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A REVIEW OF THE METHODS OF TOOTH AXIS CALCULATION BASED ON CBCT

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ABSTRACT

The long axis of a tooth is defined as the geometric axis that passes longitudinally through the tooth and through the center of the tooth, which is one of the most important reference elements for dental analysis and treatment. In the preoperative planning of dental implants, doctors usually examine the axes of adjacent teeth and occlusal axes of missing teeth. When orthognathic surgery is used to treat dental deformities, it is necessary to consider the intersection angle of upper and lower occlusal axes, so as to improve the performance and aesthetics of the masticatory system. However, the traditional method of determining the long axis of teeth depends too much on the experience of doctors, and its efficiency is inefficient and its accuracy is not guaranteed, which often affects the effect of dental treatment. Digital determination of dental long axis technology provides great possibility and convenience to improve the safety of treatment and accelerate postoperative recovery. With the popularity of cone beam computed tomography (CBCT), we can accurately calculate the long axis of teeth through the three-dimensional display of teeth and periodontal tissue. In this paper, the key technologies of tooth long axis calculation are introduced in detail.

KEYWORDS: Long axis of teeth; CBCT; Dental Sciences.

1. INTRODUCTION:

In medical image analysis, it is very important that organs or tissues can be clearly displayed, which is helpful for diagnosis and treatment. The popularity of cone beam computed tomography (CBCT) provides convenience for dental diagnosis and analysis [1]. CBCT three-dimensional images can provide more information about oral structure, making it possible to better understand and visualize data. Three-dimensional reconstruction of medical images is an important application field of scientific visualization technology, and it is the current research focus of medical image processing. It refers to the technology of using two-dimensional medical slice images to reconstruct three-dimensional images and carry out qualitative and quantitative analysis. Three-dimensional modeling of medical images, which is convenient for observation and analysis from multi-angles and multi-levels, can provide doctors with realistic three-dimensional images. In the field of dental orthodontics and implant, doctors are able to carry out preoperative planning and surgical simulation, so that doctors can know the whole operation process well before the actual operation, and choose the best operation scheme by simulating a variety of operation schemes [2]-[3]. This is of great significance to improve the success rate of operation and reduce the pain of patients.

For better dental treatment based on accurate dental analysis and diagnosis, the information of the three-dimensional axis of the tooth and the three-dimensional position of the tooth are indispensable. The axis of the tooth, also known as the long axis of the tooth, is a geometric axis that runs vertically through the tooth and through the center of the tooth, or an imaginary line that passes through the center of the tooth. Our teeth are divided into single teeth and multiple teeth. Figure 1. shows the long axis of single-root teeth and multiple-root teeth respectively. The long axis of teeth plays a very important role in the fields of orthodontics and implantology. In dental implants, doctors usually need to examine the axis of adjacent teeth and the occlusal axis of missing teeth before the implantation program. In addition to implants, the dental axis should also be considered when using the virtual surgery planning system [4]-[6] for dental surgery preparation. In the treatment of dental deformities, the angle between the upper and lower occlusal axes can be considered to improve the performance of the masticatory system and the aesthetics of teeth.

The axis of the teeth is not usually vertical because the teeth are not usually vertical in the mouth. Generally speaking, the teeth are slightly tilted on the middle, buccal, or lingual sides. Usually, the three-dimensional axis of the tooth can not be correctly estimated from the two-dimensional projection image, and the angle measurement can not describe the three-dimensional orientation of the tooth axis in the three-dimensional space. In other words, the axis of the tooth is a three-dimensional straight line in three-dimensional space, which is described by a three-dimensional vector [13]. In addition, the dentist cannot manually measure the orientation of the root because the axis of each tooth is an imaginary line contained inside the tooth, and the root is surrounded by alveolar fossa and soft tissue. So that CT scanning technology provides an imaging method to restore or reconstruct the actual three-dimensional model of the tooth and other dental bone structure. So far, researchers have shown that measuring the long axis of teeth from 3D models reconstructed from 3D CT images is usually reliable.

