and bracket failure. For the biomarkers analysis, a Brunner-Langer test model for nonparametric statistical models was used as well as a Dunnett test, and each patient was compared with him- or herself. Statistical analyses were performed

**Table I.** Patients and treatment characteristics

| *Characteristic* | *OT-PC group (n = 12)* | *COT group (n = 12)* | P *value* | *ANCOVA* |
|---|---|---|---|---|
| Age, y (mean ± SD) | 28.0 ± 6.0 | 17.1 ± 0.8 | <0.001 | $P$ = 0.505 |
| Sex (M:F) | 4:8 | 2:10 | 0.640 | |
| DI score (mean ± SD) | 16.6 ± 5.7 | 9.3 ± 5.0 | 0.003 | $P$ = 0.794 |
| Crowding score of DI (median ± IQR) | 4 ± 3 | 3 ± 3 | 0.389 | |
| Missed appointments (median ± IQR) | 0.6 ± 1.0 | 1.1 ± 2.0 | 0.276 | |
| Bracket failures (median ± IQR) | 0 ± 1 | 1 ± 3 | 0.004 | $P$ = 0.679 |
| Number of appointments (mean ± SD) | 22.0 ± 3.7 | 21.0 ± 4.8 | 0.572 | |
| ABO score (mean ± SD) | 26.2 ± 7.1 | 22.2 ± 6.9 | 0.165 | |

with the use of SPSS version 24 (IBM Corp, Armonk, New York) and SAS version 9.4 (SAS Institute, Cary, NC). A significance level of $P < 0.05$ was used.

## RESULTS

The IaCC for the DI was 0.980 between the 2 examiners for the periodontal parameters (PD, GM-CEJ, CAL). The IaCC and IeCC of the examiners for the ABO-GS were 0.982 and 0.880, respectively, showing good to excellent intra- and interexaminer reliability.

Four of the original 16 patients were excluded in the OT-PC group. Two became pregnant, one had a periapical lesion detected on the panoramic radiograph before the beginning of the trial, and another patient did not comply with the study protocol. Only 9 COT patients in the database of 292 fulfilled the selection criteria. Three additional consecutively treated individuals in 2015 were added to the COT group to have a similar number in the 2 groups. One patient was excluded for the periodontal data because he never presented himself for the posttreatment data collection.

Patient and treatment characteristics are described in Table I. The 2 groups were similar except for DI, age, and number of bracket failures. These confounding variables had no statistically significant effect on the treatment time ($P$ = 0.794, 0.505, and 0.679, respectively).

For the lower jaw, the PBA was significantly shorter by 31% in the OT-PC group (range 54-197 days) compared with the COT group (range 105-315 days). For the upper arch, the PBA was 45% shorter in the OT-PC group (range 73-285 days) compared with the COT group (range 156-383) (Fig 1). The overall treatment time was 52% shorter in the experimental group, with a mean of 14.5 months (range 314-569 days) versus 29.9 months in the control group (range 567-1149 days; Fig 2). After adjustment for DI, age, and bracket failures, the duration of treatment was significantly decreased by 54% in the OT-PC group compared with the COT group (14.0 vs 30.4 months, respectively; $P$ = 0.001).

Periodontal data are presented in Table II. There were no statistically significant changes in PD and GM-CEJ

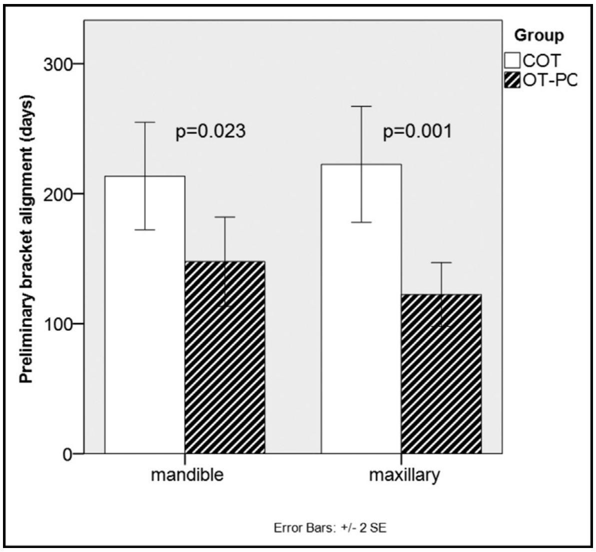


**Fig 1.** Treatment times for the preliminary bracket alignment.

before and after OT-PC treatment ($P > 0.05$). However, OT-PC participants exhibited significant CAL loss (0.09 ± 0.12 mm; $P$ = 0.024). Almost half (47.5%) of piezocorticisions caused point and line scars on the gingiva or mucosa (Fig 3). Only 1 patient showed no gingival scars.

