QUANTITATIVE ANALYSIS AND EVALUATION OF PROSTHETIC SOCKETS FOR TRANS-FEMORAL AMPUTEES

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ABSTRACT

The aim of this study is to evaluate the shape change of residual limb by donning the prosthetic socket by using finite element (FE) analysis and analyzing the change of residual limbs.

We obtained the MRI images of residual limbs of trans-femoral amputee. Then, we extracted outlines of each internal tissue (skin, fat, muscle and bone) from MRI images. Plot data extracted from MRI were interpolated to 360 data at an interval of 1degree by using spline approximation. Residual limb and prosthetic socket were modeled using outline data by FE analysis using LS-DYNA (Livermore Software Technology Corporation). From these FE models, it was simulated to transform the residual limb of donning the socket from the shape of residual limb without socket. Also, we were calculated cross-sectional area by counting the number of pixels MRI image.

In this FE analysis, higher pressure value is measured at the posterior of the residual limb. Also, von Mises stress is measured at the posterior of the residual limb and in the distal direction. We suggest that the residual limb of posterior is compressed by the socket donning.

In this analysis of cross-sectional area, it is found that deformation of the stump is different in the difference of the socket. We suggest that the different design method for the prosthetic socket was evaluated quantitatively by FE analysis based on MRI data. Also, it is found that the fat is the most deformation in internal tissue by the socket mounting. We suggest that the fat is most important of an internal tissue in prosthetic socket manufacture.

1. INTRODUCTION

Prosthesis is used to use to restore the original form and function for people are cut the leg. Socket is one of the component of prosthesis plays an important role in connect the residual limb and prosthetic leg. Prosthetic socket is often qualitative and subjective because it is manufactured by hand to suit to the amputees each person. If socket don't fit, it is considered possible to scratch the residual limb, such as pain and abrasions. Therefore, studies aimed at the development of a system supporting production of high prosthesis socket compatible without depending on the experience of the prosthetist has been developed.

From the previous research created a 3D solid model from the CT image of trans-tibial stump after extracting contour of skin and bone (Zheng shuxian, et al., 2005) and created a 3D model from the MRI images of trans-femoral stump (T.S.Douglas, et al., 1998).

Thus, research on the stump shape is the current situation that is not actually reached the concept to the realization of such socket design. Our group aims to build a socket production support system. In the study of our group, it was not possible to simulate the deformation of the stump by the socket donning.

In this study, it was aimed to quantify the change shapes by a socket donning from an MRI image and the simulation analysis using the finite element method.

2. METHOD

In this study, we calculated sectional area of bone and muscle and fat from MRI images of trans-femoral amputee with a socket and without a socket. We evaluated the change of residual limb by comparing the sectional area of socket donning and no donning. Next, we made a 3D model from information of internal tissues of residual limb and we investigated the stress distribution of residual limb of socket donning by finite element method.

Subject is an adult man of trans-femoral amputee. We measured the UCLA socket. Measurement equipment is MRI (Magnetom Symphony Maestro class, SIEMENS). We extracted MRI images using the dedicated software (Voxar3D, Barco). In addition, we used LS-dyna in the finite element simulation (Livermore Software).

Table. 1 Physical characteristics of subject

Age	39
Prosthesis history	7 years
Cutting side	Left
Height	169 cm
Weight	63 kg

3. ANALYSIS

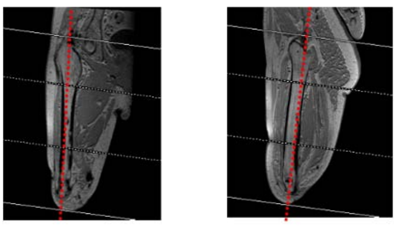
3.1 Shape change of the residual limb

In carrying analyzing the shape of the residual limb of with socket and without socket, it is necessary to match positioning of bone compared the two different conditions. In this study, we used a femur as a reference. We matched the bone to link a top end and a proximal of the convex portion of the femur in the coronal plane, the distal end and a proximal of depression of the femur in the sagittal plane.

