MODELING TECHNOLOGY AND APPLICATION OF REPAIRING BONE DEFECTS BASED ON RAPID PROTOTYPING

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Abstract: Now some people suffer from the bone defects for various reasons, and how to solve this problem has become a hot topic internationally in the field of tissue engineering. By the analysis of all kinds of the bone defects, an all-purpose approach using bionic bone scaffold to repair the bone defects is proposed in this paper to help the doctors to diagnose the state of the bone defect illness with the real models manufactured by the rapid prototyping technology. Meanwhile, a clinic application is given to prove the feasibility of this approach.

Key words: bone defects; surface reconstruction; rapid prototyping; tissue engineering; bionic scaffold.

1. INTRODUCTION

Because of the traffic accidents, production accidents, skeletal diseases and the like, the number of persons suffered from the bone defects or the bone injured is in excess of 3,000,000 annually in China.[1] Many of them need to make a bone graft surgery to repair the defects, which includes autogenous bone grafts, bone allograft[2], bionic bone grafts, etc. Due to the former two methods with the deficiencies like bones insufficiency, immunobiologic reaction, the bionic bone grafts can avoid the above deficiencies, which is a new approach to repair the bone defects.

The graft implanted to the human body is a scaffold using bionic bone grafts, which is seeded by the cells. The scaffold, depending on the tissue or

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organ in production, can be anything from a matrix of collagen, a structural protein, to synthetic biodegradable plastic laced with chemicals that stimulate cell growth and multiplication. The "seeded" cells that initiate regeneration come from laboratory cultures or from the patient's own body.[3]

How to repair the irregular bone defects is a key problem in the whole process (see Fig. 1). The process of repairing the bone defects will be proposed detailedly in this paper.

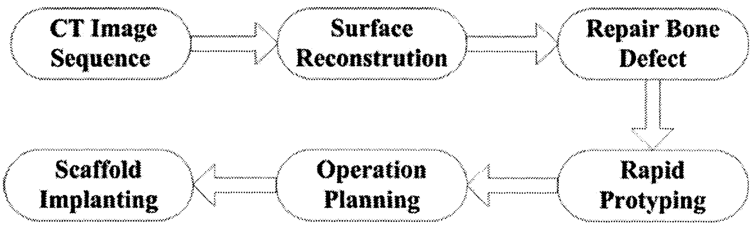

Figure 1. Repairing process

2. SURFACE RECONSTRUCTION

Many clinical situations ask for the visualization of anatomical surfaces. Common examples include hip replacement surgery, intra-operative visualization of surgical instruments or probes, visualization of planning information, and implanting surgery. The visualization of anatomical information with mesh-surfaces is useful for treatment planning and surgery.[4]

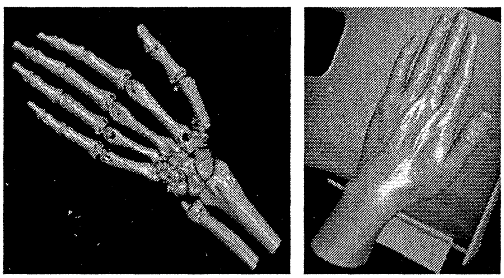

Figure 2. Reconstruction with different threshold

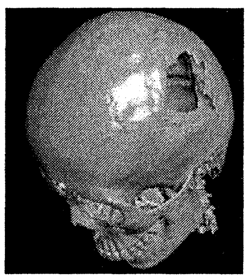

Figure 3. Model of bone defect

In order to display the model on the screen of computer, a 3D reconstruction algorithm called "Marching Cubes"(MC in short) was proposed by W. Lorensen and H. Cline in 1987.[5] The iso-surface can be reconstructed from the irregular and nonlinear volume datasets especially the medical volume datasets via the MC algorithm. And a threshold is needed to extract iso-surface, which stands for density of the substance we want to extract (see Fig. 2).

