Weight-Bearing Ankle Dorsiflexion Range of Motion—Can Side-to-Side Symmetry Be Assumed?

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Context: In clinical practice, the range of motion (ROM) of the noninvolved side often serves as the reference for comparison with the injured side. Previous investigations of non-weight-bearing (NWB) ankle dorsiflexion (DF) ROM measurements have indicated bilateral symmetry for the most part. Less is known about ankle DF measured under weight-bearing (WB) conditions. Because WB and NWB ankle DF are not strongly correlated, there is a need to determine whether WB ankle DF is also symmetrical in a healthy population.

Objective: To determine whether WB ankle DF is bilaterally symmetrical. A secondary goal was to further explore the correlation between WB and NWB ankle DF ROM.

Design: Cross-sectional study.

Setting: Training facility of the Israeli Defense Forces.

Patients or Other Participants: A total of 64 healthy males (age = 19.6 ± 1.0 years, height = 175.0 ± 6.4 cm, and body mass = 71.4 ± 7.7 kg).

Main Outcome Measure(s): Dorsiflexion ROM in WB was measured with an inclinometer and DF ROM in NWB was

measured with a universal goniometer. All measurements were taken bilaterally by a single examiner.

Results: Weight-bearing ankle DF was greater on the nondominant side compared with the dominant side ($P < .001$). Non-weight-bearing ankle DF was not different between sides ($P = .64$). The correlation between WB and NWB DF was moderate, with the NWB DF measurement accounting for 30% to 37% of the variance of the WB measurement.

Conclusions: Weight-bearing ankle DF ROM should not be assumed to be bilaterally symmetrical. These findings suggest that side-to-side differences in WB DF may need to be interpreted while considering which side is dominant. The difference in bilateral symmetry between the WB and NWB measurements, as well as the only moderate level of correlation between them, suggests that both measurements should be performed routinely.

Key Words: lower extremity, foot, measurement

Key Points

- Weight-bearing ankle dorsiflexion was greater on the nondominant side among healthy male participants.
- Side-to-side differences in weight-bearing ankle dorsiflexion among clinical populations should be interpreted while considering which side is dominant.

Adequate ankle dorsiflexion (DF) range of motion (ROM) is necessary for the normal performance of functional activities such as walking, running, and negotiating stairs. Limitation of ankle DF has been implicated as a risk factor for several lower extremity disorders, including plantar fasciitis, ankle sprain, patellofemoral pain syndrome, and patellar tendinopathy.^{1–6} Ankle DF ROM has also been associated with self-reported functional ability after an ankle fracture^{7,8} as well as with a faulty, and potentially injurious, lower extremity movement pattern during various functional activities.^{9–11} Therefore, restoring full ankle DF seems to be an important goal in the management of lower extremity injuries.

Given that preinjury ROM is often unknown, a common clinical practice is to consider the uninvolved side as the normal reference in patients presenting with a unilateral foot or ankle disorder.¹² Accordingly, interventions directed at restoring ankle DF ROM may be prescribed for patients presenting with limited ankle DF ROM on the involved side

compared with the uninvolved side. These interventions may be continued as long as a side-to-side disparity in ROM exists. In contrast, ROM interventions are discontinued, or may not be prescribed at all, when DF is symmetrical. This approach seems reasonable given the findings of previous investigators regarding the side-to-side symmetry of ankle ROM as measured in non-weight-bearing (NWB) conditions. For example, Stefanyshyn and Engsberg¹³ reported no significant side-to-side difference in the total arc of ankle motion (DF-plantar flexion),¹³ and 2 other groups^{12,14} found differences of no more than 2° in ankle DF between the sides. Although statistically significant, such differences seem of questionable clinical significance (effect size [ES] = 0.13 to 0.19).^{12,14}

