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Original Research

Athletes at late stage rehabilitation have persisting deficits in plantar- and dorsiflexion, and inversion (but not eversion) after ankle sprain

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A R T I C L E I N F O

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A B S T R A C T

Objectives: Document reliability and normative data for a novel device measuring weight-bearing ankle range of motion after ankle injury.
Design: Cross-sectional Cohort, two occasions one day apart.
Setting: Sports medicine hospital.
Participants: 87 ankle-injured male athletes at a late stage of their rehabilitation and 25 uninjured subjects. The injured athletes had met all criteria to return to functional, on-field rehabilitation.
Main outcome measures: Reliability (Intra-Class correlation Coefficient (ICC), and Minimum Detectable Change as a percent of the grand mean), weight-bearing range of motion (degrees) of dorsiflexion, plantarflexion, inversion, and eversion.
Results: Good (dorsiflexion = 0.82[0.76–0.87] and inversion = 0.81[0.75–0.86]) and excellent (plantarflexion = 0.93[0.90–0.95]) reliability was documented, however reliability for the eversion measure showed only fair reliability (0.61[0.49–0.70]). Reduced range of motion in the injured leg was seen in all 4 directions, however with different magnitudes: Large differences were plantarflexion (−8.5°, ES = 0.80), medium for dorsiflexion (−5.2°, 0.57), small for inversion (−4.8°, 0.36), and trivial for eversion (−1.7°, 0.15).
Conclusion: The device demonstrated clinically useful reliability for measuring these ranges of motion in a functional, weight-bearing position. PF ROM showed the greatest reduction in range in these athletes at a late stage of their rehabilitation.

1. Introduction

It is estimated that 70% of the general population have incurred an ankle injury during their lifetime (Hiller et al., 2012). Epidemiological data show that ankle injuries account for a large percentage of orthopedic emergency visits (attendance rates of 0.25 per 1000 person-year), (Fong et al., 2008) and that ankle sprains, particularly those involving the lateral ligament complex, are one of the most prevalent injuries occurring during sports and physical activities (Doherty et al., 2014). It is also clear that ankle sprains are associated with long term deficits, with up to 40% of people suffering joint instability, persistent pain, 'giving way', and recurrent injury (Gribble et al., 2016).

Restoring full ankle range of motion (ROM) after ankle injuries (conservatively or post operatively) is crucial for normal activities of daily living (ADL) as well as sporting activities. For example, limitation in dorsiflexion (DF) ROM can affect ascending and descending stairs, squatting, jumping, and running (Dowling, McPherson, & Paci, 2018). There is also much evidence to show that deficits in DF are associated with decreased dynamic balance performance (Hoch, Staton, & McKeon, 2011) and a higher risk of recurrent ankle sprain (Kobayashi et al., 2013). As such, quantification of ankle joint range of motion is regarded as an important outcome measure for guiding exercise-based rehabilitation progression, gauging the efficacy of therapeutic interventions, and informing return to play decisions (Delahunt et al., 2018).

Ankle ROM is conventionally measured with a goniometer and the patient supine. This approach is typically only a single plane measurement: plantarflexion (PF) and DF in the sagittal plane (Rome & Cowieson, 1996; Venturni et al., 2016). There have been few efforts at measuring supine Inversion (INV) and Eversion (EV)

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using this instrument (Araújo et al., 2014) and to date there is no readily available clinical measure of functional inversion and eversion in the frontal plane. Furthermore, weight-bearing movement patterns are different from open chain non-weight-bearing movements (Dowling et al., 2018), and it is suggested that a more functional ROM measurement is needed to better reflect the arthokinematics, motion, and function of the ankle joint.

Although there is increasing research around functional ROM of the ankle, the primary focus has been on DF measurements. Specifically, studies have employed a "knee to wall" or anterior lunge test, whereby DF measurements are quantified by measuring the distance of the toes to the wall (at the point when the knee touches the wall) or by reading an inclinometer positioned on the anterior upper third of the tibia (Konor et al., 2012). To our knowledge, no study has examined other functional ranges of motion of the ankle (e.g. PF, INV, and EV). Accordingly, the aim of this study is to present and evaluate the reliability and validity of a new device "QF-AROM" (Qatar Foundation Active Range of Motion) for measuring these four functional ankle movements.

