Minimally invasive corticotomy in orthodontics using a three-dimensional printed CAD/CAM surgical guide


Abstract. The aim of this prospective study was to evaluate the effectiveness of an innovative, minimally invasive, flapless corticotomy procedure in orthodontics. The STROBE guidelines were followed. Ten patients with severe dental crowding and a class I molar relationship were selected to receive orthodontic treatment with clear aligners and corticotomy-facilitated orthodontics. The mean age of these patients was 21 years (range 17–28, standard deviation 6.08 years); the male to female ratio was 2:1. The main outcome was a reduction in the total treatment time to correct dental crowding. The secondary outcomes were periodontal index changes, the degree of root resorption, and patient perceptions of the method used, assessed using the short-form Oral Health Impact Profile (OHIP-14). The occurrence of early surgical complications or unexpected events was also recorded. All patients completed the treatment to correct dental crowding. The average treatment time was reduced by two-thirds. The procedure did not significantly modify the periodontal indices or oral health-related quality of life. No early surgical complications or unexpected events were observed. In short, the results indicate that this new procedure is safe and accelerates tooth movement without periodontal complications or discomfort. However, the efficacy of this procedure must be confirmed in controlled clinical trials.

Keywords: corticotomy; orthodontics; CAD/CAM; minimally invasive; surgical template; 3D printer.

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The goal of orthodontic treatment is to improve the patient’s quality of life through the enhancement of dentofacial functions and aesthetics. Treatment decisions are based on considerations such as the severity of the malocclusion, pre-existing alveolar deficiencies, extraction versus non-extraction protocols, and patient expectations. The orthodontic treatment of adolescent or adult patients can be challenging; these patients often request short treatments. Rapid orthodontic tooth movement with a concomitant reduction in treatment time can be attained through a combination of orthodontic treatment and surgical alveolar corticotomies. Corticotomy is defined as any intentional surgical injury to the cortical...
bone; this technique has been claimed to dramatically reduce treatment times because the resistance of the dense cortical bone to orthodontic tooth movement is removed.\textsuperscript{1,5} With a corticotomy, shallow perforations or cuts are made only in the cortical alveolar bone; in contrast to an osteotomy, the trabecular bone is left intact.\textsuperscript{2} Orthodontic force is applied shortly after surgery to produce the desired tooth movement, but the bone remodeling process is slow.\textsuperscript{3}

It has been claimed that orthodontic treatment progresses faster and that the results are more stable after a corticotomy, with minimal risks or complications.\textsuperscript{3} However, an evaluation of recently published systematic reviews on corticotomy-facilitated orthodontics showed the inclusion of clinical trials that involved only small groups of patients and provided moderate- or low-level evidence.\textsuperscript{9,10} The use of corticotomy to accelerate orthodontic tooth movement, although effective, presents significant postoperative discomfort.\textsuperscript{9,11} The aggressive nature of these particular methods, due to the elevation of mucoperiosteal flaps and to the length of the surgery, has resulted in a reluctance to employ them among both the patient and dental communities.\textsuperscript{12} Initially the cortical incisions were performed using a bone bur that could potentially damage the roots of neighbouring teeth; more recently the corticotomy has been performed by means of a piezoelectric surgery microsaw.\textsuperscript{13,14} The use of piezoelectric instruments seems to have several advantages, including a reduction in intraoperative bleeding and surgical trauma, and improved intraoperative visibility.\textsuperscript{15,16}

To overcome the disadvantages of the corticotomy, Dibart et al. introduced the concept of ‘Piezocision’, a procedure that entails small incisions, minimal piezoelectric osseous cuts to the buccal cortex only, and bone or soft tissue grafting.\textsuperscript{17} Piezocision is performed under local anaesthesia through a tunnel approach involving approximately 10 vertical interproximal incisions per arch.\textsuperscript{18} More recently Milano et al. described a method for combining Piezocision with the use of computed tomography (CT).\textsuperscript{19} By creating a three-dimensional (3D) model of the arch, the depth and location of the corticotomies are planned and transferred to a resin surgical guide using a numerically controlled milling machine.

