Movable Ankle Joint Stretching Device by Stabilization of Ankle Position Using Tension Rod Structure

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Abstract. In this paper, we proposed a tension rod mechanism for fixing ankle rehabilitation device, which is formed of the structure tightly stretched between the patients’ sitting chair and floor, and the frictional force of the both ends of it keeps the position of the device during the ankle joint stretching. Generally, physical therapists treat their patients to prevent contracture and to improve walking function, but sufficient rehabilitation therapy does not conducted demanding their labor-tasks because of increase elderly population and shortage of personnel of physical therapists. Therefore rehabilitation robots have been proposed in order to help physical therapist to treat their patients. However, since patients have to transfer their body to the rehabilitation device in order to take mechanical therapy, caregivers every time supports their transfer which cause low back pain when the person who needs ankle rehabilitation uses it. Proposed mechanism allows the device to switch the state of fix/non-fix, so that it does not require transfer assistance by caregiver. Result of experiment based on developed device, proposed system had the function to stabilize within approximately 6 mm the device position during 60 N pushing dorsiflexion stretching.

1. Introduction
The human ankle joint plays a major role in daily activities such as walking, sitting and running. In the case of injury or disease, the ankle joint causes contracture, shortening of a muscle or joint, due to excessive immobility of the joint [1]. Once contracture occur, it is difficult to stretch these ankle joint again, so that it lower the quality and quantity of daily activity after the treatment. Therefore, rehabilitations by physical therapists are helping their patients to prevent contracture and to recover their gait function. One of the traditionally therapy by physical therapists is stretching patient’s ankle joint by pushing patient’s foot with hand. These treatments, however, does not conducted sufficient because most of physical therapist have high demanding labor tasks.
Thus, many research groups have been developed robot-aid rehabilitation device in order to support physical therapist tasks [2][3]. However, most of the previous ankle rehabilitation devices have a large mechanical body, which requires extensive setup space and transfer assistance by caregivers. This large mechanical structure is because the ankle stretching devices must have a mechanical stiffness against the reaction force generated during foot sole pushing process in order to prevent deviation of the device rotation axis [2]. Thus these devices connect ankle pushing mechanism to bed or chair in order to fixed ankle pushing parts, so that this integrated device require large space except for the ankle pushing function. In addition, more significant problem is transfer assistance which cause low back pain. This is because caregivers take heavy physical burden to support the patient’s weight to move the patients to the rehabilitation device. In fact, some research reported that the risk of back pain is increased due to transfer assistance in nursing home care facilities [4].

In this study, to address these problems, we proposed tension rod structure for fixing ankle rehabilitation device, which does not require transfer assistance.

Section 2 explains the developed ankle stretching device with proposed tension rod structure. In section 3 and 4, we confirm the function to stabilize the device position by developed equipment, and report results, respectively. Finally, we conclude in section 5.

2. Method

2.1. Developed Ankle Joint Stretching Device.
Figure 1 shows developed ankle joint stretching device. The mechanical structure of this device is functionally divided into ankle joint pushing system and the device fixing system. Both pushing of the ankle joint and fixing of the device system can be moved by the controller with patient's hand.

2.2. Ankle Joint Pushing Mechanism.
Figure 2 shows ankle joint pushing mechanism, which is composed of (a) a footplate, (b) two DC motors (Changzhou DAIWEI Motor Co. Ltd, Model: JSX 1622-31 ZY) and (c) a footrest. (a) The footplate can be rotated dorsiflexion/plantar flexion direction by (b) the DC motors which mounted on both sides of the footplate rotation axis. (c) The footrest is made of soft sponge, and the foot sole of the patient placed on the footrest is pushed by rotated (a) the footplate. One load cell is embedded in (a) the foot plate in order to measure the pressure applied to the foot sole.
Figure 2. Mechanism of the ankle joint pushing.

The foot sole of the patient is pushed by the foot plate rotated by DC motors.

Figure 3. Mechanism of the proposed tension rod structure which stable the device rotation axis by the structure between patient's sitting chair and floor.

Figure 4. Mechanical movements of the tension rod structure. This movement allow the device to switch the state of fix and non-fix.
2.3. Proposed Tension Rod Mechanism.

