Alignment of anatomical flexion axis when using one-degree-of-freedom ankle stretching exerciser

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***Abstract*—Most of the existing ankle stretching machines have one degree of freedom, whereas the human ankle has three degrees of freedom of motion. We observed the behavior of the anatomical flexion axis when the ankle was stretched in the dorsiflexion direction by using an exerciser with one degree of freedom for flexion. For this purpose, under several levels of heights and external/internal rotation angles, we monitored the difference in the angle between the anatomical axis of the ankle and the flexion axis of the exerciser. When the foot was placed on the exerciser in a slightly internally rotated state, the inversion angle of the ankle's anatomical axis was nearly aligned to that of the exerciser's flexion axis in the dorsiflexed posture. In contrast, when the foot was placed in a slightly externally rotated state, the ankle's anatomical axis and exerciser's flexion axis nearly aligned in terms of the internal/external rotation.**

***Index Terms*—rehabilitation, ankle, foot, stretching**

I. Introduction

Stretching is an important exercise for treating ankle contractures. Stretching over a long period of time is expected to improve the range of motion of the ankle joint and prevent further development of the contracture. However, for some patients, effectively performing stretching independently at home is difficult. For such patients, automatic ankle stretching machines are effective; nonetheless, such machines are not commercially available.

The anatomical axis for ankle flexion is defined by the line connecting the medial and lateral ankles, which is slightly inverted and externally rotated [1] as shown in Fig. 1. Furthermore, the position and posture of the anatomical flexion axis changes as the ankle flexes in the dorsi/plantar direction [2]. Most of the existing ankle stretching machines have one degree of freedom, normal to the sagittal plane [3]–[6], whereas the human ankle has three degrees of freedom [7]. An ankle stretching machine with multiple actuated degrees of freedom was developed in [8], [9]. Few studies have discussed this difference in the degrees of freedom of rotation axes between such machines and the human ankle. There is a common belief that the flexion axis of an ankle stretching machine and that of the ankle joint should match for effective stretching [10]. However, few studies have reported the net difference in the postures of the two flexion axes when the ankle is stretched using a one-degree-of-freedom dorsiflexion machine or exerciser.

In this study, we observe the relationships between an exerciser's flexion axis and the anatomical flexion axis of the foot when the ankle joint is stretched by an exerciser with one degree of freedom. Furthermore, we monitor the changes in these relationships according to the relative position and direction between the foot and the exerciser. As a pilot study, we report the case of one healthy participant.

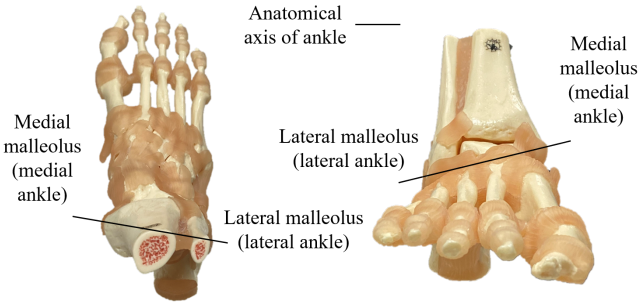

Fig. 1. Anatomical axis of ankle is defined by a line connecting the lateral and medial malleoli. This axis is slightly inverted and externally rotated.

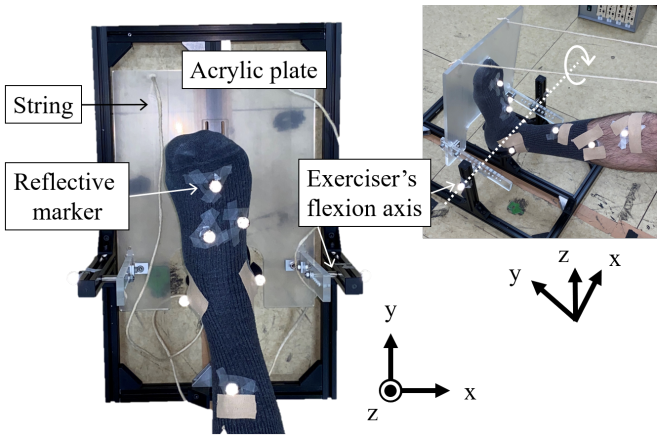

Fig. 2. Ankle exerciser. The forefoot was placed on an acrylic plate that revolves around the exerciser's flexion axis. The heel was placed on a heel holder cup.

II. Method

A. Equipment

Fig. 2 shows the foot exerciser used in the experiment. This exerciser was composed of aluminum frames and an acrylic plate that revolves around the exerciser's flexion axis. A string was fixed to the tip of the aluminum plate. The user placed his/her heel on the heel holder and pulled the string to revolve

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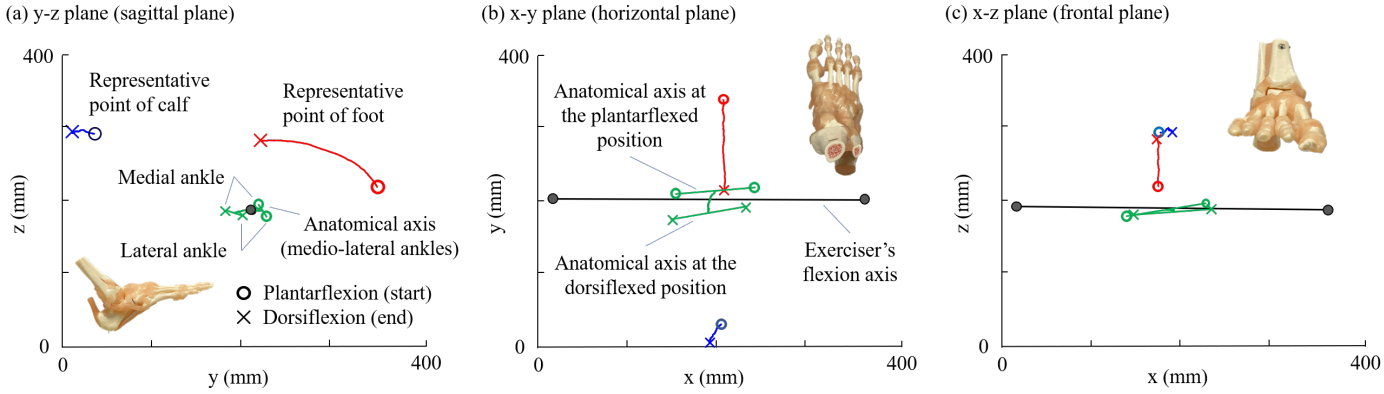