Even more recently, an innovative, minimally invasive, flapless procedure combining piezoelectric surgery cortical micro-incisions with the use of a 3D-printed computer-aided design and computer-aided manufacturing (CAD/CAM) surgical guide has been reported in the literature.\textsuperscript{19} Using this technique the cuts are made using a 3D-printed surgical guide, which can reduce the risk of damage to the anatomical structures. The aim of the present study was to evaluate the effectiveness of this new technique. It was hypothesized that corticotomy using a 3D printed surgical guide would decrease the length of time of orthodontic treatment for severe dental crowding in patients with class I molar relationships. It was also hypothesized that this new technique would not be associated with periodontal tissue damage and would not have a negative impact on patient perceptions of the treatment.

Materials and methods

This prospective cohort study was conducted at the department of orthodontics of the study institution between November 2013 and July 2015. The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for prospective cohort studies were followed. This clinical investigation was conducted in accordance with the ethical principles of the World Medical Association Declaration of Helsinki and was undertaken after informing the patient of the content, risks, and benefits of the study. Written consent was obtained from each participant. The investigation was reviewed and approved by the local ethics committee.

Eligibility criteria were as follows: systemically healthy patient; no clinical evidence of dental caries; good oral hygiene; skeletal and molar class I relationships; severe crowding of both arches (4 mm or more of discrepancy).\textsuperscript{20}

The primary outcome was a reduction in the total treatment time to correct severe dental crowding in patients with skeletal and molar class I relationships. The secondary outcomes were changes in periodontal indices, the degree of root resorption, and patient perceptions of the method used. The occurrence of early surgical complications or unexpected events was also recorded.

The patients were treated by a single operator (MC), highly experienced in orthodontics and oral surgery. The minimally invasive, flapless corticotomy procedure combining piezoelectric surgery cortical micro-incisions with the use of a 3D printed CAD/CAM surgical guide was used.\textsuperscript{19} Orthodontic force was applied to the teeth immediately after surgery using clear aligners. Before the surgical procedure, polyvinyl siloxane (PVS) impressions of the upper and lower arches were taken and sent to the manufacturer to create clear aligners for the upper and lower arches (Smiletech, Ortodontica Italia, Rome, Italy). When necessary the upper and lower teeth were reduced at each interproximal location by means of diamond-coated finishing strips used for interproximal reduction. This reduction was carried out at different stages of treatment, depending on the degree of access to the interproximal areas at any given stage. In some cases, the extraction of at least one tooth was also planned, due to a lack of space. Every aligner was put in place for 5 days rather than the standard 15 days, the time that is usually necessary to change the aligner. In this way, completion of the orthodontic treatment was planned to take approximately one third of the time needed for conventional orthodontic treatment with clear aligners. After completion of the treatment, the patients used retainers and were instructed to wear them full-time for 1 year, followed by night-time use for an indefinite period (Figs. 1–4).

![Fig. 1. Intraoral images obtained prior to the corticotomy-assisted orthodontic treatment of an 18-year-old male patient with class I molar relationship and severe crowding.](image-url)
The modified gingival index (mGI) and probing pocket depth (PPD) were determined using a UNC 15 probe. The mGI according to Mombelli et al. was used: score 0 = no bleeding; score 1 = isolated bleeding spots; score 2 = confluent blood; score 3 = profuse bleeding. The sulcular depth (the distance from the gingival margin to the base of the sulcus) of the teeth, from right first molar to left first molar, was measured at the mesiobuccal, midbuccal, distobuccal, distolingual, midlingual, and mesiolingual aspects in both arches. The measurements of each periodontal index were taken by two examiners (SC, AD), before treatment and at the end of treatment. The time frame was different for each patient, depending on the length of the orthodontic treatment. The two values were averaged.

Pre- and post-treatment ortho-panoramic radiographs were obtained. The degree of root resorption was evaluated by one author (SC) from pre-treatment and post-treatment panoramic radiographs taken after the end of active treatment. The post-treatment root lengths of all tooth groups, except third molars, were compared with the root lengths on the pretreatment radiographs. The degree of root resorption was assessed on a scale of 0 to 2: grade 0 = no radiographically visible root resorption; grade 1 = mild resorption with rounding of the root apex to about one-quarter of the root length; grade 2 = moderate to severe resorption with the loss of one-quarter or more of the root length. Panoramic radiographs were also used to assess the presence of any root damage caused by corticotomy.

