Int. J. Oral Maxillofac. Surg. 2024; xx: 1–5
https://doi.org/10.1016/j.ijom.2024.07.018, available online at https://www.sciencedirect.com

International Journal of Oral & Maxillofacial Surgery

Technical Note
Orthognathic Surgery

‘Puzzle’ cutting guides for minimally invasive Le Fort I: technical note

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F. Hernández-Alfaro, O. Saavedra, F. Duran-Vallès, A. Valls-Ontañón: ‘Puzzle’ cutting guides for minimally invasive Le Fort I: technical note. Int. J. Oral Maxillofac. Surg. 2024; xx: 1–5.

Abstract. There has been substantial progress in orthognathic surgery over the last 20 years, propelled by developments in 3D technology. These have led to enhanced predictability and precision, and simplified surgical planning. This transformative shift has introduced patient-specific implants (PSI) and cutting guides as viable alternatives to conventional techniques, elevating the overall effectiveness of surgical procedures. Nevertheless, the adoption of such hardware has been linked to the requirement for extensive incisions and approaches, particularly in the maxilla. Addressing this limitation, the current paper introduces an innovative cutting guide design that facilitates a minimally invasive approach to Le Fort I osteotomy.

Keywords: Computer simulation; Le Fort osteotomy; Minimally invasive surgery; Orthognathic surgery; Patient-specific modeling.

Accepted for publication 24 July 2024
Available online xxxx

Over the past two decades, there has been a significant shift in orthognathic surgery, marked by the emergence of three-dimensional (3D) technology. This advancement has enhanced the precision and predictability of surgical outcomes, making surgical planning simpler and more user-friendly[1]. The utilization of patient-specific splints from computer-aided design and manufacturing (CAD/CAM) has demonstrated accuracy in transferring 3D planning information to the surgical field. Furthermore, the ability to produce these splints in house has contributed to reduced manufacturing times and increased cost-effectiveness[2] .

In addition, minimally invasive surgical techniques have been introduced to reduce morbidity and the surgical time, ultimately enhancing patient recovery and satisfaction. In 2012, the current authors introduced a minimally invasive approach to the Le Fort I procedure, combining a reduced incision with an anterior pterygomaxillary disjunction, referred to as the ‘twist technique’[3]. More recently, an additional modification involves performing a transmucosal pterygomaxillary osteotomy through the palatal mucosa with a piezoelectric device, enhancing the precision of the pterygomaxillary disjunction and simplifying the down-fracturing manoeuvre[4].

Patient-specific implants (PSI) are currently being promoted as an alternative to patient-specific splints . The rationale behind this technology lies in avoiding condylar seating during maxilla and mandible repositioning, with claims of reduced surgical times and slightly increased accuracy in bone repositioning. Some studies have favoured the use of customized titanium plates, emphasizing positive results in orthognathic surgery[5]. However, a drawback of the PSI is the necessity for extensive approaches for the placement

0901-5027/xx0001 + 05

Please cite this article as: F. Hernández-Alfaro, O. Saavedra, F. Duran-Vallès et al., ‘Puzzle’ cutting guides for minimally invasive Le Fort I: technical note, Int. J. Oral Maxillofac. Surg, https://doi.org/10.1016/j.ijom.2024.07.018

of cutting guides and fixation plates . To address this challenge and avoid unnecessary extensive approaches and deperiostization , the authors propose a novel design and application of cutting guides with a puzzle connection within the framework of their minimally invasive Le Fort I osteotomy.

Technique

Workflow protocol

A pre-surgical helical computed tomography (CT) scan was obtained, and 3D planning of the surgery was performed using Dolphin software (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA), adhering to the standard virtual surgical planning protocol of Teknon Medical Centre[1]. The STL file (stereolithography file format) of the patient's 3D surgical plan was shared online with a local company, responsible for the design and manufacture of the PSI (Avinent, Barcelona, Spain). After processing the information, a video conference was held between the surgeon (F.H.A.) and one of the company engineers. The designs of the cutting guides and paranasal 'inverted T' plates were established (Figs. 1 and 2). This step is recommended, as the surgeon is ultimately responsible for the plan .

