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Gastrocnemius tightness: A population based observational study

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ABSTRACT

Background: Gastrocnemius tightness is believed to be associated with multiple musculoskeletal pathologies such as back pain, plantar fasciitis and metatarsalgia. Although surgical treatment of gastrocnemius tightness is gaining popularity the objective definition of a gastrocnemius contracture has not been determined. The aim of our study was therefore to quantify gastrocnemius tightness in a normal population.
Methods: Adult participants with no obvious foot and ankle pathology were recruited. Gastrocnemius tightness was quantified using a weightbearing lunge test. Maximal ankle-foot dorsiflexion was measured on participants with the knee in full extension and flexed to 20° using a digital inclinometer. The ankle-foot dorsiflexion index or ADI (difference in ankle dorsiflexion with the knee extended and flexed) was calculated. The ADI values were plotted on a histogram to identify the distribution of values and were compared according to participant demographics.
Results: 800 limbs from 400 participants were examined. There was a wide distribution of absolute values of maximal ankle-foot dorsiflexion ranging from 8 to 52°. The ADI ranged from 0 to19° and approximated to a normal distribution. The mean ADI was $6.04 \pm 3.49°$ and was positively correlated with age ($r = 0.132$, $P < 0.001$) and negatively correlated with physical activity ($r = -0.88$, $P = 0.015$).
Conclusion(s): Our study is the first to quantify gastrocnemius tightness in a large healthy adult population with differences observed by age and physical activity. We have defined an easy and reproducible weightbearing test that can be used in both research and clinical settings. The majority of the population have some degree of gastrocnemius tightness and values of ADI greater than 13° (>2 SD of the mean), as measured by the lunge test, may be considered abnormal.

1. Introduction

Whilst it has been suggested that gastrocnemius tightness (GT) is one of the most common causes of restriction in ankle dorsiflexion [1], no large study has been performed to assess the prevalence of GT in the general population. It has been proposed that an isolated gastrocnemius equinus deformity leads to excessive pressure and overload throughout the foot thereby causing pain and deformity [2]. GT has therefore been shown to be associated with multiple musculoskeletal pathologies such as metatarsalgia, plantar fasciitis, achilles tendinopathy, hallux valgus [3–6], knee pain [7,8] and back pain [9]. Treatment including conservative measures such as straight-kneed calf muscles stretches [10] as well as surgery in the form of gastrocnemius release or recession have been advocated as effective treatments to relieve pain in patients with isolated gastrocnemius contractures [2]. Evidence [11–14] is growing to support gastrocnemius recession for various foot and ankle pathologies. Barouk suggested that the indication for performing such a procedure is a clinically demonstrable gastrocnemius contracture that influences a variety of clinical conditions in the forefoot, hindfoot, and ankle [15]. However, the degree of contracture that should be considered significant is not well defined.

Nils Silfverskiöld (1888–1957), an orthopaedic surgeon described that the force required to dorsiflex the ankle in spastic equinus contracture decreased with knee flexion in isolated gastrocnemius contracture [16]. This description has been adapted for use in the Silfverskiöld test, a commonly performed clinical test to elicit GT. This is a nonweightbearing test used to differentiate between isolated gastrocnemius contracture and combined gastrocnemius–soleus complex contracture. It is performed by assessing the passive range of ankle dorsiflexion with the knee in extension and in flexion during application of a load under the

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forefoot. An increase in ankle dorsiflexion with the knee in flexion would suggest a degree of GT.

More recently however, weight bearing tests for GT have gained popularity due to advantages over their nonweightbearing counterparts. A weight bearing examination measures dorsiflexion of the foot on the lower leg rather than dorsiflexion isolated to the tibio-talar joint proportional to the patient's body weight rather than the examiner's applied force. It is therefore arguably more clinically relevant as it more closely reflects the load during gait and the position of a person's foot during loading. The lunge test, a weightbearing test for GT has been shown to have high intra and inter-observer with studies demonstrating an intraclass correlation of between 0.82 and 0.97 for inter-observer reliability, and between 0.88 and 0.97 for intra-observer reliability [17–20]. Furthermore, a recent study has suggested that the limiting effect of the gastrocnemius on ankle dorsiflexion during a weightbearing test can be eliminated with the knee flexed to 20° or more [21,22]. Weightbearing and nonweightbearing tests should not be used interchangeably as measures of ankle-foot dorsiflexion due to statistically significant difference between the two measures [23].

