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Computer-assisted orthognathic surgery: waferless maxillary positioning, versatility, and accuracy of an image-guided visualisation display

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Abstract

There may well be a shift towards 3-dimensional orthognathic surgery when virtual surgical planning can be applied clinically. We present a computer-assisted protocol that uses surgical navigation supplemented by an interactive image-guided visualisation display (IGVD) to transfer virtual maxillary planning precisely. The aim of this study was to analyse its accuracy and versatility in vivo. The protocol consists of maxillofacial imaging, diagnosis, planning of virtual treatment, and intraoperative surgical transfer using an IGV display. The advantage of the interactive IGV display is that the virtually planned maxilla and its real position can be completely superimposed during operation through a video graphics array (VGA) camera, thereby augmenting the surgeon's 3-dimensional perception. Sixteen adult class III patients were treated with by bimaxillary osteotomy. Seven hard tissue variables were chosen to compare (ΔT_1–T_0) the virtual maxillary planning (T_0) with the postoperative result (T_1) using 3-dimensional cephalometry. Clinically acceptable precision for the surgical planning transfer of the maxilla (<0.35 mm) was seen in the anteroposterior and mediolateral angles, and in relation to the skull base (<0.35°), and marginal precision was seen in the orthogonal dimension (<0.64 mm). An interactive IGV display complemented surgical navigation, augmented virtual and real-time reality, and provided a precise technique of waferless stereotactic maxillary positioning, which may offer an alternative approach to the use of arbitrary splints and 2-dimensional orthognathic planning.

Keywords: Orthognathic surgery; Surgical navigation; 3D-cephalometry; Virtual orthognathic planning; Interactive image-guided-visualization-display

Introduction

The virtual orthognathic 3-dimensional planning software is an excellent tool, which assists in diagnosis, the planning of virtual treatment, and postoperative evaluation of craniomaxillofacial deformities.[1] However, the surgical transfer of virtual surgical plans remains unpredictable.[2,3] Various approaches that use internal and external references and positioning devices (face-O-Meter, 3D-COSMOS) have been attempted,[4–6] but could not be established in practice.

Orthognathic surgical planning therefore still relies on the use of maxillomandibular-interocclusal splints,[7] which are required to position the maxilla.[2,3,7–9] Using this technique, malpositions of up to 5 mm have been described.[7] This approach has several limitations associated with projection radiography and dental model surgery, as well as insufficient control of the maxillary position such as rotation-translation of the basal skull because of the mobility of the mandible.

As an alternative, image-guided surgical navigation was introduced to orthognathic surgery for precise transfer of maxillary planning. Promising results were reported

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Fig. 1. Surgeon's view through the portable, interactive, image-guided, visualisation display. The maxilla was virtually augmented as a three-dimensional object in its new position.

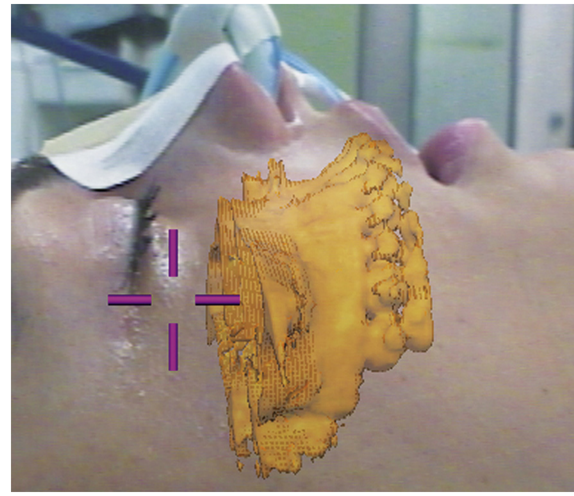

Fig. 2. Surgeon's view through the image-guided visualisation display showing the virtually superimposed maxilla.

(Zinser et al. Computer assisted secondary reconstruction of maxillofacial deformity. Paper presented at 88th annual meeting of the American Association of Oral and Maxillfacial Surgeons, 2006)[10–13]; but when using a standard image-guided pointer, only a single virtual landmark could be displayed in vivo in 3 dimensions.[10]

We therefore present a waferless stereotactic solution using an interactive IGV display that is supplementary to surgical navigation, where the 3-dimensional contours of the virtually-planned and real-time maxillary positions can be superimposed to augment the surgeon's perception (Fig. 1).[14,15]

The aim of this study was to investigate the clinical versatility and accuracy of an IGV display by analysing preoperative virtually planned (T_0) and postoperative positions (T_1) of the maxilla using 3-dimensional cephalometry.

Materials and methods

Maxillofacial imaging, diagnosis, and planning of virtual treatment

As in our previously published navigation protocol,[15] the DICOM data acquired from computed tomography (CT) or cone-beam CT were implemented in the 3-dimensional planning software (I-plan CMF®, BrainLab). After segmentation by semiautomatic thresholding and volumetric surface rendering, maxillofacial imaging can then be displayed in 3 dimensions. A tetrahedral soft tissue mesh can subsequently be built to enable soft tissue simulation using a biomechanical model.[16] However, the representation of the dentition is limited by metallic scatter artefacts. The relevant anatomical structures in all orthogonal planes and in 3 dimensions were inspected. This included the condyles, maxillofacial bone, airway, inferior alveolar nerve, and teeth.

Subsequently, we adopted a 3-phase approach to virtual planning, including anthropometric and cephalometric analyses, definition of planes of symmetry, and virtual orthognathic planning. The preoperative anthropometric assessment involves consideration of the occlusion plane, bipupillary and laugh lines, maxillary inclination and rotation, and configuration of the lips and teeth when smiling.

The virtual placement of the facial symmetrical 3-dimensional reference coordinates is therefore essential to achieve facial symmetry. The Frankfort horizontal plane (FHP) is used as the reference plane as it is unaffected by most craniofacial abnormalities. Four reference planes that correspond to the FHP are then constructed to achieve the ideal facial symmetrical coordinates including the midfacial plane, which is defined as perpendicular to the FHP through the nasion; the coronal plane, which is constructed perpendicular to the FHP through the sella; the occlusal plane, which is constructed through the upper molars and incisors; and the frontozygomatic line, which connects the right and left frontozygomatical sutures. After the ideal facial symmetry has been put in place, the maxilla can then be virtually translocated.

Surgical planning transfer using navigation and an interactive image-guided visualisation display (IGVD)

The unique aspect of this approach is the waferless stereotactic surgical transfer of the virtually planned maxilla using an interactive IGV display (Figs. 1–3). Preoperatively image-to-patient recording and referencing are required for wireless connection of the IGVD and the navigational unit (BrainLab®, Vector Vision[2]) (Zinser et al. Computer assisted secondary reconstruction of maxillofacial deformity. Paper presented at 88th annual meeting of the American Association of Oral and Maxillfacial Surgeons, 2006).[13–15]

The IGV display is portable, measures 20 cm × 25 cm (Fig. 1) and has a rear-mounted digital VGA camera that