The effects of ankle bracing on motion of the knee and the hip joint during trunk rotation tasks

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Abstract

Background. The use of prophylactic ankle braces is common during athletic activities since the ankle is one of the most commonly injured joints. Past studies have focused on the effects of ankle braces on ankle movement restriction, preventing injuries, proprioception, balance and athletic performance. However, the influence of ankle restriction on other joints has not been studied. The constraint of ankle movement may lead to an increased loading on the knee joint, which could be a potential risk of knee injuries during athletic activities. The primary goal of the current study was to determine quantitatively the effect of an ankle brace on the knee axial rotation during two different trunk turning tasks.

Methods. Ten healthy subjects performed trunk turning movements while standing on one leg: turning sideways to catch a ball and turning sideways to touch a target with the shoulder. The tasks were performed with and without an ankle brace worn on the supporting leg. The trunk axial rotation in reference to the floor and three dimensional joint angular motions of the ankle, knee and hip were determined.

Findings. The use of an ankle brace resulted in reduced trunk axial rotation during the ball catching tasks, and increased knee axial rotation during the target touching tasks.

Interpretation. The results of this study showed that the effect of the ankle brace on the knee axial rotation depended on the context of the tasks performed. Under situations that required forceful trunk turning movement while standing on a single leg, the ankle braces may cause an increase in the knee axial rotation indicating higher risk of knee injury.

Keywords: Joint injury; Knee motion; Ankle brace; Kinematics; Trunk rotation

1. Introduction

Ankle injuries, especially lateral ankle sprains, are common in sports activities (Garrik, 1977). The use of prophylactic ankle bracing in sports has increased greatly in recent years (Verhagen et al., 2000). While ankle bracing provides effective constraint for the ankle joint to reduce the risk of ankle sprain, there is a potential for increased risk of injuries in other joints due to the use of ankle bracing. The use of a rigid ski boot on the foot and ankle joint has been shown to be associated with increased knee injuries during skiing (Tuggy and Ong, 2000). It is not clear yet how an ankle brace, which is less stiff than a ski boot, may affect the knee joint during sports activities.

Past studies on ankle bracing have demonstrated its effectiveness in constraining ankle motion, especially eversion and inversion (Siegler et al., 1997; Nishikawa et al., 2000). Research on the effect of ankle bracing on joint proprioception and postural control has been controversial (Baier and Hopf, 1998; Barkoukis et al., 2002; Bennel and Goldie, 1994). The influence of ankle bracing on athletic performance is also under debate.
Pienkowski et al. (1995) and Verbrugge (1996) reported no significant differences in speed and agility between ankle braced and non-braced groups. Mackean et al. (1995) and Burks et al. (1991), however, demonstrated significant impairments in athletes wearing various types of ankle supports. Studies have also shown that different adaptation strategies may be used by subjects in performing various functional tasks while wearing an ankle brace (Caillou et al., 2002; Cirstea and Levin, 2000; Hollands et al., 2001; Steenbergen et al., 1995). However, there have been no studies that examined the effect of an ankle brace on the motion of the knee and hip joints during functional activities.

The classical mechanism of a knee injury involving the anterior cruciate ligament (ACL) is associated with a varus or valgus stress combined with a rotational loading during activities of turning and twisting (Noyes et al., 1980; Noyes et al., 1983). Ankle bracing primarily constrains the inversion/eversion of the ankle, and increases the resistance for axial rotation as well. By examining the change of knee motion, one can estimate the change of stresses in the connective tissues around the knee joint due to the use of an ankle brace during functional activities. The change in knee motion associated with the use of an ankle brace, however, may depend on the adaptation strategy used by the subject. Cowling and Steele (2001) showed significant differences in lower limb muscle-activation patterns during abrupt landing after catching a chest-high passing object compared to no catching. The difference in muscle activation patterns indicated task-dependent movement strategies. To examine the effect of an ankle brace on knee motion during trunk rotation, different task-dependent adaptations needs to be considered.