Fig. 3. Trajectories of the representative points of calf (blue) and foot (red) and the anatomical center of ankle. The circles indicate the initial position, and the crosses indicate the dorsiflexed position. Green lines are the anatomical rotation axes for the initial and dorsiflexed positions. These line segments connect the medial and lateral ankles. (a) y–z plane. (b) x–y plane. (c) x–z plane.

the acrylic plate about the exerciser's flexion axis, thereby dorsiflexing the foot. The relative position of the ankle joint and the exerciser's axis in the z direction could be adjusted in 2-cm increments.

The motions of the foot and calf were monitored using an optical motion capture system (MAC 3D system, Motion Analysis Corporation, U.S.). As shown in Fig. 2, we used 10 reflective markers: three each for the calf and the foot, one each for the medial and lateral ankles, and one each for the two ends of the fixed exerciser's flexion axis.

B. Task

One male participant, who provided an informed consent, sat on a chair with the right knee fully extended. He relaxed his lower limbs with the ankle in the naturally planterflexed state initially and then slowly pulled the exerciser's string until he felt his calf muscles stretched. He repeated this task three times for each condition defined by the combination of the relative height and external/internal-rotation levels between the foot and exerciser. Three levels were set for the relative height of the foot and exerciser. When the exerciser's rotation axis was "high," the anatomical center of the ankle was nearly coincident with the flexion axis of the exerciser. Under the "middle" and "low" conditions, the exerciser's flexion axis was located 2 and 4 cm below the anatomical center at the initial position of the task, respectively. Furthermore, three levels of the external/internal rotation angle of the foot were adopted. At each of these three levels, the foot either faced the front, was slightly externally rotated, or was internally rotated.

III. Results

We calculated the central positions of the three markers for the calf and the foot. Fig. 3 shows the example of the trajectories of these central positions, the center of anatomical flexion axis, and the exerciser's flexion axis. We investigated the internal rotation angle and inversion angle of the anatomical rotation axis when the ankle was dorsiflexed using the exerciser. These angles were defined between the anatomical rotation axis and machine's flexion ankle. Fig. 4 shows these angles at the initial planterflexed position and the final dorsiflexed position for each condition. When the foot was externally rotated at the plantarflexed position, the anatomical flexion axis was nearly aligned with the exerciser's flexion axis in terms of the external/internal rotation angle (middle in Fig. 4 (a)). When the foot was internally rotated at the plantarflexed position, the anatomical flexion axis was nearly aligned with the exerciser's flexion axis in terms of the inversion angle (right in Fig. 4 (b)). The height level exhibited virtually no effect on the results; however, these results are not conclusive because of the small sample size.

IV. Conclusion

We investigated the alignment of the flexion axes of the human ankle and an exerciser when using an ankle stretching machine. It was demonstrated that either the rotation or inversion angle could be aligned between the two flexion axes by changing the relative external/internal rotation angle between them.

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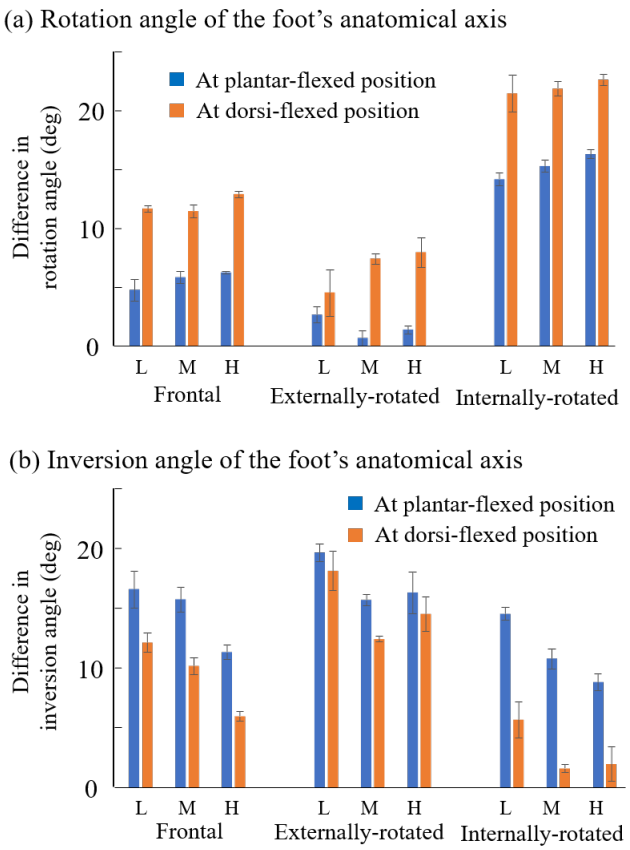

Fig. 4. Rotation angle (a) and inversion angle (b) at the initial planterflexed (blue) and final dorsiflexed (orange) positions for each condition. L, M, and H indicate the relative height of the ankle; they are low, middle, and high, respectively. Error bars represent standard errors.

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