Two roots were damaged by the piezo surgical insert (Fig 4, *A*). The injuries were minimal, ~1 mm deep and 0.5 mm wide for both, and were not associated with any clinical signs or symptoms. Four alveolar cortical plates were not completely healed (Fig 4, *B*). One pulp necrosis occurred on a central incisor, but after CBCT analysis no piezoelectric-induced root injuries were observed (Fig 4, *C*).

Table III indicates that several inflammatory mediators demonstrated peaks between 3 and 5 weeks and at 16 weeks after surgery. These variations were not statistically significant over time ($P > 0.05$).

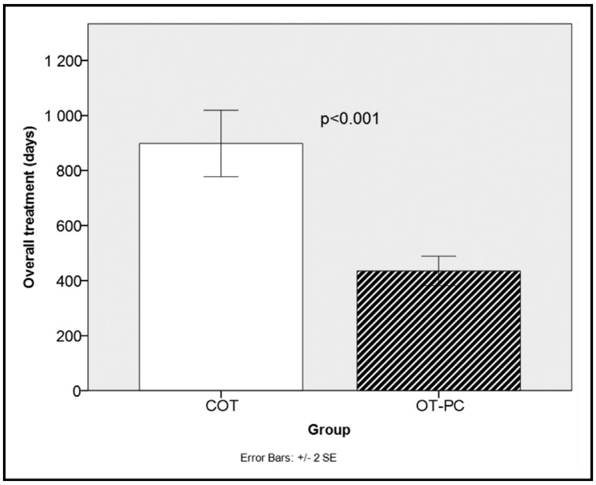


**Fig 2.** Overall treatment times.

**Table II.** Periodontal parameters in the OT-PC group (n = 11), mean ± SD

| *Variable* | *Pre-op* | *Post-op* | *Mean change** | P *value* |
|---|---|---|---|---|
| PD (mm) | 2.35 ± 0.25 | 2.20 ± 0.18 | −0.15 ± 0.23 | 0.051 |
| BR (mm) | 2.17 ± 0.20 | 2.11 ± 0.23 | −0.05 ± 0.18 | 0.340 |
| CAL (mm) | 0.14 ± 0.16 | 0.05 ± 0.07 | −0.09 ± 0.12 | 0.024 |

*Mean difference was calculated as post- minus pretreatment values.

## DISCUSSION

The main objective of this study was to compare the treatment duration between the OT-PC and the COT groups. Confounding variables did not have a significant effect on the treatment time in this trial ($P > 0.05$), despite the fact that according to the literature, DI and bracket failure could increase the duration.[20,21] Evidences have shown that age[22] as well as different methods of orthodontic bonding, such as direct versus indirect bonding,[23] do not seem to affect the treatment time. One interesting point to highlight is that the ABO-GS scores were similar in both groups. Final treatment quality ratings done by an external blind calibrated evaluator should be kept in future studies, because it excludes a major risk of bias.

The duration of the PBA was shortened in the OT-PC by 31% and 45% in the mandible and the maxilla, respectively. The difference between the 2 arches could be explained by the fact that one-fourth of the bone incisions could not be performed between lower incisors because of root proximity. This result was similar to the study by Charavet et al.[24] However, Uribe et al found no significant difference between their groups for the alignment of the lower incisors.[25] These contradictory results could be explained by the fact that the surgical procedure was less invasive in that study with 1-mm-deep and 4-mm-long piezocorticisions versus the more invasive 3-mm-deep and 5-mm-long piezocorticisions used in our study. A significant alveolar surgical injury seems to be positively associated with the orthodontic tooth movement in rats owing to the increased osteoclastic activity obtained with OT-PC.[26] This hypothesis might explain the improved results of OT-PC during canine distalization demonstrated by Aksakalli et al.[27] They performed 10-mm-long and 3-mm-deep bone incisions that resulted in a 37% increase in tooth movement compared with COT.