Next, we compared the sectional area of socket donning and no donning. In the horizontal plane of MRI image, we defined as the epiphysis at the position that we looked femur for the first time. Then, we obtained MRI images of horizontal plane in interval 1mm. Analysis range was up to just before the tissue of the thigh and the other portion is consolidated. We created binary images from MRI image in this range and calculated the sectional area by counting the number of pixels.

3.2 Simulation using finite element method

We created the 3D model from MRI images that we obtained to the shape change of the residual limb to use for simulation of finite element. We created the 3D model of interval 5mm. We got the coordinates to plot the intersection of contour of each internal tissue by lining for every 10 degrees as a reference to the center of the bone. Then, we interpolated the contour of the internal tissues by approximating the linear by Spline function and created the model.



(a)Coronal plane (b)Sagittal plane

Fig.1 Matching for bone position

4. RESULTS

4.1 The change of the sectional area

It shows the change of the sectional area of the fat of the subject in Fig. 3. The sectional area of socket donning was larger than no donning in the distal from -40 mm to 110 mm. We suggest that fat is extended the distal by socket donning. Also, the sectional area of no donning was larger than socket donning in the proximal from 110 mm to 200 mm. Therefore, we suggest that fat of this area is moved by donning the socket.

On the other hand, it shows the change of the sectional area of the muscle in Fig. 3. The sectional area of -40 mm to 80 mm didn’t change much. Therefore, we suggest that the change of muscle by donning is smaller than the change of fat. However, the sectional area of no donning was larger than socket donning in the proximal from 80 mm to 200 mm. We think that the muscle of proximal is compressed by the socket donning.

It shows the change of the sectional area of the bone of the subject in Fig. 4. In this study, we calculated the concordance rate because we matched for bone position. It was 98.7%. This result is accuracy in this study.

It shows the volume of residual limbs of two different conditions of the subject in Fig. 5. The volume of socket donning was larger than no donning. We conceive that the tissues of residual limbs were moved by donning the socket.

4.2 The simulation using finite element

It shows the pressure distribution that deform the shape of residual limb of socket donning from the no donning in Fig. 6. The pressure occurred in overall residual limb. Especially, the high pressure occurred in the posterior of residual limb. Also, negative value of pressure occurred in end of distal. We suggest that the posterior of tissues is moved by socket donning.

It shows the mises stress distribution that deform the shape of residual limb of socket donning from the no donning in Fig. 7. The mises stress occurred in the posterior and end of distal of residual limb. It is found that fat is extended by socket donning.

