

Virtual occlusal definition for orthognathic surgery

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Abstract. Computer-assisted surgical simulation is being used increasingly in orthognathic surgery. However, occlusal definition is still undertaken using model surgery with subsequent digitization via surface scanning or cone beam computed tomography. A software tool has been developed and a workflow set up in order to achieve a virtual occlusal definition. The results of a validation study carried out on 60 models of normal occlusion are presented. Inter- and intra-user correlation tests were used to investigate the reproducibility of the manual setting point procedure. The errors between the virtually set positions (test) and the digitized manually set positions (gold standard) were compared. The consistency in virtual set positions performed by three individual users was investigated by one way analysis of variance test. Inter- and intra-observer correlation coefficients for manual setting points were all greater than 0.95. Overall, the median error between the test and the gold standard positions was 1.06 mm. Errors did not differ among teeth ($F = 0.371$, $P > 0.05$). The errors were not significantly different from 1 mm ($P > 0.05$). There were no significant differences in the errors made by the three independent users ($P > 0.05$). In conclusion, this workflow for virtual occlusal definition was found to be reliable and accurate.

Key words: virtual occlusal definition; computer-assisted surgical simulation; collision detection; visual analytics.

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Virtual simulation, based on three-dimensional (3D) image planning systems, is used increasingly for preoperative planning of orthognathic surgery.^{1–6} Commercially available software packages provide convenient tools for 3D measurements, virtual osteotomy, bone segment repositioning, and soft tissue prediction. However, few of the currently available software packages provide tools for virtual occlusal definition.

In the current computer-assisted surgical simulation (CASS) workflow, the final occlusion is decided manually using model surgery with subsequent digitization via

surface scanning procedures or cone beam computed tomography (CBCT).^{7–9} As well as being time-consuming and often inaccurate, the main drawback of this model surgery based-approach is that it cannot fully enable the surgeon to visualize how the final occlusion may change the morphology of the surrounding hard and soft tissues in 3D.¹⁰

A software tool has been developed and a workflow set up in order to achieve a virtual occlusal definition within the present CASS protocol. A validation study was carried out to test its accuracy and reliability.

Materials and methods

This study was performed at a university school and hospital of stomatology in Beijing, China. The research protocol was approved by the institutional ethics committee.

Workflow of the virtual occlusal definition

The software tool was developed to realize a virtual occlusal definition based on visualization support and precise movements. A virtual workflow was set up accordingly.

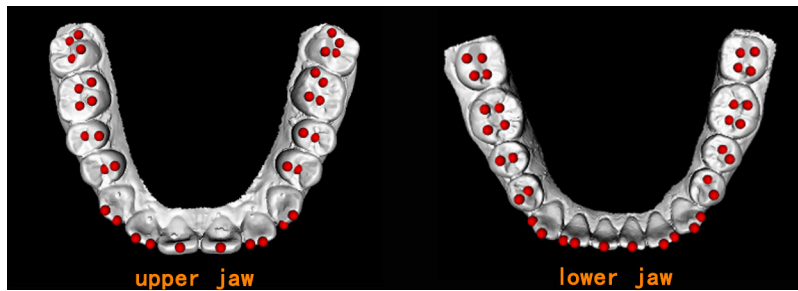


Fig. 1. Manual marking of the marker points. A total of 37 pairs of corresponding marker points are identified manually using a feature point-marking interface. These are the cusp and fossa points on each tooth.

First, the digital model data of the upper and lower jaws are imported into the virtual system. Thirty-seven pairs of corresponding marker points are then identified manually (Fig. 1). Vectors are generated automatically between the upper points and the corresponding lower points, based on the principles of prosthodontics and orthodontics. For example, the mesiobuccal cusp point on the maxillary first molar is aligned with the buccal

fissure point of the opposing mandibular first molar. The length and direction of vectors are determined by the distance and direction between theoretical corresponding points in the upper and lower jaws.

Second, with the lower dentition set as a fixed object, the position of the upper jaw is adjusted using an interactive adjustment tool, so as to align it with the lower jaw. Users are able to move the upper dentition

either by typing in instructions in a dialog box (Fig. 2A) or by using a free-hand module (Fig. 2B). Rotation and transposition along a single axis makes movement easier to handle than with 3D adjustments. During the adjustment, two representative tools assist users to obtain information about the relationship between the cusp-fossa and tooth contact.

