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Review

Three-dimensional Facial Stereography and its Application in Orthognathic Surgery

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ABSTRACT

The facial three-dimensional stereophotography technology is based on digital stereogrammetry technology. According to different light sources, it can be divided into three kinds, active, passive and hybrid. This system can show characteristics of height, width and depth of facial soft tissues . It has the advantages of high reproducibility, low precision, high reliability, fast image acquisition, non-invasiveness and repeatability. The image can be used for facial anthropometric measurement , as well as establishing a three-dimensional facial model for surgical simulation and analysis . It can also record facial features of patients which can be used for follow-up.

KEY WORDS

three-dimensional stereophotography; three-dimensional Image; orthpgnatic Surgery; Measurement and analysis

With the development of three-dimensional imaging technology, three-dimensional facial stereography technology is becoming more and more popular in clinical medicine and laboratory research. The common three-dimensional facial stereography system is based on digital stereo photogrammetry technology, which is characterized by accurate reproduction of the three-dimensional contour of the face, vivid reflection of the color and texture of the skin, fast speed of data collection, wide coverage and safety without radiation. In orthognathic surgery, facial soft tissues, facial hard tissues and dentition are three key factors. In traditional photography, two-dimensional photographs often do not reflect the characteristics of patients' three-dimensional structure. When applied to face simulation and prediction, they can only reflect the changes of facial profile, but ignore the overall and positive changes. The photographs provided by the three-dimensional facial stereography system can truly reflect the characteristics of facial soft tissues of the subjects, can be used for indirect facial measurement, and can also be applied to the establishment and analysis of three-dimensional models.

THREE-DIMENSIONAL FACIAL STEREOGRAPHY SYSTEM

Three-dimensional facial stereography system is a technology that combines photography system with computer software. According to the source of light, it can be divided into three kinds: active, passive and mixed [1-5]. The projector in the active equipment will project a certain group of light (such as circle, ellipse, square, etc.) onto the surface of the study object, and capture the reflected light by a camera at a certain distance. After the light is reflected on the surface, the original shape will be twisted and bent. Through the analysis and processing of computer software algorithm, it will be in phase with the three-dimensional space coordinates to create images. When acquiring images, this system can control the illumination of the object without additional illumination, and also eliminate the interference of external light. The mature active three-dimensional stereography system can easily capture darker skin and clothes, but the imaging time of this system is relatively long. Genex system is a commonly used active three-dimensional stereography system, which is calibrated internally without additional calibration. M4D system is a portable three-dimensional stereography system, which is small and portable, can be installed and used in a short time, can tolerate the slight movement of objects, and can be used for photography of any part of the body. Passive photography is to capture the reflection of light on the object's surface in the environment, which replies on triangulation technology on the actual surface of the object. The system relies on the details of the skin, hair, scars, freckles and so on. Therefore, it largely depends on the integrity of the pixels and requires higher camera pixels. In addition, the lighting conditions in the environment should be strictly controlled in order to minimize the impact of environmental spectral reflection on imaging. The commonly used passive three-dimensional stereography system is Di3D system, which uses high-resolution camera, does not need image projection or laser scanning, and can capture images quickly and easily. Mixed technology combines the above two technologies, and the most commonly used are 3DMD system. The 3DMD system is composed of six medical-level cameras, which can synchronize with the main body in 1.5 milliseconds. These cameras reconstruct the multi-angle images in the same three-dimensional coordinate model. The capturing time is short; and the 3DMD system can accommodate additional cameras without affecting the capturing time. However, the system requires users to calibrate them every time before use.

The accuracy of three-dimensional stereography system is mainly reflected in the repeatability and absolute accuracy. Some scholars [6] have found that the overall accuracy of 3DMD is less than 1mm with high reliability and repeatability when comparing 18 marker points measured by standard anthropometry and 3DMD system in 20 normal adults. A large number of scholars [7-9] found that the three-dimensional stereography system used in the market has high repeatability and accuracy when studying the accuracy of different imaging systems. Although there are gaps between different systems, these gaps are within the micron level, which is not very significant in the actual measurement research.