There have been a small number of studies in the literature that have attempted to quantify GT [3,24,25]; however, all involved small numbers and lacked applicability to the general population. Given the aforementioned trend toward operative intervention for GT, it is imperative to determine to what degree GT may be present in asymptomatic individuals. This knowledge would help guide clinicians in their management of patients and prevent over-treatment.

The aims of our study were, therefore, to quantify gastrocnemius tightness in the normal population without any known pathology and identify any variation in GT due to participant demographics.

2. Methods

Following ethical approval (REC reference: 14/ES/1089), healthy consenting adults were recruited into the study between February 2016 and January 2017. Potential participants were screened for exclusion criteria (Table 1). The majority of subjects were staff, students, and patient relatives from within our institution.

Standard demographics were recorded via a brief medical questionnaire. This included age, sex, gender, height, weight, hand dominance and ethnicity. Participants were also asked to rate their level of weekly physical activity (defined as a minimum of 30 min sessions) categorised as; hardly ever, less than once a week, once a week, two to three times a week and more than three times a week.

2.1. Testing procedure

A weightbearing lunge test was used to assess ankle-foot dorsiflexion with the knee flexed to at least 20° and the knee fully extended on both limbs. Ankle-foot dorsiflexion for this study was defined as the number of degrees the participant's foot could dorsiflex with respect to their lower leg (Fig. 1). Ankle-foot dorsiflexion was measured using a digital inclinometer (ACUMAR Single digital inclinometer Model number: ACU001, Lafayette Instrument Company, Indiana, USA). The use of digital inclinometers has shown excellent intra- and inter-user reliability in similar applications [19,20].

Participants were asked to be barefoot during testing. The digital inclinometer was placed around the lateral aspect of the ankle and secured using a Velcro® strap ensuring that the device

Table 1
Exclusion criteria for study participation.

Exclusion criteria
Diagnosis of foot and ankle pathology
Previous foot and ankle surgery
Pregnancy
Systemic disease affecting the musculoskeletal system
Knee pain/knee stiffness
Age < 18 years

