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Mandibular angle split osteotomy based on a novel augmented reality navigation using specialized robot-assisted arms—A feasibility study

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A B S T R A C T

Purpose: Augmented reality (AR) navigation, is a visible 3-dimensional display technology, that, when combined with robot-assisted surgery (RAS), allows precision and automation in operational procedures. In this study, we used an innovative, minimally invasive, simplified operative method to position the landmarks and specialized robot-assisted arms to apply in a rapid protyping (RP) model. This is the first report of the use of AR and RAS technology in craniomaxillofacial surgery.
Method: Five patients with prominent mandibular angle were randomly chosen for this feasibility study. We reconstructed the mandibular modules and created preoperational plans as semi-embedded and nail-fixation modules for an easy registration procedure. The left side of the mandibular modules comprised the experimental groups with use of a robot, and the right sides comprised the control groups without a robot. With AR Toolkits program tracking and display system applied, we carried out the operative plans and measured the error.
Results: Both groups were successfully treated in this study, but the RAS was more accurate and stable. The average position and angle were significant ($p < 0.01$) between the 2 groups.
Conclusions: This study reports a novel augmented reality navigation with specialized robot-assisted arms for mandibular angle split osteotomy. AR and RAS can be helpful for patients undergoing cranio-maxillofacial surgery.

1. Introduction

Mandibular angle split osteotomy (MASO) is widely used in treating prominent mandibular angle and aims to improve cosmetic results in the patients. Surgeons have conventionally performed this procedure based on computed tomography (CT) images and clinical experience. The most difficult aspects of MASO are the complexity of the anatomical structure and the narrow field of view allowed by an intraoral incision (Hong et al., 2014). The advantages of augmented reality (AR) are the ability to provide direct perception of the position of crucial structures and to assist surgeons in developing preoperational plans; which make AR an excellent solution to problems frequently encountered with MASO.

Augmented reality (AR), which is developed by computer technology, can combine reality and digital information. The major characteristic of augmented reality, which enhances the sensation of the user, are a combination of virtual reality, real-time interaction, and 3-dimensional display (Berryman, 2012). With the advent of computed tomography (CT), magnetic resonance imaging (MRI), and digital radiography, there is the possibility of creating virtual

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data to provide information for navigation systems in medical areas such as neurosurgery (Cabrilo et al., 2014), orthopedics (Zemirline et al., 2013), maxillofacial surgery (Qu et al., 2014), urology (Hughes-Hallett et al., 2014), gastrointestinal surgery (Marzano et al., 2013), pediatric surgery (Souzaki et al., 2013), and cardiology (Szabo et al., 2013), among other areas. Even though many different kinds of AR systems have been used in studies, no simple registration and minimally invasive method have been reported.

Use of medical robots may result in decreased hospitalization time, lower complication rates, less postoperative pain, and faster recovery (Pugin et al., 2011). Moreover, medical robots can also reduce tremble and fatigue in the surgeon. In the past decades, there have been many applications in areas of plastic surgery (Selber, 2014). However, considering the high cost, necessity of long-term training, and uncertain security, there is no specialized robot that is widely used in craniomaxillofacial surgery.

We chose MASO for our study because of the simplicity of the procedure. In this study, we aimed to use an innovative, minimally invasive, simplified operative method to position the landmarks for the AR system, along with specialized robot-assisted arms to apply in a rapid prototyping (RP) model. Such a method, which combines the advantages of both AR and RAS technology, is a novel approach in craniomaxillofacial surgery. By combining AR and RAS technology, we can find a new way to perform more complicated surgery, entering into a new era of intelligence, visualization, and automation for craniomaxillofacial surgery.

2. Material and methods

2.1. Model resource

Five patients with mandibular angle prominence were randomly chosen from an image work station in our department between 2011 and 2014. By reading the digital imaging and communications in medicine (DICOM) data for computed tomography (Brilliance 64 slice spiral CT, Philips, the Netherlands), the information was input in our software station (Materialise, Ann Arbor, Michigan, USA). We set a threshold value to distract bone and soft tissues for their different densities and reconstructed a 3-dimensional skull image, using rapid prototyping (RP) technology (ProJet 660 Pro, 3DSYSTEM, USA) models that were readily available.