APPLICATION OF THREE-DIMENSIONAL FACIAL STEREOGRAPHY IN ORTHOGNATHIC SURGERY

Orthognathic surgery restores normal tooth-jaw position by cutting, moving and re-fixing the jaw. Before the implementation of the treatment plan, we simulate the tooth and jaw movement process and predict the changes of facial shape after operation, and get a visual effect map. This design method and prediction method is called VOT analysis method. Its purposes include: 1. to determine the target of preoperative orthodontic treatment; 2. to screen the surgical plan that can achieve the best functional and aesthetic effect; 3. to obtain the visual picture of the changes of facial profile after operation for consultation and communication with patients [10]. With the development of computer image and image processing technology, computer-aided design methods have become very popular. The emergence and development of three-dimensional imaging technology provides the possibility of measurement, design and simulation of three-dimensional models.

The Role of Three-dimensional Facial Stereography in Facial Measurement

Traditional anthropometry is carried out in the clinical environment, which measures the distance or radian between the marker points of the object with calipers. It needs to measure the object independently, and requires several minutes of direct physical contact. It is difficult to collect data of infants or children with some developmental deficiencies and takes longer time. When three-dimensional stereography system is used for indirect measurement, it has great advantages [11]: firstly, it is finished fast, and the object can move freely after it is done; secondly, the photography system is non-invasive, safe without radiation; thirdly, after it is done, the image can be quickly viewed to determine the photographic details, if defects or deformations are found in the image, it can be recaptured in time; fourthly, the image data can be used repeatedly after archiving for research and measurement; finally, the data can be used in computer software to measure the distance and radian between marker points. The same data can be measured and analyzed by multiple people at the same time. Three-dimensional facial stereography is mainly used to measure and analyze the relationship between marker points of facial soft tissues, but not that for hard tissues. As an indirect measurement method, it cannot determine the location of marker points by touching the object directly, but can only be judged by facial contour. Computer software has the function of local enlargement. Individual differences may exist when marking points are placed. Therefore, physicians need to check the location repeatedly when marking. Whether it is traditional direct facial measurement or three-dimensional facial photogrammetry, most of them pay attention to the distance between the marker points and the linear angle relationship of the side correlation, rather than the radian of the facial contour, thus are lacking in the measurement indicators of the characteristics of three-dimensional facial photogrammetry.

Three-dimensional facial stereography also has great advantages in symmetry comparison. In anthropological research, facial symmetry is very important in human facial attraction. Local symmetry has different importance in different regions of the face, and symmetry near the midline has a greater impact. In the comparison of symmetry, two-dimensional photographs sometimes have little difference in height and width because of the lack of coordinates of one dimension, but there may be great difference in depth. In addition, a single two-dimensional photograph has less available measurement indicator points than three-dimensional model in symmetry comparison, and gives less comprehensive information. Philipp et al. [12] , when comparing the 3 methods of facial symmetry analysis via two-dimensional and three-dimensional photographs, pointed out that two-dimensional photographs have some deficiencies in the accuracy while three-dimensional photographs are more difficult to be measured due to larger number of available marker points, and suggested that the three-dimensional photos should be analyzed by referring to the symmetry index in the two-dimensional photos, so as to get the accurate results quickly. The results of symmetry analysis can provide certain guidance for the treatment plan and operation plan. Complete and accurate results can provide better treatment.

Ogawa et al. [13] used three-dimensional facial stereography system to obtain three-dimensional facial images of 1126 Japanese (865 males and 261 females aged 19-60) as samples. Under the standard anthropometric analysis, the features of eyebrow, orbit, nose and lip contours were recorded, and the differences between different ages and genders were compared to establish the database of three-dimensional facial photographs, which can not only be used to analyze the differences in facial contour and soft tissues characteristics of a group, but also to analyze the development trend of the face with age by comparing its changes horizontally. Kim [13], through the analysis of the three-dimensional facial models of 43 beauty contestants and 48 ordinary women, found the difference between the two groups: the middle of the face of beauty contestants is more three-dimensional, the nose is higher and the distance between the two sides of the nose is shorter; there is no significant difference between the vertical ratio of the lip and the lower part, but the nasolabial angle of beauty contestants is slightly larger than that of ordinary women. There are also some differences in facial features among different races. Wirthlin [14] compared three-dimensional facial models of 100 white Houstonians with 71 Chinese, and found that Houstonians have more protrusions in the middle of the face, including the eyebrow, nose, lips and chin while Chinese have wider zygomatic arch, and Chinese women have fuller cheeks than men. These differences have certain reference value in orthognathic simulation, which is conducive to the formulation of more reasonable treatment programs.