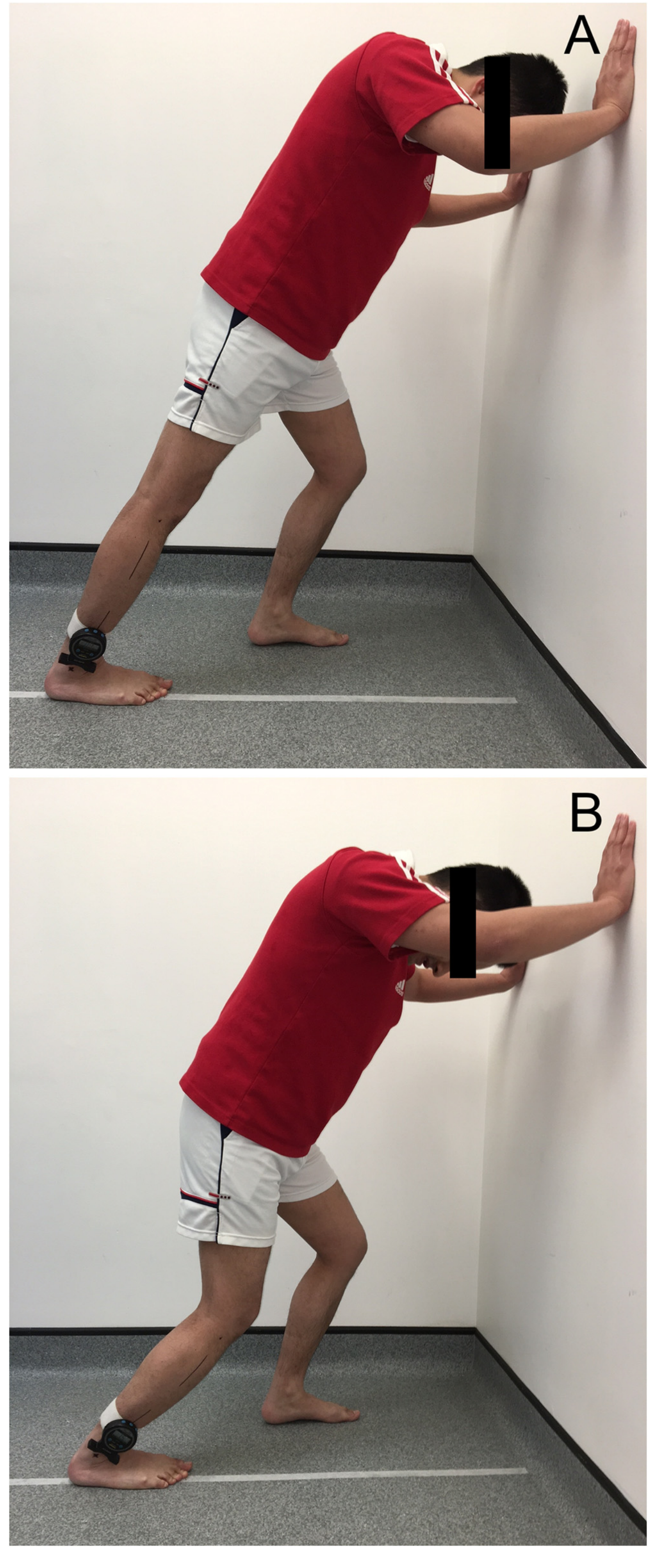

Fig. 1. A participant demonstrating the lunge test with an inclinometer applied above the ankle used to measure ankle dorsiflexion with the knee extended (A) and with the knee flexed to at least 20° (B).

was aligned with the longitudinal axis of the fibula. This was marked using a nonpermanent marker to ensure consistency of the position [26]. Subjects were first asked to stand with a natural stance with feet perpendicular to the wall and with the ankle joint at neutral. The inclinometer was then calibrated to 0° in this position. Participants were then asked to lunge against a wall using their hands to support themselves. Examiners ensured that the knee on the measured side was extended and that the contralateral leg was positioned in front with the knee flexed (Fig. 1A). Maximal dorsiflexion was measured with the heel firmly on the ground and with the second metatarsal aligned perpendicular to the wall. The use of tape on the floor perpendicular to the wall acted as a visual aid to this. Maximal ankle dorsiflexion was measured again with the ipsilateral knee flexed to at least 20° (in most cases the knee was flexed to over 30°) thereby eliminating the effect of the gastrocnemius (Fig. 1B). The difference between these two values was calculated and was referred to as the ankle-foot dorsiflexion index (ADI), a measure of gastrocnemius tightness. The digital inclinometer was then positioned on the other leg and the ADI was measured using the same methodology.

For the first twenty participants, multiple readings were taken from more than one examiner to confirm similar levels of inter and intra-observer reliability reported in the literature. Intraclass correlation coefficients of 0.958 (knee extended) and 0.969 (knee flexed) were calculated for inter-observer reliability, and 0.955 (knee extended) and 0.977 (knee flexed) for intra-observer reliability were calculated (absolute agreement, two-way mixed-effects model). For the remainder of the study single measurements were taken for each leg by one examiner.

2.2. Statistics

Statistics were undertaken using SPSS 24.0 (IBM, Armonk, New York). Ranges of ankle dorsiflexion with the knee extended and the knee flexed were plotted using histograms. The ankle-foot dorsiflexion difference was defined as the difference between maximal ankle-foot dorsiflexion with the knee in full extension and maximal ankle-foot dorsiflexion with the knee flexed was also plotted using a histogram to identify the distribution of the data amongst the tested population. Data was expressed as Mean ± SD. Any differences in the gender, side tested, ethnicity, side dominance and age were assessed using the Student T-test, or ANOVA as appropriate, with a P value <0.05, indicating statistical significance. Correlative analysis was performed for age, height, BMI and levels of physical activity by calculating the Pearson's correlation coefficient.

Sample size was determined using the following formula [27]:

$$n = 2^{*}(Z_{\alpha} + Z_{\beta})^{2} * SD^{2}/(\text{Effect Size})^{2}$$

where for a 2-sided $\alpha = 0.05$, Z_{α} equates to a constant of 1.96 and for a $\beta = 0.05$ Z_{β} equates to a constant of 1.64. In our pilot sample the SD was 3.9° and we aimed to detect a minimum effect size of 1°, therefore the sample size required was:

$$n = 2 * (1.96 + 1.64)^{2} * 5^{2}/1^{2}$$

$$n = 394$$

Therefore, we set our target sample size to 400 participants.

