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SHORT COMMUNICATION

Frontal sinus models and onlay templates in osteoplastic flap surgery

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Abstract

Objective: Precise delineation of the extent of frontal sinus pneumatisation is a crucial step in osteoplastic flap frontal sinus surgery. The authors present a novel method of achieving this objective.

Methods: First, models of the frontal area are generated using three-dimensional printing based on pre-operative computed tomography image data. These models are then used to create an onlay template of the frontal sinus, which is used intra-operatively.

Results: In a series of 10 patients undergoing osteoplastic flap frontal sinus surgery, the described frontal sinus templates were consistently accurate to within 1 mm.

Conclusion: Frontal sinus templates are potentially useful adjuncts to current techniques employed to guide frontal sinus surgery.

Key words: Frontal Sinus; Surgical Procedures, Operative

Introduction

Although most frontal sinus disease can be treated endoscopically, there still remains a role for external approaches.[1–4] Non-destructive external procedures include frontal sinus trephination and an osteoplastic flap approach; destructive procedures include an osteoplastic flap with frontal sinus obliteration, Reidle's procedure and cranialisation. External approaches may be necessary: when neoplasms are located far laterally; when either anterior or posterior frontal sinus bony margins have been eroded by infection or neoplasm; or when endoscopic median drainage procedures have failed or are considered inappropriate due to new bony growth associated with Paget's disease or chronic infection and osteoneogenesis.

Osteoplastic flap surgery allows unparalleled access to the entire frontal sinus. The procedure starts with either a coronal, mid-forehead or bilateral eyebrow incision. A skin and frontalis muscle flap is then raised, either together with the periosteum or just superficial to it, preserving the supraorbital and supratrocheal nerves. The entire anterior plate of the frontal sinus is outlined, but before removing it mini-plates are placed and burr holes drilled for them so that the frontal sinus bony flap can be accurately repositioned at the end of the procedure. After positioning the mini-plates, the anterior wall of the frontal sinus is drilled and divided from the surrounding bone, and hinged inferiorly in order to fully examine the inside of the frontal sinus. Mucoceles or neoplastic disease can thus be removed under direct vision, or the entire mucosa of the frontal sinus removed and the sinus obliterated with fat. The bony flap is then replaced and reattached to the surrounding bone using the prepared mini-plates. The skin flap is replaced over suction drains, and a tight head bandage is applied.

Delineation of the extent of the frontal sinus is a crucial step in osteoplastic flap surgery.[2,5] If bone cuts are made which are wider than the extent of frontal sinus pneumatisation, intracranial entry will result. If the bone cuts are too narrow, an overhang of anterior sinus wall will ensue; this will impede full access to the frontal sinus, potentially compromising removal of disease, and leading to mucocele formation if any mucosa remains after the remainder of the sinus has been obliterated.

Many different techniques of frontal sinus mapping have been described.[6] Traditionally, Caldwell occipito-frontal radiographs taken from 6 feet (to avoid magnification)[5] have been used. The image of the frontal sinus is cut out of the radiograph, sterilised, and used intra-operatively as an onlay guide to the frontal sinus extent. A radiograph of the frontal sinus can also be made from composite computed tomography (CT) images.[7] Some authors have advocated the placement of controlled burr holes along the proposed osteotomy line, the position of which is then checked before connecting them with an oscillating drill;[5] others have used a vein hook to check position and guide drilling.[3] Alternative mapping techniques include sinus probing and transillumination. Recently, image guidance systems have been used, and have been shown to be more accurate than Caldwell radiographs, sinus probing or transillumination.[6,8] Image guidance systems have also been shown to reduce complications;[9] however, they are expensive and not widely available in the UK.

The authors present a new method of frontal sinus mapping. First, a three-dimensional model of the frontal

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sinus and surrounding bone is created using pre-operative CT data. This model is then used to make an onlay template that exactly replicates the frontal sinus extent. The template is sterilised and used intra-operatively to determine the extent of frontal sinus pneumatisation.

Materials and methods

After importing pre-operative CT image data into Mimics Z^{TM} software (Materialise, Leuven, Belgium), a virtual three-dimensional model of the frontal sinus and adjacent area is created. This is then used to construct an actual three-dimensional model by three-dimensional printing, either in-house (using a 310plus system; Z Corporation, Burlington, Massachusetts, USA) or using an external manufacturer. The model can be drilled open either from the posterior or anterior side, allowing exact identification of frontal sinus margins (Figure 1).