The Role of Three-dimensional Facial Stereography in Preoperative Simulation

Cone-beam CT (CBCT) can provide medical image storage and transmission data, which will not lose the original information of the images, and realize the consistence of the corresponding points of two-dimensional photos with the three-dimensional spatial position and anatomical structure by marching cubes algorithm in computer graphics, to reconstruct the three-dimensional visualization model [4、15-19]. With the soft and hard tissues data provided by CBCT, a three-dimensional model is created, which is used by many scholars to simulate the hard tissues morphology after the operation by cutting and moving the jaw. This technology can also be combined with three-dimensional printing technology to print biteplate to be used during the operation. However, the accuracy of facial soft tissues data provided by CBCT is still inadequate. It cannot display the color and texture of facial tissues. Fitting the images provided by three-dimensional facial stereography with CBCT can show the overall face and contour after operation. This three-dimensional model can not only show the profile relationship, but also show the relative relationship between the positive side and the whole face. It can be used to observe the symmetry of the face. It is more intuitive than the two-dimensional simulation, and has more advantages in the determination of treatment options and doctor-patient communication.

A large number of scholars combined three-dimensional facial photographs and CBCT to simulate orthognathic surgery, and found that the accuracy of three-dimensional simulation is higher than that of two-dimensional simulation in soft tissues prediction [20-27]. The errors in three-dimensional simulation are the errors in data acquisition or processing on one hand, and the errors in simulation itself on the other hand. The error between the acquisition of three-dimensional facial stereography and the acquisition of CBCT is relatively small, but when acquiring three-dimensional facial images, the instantaneous facial images are captured. The three-dimensional image acquisition and CBCT image acquisition are not carried out at the same time; swallowing, mouth-sweeping and other movements will affect facial morphology through muscles. When the subjects are in the position of rest and occlusion, the lower third of the face may be different in height. Therefore, it is suggested that a unified image acquisition standard be established to reduce the errors caused by data fitting. In software simulation, the changes of hard tissues lead to the changes of facial muscle tension, and the changes caused by different amount of movement are different, and the changes are not completely in accordance with the linear relationship; on the other hand, there are differences in the thickness of soft tissues between different individuals, leading to differences in individual simulation. In many cases, individual differences in three-dimensional simulation are adjusted individually based on the doctor's clinical experience. There is still a lack of a database to simulate the relative relationship between soft and hard tissues in the three-dimensional simulation, which can guide the adjustment of patients with different soft tissues thickness and the amount of hard tissues movement.

2Application of Three-dimensional Facial Stereography in the Comparison of Treatment Effects

In researching the difference before and after treatment of orthognathic patients, we can mark reference points on the model, draw reference lines, compare the difference between marker points and reference lines, or use computer software combined with algorithm to overlap the three-dimensional facial models before and after treatment, observe the difference of overlapping effect in the software and analyze it. Computer software can also quantify the differences in facial volume change. Hajeer [28] compared the three-dimensional models of five patients with orthognathic surgery before and after surgery, and found that orthognathic surgery improved the symmetry of the soft tissues morphology of lower 1/3 part of the face. Three-dimensional facial photographs can record the features of facial contour, color and skin texture of the subjects. The photographing process is simple, safe and without radiation. It can be used to record facial features of orthognathic patients during subsequent re-check and follow-up. Kau et al. [29] also used it to compare the rate of swelling subsidence after orthognathic surgery, and found that within one month the individual swelling subsided by about 60%. The swelling produced by bimaxillary surgery was larger, but the rate of subsidence was faster than that of unimaxillary surgery. Combining with computer software algorithm, three-dimensional facial photographs can be used to quantify the volume changes of the face, and can be used to observe the results of treatment and analyze the prognosis in local facial filling treatment.

CONCLUSIONS & PROSPECTS

The application of three-dimensional facial stereography in facial soft tissues acquisition has the characteristics of fast speed, high accuracy, high repeatability and non-invasiveness. It can be used in the analysis and measurement of facial soft tissues. It can not only quantitatively analyze the relationship between facial markers, but also quantitatively analyze the symmetry and volume changes of the face. When it is used to build a three-dimensional facial model, it can simulate the whole facial soft tissues morphology after orthognathic surgery, and has a higher accuracy. It has a greater advantage in the determination of orthognathic treatment plans and doctor-patient communication. The system can record the facial soft tissues characteristics of the object completely, and has great advantages in the follow-up and research after operation.