Figure 3 shows the overview of the tension rod structure developed as fixed system for the ankle joint stretching device. This system is formed of a bar tightly stretched between the chair and floor (highlighted in green in fig3), and the frictional force $F_d$ of the both ends of the bar prevents the position of the device from being displaced by reaction force $F_r$ generated by dorsiflexion stretching. Fixing system movement of the developed device is shown in figure 4. This system is consisted of (a) an electric pantograph jack, (b) two casters with spring and (c) a stainless plate.

The tension rod structure of the developed device is constructed as follows; First, (a) the pantograph jack adjusts the length to the height of the chair which patient sitting, and then transmits the pressure from the lower part of the seating face of the chair to the base plate of the device. When pressure is applied, the position of the base plate is down because (b) the spring of the caster is shrunk. Finally, (c) the stainless plate which attached lower part of the device lower part is pressed the floor, so that tension rod stricture formed on the patient’s sitting chair and the floor. As show in figure 4, since the proposed system can change the state of fix and non-fix by controlled (a) the jack, this system does not require to transfer to the stretching device before/after using it. In addition, this system can adjusts the force of the ends of tension rod structure (Fig.4, red arrow), which force is measured by load cell embedded in the top of the structure.

![Figure 5](image)

**Figure 5.** Set up of the motion capture system to measure patient's ankle joint position of the subject’s and ankle rotation axis of the device.

3. Experiment

Experiment 1: The positional relationship between the ankle joint and device rotation axis during ankle joint stretching process. In this experiment, the ankle joint and device rotation axis movement trajectory during the foot sole pushing process is confirmed by using the proposed system with/without tension rod structure. One subject (age 24, adult man) is participated in the experiment. As shown in Figure 5 the trajectories were measured by motion capture camera (Flex 3, 0.3 MP (640 × 480, 100 fps), OptiTrack) which film reflective markers attached subject's ankle joint and device rotation axis. The pressure force of the end of fixed part is coordinated 150 N. The maximum pressure force of the foot is controlled under 60 N during the dorsiflexion stretching process, and if reach 60 N, foot plate is stopped 20 sec and then it is rotated planter flexion.

Experiment 2: The deviation of the device position against fixed pressure. Experiment 2 is conducted for checking the stable fixation of the device against the pressure force of the both ends of tension rod structure during the dorsiflexion stretching. One subject (age 24, adult man) is participated in this
experiment. The movement of the device rotation axis is measured as well as experiment 1. The deviation of the device is measured 5 times adjusting pressure force of the end of fixed part to 0, 50, 100 and 150 N, respectively.

**Figure 6.** Result of experiment 1: Transition of the positional relationship between ankle joint and device rotation axis during the ankle joint stretching process.

**Figure 7.** Result of experiment 2: The deviation of the device rotation axis against the pressure force of the fixed part (N = 5)
4. Result

Result of experiment 1. Figure 6 shows the positional relationship between ankle joint and device rotation axis with/without the tension rod structure during the foot sole pushing process by developed device. Without the tension rod structure, the subject’s foot drops from footrest as the device is leaved horizontal direction from the subject. Contrary to the without fixing, with the proposed tension rod structure, the positional relationships was stable at \((x, y) = (-7.5 \pm 2.4, 5.9 \pm 2.5)\) mm. Since the displacement between the subject’s ankle joint and device rotation axis was approximately only 2.5 mm, this result indicate the proposed tension rod structure has the capability of the fixed function of the stretching device.

Result of experiment 2. Figure 7 shows the displacement of the device from the initial position against the pressure force of the top of device fixed part. Less than 100 N of the fixing force, the displacement and its variation was related fixing force. On the other hand, 100 N or more, the displacement was the approximately 5.8 mm, and its variation does not depend on fixing force. This stationary displacement is considered caused by mechanical distortion of the devise, not the low pressure force of the tension rod structure. This result also supports the fixed function of the tension rod structure as well as result of experiment 1. In addition, it reveals the fixed function is appeared when the fixing pressure is over 100 N.

5. Conclusion

In this research, we have developed ankle joint stretching device by using tension rod structure, which mechanism allow the device position to fix by the frictional force of the structure between the floor and chair. In addition, this mechanism is able to switch the state of fix/non-fix, so that patient’s does not require transfer to the stretching device. The experiment 1 and 2 based on motion analysis has indicated that the tension rod structure is functioning to fix the position of the device against the reaction force \(F_r\) generated ankle pushing process. The proposed tension rod mechanism will be useful for developing a device that does not require transfer assistance to add a large force in order to the ankle pushing.

References

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