Three-dimensional virtual preoperative implant planning P3Dental using computed tomography images

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Abstract — **Introduction:** Currently there are few software systems using cone beam computed tomography (CBCT) or conventional computed tomography (CT) images to aid in oral planning surgery and produce surgical drilling guides. Although CBCT allows a lower effective radiation dose, in a short scanning time, with reduced costs, there are several artifacts that affect the image quality producing challenges for virtual surgical planning. This article presents the development of a new independent freeware software system for 3D virtual preoperative implant planning, called P3Dental, based on CT images. **Materials and Methods:** The methodology requires two CBCT acquisitions – a CBCT image of the patient dental splint with gutta-percha fiducial markers; and a typical CBCT scan protocol, using the dental splint with the fiducial markers preserved in the same position. A semi- automatic local threshold, followed by a top-hat morphological operator was used to extract the markers for the registration process. The generalized Karhunen-Loève transform was used for developing the volumetric rigid registration method. The methodology was tested with five CBCT patient images. **Results and Discussion:** The linear and angular deviations between fiducial markers in the CBCT images were between 0.5 and 2.0mm in the x axis, and between 0.5 and 5 degrees, respectively. These deviation values are compatible with other in vitro studies, showing the reliability of the software for virtual surgical planning for implantodonty using low dose CBCT images.

Keywords—**CBCT, surgical planning, registration, segmentation, fiducial marker.**

I. Introduction

If the placement of oral implants relies only on the surgeon's technique, skill, and experience, complications can occur, like root damage, penetration of maxillary sinus, and insufficient bone area for the implant. In surgical planning of oral implant placement, usually a surgical guide is used to decrease the risk of problems and to precisely locate the placement point and the vector to avoid damage to the adjacent structures [1].

Contemporary preoperative planning techniques rely on three-dimensional (3D) surface model representations of the jaw bone obtained from image data acquired with computed tomography (CT), using a segmentation algorithm for extracting the bony tissues. Computer systems with volumetric navigation enable the surgeon to locate the position of the implants. Considering the fact that conventional multi-slice CT (MSCT) protocols are generally associated with relatively high radiation dose levels, alternative CT protocols for dental visualization and modeling are being investigated [2].

Cone beam computed tomography (CBCT) allows a lower effective radiation dose, without significant loss of image quality, in a short scanning time, with reduced costs. Compared with MSCT, CBCT holds promising potential for oral and craniofacial imaging applications, playing a vital role in the diagnosis of hard tissue structures of the dentomaxillofacial region. [3].

Disadvantages of CBCT are related to scattered radiation, limited dynamic range of the X-ray detectors, truncated field of view artifact, and artifacts caused by beam hardening [4][5][6]. Other artifacts inherent to CBCT image acquisition related to detector sensitivity, X-ray beam inhomogeneity and reconstruction technique result in a noticeably higher noise level, which influence the accuracy of the 3D surface models [7]. These drawbacks may influence image quality, lowering the bone segmentation accuracy.

In all types of CT systems, metal objects presented, such as tooth fillings, implants, screws, braces, and crowns, often produce artifacts. These artifacts manifest themselves in sequential sections as scatter (i.e. discontinuous and irregular areas of high and low intensity gray values), com-

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promising any attempt to segment accurately the contours of the anatomical structures, as well as masking some structures.

Currently there are few freeware software systems using CT images to aid in oral planning surgery and produce surgical drilling guides. These guides are manufactured in such a way that they match the location, trajectory, and depth of the planned implant with a high degree of precision. These guides stabilize the drilling by restricting the degrees of freedom of the drill trajectory and depth.

This article presents the development of a new freeware software system for 3D virtual preoperative implant planning (P3Dental), based on dual acquisition of computed tomography (CT) images.

II. MATERIALS AND METHODS

A. Image acquisition

The methodology consists of several steps, corresponding to distinctive moments in the virtual planning. The system requires two CT acquisitions. First, a 3D volume of CT images of the patient dental splint (removable dental appliance reproducing a "bite") with gutta-percha fiducial markers is acquired, and is used as a radiographic template. Between three and six small gutta-percha spherical markers of 2 mm in diameter are attached along the external dental splint, serving as radiopaque fiducial markers. These markers provide a quick and accurate registration means serving as a radiological guide. Second, the patient goes through a typical CT scan protocol, using the dental splint with the fiducial markers preserved in the same position.

B. Image Processing

Both CT datasets of the dental splint only and the patient with the dental split are rendered and segmented by a semi-automatic method using a local threshold, followed by a top-hat morphological operator [8] to produce the exact points for the registration process. The registration of both images includes at least 3 points registration, determined by fiducial markers visible in the CT images. The generalized Karhunen-Loève transform was used for developing the volumetric rigid registration method [9], and was implemented using IDL language (Exelis Visual Information Solutions, http://www.exelisvis.com).

The external surface of the dental splint only is also segmented and exported in STL format (Surface Tessellation Language), using OsiriX software.

C. Software testing

For the preliminary P3Dental software testing, CT images of 5 partially edentulous anonymous patients were used. The images were acquired using two commercial CBCT systems: i-CAT (Imaging Sciences International Inc., USA), and Kodak 9500 Cone Beam 3D System (Kodak Dental Systems, Carestream Health, Rochester, NY, USA). Two sets of CBCT volumetric images were available for the methodology, allowing the volumetric reconstruction of the dental splint and the patient jaw, separately and registered. The segmentation process resulted in the virtual rendered surfaces, visualized in P3Dental planning interface.

P3Dental software is being developed in a user-friendly interface for dental professionals, offering interactive 3D image tools, zoom function, contrast settings, distance and angle measurement tools, 2D orthogonal and other arbitrary plane images, and panoramic view. A 3D and 2D conventional surface rendering view of the dental splint and the surface line in each slice plane are also available. The software is available for Windows and Mac OS X.