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Oral Implant Orientation of 3-D Imaging Based on X-Ray Computed Tomography (CT)

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Abstract: Through 3-dimension (3D) Computed Tomography (CT) images, a virtual stomatological implantation orientation Computer-Assisted Design (CAD) navigation system is proposed in this study. The system reconstructs the 3D images and the multi-plane image of the teeth with the combination of spiral X-CT, computer graph and image and 3D visualization. The height, width, shape of the (alveolar bone) of jaw bone, the accurate position of lost teeth and mentum aperture, the density of ossicles, the orientation of submaxillary, the position and shape about the bottom of nasal cavity and antrum maxillary can be got. The maxillary evaluation in terms of radiography before the tooth implantation and the guidance about the clinic localization of false tooth can be provided in the system, in which the doctor can not only greatly reduce the risk of implantation operation but also improve the stability and security of tooth implantation.

Key words: Spiral X-CT, oral implantation orientation, 3D reconstruction, visualization, Computer Assisted Design (CAD), navigation

INTRODUCTION

Tooth is not only one of the most important organs of human body but also very weak organ. Based on the research of archaeology, tooth implantation originates from ancient China and Egypt where the ancestors used the gold and ivory as substitutes for the real tooth. Until now the tooth implantation which was named as one of the four big breaks in stomatology is still the hotspot in dental research. Although the success rate of tooth implantation is as high as 90%, there are still false cases because of some objective reasons. For instance, normally the implantation is based on the radiography check. The aim of radiography check is to find the accurate location, height and width of alveolar bone and its evaluation through non-destructive test method so that the clinician could put the false tooth in accurate place. But the X-ray radiography check (root tip slice, occlude slice, linear volume slice) can only display the 2-dimensional image, the distortion and magnification of the images still exist. In order to solve the above questions, the combination of Medical CT scanning and professional tooth implantation software is a good choice; this approach can outperform the original radiography check-based tooth implantation and greatly improve the stability and security (Verstreken *et al*., 1995; Ganz *et al*., 2001; Wang, 1997).

Because the implanting tooth will be surrounded by the maxillary, parenchyma and other complex organs, the bone combination and the material dissolvability of false tooth and its relative biomechanics characteristics are very important. In fact, due to the irregularity of submaxillary and maxillary, the complex biomechanics of parenchyma, the localization of false tooth is a key part for successful implantation. With the wide application of radiology in clinic therapy and the development of computer technology, the combination of professional software and medical CT data will be accepted by more people and the corresponding tooth implantation scheme will become more popular (Lovea *et al*., 1999; Lee *et al*., 2001; Chen and Zhou, 2003).

SYSTEM PLAN AND DESIGN

The application of Computer-Assisted Design (CAD) to dental implantation orientation based on CT includes the following parts, the preprocessing of CT data, the 3-dimensionalization and figure display of CT data, interactive designing and so on. The process is shown in Fig. 1.

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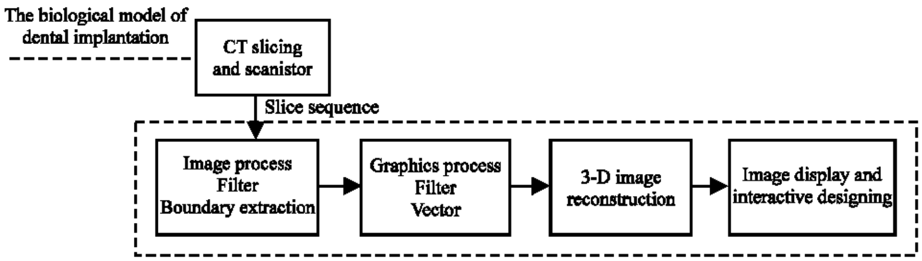


Fig. 1: CAD orientation system (processing module)

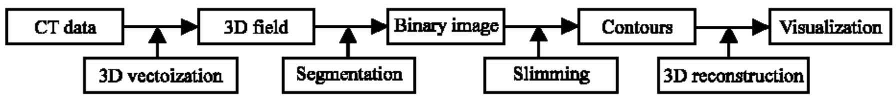


Fig. 2: The execution of marching cubes

The re-sampling and processing of CT data: The original data roots in the export files of the measuring instrument, such as screw CT and when the applied objects are changed, the requirement for data must be different. For the redundant original data, it needs proper quantization (such as 12bit->8bit). The CT system inevitably brings noise in the procession of data scanning and sampling, which have a huge impact on the visual calculation. So Wiener filtering and histogram grey scale adaptive threshold can be used to eliminate most of the noise.

Change the data of CT into three dimensions data: The 3-D Data-field is the reference of 3-D modeling. This mission is to change the Volume Data, a series of parallel sections made out of medical imaging equipment---X-CT or MRT, into 3-D Data and to describe them as field functions. The data of CT is discrete and structured, in other words, these discrete space points have a logical relationship of 3-D element. Each pixel has the corresponding attribute (layer, row, line and grey). When each layer is centered and the distances of layers, rows and lines are equalized, we can directly correspond the layer, row and line of each pixel with x, y and z in the coordinate system of descartes, or we must define the origin of coordinate first and then change the 2-D coordinate into 3-D one according to the coordinate translation and corresponding proportion.