2. Methods

Measurements were taken at XXX(Blinded for Review) by a custom made patented device (QF-AROM) for measuring ankle functional range of motion in both sagittal plane (dorsiflexion and plantar flexion) and the axial plane (eversion and inversion) (see supplementary material for a full description and video footage of the device).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ptsp.2019.04.015

2.1. Subjects

Eighty-seven consecutive male athletes with ankle injuries (injured group), ranging from 18 to 31 years, were examined between December 2015 and March 2017. At the time of assessment, each athlete was at an advanced stage of his treatment having been cleared for participation in sports-specific rehabilitation. Another 25 athletes (control group) receiving treatment without any history of lower limb injuries were also measured. After a demonstration of the procedure all volunteer subjects were informed of the nature of the study and examination and gave their informed consent. The study was conducted in accordance with the Declaration of Helsinki (2008). The injured athletes competed in a variety of sports, predominantly football (65), basketball (4), Boxing (1), Equestrian, (1), Futsal (2), Handball (3), ice hockey (2), judo (1), endurance (1), rugby (1), and volleyball (5). The comparison cohort reported participating in: football (22), futsal (2), gym (5), basketball (1), and volleyball (2). Note that a number of subjects in this comparison cohort reported participating in multiple sports.

17 athletes from the injured group were excluded from the study: fifteen returned to play before completing the second measurement (either in Qatar or overseas), one injured his knee and one had a re-injury of his ankle. From the control group three declined to participate in the second measure, and one suffered an injury to his right ankle between tests (leaving his left ankle tested twice).

Both tests were done before the start of the sports specific session to avoid the warm up effect, with one day's delay between the two tests.

2.2. Testing method

For clarity, we will describe the method for measuring the injured ankle's ROM. When measuring the uninjured ankle, the feet are swapped. Testing happens in two stages for each leg – firstly sagittal plane (plantarflexion then dorsiflexion) followed by the frontal plane (inversion then eversion). Patients are requested to move to their full range, and when recording, the limiting factor is noted along with the ROM – e.g. "tightness" – "*I just can't go any further*" or "pain" – location and quality would be noted. One trial only was performed in each position for each leg.

2.3. Sagittal plane (plantarflexion then dorsiflexion) testing

The patient stands upright behind the device using one hand as support against a wall and then places his injured foot in the retainer which is locked in the sagittal plane. Once the foot is secured to the retainer with straps, the mounted sliding plate (holding the rod) is moved to align with talo-crural joint axis using a mounted laser pointer to guide this positioning. The rotating rod is calibrated vertically to the inclined upper surface and the digital inclinometer is zeroed in this starting position. The patient moves backward taking their ankle to their maximum tolerated PF with the knee behind the foot without losing any plantar foot contact with the foot retainer. When the patient reaches their maximum PF the rod is rotated until the retaining bar touches the leg and the angular displacement shown in the inclinometer is recorded as Full Functional PF ROM (FF PF ROM) (Fig. 1a). Next, the patient is asked to make an anterior lunge until maximum DF is obtained in a "knee over toe" technique (avoiding excessive pronation), while keeping the heel flat in the foot container. At this point the angular displacement on the inclinometer is recorded for FF DF ROM (Fig. 1b)

2.4. Frontal plane (Inversion then eversion) testing

Once sagittal plane testing is completed, the foot retainer is unlocked and the patient is instructed move to the side of the device (next to one of the side-walls) rotating the foot retainer 90° with their foot until it is aligned with the axial plane of the device where it is locked. The patient then stands next to one of the side-walls in a position allowing measurement of inversion. The patient is instructed not to lift the lateral border of the foot from the retainer while stretching into inversion. The sliding plate is then repositioned to fit with the rotational axis of the foot (Fig. 1c) using the mounted laser for guidance. Once the inversion angle is recorded, the patient moves to the opposite side for eversion measurement with instructions to keep their medial foot border completely adherent to the foot retainer (Fig. 1d). The technique is then completed for all four measures on the other side.