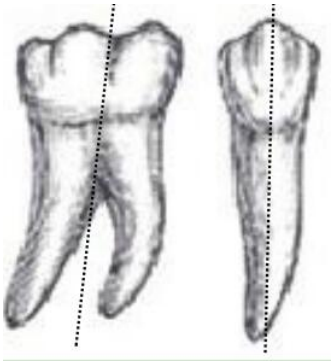

Figure 1: The long axis of multiple-root teeth and single-root teeth

2. REVIEW OF RELATED STUDIES:

2.1 3D reconstruction of tooth model:

Three-dimensional digital tooth model (**Figure 2**) is the basis of the computer-aided diagnosis system, and it is also an important prerequisite for estimating the long axis of teeth. It is very challenging to reconstruct each tooth, including the root, and to create a 3D model of the whole dentition. However, many methods are difficult to construct a three-dimensional digital anatomical model of the mandible with high-quality dentition, so that each tooth has crown details and complete roots, and distinguish the anatomical areas such as enamel, dentin, periodontal ligament and so on. Many researchers use CT data to reconstruct the tooth model, and get more accurate results. The following is a detailed introduction of the relevant literature on the three-dimensional reconstruction of the tooth model.

Figure 2: Three-dimensional reconstruction image of mandibular teeth

In 2004, Shi et al. [7] proposed a method, which can realize three-dimensional tooth model reconstruction simply and easily. Firstly, the standard data teeth are scanned by CT to obtain three-dimensional surface data and accurate internal three-dimensional structure data. Then, the inter-sectional images are interpolated. It is divided into three steps: *the first step* is to separate the corresponding regions of different objects in each sectional image, interpolate different objects separately, and then combine their interpolation results; *the second step* is to extract the boundary of each region, separate the inner boundary from the outer boundary, and subtract the inner boundary region from the inner boundary region to get the interpolated image of the object. *In the third step*, the optimal chamfer transform is used to transform the boundary curve image on each fault. Finally, the cross-sectional images of all the teeth are stacked and the three-dimensional structural data are reconstructed using OpenGL. This method has the advantages of easy data acquisition, low cost, high modeling accuracy and good effect, and the model can provide more visual effects and information.

In 2015, Naumovich SS et al. [8] used the self-developed software based on watershed transform for 3D reconstruction, and propose an algorithm to realize the reconstruction in the step-by-step threshold image segmentation in which markers are placed in the area related to teeth and bone tissue by multi-plane projection. First, a rough 3D model of the entire dentition and mandible was created. The next step is to specify the model of the jaw and cut the dentition into separate teeth. Finally, for the CBCT images with low contrast and high noise level, the reasonable segmentation threshold is selected to separate the teeth from the jaw tissue to complete the reconstruction. In this study, digital imaging and medical format computed tomography images obtained on CBCT scanners were used to create 3D models of teeth and jaws. Objective to develop a method for three-dimensional reconstruction of teeth and jaw tissue based on maxillofacial CT images and conduct clinical trials. The research results have intuitive interface and short processing time, and the obtained 3D models can be used to solve a wide range of scientific and clinical tasks.

In 2016, Wu et al. [9] proposed a 3D tooth reconstruction method based on level set active contour model according to the morphological changes and arrangement of teeth in oral CT image sequences. The purpose of this paper is to accurately locate and quantitatively evaluate the computer dental restoration. In this paper, different segmentation models are used for different parts of dental slices by using interlayer mapping mechanism. The single-phase mixed level set model is constructed by combining the prior shape constraint energy, the edge gradient energy based on the flux model and the local region energy based on the prior gray level to segment the root layer slice contour. The two-phase mixed level set model combined with regional competition constraints is used to segment the canopy slice contours. Finally, these interlayer contours are used to reconstruct the tooth 3D model. Compared with the existing methods, this method has a better segmentation effect and a higher segmentation accuracy. The average similarity index can reach 96%.

In 2017, Li et al. [10] proposed a tooth modeling method based on crown and root features, in order to solve the existing problems, such as three-dimensional scanning technology can only get the three-dimensional data model of the crown, but the gingival-wrapped root data can not be collected, and the problems such as the modeling takes a long time and the cost is high although the complete tooth data model can be obtained by using CT images. Based on the dental measurement data, the association rules between crown and root data are established, and the 3D modeling is carried out according to Cardinal spline interpolation and Laplacian mesh deformation algorithm with Tangent weight. Experiments show that the method is efficient and feasible by comparing the modeling results with the original data.

2.2 Calculation of the long axis of teeth:

In 2010, Xie et al. [11] used interactive techniques to calculate the axis of a single tooth. Firstly, the interested teeth are interactively sliced, and the virtual cutting plane is used to reconstruct the 3D CT image. Generate a 2D slice image of the teeth. Then the two-dimensional straight line is drawn interactively on the two-dimensional slice, and the tooth axis is obtained. Due to the interaction of surgical procedures, this technique largely depends on the clinical and imaging knowledge of teeth, as well as the reconstruction of three-dimensional models of teeth using three-dimensional CT images. Usually, experienced dentists can use this technique to correctly calculate the dental axis from three-dimensional CT images, but users who lack the knowledge of anatomy and CT imaging cannot. In addition, this technique requires a lot of fine interaction, so it is difficult to apply it to multiple-root teeth.