The model is then used to produce an onlay template. The template is made from light-cured acrylic resin (Triad regular pink unfibred; Dentsply, Weybridge, UK), a material which is supplied as a malleable sheet but which becomes solidified ('cured') on exposure to halogen light for 6 minutes (Triad system, Dentsply). This material was chosen for its accuracy, stability (it is autoclavable), and ease and speed of use. The template material is placed directly onto the anterior aspect of the frontal sinus model, and moulded to conform to the three-dimensional contours of the frontal bone, before being cured. A window is cut out of the template material, exposing the exact margins of the frontal sinus cavity.

The frontal sinus template thus consists of a perimeter of firm acrylic material held in a three-dimensional configuration that matches the contours of the frontal area, and a central window that exactly corresponds to the frontal sinus area (Figure 2). The template is autoclaved prior to use in the operating theatre.

Intra-operatively, after the flap is raised, the frontal sinus template is used as an onlay guide to frontal sinus pneumatisation (Figure 3). Correct template positioning is achieved using the three-dimensional configuration of the supraorbital ridges, glabella and nasion. The margins of the frontal sinus are marked with a drill, aiding the positioning of osteoplastic flap margins.

The accuracy of the templates was assessed by measuring how close to the actual frontal sinus margin the osteotomy cuts were placed. Visual inspection by the senior author suggested that the frontal sinus margins were not underestimated by more than 5 mm in any of the cases. Detailed measurements were not taken, as the margins did not require revision to improve surgical access.

The essential principle of the osteotomy into the frontal plate is to ensure that the cranial cavity is not breached and that the frontal window size facilitates maximal access. The lower osteotomy is limited by the position of the supraorbital neurovascular bundle, and by the need to avoid cosmetic deformity by not placing an osteotomy too close to the orbital rim. Therefore, the frontal window can only be maximised by ensuring the osteotomies are as close as possible to the superior and lateral margins of the frontal sinus. This also ensures that there are no overhangs which restrict access to the recesses of the frontal sinus. Assessment of the accuracy of the templates therefore aimed to measure how close to the actual superior and lateral frontal sinus edges the osteotomies had been positioned. This was achieved by making a visual assessment of the superior and lateral margins of the frontal sinus.

Results

Table I presents the details of 10 patients undergoing osteoplastic flap surgery with the aid of frontal sinus templates at

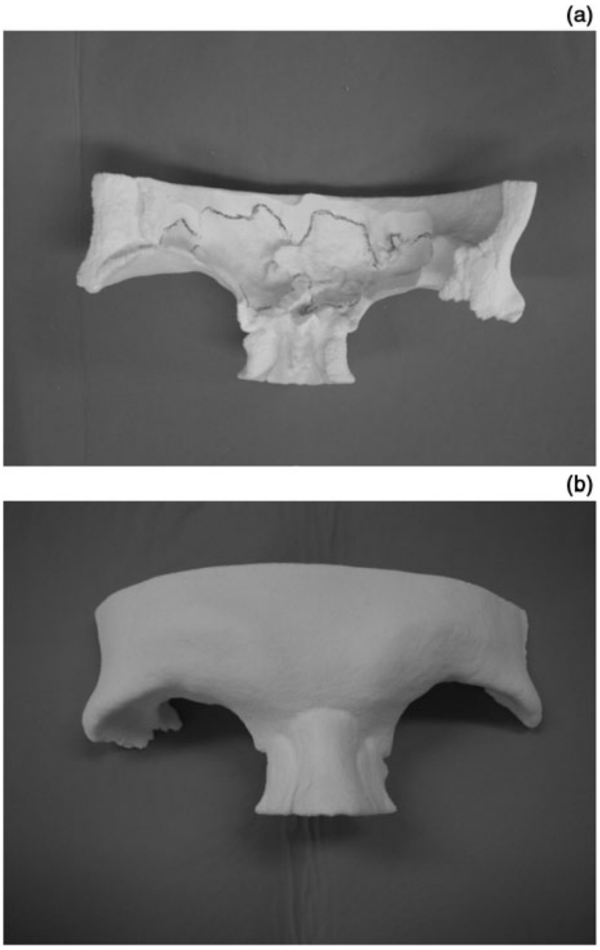

FIG. 1

(a) Three-dimensional model of the frontal sinus region. (b) Model with posterior sinus wall removed, enabling easy assessment of the sinus extent.

