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Research Paper
Orthognathic Surgery

Generation of virtual models for planning orthognathic surgery using a modified multimodal image fusion technique

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Abstract. Streak artefacts caused by dental metals deteriorate the quality of computed tomography (CT) images. We developed and evaluated a method for generating three-dimensional virtual models to plan orthognathic surgery in patients with multiple dental materials, to avoid the adverse effects of metal artefacts in image fusion. The method basically consists of four procedures: (1) fabrication of a splint in the open-mouth position with fiducial markers, (2) reconstruction of a virtual skull model in the open-mouth position from CT scanning, (3) reconstruction of two virtual dental models in the open-mouth position and either the intercuspal position (ICP) or centric relation (CR) from surface scanning, and (4) three serial steps of image registration and subsequent repositioning of the mandible to the ICP or CR. This method allows for the registration of skull and dental models under artefact-free conditions. To validate the method, CT and dental cast data from 30 patients were used. The registration accuracy was 0.080 mm for the initial registration, 0.033 mm for the second registration, and 0.028 mm for the third registration. The present method can be used to determine the occlusal relationships and craniofacial morphology of patients with dental metals and can be applied to computer-assisted diagnosis and surgery.

Key words: three-dimensional (3D); orthognathic surgery; metal artefact; multimodal image fusion; registration accuracy; virtual model.

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Recent rapidly developing computer technology has provided us with a new powerful tool for diagnosing facial and jaw deformities (computer-assisted diagnosis),[1–11] and for planning[12–17] and guiding surgical interventions (computer-assisted surgery).[18–20] Although computed tomography (CT), from which virtual skull models with dentition are generated, is a fundamental procedure in computer-assisted diagnosis and surgery, it has several disadvantages: (1) limited spatial resolution and partial volume-averaging effects of CT cause image distortion, especially when small anatomical details such as the occlusal surface of teeth are scanned; (2) the threshold condition influences the morphology of the teeth and cranial bones; and (3) information about the occlusal surface is lost if the CT scan is performed with the teeth in occlusion.[1–15,18–20] Therefore, the image quality obtained from CT scanning only is not sufficient to precisely represent tooth configuration and intercuspation, which is a

