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A novel 3D-printed computer-assisted piezocision guide for surgically facilitated orthodontics

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Surgical interventions on the alveolar ridges aimed at facilitating orthodontic tooth movement have been extensively reported. However, unexpected events or complications still occur in daily practice. The purpose of this report was to present a novel 3-dimensional (3D) computer-assisted piezocision guide (CAPG) designed to be translucent for increased visibility, rigid for enhanced support during guidance, and porous for profuse irrigation during procedure. Such a design can function to minimize the risk of surgical complications. In this case, we present a novel 3D-printed CAPG to facilitate a minimally invasive periodontal accelerated osteogenic orthodontics (PAOO) procedure with a guide that provides accuracy, adequate visibility, and greater access for the coolant to reach the surgery site. By navigating the cone-beam computed tomography data, we precisely know the cortical bone thickness, root direction, and interrelations between anatomic structures in an individual situation, which allows us to design our cutting slot for the required length and depth according to the operator's knowledge. Finally, 3D printing was applied, transferring our surgical plan to fabricate the CAPG. Moreover, the well designed pores on the CAPG allow effective irrigation during the piezocision procedure. This minimally invasive procedure was uneventful, and no devitalized tooth or alveolar bone was found. (Am J Orthod Dentofacial Orthop 2019;155:584-91)

With increasing demands on fast-paced and esthetics-centered orthodontic treatment in adult patients, orthodontists are often greatly challenged to formulate a suitable treatment plan concerning esthetics and a shorter therapeutic time.[1-3] Surgical interventions on the alveolar ridges aimed at facilitating orthodontic tooth movement have been extensively reported since the end of the 19th century.[1,2,4-8] Traditionally, on the basis of "bone block movement," some types of interdental vertical and subapical horizontal alveolar osteotomies have had an increased risk of postoperative tooth devitalization or even bone necrosis.[5] Recent evidence suggests a localized osteoporosis state, as part of a healing event called the regional acceleratory phenomenon (RAP), may be responsible for the rapid tooth movement after surgically facilitated procedures.[7] Corticotomy-accelerated orthodontics (CAO), based on the principle of RAP, is an evidence-based treatment modality reported to reduce orthodontic treatment time.[6] Taking into account advantages and drawbacks of CAO, Wilcko et al described an innovative strategy of combining corticotomy alveolar surgery with alveolar grafting in a technique referred to as periodontal accelerated osteogenic orthodontics (PAOO).[8]

Currently, to prevent the risk of dehiscence and fenestration while increasing the scope of orthodontic corrections, PAOO has been demonstrated to be a promising technique in accelerating orthodontic movement by activating RAP, resulting in increased catabolic and anabolic changes to the periodontium and alveolus complex.[7,8] However, this technique may still have several drawbacks, such as increased possibility of damaging tooth-supporting tissue, devitalization of teeth, and possibility of postoperative discomfort and complications.[9,10]

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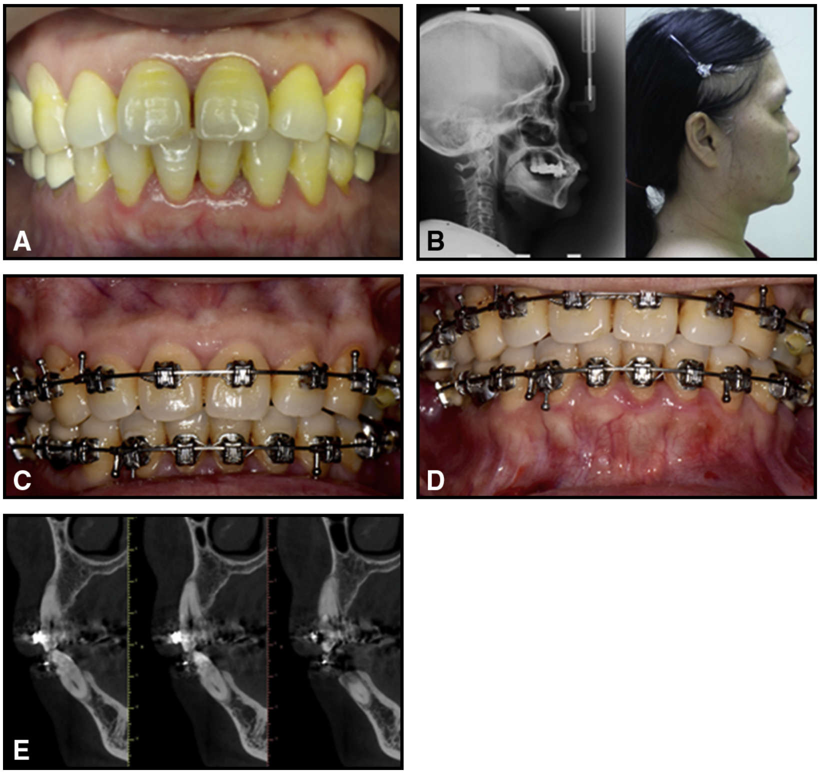