In 2012, Kim et al. [12] proposed a new method to automatically calculate a single tooth shaft. The plane of separating a single tooth is automatically calculated by using the cost profile analysis along the central arch of the tooth. In the calculation, a new plane cost function considering strength and gradient is proposed, which is beneficial to the tooth surface passing through the backlash and suppresses the inappropriate tooth surface that may be detected to pass through the soft tissue. Then, the soft pulp and dentin of each separated tooth are segmented by two newly proposed velocity functions. Finally, the principal component analysis method is used to calculate the axial direction of each tooth. This method solves the problem that it is difficult to automatically identify the axial direction of teeth in dental CT images because of the high connectivity of adjacent teeth and jawbone. It can accurately identify each dental axis and provide effective help for dentists in dental implant and orthognathic surgery.

In 2015, Wang et al. [13] proposed a new method to calculate the three-dimensional dental axis from the existing three-dimensional CT images of single or multiple teeth and to estimate the three-dimensional dental axis from the three-dimensional CT images of missing teeth. The researchers determined the tooth axis of a single tooth by segmenting the pulp cavity and calculating the main direction of the pulp cavity, and modeled the tooth axis estimation of the missing tooth as the problem of quaternion interpolation along the three-dimensional curve. The orientation of dental axis is an important quantitative information in dental diagnosis and operation planning. However, their calculation is a complex problem, and the existing methods have their own limitations. This method cannot only avoid the difficulty of tooth segmentation, but also improve the limitations of existing methods. The effectiveness and practicability of this method are verified by the experimental results of different clinical three-dimensional CT images.

The existing methods to calculate the long axis of teeth need to segment the teeth from the CT image, and then estimate the axial direction of the teeth. However, due to the challenge of tooth segmentation in CT images, the existing segmentation methods are not effective, especially for angled molars, which may lead to the failure of axis estimation. In 2016, in order to solve this problem, Zhang et al. [14] proposed a molar axis estimation method based on CT image. This method no longer extracts the three-dimensional axis of each molar from the segmented volume, but extracts the three-dimensional axis of each molar from two projection images. First, the three-dimensional image of each molar is projected onto two two-dimensional image planes, and then the molar contour is segmented in each two-dimensional projection image. The principal component analysis and the improved symmetry axis detection algorithm are used to extract the two-dimensional axis from the segmented molar contour. Finally, the three-dimensional molar axis is obtained by combining two two-dimensional axes.

At present, restoration-driven surgery is widely used in implant surgery, and the long axis of teeth is very important in implant surgery, which greatly affects the effect of postoperative restoration. In 2017, Li et al. [15] aimed to provide a simple and effective method for automatically locating surgical guide holes, and we can also regard it as a disguised problem of determining the long axis of teeth, so as to reduce the experience of operators. improve the design efficiency and quality of surgical guide holes. First of all, the local coordinate system of each target tooth is geometrically constructed in the CAD system, which can well represent the anatomical characteristics of the teeth. Then, in this coordinate system, the central axis of the target tooth (coincident with the corresponding guide hole axis) can be quickly calculated to complete the positioning of the guide hole. Finally, by comparing the manual operation method of skilled doctors and the automatic operation method of Simplant, and analyzing the stress distribution during mastication and occlusion, it is determined that the stress distribution of this method is obviously better than that of manual operation and slightly better than that of simulated operation, which can significantly reduce the risk of cervical marginal collapse and prolong the service life of the restoration.

In 2019, Kazuto Terada et al. [16] determined the long axis of multiple molars by ordinary least square regression and compared it with the long axis determined by principal component analysis. First of all, they used CBCT for three-dimensional imaging of the experimental skull, and the three-dimensional image visualization system was used to extract the data of maxillary first molar and mandibular first molar from CBCT data. Then, the obtained data is reconstructed and the three-dimensional coordinate values are extracted. Finally, the long axis is estimated by the ordinary least square regression algorithm. Comparing the molar axis defined in this study with the molar axis defined by principal component analysis, the long axis of molars estimated by the two methods are basically the same, and their accuracy is of great significance for clinical application.

