Proposing the Safety Mechanism of Ankle Joint Pushing Machine to Prevent the Over Stretching

Takahiro Yamaguchi¹,∗ and Hideki Toda¹

¹Department of Electrical and Electronic System Eng., Faculty of Engineering, University of Toyama, Gofuku Campus, 3190 Gofuku, Toyama 930-8555 Japan

∗Corresponding author

Keywords: Ankle joint contracture removal, Ankle joint pushing mechanism, Mechanical fuse, Manual start angle adjustment.

Abstract. In this paper, an ankle joint pushing system concerning about the safety mechanism of preventing the over stretching was proposed, and the effect of the safety mechanism was examined in the system. The bending of the ankle joint is an important medical treatment that physical therapist (PT’s) utilize to help their patients recover their ability to walk and to prevent contracture. Since the ankle treatment requires a large amount of force (nearly equal to the subject’s weight) plus precise angle and power control, manual treatment by PTs has not been replaced by mechanical treatment systems. In order to realize the safety mechanism of the ankle joint pushing treatment, the developed system uses two features. (1) The proposed device can control the starting angle of the ankle joint pushing treatment by manual setting. (2) The proposed device can realize the over stretching prevention by proposing mechanical fuse using nylon wire. Above two mechanisms can realize to get shorter the total time of the treatment, and it can release the pushing force to the toe when the setting force is exceeded. The total time of the treatment was shortened to 56% compared with previously proposed our developed automatic ankle joint pushing system, and the developed overload prevention mechanism working force was measured as $36.5 \pm 4.4 \text{N}$ when 58 N nylon wire used. The proposed two set of the safety mechanisms will effectively work to develop ankle joint treatment system.

Introduction

The ankle is an indispensable body part for carrying out daily activities such as walking, running, and sitting and so on. It has ruggedness enough to withstand a heavy load that is received in daily life. If the ankle joint could not work for a long time due to sickness or injury, it will suffer an ankle joint contracting state. As a general ankle contracture prevention treatment, physiotherapists perform the ankle joint stretching by manual therapy (Fig. 1(a)). Manual therapy has advantages of easy pushing of a large force safely to the ankle, easier to deal with the reactions of the patient, but it is necessary to apply the force equivalent to the body weight in order to stretch the ankle joint. In addition, it requires about 20 to 40 minutes of exercise at one time, it is hard work for the physiotherapists.

On the other hand, ankle joint pushing machines have been tried to develop for a long time, however, the difficulty of the precise power and angle control without causing the patient any pain has been prevented the mechanization [1-5]. To realize the mechanization, though it is necessary to guarantee the subject safety, there is a possibility that the device malfunctions due to a human error such as a mistake in an operation of the patient or a system error due to a failure of the machine controller devices [6]. Since these errors occur accidentally, the patient's risk avoidance behavior was delayed, and the patient was injured (Fig. 1(b)).

In this paper, we focused on the manual adjustment mechanism that is a feature of a cardiac massage machine (Fig. 2(b)) similar to rehabilitation machines that have a mechanism to add power to the patient when considering patient safety. The cardiac massager is a mechanism that adjusts the height of the indentation pad on the chest of the patient by manual adjustment, and then repeatedly pushes a certain indentation distance by automatic operation [7]. Since the manual adjustment
mechanism of the device simplifies the automatic system, it easier for the user to control, and would get human error reduced. As shown in (Fig. 2(b)), the manual adjustment mechanism ankle joint pushing machine is proposed in this paper. In addition, in order to avoid unintended accidents, the device that fulfills the role of a mechanical fuse by avoiding danger when malfunctioning was proposed and confirm the effectiveness (Fig. 2(c)).

Figure 1. An important medical treatment that physical therapist (PT's) of bending of the ankle joint utilize to help their patients recover their ability to walk and to prevent contracture, and the demand of the mechanization.

Proposed Manual Adjustment and Prevent Over Stretching Mechanism

Figure 2. shows that proposed ankle joint pushing treatment system including the (1) manual adjustment mechanism and the (2) overload prevention mechanism. The device was made of the base stainless steel (SUS303) stand, (4) bucket, (5) foot rest and actuator system (1) to (3). The (4) bucket was rotated by the actuator system’s pushing movement around the (6) rotation center as shown by a yellow circle. The operation of the device is as follows. After placing the Achilles tendon on the (5) foot rest, manually adjust the length of part (1) and fix the bucket angle to touch on the sole where the load of the ankle begins to be applied. In order to fix the length of the (1) manual adjustment part, there is a fixing knob at the pipe. It is first proposed a mechanism in this paper. After the fixation, the ankle dorsiflexion movement by an (3) automatic linear actuator (Tsugawa electronics Co., KL60-0512, DC12V, 490 N) both ways operation is started.

The advantages of the proposed ankle joint stretching mechanism are here. (1) By placing the Achilles tendon on the foot rest and using the ankle as the pushing axis of rotation, any pain occurs in the ankle and the heel. (2) By using the patient weight when using the device, it is not necessary to fix the patient’s leg and the device with the belt, so pains on the patient’s foot are not applied. (3) As with the cardiac massage machine, since the automated system is simple, it is easy for the user to operate, and system and human errors hardly occur.

