Department of Veterans Affairs

Journal of Rehabilitation Research and Development Vol. 38 No. 5, September/October 2001
Pages 471–475

Design and validation of an instrument package designed to increase the reliability of ankle range of motion measurements

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Abstract—Objective: To validate a novel device termed the equinometer, which is designed to accurately measure ankle dorsiflexion. Design: Test retest reliability analysis using serial measurements of dorsiflexion endpoint in a group of normal individuals. Setting: Motion analysis laboratory. Participants: Ten healthy individuals. Primary Outcome Measure: The mean and standard deviation of the absolute difference in dorsiflexion endpoint for the group. Results: The mean absolute change in dorsiflexion endpoint for the group was 0.45 degrees with a standard deviation of 0.43 degrees. Conclusions: With the use of the device described, the mean change in dorsiflexion endpoint was well within acceptable clinical limits. The reliability of measurements obtained with the equinometer exceeds that which has been published with other techniques and devices.

Key words: *ankle, contracture, equinus, goniometer, reliability.*

This material is based upon work supported by the Department of Veterans Affairs, Veterans Health Administration, Rehabilitation Research and Development Service (project number F2200-C). Dr. Bruce Sangeorzan is Director, Rehabilitation Research Center of Excellence, at VA Puget Sound Health Care System, Seattle, WA.

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INTRODUCTION

Equinus contracture has been associated with increased plantar pressure and ulceration (1). Many therapeutic, pharmacological, and surgical interventions are therefore aimed at increasing the range of motion (ROM) of this joint. For proper evaluations of such interventions, the accurate measurement of ankle ROM is required.

The accurate assessment of joint ROM in general and ankle ROM in particular can be surprisingly difficult. Even when trained examiners are used, joint motion measurements have been shown to have poor inter- and intraexaminer reliability (2–4). The repeatability of these measures depends on a number of factors, including the experience of the examiner (5), the technique used in the assessment (3), the subjects studied (6–8), and the device used, if any (5,9–12). When joint ROM is assessed with a goniometer, measurement accuracy is also joint specific (12,13).

Joints with short, complex adjacent segments and poor landmarks for device alignment, such as the foot, are particularly difficult to measure. Accurate measurement of tibiotalar joint motion is complicated by a number of factors. Uncontrolled motion at the subtalar joint can produce apparent plantarflexion or dorsiflexion. The foot is

shorter than other segments and can be deformed at the midfoot joints. The ankle plantarflexors, which have a large physiologic cross-sectional area and even modest levels of activation, such as are present with incomplete relaxation during an examination, can give the erroneous impression of an "endpoint." Such incomplete relaxation will result in the recording of a position of maximum dorsiflexion that is too plantarflexed. The posterior musculature also has a significant in-series elastic component and the dorsiflexion endpoint measured in a given subject can vary significantly depending on the force applied to the sole of the foot during the assessment.

Finally, the anatomic landmarks in the foot and leg used to align the goniometer can be deceptively difficult to localize. Perhaps as a result of these factors, ROM measurements at the tibiotalar joint have not only been shown to be more unreliable than those at other joints in the lower limb (2,13) but have also been reported to have errors as high as 20 to 30 degrees (6). Despite this, no study concerning ankle ROM has attempted to control all the above issues, and indeed the majority of studies have made no mention of them.

Because of the need for accurate and precise measurements of equinus contracture, we have developed and validated an innovative instrument termed the equinometer, intended to reliably measure the dorsiflexion endpoint by addressing the issues above.

METHODS

The following requirements were used to guide the design and development of the equinometer: The instrument will control for muscle activity in the ankle dorsiflexors and plantarflexors, the in-series elastic elements of the calf musculature, and motion of the hindfoot. Additionally, the instrument should be constructed so that it may be aligned over readily identified anatomic landmarks.

Design of the Instrument

The custom instrument includes an electrogoniometer and a footplate designed to eliminate hindfoot motion. The device features a linkage that corrects for misalignment of the goniometer with the instantaneous axis of rotation of the foot. To control for in-series elasticity of the plantarflexor muscles the footplate is integrated with a load cell that permits calculation of the moment applied by the examiner. In addition, a portable EMG unit verifies that the subject is relaxed during examination. Finally, a laptop computer visually displays and processes the data and guides the examiner through the test procedure.

As shown in **Figure 1**, the portion of the instrument fitted to the patient has two component parts, a shank component and a foot component. The former is fit and aligned to the subject's shank with soft Velcro straps. A fixed-length parallelogram transfer apparatus (four-bar linkage) attached to the shank component permits translation of the foot's axis of rotation without an apparent change in plantarflexion or dorsiflexion; thus device alignment is greatly simplified. The foot component joins to the shank component at a rotary potentiometer (New England Instrument Co., 78CBB103-10K Ohm) that records the angular position of the foot in relation to the shank component. The foot component also includes a metatarsal platform that can be positioned under the metatarsal heads. This comprises an aluminum plate with a plastic grip. Between the plate and the grip is a compressive load cell (Transducer Techniques SLB-50), which measures the force applied to the metatarsal region of the subject's foot. Because hindfoot position can be influenced by subtalar axis, the hindfoot is captured in the neutral position in a stiff heel cup that is fixed to the footplate.