Fig 1. Pretreatment evaluation and analysis. **(A)** Pretreatment intraoral frontal view. **(B)** Lateral facial profile and cephalometric radiograph before treatment. The patient presented a skeletal class I malocclusion with bimaxillary incisal proclination. **(C, D)** Frontal view of the patient before PAOO procedure (33 months after receiving initial orthodontic treatment). **(E)** Presurgical CBCT images showed thin facial bone of upper and lower anterior teeth.

To overcome the aforementioned disadvantages, Dibart et al introduced an innovative concept of piezocision to achieve rapid tooth movements while preserving periodontal support without extensive surgical trauma.[4,11] Piezocision is characterized by multiple small mucoperiosteal vertical incisions, minimal piezoelectric osseous cuts to the buccal cortex only, with the use of a piezoelectric knife and the convenience of allowing concurrent application of bone or soft tissue graft.[2,4,11]

Recently, an innovative, minimally invasive, and flapless procedure combining piezoelectric surgery cortical microincisions with the use of a 3-dimensionally (3D) printed computer-aided design/computer-aided manufacturing (CAD/CAM) surgical guide has been advocated with the term computer-guided piezocision.[2,9,10,12,13] These advancements provide greater control and minimize the risks related to piezocision, such as incidental contact of tooth roots or any critical anatomic structure, which could otherwise result in significant complications.[6] However, the risk of deviation between the planned incision and actual incision (ie, errors in positioning the surgical guide) and the possible occurrence of unexpected events or complications are relevant (ie, mucosa- and bone-overheating injuries in 28 of 112 prepared sites, resulting in greater pain).[6]

The purpose of the present report is to present a novel 3D computer-assisted piezocision guide (CAPG) designed to be translucent for increased visibility, rigid for enhanced support during guidance, and porous for profuse irrigation to provide greater access of coolant to reach the surgery site. Such a design can function to minimize the risk of surgical complications.

CASE REPORT

A 56-year-old healthy woman was referred to the department of orthodontics with the chief complaint of teeth displacement and frequently lip biting when chewing. On clinical examination, the patient revealed mesofacial characteristics with mild asymmetry and protrusion both lips (Fig 1, *A* and *B*). There was no lip incompetence or gummy smile. The model analysis

Table I. Total dentition space analysis

Measure (mm)	*Maxilla*	*Mandible*
Anterior denture area		
A. Teeth width	49.1	38.9
B. Available space	47.8	36
C. Tooth arch disc	−1.3	−2.9
D. Headfilm correction	−11.2	−8.8
Sum of anterior	−12.5	−11.7
Mid-arch denture area		
A. Teeth width	43.9	29.2
B. Available space	53.2	51.7
C. Tooth arch disc	9.3	22.5
D. Curve of spee	0	2.6
Sum of mid-arch	9.3	19.9
Posterior denture area		
A. Teeth width	18.6	0
B. Available space	20	14.1
C. Tooth arch disc	1.4	14.1
D. Estimated increase	0	0
Sum of posterior	1.4	14.1
Denture total	−1.8	22.3

