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Passive dorsiflexion stiffness is poorly correlated with passive dorsiflexion range of motion

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Abstract

The purpose of this study was to determine the relationships among passive measures of weight-bearing dorsiflexionrange of motion, non-weight-bearing dorsiflexionrange of motion and dorsiflexionstiffness, thereby establishing whether they assess similar mechanical characteristics, as each measure has been implicated in injury risk during landings.

Keywords

stiffness, passive, poorly, motion, correlated, dorsiflexion, range

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Abstract

Objectives: The purpose of this study was to determine the relationships among passive measures of weight-bearing (WB) dorsiflexion range of motion (DROM), non-weight-bearing (NWB) DROM and dorsiflexion stiffness, thereby establishing whether they assess similar mechanical characteristics, as each measure has been implicated in injury risk during landings. *Design:* Cross-sectional study. *Methods:* Passive WB DROM, NWB DROM and dorsiflexion stiffness were quantified for 42 males (22.8 ± 5.0 years). The relationship between each data set was calculated using Pearson product-moment correlation coefficients. *Results:* Although WB DROM and NWB DROM were significantly correlated, the strength of the relationship was poor ($r^2 = 0.18$; $p = 0.004$). WB DROM (mean = 43.0 ± 5.0°) was significantly greater than NWB DROM (29.8 ± 5.9°; $p < 0.001$) and WB DROM and NWB DROM were also poorly correlated with passive dorsiflexion stiffness (1.48 ± 0.55 $\mathrm{Nm.}^{\circ-1}$; $r^2 = 0.04$ and $r^2 = 0.14$, respectively), despite the latter relationship being significant ($p = 0.017$). *Conclusions:* Passive dorsiflexion stiffness was not strongly associated with DROM, despite the significant correlation in the NWB condition. It must be acknowledged that passive dorsiflexion stiffness was weakly associated with DROM, although the strength of the association suggests that it may not necessarily determine DROM. Furthermore, the functional dorsiflexion limits of the ankle during weight-bearing tasks may be underestimated or misrepresented by non-weight-bearing measures of DROM. Therefore, although ankle DROM and dorsiflexion stiffness have been implicated in injury risk during weight-bearing tasks such as landings, it may be due to different mechanisms.

Keywords: Ankle; Achilles tendon; Flexibility; Athletic injuries.

1. Introduction

Various measures of joint flexibility, such as range of motion (ROM), have been studied extensively in investigations of injury incidence, risk and prevention. For example, reduced ankle dorsiflexion ROM (DROM) has been associated with increased injury risk in both acute and overuse injuries to the ankle joint and surrounding tissues, which are among the most common of all sporting injuries.[1-3] Despite this extensive research ambiguity exists regarding what constitutes joint ROM and how it can best be measured.[4-6]

One proposed determinant of joint ROM[6,7], and in turn injury risk[8], is muscle-tendon unit (MTU) compliance. Compliance of a MTU is often defined and measured as passive joint stiffness or as tolerable passive joint torque.[4,9] Long-term stretching training studies have demonstrated that reductions in passive joint tension[10] or passive stiffness[6] occur with concomitant increases in joint ROM, suggesting that joint ROM may be dependent upon joint stiffness. Other research, however, has shown significant increases in joint ROM post-stretch training, with no change in joint or joint stiffness.[7,11] Although limited ROM at joints, such as the ankle, has been linked to dysfunctional movement and increased risk of injury[1,5,12], the biomechanical determinants and restraints to ROM are not thoroughly understood. Therefore, the relationships between various measures of joint flexibility, such as joint ROM and joint stiffness, as well as whether a stiff joint is responsible for restricting joint ROM and whether this affects injury risk, remain unknown.

In terms of the ankle, DROM is commonly assessed as a gauge of health and function in elderly, pathological and highly active populations.[1,12] Researchers and clinicians agree that sufficient DROM is required to optimise muscle activation, minimise injury risk and, in turn, perform athletic tasks and activities of daily living effectively and safely.[13,14] Assessment techniques used to measure DROM, however, vary considerably in the literature.[5,15,16] Ankle DROM results will vary if they are measured in weight-bearing versus non-weight bearing positions[15] and will also vary between knee-flexed and knee-extended postures.[17] This variability in DROM assessment methodology makes comparison between studies, and any subsequent determination regarding the sufficiency of DROM for different tasks, difficult.

