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Computed tomography-based virtual fracture reduction techniques in bimandibular fractures

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ABSTRACT

Purpose: Computer-assisted preoperative planning (CAPP) usually relies on computed tomography (CT) or cone beam CT (CBCT) and has already become an established technique in craniomaxillofacial surgery. The purpose of this study was to implement CT-based virtual fracture reduction as a key planning feature in patients with bimandibular fractures.
Material and methods: Nine routine preoperative CT scans of patients with bilateral mandibular fractures were acquired and post-processed using a mean model of the mandible and Amira software extended by custom-made scripting and programming modules.
Results: A computerized technique was developed that allowed three-dimensional modeling, separation of the mandible from the cranium, distinction of the fracture fragments, and virtual fracture reduction. User interaction was required to label the mandibular fragments by landmarks. Virtual fracture reduction was achieved by optionally using the landmarks or the contralateral unaffected side as anatomical references.
Conclusion: We successfully elaborated an effective technique for virtual fracture reduction of the mandible using a standard CT protocol. It offers expanded planning options for osteosynthesis construction or the manufacturing of personalized rapid prototyping guides in fracture reduction procedures. CAPP is justified in complex mandibular fractures and may be adopted in addition to routine preoperative CT assessment.

1. Introduction

Mandibular fractures are common facial injuries, accounting for 20%–60% of all facial fractures (Gassner et al., 2003; Pombo et al., 2013; Arabion et al., 2014). Although the majority of mandibular fractures occur in young men, mainly between the second and third decades of life (Ellis et al., 1985; Fridrich et al., 1992; Bormann et al., 2009), elderly persons with an edentulous and atrophic mandible also exhibit a high risk of mandibular fractures (Ellis and Price, 2008; Benech et al., 2013).

There are wide regional variations regarding the cause, frequency, and anatomical distribution in mandibular fractures, although fractures of the condyle, body, and the ramus are the most frequently affected (Ellis et al., 1985; Fridrich et al., 1992; Bormann et al., 2009; Eskitascioglu et al., 2013). In around 40%–50% of cases, mandibular fractures occur at multiple anatomical distributions (Ellis et al., 1985; Eskitascioglu et al., 2013). Due to the distinctive shape of the condyle and the nature of the applied forces responsible for the fracture, condylar/subcondylar fractures in combination with symphyseal/parasymphyseal fractures are common in bilateral fractures (Eskitascioglu et al., 2013).

Routine diagnostic procedures include conventional radiographs and the increasing use of computed tomography (CT). Further evidence about the three-dimensional (3D) facture pattern might be obtained by inspecting two-dimensional (2D) multiplanar CT reconstructions and using 3D standard visualizations, as provided by the CT workstation or by additional software applications.

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Treatment options comprise nonsurgical handling (Walker, 1994) as well as varying surgical open reduction with or without internal fixation approaches (Hall, 1994), and are highly dependent not only on the fracture pattern itself but also on patient-specific circumstances (Sawhney et al., 2013). Surgical fixation requires the exact reduction of the fracture segments in order to re-establish the dental occlusion, masticatory function, and pre-injury bony anatomy (Ellis and Throckmorton, 2005); otherwise, malocclusion, altered temporomandibular joint function, limited mouth opening and lateral protrusion, ramus shortening with facial asymmetry, nerve impairment, osteoarthrosis, and even resorption may occur (Talwar et al., 1998; Chen et al., 2011; Eskitascioglu et al., 2013).

We believe that standard options in the preoperative assessment display optimization requirements, as further relevant information is not used and yet not readily available prior to starting the surgical procedure. A diagnostic and therapeutic aid might be to adopt computer-assisted preoperative planning (CAPP) for the reconstruction of traumatic injuries of the mandible, especially for the reconstruction of complex fracture cases such as bimandibular fractures. CAPP has been rapidly gaining interest in the field of craniomaxillofacial surgery and has been particularly used in the field of orthognathic and reconstructive surgery (Swennen et al., 2009; Farrell et al., 2014; Stokbro et al., 2014).

However, CAPP of complex traumatic injuries necessitates other considerations. It remains a particular technical challenge, and, until now, necessary technologies have not been well established. The application of CAPP within routine clinical settings in cases of severe traumatic injuries represents a new consideration and has not yet become integrated in standard planning procedures.