However, when three-dimensional facial photos are used in three-dimensional simulation, the lack of a three-dimensional database leads to errors in simulation. Although many scholars are gradually expanding the amount of data in order to establish a perfect database, there is no unified conclusion on the correlation between preoperative simulation and postoperative three-dimensional facial photographs in orthognathic surgery simulation, and doctors still need to explore and summarize. There is also a lack of standardization in three-dimensional facial photo acquisition, which will affect the accuracy of data acquisition and the accuracy of three-dimensional simulation results.

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REFERENCES

[1] Knoops P G M , Beaumont C A A , Borghi A , et al. Comparison of three-dimensional scanner systems for craniomaxillofacial imaging[J]. Journal of Plastic, Reconstructive & Aesthetic Surgery, 2017, 70(4):441-449. DOI：10.1016/j.bjps.2016.12.015.

[2] Tuncay O C . Three-dimensional imaging andmotion animation *[J]. Seminars in Orthodontics, 2001, 7(4):244-250.DOI: 10.1053/

sodo.2001.25402.

[3] Bourne C O , Kerr W J S , Ayoub A F . Development of a three-dimensional imaging system for analysis of facial change[J]. Orthodontics & Craniofacial Research, 2010, 4(2):105-111.DOI: 10.1034/j.1600-0544.2001.040207.x.

[4] Lane C , Jr W H . Completing the 3-dimensional picture[J]. American Journal of Orthodontics & Dentofacial Orthopedics, 2008, 133(4):612-620.DOI: 10.1016/j.ajodo.2007.03.023.

[5] Xie Liuping Zhang Weibing. .The application of three-dimensional stereophotography in facial soft tissues[J]. International Journal of Stomatology, 43(2).DOI: 10.7518/gjkq.2016.02.019

[6] Wong J Y , Oh A K , Ohta E , et al. Validity and Reliability of Craniofacial Anthropometric Measurement of 3D Digital Photogrammetric Images[J]. The Cleft Palate-Craniofacial Journal, 2008, 45(3):232-239.DOI: 10.1597/06-175.

[7] Fourie Z , Damstra J , Gerrits P O , et al. Evaluation of anthropometric accuracy and reliability using different three-dimensional scanning systems[J]. Forensic Science International, 2011, 207(1-3):127-134.DOI: 10.1016/j.forsciint.2010.09.018

[8] Khambay B , Nairn N , Bell A , et al. Validation and reproducibility of a high-resolution three-dimensional facial imaging system[J]. British Journal of Oral & Maxillofacial Surgery, 2008, 46(1):0-32.DOI: 10.1016/j.bjoms.2007.04.017.

[9] Weinberg S M , Naidoo S , Govier D P , et al. Anthropometric Precision and Accuracy of Digital Three-Dimensional Photogrammetry[J]. Journal of Craniofacial Surgery, 2006, 17(3):477-483.DOI: 10.1097/00001665-200605000-00015.

[10] ZHAN Zhiyuan, YU Guangyan. Oral and Maxillofacial Surgery [M]. 7th Edition. Beijing: People's Health Publishing House,2014:507

[11] Berssenbrügge, Philipp, Berlin N F , Kebeck, Günther, et al. 2D and 3D analysis methods of facial asymmetry in comparison[J]. Journal of Cranio-Maxillofacial Surgery, 2014, 42(6):e327-e334. DOI: 10.1016/j.jcms.2014.01.028

[12] Ogawa Y , Wada B , Taniguchi K , et al. Photo anthropometric variations in Japanese facial features: Establishment of large-sample standard reference data for personal identification using a three-dimensional capture system[J]. Forensic Science International, 2015, 257:511.e1-511.e9.DOI: 10.1016/j.forsciint.2015.07.046

[13] Kim S C , Kim H B , Jeong W S , et al. Comparison of Facial Proportions Between Beauty Pageant Contestants and Ordinary Young Women of Korean Ethnicity: A Three-Dimensional Photogrammetric Analysis[J]. Aesthetic Plastic Surgery, 2018. DOI: 10.1007/s00266-018-1071-8

[14] Wirthlin J , Kau C H , English J D , et al. Comparison of facial morphologies between adult Chinese and Houstonian Caucasian populations using three-dimensional imaging[J]. International Journal of Oral and Maxillofacial Surgery, 2013, 42(9):1100-1107.DOI: 10.1016/j.ijom.2013.03.008

[15] Hammoudeh J A , Howell L K , Boutros S , et al. Current Status of Surgical Planning for Orthognathic Surgery: Traditional Methods versus 3D Surgical Planning[J]. Plast Reconstr Surg Glob Open, 2015, 3(2):e307.DOI: 10.1097/GOX.0000000000000184

