Development of a non-actuated wearable device to prevent knee buckling

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***Abstract*—Wearable devices are required not only for assisting the gait motion of the elderly but also for improving the gait stability. Thus, a non-actuated wearable device was developed in this study. The device intended to prevent knee buckling by supporting knee using string placed along with body surface. In order to arrange the force pattern, a string length adjustment mechanism was developed. The experimental result suggested that this wearable device could successfully generate knee extension torque which mitigated knee buckling.**

***Index Terms*—wearable device, knee buckling, gait assist**

I. Introduction

Decrease of walking ability of the elderly owing to aging increases the risk of fall. Recently, many wearable devices intended to improve the walking ability of the elderly [1] because fall sometimes compelled the elderly to be a nursing care [2]. Thus, we previously developed a wearable device which could generate and arrange the pattern of assistive torque without actuator using strings placed along with body surface [3]. Now, assist devices can be classified into following two types, the actuator type and the supporter type. Whereas the actuator type can generate the large torque and adjust the assist pattern, it tends to become heavy and it's attach process becomes complex. On the other hand, the supporter type is very light and easy to attach. However, the assist of it is constant or passive in addition to small assist force. Our device aims to resolve drawbacks of them. The features of them are shown in the TABLE 1. In this study, knee buckling, which was a factor of fall of the elderly, was focused. The knee buckling, which is sometimes caused by insufficient knee extension torque, causes gait instability especially when loading weight on knee during support phase. To prevent knee buckling, a device, which exerted the knee extension torque only during stance phase, was developed.

II. Development of the wearable device

Overview of the developed device is shown in Fig. 1. This device consists of strings and string guides fixed on the body surface. Tension force of string applies torque to knee joint through string guides. When a wearer steps on the foot switch during stance phase, the length of string is fixed. The string generates knee extension torque, which prevents knee buckling, when the knee begins to flex through the increase of string tension. On the other hand, during swing phase, the foot switch doesn't fix the string length. Thus, the string length becomes longer owing to the extension of spring and doesn't prevent knee flexion.

By arranging the position of string guide, path of strings can be tuned. Because the pattern of assistive torque was determined by the layout of string path, a simulator, which estimated the pattern of assistive torque and optimize the position of string guide, was developed. The optimization was based on sequential quadratic programing and evaluation index was designed to maximize the knee extension torque during support phase.

III. Experimental condition

Experiments were performed with the permission of the institutional review board of the Nagoya University. Two healthy young males participated in the experiment. The following experiments were conducted in order to verify the effect of the developed device.

TABLE I
Type of walking assist device

Type	Actuator	Supporter	Our device
Assist power	◎	×	○
Assist pattern	Variable	Constant	Variable
Weight	×	◎	○
Removal performance	×	◎	○

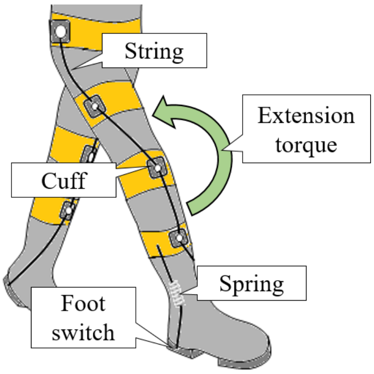

Fig. 1. Overview of the device

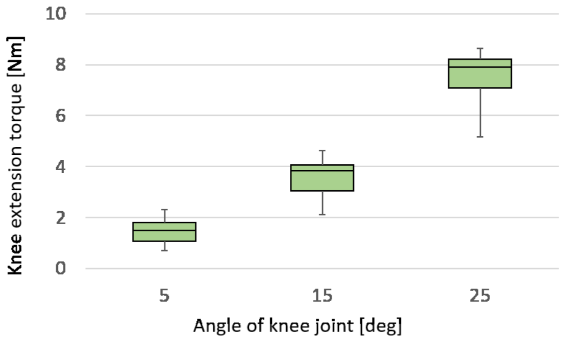

Fig. 2. Knee extension torque

A. Knee buckling prevention effect verification experiment

An experiment was conducted in order to estimate the knee extension torque to the knee buckling in the angles of the knee joint (5, 15, and 25°). At first, 5 N tension was applied to the string in an upright position. Then, the subject bended by the designated angle and the sting tension was measured by the strain gage five times at each angle.

B. Walking experiment

The developed device controls the string length using the foot switch and spring. Thus, an experiment was designed to verify the influence of spring coefficient on knee joint by using different springs (0.36, 0.49, 0.57 N/mm). To prevent strings to slack, small tension was applied to the string in the upright position. The subject walked on the treadmill for three minutes with self-selected speed. Angle of each joint was measured by a motion capture system (MAC 3D Systems, Motion Analysis).

IV. Experiment Result

A. Knee buckling prevention effect verification experiment

The knee extension torque is shown in Fig. 2. It was clear that the knee extension torque increased as the knee flexed. The knee extension torque of 25° became approximately quarter as volume as the maximum knee extension torque of normal adults during support phase [4]. These results suggested that the device exerted knee extension torque which probably prevented knee buckling.

B. Walking experiment

The pattern of knee angle is shown in Fig. 3 and the string tension is shown in Fig. 4. According to Fig. 3, compared to no spring, weak springs increased knee angle during swing phase. However, it should be noted that knee angle under such conditions became smaller than that of normal walking, which was the gait motion without using the assist device. This was because the spring applied extension torque to knee joint during swing phase. In addition, Fig. 4 suggested that the string did not slack during the walking because the tension of each spring does not go below the pre-tension. Thus, the result suggested that the spring with a small spring constant was sufficient to keep string length.

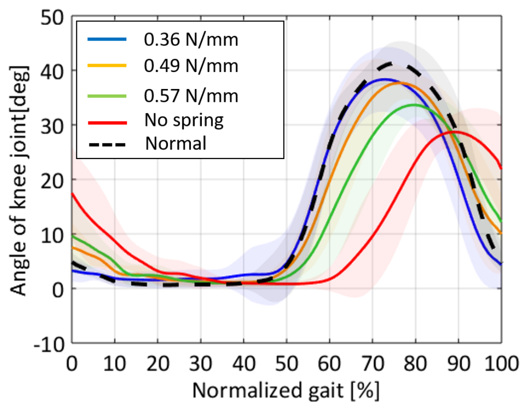

Fig. 3. Angle of the knee joint

V. Conclusion

A non-actuated gait assist device, which intended to prevent knee buckling, was developed and tested in this study. The result of knee buckling prevention experiment suggested that the device successfully exerted knee extension torque, which probably prevented knee buckling, during stance phase. Furthermore, the walking experiment suggested that the string did not slack during walking, which was necessary to apply knee extension torque during stance phase, using the foot switch and

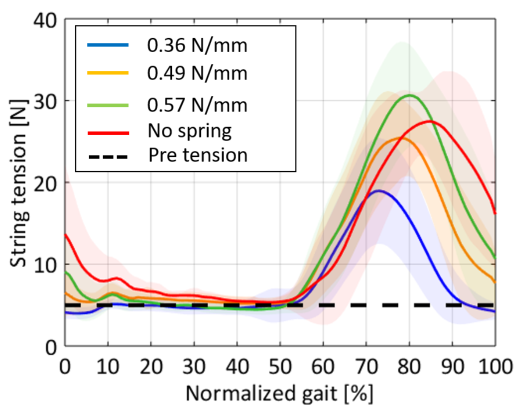

Fig. 4. String tension

spring although the device slightly affected the angle pattern during swing phase.

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