3. Results

Four hundred and eighty-nine subjects were screened, Eighty-nine subjects met exclusion criteria (61 had either a diagnosis of or had previous surgery for foot and pathology; 12 were less than 18 years of age; 11 had knee pain/stiffness and 5 had a diagnosis of systemic musculoskeletal disease) leaving 800 limbs in 400 subjects (161 men and 239 women) who were recruited to the study. The mean age of the participants was 40.2 ± 13.1 years. The mean height and BMI of participants were 1.68 ± 0.100 m and 25.4 ± 4.55 kg/m^{2} respectively. Five broad ethnic groups (Table 3) and 61 occupations were represented.

There was a wide distribution of absolute values of ankle-foot dorsiflexion ranging from 8 to 52 ° (Fig. 2 and Table 2). The mean ankle-foot dorsiflexion in 800 feet with the knee extended was found to be 26.52 ± 6.85° and the mean ankle-foot dorsiflexion with the knee flexed (by at least 20°) was 32.56 ± 6.74°.

The ankle-foot dorsiflexion index (ADI) ranged from 0 to19° and the mean was found to be 6.04 ± 3.49°. The distribution of results is shown in Fig. 3. The data approximates to a normal distribution as illustrated by the normality lines. The ADI value 2 standard deviations about the mean was found to 13.02°.

A small difference was noted in the ADI between participant's side dominance (means: Right 5.96 ± 3.46° Left 6.13 ± 3.51°) and

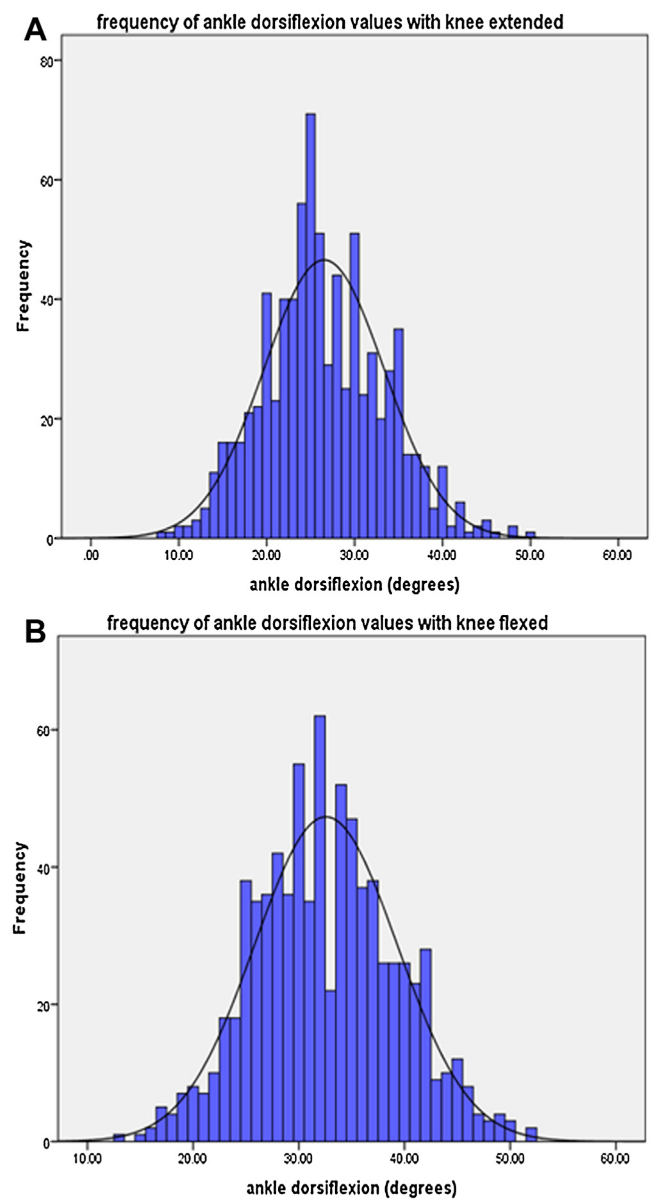

Fig. 2. Histograms showing frequency of ankle dorsiflexion (in degrees) with the knee in extension (A) and in flexion (B). Normality lines show the approximate distribution of data.

Table 2
Mean ankle dorsiflexion values and mean ADI values classified by age. Values are shown with standard deviations in degrees to 2 decimal places.