Table II. Pretreatment cephalometric analysis

Measurement	*Value*	*Normal range*
SNA	84.9°	80° to 84°
SNB	84.7°	78° to 82°
ANB	0.2°	0° to 4°
SN-MP	32.4°	27° to 37°
FMA	28.9°	22° to 28°
1 to NA	13.5 mm	1.0 to 5.0 mm
1 to SN	122°	98° to 108°
1′ to NB	11.4 mm	1.0 to 5.0 mm
1′ to MP	101°	88° to 94°
FMIA	50.1°	65° to 68°
Overjet	2 mm	2 to 3 mm
Overbite	2.5 mm	1 to 2 mm
Upper lip to E-line	3.2 mm	
Lower lip to E-line	5.1 mm	

demonstrated a bilateral class I canine relationship with 2 mm overjet and 2.5 mm overbite, and the maxillary dental midline was deviated by 0.5 mm toward the right side of the facial midline (Table I). Space analysis displayed bimaxillary incisal proclination and anterior arch discrepancy (Table I). The cephalometric image and analysis demonstrated a Class I skeletal relationship (ANB, 0.2°) with bimaxillary prognathism (1 to SN 122°, 1′ to MP 101°), and poor esthetic balance (FMIA 50.1°, Z-angle 63.3°) (Fig 1, *B*; Table II). The treatment plan involved comprehensive orthodontic treatment with temporary anchorage devices (TADs) over the maxilla to align the upper and lower teeth and achieve distalization of the maxillary and mandibular arches to correct lip protrusion and incisal inclination (Figs 1, *C* and *D*). However, after about 33 months of treatment, the amount of retraction did not correspond to what had been expected, and the patient requested alternate methods to aid in the correction of her profile. After navigating cone-beam computed tomographic (CBCT) images, we determined that the buccal plates of both upper and lower anterior arches were too thin to keep on retracting both arches over the upper and lower anterior arches (Fig 1, *E*). Therefore, she was referred to our department and planned for the PAOO procedure in both arches for accelerating the tooth movement.

Clinically, maxilla and mandible impressions were taken, poured into stone models, and scanned as 3D digital stone model files. On radiographic examination, without sacrificing image quality while following the as-low-as-reasonably-achievable principle, the CBCT image was acquired by board-certified radiologists with the x-ray tube at an accelerated potential of 110 kV peak, a beam current of 11.94 mA (Newtom 5G; QR, Verona, Italy), and automatic adjustment of exposure time according to the area of the scan (∼7 seconds for a full arch).[14] The examined CBCT image was stored in the Digital Imaging and Communications in Medicine (DICOM) format and inputted into interactive medical software (itk-Snap 3.0.6; University of Pennsylvania) for preoperative diagnosis and virtual surgical treatment plan (Fig 1, *E*). All digital files, including CBCT and 3D digital stone model files were then incorporated into CAD software (Meshmixer 3.2; Autodesk; Fig 2, *A*). A CAPG was digitally designed and characterized by buccal slots for performing piezocision vertically in precise locations, depths, and angulations (Fig 2, *B*). A draining system with multiple pores and drain tubes was designed for greater access of copious saline irrigation to the surgery site (Fig 2, *C*). Finally, the CAPG guide was printed by a desktop stereolithography 3D printer (Form 2; Formlabs, Somerville, Mass) with transparent material to facilitate better direct inspection fields (Fig 2, *D*).

After sterilization, the CAPG was positioned intraorally by applying the extension part onto the occlusal surface in the patient's mouth, and the stability and fitness of the CAPG were checked before surgery (Figs 2, *E* and *F*). Local infiltration anesthesia (Xylestesin-A; 1.7 mL 2% lidocaine containing 1:80,000 epinephrine) was given to the patient with the use of a long (30 mm) 27-gauge needle. After the injection, full-thickness mucogingival vertical incisions were made with the use of a #15 scalpel blade along the slots of the CAPG to ensure that the position and length of each incisions followed the presurgery design. The minimally invasive piezocision procedure was performed with the use of a piezosurgical device (Piezotome Solo; Satelec Acteon Group, Mérignac, France) with ultrasonic tips (Piezocision PZ

