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Technical Note
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Three-dimensional surgical planning and simulation to improve surgical accuracy and reduce invasiveness of cranioplasties

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Abstract. Patients with too large a frontal prominence may suffer discomfort and subsequent self-esteem problems. The case of a 29-year-old male with a prominent forehead is presented. After three-dimensional (3D) virtual simulation of the procedure, a stereolithographic model of the skull and a surgical cutting guide were fabricated. The forehead recontouring and reconstruction procedure was performed under general anaesthesia and the postoperative course was uneventful. At the 12-month postoperative follow-up, clinical and radiographic documentation confirmed softening of the frontal prominence from 14.48 mm to 8.56 mm, a nasofrontal angle increase of 22°, and overall high patient satisfaction. The proposed workflow results in greater surgical precision, shorter reconstruction times, reduced patient morbidity due to a reduced risk of dural exposure and postoperative infection, and overall higher predictability and patient satisfaction.

Key words: frontal sinus; frontal bone; forehead; cone beam computed tomography; surgical planning software; surgical cutting guide; cranioplasty; aesthetic surgery; feminization.

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Comprehensive aesthetic analysis of the upper facial third entails consideration of three key-areas: the frontal sinus prominence, the superciliary and supraorbital ridge, and the nasoglabellar angle. In particular, a prominent frontal vault is an inherent masculine characteristic that may be due to large frontal sinuses and/or thick supraorbital ridges.[1] Consequently, the nasofrontal angle is often acute in men, while it is much more obtuse in women in response to very little — if any — brow fullness.[2]

The frontal sinuses are the last facial sinuses to achieve complete development. After slow progressive growth, they become pneumatized and reach their full size at puberty.[3] Lee et al. described frontal sinus anatomy and sex variations from computed tomography (CT) scan images and concluded that males have greater dimensions in most frontal sinus measurements: male foreheads were characterized by a more acute nasofrontal angle (119.9°

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vs. 133.5°), a steeper posterior forehead inclination (−7.2° vs. −3.5°), and a wider glabella (44.4 mm vs. 33.9 mm), frequently protruding beyond the ideal forehead slope line (51% vs. 30%).[4]

According to the classification of Urken et al., an abnormally large frontal sinus may be due to three different conditions: hypersinus, pneumosinus dilatans, and pneumocele.[5] A hypersinus is an enlarged frontal sinus that does not extend beyond the normal limits of the frontal bone and has normal wall thickness. Pneumosinus dilatans is a situation where the sinus expands abnormally beyond the normal limits of the frontal bone, yet the bony walls of the sinus are of normal thickness. Finally, an aerated sinus with variable thinning of its walls characterizes a pneumocele. This condition differs from the two previous ones in that it is considered a pathological status secondary to a sinus drainage disturbance.[3]

While the chief patient complaint is an annoying prominent forehead, related symptoms include local painful pressure, nasal bleeding, anosmia, diplopia, and headache. In women with bossing foreheads, substantial aesthetic disharmony and facial masculinization may result.[1–3] Likewise, men with too large a frontal prominence may refer to discomfort and self-esteem problems. Surgical reshaping of the upper facial third is an effective solution to the aforementioned clinical and psychological symptoms.

The aim of this article is to describe a specific workflow for three-dimensional (3D) planning and execution of forehead recontouring and reconstruction, to analyze its advantages and limitations, and to discuss potential possibilities for future improvement.

Methods

A 29-year-old male was referred to the department of oral and maxillofacial surgery of a tertiary hospital complaining of a prominent forehead and self-esteem problems related to his facial appearance (Fig. 1). The patient was otherwise asymptomatic and denied any symptoms consistent with sinus disease. The remainder of his medical history was unremarkable, with no history of trauma, infectious rhinitis, or allergies.

Physical examination revealed a prominent frontal vault and an acute nasofrontal angle. Otorhinolaryngological, ophthalmological, hormonal, and neurological examinations were normal.

A cone beam computed tomography (CBCT) examination was performed (i-CAT scanner; Imaging Sciences International, Inc., Hatfield, PA, USA) and showed diffuse enlargement of both frontal sinuses. No signs of intracranial or orbital involvement were detected. Similarly, a sinus pathology was ruled out. Metric analysis was performed at the facial midline. The frontal sinus height, width, and depth measured 36.47 mm, 58.84 mm, and 14.58 mm, respectively. The thickness of the anterior table was 2.24 mm. Despite mild thinning of the anterior cortical wall, the anatomical deformity was categorized as a pneumosinus dilatans owing to frontal sinus expansion beyond the normal limits of the frontal bone with signs or symptoms of sinus drainage disturbance.