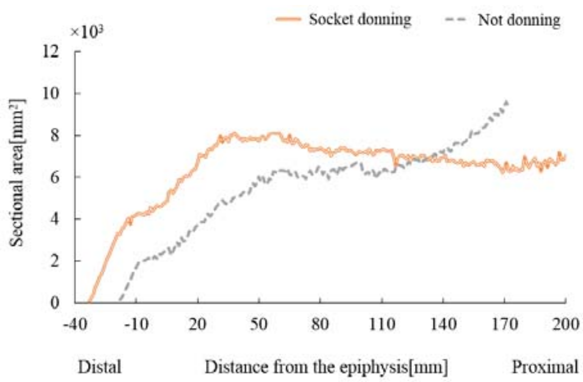


Fig.2 Change of fat’s sectional area

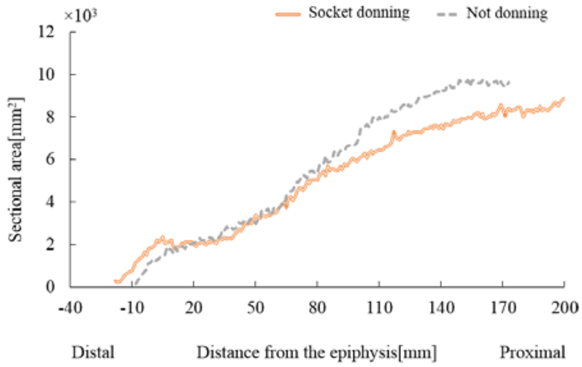


Fig.3 Change of muscle's sectional area

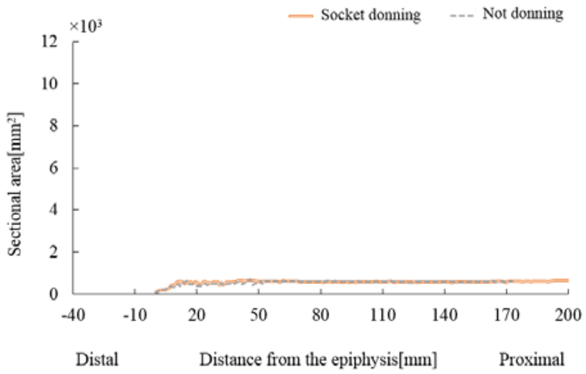


Fig.4 Change of bone's sectional area

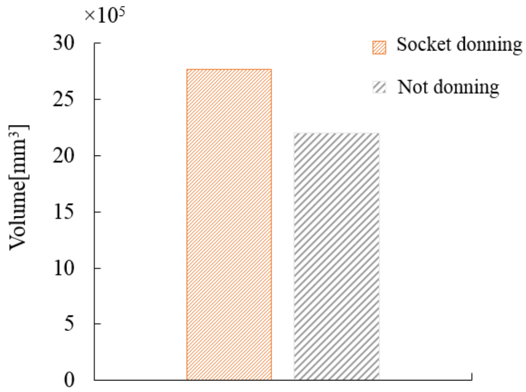


Fig.5 The volume of the residual limbs

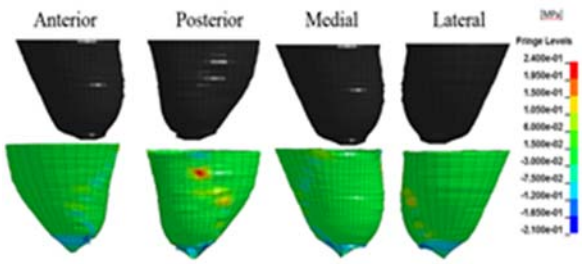


Fig.6 Pressure distribution of forced displacement

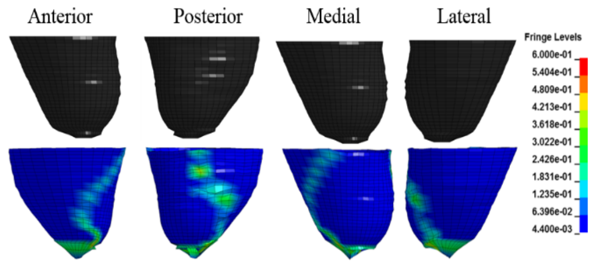


Fig.7 Mises stress distribution of forced displacement

5. CONCLUSION

In this study, we observed that fat is extended by socket donning. Also, we observed fat is more deformed than muscle. Therefore, we suggest that fat is the important tissues in socket manufacturing.

In the simulation using the finite element, high pressure is at the posterior of residual limb and high mises stress is at the distal end. Therefore, we suggest that fat of the posterior is moved to distal by socket donning.

In the future, we'll reconstruct the model of finite element. Prosthetic socket is supported at ischial tuberosity in reality. So, we'll reconstruct the model are of ischial tuberosity and simulate by using this model. In addition, we already had measured two difference sockets. We'll analyze it and scrutinize the differences between sockets.

REFERENCES

Zheng Shuxian, 3Dreconstruction of a residual limb for customizing the design of a prosthetic socket, Medical Engineering & Physics 27, 67-74, 2005

T.S.Douglas, Automatic segmentation of magnetic resonance images of the trans-femoral residual limb, Medical Engineering & Physics 20, 756-763, 1998

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