FIG. 2

Frontal regional model and frontal sinus template.

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FIG. 3
Use of the frontal sinus template intra-operatively.

our unit. We found the method to be consistently accurate, with osteoplastic flap margins always within 1 mm of the actual frontal sinus margins. No inadvertent intracranial breaches had occurred at the time of writing.

Discussion

The described technique for the creation of a frontal sinus model uses technology already available in most large hospitals. Computed tomography scans are always included as part of pre-operative planning, and external three-dimensional printing bureaus are already widely used (e.g. PDR, The National Centre for Product Design and Development Research; UWIC, University of Wales Institute, Cardiff), with innovative in-house services also being developed. The frontal sinus models created in the present study were consistently accurate. Because such models are three-dimensional, positioning over the frontal sinus area is likely to be more precise than the positioning of a two-dimensional Caldwell view or CT composite film. The accuracy rate of three-dimensional frontal sinus templates, as presented in this paper, compares favourably with the 17 per cent inaccuracy rate reported for Caldwell radiographs.[10] However, at present no data are available comparing the within-patient accuracy of the above technique with that of other methods of frontal sinus mapping, particularly image guidance systems.

Although the literature suggests that image guidance systems enable the most accurate frontal sinus delineation, the intra-operative availability of frontal sinus templates provides an additional method of cross-checking accuracy. The authors found that having the original three-dimensional model in the operating theatre enhanced visualisation of the frontal sinus as a three-dimensional structure, as an adjunct to the use of CT images alone, and also provided a useful training aid. As some image guidance systems require the placement of the registration headset on the forehead, the use of image guidance systems during osteoplastic flap surgery may unfortunately not be possible; in such circumstances the use of a frontal sinus template would be preferable.

The frontal sinus models and templates are produced from CT image data, and their accuracy therefore depends upon the quality of the CT scan. In patients with chronic infection and multiple previous procedures, bone may be difficult to differentiate on CT, affecting the quality of the frontal sinus model and thus the three-dimensional template. Pre-operative planning is essential, requiring close cooperation between the ENT surgeon and a specialist maxillofacial laboratory. Planning and construction time of approximately one week should be allowed.

Frontal sinus models and templates are cheaper than image guidance systems, although more expensive than Caldwell radiographs. The Mimics Z software required to convert CT data into three-dimensional image files currently costs £4000, but this cost can be spread across the different surgical specialties which will use three-dimensional printing. It is useful to have this software available in-house in order to identify the sinus extents with the surgeon, as in complex cases identification cannot easily be achieved using an external bureau. Each ZCorp three-dimensional model costs approximately £20, and the sinus template costs £25.

This three-dimensional printing technique could be further developed to directly manufacture a template from a computer-aided design program, removing the need to generate a three-dimensional frontal model. Such software is expensive to acquire in-house (e.g. £6000 for Magics Z, Materialise); however, the use of an external bureau would leave template design in the hands of non-medical personnel. Furthermore, the benefits of having the three-dimensional model available in the operating theatre would be lost.

TABLE I
DATA FOR 10 PATIENTS UNDERGOING OSTEOPLASTIC FLAP SURGERY USING FRONTAL SINUS TEMPLATES

Pt no	Age (y)	Sex	Prev surg (*n*)		Diagnosis	Complications
			Ext	ESS		
1	50	F	0	8	Mucocele	Nil
2	27	M	2	2	Osteomyelitis	Nil
3	63	M	0	2	Inverted papilloma	Nil
4	78	M	0	3	Inverted papilloma	Nil
5	62	F	0	5	Inverted papilloma	Nil
6	37	M	0	2	Rhinosinusitis	Nil
7	60	M	1	1	Mucocele	Nil
8	39	M	3	4	Rhinosinusitis	Nil
9	64	M	1	3	Inverted papilloma	Nil
10	24	F	1	12	Mucocele Samter's polyps	Infection

Pt no = patient number; y = years; prev surg = previous surgical procedures; ext = external procedures; ESS = endoscopic sinus surgery; F = female; M = male

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Conclusion

Three-dimensional models of the frontal sinus region, generated from CT data, can be utilised to create accurate three-dimensional templates of the frontal sinus. These templates can be used intra-operatively as an onlay guide to frontal sinus mapping. Early experience shows them to be consistently accurate to within 1 mm, suggesting that they could be a useful adjunct to current techniques. Future work must include comparison with other mapping techniques.

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