Fig. 1. Preoperative and postoperative pictures illustrating the successful result.

Primary DICOM files (digital imaging and communications in medicine) from the CBCT analysis were imported into specific treatment planning software (SimPlant O&O version 13.0; Dentsply, Leuven, Belgium). After careful manual segmentation of the raw dataset, the 3D skull model of the patient was exported in .stl (stereolithography file) format in order to fabricate a stereolithographic model. The complete forehead recontouring and reconstruction procedure was simulated virtually. The virtual plan was reproduced in the stereolithographic skull model, and a surgical cutting template was fabricated.

Under general anaesthesia, the frontal bossing was reached through a coronal approach. The incision was performed in an oblique fashion in order to preserve the maximum amount of hair follicles. Once the frontal bone, glabella, and superior orbital rim were exposed, both supraorbital neurovascular bundles were dissected carefully. The limits of the frontal sinus were marked on the anterior cortical wall with the help of the prefabricated surgical cutting guide (Fig. 2). Then, the anterior wall was removed integrally using a piezoelectric device (Implant Center 2; Satelec-Acteon Group, Tuttlingen, Germany) (Fig. 3). The tip of the piezoelectric saw was inclined obliquely at an angle greater than 45° to the bone surface, taking care to avoid any perforations and subsequent dural exposure. The mucosa of the sinus was removed, and both frontonasal ducts and frontal sinuses were obliterated with fibre-reinforced calcium phosphate (Norian CRS; Synthes Inc., West Chester, PA, USA). The previously removed anterior wall fragment was meticulously sculpted and flattened with a surgical burr (round cutting, 6-mm diameter head) and then repositioned. The sharp edges of the repo-

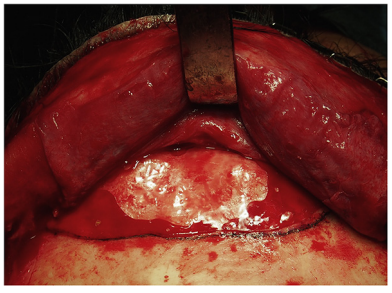

Fig. 2. Intraoperative picture: limits of the frontal sinus marked on the anterior cortical wall with the help of the prefabricated surgical cutting guide.

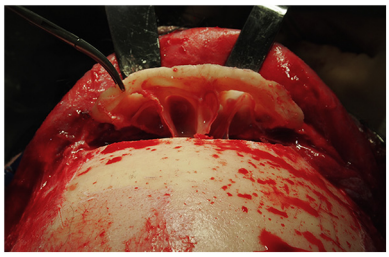

Fig. 3. Intraoperative picture: frontal bone anterior wall osteotomy.

sitioned anterior wall bone were polished with the same burr in order to achieve a smooth continuity with the margins of the resection. Furthermore, the excessively prominent supraorbital ridges were recontoured, taking care to avoid the supraorbital neurovascular bundles. After haemostasis revision, standard closure of the coronal approach in two layers was completed: the scalp was closed with 3–0 Vicryl sutures (Ethicon, Sommerville, NJ, USA) and the skin with 3–0 Prolene sutures (Ethicon, Sommerville, NJ, USA).

A compressive forehead dressing and two active drains were maintained for 24 h. In addition, a closed-circuit cold-water mask (17 °C) was worn during the first postoperative day. Standard antibiotic and anti-inflammatory prophylaxis was prescribed for 1 week.

Results

The postoperative course was uneventful. No complications such as alopecia, haematoma, or contour deformities occurred, and a pleasing aesthetic result was achieved.

At the 12-month follow-up, the patient remained satisfied with the outcome and did not wish any further surgery (Fig. 1). A control CBCT scan was obtained in order to evaluate the postoperative outcome. The files were exported to Dolphin Imaging 3D version 11.8 software (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) to superimpose the pre- and postoperative datasets by means of surface matching. To this effect, the anterior and middle cranial fossae served as reference landmarks. Two- and three-dimensional morphometric comparisons (Fig. 4) revealed softening of the frontal bossing from 14.48 mm to 8.56 mm, and an increase in the nasofrontal angle from 110° to 132°.