Each cutting guide fitted the rim at the piriform aperture and was adapted to the sinuous anatomy of the premaxillary region, and the two guides were assembled under the right side of the nasal spine with a puzzle connection. Thus, the guides feature three supports, designed to provide rigidity during adaptation manoeuvres and to keep the two parts of the guide together: the edges of the two piriform openings and the anterior premaxillary crest. The guides were designed to extend just 2 cm distal to the rim, with drill positions for three proximal horizontal and three vertical paranasal holes; the two distal holes were not included in the guide (although their positions were evaluated virtually so as not to damage any tooth roots) . The guide holes themselves were later used to secure the plates, ensuring the proper position of the fixation plates and screws within the bone. The guides were printed using a selective laser sintering (SLS) method (Fig. 3). Two

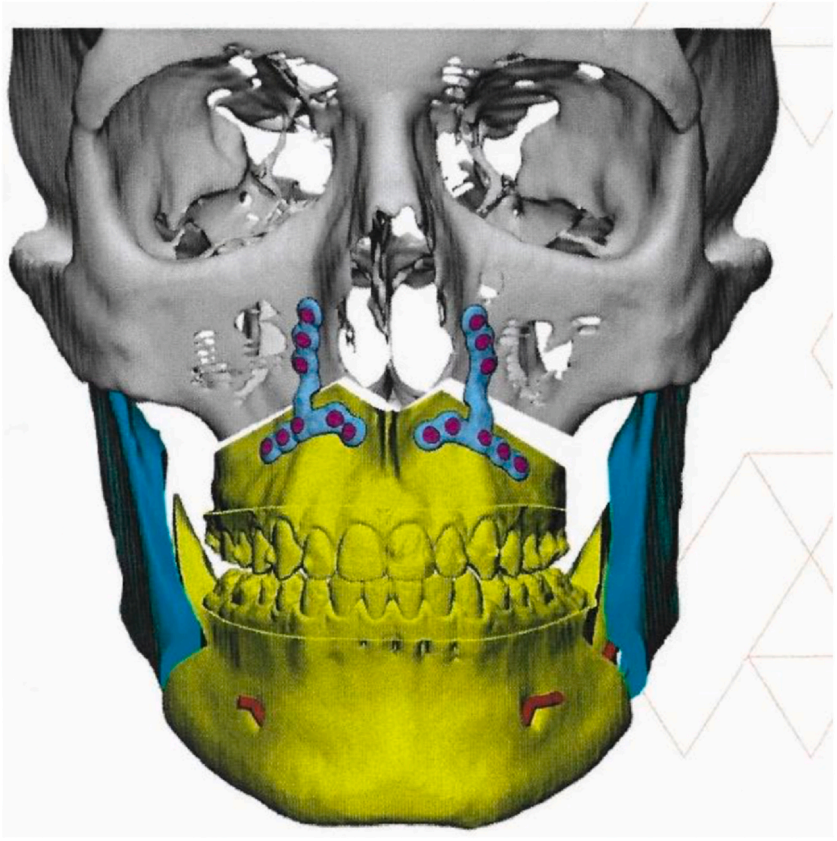

Fig. 2. The virtual orthognathic surgical plan is converted into an STL file, which is then used by the manufacturing company to design and fabricate the custom plates.

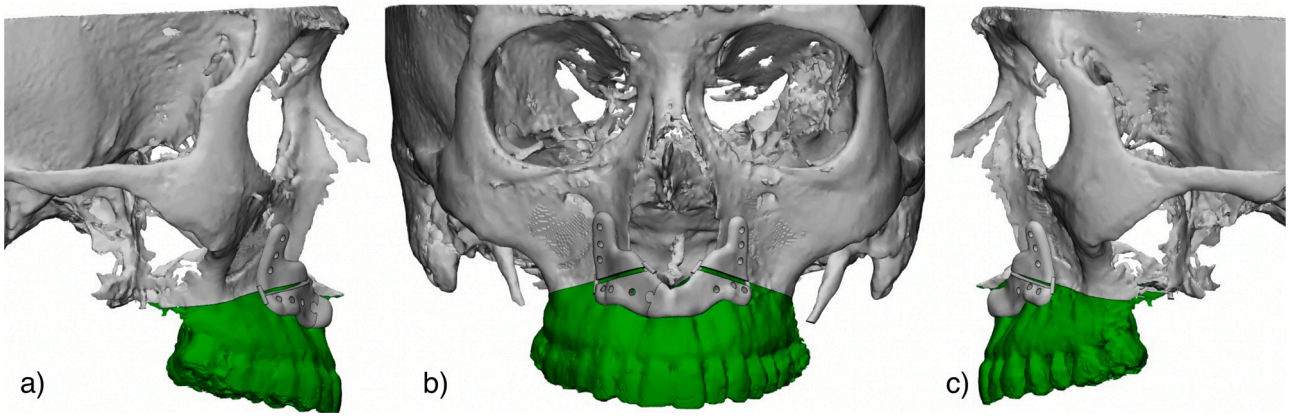

Fig. 1. Design of the cutting and drilling guides over the initial position of the maxilla: (a) right lateral, (b) frontal, and (c) left lateral views. The design of the cutting and drilling guides features an approximately 45° inclined posterior edge. The anatomical retention of the guide is located on its anterior edge, which aligns with the free margin of the piriform aperture. The guide is secured with two screws, one on each side of the osteotomy, and features three supports to provide rigidity during adaptation manoeuvres and to keep the two parts of the guide together.