As commonly performed tasks such as walking, running, jumping and landing are performed in a closed kinetic chain, it seems appropriate to measure DROM in a weight-bearing position, approximating functional requirements[15,16], rather than in a non-weight-bearing position. Although reliable methods for assessing functional DROM in weight-bearing positions have been developed[16,18,19], there has been limited research regarding the correlation between weight-bearing and non-weight-bearing methods of assessing DROM.[15] The lack of conclusive evidence is problematic for clinicians and trainers, particularly when non-weight-bearing assessments of DROM are used to determine whether a patient or athlete has sufficient ankle ROM to perform a weight-bearing task.[20] Furthermore, although limited research has associated passive stiffness with joint ROM[4,6], these studies have used non-weight-bearing open kinetic chain positions. It remains unknown whether these associations hold true for closed kinetic chain weight-bearing DROM assessments. Therefore, the purpose of this study was to investigate the relationships among passive measures of non-weight-bearing DROM, standing weight-bearing DROM and ankle dorsiflexion stiffness. We hypothesised that non-weight-bearing measures of passive ankle DROM and dorsiflexion stiffness would be significantly and strongly correlated, although poorly correlated with weight-bearing DROM due to the different posture adopted in the latter assessment task.

2. Methods

Forty eight physically active males were recruited from within the campus population of the University of Wollongong to participate in the study. Prior to participating, each recruit completed injury history and 'Physical Activity Readiness'[14] questionnaires and written informed consent. Potential participants with any current or previous injuries contraindicated for completing the experimental protocol were excluded. Ethical clearance for the study was obtained from the University of Wollongong Human Research Ethics Committee (HE06/333).

The test limb selected for all assessments was determined by asking each participant to drop from a height of 32 cm on to their preferred landing foot, which was deemed to be the test limb.[19] The weight-bearing (WB) DROM for each participant's test limb was measured with a Gollehon extendable goniometer (Model 01135; Lafayette Instrument Co., USA) and using the standing lunge test developed by Bennell et al.[16] A high reliability coefficient (ICC = 0.97, two-way mixed effects model for consistency of single measures) for the same assessor [JWW], irrespective of the leg measured, was established using this method by measuring four trials over three separate days for each leg of six participants unassociated with the study.[19] Passive non-weight-bearing (NWB) DROM was measured with each participant in a prone position on a KinCom dynamometer (Kinetic Communicator, Chattecx Corp., Chattanooga, TN) with the foot of their test limb firmly strapped to the dynamometer foot-plate. Dense rubber padding was placed beneath the ankle strap and between the malleoli and the ankle housing on the foot pedal, thereby preventing lateral ankle movement or 'heel lift' during the dorsiflexion movements. The lateral malleolus was aligned with the axis of rotation of the dynamometer head and, using the lateral femoral condyle and the greater trochanter, the knee was positioned in a statically flexed position (10°; goniometer). The NWB DROM result was deemed the maximum angle of three trials of passive ankle dorsiflexion, whereby an examiner manually rotated the foot pedal from 5° of plantar-flexion to each participant's self-selected stretch limit of dorsiflexion[15], without inducing discomfort.

Passive dorsiflexion stiffness was measured in the same position that was used for NWB DROM assessment on the KinCom dynamometer, with the ankle passively dorsiflexed at a slow, constant velocity of $5°.s^{-1}$ from 5° of plantar-flexion to their pre-determined stretch limit, ensuring that the participants relaxed their 'calf' muscles and did not actively resist the movement. A slow velocity was used to limit muscular activation from stretch reflexes.[4,7,9] Passive dorsiflexion stiffness values were determined by measuring the slope of the torque-angle curve[4] generated between 15° and 20° of dorsiflexion. Analogue data pertaining to the angular position, angular velocity and torque were sampled at 100 Hz directly from the KinCom PC via a National Instruments DAQpad 6015/1016 and using MyoResearch XP collection software (Version 1.04.02, Noraxon Inc, Scottsdale, AZ).

To ensure that the movements were truly passive, electromyography data were simultaneously sampled from the tibialis anterior, soleus and medial and lateral gastrocnemius muscles and synchronised with the KinCom output data using the same MyoResearch software. The surface electrode sites were located according to the recommendations of Cram et al.[21] and were confirmed by manually palpating the centre of each muscle belly. Silver/silver chloride surface electrodes (Ambu Blue Sensor N-00-S; Medicotest, Ølstykke, DEN) were aligned parallel with the direction of the muscle fibres and with an inter-electrode spacing no greater than 22 mm to minimise cross-talk between adjacent muscle bellies. A reference electrode was positioned over the tibial tuberosity. The EMG signals were relayed from the electrodes to a Telemyo 900 battery-powered transmitter (Noraxon, Scottsdale, AZ), and then transmitted to a Telemyo 900 receiver via an antenna and sampled at 1000 Hz (bandwidth 16-500 Hz). Replicating previous studies, a research assistant, trained by the primary researcher in the present experiment, monitored the EMG traces in real-time during data collection to ensure there was no myoelectric activity visible above the signal baseline (±10 μV) and gave feedback to the participants where necessary.[22,23] During later inspection of all EMG signals, any participants who displayed trials involving muscle activation with signals visibly above or below the baseline (±10 μV) were discarded, resulting in data sets for a cohort of 42 participants for the subsequent statistical analyses (mean age = 22.8 ± 5.0 years; height = 180.3 ± 7.8 cm; mass = 75.7 ± 10.9 kg).