Our OT-PC protocol decreased the overall treatment time by approximately half. These results were similar to those from a recent randomized clinical trial conducted by Charavet et al[24], who showed a 43% decrease in treatment time. Similar reduced treatment time (<1 y) was reported earlier in a case report of Class II malocclusion patients treated with the use of OT-PC.[28] The mean duration for the overall treatment in the COT group was higher (29.9 months) than the 20.0 months described in a recent systematic review.[29] This difference can be explained by the fact that our trial was performed in an academic environment by a resident enrolled in a postgraduate orthodontic program. Although very few prospective controlled studies have been published on the effect of piezocorticisions on duration of orthodontic treatment, our findings are encouraging.

In agreement with a recent systematic review,[13] our study also confirmed that the OT-PC can be considered to be a safe procedure. The piezocorticision-related injuries were scarce and minimal. Four cortical bone plates did not completely heal, probably because of migration of epithelial cells into the wound margins. For the pulpal necrosis that occurred on one anterior tooth, the cause may not have been associated with the surgery, because no piezocorticision-related injury was observed on the CBCT. However, the specific causes might be multifactorial although they remain unclear. It could have been caused by the orthodontic tooth movement or due to occlusal trauma, because before treatment, the patient presented with a complete anterior crossbite except for that tooth. Piezocorticisions did not significantly influence periodontal parameters such as PD and GM-CEJ, except for a statistically significant attachment loss (mean −0.09 mm; $P = 0.024$) which was not clinically significant. Except for 1 patient, all subjects had at least 1 gingival or mucosal scar. That was higher than the 50% described elsewhere.[24] Almost half of piezocorticisions induced a point or linear scar. Consequently, this minor complication should be discussed with the patient during the informed consent process. Also, in patients

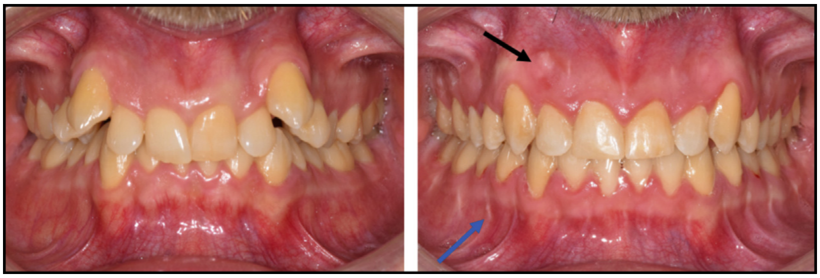

**Fig 3.** Example of gingival or mucosal scars: line (*blue arrow*) and point (*black arrow*).

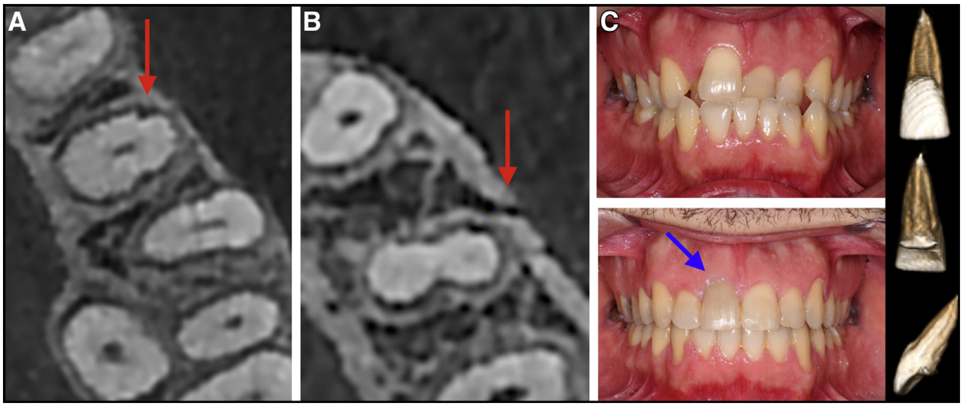


**Fig 4.** Root and cortical bone injuries. CBCT images illustrating **A,** subtle root damage and **B,** incomplete healing of the cortical plate. **C,** Pulpal necrosis involving the upper right central incisor. The specific causes remain unknown because no piezocorticision-related injury was observed.