3. REPAIRING THE BONE DEFECT

There are some methods to repair the bone defects such as: mirror-image method, surface interpolation method and neural network method[6], etc. Mirror-image method is a common method to repair the bone defects, but it is based on the hypothesis that the repaired object is symmetrical. In fact, the bone is not always naturally symmetric. The results of the surface interpolation method depend on the selection of control vertices and basis function, which form a smooth profile. Now an all-purpose approach is proposed to repair bone defects by constructing free-form surfaces in this paper, which can meet the individuation of different bone defects.

For the sake of interpreting the process of repairing the bone defect, a 3D model reconstructed from CT images (see Fig. 3) is taken for example. The model is composed of so many spatial discrete points, which can be organized to a point cloud data to be dealt with via Imageware software. The point cloud can be handled as you like by the strong operation of Imageware.

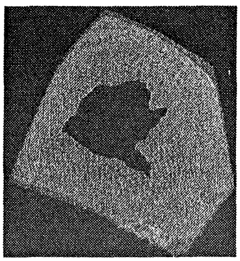

Figure 4. Region of interest

Figure 5. 3D B-Splines

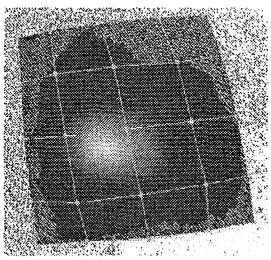

Figure 6. Free-form surface with control points

Fist of all, the point cloud of 3D bone model is imported to the software, and the quantum of the point cloud should be reduced to leave the region of interest (like the defect as shown in Fig. 4) in order to increase the velocity of each operation, because the whole data of the model is so big that the runtime of each operation is much longer.

For the exterior surface, curves can be created through several points chosen from the points along the margin of the defect on the exterior surface, which are 3D B-Splines in the 3D space. Generally, 4 B-Splines (see Fig. 5) are enough to enclose the defect fully. If the defect is too complex to fit the outline of the defect with 4 B-Splines, more 3D B-Splines are needed to fit the outline.

A free-form surface on the exterior surface is swept through these 3D B-Splines. It also can be adjusted to fit the trend of the whole curved surface through the control points (see Fig. 6), and its boundaries also should be adjusted to cover the defect. As for the internal surface, do the above process again to generate another free-form surface (see Fig. 7).

Figure 7. Upper and lower surface

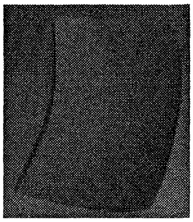

Figure 8. Solid block

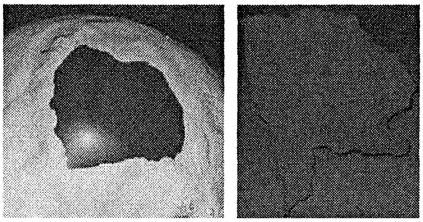

Figure 9. Subtraction operation

Afterwards, the other 4 surfaces can be blended to occlude the whole surface through the corresponding boundaries between upper surface and the lower surface. The 6 surfaces can be sewed together to form a solid block (see Fig. 8). In the end, the bone model is subtracted from the block, and the remnant of the block is the model fitting the defect we want (see Fig. 9). Sometimes, there are some edges and corners around the brim of the remnant, which are not necessary commonly for the clinic application. No matter how complex the bone defect is, it can be solved through this method. It is an all-purpose method to deal with all kinds of bone defects.

4. MANUFACTURING THE MODELS

The models of the bone and the substitute are so helpful that the doctor can make a pre-simulation of the implanting surgery and make an operation planning. On the basis of the analysis of models, the doctor can get the reasonable shape of implant and manufacture the scaffold with porous structure. But how to manufacture the model of he bone and the scaffold is very difficult, because the structure of the bone and the scaffold is quite complex and the surface is too irregular and the shape differs from each other. Using the traditional manufacturing technology, the production cycle will be longer and the shape could not accord to the real shape absolutely. In the field of medicine and engineering, an engineering method is being explored to manufacture the scaffold, which helps to solve the repair of the bone defects.