Ankle DF is often measured under weight-bearing (WB) conditions, most often using a WB lunge test. During the test, the participant lunges forward in front of a wall in an attempt to contact the wall with his or her knee. The maximal distance between the foot and the wall from which

the participant is still able to reach the wall serves as an estimate of the DF ROM. Weight-bearing DF measurements have several advantages over NWB measurements. First, they are relatively easy to perform. Second, they potentially apply a greater torque to the ankle via the participant's own body weight; thus, they may be able to stress the joint more fully through its available range. Third, they are performed in a more functional position, and finally, they seem to be more reliable.^{15–21} Previous authors²² compared WB and NWB ankle DF and demonstrated that the range recorded in WB was more than twice that recorded in NWB. More important, the 2 measurements correlated only moderately with one another ($r = 0.6$ to 0.64).²² These findings suggest that the WB and NWB DF measurements may actually be assessing 2 different constructs. Consequently, it seems important to examine whether the frequent assumption of bilateral symmetry in ROM applies to WB DF ROM as well. Two recent investigations^{23,24} of bilateral WB DF ROM in healthy participants have indicated that, although side-to-side differences are common, they do not favor either side, and thus, overall, WB ROM is bilaterally symmetrical. Nevertheless, the actual range measured in these 2 studies seems less than that measured in previous research.^{11,19,22} It is possible, therefore, that the measurement techniques used in these studies may not have sufficiently stressed the ankle through its full excursion.

Therefore, the primary aim of our study was to further explore whether ankle DF ROM as measured in WB was bilaterally symmetrical among healthy male participants. As a secondary goal, we aimed to further explore the correlation between WB and NWB ankle DF in healthy male participants.

METHODS

This study was approved by the Institutional Review Board of the Israeli Defense Forces. All participants read and signed an informed consent form before the study began. Data for this study were collected within the framework of a larger prospective investigation into potential risk factors for various musculoskeletal injuries during army basic training.

Participants

A total of 64 participants were recruited. All were healthy military recruits who were thoroughly screened for any musculoskeletal injury or condition before beginning 14 weeks of army basic training. Individuals were included if they were 18 years or older and without any current complaint of pain in the lower extremities or lumbar spine. Volunteers were excluded from participation if they reported having had any ankle or foot pain or injury in the 2 years preceding the study. This information was self-reported and subsequently verified by a research assistant.

Procedures

One examiner (A.R.) performed all clinical measurements for this study. This examiner had 13 years of clinical experience in the physical therapy management of various musculoskeletal conditions. Before collecting data for this study, the examiner reviewed and practiced all measure-

Figure 1. Weight-bearing dorsiflexion measurement.

ment procedures. Data collection took place in a large teaching hall in one of the Israeli Defense Forces facilities during a single day. First, demographic information was collected through a standardized questionnaire. This information included age, height, body mass, and *dominant leg* (defined as the leg used to kick a ball). Next, each participant's anterior tibia was marked with black ink 15 cm distal to the tibial tuberosity. This mark was later used in the measurement of WB ankle DF. Data-collection time for each participant was approximately 10 minutes.

Description of Measurements

The examiner measured dorsiflexion ROM according to procedures described previously.^{11,22} Ankle DF in WB was measured with a fluid-filled inclinometer with 1° increments (MIE Medical Research Ltd, Leeks, UK). A line 50 cm long was marked on the floor and a continuous line 60 cm long was marked on the wall where the test was performed. The participant placed the test foot along the floor line, 30 cm away from the wall, so that the line bisected his heel and his second toe was on the line. To allow the participant to reach his full ROM, the nontest foot was placed in a comfortable position 50 cm behind the tested foot. The participant was then asked to lunge forward and bring his patella as close as possible to the vertical line drawn on the wall without lifting the heel of the test foot off the floor (Figure 1). No attempt was made to control trunk, hip, or subtalar motion during the test. The participant was also allowed to lift the opposite (nontest) heel off the floor during the test; however, the forefoot had to remain in contact with the floor. Once maximal DF was reached, the examiner placed the inclinometer, which was first zeroed on a fixed vertical reference, over the previously marked spot on the anterior tibia of the participant. The DF angle was recorded and the participant returned to the starting position. Participants were given 3 trials to familiarize themselves with the procedure and to precondition the tissue. The average of the next 3 trials was recorded and served as the WB ROM. This measurement procedure had

Figure 2. Non-weight-bearing dorsiflexion measurement.

shown excellent interrater reliability in a previous investigation¹¹ involving the same examiner who performed the measurements in the current study (intraclass correlation coefficient [ICC] = 0.95).