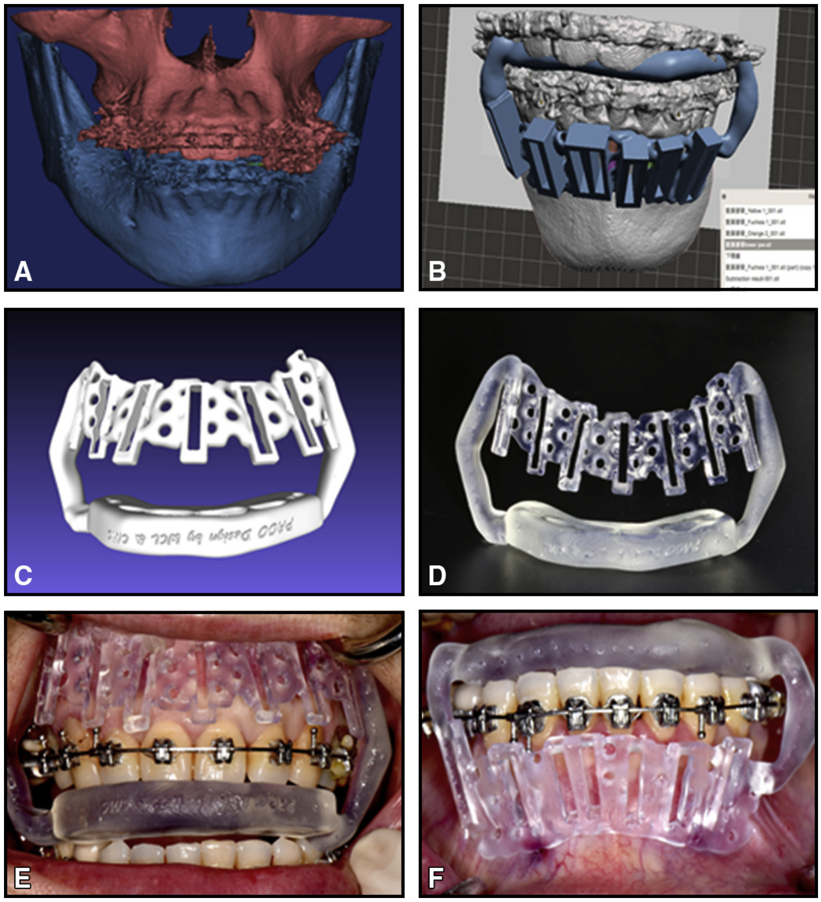

Fig 2. Presurgical treatment planning and fabrication of 3D-printed CAPG. The DICOM datasets of maxilla and mandible were imported into medical image software and 3D-rendering models constructed. **(A)** The maxillary and mandibular stone models were scanned and 3D CBCT images of maxilla and mandible were superimposed accordingly. **(B)** The incision slots for piezocision cutting were designed via 3D CAD software. **(C)** Multiple draining pores and holes for irrigated cooling system was designed to prevent overheating-associated injury. **(D)** Then the CAPG files were printed in a solid material based on the rapid-prototype process of stereolithography. **(E, F)** 3D-printed transparent CAPGs were tested to position precisely and seat steadily on the surgical area with desirable stability.

kit; Satelec Acteon Group). Piezoelectric osseous cuts were made carefully with a modulated ultrasonic frequency at 30 kHz to reach the designated lengths and depths following the designated guiding slots of the CAPG, leaving nerves, blood vessels, mucosa, periosteum, periodontal ligament, and other soft tissue unharmed (Fig 3). After that, the tunnel-like pouches were created by insertion of an elevator (Buser periosteal elevator; Hu-Friedy, Chicago, Ill) between the incisions and elevating full-thickness flap to create sufficient spaces for accommodation of bone substitutes. Freeze-dried bone allografts (Bone Bank Allografts, San Antonio, Texas) were then prepared and placed into the tunnel-like pouches carefully. The whole procedure ended with simple interrupted suturing (Gore-Tex Suture CV5; WL Gore and Associates, Flagstaff, Ariz) of the vertical incisions (Fig 3). The patient was prescribed with analgesics, antibiotics, and chlorhexidine gluconate for mouth rinsing.

Healing assessment and suture removal were performed 2 weeks later (Figs 4, *A* and *B*). The gingiva achieved harmonious healing results without unexpected wound dehiscence or infection. After the surgery, the upper and lower arch continued to be retracted with the use of a nickel-titanium open coil spring with 200 g force from hook to TADs. At 3-month (Figs 4, *C* and *D*) and 12-month (Fig 4, *E*) follow-ups, the mucogingival dimensions were stable without soft tissue discrepancy