However, a new advanced manufacturing technology called rapid prototyping emerged in the past few years, which is capable of directly generating physical objects from CAD models. The prototype is produced by adding materials rather than removing materials. The model of the prototype is mathematically sliced into a series of parallel cross-section pieces. For each piece, the curing or binding paths are generated, which are directly used to instruct the machine for producing the part by solidifying a line of material. After a layer is built, a new layer is built on the previous one in the same way. Thus, the model is built layer by layer from the bottom to the top.[7] The models of the bone and the scaffold are quite complex, but they are can be manufactured by rapid prototyping technology. The production cycle will be shorter and the shape will accord to the real model (see Fig. 10).

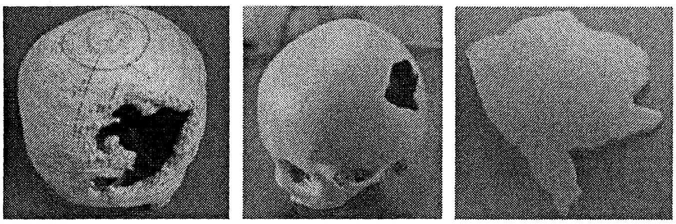

Figure 10. Models manufactured by rapid prototyping technology

5. CLINICAL CASE

For a male patient, there is a defect in the up left corner of the skull (see Fig. 11), which results from cell tumor. In the beginning, the model of skull should be reconstructed and repaired, and then, the models (see Fig. 12) should be manufactured by rapid prototyping for the doctors to simulate the surgery and make an operation planning. The models also supply references to the shape of the implant. Sometimes there is no need to keep the edges and corners along the boundary of the implant (see Fig. 13), which can make the surgery easier to carry out.

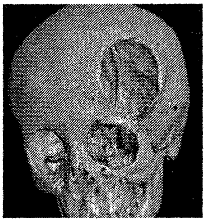

Figure 11. Defect

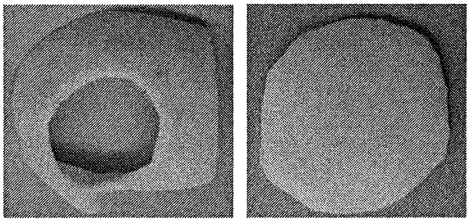

Figure 12. Models

When the shape of the implant is identified after surgery pre-simulation, the doctor divides the implant into several parts, and the parts are manufactured using biologic material, which structure is porous. The reason why doing so is that it could avoid the dead bone, because the implant needs to be seeded the cells in order to make the implant and the bone growing together.

According to the return visit with the doctors, there is a wonderful concrescence between the implant and the bone, and the patient recovers gradually (see Fig. 14 and Fig. 15).

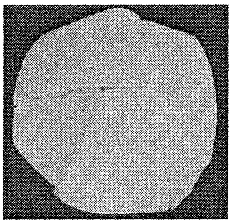

Figure 13. Implant

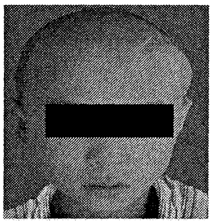

Figure 14. Ante-operative photograph

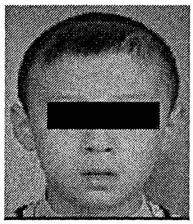

Figure 15. Post-operative photograph

6. CONCLUSION

In this paper, we have presented a new approach to repair the bone defects, and the repairing process is depicted in detail. This approach is proved to be feasible by the successful clinic application. Through this method, the diagnosis of bone defects will no longer depend upon the experience of the doctors mostly, and the success rate of cure will be increased greatly. It can be predicted that the rapid prototyping technology will be widely applied in the field of biomedicine with its strong superiorities. The combination of rapid prototyping with material, biology, medicine and other interrelated subjects, will make it possible that the bone defects are fully cured, which result from disease, accident, war and so on.

7. REFERENCE

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