3. CONCLUSIONS AND DISCUSSION:

Dentists face more and more challenges in clinical diagnosis and treatment. Dental axes are valuable information used in dental diagnosis and surgical planning, and its calculation is an important problem. Effective calculation methods are related to the success of diagnosis or treatment. However, the current technology faces many problems, for example, calculating the axial direction of teeth by CT sometimes requires manual interaction, which is very user unfriendly to inexperienced doctors and the tedious interaction makes the accuracy not guaranteed; When the axial estimation is carried out by segmentation, the segmentation is not accurate because of the high connectivity between tissues, resulting in the distortion of tooth axis calculation and so on. This paper reviews the literature related to dental axis calculation in recent years. Researchers have solved most of the problems, but there are still many problems to be solved. Tooth segmentation is a very challenging research area, we should consider how to avoid tooth segmentation and accurately calculate the tooth long axis in the future, and how to calculate the tooth long axis by a higher automated method. We hope we can improve the method of tooth axis computation in the future to save more time of dentists and to improve the efficiency of dental diagnosis and treatment.

REFERENCES:

I. Jing Qiao, Shiying Wang, Jinyu Duan, Yong Zhang, Yun Qiu, Changzhou Sun, Denggao Liu. The accuracy of cone-beam computed tomography in assessing maxillary molar furcation involvement [J]. Journal of Clinical Periodontology, 2014, 41(3).

II. 艾毅龙, 吴斯媛, 邹晨.基于CBCT三维重建数据的尖牙冠根形态研究 [J]. 口腔疾病防治, 2020, 28(06):372-376.

III. 欧阳骞, 张凌鹏, 王晋, 娄慧全, 黄月苏. CBCT三维影像配合3D手术导板应用于种植牙的临床价值探讨[J]. 影像研究与医学应用, 2020, 4(13):88-89.

IV. I. Turkyilmaz, Implant Dentistry - The Most Promising Discipline of Den-tistry. Rijeka, Croatia: InTech, 2011.

V. G. R. Swennen, W. Mollemans, D. Clercq, J. Abeloos, P. Lamoral,F. Lippens, N. Neyt, J. Casselman, and F. Schutyser, "A cone-beam com-puted tomography triple scan procedure to obtain a three-dimensional augmented virtual skull model appropriate for orthognathic surgery plan-ning," J. Craniofac Surg., vol. 20, no. 2, pp. 297-307, 2009.

VI. B. Chow and A. Lau, "The planning of orthognathic surgery - The digital era," Hong Kong Med. Diary, vol. 14, no. 6, pp. 11-14, 2009.

VII. 史久慧, 孙达.利用CT图像计算机三维重建牙齿模型 [J]. 实用口腔医学杂志, 2004(06):784-785.

VIII. Naumovich S S, Naumovich S A, Goncharenko V G. Three-dimensional reconstruction of teeth and jaws based on segmentation of CT images using watershed transformation. [J]. Dento maxillo facial radiology, 2015, 44(4).

IX. Wu T Zhang L B. Three dimention tooth reconstruction using level set active contour model [J]. Journal of Image and Graphics, 2016, 21(8):1078-1087.

X. 李占利, 高天宇, 李洪安, 武璠菲. 基于牙冠与牙根特征的牙齿建模方法 [J]. 图学学报, 2017, 38(04):483-488.

XI. Xie J, Liu Y, Yin J, Qiu T, Huang Y, Wang L. An interactive method for computing tooth-root axis from 3D CT image. 2010 Inter-national Conference on Medical Image Analysis and Clinical Application, MIACA 2010, pp. 42-45.

XII. Kim Gyehyun, Lee Jeongjin, Seo Jinwook, Lee Wooshik, Shin Yeong-Gil, Kim Bohyoung. Automatic teeth axes calculation for well-aligned teeth using cost profile analysis along teeth center arch. [J]. IEEE transactions on bio-medical engineering, 2012, 59(4).

XII. Wang Yang,Wu Lin,Guo Huayan,Qiu Tiantian,Huang Yuanliang,Lin Bin,Wang Lisheng. Computation of tooth axes of existent and missing teeth from 3D CT images. [J]. Biomedizinische Technik. Biomedical engineering, 2015, 60(6).

XIV. Dongxia Zhang,Yangzhou Gan,Zeyang Xia,Xinwen Zhou,Shoubin Liu,Jing Xiong, Guanglin Li. Molar axis estimation from computed tomography images. [J]. Conference proceedings: ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual Conference, 2016, 2016.

XV. Li X, Chen M, Tang K. A Simple and Automatic Method for Locating Surgical Guide Hole [J]. 3d Research, 2017, 8(4):36.

XVI. Terada K, Kameda T, Kageyama I, et al. Estimation of three-dimensional long axes of the maxillary and mandibular first molars with regression analysis [J]. Anatomical ence International, 2020, 95(1):126-133.