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A pilot study to assess the feasibility and accuracy of using haptic technology to occlude digital dental models

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ABSTRACT

Objectives: The use of haptic technology as an adjunct to clinical teaching is well documented in medicine and dentistry. However its application in clinical patient care is less well documented. The aim of this pilot study was to determine the feasibility and accuracy of using a haptic device to determine the occlusion of virtual dental models.
Methods: The non-occluded digital models of 20 pre-treatment individuals were chosen from the database of Faculty of Dentistry, The University of Hong Kong. Following minimal training with the haptic device (Geomagic® Touch™), the upper model was occluded with the lower model until a stable occlusion was achieved. Seven landmarks were placed on each of the corners of the original and haptically aligned upper model bases. The absolute distance between the landmarks was calculated. Intra- and inter-operator errors were assessed.
Results: The absolute distance between the 7 landmarks for each original and corresponding haptically aligned model was 0.54 ± 0.40 mm in the *x*-direction (lateral), 0.73 ± 0.63 mm in the *y*-direction (anterior–posterior) and 0.55 ± 0.48 mm in the *z*-direction (inferior–superior).
Conclusion: Based on initial collision detection to prevent interpenetration of the upper and lower digital model surfaces, and contact form resistance during contact, it is possible to use a haptic device to occlude digital study models.
Clinical Significance: The use of 3D digital study models is routine, but new problems arise, such as the lack of "touch" in a virtual environment. Occluding study models requires the sense of touch. For the first time, using haptic technology, it is possible to occlude digital study models in a virtual environment.

1. Introduction

Conventional plaster study models have been used in dentistry for centuries. Over the last decade there has been a drive to replace them with digital study models to overcome common problems; including storage space issues, loss, damage or degradation of the plaster models over time [1].

The common methods of obtaining digital study models include surface scanning the plaster model or impression [2,3], direct intra-oral scanning [4,5] and volumetric scanning of plaster models or impressions [6] with the ability to produce surface images at a later stage if necessary. Digital dental models have been used for crown and bridge fabrication [7], orthodontic treatment planning and appliance fabrication [8], implant planning and stent production [9], partial denture frame work manufacture [10], orthognathic surgery planning and final wafer fabrication [11]. The majority of these procedures can be performed on models of a single arch. For orthodontic aligners or pre-fabricated custom orthodontic appliances the entire upper and lower arches are imaged out of occlusion to capture all the occlusal detail and then in occlusion to obtain the correct inter-occlusal relationship. The individual teeth are segmented and moved into the desired position without being able to assess the subsequent inter-occlusal consequences. During crown and bridge fabrication often only a localised region of the arch constituting the preparation and adjacent teeth is imaged, together with the corresponding region of the opposing arch. This enables the CAD/CAM crown to be designed with the correct static inter-occlusal relationship. At present it is not possible to "feel" the final occlusion following any "virtual laboratory work" fabricated on the virtual dental models.

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A possible solution is to use "haptic" technology. Haptic technology or haptics, is tactile feedback technology which recreates the sense of touch by applying forces, vibrations, or motions to the user through a haptic device. Haptics has been used in dentistry for training including cavity preparation [12], implant placement [13] and surgical simulators [14]. The outcome of its use has mainly been assessed from an educational perspective as an adjunct or alterative to actual "live" clinical exposure [15,16]. Currently physical dental models are used routinely in dentistry. By using 3D imaging the visual topological characteristics are maintained but the physical characteristics are lost. These can be re-established by printing the model and going full circle or using haptic technology and remaining in the virtual environment.

One of the simplest and most common tasks is to occlude physical study models. Now that 3D digital models are nearly routine practice, is the same possible? Therefore, the aim of this paper is to determine the feasibility and accuracy of using a haptic device to determine the occlusion of dental models and discuss possible future uses. The null hypothesis tested was that there were no statistical significance differences between the mean distance of the landmarks in the *x* (medio-lateral), *y* (anterior–posterior) and *z* (inferior–superior) directions, on the original model, and on the haptically aligned upper models.

2. Materials and methods

Approval was granted by the Institutional Review Board (IRB) of The University of Hong Kong and Hospital Authority Hong Kong West Cluster (UW11-385) to access this retrospective data, which formed part of a larger cohort study. The orthodontic plaster models were selected from the Faculty of Dentistry, The University of Hong Kong. Only pre-treatment plaster models which could be hand articulated into a single position without any instability e.g. no anterior open bite were included. The correct occlusion had been determined by the inter-occlusal registration or bite that was taken during the clinical examination and record taking session. In total 20 sets of plaster models were selected and the patient hospital numbers recorded. The patient identifier was used to download the corresponding digital models and all images were anonymous and de-identified prior to use.