2.2. Preoperational design

The most common complication of MASO is nerve damage after surgery. To prevent this problem, the first step was to mark the mandibular branch of the facial nerve. To ensure the section plane, we selected 6 key points, based on clinical experience, for achieving cosmetic results without damaging the nerve and to maintain a safe distance during the operation.

By using RAS technology, we performed a drilling method as a means of transitioning to automatic MASO. In theory, numerous hole paths can be used to create a cutting plane, and with the force-control device of robot-assisted arms, the finishing drilling point must stop at the bone part as well as plan. For a better perception of the AR, we also added a virtual model of a drill for better viewing of the navigation system (2-mm-diameter drills, GD456M, Aesculap, Germany) (Fig. 1).

2.3. Mark complex

In this study, we created a new method by computer-assisted design (CAD) software to make a semi-embedded and nail-fixation mark complex (MC). The first step in making a fixation module involved drilling 3 holes 3–4 mm in thickness for screws. As a result, there was no extra damage to the patient because the fixation part was cut as planned. Then, we designed a delicate and custom-made module connector that attached to the mark module. These 3 parts comprised the mark complex (MC). Finally, we output the MC data as an STL file with computer-aided manufacturing (CAM) technology to create an actual model (Fig. 2).

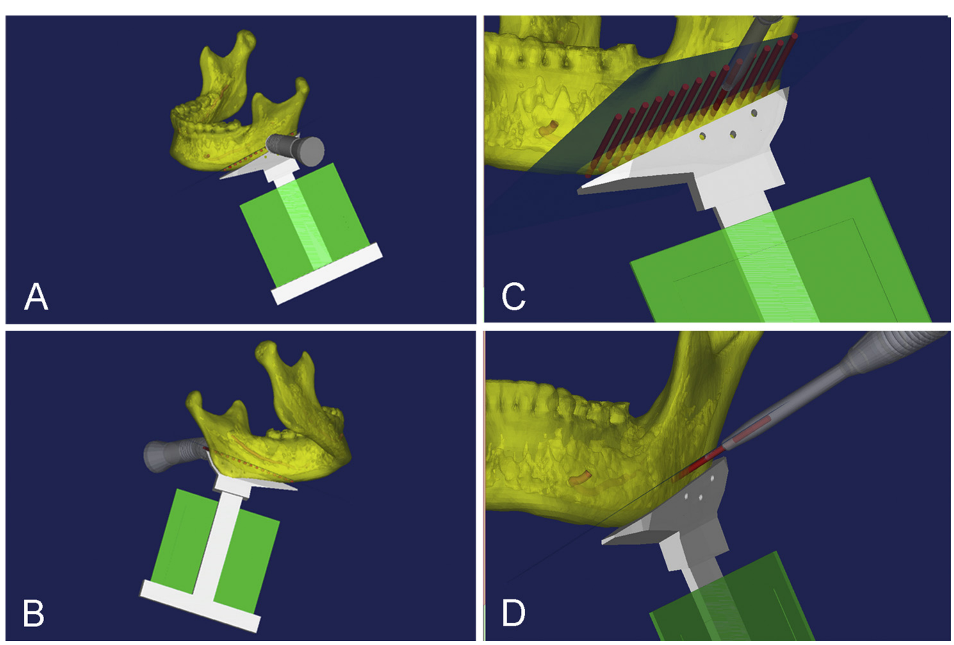

Fig. 1. Preoperational design. (A) Anterior portion of the preoperational design. (B) Posterior portion of the preoperational design. (C) Perspective of the preoperational design. (D) Single path of the preoperational design. Yellow: mandible; blue: cutting plane; light red: nerve; dark red: drilling path; white: mark complex; green: mark simulation; gray: drill simulation.