Proceedings of the ASME 2009 International Mechanical Engineering Congress & Exposition
IMECE2009
November 13-19, Lake Buena Vista, Florida, USA

IMECE2009-10835

THE APPLICATION OF VACUUM CASTING SYSTEM FOR SIMPLIFYING THE DESIGN OF TRANSTIBIAL SOCKETS

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ABSTRACT

Prosthetic sockets are one of the most important pieces of equipment for a transtibial amputee to maintain a regular life. Rapid Prototyping is becoming mature and low-cost to fit the CAD system that can conserve the shapes of the stump and socket for reproducing the sockets. If the stump shape can be accurately obtained and the prosthetists' expertise can be included in a CAD system, then a prosthetic socket will be easily designed by a prosthetist. The stump was scanned to get the shape for the construction and modification of the stump model in a CAD system. However, the stump trembled during the scanning process, the scanner was sensitive about the skin move, so that the scanned data will not exactly represent the real stump shape.

This study used a vacuum casting system to gain the stump model instead of creating a positive plaster model in the traditional process of fabricating prosthetic sockets. The stump shape under various vacuum pressures was obtained using a scanning machine and built in a CAD system. The CAD model of the stump will be modified to meet the load-bearing capability of the specific amputee. The use of the vacuum casting method is expected to simplify the design of a socket that will be fabricated by a rapid prototyping machine. Simplifying the designs of transtibial socket can decrease the dependence of human experience and promote the quality and stability of prosthetic sockets.

INTRODUCTION

The shape of prosthetic sockets is key to whether the amputee would wear it or not. Prosthetists' expertise and patient's opinion are needed to modify a fit shape. The traditional method is to use plaster of Paris [1] bandages to capture the geometry of the residual limb, then the wrap cast is filled with plaster of Paris slurry to form a positive mould that can fabricate a socket. As soon as the socket is complete, the plaster of Paris is then destroyed immediately. If the amputee feels pain, then the plaster of Paris needs to be remade.

CAD system could be used to withdraw the modified stump data to reshape [2,3], without making positive mould once more, till the socket is suitable enough to wear. At first, the stump was scanned to obtain the profile and prosthetist made use of modification software to alter the stump shape, and then exported data to rapid prototyping (RP) machine [4] to make a RP socket. Because the stump would shake during the scanning process, manufacturing a stump model to scan is needed.

This study took advantage of a vacuum casting system [5,6] to replace the plaster of Paris, which can reduce time-consuming processes and environment pollution. This system used flexible fabric filled with Styrofoam balls as the negative mould and plastic bags filled with sand as the positive mould. Positive sand moulds can be made easily to substitute for plaster of Paris, and sand is recyclable which could become more convenient and quick to fabricate a RP socket by CAD system.

METHODOLOGY

This experiment has 4 main steps: (1) preparing the stump, (2) fabrication of the negative mould, (3) making a positive sand mould, and (4), scanning the positive sand mould and stump.

To check the shape difference between the stump and the positive sand mould is one way to confirm the suitability of this casting system. Therefore, one end socket is used instead of the stump to manufacture the positive sand mould, without modifying its shape and direct scanning the socket along with the positive sand mould to compare the shape difference between them.

Preparing the stump

Employing a one open end socket (fig. 1) in place of the stump, the socket is filled 20 percent full of sand and a bar is inserted and then stuffed up with sand. A piece of cardboard is cut to cover the open end of the socket, and then the edges are sealed(fig. 2)to prevent the sand from going out.

Fig. 1. One open end socket

Fig. 2 socket device to replace the stump to fabricate a negative mould

Fabrication of the negative mould

The negative mould is made of a 60 centimeter long, 40 centimeter wide elastic stockinet. Put a bottle mouth on one end and sew its edges (fig. 3), then fill with 1 millimeter in diameter Styrofoam to 70 percent full.

The elasticity of the stockinet is important to provide total contact with the stump when vacuuming.