The digital models had been commercially produced by laser scanning the plaster models using the following process (Modern Dental Laboratory, Cheung Sha Wan, Kowloon, Hong Kong). All dento-alveloar surfaces of the individual upper and lower models were individually scanned together with the full buccal surfaces of the teeth with the models in occlusion (3Shape, Copenhagen, Denmark). The bases of the plaster models had been previous trimmed according to the bite taken at the clinical appointment; this ensured the correct occlusal relationship during scanning. Following scanning the upper and lower models were automatically aligned to the image of the buccal teeth in occlusion (OrthoCAD®, Cadent, Carlstadt, NJ). New "orthodontically trimmed digital bases" were added to the models. Following scanning, the occlusal contacts of the upper and lower model were assessed using a colour error as well as being visually compared to the original plaster model. The final models were saved as STL files and stored.

Each set of digital study models was imported into VRMesh (VirtualGrid Company, Seattle City, U.S.A.) and decimated by 50% to reduce the number of triangles and enable faster processing (Fig. 1A). The original base of the upper model was removed leaving only the teeth and alveolar regions. The lower model was not altered and remained in the same 3D space. The upper model was moved away from the lower model, its orientation changed, (Fig. 1B) and then re-saved in its new position in 3D space.

A prototype system was implemented on a desktop PC with an Intel® CoreTM i7-3930K CPU and an NVIDIA GeForce GTX 680 display card (Santa Clara, California) connecting the Geomagic® Touch™ (3D Systems, Rock Hill, South Carolina) haptic device (formerly Sensable Phantom Omni). The Geomagic® Touch™ provided 6 degrees of freedom (DOF) input and 3DOF force feedback output (Fig. 2). The graphics rendering, and haptic rendering components worked in parallel. The upper dental model was manipulated through the stylus of the haptic device. As haptic

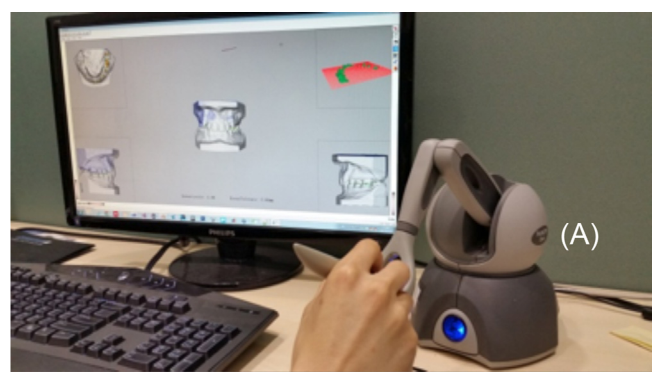

Fig. 2. Haptic prototype system in use during training session. (A) Pen shaped haptic device (Geomagic® Touch™ haptic device, formerly Sensable Phantom Omni).

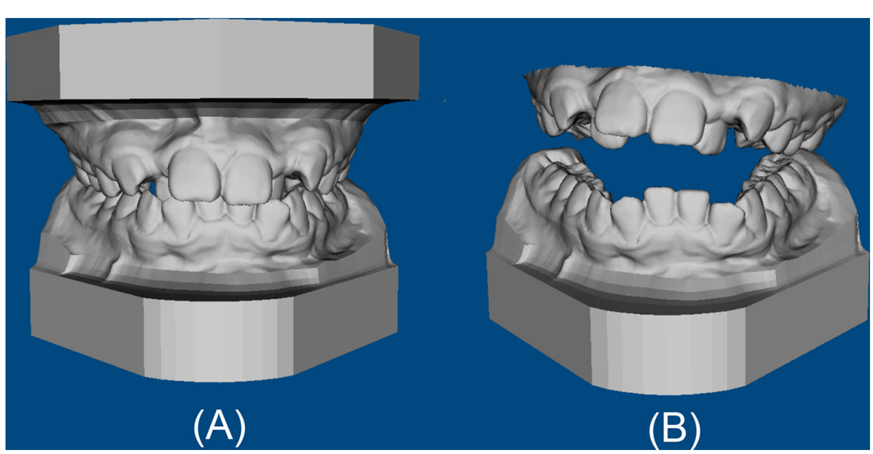

Fig. 1. (A) Final original digital models in occlusion. (B) Upper and lower digital models with virtual bases removed leaving only the teeth and alveolar regions. Removing the bases ensured there were no visible indications for the upper model position.