Fig. 3. Cutting and drilling guides printed using SLS technology.

'inverted T' plates were designed, one on each anterior buttress; these were 2 mm thick and included eight holes for maxillary fixation .

The plan was sent for production: the outside company 3D-printed the plates in titanium, while the cutting guides were printed in house in the authors' department and sterilized in an autoclave at 130 °C for 15 min. For added assurance, an intermediate and final patient-specific splint for a maxilla-first protocol were also printed as backups to verify the treatment plan . The entire process can be completed in 4 days, with surgery occurring as planned on day 4.

Surgery

All surgeries were conducted by the senior surgeon of the team (F.H.A.), and the sequence followed was the maxilla-first protocol. Despite the utilization of PSI, a minimally invasive Le Fort I technique was applied in all patients.

The procedure commenced with a bilateral palatal transmucosal pterygomaxillary disjunction performed using a piezoelectric device[4]. A 2-cm incision from lateral incisor to lateral incisor allowed access to the maxilla. Then, the anterior and lateral walls of the maxilla were subperiosteally elevated from the pyriform aperture to the pterygoid region with a tunnelling technique. Hence, the subperiosteal dissection was limited to the path where the Le Fort I osteotomy was planned (5 mm above and 5 mm below). Additionally, a paranasal and premaxillary subperiosteal dissection was performed to lodge the cutting guides as well as the custom miniplates. Next, the nasal spine was separated from the maxilla using a piezoelectric saw, the nasal mucosa was detached from the nasal floor using a periosteal elevator, and the nasal septum was luxated laterally to separate it from the nasal crest of the maxilla.

Following this, the two cutting guides were introduced separately, then assembled with the puzzle connection and fixed on each side using two screws (one per side) (Fig. 4). The three proximal horizontal and three vertical

Fig. 4. Intraoperative photographs showing placement of the cutting guides through a minimally invasive approach. In images (a) and (c), the fixation screws for the guide and the cutting rails are partially visible. The remaining drilling holes are not visible but approachable. In image (b), the subspinal osteotomy can be seen. Additionally, the 'curve' of the guide that encircles the edge of the piriform opening can be observed, as well as the adaptation of the two guides to the sinuous anatomy of the premaxillary region . The guides feature three supports, designed to provide rigidity during adaptation manoeuvres and to keep the two parts of the guide together.

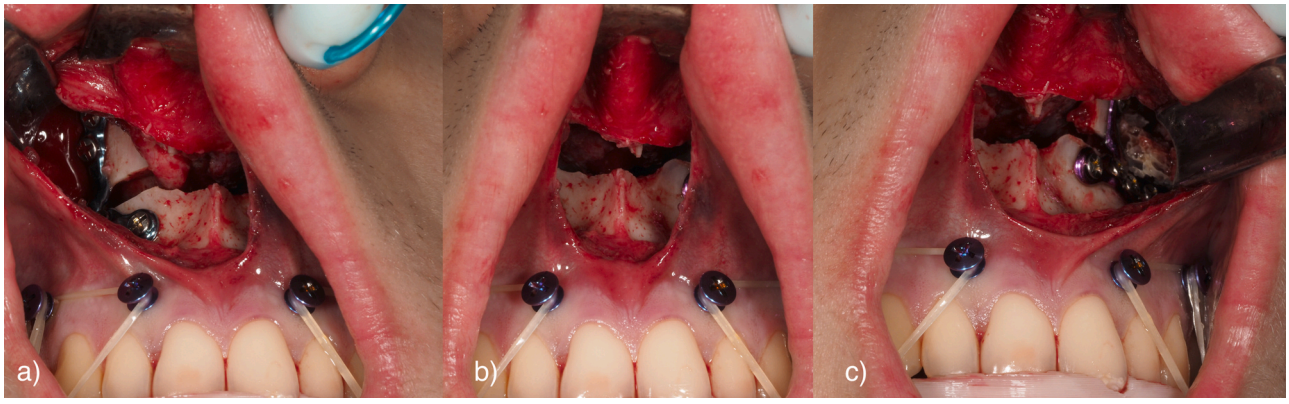

Fig. 5. Final intraoperative photographs. The minimally invasive Le Fort I approach extending from the right to the left lateral incisor is maintained after maxillary osteotomy (b), with placement of rigid fixation on the right side (a) and (c) left side . Note that the final splint is used to guide the position of the mandible.