All data sets were tested for normality using the Kolmogorov-Smirnov statistic with a Lilliefors significance correction. Mean (± SD) values were calculated for the WB DROM, NWB DROM and passive stiffness data sets and a paired samples *t*-test was performed to compare the WB DROM and NWB DROM data. A series of Pearson product-moment correlations were then performed between the data sets for each of the outcome variables. An alpha level was set at 0.05 for all statistical analyses and all data were analysed using SPSS for Windows (SPSS Inc., Chicago, IL; Version 17).

3. Results

Mean (± SD) values for WB DROM, NWB DROM and passive stiffness were 43.0 ± 5.0°, 29.8 ± 5.9° and 1.48 ± 0.55 $\text{Nm.}^{\circ -1}$, respectively. WB DROM was significantly ($p < 0.001$) greater than NWB DROM. Although significantly correlated, the strength of the relationship between the WB DROM and NWB DROM data sets was poor (Figure 1), with only 18% of the variation in the NWB DROM values explained by their relationship with the WB DROM values. Measures for WB DROM and NWB DROM were also each poorly correlated with the passive dorsiflexion stiffness values (Figure 2 and 3), with only 4% and 14% of the values for passive dorsiflexion stiffness explained by the corresponding measures of WB DROM and NWB DROM, respectively.

<Insert Figures 1 to 3 about here>

4. Discussion

The mean WB DROM and NWB DROM values reported in the current study are similar to values reported by others, who have used similar participant cohorts and DROM assessment techniques.[4,6,16] The mean passive stiffness value (1.48 ± 0.55 Nm.$^{\circ-1}$; N = 42) also closely approximated the mean passive stiffness value reported by Kubo et al.[4] (~1.4 Nm.$^{\circ-1}$), who assessed a similar cohort of young adult males. In agreement with the literature, participants in the current study were able to achieve significantly greater DROM when standing compared to when prone.[15] Furthermore, although WB DROM and NWB DROM were positively and significantly correlated (Figure 1; $p = 0.004$), the strength of the correlation was weak ($r^2 = 0.18$). These results show that non-weight-bearing assessments of DROM may not reflect the functional capacity of the talocrural joint to flex, such as when an individual adopts a more functional weight-bearing position.

Gait tasks, activities of daily living and sporting activities usually require individuals to dorsiflex their ankles while in weight-bearing postures. Healthy individuals use between 10° and 20° of DROM in a weight-bearing position during unimpeded level-ground gait[24] and between 20° and 40° of WB DROM when performing more demanding tasks such as descending stairs or landing from a jump.[5,19] When assessing an individual's ability to achieve the required dorsiflexion angle to perform any given weight-bearing task safely and effectively, our results imply that a non-weight-bearing assessment may underestimate[15] and even misrepresent the individual's functional ankle DROM.[12,16,18] Although patients may be contraindicated to perform a WB DROM assessment during rehabilitation after an ankle injury, clinicians must be aware of the weak correlation between weight-bearing and non-weight-bearing assessments of DROM, which suggests that these two assessment types should not be used interchangeably. As many gait and sporting tasks are performed during weight-bearing closed kinetic chain activities, it is recommended that the available passive DROM required should be assessed in a weight-bearing manner.

It must be acknowledged that NWB DROM was significantly correlated with NWB dorsiflexion stiffness, although the results of the present study also demonstrate that ankle joint compliance, as characterised by the passive dorsiflexion stiffness measure, was only weakly associated with either measure of DROM (Figures 2 and 3). Consequently, although passive stiffness assessments are often made using non-weight-bearing methods[4,6], there may be no justification for assessing DROM in the same non-weight-bearing position in an attempt to relate the two measures. If high or low dorsiflexion stiffness is implicated in injury potential during dynamic ankle dorsiflexion movements that elongate the plantar-flexors, it may be for reasons other than the effects of joint stiffness on joint ROM. Therefore, although a limited passive DROM may alter ankle kinematics or potentially increase plantar-flexor MTU strain during weight-bearing tasks[5,12,19], high or low dorsiflexion stiffness may affect injury potential by alternative mechanisms. For instance, the stiffness of one or more individual structures within the MTU alone, including muscle, fascia or tendon, may influence overall joint stiffness and, therefore, be involved in function and injury risk by influencing the stiffness of adjacent structures.