Non-weight-bearing ankle DF was measured with the participant in a prone position with the knee bent to 90°. A universal goniometer with 1° increments was used for the measurement. The examiner manually verified the subtalar neutral position and placed the ankle in full DF (ie, a definitive end-feel resistance was noted) (Figure 2). Dorsiflexion was measured as the angle between the lateral midline of the lower leg (a line from the head of the fibula to the tip of the lateral malleolus) and the lateral border of the foot (a line along the rear-foot and calcaneus). The examiner took the ankle into end-range DF 3 times to precondition the tissue, and the average of the next 3 measurements was recorded. This measurement procedure had also shown excellent interrater reliability in a previous investigation¹¹ involving the same examiner (ICC = 0.86). For both DF measurements, the side tested first was alternated between consecutive participants to avoid a possible order effect. Accordingly, if the right side was measured first on a given participant, the left side was measured first on the next participant. Furthermore, the order of the WB and NWB measurement of each participant was also alternated between consecutive participants.

Data Analysis

We calculated descriptive statistics (average $\pm$ SD) for all demographic variables and ankle DF in WB and NWB. For the primary purpose of the study, a paired *t* test was

performed to analyze the differences between the dominant and nondominant ankle DF in WB and NWB. The ES was calculated for each comparison by dividing the raw difference between the dominant and nondominant sides by their pooled standard deviation. An ES of 0.2 is considered *small*, 0.5 is *medium*, and 0.8 or greater is *large*.²⁵ For the secondary purpose of the study, we used a Pearson (*r*) product moment correlation coefficient to examine the correlation between the WB and NWB ankle DF ROM of either side (dominant and nondominant). The coefficient of determination (*r*²) was calculated to express the amount of variance in 1 DF measurement that could be explained by the other DF measurement. All statistical analyses were performed using SPSS software (version 19; SPSS Inc, Chicago, IL) with an a priori level of significance of *P* < .05.

RESULTS

A total of 73 participants were screened for eligibility. Nine participants had sustained an ankle sprain in the 2 years preceding the study and therefore were excluded. Thus, 64 participants were included in the final analysis: age = 19.6 $\pm$ 1.0 years, height = 175.0 $\pm$ 6.4 cm, and body mass = 71.4 $\pm$ 7.7 kg. Fifty-nine participants (92%) reported the right leg was dominant, and 5 participants reported the left leg as dominant.

Weight-bearing and NWB ankle DF ROM on the dominant and nondominant sides are summarized in the Table. Weight-bearing ankle DF was significantly greater on the nondominant side compared with the dominant side (*P* < .001). There were no differences in NWB ankle DF between the dominant and nondominant sides (*P* = .64).

The correlation (*r*) between NWB and WB DF on the dominant and nondominant sides was moderate (0.61 and 0.55, respectively; *P* < .001). This indicates that the NWB measurement explains from 30% to 37% of the variance in the WB measurement, and vice versa.

DISCUSSION

Our results suggest that, unlike NWB DF ROM, ankle DF as measured in WB is not symmetrical among healthy male participants. Weight-bearing ankle DF was greater on the nondominant side than the dominant side. The average dominant versus nondominant difference in WB DF (5.9°) was associated with a large ES and also exceeded the minimal detectable change of this measurement as determined by a previous investigation (4.5°).²² We believe that most clinicians would also consider such a difference clinically meaningful. In addition, it is worth noting that among 45 of the 64 participants (70%), the side-to-side WB difference exceeded the minimum detectable change, and among 15 participants (23%), this difference exceeded 10°.

Table. Comparison of Weight-Bearing and Non-Weight-Bearing Ankle Dorsiflexion Range of Motion on the Dominant and Nondominant Sides

Ankle Dorsiflexion, °	Range of Motion, ° (Mean $\pm$ SD)		Difference (95% Confidence Interval)	Effect Size
	Dominant Side	Nondominant Side		
Weight bearing ^a	50.4 $\pm$ 6.6	56.3 $\pm$ 7.3	-5.8 (-4.4, -7.3)	0.83
Non-weight bearing	27.1 $\pm$ 6.3	27.3 $\pm$ 6.3	-0.2 (-1.2, -0.7)	0.03

^a Significant difference between dominant and nondominant sides (*P* < .001).