The purpose of this study was to evaluate the effects of an ankle brace on the motions of the knee joint, especially axial rotation during two different trunk-turning tasks. The open task was to turn and catch a tossed ball. The closed task was to turn the trunk to a certain degree of axial rotation till the shoulder of the subject touched a fixed target. These two tasks were designed to examine task dependent adaptation strategies of the subjects and their consequences on the motions of the ankle, knee, and other body segments.

2. Methods

A total of 10 healthy young subjects (4 males, 6 females, mean age of 26.4 years) participated in this experiment after they signed the informed consent approved by the Institutional Review Board of the University of Kansas Medical Center. The exclusion criteria included: (1) previous experience with the use of ankle braces, (2) any history of severe or acute ankle sprain and or ankle instability, (3) any knee, hip, or back pathology that would make performing the task difficult, and (4) any known balance disorders.

2.1. Instrumentation and experimental set-up

Prior to testing, each subject was explained the procedure of the experiment. A three dimensional motion analysis system (OPTOTRAK, Northern Digital Inc., Waterloo, Ontario, Canada) was used to measure motions of the ankle, knee, and hip joints during the tasks. Three small plastic pieces, each with three-infrared light emitting diodes (LEDs) were attached on the subjects’ skin on the right shank, thigh, and pelvis using double stick tape and a Velcro strap. The skin area on each body segment with a relatively small amount of soft tissue movement during the task was chosen for each plastic piece. The plastic pieces were placed on the posterior–lateral surface of the shank below the gastrocnemius’ belly, the posterior–lateral aspect of the hamstring of the thigh superior to the popliteal fossa area, and the palpable area of the sacrum on which the plastic piece has specially designed shape so that the posterior superior iliac spine (PSIS) was exposed for digitization. The subject wore low-top athletic shoes. Another plastic piece with three LEDs was taped on the shoe at the area of lateral calcaneous behind the lateral maleolus. There was no need for a precise location of this plastic piece. Markers on these plastic pieces were used to establish measurement frames for each body segment. The anatomical co-ordinate system for each body segment was determined through digitized bony-markers described in the following.

Using the tip of a digitizing probe of the OPTOTRAK to touch the skin of bony landmarks, 11 bony-marker points  (Fig. 1) on the lower limb and low back were digitized: (1) tip of lateral malleolus, (2) tip of medial malleolus, (3) tibial tuberosity, (4) the most lateral point on the border of the lateral tibial condyle, (5) the most medial point on the border of the medial tibial condyle, (6) the most lateral point on border of lateral femoral epicondyle, (7) the most medial point on the border of the medial femoral epicondyle, (8) right anterior superior iliac spine (ASIS), (9) left ASIS, (10) right posterior superior iliac spine (PSIS), (11) left PSIS.

These marks were chosen based on recommended standard for joint anatomical co-ordinate system by the International Society of Biomechanics (ISB) (Wu, 2002). For the ankle joint, the first 5 digitized bony-marks were used to establish segmental anatomical coordinate systems for the calcaneous and the tibia (Wu, 2002). As described in details in the cited reference, the digitization for these five bony-marks was referenced in the tibia measurement frame. A fixed relationship between the anatomical coordinate system and the measurement frame for the tibia was directly established. However, such a fixed relationship between the
anatomical coordinate system and the measurement frame for the calcaneous was later established after recording of ankle neutral position as described later. For the knee joint, the anatomical coordinates for the tibia and the femur was built using the center of the hip, digitized points #6 and #7 according to the procedure described in the Grood and Suntay (1983). The middle point of digitized points #10 and #11 was taken as the sacrum bony-mark. A regression model (Vaughan et al., 1992) was used to estimate the center of hip joint based on the coordinates of two ASIS points (#8 and #9) and the sacrum. For the hip joint, additional anatomical coordinate system for the pelvis was established in accordance to the ISB standard (Wu, 2002) with the help of two digitized ASIS bony-marks and the sacrum bony-mark. Fixed relationship between the anatomical coordinate system and the measurement frame was established for each body segment.

An additional plastic piece with also three LED’s was placed on the subject’s back (Apex of thoracic spine). Three separate LEDs were fixed at three corners of the standing floor. These six LEDs were used to register the rotation of the upper trunk relative to the floor during tasks performed by the subject.