A power supply and signal conditioner unit powers and amplifies the potentiometer and load cell. A two-channel EMG amplifier records the surface electromyographic signal over the tibialis anterior and soleus muscles. The data from the load cell, potentiometer, and EMG amplifier are recorded and displayed in real time on an Apple G3 laptop computer that features a National Instruments DAQCard 1200 data acquisition card operating at a sample rate of 100 Hz. A schematic of the device is shown in **Figure 2**.

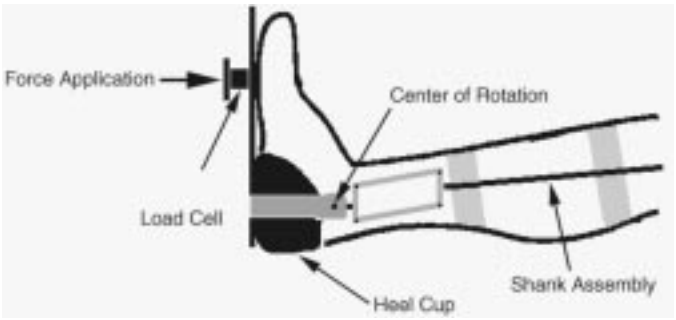

Figure 1.
Equinometer design showing load cell and point of force application.

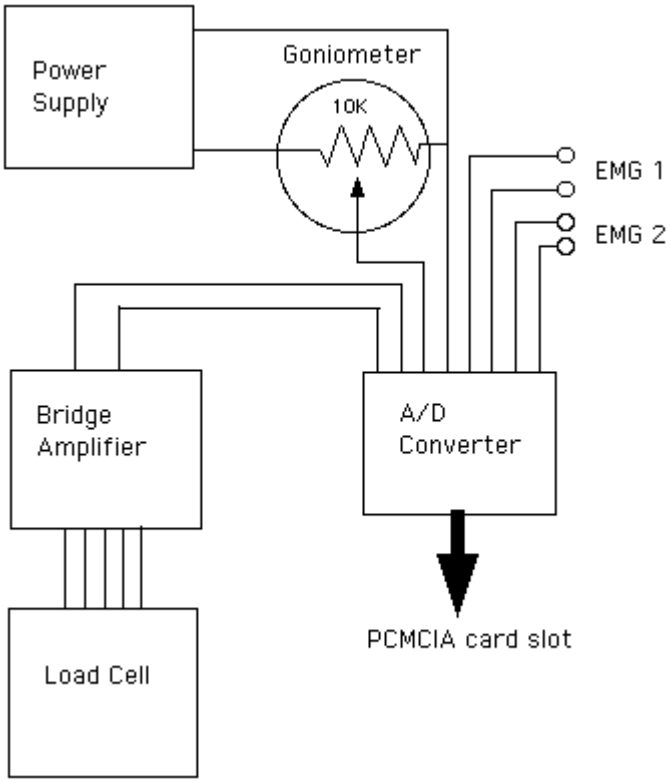

Figure 2.
Equinometer data collection circuitry.

Custom software was developed that permits calibration and use of the device. The software prompts the examiner for the distance between the load application point and the ankle joint in order to compute the applied torque. Angle and torque levels are displayed in real time along with an indication of when the prescribed torque level has been achieved. Beeps indicate the beginning and end of the test. An angle and torque versus time plot is generated along with the average angle at the prescribed torque applied at the ankle over a prescribed time interval.

The torque applied across the ankle of all subjects during the assessment was 10 Newton meters (N•m). A single torque was used in all patients to decreased the variability in dorsiflexion endpoint, which would have resulted from different amounts of stretch produced if the torque applied to each patient was allowed to vary. This standardized value was arrived at by averaging the torque applied by three clinicians during their assessment of the heelcord of the same normal subject. This was chosen because we felt it would represent the torque applied during office exam. The three individuals used were an attending orthopedic foot and ankle surgeon, an attending physiatrist with experience in lower-limb assessment, and an orthopedic foot fellow.

Data Collection Protocol

The same examiner did all the testing. The same protocol was followed for all subjects. The left lower limb of each subject was studied. The shank component of the device was attached to each subject and aligned to a line passing through the distal tip of the fibular head and the distal tip of the lateral malleolus. The Velcro straps were securely fastened so that there was no motion between the apparatus and the patient. Zero degrees of dorsiflexion or “neutral” was defined as the ankle position where the line defined by the footplate and the line defined by the bony landmarks above, subtended a 90-degree angle. Dorsiflexion from this “neutral” position was taken as positive. The foot assembly was applied and set so that the force transducer was located under the second metatarsal head. The distance between the center of ankle motion and the midpoint of the footplate was measured and entered into the software package. Surface EMG electrodes were placed over the tibialis anterior and soleus muscles. The capability of the surface EMG display to pick up minimal levels of plantarflexor activation was ensured by the presence in all subjects of a clear, recognizable surface EMG signal when each subject plantarflexed and dorsiflexed gently against the fingertips of the examiner.