In contrast, the NWB side-to-side difference exceeded the minimal detectable change of the NWB measurement (6.2°) in only 8 participants (13%) and never exceeded 9° .

The greater WB ankle DF ROM on the nondominant side may reflect differences in the functional demands of the 2 sides. Dominance of the lower extremity is manifested more by the types of activities the extremity is used for, rather than the frequency of its use.²⁶ Our definition of dominance was based on the act of kicking a ball, which is consistent with previous literature.^{9,26} This implies that the nondominant limb of our participants is the preferred limb for providing stability and balance. The increased WB DF ROM may be a consequence of the deforming forces sustained by this side during the balance and stability functions it performs. Sadeghi et al^{26,27} demonstrated different power generation in the left and right legs of healthy individuals during gait. The authors concluded that the power generation of the right leg was associated more with propulsion, whereas that of the left leg was associated more with postural control.²⁷ Healthy, physically active individuals have also been shown²⁸ to use an ankle strategy more frequently to maintain their balance while standing on their nondominant lower extremity compared with their dominant lower extremity. The greater WB DF ROM on the nondominant side may represent an adaptation to these functional, bilateral differences.

Unlike the WB measurement, ankle DF as measured in NWB was not different between the dominant and nondominant sides. The differences between the WB and NWB measurements have several possible explanations. First, the WB measurement was not likely to isolate motion to the talocrural joint as well as the NWB measurement did. During the WB measurement, other than asking our participants to aim their knees at the line drawn on the wall, we did not attempt to control the motion of joints distal or proximal to the talocrural joint. In contrast, the NWB measurement was performed in subtalar neutral position with the distal arm of the goniometer along the lateral aspect of the calcaneus as opposed to a more distal reference point such as the fifth metatarsal; thus, it was likely to isolate motion to the talocrural joint much better than the WB measurement. Consequently, it may be that the asymmetry detected in the WB measurement is more reflective of side-to-side differences in the subtalar and midtarsal joints, or possibly even the knee, hip, or trunk. In fact, post hoc analysis indicated that less than 1% of the variance in the side-to-side difference in WB can be explained by the side-to-side difference in NWB. Ferrario et al²⁹ found that 50% of healthy participants exhibited side-to-side asymmetries of more than 5° in frontal- and horizontal-plane foot movements associated with ankle DF-plantar flexion.²⁹ If, in fact, the WB measurement incorporates greater subtalar or midtarsal motion (or both) compared with the NWB measurement, this finding may help to explain the differences between the 2 measurements.

Another possible explanation for the greater DF on the nondominant side is the greater torque that was likely applied to the ankle during the WB measurement. In pilot testing, we observed that the torque applied during the WB measurement was more than 3 times greater than that applied during the NWB measurement.²² Therefore, it may be that the ROM of the talocrural joint is indeed greater on

the nondominant side of healthy male participants; however, this asymmetry can be detected only when a sufficient load is applied to the ankle.

Several recent studies looking directly or indirectly at side-to-side differences in ankle DF ROM warrant further discussion. Cosby and Hertel²⁴ measured bilateral ankle DF under WB and NWB conditions in a healthy population of males and females and found no side-to-side differences. Another investigation²³ of healthy males and females indicated frequent asymmetries of up to 1.5 cm (translating into 5.4°). However, in contrast to our findings, asymmetries were evenly distributed between the sides.²³ Finally, the data of a third study,³⁰ which investigated the reliability of 3 measurement techniques of WB DF, also suggest that significant side-to-side differences were unlikely.