**Table III.** Biomarkers of inflammatory process (pg/μL), mean ± SD

| *Biomarker* | *0* | *3* | *5* | *8* | *16* | *24* | P *value* |
|---|---|---|---|---|---|---|---|
| GM-CSF | 3.43 ± 2.49 | 3.58 ± 3.36 | 3.23 ± 1.99 | 2.42 ± 1.24 | 2.60 ± 0.85 | 2.75 ± 2.29 | 0.776 |
| IFN-γ | 1.61 ± 0.60 | 1.56 ± 0.63 | 1.63 ± 0.50 | 1.41 ± 0.32 | 1.57 ± 0.41 | 1.49 ± 0.45 | 0.717 |
| IL-10 | 4.94 ± 4.22 | 6.89 ± 7.21 | 5.80 ± 8.27 | 4.80 ± 4.52 | 6.19 ± 3.97 | 5.32 ± 5.11 | 0.699 |
| IL-1β | 13.76 ± 13.86 | 37.68 ± 49.22 | 30.96 ± 21.06 | 13.26 ± 13.40 | 26.24 ± 30.99 | 24.98 ± 23.67 | 0.444 |
| IL-2 | 0.80 ± 0.65 | 0.89 ± 0.60 | 0.84 ± 0.55 | 0.79 ± 0.54 | 0.89 ± 0.50 | 0.72 ± 0.47 | 0.977 |
| IL-6 | 4.88 ± 5.79 | 2.64 ± 2.40 | 2.63 ± 2.17 | 2.94 ± 2.77 | 2.98 ± 1.95 | 1.84 ± 1.61 | 0.271 |
| IL-8 | 0.88 ± 0.69 | 1.12 ± 0.59 | 1.02 ± 0.92 | 0.69 ± 0.36 | 0.83 ± 0.54 | 0.82 ± 1.09 | 0.243 |
| MIP-1α | 16.61 ± 15.23 | 15.76 ± 7.53 | 15.79 ± 11.81 | 11.80 ± 5.68 | 16.88 ± 12.05 | 14.17 ± 13.77 | 0.747 |
| TNF-α | 5.49 ± 5.06 | 6.08 ± 6.30 | 3.55 ± 2.52 | 4.79 ± 6.48 | 5.21 ± 5.54 | 5.38 ± 8.50 | 0.701 |
| RANKL | 3.11 ± 1.95 | 3.59 ± 1.36 | 3.22 ± 1.68 | 2.76 ± 1.16 | 2.83 ± 1.17 | 2.74 ± 1.56 | 0.629 |
| OPG | 31.67 ± 27.60 | 60.82 ± 61.35 | 51.85 ± 63.03 | 30.10 ± 23.37 | 44.35 ± 48.87 | 32.99 ± 22.39 | 0.560 |
| RANKL/OPG | 0.16 ± 0.11 | 0.13 ± 0.12 | 0.15 ± 0.12 | 0.20 ± 0.22 | 0.13 ± 0.10 | 0.17 ± 0.25 | 0.843 |
| MIP-1β | 21.13 ± 24.56 | 17.86 ± 9.80 | 15.53 ± 13.24 | 12.63 ± 7.60 | 19.30 ± 17.50 | 14.51 ± 16.48 | 0.427 |

All pairwise comparisons with baseline were not statistically significant ($P > 0.15$, Dunnet test).

with a high smile line, this technique might be contraindicated for esthetic reasons. A future controlled trial with a surgical protocol including sutures or the use of a tissue glue should be carried out to evaluate their potential to prevent scar formation. Interestingly, no participant complained about the OT-PC. The acceptance of the piezocorticision procedure was considerably high compared with corticotomy-assisted orthodontics, which is a more invasive surgery. A study in corticotomy-assisted orthodontics conducted in Saudi Arabia reported that only 32% of the patients would again undergo that modality.[10] However, it is worth mentioning that cultural differences in attitude toward surgery may also influence the degree of patient and clinician satisfaction.

Although not statistically significant, several proinflammatory markers showed clinical peaks of upregulation at 3-5 and 16 weeks. The lack of power or interindividual variations could explain why these variations remained nonsignificant. These results were unexpected; a peak in the first month was anticipated, to be followed by a gradual decrease over time and remaining above the initial level. It is possible that a higher peak occurred during the first week, as has been reported by others in patients treated with the use of COT.[30] However, because our second sampling was carried out at 3 weeks, that evidence could not be detected in our study. Sampling appointments were deliberately spaced at longer time intervals to evaluate the fluctuations of the inflammatory process in the periodontal tissues at mid- and long-term follow-ups. The objective was to provide some preliminary data on the duration of the RAP for the OT-PC group. The second peak could be explained by the reactivation of the inflammatory process as an oscillating phenomenon. This hypothesis has already been discussed by other investigators and could explain why some considered a second corticotomy surgery to not be efficient,[31] and it could challenge the conclusion that the RAP is effective after 2-3 months in humans.[32,33] These assumptions will have to be confirmed in future studies.

