

## Assessment of an electronic goniometer designed to measure equinus contracture

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**Abstract**—To achieve more objective and repeatable measurements of equinus contracture, we developed the equinometer, a device that allows the measurement of ankle range of motion under controlled torque conditions. This study assessed its accuracy across different subjects and examiners. Two examiners used the equinometer to measure the angle of ankle dorsiflexion at 15 N•m torque on five subjects. Accounting for variation in measurements because of subjects, examiners, and placement of device, we used linear mixed-effects models. Accounting for the variation because of subject, different placements of the equinometer within each subject and the adjustment for the effects of examiner and trial sequence, the standard deviation was 0.94°, 95% confidence interval (0.79°, 1.13°). An upper standard deviation of 1.36° is felt to be acceptable for clinical investigation.

**Key words:** ankle, equinus, goniometer accuracy.

### INTRODUCTION

The condition in which ankle dorsiflexion is restricted is known as equinus contracture (EC). Equinus contracture is a common clinical finding in individuals with neurological impairment [1–7]. It has also been found to have a significant prevalence among individuals with forefoot disorders, flat feet, and plantar ulcers [1,8–10]. A spectrum of therapeutic interventions have been recom-

mended, from more conservative stretching protocols to multiple surgical techniques aimed at lengthening the posterior musculotendinous structures of the leg. Diagnosis of EC by physical examination alone is difficult and depends on the examiner's experience [3]. The magnitude of force applied to the plantar surface of the foot during physical examination and the site of load application determine the applied torque, which directly influences the ankle dorsiflexion angle. Similarly, identification of the anatomical landmarks used clinically to determine the ankle dorsiflexion angle could greatly influence the measured range of motion.

**Abbreviations:** CI = confidence interval, EC = equinus contracture, SD = standard deviation.

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Since EC is a condition that (1) is difficult for untrained examiners to evaluate, (2) may have a deleterious effect on foot function and (3), in most circumstances, may respond to treatment, an instrument that could provide physicians and researchers with accurate and reliable measurements would be beneficial.

Weaver et al. developed an instrument controlling for torque and angle measurements [11]. It is a custom-made device consisting of a potentiometer to measure ankle angles and a load cell to monitor and control the amount of torque applied to the foot. The current study aims to determine the test-retest reliability and the interrater reliability of the developed instrument in the measurement of EC of the ankle.

## MATERIALS AND METHODS

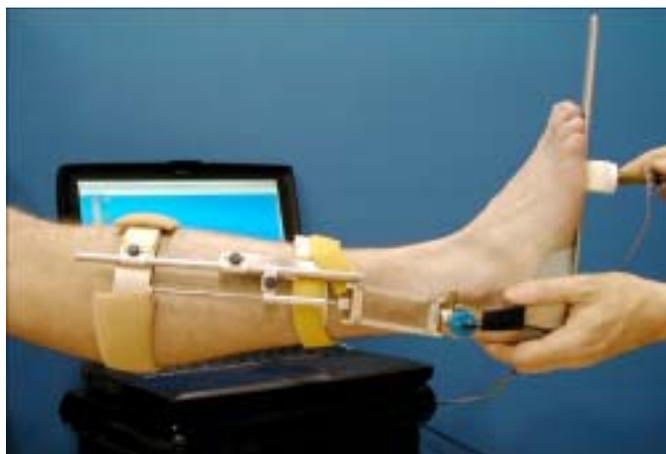
### Subjects Enrollment

Subsequent to obtaining the Institutional Review Board (IRB) approval, we enrolled five subjects, two males and three females. These subjects had no history of foot and ankle trauma, surgery, or pain. They were healthy subjects with no history of neurological disease or systemic disease potentially affecting the foot and ankle. They had no apparent foot deformity on clinical examination.

### Equinometer Testing

Maximum ankle dorsiflexion was measured with the subject seated with the leg in extension with the use of a custom fabricated device we call an "equinometer" (Figure 1). This instrument is similar to an electrogoniometer in which a ring potentiometer measures the angle between the lateral leg attachment and the underlying footplate. A force transducer is positioned under the metatarsal heads and measures the amount of force applied to the foot.

During the application of the device, the examiner must first identify the fibula and the second metatarsal head and measure the distance from the tip of the fibula to the center of the second metatarsal head (i.e., the moment arm of the applied force). The device is then carefully positioned alongside the lateral aspect of the leg, in line with the fibula, and stabilized with two Velcro straps. The fibula serves as a very reproducible anatomic landmark, and the tip of the lateral malleolus approximates the center of rotation of the ankle joint. The footplate and



**Figure 1.**

Use of equinometer. Ankle dorsiflexion was measured with a custom fabricated instrument. This instrument measures ankle dorsiflexion angle along with torque applied by clinician to subject's foot. Torque and angle are displayed and recorded on a Macintosh computer.

accompanying force transducer are attached to the under-surface of the neutrally aligned foot. The ankle angle and applied force are sampled at 57 Hz with a Macintosh G3 series computer, running a customized LabVIEW™ virtual instrument (National Instruments Corporation, Austin, Texas). The software displays ankle position and torque in the sagittal plane. Both visual and auditory feedbacks are provided to allow the examiner to control the torque at  $15 \text{ N}\cdot\text{m} \pm 0.1 \text{ N}\cdot\text{m}$ . Angular position of the ankle is recorded for 2 s with the torque in control range, and then an average is calculated.