Once the alignment was completed, the subject was allowed to sit in a comfortable position with his or her left knee fully extended. Two 30-second periods of passive stretch were applied to the ankle plantarflexors. After this, three trials were recorded. During each of the trials the foot was slowly brought to full dorsiflexion by the examiner applying a dorsally directed force (i.e., perpendicular to the foot) through the force transducer, to the plantar surface of the subject’s foot. The software package continuously calculated and displayed the torque applied about the subject’s ankle. An indicator was included on the computer display so that the examiner could restrict the torque applied to the foot to the prescribed level, ±1 N•m. When the torque applied was maintained at the prescribed torque level for five seconds, the trial was ended and the average ankle angle during that time period was displayed. During each trial, the examiner maintained the hindfoot in neutral and the dynamic EMG was monitored to ensure that the subject

was fully relaxed. Three trials were recorded and then averaged.

Validation Protocol

To evaluate the reliability of the measurements obtained with the instrument, ten normal subjects (six males and four females) were assessed on two consecutive days. Their average age was 36 years (SD 14.68). The dorsiflexion endpoint was measured with the use of the methods described above.

RESULTS

The entire procedure—application of the instrument and electrodes, passive stretching, and recording three trials—required approximately 10 minutes and was well tolerated by all subjects. The mean dorsiflexion endpoint for the ten subjects with knee extended was 6.7 degrees on day one and 6.7 degrees on day two. The mean absolute change for each of the ten subjects between the two data collection sessions was 0.45 degrees. The test retest correlation coefficient for the dorsiflexion endpoint with the knee extended was 0.983. The results are tabulated in **Table 1**.

DISCUSSION

Our data obtained with the equinometer compare favorably to data in other publications. Rome et al. (10) measured the mean dorsiflexion endpoint on two occasions in five normal subjects with a universal goniometer, an "electrogoniometer," and a "fluid goniometer." As in our study, the average dorsiflexion endpoint for the group did not change between the two measurements when the fluid goniometer or the electrogoniometer was used. There was a 1.5-degree change as measured by a standard universal goniometer from day to day.

Muwanga and Dove published test retest data on 32 normal subjects using a custom goniometer. This device included a metal plate applied to the sole of the foot with Velcro and was allowed to rotate within a second larger assembly, attached to a calibrated wheel. The authors report that the difference in maximum dorsiflexion was less than three degrees in 83 percent of the subjects and less than four degrees in 92.4 percent of the subjects (14). The maximum difference in dorsiflexion endpoint between day one and day two in our ten subjects was 1.53 degrees with a mean change of 0.45 degrees.

Other publications have relied on correlation coefficients to document the reliability of ankle range of motion measurements. These are calculated using repeated measurements of dorsiflexion endpoint in the same subjects. Although simple to calculate and common in the literature on joint ROM reliability, correlation coefficients are nonintuitive and do not directly translate into clinically meaningful estimates of reliability. We present it only to facilitate comparison with the literature. With the use of a single examiner and our group of ten subjects measured on two occasions, our correlation coefficient was 0.98, which exceeds the values 0.64 to 0.92 that previously have been published about tests using a single examiner (2,12,15,16).

Previous publications have used a variety of outcome measures to describe the reliability of various techniques for measuring dorsiflexion endpoint. These outcome measures have included the day-to-day change in the mean dorsiflexion endpoint for a group of subjects, correlation coefficients, as well as other measures. We have calculated a correlation coefficient and day-to-day change of mean dorsiflexion in order to facilitate comparison with the literature. We feel that a much more clinically useful measure is the mean absolute day-to-day change in the measure. The mean absolute change in dorsiflexion endpoint for our ten subjects was 0.45 degrees, with a standard deviation of 0.43. Therefore, with the equinometer, a change in dorsiflexion endpoint as small as 1.32 degrees may be recognized.

As noted previously, the clinical assessment of plantarflexion contractures with hand-held goniometers is deceptively difficult to do well. Some of the reasons for this include poor control of the subtalar joint, a lack of standardization of the torque applied to the foot,

Table 1.
Dorsiflexion data obtained with equinometer.

Day one average dorsiflexion endpoint (SD)	Day two average dorsiflexion endpoint (SD)	Average absolute change in dorsiflexion endpoint (SD)
6.7 (3.16)	6.7 (2.84)	0.45 (0.43)

incomplete muscle relaxation of the subject, and the use of nonstandardized landmarks during measurement. The design features of our innovative instrument, which we have termed the "equinometer," help to control for these variables. While other instruments have been developed to improve the accuracy of joint ROM measurement (10,12,14), we are not aware of any that include the elements of the instrument described herein. The equinometer has proven to be easy to apply to normal individuals and in the small number of subjects presented here the repeatability of the measurements exceeds that which has been previously published using other instruments.

While we feel that the results presented here are promising, they represent findings from a small group made up exclusively of normal individuals. Further studies with the use of larger numbers of subjects as well as subjects with neurological or orthopedic pathology are required.

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Submitted for publication October 5, 2000. Accepted in revised form May 30, 2001.