For the reliability analysis an $ICC_{(2,1)}$ (absolute agreement) (Portney & Watkins, 2000) was conducted and estimates reported according to their magnitude (Cohen, 1988). The Minimum Detectable Change (MDC) was defined as: 1.96 X $\sqrt{2}$ X the Standard Error of the Measure (Portney & Watkins, 2000). The Standard Error of the Measure was defined as the square root of the mean square error of the residual from the ICC ANOVA (Portney & Watkins, 2000). The MDC was expressed both in absolute terms, and as a percentage of the grand mean of the measure in consideration. Between group comparisons (injured versus uninjured) were independent samples Student t-tests with absolute differences and effect sizes reported along with statistical significance. Normality was assessed through a combination of Shapiro-Wilk tests and visual inspection of both Q-Q and Box plots. P values were set at 0.05 a priori, and all analyses were conducted in SPSSS v21 (IBM Corp, Amarok, USA).

Fig. 1. Sample images of weight-bearing active ankle range of motion measurement. a: Platarflexion, b: Dorsiflexion, c: Inversion, d: Eversion. Online supplementary material shows a video of the entire measurement procedure with an extended description of the measurement device.

3. Results

3.1. Participant demographics are presented in Table 1

Intra-rater reliability and clinimetrics of the ankle range of motion measures are shown in Table 2. Standard errors of the measure ranged from 2.1° (Plantarflexion) to 4.1° (Eversion). Statistically significant reductions in range of motion of the injured legs with moderate to large effect sizes were seen for plantarflexion, dorsiflexion, and inversion, but not eversion (Table 2, Fig. 1). Plantarflexion range of motion showed the largest reduction comparing injured and healthy groups, and eversion the smallest. Good (dorsiflexion and inversion) and excellent (plantarflexion) reliability was documented, however reliability for the eversion measure was fair (the lower bound of the confidence interval for the ICC was 0.49). Note however that with the exception of plantarflexion, these differences were less than the minimum detectable change for the measures (see Table 3).

4. Discussion

In this study we presented, for the first time, a device for measuring active weight-bearing two axis (sagittal and frontal) functional ankle ROM, which is seen to be safe, reliable, and easy to use. This study has confirmed previous findings of the injured leg displaying reductions in DF ROM (Denegar, Hertel, & Fonseca,

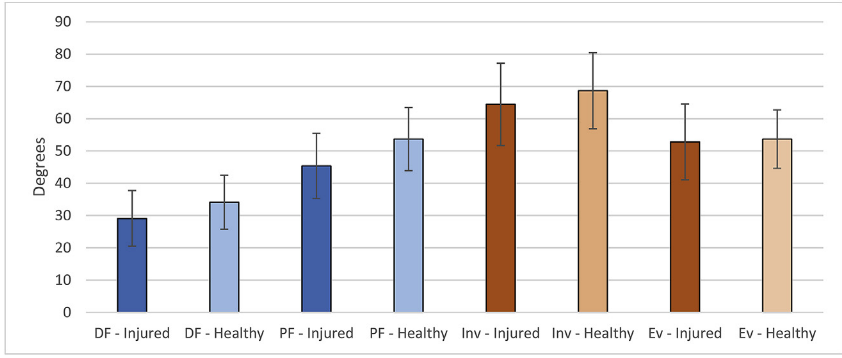

Fig. 2. Between group differences for range of motion for the 4 movements in the injured and healthy subjects. All comparisons between injured and uninjured groups were statistically significant with the exception of Eversion (Ev). DF: Dorsiflexion, PF: Plantarflexion, Inv: Inversion, Ev: Eversion.

Table 1
Participant demographics. Values presented are: average (standard deviation, range).

	Comparison group (n = 25)	Injured Athletes (n = 87)
Age	36.8 (10.73, 17 to 56)	28.4 (7.33, 18 to 31)
Height	174.7 (7.54, 164 to 190)	178.0 (9.44, 160 to 205)
Weight	74.8 (8.38, 58 to 94)	77.6 (14.80, 55 to 127)
BMI	24.5 (2.51, 20 to 29)	24.4 (3.30, 19 to 37)

2002), and extends this body of work to show a previously undocumented, and larger deficit of PF in the injured ankles.

