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DEVELOPMENT OF 3D PRINTED TENDON ANCHOR FOR FORCE TRANSMISSION IN WEARABLE KNEE EXOSKELETON

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ABSTRACT: Tendon Anchor was developed for force transmission in tendon-driven soft wearable robot, which is the only rigid part that is attached to the human body. While developing Tendon Anchor, customization on human body was important feature due to the pressure distribution on human skin while actuating. To satisfy this criterion, fabrication process using 3D printer was established. While actuating tendon, pressure was measured to see the performance of force distribution. The shape of the anchor was optimized based on the measurement and printed with a 3D printer. In development of any tendon-driven wearable soft exoskeleton, anchoring tendon is important for force transmission. 3D printer allows customization of the part for each person which increases the wear-ability of the soft exoskeleton.

INTRODUCTION

Since the world is rapidly aging, the number of elderly is increasing dramatically. Among these people, many of them are experiencing decrease in their physical function and having trouble in walking. In order to assist lower limb movement, some rigid wearable device that assist pelvis movement has been developed [2-3]. Not only for the elderly, but for assistive and rehabilitation purposes, many research groups are developing rigid exoskeleton using linear motors or pneumatic actuators [1,5] and soft exoskeleton using linear motors or pneumatic actuators [4,6].

Tendon-driven knee assisting soft exoskeleton for assisting climbing stair motion of the elderly is being developed. In rigid exoskeletons, force can be transmitted to the actuation target easily. However, in tendon-driven soft wearable robot, force transmission is not an easy issue. In order to handle this issue, this paper presents development of Tendon Anchor. Since the key feature of Tendon Anchor is customization, fabrication process has been established for easy customization and presented in this paper. Due to the direct attachment of Tendon Anchor to body, force acting on the Tendon Anchor has to be well distributed. The Tendon Anchor is designed and fabricated and experiment was performed to see pressure distribution on calf.

FABRICATION PROCESS

Figure 1. (a) Front view of calf and minor axis of oval, (b) Side view of calf and major axis of oval, (c) Tendon Anchor CAD file, (d) Final prototype of Tendon Anchor, (e) Tendon Anchor with subject

When designing the Tendon Anchor, customization is the most important feature. As mentioned earlier in this paper, the Tendon Anchor is the only rigid part in soft exoskeleton and is directly in contact with the human body. When actuating one end of the wire by winding the motor of the soft exoskeleton, the motor is placed above the knee, while the other end of the wire has to be fixed below the knee. This allows the tension of the wire to be directly transmitted to the target motion, the knee extension. The Tendon Anchor was developed to fix one end of the wire on the calf. While actuating the soft exoskeleton, the Tendon Anchor has to be well fixed even all the wire tension is delivered to the Tendon Anchor and pull up to the knee, pressure acting on the calf has to be well distributed to prevent injury. Also, the movement of the Tendon Anchor means loss of tendon actuation which causes the efficiency of the soft exoskeleton to drop. Therefore, customization of the Tendon Anchor is very important to be fixed on calf and distribute the pressure well.

Fabrication process of the Tendon Anchor is divided into 4 stages; measuring stage, initial prototyping stage, revising stage for better customization and final product manufacturing stage. In measuring stage, we take the picture of the front and side view of the calf, as shown in Figure 1(a) and (b). In this stage, to simplify the fabrication process, assumption has been made to treat the cross section of the calf as an oval. Based on this assumption and the pictures, lines will be drawn horizontally and measured and used as minor and major axis of an oval. Ovals will be taken every 5mm apart and staking these ovals every 5 mm will be the inner dimension of the Tendon Anchor and this is presented in Figure 1(c). Also, the offset measurement of center of axis from the

pictures of the calf will be taken into account when designing the Tendon Anchor. Therefore, the Tendon Anchor is not symmetric.

In initial prototyping stage, the first prototype of the Tendon Anchor will be designed with the SolidWorks based on the dimensions of the ovals from first stage. CAD file designed in this stage will be printed using a 3D printer (3DISON, Korea). In the revising stage, the printed Tendon Anchor prototype will be tried on the subject and gap between the subject and the Tendon Anchor will be measured. This error will be revised into the first prototype CAD design and second prototype will be printed. This procedure will be repeated until the Tendon Anchor is customized to fit to the subject. When this customizing process is done, in final product manufacturing stage, final prototype will be fabricated with the 3D printer. Figure 1(d) shows the final product of the Tendon Anchor manufactured with the 3D printer and Figure 1(e) is the picture of the actual subject wearing the Tendon Anchor.

The advantage of this fabrication process is that customization for different user is easy. Also, considering that the Tendon Anchor is small, manufacturing time for each prototype of the Tendon Anchor is fast and this can be done only with a 3D printer.

EXPERIMENT

While actuating the soft exoskeleton, force transmitted to the Tendon Anchor will directly press the calf. In order to prevent injury while actuation, pressure has to be well distributed. To verify the pressure distribution, pressure between the leg and the Tendon Anchor has been measured using pressure plate (Novel, Germany). To compare the pressure distribution, hollow cylindrical Tendon Anchor, not customized, was built and pressure was measured during actuation as a comparison prototype.

While measuring the pressure between the Tendon Anchor and the leg, the tendon was actuated with a tension of 30N. Figure 2(a) shows the pressure distribution of the customized Tendon

Figure 2. Pressure distribution of the Tendon Anchor surrounding the calf, starting from front part on left, to the back part on the right (numbers are in kPa) (a) Pressure distribution of the customized Tendon Anchor, (b) Pressure distribution of the non-customized Tendon Anchor

Anchor and figure 2(b) shows the pressure distribution of the non-customized Tendon Anchor. As shown in figure 2, most of the pressure is loaded at the front and the back, due to the generated moment in the Tendon Anchor.

To see the distribution of the pressure, the maximum pressure and the contact area have to be seen. The maximum pressure of the customized Tendon Anchor was 51 kPa at the back of the calf. For the non-customized cylindrical Tendon Anchor, the maximum pressure was 76 kPa occurred at the front of the calf. Also, higher pressure is applied at the calf in more wide range for the non-customized Tendon Anchor than the customized Tendon Anchor. Contact area is not easy to compare in this pressure measurement experiment. Single pressure measurement unit is not small enough to well identify the contact area. However, there are more actuated pressure cells spread along the diagonal direction in the customized Tendon Anchor than in the non-customized Tendon Anchor, which means more contact area.

By comparing the pressure distribution on the calf, customization does increase the contact area and reduce the maximum pressure acting on human body by one third at 30N actuation. By adding soft polymer or thin sponge would increase pressure distribution by increasing contact area.

CONCLUSION

This paper presented the development and the fabrication of the Tendon Anchor for tendon-driven soft exoskeleton for the knee. The Fabrication process of the Tendon Anchor was established so that customization on different size of calf for different users to be simple by using a 3D printer. Customization of the Tendon Anchor is important because of fixation on calf for force transmission and increased pressure distribution. To verify the effect of customization of the Tendon Anchor, pressure was measured on the customized Tendon Anchor and the cylindrical non-customized Tendon Anchor during actuation. The result of the experiment verified that the pressure is better distributed after customization. In future, pressure acting on the body still needs to be more decreased by increasing the contact area on the body and some additional fabrication method needs to be established.

Force transmission of wire tension to the target actuation point is an important issue in development of the tendon-driven soft wearable exoskeleton. Tendon Anchor, presented in this paper, can suggest one good way to solve this issue.

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