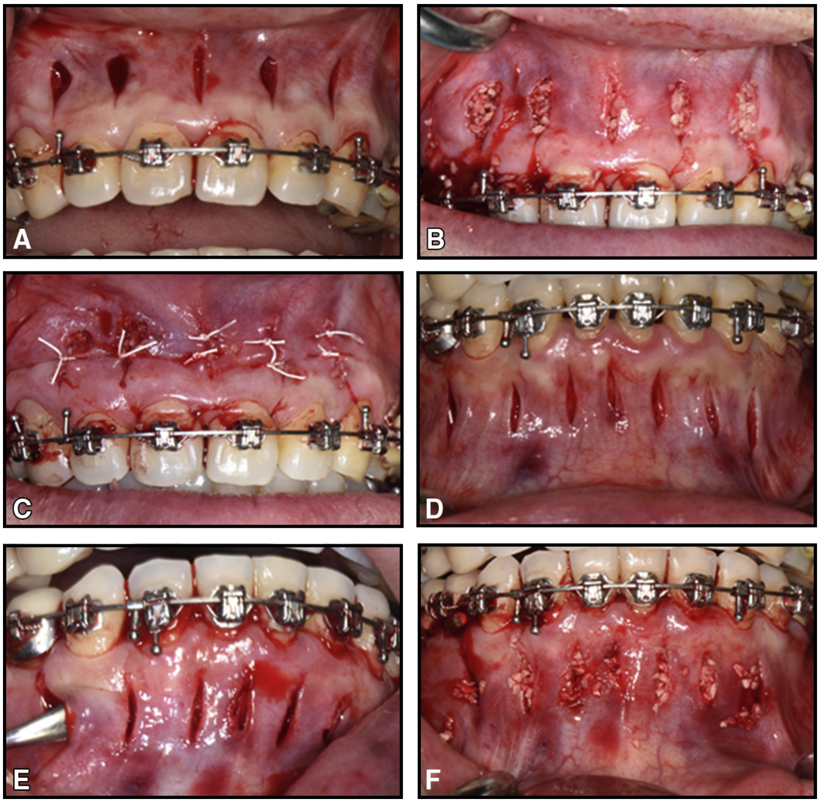

Fig 3. Minimally invasive piezocision with the use of the novel design of 3D-printed CAPG. **(A)** Microincisions were made with the use of #15 scalpel through the pre-designed slots of the surgical guide. Then piezocision was performed following the incisions to penetrate the cortical bone with the use of a PZ1 tip to the programmed depth. **(B)** A tunnel-like pouch was prepared with the use of the periosteal elevator (Hu-Friedy) to elevate full-thickness mucoperiosteal flap to accommodate the bone substitute. Freeze-dried bone allograft was used as bone substitute and inserted carefully underneath the periosteum. **(C)** Each incision was secured tightly by means of simple interrupted suture (5-0 Gore-Tex). It should be noted that this precise procedure restricted the tissue damage as much as possible and allowed rapid and comfortable wound healing. **(D, E, F)** The same procedure for the mandible.

and obvious gingival recession. Before debonding of the orthodontic brackets, she returned for a follow-up CT scan to assess the results of the treatment. The CT scans (sagittal and axial views) showed adequate positioning of teeth within intact bony housing (Fig 4, *F*). Seeing these designated approaches, the patient was satisfied with the reduced treatment time, achieved stable orthodontic results, and will continue follow-up appointments for long-term outcome assessment.

DISCUSSION

To our knowledge, this is the first case report to use a novel 3D-printed CAPG featuring translucency for increased visibility, rigidity for enhanced stability and support, and a design facilitating greater access for the coolant to reach the surgery site to perform a precise and minimally invasive piezocision procedure. After collection and integration of essential information from clinical examination, dental model, and CBCT images (Fig 1; Table II), the interrelationships between anatomic structures, such as root direction, interdental distance, and cortical bone thickness were analyzed (Figs 2, *A* and *B*). Then the location, depth, and angulation of cutting slots, as well as cooling drainage systems, were planned accordingly and the CAPG fabricated by 3D printing (Figs 2, *C* and *D*). These novel features of the CAPG provide convenient and versatile ways for a clinician to achieve a high quality and predictable outcome in a computer-guided minimally invasive piezocision procedure. During the procedure, the new guide design allowed adequate access for profuse irrigated cooling, effectively overcomes potential mucosa and alveolar bone overheating injuries.

