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Applications of 3D orbital computer-assisted surgery (CAS)☆

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ABSTRACT

Introduction: The purpose of the present report is to describe the indications for use of 3D orbital computer-assisted surgery (CAS).
Patients and methods: We analyzed the clinical and radiological data of all patients with orbital deformities treated using intra-operative navigation and CAD/CAM techniques at the Hôpitaux Universitaires de Genève, Switzerland, between 2009 and 2016. We recorded age and gender, orbital deformity, technical and surgical procedure and postoperative complications.
Results: One hundred and three patients were included. Mean age was 39.5 years (range, 5 to 84 years) and 85 (87.5%) were men. Of the 103 patients, 96 had intra-operative navigation (34 for primary and 3 for secondary orbito-zygomatic fractures, 15 for Le Fort fractures, 16 for orbital floor fractures, 10 for combined orbital floor and medial wall fractures, 7 for orbital medial wall fractures, 3 for NOE (naso-orbito-ethmoidal) fractures, 2 for isolated comminuted zygomatic arch fractures, 1 for enophthalmos, 3 for TMJ ankylosis and 2 for fibrous dysplasia bone recontouring), 8 patients had CAD/CAM PEEK-PSI for correction of residual orbital bone contour following craniomaxillofacial trauma, and 1 patient had CAD/CAM surgical splints and cutting guides for correction of orbital hypertelorism. Two patient (1.9%) required revision surgery for readjustment of an orbital mesh. The 1-year follow-up examination showed stable cosmetic and dimensional results in all patients.
Conclusion: This study demonstrated that the application of 3D orbital CAS with regards to intra-operative navigation and CAD/CAM techniques allowed for a successful outcome in the patients presented in this series.

1. Introduction

Since the mid-1990s, computer-assisted surgery (CAS) has developed dramatically leading to a remarkable unprecedented improvement and optimization of the global approach of reconstructive craniofacial surgery, especially with regards to the management of deformities in the orbital region [1–10].

Intraoperative navigation and computer-aided design/computer-aided manufacturing (CAD/CAM) techniques represent by far the two most attractive, versatile and complementary alternatives to the traditional non-computer-assisted freehand approach [1–16].

The CAS techniques assist the surgeon in the visualization and transfer of the previously determined preoperative 3D virtual surgical planning to the operating room: navigation via a simultaneous real-time 3D localization of tracked instruments on the patient's target area as well as on the preoperative images, thus augmenting the information provided by the real world and CAD/CAM techniques by means of patient-specific implants (PSI) and/or surgical drilling/cutting guides [11–21].

Navigation systems' performance has progressively been enhanced by implementing specific software that supports the "mirroring" of the healthy side onto the affected side and by integrating virtual objects such as 3D preformed orbital meshes into the preoperative planning. This advance has led to a substantial improvement in obtaining the most accurate symmetric facial reconstruction [1–10].

Moreover, navigation systems coupled with cone-beam computed tomography (CBCT) or computerized tomographies (CT) in a multidimodal hybrid environment provide a linear sequential computer-based workflow of the pre-, intra- and post-operative steps [5–9]. This has strongly contributed to a global improvement in the surgical task with regards to accuracy, predictability and patient outcomes, while potentially reducing costs, operating times and need for further surgical revision.

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The purpose of the present report is to describe our current indications for the use of 3D orbital CAS with regards to intra-operative navigation and CAD/CAM techniques.

2. Patients and methods

2.1. Study design

This retrospective study included all patients who underwent 3D orbital CAS at the Hôpitaux Universitaires de Genève, Switzerland between 2009 and 2016.

This study followed the Declaration of Helsinki on medical protocol and was approved by our local ethical board. The variables reviewed included age and gender, orbital deformity, technical and surgical procedure and postoperative complications.

2.2. Technical procedures

2.2.1. Navigation

2.2.1.1. Image data acquisition and processing. The CT-scan DICOM images were imported to the BrainLAB format using the iPlan® CranialVersion 2.6 software platform (BrainLAB AG Kapellenstrasse 12, 85622 Feldkirchen, Germany, support@brainlab.com) (Fig. 1).

2.2.1.2. Image segmentation and 3D virtual planning. Images were first re-aligned symmetrically to the horizontal Frankfort and mid-sagittal planes. A semi-automatic segmentation of the volumetric region of interest was performed on the CT images windowed into bone-specific Hounsfield units. A 3D template of the healthy side was mirrored and superimposed on the affected side's original CT scans to outline the margins needed to obtain symmetry. The new data sets of the treatment plan were loaded and exported to the navigation software platform VectorVision Cranial 7.8 (BrainLAB AG Kapellenstrasse 12, 85622 Feldkirchen, Germany, support@brainlab.com) for intra-operative imaging.