Discussion

Radiological evaluation with CT or CBCT permits a comprehensive evaluation of the patient's anatomy (sinus size and wall thickness) and sinus pathology in order to select the appropriate surgical technique and anticipate potential complications.[6] Furthermore, DICOM data processing with appropriate third-party software enables virtual simulation of the surgical procedure and .stl file exportation in order to fabricate anatomical models and/or surgical guides. In the authors' experience, these guides enable accurate delimitation of the surgical defect on the anterior cortical wall, thereby facilitating the procedure and reducing the operative time, and improve the final outcome globally.

Recently, the development of surgical navigation systems has provided real-time intraoperative guidance based on a preoperatively simulated treatment plan. Moreover, the rapidly developing technologies for 3D visualization, interactive localization, and point mapping enable the precise identification and preservation of critical areas. It is logical to expect that the incorporation of these simulation-guided navigation systems into the clinical routine will further improve the accuracy of craniofacial reconstructions and reproducibility of the surgical plan, and will minimize the need for intraoperative improvisation and the risk of complications.[7]

Several surgical techniques have been described for forehead recontouring and reconstruction in particular.[8,9] The most suitable procedure remains the preference of the clinician based on personal experience and the patient's specific forehead anatomy. Individuals can be classified into two major categories based on their forehead anatomy.[1] Group I comprises subjects with a thick cortical bone over the frontal bulge, the sinuses meanwhile being of normal or small size. In these patients, sculpting using a burr without penetrating the frontal sinus is sufficient. Group II comprises subjects in whom the frontal protuberance is associated with comparatively thin bone over the frontal sinuses. In these cases, an anterior wall frontal bone osteotomy is required, and the anterior wall of the forehead sinus must be set back, repositioned, and secured. Needless to say, group II surgery entails substantially greater technical complexity and subsequent risk of complications. It is important to point out that most patients' frontal sinus anatomy falls into group II, such that a detailed surgical plan is absolutely mandatory.[1–3,8,9]

While an endoscopic approach[10] is possible in order to avoid the classical standard or modified coronal approaches and the subsequent risk of large scars or alopecia,[8] this minimally invasive technique is best suited for properly selected group I patients.[1]

Technically, the authors prefer executing the osteotomy of the anterior wall of the frontal sinus with a piezoelectric device because it offers excellent control of the direction of the cut and minimizes the risk of dural exposure. In the case reported herein, the anterior wall of the frontal sinus was removed in one piece and recontoured carefully before repositioning. Alternatively, the anterior cortical wall can be fragmented into several pieces.[1,3,8] In any case, gentle manipulation of the fragmented bone and preservation of the periosteum are essential in order to avoid irregularities in forehead contour. Should flattening of the frontal bone lead to an excess of overlying forehead skin and brow ptosis, a concomitant brow lift through the same coronal approach can be considered.

As mentioned previously, detailed preoperative analysis with CT or CBCT helps the surgeon anticipate potential sinus drainage problems. When the frontonasal duct is involved, it is essential to re-establish an appropriate drainage. However, there is no consensus regarding the management of the healthy mucosa. Some authors advocate removing the sinus mucosa and obliterating the lumen with fat or galea grafts, autologous, homologous, or heterologous bone grafts,[9] and even alloplastic materials such as methylmethacrylate. Nevertheless, most authors prefer to keep the mucosa intact, always avoiding

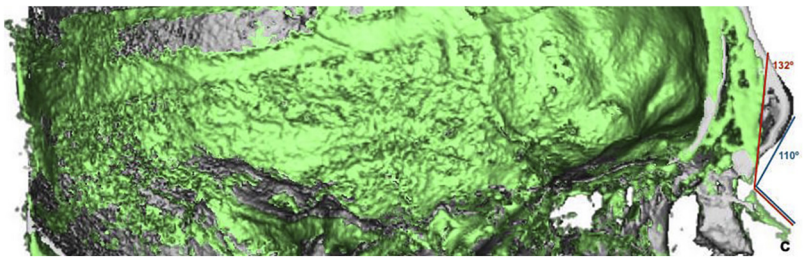

Fig. 4. Superimposition images where grey represents the preoperative data and green the postoperative data (12 months).

mucosal engagement between bone fragments and maintaining the patency of the frontonasal duct to prevent mucocele formation in the frontal sinus.[3]

In conclusion, specific DICOM-processing software enables a comprehensive 3D diagnostic analysis, simulation of the surgical procedure, and the fabrication of patient-specific guides. This methodology has the potential to improve surgical accuracy and predictability, shorten the duration of the reconstruction procedure, and reduce patient morbidity.

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Competing interests

None.

Ethical approval

Not required.

Patient consent

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