Previous research typically examined ranges of motion in a non-weight-bearing condition as either cardinal plane movements (Menadue et al., 2006) or more recently as a combined circumduction (Theurillat et al., 2018). Menadue et al. (Menadue et al., 2006) reported lower values for both inversion and eversion in a prone position compared to sitting (inversion: 31°–15°, eversion: 11°–8°), with similar values reported for a 3D motion capture approach examining a circumduction movement (inversion: 23°, eversion: 17°) whereas the values reported here in our weight-bearing method are more than double these: inversion: 69° and eversion: 53°. These differences need to be considered when interpreting non-weight-bearing measures in the context of injury conditions which are typically weight-bearing (Skazalski et al., 2018). We suggest that the face-validity of a weight-bearing test would recommend this examination approach over the non-weight-bearing approaches given the stark differences noted here. Further, the MDC as a percentage of the mean values are lower for the current test in comparison to those documented previously[16 17] and we therefore suggest that this may allow better detection of between subject differences than the non-weight-bearing tests. Our MDC figures for dorsiflexion are comparable to those reported for the commonly used weight bearing lunge test (estimated at 6.4°–7.6°) (Searle, Spink, & Chuter, 2018).

Best practice guidelines (Vuurberg et al., 2018) suggest the importance of restoration of ankle DF ROM post injury, however typically less attention is paid to PF ROM. The reduced PF ROM in the injured athletes seen here is, to our knowledge, a novel finding, and one worth further examination. A recent systematic review reported that during walking, subjects with chronic ankle instability display increased ankle and rear-foot inversion, ankle plantarflexion, lateral foot vertical forces, and peroneus longus muscle activity (Moisan, Descarreaux, & Cantin, 2017). Hertel and Chinn studied ankle kinematics in the frontal and sagittal planes in patients with CAI during treadmill walking and jogging and found

Table 2
Reliability and Minimum detectable change for the 4 range of motion measures. The mean values, range, SEM, MDC, and SD values are all measurements in degrees. The total number of measurements (n) includes all ankles (injured and healthy) tested on the two occasions.

	Measurement	ICC (95CI)	Mean (SD)	Range	Mean (SD) Day 1	Mean (SD) Day 2	SEM	MDC	MDC as % of mean	n	p
Intra-rater Reliability	Dorsiflexion	0.82 (0.76–0.87)	32.5 (7.3)	7.4 to 49.7	32.0 (7.2)	33.0 (7.4)	3.42	9.5	29.6%	138	<0.001
	Plantarflexion	0.93 (0.90–0.95)	52.8 (8.0)	28.6 to 72.7	52.9 (8.1)	52.7 (7.9)	2.13	5.9	11.2%	138	<0.001
	Inversion	0.81 (0.75–0.86)	69.0 (8.3)	37.1 to 88.9	69.1 (8.4)	69.0 (8.3)	3.64	10.1	14.6%	138	<0.001
	Eversion	0.61 (0.49–0.70)	53.6 (7.0)	22.3 to 83.2	53.8 (6.5)	53.4 (7.5)	4.06	11.3	20.9%	138	<0.001

Table 3
Between group differences for range of motion at the ankle: injured compared to uninjured subjects.

	DF - Injured	DF - Healthy	PF - Injured	PF - Healthy	Inv - Injured	Inv - Healthy	Ev - Injured	Ev - Healthy
Mean	29.1	34.1	45.4	53.7	64.5	68.7	52.8	53.7
Median	30.6	35.2	46.2	54.0	65.4	69.5	55.3	54.3
SD	8.6	8.4	10.1	9.8	12.7	11.8	11.8	9.0
Subjects	91	136	91	136	91	136	91	136
p	0.000		0.000		0.000		0.148	
Difference	5.02		8.33		4.21		0.88	
Effect Size	0.59		0.84		0.34		0.08	

that the CAI group were more plantar flexed in both walking and jogging and more inverted in the frontal plane while jogging (Chinn, Dicharry, & Hertel, 2013). More recently these authors (Chinn et al., 2014) found that while walking participants with CAI are less plantar-flexed (5.73° ± 0.54°), less inverted (4.34° ± 0.65°); and while jogging are less dorsiflexed (4.91° ± 0.18°) and less inverted (6.52° ± 0.12°) when taped. We suggest future research may address the relation between passive ROM and displayed ROM during activity to shed more light on whether these movements are meaningfully related to injury.

