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Development and first clinical application of automated virtual reconstruction of unilateral midface defects☆

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ABSTRACT

Purpose: Computer-assisted surgery is used for decision making, treatment, and quality control throughout the reconstruction process of unilateral midface defects. The current approaches exploit the symmetry of the face by mirroring the intact side on the defect side using various segmentation methods. All commercially available implementations, however, are somewhat time consuming and dependent on the level of expertise of the user. We present a method for automatic reconstruction of unilateral midface defects using registration.

Material and methods: To reconstruct a skull by registration, the defect volume has to be virtually deleted from the skull. This modified data set is then mirrored and registered onto the original, defect-free skull. The fusion of these two skulls is the virtual reconstructed skull bridging the defect. Reconstruction by registration was performed for 24 different skulls without motion or dental restoration artifacts. Subsequently, simulation was performed with four accurately defined, various-sized, defects of the orbito-zygomatic complex. The results of the automated virtual reconstructions were compared with those obtained for the same defects as determined using conventional atlas-based planning software (iPlan). To simulate various clinical situations, four groups each containing six skulls were evaluated: the complete skull, midface and neurocranium, midface and lower jaw, and midface alone. The differences were compared using the similarity coefficients of Sørensen-Dice and Jaccard. Statistical analyses were performed using the t-test and Mann–Whitney U test.

Results: The reconstruction results were similar for all the groups. The Sørensen-Dice coefficients of similarity for all reconstructed skulls were 0.869 and 0.874 for the registration and atlas-based reconstructions, respectively. The corresponding Jaccard coefficients were 0.774 and 0.781, respectively. Atlas-based reconstruction showed significantly better results in group 3 (midface and lower jaw) alone.

Conclusion: Virtual automated reconstruction by registration had equivalent accuracy to conventional atlas-based reconstruction across a spectrum of defects, from simple orbital to complex orbito-zygomatic defects. However, for those involving the midface and lower jaw, atlas-based reconstruction showed significantly better results. Although the new approach is somewhat hardware demanding, it is user independent, dispensing with the need for time-consuming adjustments to the results of planning. The first clinical application of registration reconstruction revealed performance equivalent to that of the conventional approach.

1. Introduction

Close proximity of various critical structures poses a challenge in terms of functional as well as aesthetic outcome in craniomaxillofacial surgery. For most reconstruction purposes,

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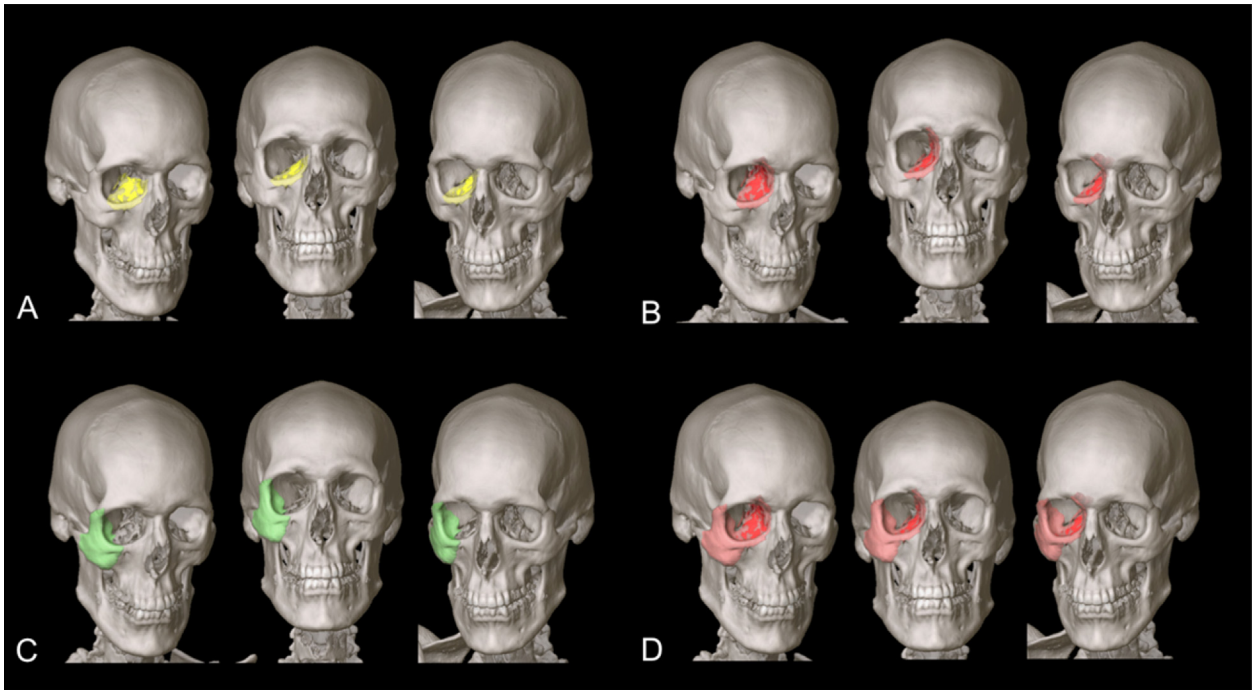

