Computer-assisted design and rapid prototyping technology for the underlay of hemifacial atrophy**☆

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Supported by: Youth Talent Innovation Fund of Fujian Provincial Science and Technology Ministry, No. 2008F3089*, 2008F3088*

Received: 2009-12-30
Accepted: 2010-03-15
(20091230009/GW)

Gong ZY, Li GH, Liu YP, He LS, Zhou SX.Computer-assisted design and rapid prototyping technology for the underlay of hemifacial atrophy. Zhongguo Zuzhi Gongcheng Yanjiu yu Linchuang Kangfu. 2010;14(22): 4172-4175.

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Abstract

BACKGROUND: There are many methods for repairing the hemifacial atrophy, the most common is preparing plaster facial mold of the patient, with wax piled on the surface to restore the patient's facial shape, and wax pattern serves as a reference of surgical pad. However, the therapeutic effect for the correction and treatment is not satisfactory due to varied abnormality and difficult plans.

OBJECTIVE: To discuss the feasibility of manufacturing underlay for the treatment of hemifacial atrophy using computer-assisted design and rapid prototyping technology.

METHODS: Skull of the hemifacial atrophy patient was scanned with Picker 6000 SCT, and the data obtained were processed in Voxel Q image workstation for 3-D reconstruction with volume rendering technique. After the interval lamination, the images were downloaded at 0.4-mm interval in a BMP format using CuteFTP 4.0 software. Then the transaxial 2-D image data were converted into digitized 2-D contour data by using image processing software developed by experimental team through a series of processes, including filtering, screening, noise reduction, and distortion correction. The edges and contour of the images was extracted to obtain a vector diagram of facial cranial cortical bone contour line. The digitized data were inputted into image processing software of Surfacer 9.0 for vector superposing, thus the 3-D wire frame and solid images of skull could be reconstructed. According to mirror-image symmetry relation, the point-cloud data of facial bone on the normal side was duplicated to the atrophied side. Thus a 3-D model of the underlay was produced between the atrophied bone and the mirror image of normal side. In order to compensate the atrophy of soft tissues, the model was designed 1.5 mm thicker. After the three-dimensional Surfacer data on the CAD were re-stratified, the contour editing of the underlay and the supporting set of prototype were completed in RpDataRepare, forming RP files and creating underlay template through rapidly output of the processing file for rapid prototyping required, as a reference of surgical procedures.

RESULTS AND CONCLUSION: The 3-D solid model of the patient skull bone surface contour was obtained and simulacrum of the underlay was prepared with computer assistance and rapid prototyping. According to the simulacrum, the operation was carried out and got a satisfactory result. The manufacture of underlay for the treatment of hemifacial atrophy could be accomplished by computer assisted design and rapid prototyping in a highly precise and rapid manner. It is a promising technique in the field of individualized underlay making in craniofacial surgery.

INTRODUCTION

Hemifacial atrophy (Rombeng syndrome) is an unilateral atrophic disease lesioned soft tissue or muscle, bone, belonging to tissue nutritional disorders. At present, there is no effective treatment, various surgical methods should be selected in accordance with the deformity severity and extent. The plastic repair only adopts implants filling tissues, to make a full contour and a symmetry with normal side, the majority of treatments are dermal fat graft or medical silicone filling. Due to varied abnormal changes and difficult treatment planning, the therapeutic effect is not satisfactory, no matter which method is used for restoration, we all need to preoperatively measure the facial contour and have a quantitative understanding on the severity of the malformation. The most common used method is to prepare a plaster facial mold of the patient, with wax piled on the surface to restore the patient's facial shape, and wax pattern serves as a reference of surgical pad. Also, face bow is applied to measure and calculate the height difference between facial symmetrical points, thus obtaining the thickness of the underlay. The advantages of these above methods are simple, economic, easy to modify, and both doctors and patients can be informed of expected results, but they are both based on the manual and visual observation, which is subjective and not very accurate, the relevant data and information are difficult to preserve and share. Moire fringe and biostermetric measurement technique fit for the qualitative and quantitative analysis of three-dimensional facial contour of the patient, but they are poor direct-viewing and can not design and manufacture underlay or prosthesis. Rapid prototyping, developed in 1980s, is a new digital prototyping technology based on the discrete and accumulated shape principle of accurate accumulation and prototype manufacturing, under the control of the computer, according to object data such as CAD models or CT, without the aid of other equipment. It embodies the comprehensive applications of multi-disciplinary and multi- technology, such as CAD, laser processing, digital and new material development. Designers can directly observe the ideas in their minds about the product on computer screen. This experiment was aimed to produce accurate underlay model by use of rapid prototyping technology, to provide an important basis for the operation and to achieve a better result.