Our study has some limitations. The COT group was selected from a pool of previously treated patients, thus increasing the risk of selection bias. A prospective randomized controlled clinical trial would have been more powerful to evaluate the potential effect of OT-PC on treatment time, periodontal parameters, patient's satisfaction, and inflammatory process. Nevertheless, disparities in patient and treatment characteristics such as sex, age, DI, bracket failure, and different bonding techniques were not found to have a significant effect on the outcomes, although a few other trials have found an opposite effect for DI and bracket failure. Although the numbers of appointments were similar between groups, the shorter appointment intervals in the OT-PC group could have had a favorable impact on reducing the treatment time compared with the COT group. Whereas the follow-ups of the OT-PC patients were at every 2 weeks, the COT patients were seen at every 6 weeks. Moreover, in this study, the criteria of inclusion did not include cases with tooth extractions or major skeletal disharmonies. Consequently, our findings can not be extrapolated to more complex orthodontic cases. Further randomized controlled trials are recommended before OT-PC can be proposed routinely to patients undergoing orthodontic therapy.

## CONCLUSIONS

The OT-PC protocol decreased overall treatment time by approximately half compared with COT. In addition, most patients indicated that they would be willing to undergo an OT-PC procedure again. Minimal effects on periodontal parameters were observed despite the presence of gingival scars. Although not statistically significant, proinflammatory markers showed clinical peaks at 3-5 and 16 weeks following surgery.

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## REFERENCES

1. Proffit WR, Fields HJ. Contemporary orthodontics. 5th ed. St Louis: Elsevier Mosby; 2012.
2. Pacheco-Pereira C, Pereira JR, Dick BD, Perez A, Flores-Mir C. Factors associated with patient and parent satisfaction after orthodontic treatment: a systematic review. Am J Orthod Dentofacial Orthop 2015;148:652-9.
3. Uribe F, Padala S, Allareddy V, Nanda R. Patients', parents', and orthodontists' perceptions of the need for and costs of additional procedures to reduce treatment time. Am J Orthod Dentofacial Orthop 2014;145:S65-73.
4. El-Angbawi A, McIntyre GT, Fleming PS, Bearn DR. Nonsurgical adjunctive interventions for accelerating tooth movement in patients undergoing fixed orthodontic treatment. Cochrane Database Syst Rev 2015;(11):CD010887.
5. Fleming PS, Fedorowicz Z, Johal A, El-Angbawi A, Pandis N. Surgical adjunctive procedures for accelerating orthodontic treatment. Cochrane Database Syst Rev 2015;(6):CD010572.
6. Wilcko WM, Wilcko T, Bouquot JE, Ferguson DJ. Rapid orthodontics with alveolar reshaping: two case reports of decrowding. Int J Periodontics Restorative Dent 2001;21:9-19.
7. Frost HM. The regional acceleratory phenomenon: a review. Henry Ford Hosp Med J 1983;31:3-9.
8. Strippoli J, Aknin JJ. [Accelerated tooth movement by alveolar corticotomy or piezocision]. Orthod Fr 2012;83:155-64. French.
9. Huang H, Williams RC, Kyrkanides S. Accelerated orthodontic tooth movement: molecular mechanisms. Am J Orthod Dentofacial Orthop 2014;146:620-32.
10. Zawawi KH. Patients' acceptance of corticotomy-assisted orthodontics. Patient Prefer Adherence 2015;9:1153-8.
11. Dibart S, Sebaoun JD, Surmenian J. Piezocision: a minimally invasive, periodontally accelerated orthodontic tooth movement procedure. Compend Contin Educ Dent 2009;30:342-50.
12. Hoffmann S, Papadopoulos N, Visel D, Visel T, Jost-Brinkmann PG, Prager TM. Influence of piezotomy and osteoperforation of the alveolar process on the rate of orthodontic tooth movement: a systematic review. J Orofac Orthop 2017;78:301-11.