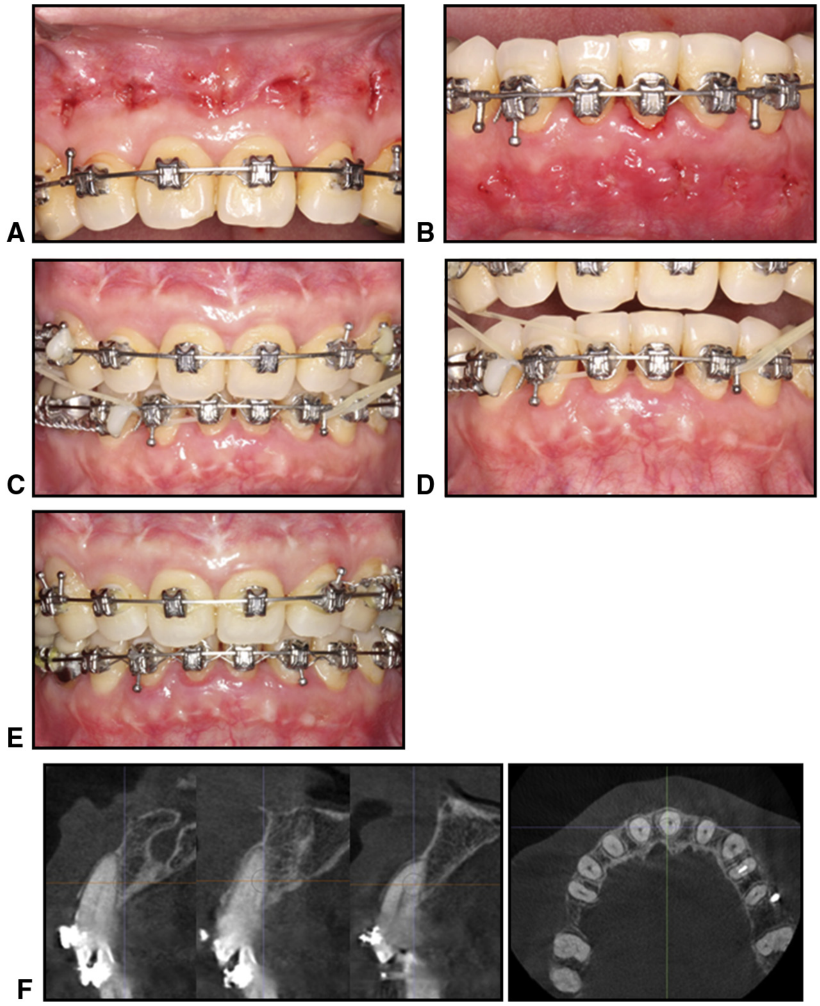

Fig 4. Postprocedure healing. **(A, B)** Intraoral frontal view of maxilla and mandible 2 weeks after operation. **(C, D)** 3-month follow-up. The appearance of the mucosa and the position of gingival margin remain stable. Note the relatively invisible scar tissue on the mucogingival junction. (**E**) 12-month follow-up. Clinically, the mucogingival dimensions were stable without soft tissue discrepancy or obvious gingival recession. (**F**) CT scans were taken from sagittal and axial views before debonding of orthodontic brackets, demonstrating adequate positioning of teeth within intact bony housing.

Surgery-assisted orthodontic treatment is considered to enhance alveolar bone turnover rate, ie, anabolic and catabolic activities leading to rapid movements of orthodontically activated teeth.[2,8,11] Recently, piezocision, a minimally invasive periodontally accelerated orthodontic tooth movement procedure, has been described to combine microincisions limited to the buccal gingiva that allow for the use of the piezoelectric knife to decorticate the alveolar bone and then initiate RAP.[2-4,7,11,15] With its minimally invasive characteristics, piezocision has the advantage of allowing for hard or soft tissue grafting via selective tunnel technique to correct gingival recessions or bony defects in orthodontic patients. Currently, piezocision has been successfully applied in several orthodontic indications, such as class II malocclusion,[4] Invisalign,[3] lingual orthodontics,[15] etc. In the present case, the primary objective was to improve the outcome of bimaxillary retraction that would be satisfying to the patient with reduced treatment time. Also, this procedure could increase posttreatment stability, and improve a patient's appearance quickly.[2,11,16]

CAPG has been developed in recent years[6,9,10,12]; however, this procedure may encounter difficulties when using it on patients with orthodontic brackets or braces. It is hard to seat the guide steady on an irregular surface over these brackets; therefore, inaccuracy in position and/or inadequate engagement of the guide on teeth would lead to disappointing performance.[2,6] To overcome this problem, the CAPG was designed and printed with translucent properties that greatly improves visibility of surrounding anatomic structures and facilitates the engagement on orthodontically activated teeth (Fig 2). In addition, in contrast to a previous report,[9] our CAPG used a plate-like design with an occlusal-apical insertion path so that the CAPG could seat it steadily on the teeth, and there is no need to remove brackets or braces before the piezocision procedure.