[16] Nilsson J , Richards R G , Thor A , et al. Virtual bite registration using intraoral digital scanning, CT and CBCT: In vitro evaluation of a new method and its implication for orthognathic surgery[J]. Journal of Cranio-Maxillofacial Surgery, 2016:S1010518216301019.DOI :10.1016/j.jcms.2016.06.013

[17] Ayoub A F , Xiao Y , Khambay B , et al. Towards building a photo-realistic virtual human face for craniomaxillofacial diagnosis and treatment planning[J]. International Journal of Oral & Maxillofacial Surgery, 2007, 36(5):0-428.DOI: 10.1016/j.ijom.2007.02.003

[18] Schendel S A , Jacobson R . Three-Dimensional Imaging and Computer Simulation For Office-Based Surgery[J]. Journal of Oral & Maxillofacial Surgery Official Journal of the American Association of Oral & Maxillofacial Surgeons, 2009, 67(10):2107-2114.DOI: 10.1016/j.joms.2009.04.111

[19] Swennen G R J , Mollemans W , Schutyser F . Three-Dimensional Treatment Planning of Orthognathic Surgery in the Era of Virtual Imaging[J]. Journal of Oral & Maxillofacial Surgery, 2009, 67(10):2080-2092.DOI: 10.1016/j.joms.2009.06.007

[20] Liebregts J H F , Timmermans M , De Koning M J J , et al. Three-Dimensional Facial Simulation in Bilateral Sagittal Split Osteotomy: A Validation Study of 100 Patients[J]. Journal of Oral and Maxillofacial Surgery, 2015, 73(5):961-970.DOI: 10.1016/j.joms.2014.11.006

[21] Resnick C M , Dang R R , Glick S J , et al. Accuracy of three-dimensional soft tissue prediction for Le Fort I osteotomy using Dolphin 3D software: a pilot study[J]. Int J Oral Maxillofac Surg, 2017, 46(3):289.DOI: 10.1016/j.ijom.2016.10.016

[22] Stebel A , Desmedt D , Bronkhorst E , et al. Rating nasolabial appearance on three-dimensional images in cleft lip and palate: a comparison with standard photographs[J]. The European Journal of Orthodontics, 2015:cjv024.DOI: 10.1093/ejo/cjv024

[23] Tran N H , Tantidhnazet S , Raocharernporn S , et al. Accuracy of Three-Dimensional Planning in Surgery-First Orthognathic Surgery: Planning Versus Outcome.[J]. Journal of Clinical Medicine Research, 2018, 10(5):429-436.DOI: 10.14740/jocmr3372w

[24] De Riu G , Virdis P I , Meloni S M , et al. Accuracy of computer-assisted orthognathic surgery[J]. Journal of Cranio-Maxillofacial Surgery, 2017:S101051821730416X.DOI: 10.1016/j.jcms.2017.11.023

[25] Schneider D , Peer W. Kämmerer, Hennig M , et al. Customized virtual surgical planning in bimaxillary orthognathic surgery: a prospective randomized trial[J]. 2018.DOI: 10.1007/s00784-018-2732-3

[26] Chang Y J , Ruellas A C O , Yatabe M S , et al. Soft Tissue Changes Measured With Three-Dimensional Software Provides New Insights for Surgical Predictions[J]. Journal of Oral and Maxillofacial Surgery, 2017:S0278239117305396.DOI: 10.1016/j.joms.2017.05.010

[27] Daniel H , Philipp J , Kamal S , et al. Accuracy of soft tissue prediction in surgery-first treatment concept in orthognathic surgery: A prospective study[J]. Journal of Cranio-Maxillofacial Surgery, 2018:S101051821830372X-.DOI: 10.1016/j.jcms.2018.05.055

[28] Geert Van Hemelen, Maarten Van Genechten, Lieven Renier et al. Three-dimensional virtual planning in orthognathic surgery enhances the accuracy of soft tissue prediction[J]. Journal of Cranio-Maxillofacial Surgery, 2015, 43(6):918-925.DOI: 10.1016/j.jcms.2015.04.006

[29] Kau C H , Cronin A J , Richmond S . A Three-Dimensional Evaluation of Postoperative Swelling following Orthognathic Surgery at 6 Months[J]. Plastic and Reconstructive Surgery, 2007, 119(7):2192-2199. DOI: 10.1097/01.prs.0000260707.99001.79