Adequate 3D CT visualization and modeling with properly identified and virtually reduced fracture segments represent key planning features and potentially offer extended patient assessment, planning, and treatment options.

Inspired by the idea of increasing efficiency in the preoperative assessment of cases with severe injuries of the mandible, we hypothesise that based on the use of preoperative CT scans, it is possible to define a clinically feasible workflow to virtually reduce mandibular fractures and to supply the user with useful information about the possibility of custom-made repositioning and fixation tools.

The objectives of this study were (1) to demonstrate the technical feasibility of virtual fracture reduction in traumatic injuries of the mandible, and (2) to exemplify expanded planning options by designing personalized guide templates for fracture reduction and fixation.

2. Material and methods

2.1. Image data acquisition

Nine retrospectively selected, anonymized, preoperative CT scans were acquired at the Department of Oral and Maxillofacial

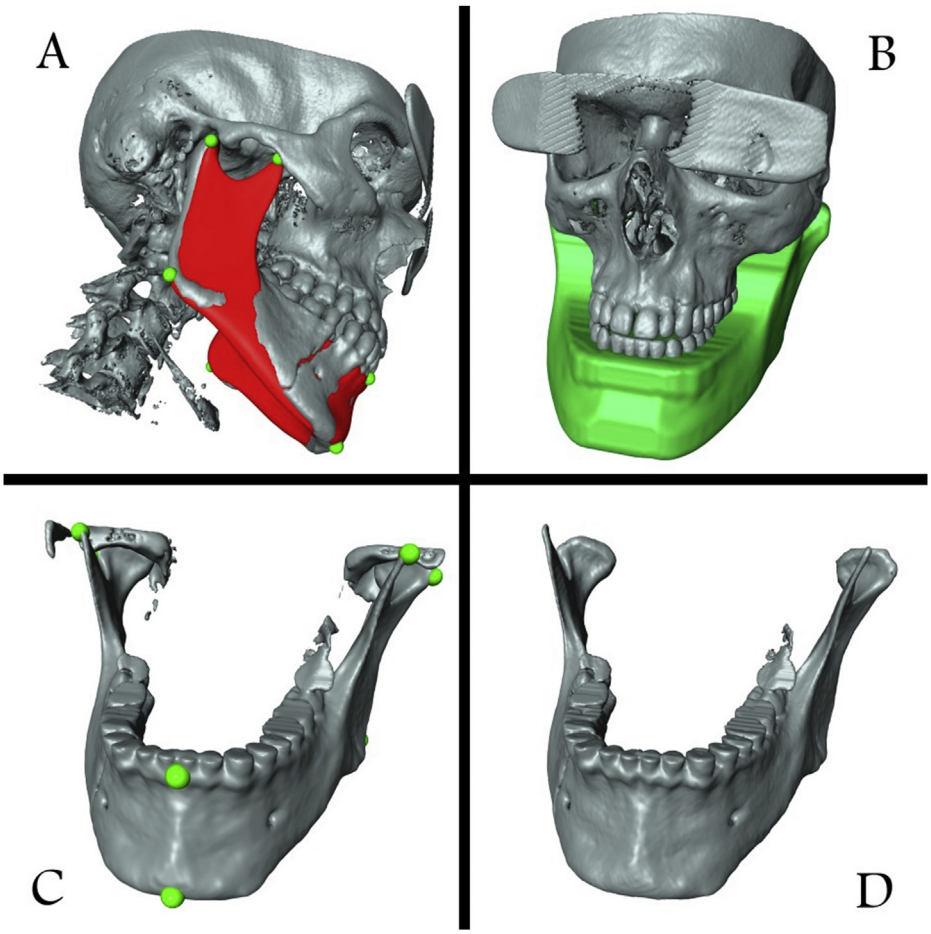

Fig. 1. Separation of the mandible. (A) Landmarks (green) manually placed on a given 3D CT case (gray) to register the mean model of the mandible (red). (B) The enlarged mean model (green) defines a mandibular region of interest (ROI). (C) The affected mandible is selected according to the enlarged ROI. (D) The mandible is separated and available for further post-processing.

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