The ordinary 3D reconstruction algorithm: Commonly there are 2 categories of arithmetic in 3-D reconstruction. One is called Volume Rendering, which shows the 2-D image, direct produced from 3-D Data-field and based on the definite optics-model and projection-arithmetic, on the screen. The image of Volume Rendering has a good quality and is convenient for collateral disposal, but it is consumptive of calculation which makes against real time rendering (Verstreken *et al.*, 1995). The other is called Surface Rendering. At first you construct graph elements (such as curved surface? plane and so on) of geometry from the 3-D Data-field and then render based on the computer graphics. High speed is one of its characteristics, so it is easy to execute drawing graphics by hardware. The representative one of Surface Rendering is Marching Cubes (MC) (Tang, 1999). In this study, we will introduce the execution of Marching Cubes (Fig. 2).

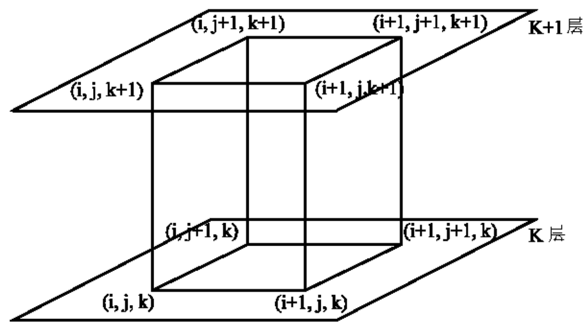


Fig. 3: Sketch map of volume data

3-D modeling of MC

Constructing field functions: Considering all the sections of CT contain a series of contour line as $P_1, P_2, \ldots, P_n$, the field function of each point in Volume Data is given by

$$f_{(x,y,z)} = \begin{cases} -1, & (x,y,z) \text{ out of the contour} \\ 0, & (x,y,z) \text{ on the contour} \\ +1, & (x,y,z) \text{ in the contour} \end{cases}$$

In this way, three dimensional volume data is transformed into three dimensional fields (Tang, 1999).

Surface generation simulation: As Fig. 3, a tiny volume in 3D data field consists of four pixels of the neighboring

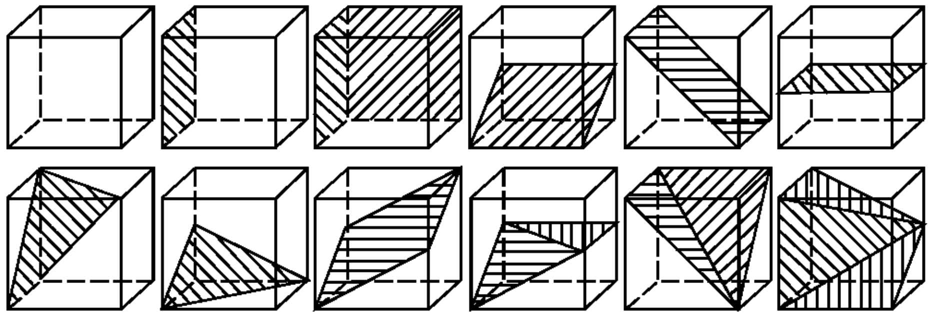


Fig. 4: The different conditions of surface construction

layer, according to field function and the possible value of every culmination on the tiny volume is 0, -1, or +1. Obviously, boundary plane will pass through the culmination whose filed function value is 0; if the two culminations of certain arris on tiny volume are respective -1 and +1, then the boundary plane must intersect the arris. Considering the high resolution of CT images, we can consider the midpoint of the arris as the point of intersection; if the values of the two culminations of the arris have the same sign, the boundary plane cannot intersect the arris. So we can know whether the boundary plane passes through the tiny volume and through connecting all boundary planes of tiny volume, surface 3D image of the reconstructed object can be obtained.

As there is three state (0,-1,+1) for every culmination, therefore every tiny volume has 3^8 = 6561 conditions. Through its symmetry and according to logicality and experimental statistic, more than 95% boundary planes are composed of tiny volumes as following conditions shown in Fig. 4.

At the premise that the obtained triangular planes consist of the space point a,b,c and

$$\vec{N}_1 = \{x_a - x_b, y_a - y_b, z_a - z_b\},$$
$$\vec{N}_2 = \{x_a - x_c, y_a - y_c, z_a - z_c\},$$

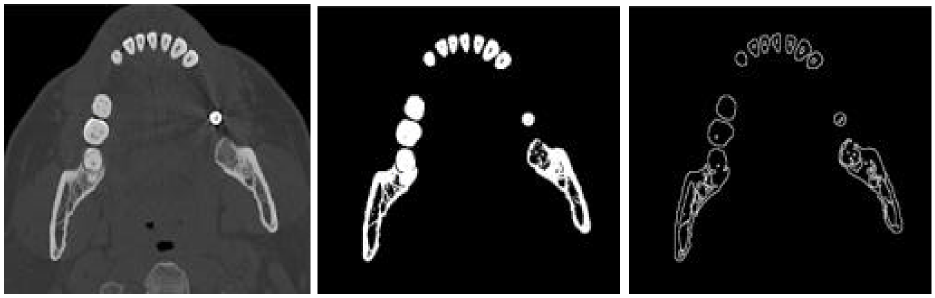
then the triangle's vertical vector $\vec{N} = \vec{N}_1 \times \vec{N}_2$.