2.2. Tasks for subjects

Two types of tasks were performed: (1) open task (OT) and (2) closed task (CT). In the OT task, the subject was instructed first to stand steady on one leg (right leg) on the stable surface with the knee slightly flexed. The left leg was flexed in a comfortable position. The subject was asked to face forward holding on to a supporting bar placed in front of him (Fig. 2A). Once a stable balance was attained, the subject would notify the testers. The data recording would start simultaneously
with a verbal signal “go”, given to the subject. Upon the verbal command the subject released their hands and turned the trunk to the left in order to catch, with two hands, a rubber ball tossed by one of the testers from the left side about 3 m away from the subject (Fig. 2B). In the CT task, the experimental procedure was the same as in the OT task, except that the subjects were instructed to turn the trunk to the left in order to touch a target with their shoulder placed in front of them while keeping the arms relaxed by the sides of the body (Fig 2C). The target was a wooden stick fixed on a frame and was aligned with the clavicular notch with the subject standing erect on a single leg facing forward. It required about 70° of trunk axial rotation for the subject to touch the target. The subjects were randomly instructed to perform 10 OT and CT movement trials with and without an ankle brace (Active Ankle™ by Active Ankle Systems, Inc. Louisville, Kentucky, USA). In both tasks, the experiment would start with a neutral position recorded for 1 s at 200 samples while the subjects stood on one leg naturally with their hands holding a supporting bar placed in front of them for stabilization.

2.3. Data processing and analysis

Three-dimensional coordinates of all markers recorded during tasks were processed using a computer program developed in the laboratory to reconstruct 3D joint motions of the ankle, knee and hip joints including flexion/extension, adduction/abduction, and internal/external rotation. These motions were defined according to ISB recommendations (Grood and Sunay, 1983; Wu, 2002). The axial motions of the trunk relative to the floor were also computed from three-dimensional coordinates of trunk markers. Peak trunk axial rotation and peak values of motion variables at the ankle, knee, and hip joints around the time point for peak trunk axial rotation were determined. For each motion variable, averaged value of the peak values over 10 trials of the same task (OT or CT) and same condition (brace or no brace) for each subject was used in the data analysis. A paired t-test was conducted on the primary variable of the study, the knee axial rotation, to determine the effect of ankle bracing during performance of each of two tasks. The trunk axial rotation was also tested using the paired t-test to examine the difference between two conditions, with and without an ankle brace, and to see whether this difference depended on the task.

3. Results

The curves of trunk axial rotation showed a bell shape pattern indicating the subjects turning to the target and then back to the starting position during all tasks (Fig. 3). For a typical subject shown in Fig. 3, the trunk axial rotation during the OT tasks showed smaller amplitude with the ankle brace compared to no ankle brace, while the knee axial rotations were
similar in both conditions. However, the amplitude of knee internal rotation during CT task was greater with the ankle brace than that without the ankle brace while the trunk rotated axially the same angles.

For the subjects studied, during the OT tasks the use of an ankle brace significantly \((P < 0.05)\) reduced the group mean value of trunk axial rotation from 67.55° (SD, 5.9°) to 61.59° (SD, 10.3°) (Fig. 4). There was no significant change in knee axial rotation between an ankle brace 16.8° (SD, 12.9°), and no ankle bracing 20.9° (SD, 8.9°) used. In contrast, for CT the trunk axial rotation was controlled well by all subjects to be similar with and without the ankle brace, with group mean values of the trunk axial rotation of 69.62° (SD, 5.2°) and 71.49° (SD, 4.5°), respectively (Fig. 5). However, the knee internal rotations showed a significant \((P < 0.05)\) increase from 14.86° (SD, 9.4°) to 21.34° (SD, 12.13°) with the use of an ankle brace.