Fig. 1. 3D visualization of the simulated defect areas. A: orbital floor, B: orbital floor and medial wall, C: zygoma, D: orbital wall, medial wall, and zygoma.

computer-assisted surgery (CAS) offers great advantages for diagnosis, planning, therapy, and quality control. As a result, this approach has been widely accepted, and its importance has increased progressively over the last two decades. The more complex the deformation is, the more likely the patient will benefit from CAS, which limits the likelihood of complications (Cohen and Kawamoto, 1992). The main clinical applications of CAS in craniomaxillofacial surgery are trauma (Gellrich et al., 1999; Mustafa et al., 2011), reconstruction of malformations and post-tumor ablation defects (Westendorff et al., 2007; Essig et al., 2011a), secondary reconstruction (Watzinger et al., 1997; Gellrich et al., 2002), and orthognathic surgery (Zizelmann et al., 2012; Gander et al., 2015a) Segmentation of pathologic soft tissue structures has gained more popularity over the last few years (Schramm et al., 2008). Such segmentation can be used not only for tumor resection but also for postoperative radiotherapy (Essig et al., 2011b). In addition, CAS can be used to compensate for missing landmarks in discrete defects (Hammer and Prein, 1995).

In the classical planning process for unilateral deformations or defects, the unaffected side of the skull is mirrored onto the affected side based on the assumption of facial symmetry (Schramm et al., 1999). In this process, the target hard tissue structures can be segmented with a preset of stored similar structures—the so-called atlas-based segmentation (Metzger et al., 2013). Unfortunately, this way of virtual reconstruction is time consuming and highly dependent on the level of expertise of the operator. A more automated reconstruction technique would substitute for the necessary user interactions and therefore decrease the time needed for virtual reconstruction. To the best of our knowledge, there is no software currently available for routine application in the clinic that is capable of performing these tasks automatically. Therefore, developing new concepts that can perform these tasks automatically would be of great clinical impact.

To accomplish this, we used image registration algorithms. Image registration generally means the process of transforming one image into another based on certain preset parameters (Broit, 1981). The aim is therefore to transform one image in the same coordinate system as the target image. Registration is already used in various clinical aspects of CAS in craniomaxillofacial surgery, including image fusion, intraoperative navigation, and postoperative quality control (Hassfeld et al., 1997; Plooij et al., 2011). The complexity of the registration process increases with increasing differences between the two images to be registered. Most of the image registration techniques in routine clinical use are capable of performing simple registration tasks.

More complex registration algorithms combined with the idea of the symmetry of the skull could be used to advance virtual and, therefore, real reconstruction of unilateral defects to a new level. To achieve this, the defect areas have to be deleted. This 'defect-free' skull is mirrored and registered onto the original skull. The registered result and the skull without the defect are fused thereafter. The result with the replaced defect area can then be used for clinical reconstruction. We are not aware of any reports on the use of this technique and its clinical application for reconstruction of unilateral midfacial defects.

The aim of this study was to evaluate the registration algorithm for the virtual reconstruction of different midfacial defects and to compare automated registration with conventional atlas-based registration via mirroring, the current standard in clinical use. The first clinical application of automated registration was also demonstrated here.

2. Material and methods

This study was performed after obtaining institutional ethics committee approval (MHH 2156-2014). Dataset selection and processing with the iPlan 3.0.5 software (Brainlab, Feldkirchen, Germany) were performed on a standard personal computer (Windows 7 or Windows 8, Intel Core i7, 8 GB RAM). All datasets used were collected from the image database of our department. A total of 24 different skulls were selected based on image quality