RESULTS

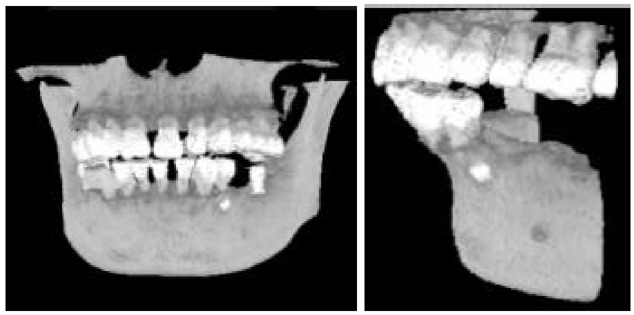
Applying MC algorithm, we make use of CT data to do 3D reconstruction experiment .The data of Fig. 5 is the result of the CT scan of a sick needing to receive teeth cultivating operation, the image format is 512*512*156, the pixel level is 8bit. From Fig. 5(D), we can know the state of the patient's teeth and jaw bone, even the beams of alveolar nerves vas can be seen clearly on Fig. 5 (E), which makes the surgery more secure.

By testing the sclerotin and the frame of the jaw bone in these areas and positions shown in the transect image, it is easier accomplished to select an appropriate manual tooth implantation body and avoid piercing the bone sideways, penetrating maxillary antrum to the bottom or destroying other important structures. In practice, a design based on ordinary X-ray image for testing always cannot exactly measure the density of jawbone which avails manual tooth implantation or detect the osteoporosis and the bone damage, so that the clinician always gets into a very passive condition in the operation of tooth implantation (Rosenfeld and Mecall, 1998). In the testing on tooth implantation body after operation, it is more difficult for ordinary X-ray image to reflect the condition of the bone-combination and the bone damage, especially the bone damage on the buccal tongue side of the tooth implantation body. After capturing the imaging information by spiral scanning, 3D CT can randomly ascertain the line of arc trace, the depth and the height of the body. With the panoramic image of the jaw bone acquired by such a way, the operator can more comprehensively hold the condition. For example, a common panoramic jaw bone image of the first grind-teeth area of the mandible of a sufferer shows there exists sclerotin damages and insufficiency of height. However, by examining the panoramic jaw bone multi-faultage images, including the image on tongue side, in the middle and on cheek side, it is found that on the cheek side and in the middle area the jawbone has an enough height so that the sufferer can accept the operation of tooth implantation.

The more significance of the 3-dimensional CT picture is that it can exhibit anyone ichnographic structure of jowl and from the transect picture of the jowl we can distinguish the thickness of the bone cortex clearly, the acreage of the loose bone, the density of the bone cortex, ascertain the proportion of the bone cortex and the loose bone and classify the structure of the bone cortex exactly. Jowl bone cortex are usually classified into four kinds



(A) Original image (B) Binary image after segmentation (C) Contours



(D) 3D image of teeth and jaw (E) Region of implantation

Fig. 5: Demo of 3D reconstruction

(Preda *et al.*, 1997). While artificial tooth plant technologies usually need better bone cortex structure, it is helpful to the success of the artificial tooth plant and the patient can chew freely, the worse bone cortex structure needs more carefulness to chose the adaptive plant and design the plant way. The normal x-ray photo is usually considered to be useful in artificial tooth plant, while our group's experiences indicate that 3-dimensional CT picture is more suitable for this kind of plant condition.

The floor of genyantrum, the floor of nose, the nasaltube and mandibular canal should be paid more attention to avoid being hurt in tooth planting. From experiment, we reconstructed thirty one pieces of CT images. All the images, contrasted with the 2-D image using X-ray, can show the 3-D positions and the distances of these structures precisely. Original X image can only show the 2-D relationship of these structures. It is very important in operation and works after operation from these 3-D image, we can known whether the substantia ossea is suitable for tooth planting or not before operation. And we also knew from image whether the quantity of bone is enough for operation. But these are not being found in X-ray image. So using this system we will get more potentiality than other method in tooth planting.

With the wider application of Spiral X-CT, which is one of the most advanced radiography check methods, the dentist will get more information about the structure of jaw bone so that the operation can reduce the blindness of tooth implantation and get more accurate implanting position and better restoring effects. The tooth implantation CAD navigation system based on 3D CT visualization technology will become a new trend of future stomatology clinical diagnosis.

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