SUBJECTS AND METHODS

Participant

Male, 23 years old, left facial non-chubbiness for 8 years. Review of the disease history found that the patient was injured in the left mandible by the inadvertent movement at the age of 10 years, the pain was obvious at that time and relieved 1 day later, receiving no any treatment. Since the age of 15, left facial non-chubbiness was found and gradually aggravated, without other discomforts. At 18 years old, the atrophy reached a peak and then exhibited no significant progress. Specialist examination diagnosed facial asymmetry and left facial non-chubbiness, especially inferior 1/3 face, left mandible was short, surface soft tissues were thin, bilateral lower lip thickness had a 3-mm deviation, the thickness of the upper lip was uniform, the angle and shape of mouth opening were normal, with a normal occluding relation, normal facial muscle movement. Panoramic radiography showed the left mandibular bone body and ascending branch were smaller than the contralateral, the difference on the maximum width was about 1 cm, no mandible bone damage and proliferative lesion were found. Patients were informed of and gave consents to the treatment and experiment.

Experimental methods

CT scan

Picker 6000 spiral CT scanner was used at a scan condition of 120 kV, 65 mA, 1.0 s, slice thickness 3 mm, pitch 2.0, matrix 512 × 512, window width 2 500, window level 100. When scanning, the patient was located on the examination bed in a supination position, scanning range was from oculi rimae plane to cricoid cartilage plane in a horizontal line.

CT image download

Login local area network workstations composing Picker 6000 main engine and Voxel Q 4.0 image workstations, for three-dimensional volume reconstruction of the scanned images, at a matrix of 1 024 × 1 024, the reconstructed three-dimensional images were then subjected to cross-sectional layer at an interval of 0.4 mm, 2.0 fold amplified two-dimensional layered image, the best cognition of the bone boundary was achieved by adjusting the image gray scale and setting the contrast and other parameters[1], then down-loaded in a BMP format using CuteFTP 4.0 software.

Vectorized three-dimensional modeling

By use of a CT image-processing software developed by the research group, the downloaded two-dimensional images were processed by filtering, screening, noise reduction and distortion correction, the edge and contour of the images were extracted to obtain a contour vector diagram of cortical bone of facial cranium, the vector bone contour diagram data were inputted into Surfacer 9.0 reconstruction software (Imageware, USA), the CT image scale served as a two-dimensional registration symbol, the input image interval was 0.2 mm. Then the contour curve was vector overlaid to obtain three-dimensional triangular facets wire frame model and solid model of facial cranial bone [2], and edited according to the design needs, computer-aided three-dimensional model of the underlay could be prepared.

Three-dimensional model of the underlay

In the three-dimensional model of facial cranial bone, the point-cloud data of facial bone on the normal side was duplicated to the atrophied side according to mirror-image symmetry relation. Thus a 3-D model of the underlay was produced between the atrophied bone and the mirror image of normal side. The internal surface of the model was the surface of mandible bone on the lesioned side, while the outer surface was the mirror image on the lesioned side of normal mandible bone. In order to compensate the atrophy of soft tissues, the outer surface of model was designed 1.5 mm thicker and 25 mm high, so as to avoid surpassing vestibular groove.

Rapid prototyping

Three-dimensional Surfacer data on the CAD were re-stratified and then adjusted to 0.1-mm interval, to ensure rapid prototyping resin can closely bond. The process is implemented using rapid prototyping data preparation software RpDataRepare, an accessory of LPS600 rapid prototyping machine, which is produced by Institute of Advanced Manufacturing Technology, Xi'an Jiaotong University. In RpDataRepare the contours editing and the support device were performed, then forming RP project files, finally the processing file .par required for rapid prototyping was output. System parameters: slice thickness 0.1 mm; processing speed 500 mm/s; laser power 40 mW; wavelength 325 mm; spot diameter 0.1 mm; temperature (40±2) ℃[3]. The whole process was about 7 hours. The support was removed after the machine work was over, the surface residual resin was rinsed using volume fraction φ of 0.95 ethanol, then trimmed and polished prototype.