2.2.1.3. Patient registration and accuracy evaluation. Registration was performed by using titanium screws placed on the skull or by randomly scanning a cutaneous surface of the patient's head with a z-touch laser pointer. The registration's accuracy was determined by means of a tracked probe positioned on the head's screws or on the patient's teeth.

2.2.1.4. Intraoperative procedure. In orbito-zygomatic and NOE cases, the fractures or osteotomy sites were first exposed. After bone mobilization and repositioning, the three-dimensional positioning and matching between the planned and the actual position was verified by means of the tracked probe. Next, the bone fragments were fixed according to the planned position. In pure orbital fractures, a preformed mesh was first placed and then tracked to confirm the optimal positioning according to the mirrored orbital outline or to the surface of the virtual 3D mesh. Finally, in bone recontouring fibrous dysplasia cases, the dysplastic bone was first separated into several rectangles of bone whose depths were determined by the previous planning and regularly checked by using the pointer. The fragmented lesion was then removed by mobilization of the different pieces with a bone chisel, and once the satisfactory recontouring was achieved, the residual bone was then regularized by using a "pineapple" burr.

2.2.2. CAD/CAM patient specific cutting guides

The virtual 3D pre-operative computational planning was elaborated via the web-based Synthes PROPLAN CMF® service (GoToMeeting®, Citrix Online, Santa Barbara, CA) together with a clinical engineer at Materialise in Belgium as follows (Fig. 2).

2.2.2.1. Image transfer and processing. The CT scan images in *Digital Imaging and Communications in Medicine* (DICOM) format were processed using *ProPlan CMF 2.0* software (Materialise, Technologielaan 15, 3001 Leuven, Belgium - www.materialise.com).

2.2.2.2. Image segmentation and 3D virtual planning orbital hypertelorism case. The 3D bone segments corresponding to a frontal craniotomy and orbital box osteotomies separated by a 1 cm high frontal "crown" were first segmented. A 1 cm wide central segment, corresponding to the naso-fronto-ethmoidal to be removed in order to bring the orbital boxes closer together toward the midline was determined. The orbital boxes were then virtually slid to obtain correction of OH. Patient-specific surgical cutting guides were created according to the osteotomy lines previously determined and were sent by the manufacturer to the surgeon and sterilized by autoclave prior to their utilization in our hospital.

2.2.2.3. Intraoperative procedure. Coronal, transconjonctival and upper buccal sulcus approaches were performed to expose the frontal calvarial vault, the orbital walls, the zygoma and zygomatic arches. Two fronto-orbital, two maxillary and a central nasal cutting guides were temporarily fixed with two 2.0 mm screws. Osteotomies were performed with a reciprocating saw or Piezosurgery 3 (Mectron spa, Carasco, Italy; www.piezosurgery.com), following the cutting guide's flanges. The cutting guides were removed and then the resulting two orbital boxes were mobilized and translated medially and fixed together and to the frontal "crown" with wires. The coronal incision was closed in two layers over two closed suction drains, using a transconjonctival approach with uninterrupted 6-0 Maxon sutures and an upper buccal sulcus with uninterrupted 3-0 Vicryl sutures.

2.2.3. CAD/CAM PEEK-PSI (PolyEtherEtherKetone-patient-specific implants)

The virtual 3D pre-operative computational planning was elaborated via a web-based Synthes® platform (Oberdorf, Switzerland) using FreeForm® Modeling™ software (SensAble Technologies, Inc., 181 Ballardvale Street, Wilmington, MA 01887-USA - www.sensable.com) as follows (Fig. 3).

2.2.3.1. Image segmentation. A semi-automatic segmentation of the volumetric region of interest was first performed to obtain a 3D template of the healthy side. The template was mirrored and superimposed on the contralateral side to fit the residual bony defect as precisely as possible in order to obtain ideal and symmetrical positioning.

2.2.3.2. Manufacturing. The implant design was approved by the surgeon first based upon the images and then after carefully reviewing the adaptation of a 3D printed implant prototype on the stereolithographic skull model. The definitive non-sterile PEEK-PSI was thus sent by the manufacturer to the surgeon and sterilized by autoclave prior to its utilization in our hospital. Skull and implant models were sent to the surgeon for review and/or final approval before the definitive manufacturing.

2.3. Surgical procedure

The implants were inserted by a coronal approach in 6 patients, a combined coronal, transconjonctival and intraoral approach in 1 patient and a combined transconjonctival and intraoral in 1 patient. The implants perfectly matched the dimensions of the residual bone defect without the need for any further

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