Fig. 3 An elastic stockinet bag filled with Styrofoam

Making a positive sand mould

When the negative mould was set, the flexible plastic bag was put on the stump. The negative mould was pushed to cover the whole stump (fig. 4), and the flexible plastic bag was pulled down to attach to the vacuum valve (fig. 5). As the negative mould is vacuumed to obtain the stump shape, starting to vacuum the negative mould to obtain the stump shape (fig.6 left), the stump was pulled out and left a vacant container (fig. 6 right).

Fig. 4 The negative mould enclose the entire stump

Fig. 5 Vacuum valve connected to the plastic bag

Fig. 6 The negative mould was vacuuming(left), and the stump was pulled out (right)

The vacuum stick (fig. 7) has two sides. The left side of the stick is to suck the air out of the sand, and the right side is connected to the vacuum machine. The hollow stick was filled with cotton to get rid of the sand sucked into the vacuum machine. A flexible plastic bag was put into the negative mould, and the sand was poured to 20% of the stump height (fig.8). The stick was inserted then filled with the sand until full. The plastic bag was sealed with gummed tape, and the positive mould was vacuumed (fig. 9). The negative mould removed its suction to take out of the positive mould.

Fig. 7 The vacuum stick

Fig. 8 The plastic bag was filled with sand to form a positive mould

Fig. 7 The positive sand mould was sucked to form the stump shape

Scanning the positive sand mould and stump

When the positive sand mould was completed, the iron tube of the positive mould connected to a reverse valve with the sand mould kept on a vacuumed state (fig. 7, left side). The scanning machine is non-contact, and the scanned positive mould was painted white on the surface to ease the scanning then put on a table. If the surface of the positive mould is rough, 10 to 15 faces should be scanned to form a complete mould shape,5 to 7 faces should be scanned due to the smooth surface. The scanned mould of the sand mould and stump was output to STL format. Using a CAD system, such as CATIA, to analyze the shape differences between them to verify the possibility of using the vacuum casting system to simplify the shape design of a prosthetic socket.

RESULT

Shape inequality between stump and positive sand mould in different vacuum pressures

The sand mould and stump files were compared by putting together on the same central axis in CATIA. The inconformity between them was counted by the diameter of each height. The maximum and average differences of different pressure were presented on table 1. There were two mercury tubes at the vacuum pressure gauge. If the height difference of the mercury tubes is 50 mm, the vacuum pressure would be 710 Torr (760 mm minus 50 mm equaled to 710 mm).

Table 1 Maximum difference and average difference at different vacuum pressure.

Vacuum Pressure (Torr)	Maximum difference (mm)	Average difference(mm)
710	2.73	0.86
660	3.12	0.68
610	2.88	0.75

DISCUSSION

Contrast the original stump with the positive sand mould in different vacuum pressures

The positive sand mould doesn't need to be precise [7]. It can be modified by the software further, and a better shape would be simple. The shape difference at the protruding bones and the place near the patella tendon are bigger, but these areas will be modified on the software later. The difference on the surface of the whole stump is more important for analysis. If the average difference of the whole stump less than 1 mm, then the sand casting system can totally replace the plaster of Paris. From the table 1, the average difference on every pressure is less than 1 mm, and the magnitude of the pressure is not affecting the difference. If the vacuum pressure is big enough to maintain the positive mould shape ,the shape differences between stump and positive mould would be acceptable. This method can be used to make a positive mould for the RP socket manufacturing process.

Check the recyclability and fabrication environment of the positive sand mould

The plaster-based process would produce a bad flavor, and the negative and positive moulds made of plaster are not recyclable (table 2). However, the negative Styrofoam mould and positive sand mould are both recyclable, and it won't generate baleful results.

Table 2 Recyclable components of the different processes

Method	Component	Recyclable
Plaster-based method	Negative mould	No
	Positive mould	No
Vacuum casting method	Negative mould	Yes
	Positive mould	Yes
	Plastic bag	No

ACKNOWLEGEMENT

The authors wish to acknowledge the National Science Council of Taiwan for the grant NSC97-2221-E-006-105 in support of this study.

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