Measures of passive joint stiffness can provide some insight into the ability of the passive structures of an adjacent MTU to resist stretch or deformation while under tensile load. As passive dorsiflexion stiffness was only weakly associated with passive DROM, it is not likely to be a substantial determinant of total ROM. We postulate that joint stiffness may affect MTU strain type injury potential by allowing the MTU to either strain too far under a given load or by protecting some passive structures within an MTU at the expense of transferring load more readily to others. For example, the incidence of Achilles tendinopathy[25] may be increased in individuals who have joints with low stiffness, which are consequently less able to resist elongation and therefore deform to injurious lengths, particularly where dorsiflexion ROM is not necessarily a limiting factor. Conversely, individuals who have joints with high stiffness may not be able to absorb sufficient strain energy via their Achilles tendon in order to prevent other structures, such as the muscle fibres, from incurring excessive and injurious strains.[8] As strain type injuries to both tendon and muscular apparatus are thought to be more a factor of the actual strain and less dependent upon the magnitude of the tensile force[25-27], it may be necessary for researchers to more thoroughly investigate the effects of joint and MTU stiffness, and not just joint ROM, on joint mechanics in order to better understand MTU injury risk.

Although the present study did not assess the stiffness of individual MTU structures, such as the Achilles tendon, any discussion of dorsiflexion stiffness needs to consider the Achilles tendon. Achilles tendon stiffness has been strongly correlated with ankle dorsiflexion stiffness[28], possibly due to the fact that the Achilles tendon is the largest tendon in the human body[29] and, therefore, the largest tendon offering resistance during ankle dorsiflexion. It must also be noted, however, that the method for measuring passive torque and subsequently passive stiffness during ankle dorsiflexion in the present study, was assessing the passive resistance of the entire talocrural joint and not just the plantar-flexor MTU. This limitation was present, however, in each of the passive DROM assessments, thereby allowing for a meaningful analysis in the current study of the relationships that exist between each of the measures of ankle ROM during passive dorsiflexion. Another limitation of the present study was that the passive stiffness tests, like the NWB DROM tests, were performed on the KinCom dynamometer, whereas the WB DROM tests were not performed on this device. It must be acknowledged, however, that measuring both NWB DROM and dorsiflexion stiffness in the same position may also be a limitation, whereby discerning differences in what these tests measure may be difficult. Nonetheless, the comparison between these test positions was necessary to provide some insight into the mechanical properties displayed during these different tests.

5. Conclusion

Albeit significant, the weight-bearing and non-weight-bearing measures of passive ankle DROM were poorly correlated, with participants displaying significantly greater passive DROM while in the weight-bearing posture compared to the non-weight-bearing posture. This finding supports the notion that non-weight-bearing assessments of DROM may underestimate or even misrepresent the functional capacity of the talocrural joint to dorsiflex during dynamic weight-bearing tasks. Although non-weight-bearing assessments of DROM may be useful in assessing the effectiveness of rehabilitation for patients contraindicated for performing WB DROM assessments, they may not be useful in determining the ability of a patient or athlete to perform a weight-bearing task safely or effectively. Both DROM assessments were also poorly correlated with passive dorsiflexion stiffness, indicating that dorsiflexion stiffness may not be a strong determinant of DROM, irrespective of the posture used for assessment. Therefore, although ankle DROM and dorsiflexion stiffness may be implicated in injury risk during dynamic weight-bearing tasks such as landing movements, it is likely due to different biomechanical mechanisms.

Practical implications

- Weight-bearing and non-weight-bearing measures of ankle dorsiflexion range of motion are not strongly correlated and should not be used interchangeably.
- Non-weight-bearing measures of ankle range of motion may mislead clinicians regarding the ability of an individual to dorsiflex their ankle when standing or during other functional weight-bearing tasks.
- Clinicians should use functional measures of ankle dorsiflexion range of motion when assessing the capacity of an individual to perform functional weight-bearing tasks.
- Measures of non-weight-bearing dorsiflexion stiffness describe different aspects of ankle dorsiflexion flexibility than measures of weight-bearing dorsiflexion range of motion and, therefore, may have different implications for injury potential during dorsiflexion movements.

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Figure Legends

Figure 1: Pearson product-moment correlation demonstrating the relationship between non-weight-bearing (NWB) and weight-bearing (WB) measures of ankle dorsiflexion range of motion (DROM).

Figure 2: Pearson product-moment correlation demonstrating the relationship between measures of passive dorsiflexion stiffness and weight-bearing (WB) ankle dorsiflexion range of motion (DROM).

Figure 3: Pearson product-moment correlation demonstrating the relationship between measures of passive dorsiflexion stiffness and non-weight-bearing (NWB) ankle dorsiflexion range of motion (DROM).