A recent investigation examining gait and physical impairment in those with acute ankle sprain who didn't seek treatment (Punt et al., 2015) showed that these subjects walk more slowly with a shorter step length, shorter single loading phase, and reduced and delayed maximum plantar flexion compared to uninjured subjects. Finally, a cross-sectional MRI investigation of ankle sprain in athletes showed 1 in 5 to have associated damage to the syndesmosis (Roemer et al., 2014). Syndesmotic injury is reported to be associated with reduced PF ROM – it would be instructive for future research to delve further into the association between pathoanatomic findings and specific reductions in ROM. We can speculate that a consequence of the PF ROM deficit and associated gait changes may be alterations in muscle activation and joint kinematics which may not resolve prior to athletes returning to sport and could be associated with reinjury or reduced performance. We suggest that measuring and therefore adequately addressing reductions in active ROM may enhance our clinical outcomes, especially in light of the previously undocumented reductions in weightbearing PF ROM shown here (Fox et al., 2008). Speculatively we suggest that reductions in plantarflexion strength and control may contribute to the deficits documented here, and future research should further examine the causes of the PF deficit, as well as the effect of more complete rehabilitation on ultimate outcomes.

The current data provide not only reliability estimates for the measures, but more importantly estimates of the minimum detectable change. This value is more useful clinically where the requirement is figuring out, for example, if a patient has improved after a treatment by a measurable amount or not.

4.1. Limitations

It is noted that when positioning the ankle over a decline board, it can be difficult to control the movement toward eversion as the medial aspect of the foot can come away from the board, and this likely contributes to the poorer reliability of this measure.

This study shows that it is possible to accurately quantify ankle movements occurring across two of the primary body planes (sagittal and frontal). We note that as the subtalar joint axis is triplanar, it also allows movement of the foot (relative to the shank) across the transverse plane. Subtalar joint anatomy is complex and can show wide variation; in particular the spatial location of the subtalar joint axis is not consistent between individuals (Lewis, Kirby, & Piazza, 2007). Although the average inclination of the subtalar joint (the angle it makes with the horizontal) is estimated at 40°, values between 28° (van Langelaan, 1983) and 61° (Leardini, Stagni, & O'Connor, 2001) have been reported. We could postulate that our testing set up is perhaps most applicable for individuals with smaller inclination angles at their subtalar joint, as this is associated with frontal plane dominance. These reliability data are also most valid for relatively young athletic, adult males, and may not be applicable to other populations such as sedentary, adolescents, the elderly, or females.

Finally, it is difficult to fully control for any small subtle mid-foot movements during testing. This is a perennial problem in biomechanical studies and can only be addressed through more invasive approaches such as intra-cortical bone markers.

5. Conclusions

Realistic Functional Ankle ROM can now be measured using the QF-AROM device. The weight bearing measures in inversion and eversion are substantially higher than those reported for non-weight-bearing tests. We note a previously undocumented reduction in PF deficit in injured athletes that may be associated with risk of re-injury. Data for the healthy limbs may be used for normative values for comparison. Future research should examine the effect of restoring PF ROM and outcomes after an ankle injury.

Declarations of interest

Mohsen Abassi declares that he has a patent application in process for the Ankle range of motion testing device (Attorney docket number: 32905.09, small entity status under 37 CFR 1.27).

Rod Whiteley and **Chris Bleakley** have no declarations of interest.

The authors declare that this paper has not been published previously and is not currently under consideration for publication in any other journal.

All authors have read and approved of the submitted paper and declare this to be their own work for which they have each made substantial intellectual contribution.

Ethics statement

Eighty-seven male athletes with ankle injuries (injured group), ranging from 18 to 31 years, were examined between December 2015 and March 2017. At the time of assessment, each athlete was at an advanced stage of his treatment having been cleared for participation in sports-specific rehabilitation. Another 25 athletes (control group) receiving treatment without any history of lower limb injuries were also measured. After a demonstration of the procedure all volunteer subjects were informed of the nature of the study and examination and gave their informed consent. The study was conducted in accordance with the Declaration of Helsinki (2008).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.04.015.

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