Age range (years)	No. participants (no. feet)	Mean ankle dorsiflexion with knee extended (°)	Mean ankle dorsiflexion with knee flexion (°)	Mean ADI (°)
18–30	110 (220)	27.40 ± 6.62	32.67 ± 6.52	5.30 ± 3.38
31–40	105 (210)	27.29 ± 6.74	33.41 ± 6.52	6.12 ± 3.49
41–50	88 (176)	26.69 ± 6.89	32.97 ± 7.01	6.28 ± 3.34
51–60	68 (136)	24.62 ± 7.32	31.28 ± 7.03	6.55 ± 3.51
>60	29 (58)	24.29 ± 5.60	30.86 ± 6.30	6.70 ± 3.85
All participants	400 (800)	26.52 ± 6.85	32.56 ± 6.74	6.04 ± 3.49

Table 3
Mean ankle dorsiflexion values and mean ADI values in different ethnic groups. Values are shown with standard deviations in degrees to 2 decimal places.

Ethnicity	No. participants	Mean age (years)	Mean ankle dorsiflexion with knee extended (°)	Mean ankle dorsiflexion with knee flexion (°)	Mean ADI (°)
White British	208	40.46 ± 13.64	25.68 ± 6.45	31.31 ± 6.36	5.64 ± 3.43
White-Other	29	41.93 ± 13.66	26.38 ± 7.09	32.00 ± 6.37	5.62 ± 3.12
Asian sub-continent	69	39.75 ± 12.40	27.59 ± 7.23	33.86 ± 7.16	6.27 ± 3.51
South-East Asian	31	40.32 ± 14.39	28.84 ± 7.25	35.08 ± 7.07	6.24 ± 3.39
Afro-Caribbean	37	41.54 ± 11.36	25.42 ± 6.94	33.68 ± 6.46	8.26 ± 3.52
Other	26 (not included in sub-analysis)				

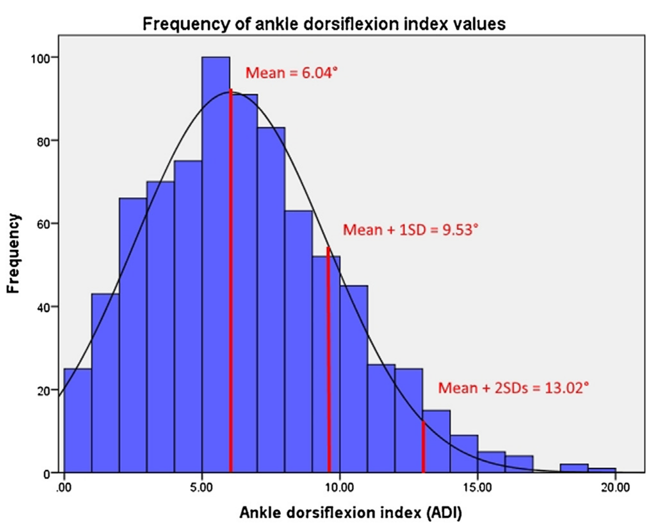

Fig. 3. Histogram showing frequency of ankle foot dorsiflexion index (ADI) expressed in degrees. The black curved line highlights the general distribution of results. Red lines show mean ADI, mean +1 and 2 standard deviations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

between male and female participants (means: Male 5.90 ± 3.24° Female 6.14 ± 3.64°) However these differences were not found to be statistically significant. Height and BMI of our study population were found not to be correlated with ADI.

3.1. Results by age

The number of participants and mean ADI within each age range is shown in Table 2.

The results show that mean ankle-foot dorsiflexion with the knee in extension decreases with age. This is supported by a Pearson's correlation co-efficient of $r = -0.144$ ($P = 0.0003$). The mean ADI was observed to increase with age. This was confirmed by correlative analysis with a Pearson's correlation co-efficient of $r = 0.132$ ($P = 0.0016$).

3.2. Results by ethnicity

Although data was collected on participants from over 20 ethnicities, subjects were grouped into broad ethnic groups for analysis. The results of each broad group are shown in Table 3.

The most common ethnicity in our study population was White British, accounting for over 50%. No significant difference was observed in the ages or levels of physical activity of participants from different ethnic backgrounds. The Afro-Caribbean cohort had the highest ADI amongst the different ethnic groups (8.26° ± 3.52 °), which was statistically significantly higher (P values all <0.05) compared to all other groups with the numbers available.