paranasal holes for future plate fixation were predrilled at this stage. The standard Le Fort I osteotomies were performed using a reciprocating saw with a 4-cm blade, and the cutting guides were subsequently removed. Pterygomaxillary disjunction was performed through an anterior approach using a sharp, straight, 2-cm osteotome driven from the nasal crest of the maxilla to the pterygomaxillary junction, known as the 'twist technique'. The neurovascular pedicles were identified on both sides, and soft tissue was stretched enough to reposition the maxilla in the new position without tension. At this stage, it was verified that the custom plates fitted the maxillary shape and coincided with the predrilled holes, and they were fixed with three screws on each side in the pre-drilled holes of the mobile maxilla. The two distal holes that were not pre-drilled with the cutting guide were then drilled and screws inserted at this point . The maxilla was then moved with a small hook in the anterior nasal floor, to align the miniplates with the predrilled holes in the upper section of the osteotomy, thus replicating the planned 3D repositioning of the maxilla (Fig. 5). The maxilla was fixed with the upper screws. Muscle cross-suturing was performed with 4–0 Vicryl (Ethicon, Inc.,), as published elsewhere[6], and the mucosa was closed with running 5–0 Monocryl (Ethicon, Inc.).

The backup intermediate patient-specific splint was not required in any of the cases . Mandibular surgery was then performed in the conventional manner with standard miniplates. Since mandibular repositioning was not customized, the final splint was used before mandibular fixation.

Discussion

This technical note illustrates the feasibility of employing a minimally invasive approach when utilizing patient-specific cutting guides and implants for Le Fort I osteotomy. Prior research has predominantly featured extensive incisions and degloving for the accommodation of cutting guides and custom plates[7]. Non-minimally invasive surgeries with wide exposure increase patient morbidity, and there is an increased risk of nerve injury and the potential long-term illusion of aging due to muscle sag, among others. In contrast, the miniaturized and compact cutting guides presented here connected sub-spinally with a puzzle connection and were tailored to the piriform rim, ensuring manoeuvrability, aligning with a minimally invasive strategy. Also, only one 2-mm profile 'inverted T' plate was applied on each anterior buttress . Nevertheless, it must be mentioned that the proposed technique is one choice among many others already described and consolidated in the scientific literature[5,7,9] .

A commonly cited drawback of the PSI is the increased cost when compared to conventional CAD/CAM splints and miniplates. A 2022 systematic review addressing protocol costs found limited relevant data, mentioning a cost of USD $780 for a PSI versus USD $280 for conventional plates[8] . However, the protocol presented here mitigates expenses by reducing the customized hardware to two plates and allowing in-house printing of the cutting guides. Additionally, adopting the traditional maxilla-first sequence eliminates the need for mixed or hybrid fixation, as required during the mandible-first sequence, resulting in the savings of a mandibular bicortical screw per side, since the mandible is no longer the reference positioning bone[9] .

Thus, the protocol presented here addresses some major challenges related to PSI for Le Fort I osteotomy, such as extensive approaches, prolonged material design and production timelines, and increased costs. Conversely, the literature suggests significant benefits of PSI, including reduced surgical times and slightly higher accuracy. Although a comparative study was hindered by the limited sample size , the average time for Le Fort I surgery from incision to fixation for the first four cases operated on with this protocol at the authors' institution was 35 min. The enhanced accuracy is attributed to the maxilla-first sequence with rigid maxillary fixation using a customized plate, because there is no dependence on condylar seating for maxilla and mandible repositioning, thus eliminating potential errors in condylar position[9] .

The literature indicates that differences less than 2 mm in translation and less than 4° in rotation between the virtual plan and surgical outcome are clinically insignificant. Customized plates are reported to match or even improve this precision, making the adoption of this technology beneficial for both patients and treating physicians[10]. In conclusion, the presented novel design of compact customized cutting guides with a puzzle connection allows for minimally invasive Le Fort I osteotomy by using patient-specific implants.

Ethical approval

This study was approved by the Institutional Review Board of Grupo

Hospitalario Quirónsalud-Catalunya (Ref. 2023/103-MAX-CMT).

Patient consent

Obtained.

Funding

None.

Competing interests

None.

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