The collision heat map tool shows the vertical distance and contact between corresponding points using a colour scale. A collision detection algorithm calculates whether points on the upper and lower dentitions are in contact with, or overlap each other (Fig. 2C). Contact detection is only looked for in a small region, near the occlusal plane. This greatly reduces the calculations required, helping the software run smoothly.

The distance projection tool shows the directions of occlusal deviations. Vectors between corresponding points are projected onto the occlusal plane to determine sagittal and transverse deviations (Fig. 2D). In an ideal occlusion, bilateral vectors should be symmetrical in direction and length. Users

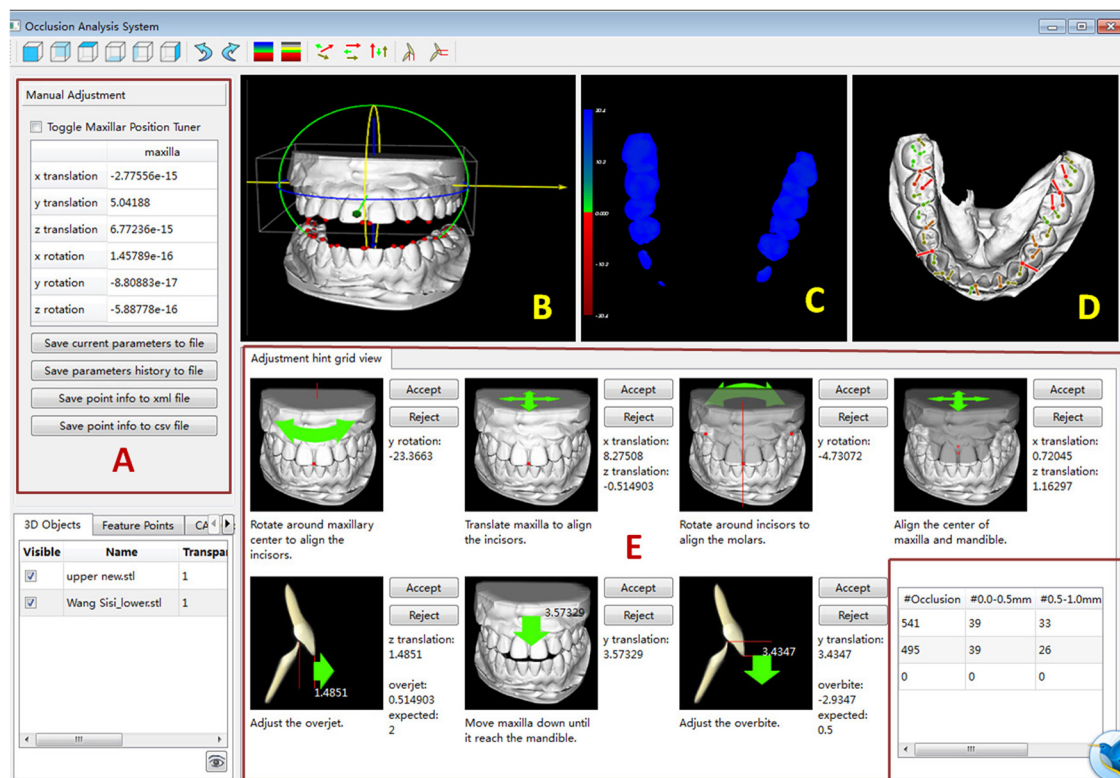


Fig. 2. Software tool for virtual occlusal definition. (A) Motivation dialog box: the user can adjust the position of the upper dentition by typing parameters into the box. (B) Free-hand engine: the user can move or rotate the upper dentition along a single direction by dragging the axis or circles freely using the mouse. (C) Collision heat map: the vertical distances between the upper and the lower dentitions are shown on a colour map. (D) Distance projection view: vectors between corresponding points are projected onto the occlusal plane to demonstrate sagittal and transverse deviations. (E) Adjustment hint grid view: this includes seven single-direction automatic minor revision tools that are applied when the upper and lower dentitions are close to each other. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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