Surgery

Under general anesthesia, submandibular incision on the lesion site of the patient was taken out, to expose mandible bone surface, according to the prepared underlay template, high-density porous polyethylene material (trade name MEDPOR, Porex Corporation, USA) was graved using knives and implanted into the periosteum. After identifying the bilateral facial symmetry, the titanium screw fixation, wound washing, and layered suture were given.

RESULTS

The front image of the patient showed facial asymmetry, left facial non-chubbiness, especially inferior 1/3 face, bilateral lower lip thickness had a 3-mm deviation. CT image of inferior face (Figure 1) revealed left soft tissues were thinner and mandibular ascending branch was slimmer than the contralateral.

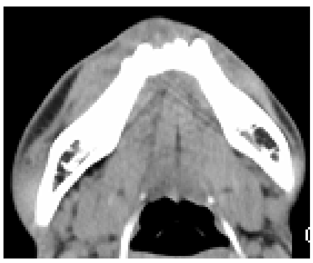

Figure 1 CT image shows left soft tissues and mandibular ascending are thinner than those of right side

Through three-dimensional modeling in facial cranial bone (Figure 2), we can observe on the computer screen at any rotation angle, showing a dramatic atrophy in the left mandible, three-dimensional model of the underlay designed to adhere its surface (Figure 3), the patient's wound healed well with a satisfied appearance (Figure 4), then scheduled removal of stitches, the patient was discharged.

Figure 2 Three-dimensional model of facial cranium shows atrophy in left mandible

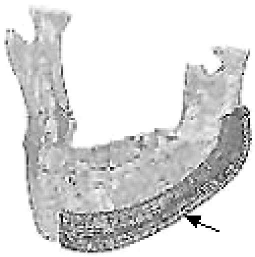

Figure 3 The designed underlay model

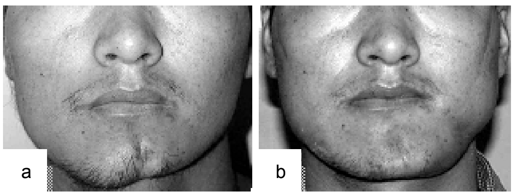

Figure 4 Pre-operation (a) and post-operation (b) photos of the patient

DISCUSSION

Progressive hemifacial atrophy is a rare disease termed as unilateral skin, subcutaneous tissue and bone structure atrophy. It is firstly reported by Parry in 1825, then described by Romberg in 1846 of the typical characteristics of the disease in details, thus it is also known as Parry Romberg syndrome or Romberg disease[4-8]. So far, the disease pathogenesis is unknown and there are many etiology hypotheses, including the sympathetic nerve theory, neurotrophic theory, infection theory, injury theory, trigeminal nerve theory, immune theory, genetics theory, they are so far inconclusive. The repairing methods for hemifacial atrophy are various, because of changes in deformity and difficulty in treatment design, the therapeutic effect is not good enough. Moire fringe and biostermetric technique can be applied on the qualitative and quantitative analysis of three-dimensional facial morphology, but they are poor direct-view and cannot design and manufacture the underlay or prosthesis.

Three-dimensional model of craniofacial bone tissue can be visualized and quantitatively analyzed, also reflect the three-dimensional structure, it not only provides clinicians with massive information, but also benefits individual designs and three-dimensional model of the prosthesis, thus producing solid model. The patient mentioned in this study has a specialty, that is the deformity mainly locates in 1/3 low face, while the maxilla and zygomatic atrophy was not obvious, so the treatment is only designed to focus on mandible bone and surrounding soft tissue atrophy, rapid prototyping technology provides a precise basis. Rapid prototyping, developed in 1980s, is a new digital prototyping technology based on the discrete and accumulated shape principle of accurate accumulation and prototype manufacturing, under the control of the computer, according to object data such as CAD models or CT, without the aid of other equipment[1]. It embodies the comprehensive applications of multi-disciplinary and multi-technology, such as CAD, laser processing, digital and new material development. Designers can directly observe the ideas in their minds about the product on computer screen, rapid prototyping technology is particularly suitable for complex structure objects, single or small batch production. As CT and MRI scans are similar with rapid prototyping slice data format, the reverse biosystem surface profile can be achieved through CT data conversion, also accurately replicate the same shape as biosystem[5], From the solid model to manufacturing real object, the precision of RP technology has reached 0.1 mm or less[6], the main factor affecting product precision in the medical field is the source of the original data-CT scan thickness[7]. Rapid prototyping technology-produced template serves as the location and height of surgical underlay, so that the surgeons can accurately formulate preoperative surgical planning, pre-implant biological material, determine the shape and number of transplanted tissue, reduce intraoperative bleeding and trauma, greatly save surgery and anesthesia time, also change the previous outcomes depending on visual observation and experience, more real and more accurate than two-dimensional surgical simulation based on X-ray lateral projection, increase the operation precise, ensure the plastic repair therapeutic effect on both shape and function, therefore it is a recommendable method.