3.3. Results by physical activity

Data regarding physical activity was collected from 389 out of 400 participants. The results are shown in Table 4.

No statistically significant difference was noted in the age of participants between the groups and no significant difference was

Table 4
Mean ankle dorsiflexion values and mean ADI values classified by level of physical activity. Values are shown with standard deviations in degrees and to 2 decimal places.

Physical activity	No. participants	Mean age (years)	Mean ankle dorsiflexion with knee extended (°)	Mean ankle dorsiflexion with knee flexion (°)	Mean ADI (°)
Hardly ever	55	41.85 ± 12.40	26.39 ± 7.17	32.92 ± 6.74	6.53 ± 3.16
Less than once a week	44	40.89 ± 11.39	27.08 ± 7.86	33.81 ± 7.57	6.73 ± 3.46
Once a week	91	39.15 ± 13.27	26.16 ± 6.67	32.13 ± 6.57	5.97 ± 3.42
2–3 times a week	104	38.13 ± 13.66	26.41 ± 6.94	32.35 ± 7.00	5.93 ± 3.59
>3 times a week	95	41.27 ± 13.36	26.99 ± 6.20	32.71 ± 6.11	5.71 ± 3.64

detected in absolute ankle dorsiflexion with the knee extended or flexed. The mean ADI decreased with the level of participant reported physical activity. This was supported by a Pearson's correlation co-efficient of $r = -0.88$ ($P = 0.015$).

4. Discussion

Our study is the first to quantify gastrocnemius tightness in a general large healthy adult population and stratify results according to patient demographics. The previous largest study was of 59 participants but all were within the ages of 18–35 [24]. With 800 data points in 400 subjects our study carries significant weight in quantifying gastrocnemius tightness.

The range of ankle-foot dorsiflexion reported in our study is generally higher than 20°, which is close to the maximal range possible at the tibio-talar joint [28]. Our study uses a weightbearing lunge test which does not isolate movement solely at the ankle joint and effectively measures tibia to floor motion, which arguably is a more clinically relevant marker of ankle function [26]. Movement at other surrounding joints such as the mid-foot will also contribute to the maximal ankle-foot dorsiflexion using this test.

Because the lunge test is simple to do and is reproducible and is a weightbearing test, we believe that it is a clinically relevant test. Weight-bearing lunge tests have been validated in comparison to non-weight-bearing tests and found to be accurate [29]. Proponents of non-weight-bearing tests emphasise the importance of adequately stabilising the subtalar and midfoot joints during testing to eliminate the effect of movement of these joints during testing [21]. However, during the weight-bearing tests, these joints are already loaded during testing with the knee extended, and this may partly contribute to the increased values of absolute dorsiflexion seen with this method of testing. Furthermore, since the ADI is a measured difference between dorsiflexion with the knee extended and flexed, the contribution of hindfoot and midfoot joints is effectively eliminated.

We have found that the measurements of ankle-foot dorsiflexion both with the knee extended and the knee flexed to vary widely within our population (8–52°). In contrast the ADI (difference of ankle dorsiflexion between the knee flexed and the knee extended) has a much lower spread (0–19°). We therefore propose the ADI as a better reflection of gastrocnemius tightness.

The observed ADI in our study population approximates to a normal distribution with the normality line applied in Fig. 2 providing a good fit. Our mean ADI was found to be $6.04 \pm 3.49°$. Previous studies have calculated the average ADI but have found the difference to be 9 and 10° respectively [3,24]. DiGiovanni's study assessed 34 subjects [3] and Baumbach's 59 subjects [24]. Different methods were used to assess ankle dorsiflexion in the 2 studies: DiGiovanni used an electro goniometer during a non-weight-bearing test while Baumbach's group used a mixture of nonweightbearing and weightbearing tests using a standard goniometer. Jastifer and Marston have also investigated gastrocnemius contracture in patients with and without foot pathology using a non weight-bearing range of movement device [25]. They found that the pathological group had lower mean ankle dorsiflexion (11.6°) compared with their controls (17.2°) with the knee in extension. However comparative ankle dorsiflexion with the knee in flexion was not reported.

Other studies have assessed ankle dorsiflexion with knee extension using different measurement techniques [20,30] and have all shown varying results. This highlights the highly variable and non-standardised methods used to assess ankle dorsiflexion.

We feel that the use of a simple and reproducible standardised test such as the lunge test in combination with an inclinometer has great applicability in the clinical setting.