### Testing Protocol

Our protocol included two examiners and five subjects. Each subject had a series of 18 consecutive measurements divided into six sets of three trials per set. Each examiner in random order alternately applied and removed the device between each set. All trials were performed on the same day. Before the first trial, the examiner applied a 30 s passive stretch. This stretch was followed by a 30 s rest period before the first trial. Between each trial, a 1 min rest period was observed to allow for muscle-tendon unit relaxation.

### Statistical Methods

We assessed the precision of the equinometer by calculating the standard deviation (SD) of the angle of ankle dorsiflexion measured by the equinometer. Before

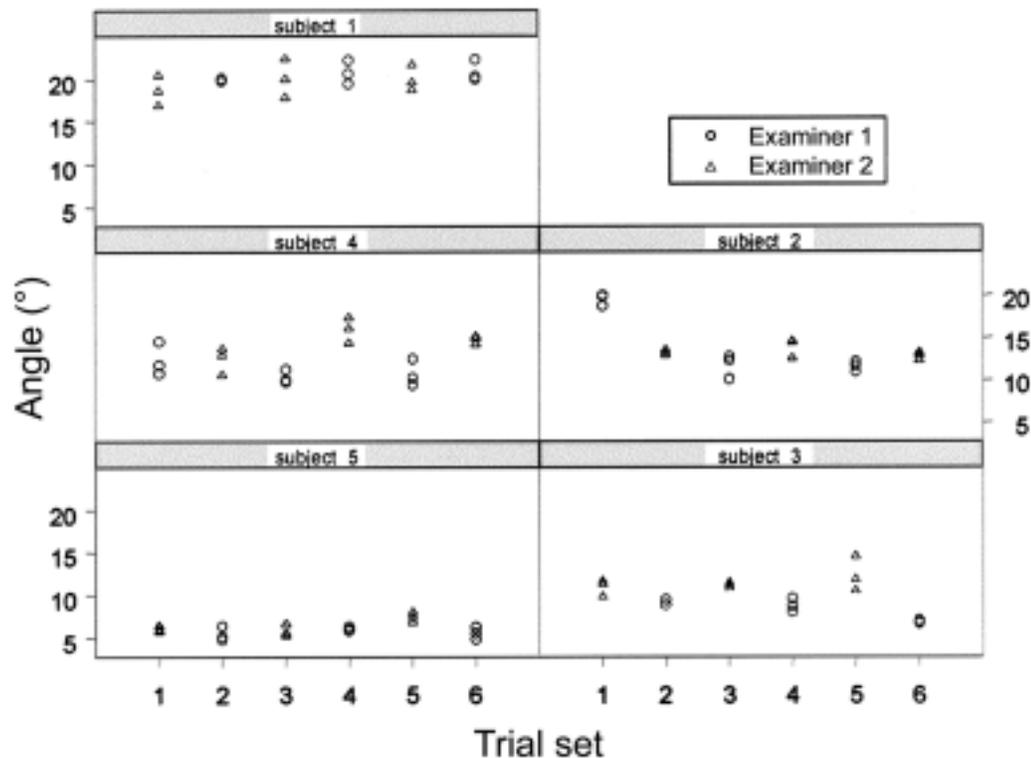
analysis, we determined that an SD of less than  $2^\circ$  was a reasonable range of precision. We used linear mixed-effects models to obtain estimates and 95 percent confidence intervals (CI) for the SD, accounting for differences in subjects, examiners, and placement of device [12]. These models are a generalization of linear regression, allowing the estimation of the association of an outcome measure with predictor variables of interest (the latter are classified as fixed effects) and the estimation of the variation in the outcome measure because of parameters, which are selected randomly. Subject and placement were considered random effects. Examiner and trial number were modeled as fixed effects. Thus, these models allow the estimation of the difference in ankle dorsiflexion measurement because of the examiner, the change in angle because of successive trial, and the SD of ankle dorsiflexion angle attributable to variation in subject and placement within subject. We tested the significance of the contribution of the random effects using the likelihood ratio test, and the contribution of the fixed effects using conditional F-tests. Statistical analysis was

performed using S-PLUS 2000 (Insightful Corporation, Seattle, Washington).