Deviation of the bony incisions may damage critical anatomic structures.[17] The CAPG can be made to set the ideal location, depth, and angulation for the incisions by surgical blade or piezoelectric microsaw. For example, in this case, thin buccal cortical bone of maxilla and mandible were anticipated from presurgical cross-sectional images (Fig 1, *E*). It has been suggested that the cutting depth by piezocision should be ~3 mm.[2,18] However, the cortical bone thickness of every patient varies depending on race and location of teeth.[19] The precise orientation and depth of cortical incision can be unpredictable when facing patients with a large variety of cortical bone thickness and teeth alignment.[2,17] Assisted by a CAD/CAM system combined with 3D printing technology, a precise incision would suggest a more promising outcome even with a minimally invasive and flapless procedure.[6,10,12] Although high levels of accuracy for computer-guided piezocision was demonstrated,[6] deviation in entry point and cutting depth between the planned and the actual cuts were still observed.[6] Therefore, Cassetta et al suggested that a safety distance of 1.5 mm should be considered to avoid incidental contact of the piezoelectric microsaw with any critical anatomic structure or tooth roots.[6] In the present case, the CAPG is successfully applied in clinical practice, which was properly seated, and piezocision cuts were positioned precisely following the presurgical plans without surgical complications and unexpected events (Figs 2 and 3). However, the reproducibility and deviations of CAPGs between designed plans should be determined to minimize risks and complications.

Possible procedure-related complications must be brought to attention, such as mucosa- and bone-overheating injuries during the piezocision procedure, which has been recorded in several reported cases.[6] In the present case, the CAPG was designed for ample coolant access directly at the site during piezo surgery, thereby assuring profuse cooling irrigation (Fig 2). Furthermore, the follow-up clinical photos and CT scans taken after completion of surgery and orthodontic treatment showed healthy and intact periodontal-supporting tissue (including soft and hard tissue) at the surgical sites (Fig 4). Consequently, it is suggested that the risk of overheating on critical structures, especially on posterior area, could be minimized effectively by copious irrigation and regular pauses during the microsaw cutting or piezocision procedure.[6]

It should be used with caution, because inaccuracy of the CAPG may still occur through imaging transformation, computing data, material distortion, improper positioning of surgical guide during surgery, etc.[1,2,6] Because the safety, accuracy, and efficacy of using a CAPG needs more solid documented evidence and comparison with a nonguided approach, there would obviously be increased cost and labor in using these techniques (ie, presurgical planning based on CBCT scanning, navigation software, and 3D-printed CAD/CAM system). However, in this case, the CAPG provides a convenient and versatile way for clinicians to perform a high quality and predictable procedure in operation.

In the present case, we noticed that some improvements in CAPG may facilitate accuracy and patient comfort while performing this procedure. First, difficulties were encountered when taking the impression and pouring the stone model from a patient with orthodontic brackets and braces. These irregular surfaces may impede further analysis and treatment plans. Nowadays, intraoral scanning systems may avoid problems in interpretation, and could be considered as an alternate approach in the future. Secondly, frenulum position should be taken into account while fabricating the CAPG, which may affect the ability of the CAPG to engage rigidly on orthodontically activated teeth.

CONCLUSION

This novel 3D-printed CAPG provides several effective features compared with previously reported guides, such as translucency for increased visibility, rigidity for enhanced stability and support, buccal slots for precision in location, depth, and angulation, and greater access for coolant to reach the piezo surgery site, for performing a minimally invasive PAOO procedure in an adult orthodontic patient. This innovative design of CAPG is beneficial in reducing the time of surgery, increasing patient comfort, and facilitating promising treatment outcomes. However, further randomized clinical investigations should be performed to evaluate the reproducibility, accuracy, and efficacy of this novel CAPG.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at https://doi.org/10.1016/j.ajodo.2018.11.010.

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