Our study has not demonstrated an association between gastrocnemius tightness as measured by the ADI and sex, height and body weight. The results of this study show that ADI varies according to age, ethnicity and physical activity. It has been postulated that as people age, activity decreases and with limited exposure to range of motion, muscle tendon units fail to reach their ultimate length with regularity [31]. Davis's law relates to soft tissue modelling in response to demands and states that "when ligaments, or rather soft tissues, remain uninterruptedly in a loose or lax state, they will gradually shorten" [32]. A recent study has also shown that muscle stiffness and tone increase while elasticity decreases with age [33]. If the argument that decreased muscle activity and usage are related to shortening holds true, we would expect that people who are more active would display a lower ADI and therefore less gastrocnemius tightness. Indeed, when our results are analysed according to participant reported activity, there is a statistically significant negative correlation between levels of physical activity and ADI.

A statistically significant difference in ADI was also detected between broad ethnic groups, with the Afro-Caribbean cohort demonstrating a statistically significantly higher ADI. Although admittedly it is difficult to make any firm conclusions from the relatively small numbers within each ethnic group, the Afro-Carribbean cohort for example accounted for less than 10% of our tested population. There was however no difference in demographics and activity between ethnic groups samples and therefore suggests a possible genetic tendency to gastrocnemius tightness. Although no study has been performed comparing muscle tone, stiffness and elasticity between different ethnic groups, muscles biopsies have revealed that Afro-Caribbean muscle contains more type II and fewer type I muscle fibres [34]. Hypermobility is also thought to be more prevalent amongst this ethnic group [35] which further supports that genetics influences soft tissue properties.

This study was designed to assess gastrocnemius tightness in the general population without foot or ankle pathology. We accept that a limitation of this study is the possibility that some subjects might have subclinical issues that were not appreciated; this may, for example, result in restricted ankle dorsiflexion. However, these issues would not necessarily impact GT and with a large cohort we feel that this is representative of the normal asymptomatic population. With 800 measurements, this is the largest study to date assessing the effect of gastrocnemius tightness on ankle-foot dorsiflexion in the general population. Foot posture such as relatively low or high arches might be a confounding factor but as one measurement is being subtracted from another on the same subject regardless of foot posture to calculate the ADI, we feel that this potential confounder is eliminated.

Our results show that whilst range of ankle motion varied considerably, ADI ranged from 0 to 19° in our population with a mean of 6.04 and a standard deviation of 3.49°. Since roughly 95% of the population are covered within 2 standard deviations from the mean, we postulate that 97.5% of the population will have an ADI of less than 13° and suggest that patients who have an ADI of more than 13° could be considered as having a greater degree of gastrocnemius tightness as compared to the normal population. Although we cannot determine from this study whether greater degrees of GT necessarily correlate with pathology, patients with an ADI of greater than 13° may warrant specific treatment focused on GT (surgical and non-surgical) as part of the overall management plan for their underlying condition. Similarly, our findings question the degree of symptoms attributable to GT in patients with a measured ADI of less than 13°. Further work will be needed to determine the normal range of ADI in patients with foot and ankle pathology.

Our test using the lunge test method can be used for assessing patients in a clinical setting or testing subjects for research purposes. The values we put forward may also be used as the basis for future research and assessment. Work is ongoing to assess gastrocnemius tightness in the population of patients with foot and ankle pathology or back pain. We hope that the quantification of gastrocnemius tightness will aid in the diagnosis and monitoring as well as the decision making process with regards to offering surgery, such as a gastrocnemius recession.

5. Conclusion

This study utilises an easy and reproducible weightbearing lunge test to quantify isolated gastrocnemius tightness that can be used in both research and clinical settings. We have shown in a population of 800 healthy ankles that the range of ankle dorsiflexion varies widely and is therefore not a useful variable in itself. We recommend the ADI as a simple measure of isolated gastrocnemius tightness. The ADI data in our population approximated to a normal distribution with a range of 0–19° with a mean of $6.04 \pm 3.49°$. Our data suggests that an ADI of more than 13° lies outside 2 standard deviations and should be considered abnormal although age, ethnicity and physical activity may influence gastrocnemius tightness. Further work is required in patients with pathology to determine at what degree of tightness patients become symptomatic.

Conflicts of interest

There are no conflicts of interest to report from any of the authors.

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