We believe the main reason for the differences between our findings and previous findings relates to our measurement technique. In an attempt to facilitate full ROM, we purposely had our participants place the test foot well away from the wall to promote a forward shift of their body weight during the test. In 2 of the previously mentioned studies,^{23,30} the test foot was much closer to the wall because the measurement was based on the distance between the foot and the wall. In the third study,²⁴ the test foot was placed behind the nontest foot. We believe that standing close to the wall or placing the tested foot behind the nontested foot may have limited the participant's ability to shift his body weight forward and place an adequate DF torque on the ankle. We also had our participants assume a relatively wide, staggered stance to promote balance and allowed them to lift the nontest heel off the floor during the test. Previous researchers^{23,30} seem to have used a narrower stance during the test, and it is not clear whether the nontest heel was allowed to lift off the floor. The narrower stance could have limited participants' ability to lunge forward during the test, and, in addition, if they maintained both heels in contact with the floor during the test, this could have prevented 1 side from reaching full ROM due to more limited ROM on the other side. The WB ROM measured in our study was indeed greater than the range measured in these previous studies,^{23,24,30} and we believe these differences in measurement technique are at least partly responsible.

Similar to previous findings,²² our study also indicates only a moderate correlation between WB and NWB ankle DF on either side of healthy male participants ($r = 0.55$ to 0.61). This means that much of the variance in the WB measurement is explained by factors other than the NWB DF. As previously stated, the motion at the more distal or proximal joints of the extremity may account for this finding, as well as the difference in the magnitude of torque applied to the ankle during the 2 measurements. Furthermore, it has been shown recently that during a squat, the forward inclination of the tibia is accompanied by plantar flexion of the calcaneus. Because little motion occurs in the sagittal plane between the talus and the calcaneus, calcaneal plantar flexion likely results in plantar flexion of the talus, which in turn, may allow a greater anterior inclination of the leg relative to the ground.³¹ If the NWB DF measurement involves less calcaneal plantar flexion, it may also help to explain some of the difference between the WB and NWB measurement. Finally, another possible source for the moderate correlation between the WB and

NWB measurement is the measuring instrument. We used a fluid-filled inclinometer for the WB measurement and a universal goniometer for the NWB measurement. Our choice of measuring instrument was meant to reflect common clinical practice. Weight-bearing DF is often measured with an inclinometer,^{6,19,21} whereas NWB DF is typically measured with a goniometer.^{2,4,16–18}

Our study has several clinical implications. First, ankle DF ROM symmetry should not be assumed when the measurement is performed in WB. Aside from any actual side-to-side difference in ROM, clinicians may need to account for side dominance when interpreting their findings. For example, among patients with a dominant-side injury, a 5° to 6° reduction in WB DF compared with the nondominant (healthy) side should not automatically be assumed as a limitation of ROM. Furthermore, side-to-side symmetry should not necessarily be considered a treatment goal if the dominant side is the injured side. In contrast, among patients with a non-dominant-side injury, symmetry in WB DF ROM may actually indicate a limitation. Finally, the selective asymmetry of the WB versus the NWB DF ROM, as well as the only moderate correlation between them, suggests that these measurements should not be viewed as alternate techniques for measuring ankle DF but rather as complementary measurements that, when combined, may shed more light on the status of a patient. Accordingly, bilateral differences in WB DF, along with relative symmetry in NWB DF, may suggest increased or excessive subtalar or midtarsal mobility on the 1 side.

Our study had several limitations. First, our sample was fairly young and consisted of physically active male participants only. Therefore, our results may not be generalizable to girls or women or even to boys or men in other age groups. Future studies are encouraged to determine whether our findings can be replicated among other populations. In addition, studies examining the bilateral kinematics of the foot and ankle during the WB DF measurement may further help to explain the source of the side-to-side asymmetry of this measurement, as well as the differences between the WB and the NWB measurements. Another limitation of the current investigation is the lack of a reliability analysis. Due to the limited availability of our participants, we could not collect data for an intrarater or an interrater reliability assessment. However, the measurement techniques used in this study have been found reliable in separate investigations involving 2 of the investigators in the current study (A.R., Z.K.).^{11,22}

CONCLUSIONS

Ankle DF as measured in WB was greater on the nondominant side compared with the dominant side of healthy male participants. This implies that any side-to-side difference in WB DF ROM among a clinical population should be interpreted while considering limb dominance. Furthermore, because the WB and NWB measurements correlate only moderately with one another, we recommend that both be included routinely in clinical practice as well as in research projects.

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