Oral health-related quality of life (OHRQoL) was assessed using the Italian version of the short-form Oral Health Impact Profile (OHIP-14). The OHIP-14 contains 14 questions, representing seven dimensions of OHRQoL: functional limitation, physical pain, psychological discomfort, physical disability, psychological disability, social disability, and handicap. These questions retain the original conceptual dimensions of the OHIP, thus the instrument should be useful for quantifying levels of impact on wellbeing in settings where only a limited number of questions can be administered. The patient received the OHIP-14 questionnaire after being provided with instructions on its completion. The self-administered questionnaire was completed by the patient.

Fig. 2. (A) The 3D printed CAD/CAM surgical guide positioned on the upper arch to avoid the reflection of a full-thickness flap. After positioning the surgical guide, the stability is checked and the patient invited to bite. The guide presents an extension on the occlusal surface of the teeth, with interincisalizations that allow further stabilization of the guide when the patient closes their teeth. Images (B) to (D) show the patient after gingival vertical incisions and interproximal corticotomy cuts. (E) Suture of the vertical incisions using Vicryl 3–0 thread (Vicryl; Ethicon, Johnson & Johnson, Somerville, NJ, USA). (F) Positioning of the lower 3D printed surgical guide. (G) Gingival vertical incisions made interproximally below the interdental papilla using a number 15 blade. The incisions must cross the periosteum allowing the blade to come into contact with the alveolar bone. (H) The corticotomy cuts performed through the gingival incisions 2 mm beyond the apices of the teeth. Interproximal corticotomy cuts were extended through the entire thickness of the cortical layer, just barely penetrating the medullary bone. The design of the vertical cuts was finalized to maximize the marrow penetration and bleeding. The corticotomy was performed with a piezoelectric surgery device (Easy Surgery; BioSAF, Assago, Milan, Italy), using insert 511 to realize the vertical cuts. (I) The right lower lateral incisor was extracted because of the severe crowding, and the gingival vertical incisions were sutured. (L) Immediately afterwards, the thermoformed aligners (Smiletech, Ortodontica Italia, Rome, Italy) were positioned and the orthodontic treatment was started.

Fig. 3. After 8 months, the orthodontic treatment was completed. All the orthodontic treatment goals were achieved in a shorter time and without periodontal tissue damage.

Fig. 4. Comparison of pre- and post-treatment ortho-panoramic images. Root resorption and root damage were absent.
in the ward, before the start of treatment (T1) and at 3 days (T2) and 7 days (T3) after treatment. Responses were indicated on an ordinal 5-point adjectival scale: 0 = never, 1 = hardly ever, 2 = occasionally, 3 = fairly often, 4 = very often. OHRQoL is characterized by the summary score of the OHIP-14 items; a higher score indicates a stronger negative influence on OHRQoL.

In order to reduce the potential sources of bias, the same operator performed the surgical and orthodontic treatments (MC). Furthermore, two researchers (SC, AD) recorded the periodontal indices. The measurements of each periodontal index were taken by two examiners and the two values were averaged in order to reduce the sources of bias. When the degree of root resorption was evaluated, all panoramic radiographs in which the roots were distorted and not clearly visible were rejected and performed again.

For the statistical analysis, descriptive statistics, including mean values and standard deviations, were used. A database was created using Excel (Microsoft, Redmond, WA, USA), with appropriate checks to identify errors. The kappa statistic was used to compute inter-examiner reliability for the evaluation of mGI and PPD. The inter-examiner kappa coefficient was 0.79. Data were evaluated using the statistical analysis software SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). The t-test was used to determine if there was a statistically significant difference between the pre- and post-treatment periodontal indices (paired groups). The t-test was also used to determine the influence of the minimally invasive, flapless corticotomy procedure on OHIP-14 scores. The internal consistency of the scale, which means that each domain of the instrument assesses distinct aspects of the same attribute or construct, was evaluated using Cronbach’s alpha. For all analyses, a P-value of ≤0.05 was considered to indicate statistical significance.

Results

Two hundred patients were assessed for eligibility. One hundred and eighty-eight patients were not eligible, as they did not meet the inclusion criteria, and two patients did not provide consent. Thus, 10 patients were assigned to receive corticotomy-facilitated orthodontic treatment. The mean age of the selected patients was 21 years (range 17–28, standard deviation (SD) 6.08 years); the male to female ratio was 2:1. The dental crowding was corrected in all patients. The average duration of treatment was 300 days (range 240–390, SD 79.37 days). The first patient was enrolled on 5 December 2013, and the final patient was enrolled on 22 October 2014. No patient was excluded at any stage of the study.