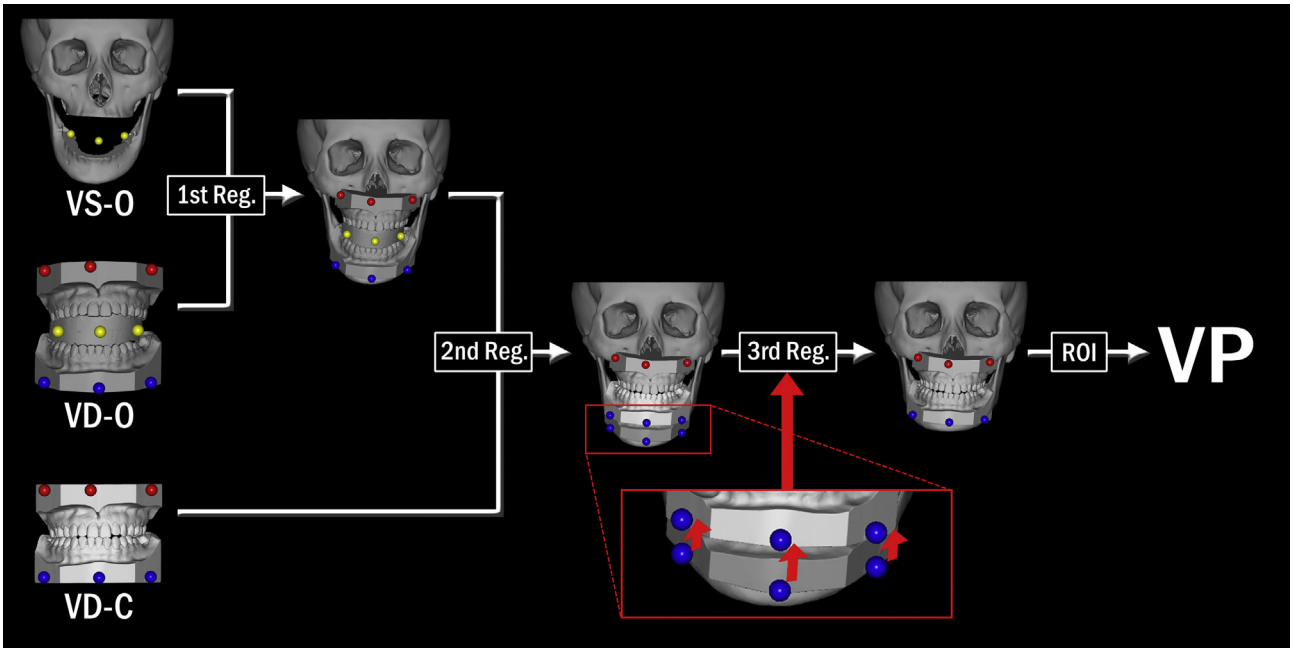

Fig. 1. Flow diagram of the present method for generating a virtual patient model. 1st Reg.: Initial registration of the virtual skull model (VS-O) and virtual dentition model (VD-O) in the open-mouth position. 2nd Reg.: Second registration of the virtual skull and dentition model in the open-mouth position (fusion image of VS-O and VD-O) and virtual dentition model in the ICP or CR (VD-C). 3rd Reg.: Third registration for repositioning the mandible in the ICP or CR. Generation of the virtual patient model in the ICP or CR (VP) is completed after extraction of the region of interest (ROI). ICP, intercuspal position; CR, centric relation.

definite disadvantage for predicting jaw position after orthognathic surgery. To overcome these problems, an image-fusion technique,[21–23] in which a virtual skull model obtained from CT scanning and a virtual dental model obtained from laser scanning of a dental cast or CT scanning of an impression, was introduced into three-dimensional (3D) reconstruction methods to diagnose skeletal deformities.[1–15,18–20]

In addition to the above-mentioned disadvantages of CT scanning, another significant problem is streak artefacts caused by strongly attenuating objects, i.e., metal artefacts.[24–26] The presence of metal restorations, prostheses, dental implants, and orthodontic appliances in the field of view of the CT scan causes the metal artefacts, which may drastically degrade the CT images and limit the application of CT.[2,3,13,24–26] This problem cannot be resolved entirely, even using the image-fusion technique, if the multiple and extensive artefacts extend into the fiducial markers used for image integration, thereby disturbing precise image fusion.

The aim of this study was to develop a method for generating virtual models that can realize the tooth configuration, occlusal relationships, and craniofacial morphology of patients with multiple metallic dental materials, to avoid the adverse effects of metal artefacts in the image-fusion process. In doing so, the accuracy of the generated virtual patient models may be improved and their application extended to a wide range of patients who need 3D diagnoses and surgical simulation.

Materials and methods

Thirty patients (10 males, 20 females) who were diagnosed with severe skeletal deformities and required orthognathic surgery were examined. The patients ranged in age from 15.3 years to 34.4 years, with a mean age of 26.4 years. All patients were treated in the university maxillofacial deformities clinic. Inclusion criteria were as follows: (1) patients with complicated 3D jaw deformities involving skeletal asymmetry, who were expected to need complicated movements of the segmented bones, including multidirectional translation and/or rotation with more than two rotational axes, and (2) patients with multiple dental metals, such as orthodontic appliances, restorations, and prostheses. Materials including CT data and dental cast models were obtained at the initial examination or just before orthognathic surgery. Ethical approval was granted, and all patients gave their informed consent to participate. When the patients were under 20 years of age, further informed consent was obtained from their parents.

The system, which consisted of an X-ray CT apparatus, non-contact surface scanner, and their related software, was used to generate a virtual patient model (fusion model of a virtual skull and dentition in the intercuspal position (ICP) or centric relation (CR)). Details of the generation method have been described previously.[14] In a previous study, dental casts occluded in the ICP or CR were used as a starting model.[14] In this study, however, dental casts in the open-mouth position and either ICP or CR were used (Fig. 1). Our method consisted of the following five procedures: (1) reconstruction of a virtual skull model from CT scanning in the open-mouth position pre-surgery (VS-O), (2) reconstruction of two virtual dental models from the 3D surface scanning of dental casts in the open-mouth position and ICP

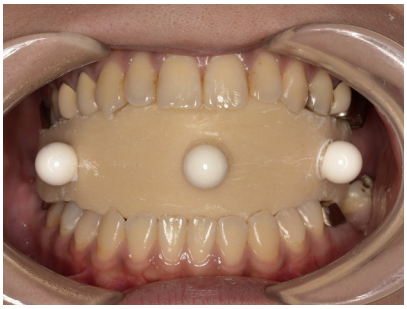

Fig. 2. Reference splint in the open-mouth position.