Group mean values for other non-focus variables were reported in the following without statistical analyses. During OT tasks, both the ankle and hip axial rotations decreased with the use of the ankle brace (from 8.86° (SD, 5.7°) to 5.84° (SD, 4.7°) for the ankle joint, and from 24.54° (SD, 6.5°) to 20.83° (SD, 8.3°) for the hip joint). During CT tasks, the axial rotations of the ankle and hip joints were similar without and with the ankle brace (5.79° (SD 5.7°) and 6.8° (SD, 8.4) for the ankle joint and 26.9° (SD, 5.6°) and 27° (SD, 6.5°) for the hip joint). In both OT and CT tasks, the ankle eversion decreased when the ankle brace was worn: from

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Fig. 3. Rotational motion of the trunk and knee joint recorded from one subject with (dotted lines) and without (solid lines) brace during the open and close tasks.

Fig. 4. The group mean values of the axial rotations of the ankle, knee, hip and trunk during open tasks (mean and standard error of the mean). Statistical analysis was conducted for axial rotations at the knee and trunk only. The difference in trunk axial rotations between conditions of with and without the ankle brace was significant (+).

Fig. 5. The group mean values of the axial rotations of the ankle, knee, hip and trunk during close tasks (mean and standard error of the mean). Statistical analysis was conducted for axial rotations at the knee and trunk only. The difference in knee axial rotations between conditions of with and without the ankle brace was significant (+).
5.37° (SD, 1.9°) to 3.27° (SD, 2.1°) during OT tasks, and from 5.13° (SD, 3.6°) to 3.71° (SD, 2.9°) during CT tasks.

4. Discussion

During trunk turning movements standing on a single leg, the study subjects demonstrated task dependent patterns of joint motions in the lower extremity in response to an ankle brace. During the open tasks in which the goal was to catch the ball passed from left side using two hands, the subjects showed a significant decrease in the trunk axial rotation when wearing an ankle brace compared to no brace. The subjects successfully completed all trials with reduced trunk axial rotation probably through increased motions in the upper extremity, such as the shoulder and elbow joints. The decreased trunk axial rotation could be the result of decreased internal rotation in the hip and ankle joints associated with the use of ankle brace. A strategy used by the subjects seems to reduce or control the motion or stress in the lower extremity while compensating the loss of trunk axial rotation with increased motion in the upper extremity. However, in the closed tasks the strategy used by the subjects was different. During the closed task, the subjects were forced to rotate the trunk to a certain degree in order to reach a target with their shoulders. There was no way to compensate for the loss of motion at the ankle joint due to the ankle brace by the upper extremity during such task. Therefore, the subjects were forced to increase the internal rotation of the knee in order to complete the tasks.

The primary question for this study is whether or not the ankle brace may increase the angular motion of the knee joint, indicating increased load or risk of injury at the knee joint. The knee ACL injury is a common injury in sports (Noyes et al., 1980). The primary function of the ACL is limiting the knee anterior sliding and axial rotation (Andersen and Dyhre-Poulsen, 1990). Noyes et al. (1983) reported that rotational movements, such as turning or twisting, usually in strenuous sports were strongly related to the risk of knee injury. In this study, a task involving primarily trunk axial rotation was performed by the subjects while standing on one leg. This movement was chosen in order to generate axial rotational motion in the knee joint. Studies of analyzing joint kinematics and kinetics in the lower extremity during landing after vertical and vertical–horizontal jumps have demonstrated that joints torques are proportional distributed during these movements (Devita and Skelly, 1992; Kovacs et al., 1999). Increased knee internal rotation, due to the use of ankle braces while performing the trunk turning tasks, would indicate an increase of the stress in the knee ligaments and other connective tissues, therefore increasing the risk of knee injury. The results of this study indicated that the use of ankle braces might increase knee axial rotation and the risk of knee injury, depending on the tasks. In the open task to catch a rubber ball using two hands, the subjects reduced trunk axial rotation while wearing an ankle brace. The internal rotation of the knee did not increase. Compensation from the upper extremity was most likely the strategy used by the subjects to avoid the stress increase on the knee and other joints in the lower extremity. When the subjects performed more strenuous tasks that required the same amount of trunk axial rotation with and without an ankle brace, the knee internal rotation increased significantly with the use of an ankle brace. Such situation may not be rare in many sports such as basketball, soccer, etc. It has been reported that the use of rigid boots is a risk factor for the increased knee injuries in skiing (Rossi et al., 2003; Tuggy and Ong, 2000). The prophylactic use of an ankle brace or other supports in sports may reduce the risk of ankle injuries, but it may leave the knee joint more susceptible to injuries. Coaches, athletic trainers, and athletes should evaluate the circumstances where the use of ankle bracing is appropriate to avoid unnecessary risk of knee injury.