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计算机辅助设计和快速成型技术制造颜面萎缩衬垫物的可能性**☆

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摘要

背景：半侧颜面萎缩畸形的整复方法较多，以往常通过制备患者的石膏面模，在上面堆蜡来恢复患者的面形，蜡型用作手术中衬垫的参考。但由于畸形的变化多，矫治设计的难度大，矫治效果不甚理想。

目的：探讨应用计算机辅助设计和快速成型技术制造用于矫正半侧颜面萎缩等凹陷畸形衬垫物的可能性。

方法：对半侧颜面萎缩患者行螺旋CT扫描，利用工作站进行扫描图像的容积三维重建后，重新间隔分层，利用CuteFTP 4.0软件以BMP格式下载。应用课题组自主开发的CT图像处理软件对已下载的二维图像进行过滤、筛减、降噪、校正失真等处理，对图像的边缘轮廓进行提取，得到面颅骨皮质骨边缘轮廓的矢量化线图，将该线图数据输入Surfacer 9.0重建软件，对轮廓曲线进行矢量叠加，从而得到面颅骨的三维三角形面片线框模型及实体模型。将健侧面颅骨的点云数据按镜像对称变换到患侧，这样在患侧骨和健侧镜像之间就形成了充填物的三维模型，为补偿软组织的萎缩，将其外表面点云数据外移1.5 mm。对CAD后的三维Surfacer数据重新分层,在RpDataRepare中完成充填物的轮廓编辑和成型的支撑设置，形成RP项目文件，输出快速原型所需的加工文件.par，制造出衬垫物模板，作为实施手术过程中的参照。

结果与结论：获得了患者颅面骨表面轮廓的三维实体模型，并由计算机辅助设计，快速成型制造出衬垫物模板，并以此为参照完成手术，效果满意。说明应用快速成型技术可以完成半侧颜面萎缩等凹陷畸形的衬垫物的制造，精度高，快捷，在颅颌面外科假体的个体化制造方面有良好的应用前景。

关键词：体层摄影术；计算机辅助；图像处理；半侧颜面萎缩；快速成型；数字化医学
doi:10.3969/j.issn.1673-8225.2010.22.045
中图分类号: R318 文献标识码: B
文章编号: 1673-8225(2010)22-04172-04
龚振宇，李国华，刘彦普，何黎升，周树夏. 计算机辅助设计和快速成型技术制造颜面萎缩衬垫物的可能性[J].中国组织工程研究与临床康复，2010，14(22):4172-4175.
[http://www.crter.org http://cn.zglckf.com]
(Edited by Liu L/Yang Y/Wang L)

来自本文课题的更多信息--

基金资助: 福建省科技厅青年人才创新基金资助项目(2008F3089)及福建省科技厅青年人才创新基金资助项目(2008 F3088)。

利益冲突: 无利益冲突。

课题的创新点: 本文采用快速成型技术辅助治疗偏面萎缩畸形，对治疗偏面萎缩畸形提供了一种新的方法，具有创新性。

课题评估的“金标准”: 目前尚无此方面的金标准。

设计或课题的偏倚与不足: 样本含量不足仅1例; 另外，缺乏传统方法作为对照。

提供临床借鉴的价值: 三维测量和快速成型技术是利用CT数据进行三维建模，并采用快速成型进行加工从而获得颅颌面的三维实体模型及衬垫物模版。该技术可以有效地促进颅颌面外科手术的精确性，对提高临床治疗效果具有积极意义。