## RESULTS

**Figure 2** shows the measurements of ankle dorsiflexion by the equinometer across the six sets of trials for each of the five subjects. When we separate out the variation because of the subject and different placements of the equinometer within each subject, the SD of ankle dorsiflexion was calculated as  $1.14^\circ$  with 95 percent CI ( $0.95^\circ$ ,  $1.36^\circ$ ). In addition, accounting for the effects of examiner and trial sequence reduced the SD to  $0.94^\circ$ , 95 percent CI ( $0.79^\circ$ ,  $1.13^\circ$ ).

Both subjects (calculated SD =  $5.1^\circ$ ) and placement of the equinometer within subject (calculated SD =  $1.8^\circ$ ) contributed significantly to the variation of ankle dorsiflexion, ( $p < 0.0001$  for both variables). Examiner was not significantly related to ankle dorsiflexion ( $p = 0.14$ ). However, if we exclude the first set of three trials from



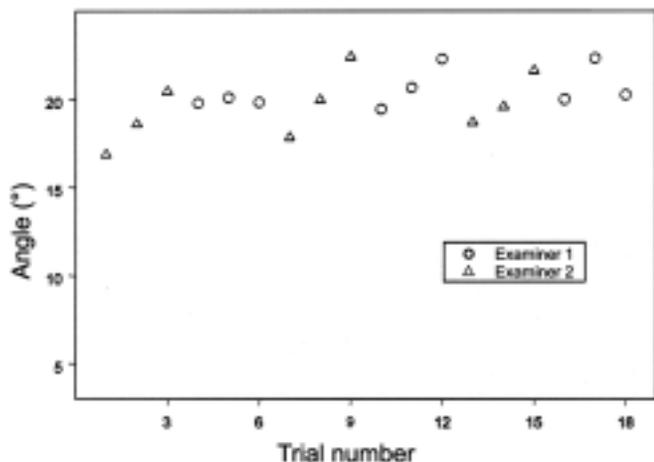
**Figure 2.**

Angle of ankle dorsiflexion measured by equinometer. Each subject is shown in a separate panel. Subjects underwent six consecutive trial sets with alternating examiners for each set.

subject 2, then examiner 2 tended to measure ankle dorsiflexion higher (by an average  $1.6^\circ$ ) than examiner 1 ( $p = 0.0025$ ). We also found a significant effect because of the three-trial sequence within subject, within placement: the angle tended to be higher with each successive trial by approximately  $0.6^\circ$ ,  $p < 0.0001$ . **Figure 3** illustrates this effect for subject 1 in whom the effect was the strongest. Trial sequences with the widest variation were those where angle increased the most steeply across the three-trial sequence. However, when we looked at the sequence of 18 trials within each subject without accounting for placement, the effect of trial was no longer significant (slope =  $0.1^\circ$ ,  $p = 0.077$ ).

## DISCUSSION

When applying the statistical model that best fits the data (accounting for variation in subject, examiner reading, placement of device, and trial sequence), we found that the upper range of the 95 percent CI for the SD was  $1.13^\circ$ . Even in the less accurate situation where the effects of examiner and trial sequence were not separated, the upper range was  $1.36^\circ$ . An upper SD of  $1.36^\circ$  is felt to be acceptable for clinical investigation. These results suggest that the equinometer is a precise instrument for measuring ankle dorsiflexion once variation because of subject and placement is considered. When using the equinometer, one should minimize changing



**Figure 3.** Angle of ankle dorsiflexion measured by equinometer for subject 1. Subjects underwent 18 trials. After every three trials, examiners alternated and equinometer was removed and reapplied.

the placement of the device on a subject because this contributes to measurement error.

When excluding the first three-trial set from subject 2, one examiner tended to measure ankle dorsiflexion consistently higher than the other. Thus, there may be some bias in angle measurement by the equinometer because of its application by different examiners. Future use of the equinometer may elucidate this phenomenon further. We also observed an increase in ankle dorsiflexion across successive measurements within the three-trial set. One hypothesis that might explain this effect could be the increased stretching of the musculotendinous unit from repeated trials in quick succession. When this effect is accounted for, the precision of the equinometer increased. However, there was less evidence for increased stretching of the musculotendinous unit across the entire sequence of 18 trials. The process of removing and reapplying the equinometer between each of the six three-trial sets may have provided some time for the musculotendinous unit to return to a more normal state. Although the current study cannot clearly determine the effect of repeat measurements and stretching of the musculotendinous unit, we recommend that when using the equinometer, a rest period of a few minutes should be included between each trial to minimize possible stretching of the musculotendinous unit.

A number of factors can influence clinical assessment of EC. The amount of torque applied to the foot during examination and the anatomic landmarks used to measure the angle of ankle dorsiflexion are the most important ones. To control for them, we have developed an instrument whose ultimate goal is to provide clinicians and researchers with more objective and reproducible measurements of EC. The current study suggests that the developed equinometer is an appropriate instrument for measuring ankle dorsiflexion.

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