With regard to the primary outcome, it was possible to complete the orthodontic treatment in approximately a third of the time needed for conventional orthodontic treatment with clear aligners in all cases. For all patients, every aligner was in place for 5 days rather than 15 days, correcting the first class malocclusion with severe crowding.

With regard to the secondary outcomes, there was no statistically significant difference between the pre- and post-treatment periodontal indices (mGI, PPD). The mean mGI value pre-treatment was 0.15 and post-treatment was 0.10 (P = 0.10). The mean PPD value pre-treatment was 1.93 and post-treatment was 1.68 (P = 0.08). No root resorption was recorded. No surgical complications or unexpected events, such as the presence of root damage caused by corticotomy, were observed. OHRQoL was measured using the OHIP-14 deteriorated from T1 (mean 8.67, range 0–19, SD 9.61) to first follow-up, T2 (mean 17.33, range 20.00–13.00, SD 3.79). At 7 days of follow-up (T3), there was a near complete recovery of the original OHIP-14 values (mean 7.67, range 4–12, SD 4.04). On the basis of the statistical analysis, the minimally invasive, flapless corticotomy procedure did not significantly modify the OHIP-14 scores at 3 days (P = 0.20) or 7 days (P = 0.89) of follow-up. Cronbach’s alpha values indicated excellent internal consistency reliability in all self-administered questionnaires.

Discussion

The two hypotheses of the present study were confirmed by the results. The minimally invasive, flapless procedure combining piezoelectric surgery cortical microincisions with the use of a 3D printed CAD/CAM surgical guide reduced the treatment time for the correction of severe dental crowding in patients with class I molar relationships, without periodontal tissue damage, surgical complications, or unexpected events. This technique was also characterized by a low negative impact on OHRQoL. This flapless procedure, by removing the need for flap elevation, overcomes some of the disadvantages of corticotomy through reducing the length of the surgery time and the reluctance among both patients and the dental community.

In terms of the limitations of this study, a source of bias is the difficulty in determining the presence of root damage on traditional panoramic radiographs. If two-dimensional X-ray imaging is used, this complication could be underestimated; however the economic and biological costs of 3D X-ray imaging (CT or cone beam CT) are not, in any case, justified. 

Corticotomy to accelerate orthodontic tooth movement involves selective alveolar decortication in the form of lines and dots made around the teeth that are to be moved. This is done to induce a state of increased tissue turnover and a transient osteopenia, which is followed by a faster rate of orthodontic tooth movement. To date, several novel modalities have been reported to accelerate orthodontic tooth movement, including low-level laser therapy, pulsed electromagnetic fields, electrical currents, distraction osteogenesis, and mechanical vibration, but only corticotomy has shown consistent results in accelerating the orthodontic tooth movement. Corticotomy is safe and able to accelerate orthodontic tooth movement, but there are few available studies on its efficacy. The present study confirms that corticotomy accelerates tooth movement even if it is performed using a minimally invasive technique. Using this new surgical technique, the duration of orthodontic treatment was reduced by two-thirds.

For the traditional method, micro-drills are the surgical instruments used to realize the corticotomy cuts. Piezoelectric surgery (Piezosurgery) is a recently-developed system for cutting bone with microvibrations, which uses low frequency ultrasonic waves (24.7–29.5 kHz); the machine is programmed in accordance with the density of the bone and works only on mineralized hard tissue, not on soft tissue. The use of ultrasonic techniques for the osteotomy has advantages over the use of conventional instruments, including a highly precise cutting geometry without the need for excessive force, efficient bone ablation, and a minimized risk of accidental damage to the soft tissues, therefore decreasing the risk of nerve damage, especially when the corticotomy is performed near the emergency of the mental nerve. The greatest disadvantage in the routine clinical use of piezoelectric surgery is the longer time required for the osteotomy. However, Barone et al. compared the use of a piezoelectric device to the use of conventional rotary instruments in performing a maxillary sinus augmentation procedure and showed that the time necessary for the osteotomy and sinus membrane elevation was 10.2 ± 2.4 min with conventional instruments, while it was 11.5 ± 3.8 min with the piezoelectric device; this difference was not statistically significant. This is in agreement with the
data recorded in a study designed to compare the use of piezoelectric surgery with that of the rotary instrument osteotomy technique for corticotomy to accelerate orthodontic tooth movement. In that study, the piezoelectric surgery procedure took longer to complete than the conventional rotary instrument osteotomy, but the difference was not statistically significant.