13. Yi J, Xiao J, Li Y, Li X, Zhao Z. Efficacy of piezocision on accelerating orthodontic tooth movement: A systematic review. Angle Orthod 2017;87:491-8.
14. Gauthier M, Gandet C. Evaluation et quantification de différents facteurs influençant le temps de traitement orthodontique: [thesis]. Université de Montréal; 2017.
15. Cangialosi TJ, Riolo ML, Owens SE Jr, Dykhouse VJ, Moffitt AH, Grubb JE, et al. The ABO discrepancy index: a measure of case complexity. Am J Orthod Dentofacial Orthop 2004;125:270-8.
16. Strippoli J, Schmittbuhl M, Voyer R, Rompré P, Nishio C. Pain and quality of life in patients undergoing guided piezocorticision-assisted orthodontic treatment. J Clin Orthod 2017;51:792-9.
17. Menezes CC, Janson G, da Silveira Massaro C, Cambiaghi L, Garib DG. Precision, reproducibility, and accuracy of bone crest level measurements of CBCT cross sections using different resolutions. Angle Orthod 2016;86:535-42.
18. Casko JS, Vaden JL, Kokich VG, Damone J, James RD, Cangialosi TJ, et al. American Board of Orthodontics. Objective grading system for dental casts and panoramic radiographs. Am J Orthod Dentofacial Orthop 1998;114:589-99.
19. Offenbacher S, Odle BM, van Dyke TE. The use of crevicular fluid prostaglandin E2 levels as a predictor of periodontal attachment loss. J Periodontal Res 1986;21:101-12.
20. Parrish LD, Roberts WE, Maupome G, Stewart KT, Bandy RW, Kula KS. The relationship between the ABO discrepancy index and treatment duration in a graduate orthodontic clinic. Angle Orthod 2011;81:192-7.
21. Skidmore KJ, Brook KJ, Thomson WM, Harding WJ. Factors influencing treatment time in orthodontic patients. Am J Orthod Dentofacial Orthop 2006;129:230-8.
22. Mavreas D, Athanasiou AE. Factors affecting the duration of orthodontic treatment: a systematic review. Eur J Orthod 2008;30:386-95.
23. Deahl ST, Salome N, Hatch JP, Rugh JD. Practice-based comparison of direct and indirect bonding. Am J Orthod Dentofacial Orthop 2007;132:738-42.
24. Charavet C, Lecloux G, Bruwier A, Rompen E, Maes N, Limme M, et al. Localized piezoelectric alveolar decortication for orthodontic treatment in adults: a randomized controlled trial. J Dent Res 2016;95:1003-9.
25. Uribe F, Davoody L, Mehr R, Jayaratne YS, Almas K, Sobue T, et al. Efficiency of piezotome-corticision assisted orthodontics in alleviating mandibular anterior crowding—a randomized clinical trial. Eur J Orthod 2017;39(6):595-600.
26. Dibart S, Yee C, Surmenian J, Sebaoun JD, Baloul S, Goguet-Surmenian E, et al. Tissue response during piezocision-assisted tooth movement: a histological study in rats. Eur J Orthod 2014;36:457-64.
27. Aksakalli S, Calik B, Kara B, Ezirganhi S. Accelerated tooth movement with piezocision and its periodontal-transversal effects in patients with Class II malocclusion. Angle Orthod 2015;86(1):59-65.
28. Dibart S, Surmenian J, Sebaoun JD, Montesani L. Rapid treatment of Class II malocclusion with piezocision: two case reports. Int J Periodontics Restorative Dent 2010;30:487-93.
29. Tsichlaki A, Chin SY, Pandis N, Fleming PS. How long does treatment with fixed orthodontic appliances last? A systematic review. Am J Orthod Dentofacial Orthop 2016;149:308-18.
30. Kapoor P, Kharbanda OP, Monga N, Miglani R, Kapila S. Effect of orthodontic forces on cytokine and receptor levels in gingival crevicular fluid: a systematic review. Prog Orthod 2014;15:65.
31. Sanjideh PA, Rossouw PE, Campbell PM, Opperman LA, Buschang PH. Tooth movements in foxhounds after one or two alveolar corticotomies. Eur J Orthod 2010;32:106-13.
32. Buschang PH, Campbell PM, Stephen R. Accelerating tooth movement with corticotomies: is it possible and desirable? Semin Orthod 2012;18:286-94.
33. Mathews DP, Kokich VG. Accelerating tooth movement: the case against corticotomy-induced orthodontics. Am J Orthod Dentofacial Orthop 2013;144:5-13.