As next proposed mechanism, a device that avoids overload accidents when the device malfunctions are proposed ((2) and (c) of Fig. 2). The device is positioned between the (4) bucket and
the (1) manual angle control mechanism, and two square pipes are fixed with fishing nylon line (red line part in Fig. 2(c)). When a pressure equal to or higher than the tension of the line is applied to both ends of the square pipes, the line fixing the square pipes breaks, and the mechanism becomes shorter the overall length. This device mechanically performs the function of the fuse, and even if overload is applied to the ankle at the time of malfunctioning, it is the mechanism to ensure patient safety by shortening the device by cutting the nylon line.

**Experiment**

**Experiment 1: Time Measurement of One-time Ankle Joint Dorsiflexion Stretching Process**

In this experiment, (1) with the manual adjustment mechanism and (2) without the manual adjustment mechanism cases were compared during the period from the patient sitting to the end of one-time of dorsiflexion stretching process of the ankle joint. Setup of the experiment is shown in Fig. 3, and one subject (age 21, adult man) participates in the experiment. The subject was trained the process of the setup and usage of the system, and the total time of the two conditions was measured.

![Figure 3. Setup of one-time ankle joint dorsiflexion stretching experiment.](image)

**Experiment 2: Performance Evaluation of Overload Prevention Device**

In the experiment 2, the performance of the overload prevention device is confirmed. The setup of the experiment is shown in Fig. 4. After the device is positioned on the load cell sensor (Seeed Studio Co., 0-490 N), the force is applied to the device from the upper part by a linear actuator (Tsugawa electronics Co., KL60-0512). The range of the force was changed from 0 to 50 N in the experiment. No. 3 fishing nylon line (YGK Co., No. 3) is used, and the strength of the tension is about 58 N (6 kgf).

![Figure 4. Overload prevention device using fishing nylon line and the experimental setup.](image)
Result

Result 1. Figure 5. shows the result with/without the manual adjustment mechanism (see (1) of Fig. 2). The horizontal axis shows the time [sec] and the vertical axis shows the bucket angle [deg]. Black solid line shows the case of without manual adjustment mechanism. From the subject sitting time of 10 sec, the bucket angle was increasing from 0 deg, and the bucket was contacted with the subject toe about 30 deg. After the contacting, the bucket was pushing the subject ankle joint to about 50 deg until 43.0 sec. On the other hand, the red solid line shows the case of with manual adjustment mechanism. From the subject sitting time of 10 sec, the bucket angle was adjusted by the manual adjustment mechanism to 30 deg with 2.6 sec (area (1)), and 5.5 sec is necessary to fix the knob to maintain the pipe length (area (2)). After fixing the manual adjustment, the linear actuator begins to pushing the toe. To reach the pushing angle 50 deg, it is necessary to 26.2 sec in this case. By comparing 43.0 and 26.2 sec, 16.8 sec total time of one-time ankle joint stretching from sitting time was reduced by the manual setting mechanism. Total time was reduced 1 − 26.2/43.0 = 39 % comparing with without manual adjustment mechanism.

![Figure 5. Result of experiment 1: Total time of one-time ankle joint stretching from sitting time with/without manual adjustment mechanism.](image)

Result 2. Figure 6. shows the result the performance of the overload prevention mechanism (Figure 4.). The horizontal axis is time [sec] and the vertical axis is the output of the load cell sensor [N]. In the five times experiment, the nylon line was cut around 14 sec. The lower graph of the Figure 6. shows five times average and standard deviation (S.D.) of force just before cutting. The average was 36.5 N, and S.D. is 4.4 N when the nylon line strength of tension was 58 N (6 kgf). The strength of tension of the nylon line was reduced 36.5/58.0 = 63 % from the nylon line design standard. Generally, the overload prevention force will be designed for the kind of ankle joint treatments and the condition of the subjects. And by using the proposed mechanism, even if the nylon line was cut during the treatment, the PT could change the nylon line when he restarts the treatment. By changing the nylon line strength (generally nylon line No.), it is possible to change the setting that the PT desired. Considering that the ankle joint could support body weight (about 70 kg = 784 N), the maximum setting of the nylon line would be around 700 N.
Conclusion

In this paper, an ankle joint pushing system concerning about the safety mechanism of preventing the over stretching was proposed, and the effect of the safety mechanism was examined in the system. To realize the safety mechanism of the ankle joint pushing treatment, the developed system has (1) the starting angle adjusting mechanism of the ankle joint pushing treatment by manual setting and (2) it can realize the over stretching prevention by using nylon wire. Above two mechanisms can realize to get shorter the total time of the treatment, and it can release the pushing force to the toe when the setting force is exceeded. The total time of the treatment was shortened to 56% compared with previously proposed our developed automatic ankle joint pushing system. In addition, the developed overload prevention mechanism working force was measured as $4.45 \pm 0.36 \text{N}$ when 58 N nylon wire used. The proposed two set of the safety mechanisms will effectively work to develop ankle joint treatment system.

References