In the present study the osteotomy cuts were performed without raising a mucoperiosteal flap. The piezoelectric surgery micro-saw came into contact with the soft tissue, but this was not damaged. While characterized by a lower cutting speed, piezoelectric surgery must necessarily be used in association with a minimally invasive technique.

In terms of patient-centred outcome scales, only one study on patient perceptions of quality of life and the risk factors for severe discomfort after corticotomy to accelerate orthodontic tooth movement was found in the literature. In that study, the osteotomy was performed with a piezoelectric device (PS group) or with a round multi-blade bur fitted on a high-speed hand-piece (RT group). An orthodontic force was applied to the teeth with a fixed orthodontic appliance at the end of surgery. OHRQoL as assessed with the OHIP-14 deteriorated from baseline (mean 6.33, range 0–14) to the first follow-up at 3 days after surgery in both groups (PS group: mean 22.67, range 7–45; RT group: mean 21.33, range 16–26). There was a near complete recovery to the original OHIP-14 values at the 7-day follow-up (PS group: mean 16.33, range 2–25; RT group: mean 10.67, range 5–22), which was more rapid with the conventional rotary osteotomy technique. However the osteotomy technique variable did not significantly modify the OHIP-14 scores at the 3-day (P = 0.862) or 7-day (P = 0.352) follow-up. The authors stated that the more rapid return to baseline OHIP-14 values with the use of the conventional rotary osteotomy technique may have been due to the shorter duration of surgery in that group.

In the present study, the minimally invasive, flapless corticotomy procedure did not significantly modify the baseline OHIP-14 scores at the 3- or 7-day follow-up. This means that by using the minimally invasive surgery, a reduction in the treatment time is possible, which overcomes the disadvantages of corticotony and the longer surgical times of piezoelectric surgery.

While the patient treated with corticotony should present a stable periodontium without periodontal disease, the present technique seems particularly indicated in adults with gingival recession and a thin gingival biotype. The present flapless procedure combining piezoelectric surgery cortical micro-incisions with the use of a stereolithographic CAD/CAM surgical guide does not interfere with the marginal periodontium. The technique described, without flap reflection and in conjunction with piezoelectric surgery, involves significantly less trauma to the periodontal tissues and does not require hard or soft tissue grafting. The use of CAD/CAM technology in corticotomy also reduces the total surgical treatment time, allowing the surgeon to perform the procedure in all areas of the mouth. The use of ultrasonic techniques has advantages over other conventional instruments, including a highly precise cutting geometry without the need for excessive force, efficient bone ablation, and a minimal risk of accidental damage to the soft tissues, therefore decreasing the risk of nerve damage.

In conclusion, despite the different techniques described in the literature, corticotomy appears to be the only effective and safe method to accelerate orthodontic tooth movement, although few reports on this subject are currently available. All of the corticotomy techniques described up to now are characterized by high morbidity and by possible damage to the periodontal tissues. The limited deterioration in postoperative oral health-related quality of life and the effectiveness of this minimally invasive corticotomy surgical technique should encourage the clinician to use this technique more widely. However, it must be highlighted that the efficacy of this combined approach must be confirmed in controlled clinical trials.

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None.

Competing interests
No conflict of interest to declare.

Ethical approval
This study was reviewed and approved by the local ethics committee (Umberto I Policlinico di Roma “Valutazione della qualità della vita nei pazienti sottoposti a CAOT” (prot. N. 983/13; Rif. 2947/24.10.2013)).

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Patient consent
Written patient consent was obtained.

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Address:
Michele Cassetta
Department of Oral and Maxillofacial Sciences
School of Dentistry “Sapienza” University of Rome
V le Cesare Pavese 85
00144 Rome
Italy. Fax: +39 06 5016612
E-mail: michele.cassetta@uniroma1.it