A compensative strategy observed in this study is another interesting finding associated with the use of ankle braces. Motor adaptations to the new environment and new tasks have been observed by numerous reports, even for patients with neurological diseases (Caillou et al., 2002; Cirstea and Levin, 2000; Hollands et al., 2001; Steenbergen et al., 1995). In this study, the strategy of the neuro-motor system in response to the constraint of ankle motion was shown to prevent the increase of lower extremity joint stress through increased motion in the upper extremity during the performance of the ball-catch task (OT). When this compensative strategy was ineffective, such as in the closed tasks, the neuro-motor system then increased the internal rotation at the knee joint in order to complete the task.

In the past, studies on the influence of ankle constraint on sports performance have reported controversial results. Some investigators (Pienkowski et al., 1995) did not find any significant difference in tasks like jumping and running when they compared performance of the subjects with and without the use of ankle taping or bracing. On the other hand, Burks et al. (1991) and Mackean et al. (1995) have observed that tape and ankle braces had adverse impact on the most performances tested when compared with those performed without a brace. The discrepancy in the past study may reflect variations in the restrictive properties of different ankle supports as well as compensative strategies depended on the tasks.

In this study, the Active Ankle brace was used to provide the constraint during the experiments. Major limitations imposed by this type of ankle brace are the eversion and inversion, and internal and external
rotation of the ankle joint (Siegler et al., 1997). In our experiments, reduced eversion at the ankle joint due to the use of the ankle brace was found consistently during both the OT and CT tasks. The axial rotation of the ankle joint was reduced with the use of the ankle brace during the OT tasks, but not during the CT tasks. A possible explanation for this discrepancy is that the subjects increased the effort in stretching their lower extremities during the CT tasks when wearing an ankle brace, so that they can reach the target. This could be the same reason for the increase in knee internal rotation.

There were limitations associated with the current study. In this study, the subjects were not familiar with the use of the ankle brace, and may modify their compensatory strategies if repeated exposure to the same tasks. The analysis of kinetics was not included in this study. The errors in joint motion measurements due to skin motion might also affect the results of the current study. There have been a few studies examined the deviations of estimated joint motions using surface markers from the measured results of markers fixed on bone pines during walking (Holden et al., 1997; Manal et al., 2000; Houck et al., 2004). For instance, Manal et al. (2000) reported the peak deviations in tibial axial rotation among their subjects ranged from 4° to 7°. The movement tasks in our study might be close to the walking condition in terms of soft tissue motion. The measured knee axial rotations in our study were around 20° on average in all testing conditions. This range of axial rotation was much greater than the possible measurement errors. Further more, in the current study, we were interested in the comparison of knee axial rotations in both tasks with or without an ankle brace. The addition of the ankle brace did not change any experimental set-up, therefore, would have minimal influence on the measurement error due to skin motion. In other words, the measurement errors due to skin motion should be virtually the same with or without the ankle brace. The significant increase (6.5° on average) in knee axial rotation during closed tasks due to the ankle brace was also greater than the possible skin-induced errors. Therefore, the skin-induced error should not be a critical factor that might have affected the results and conclusion of the current study.

5. Conclusion

In the present study, we demonstrated through a quantitative analysis of joint motions under controlled laboratory condition that subjects compensated for the ankle constraint due to use of ankle brace by increasing rotation of the knee joint during closed trunk turning task. The closed task required the same amount of trunk axial rotation and no possibility of compensation from upper limb. The increased knee internal rotation indicated the increase of proximal joint stress (and risk of injury) if the trunk is under the strenuous rotations. However, during open task in which the subjects could compensate the loss of ankle motion due to an ankle brace by increasing the motion at the upper extremity, the subjects showed reduced trunk rotation and no change in the knee motion while successfully completing the tasks. The compensative strategy of the subjects depended on the tasks. Finally, this study is an important first step in looking into the effect of prophylactic bracing for potential risks of the knee injury.

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References


