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Reliability of Gastrocnemius Pennation Angle Using Ultrasound with 15 Degree Adduction and Abduction in Standing Position

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Reliability of Gastrocnemius Pennation Angle Using Ultrasound with 15 Degree Adduction and Abduction in Standing Position

An Honors Thesis submitted in partial fulfillment of the requirements for Honors in the Department of Health and Human Sciences at Georgia Southern University

By

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Under the mentorship of Dr. Czech and Dr. Li

ABSTRACT

Pennation angle is formed when a pennate muscles contract and shorten. A pennate muscle has fascicles that attach obliquely to its tendon. In parallel, more fascicles can be aligned allowing for greater production of force. In previous research, pennation angle has been measured using ultrasound while in a laying supine position. The purpose of this study was to measure pennation angle of the gastrocnemius muscle with ultrasound while standing neutral, in a mechanically loaded position. 16 participants, one two separate days, had their ultrasound imaging taken in three different foot orientations: neutral, fifteen degree adduction / abduction positions. This information was then be analyzed using ImageJ software. This research shows the measurements of the gastrocnemius muscle pennation angle during standing are reliable, and can be used to study the effect of pennation angle on force production. As hypothesized, pennation angle measurements were reliable over a two day period while standing in an upright position. For laying in the prone position, the mean and standard deviations from the reliability of pennation angles were 9.4 ± 0.9 laterally and 12.6 ± 0.7 medially. For standing in the neutral position, the mean and standard deviation from the reliability of pennation angles were 9.5 ± 0.9 laterally and 12.3 ± 0.8 medially.

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Introduction

Human skeletal muscle architectures such as pennation angle, influence contractile force, and essentially power output during dynamic actions (McMahon, 2016).

Pennation angle is the angle formed between a muscle fiber and the deep aponeurosis. The angle is increased with muscle activation and contraction. With muscle fibers being the basic unit of muscle contraction, during a greater pennation angle, smaller components of force produced by muscle fibers will contribute to the overall muscle force (Zhou, et al. 2015). Studying pennation angles allows for the understanding of contraction mechanics at muscle level.

Studies regarding the muscle fascicle pennation angle (Zhou, Guang- Quan Chan, Poebe Zheng, & Yong-Ping, 2015) have been conducted with the use of real time ultrasound imaging. The studies displayed the numerous functions of an ultrasound, one of which is to provide an accurate and precise measurement of the pennation angle of a muscle. In this research, patients were placed in a supine position not allowing the muscle to be in a natural mechanically loaded position (Zhou et al., 2015). The method and needed skills for measuring the muscle fascicle pennation angle while in a standing/mechanically loaded position, have not been represented in previous research studies. In fact, the benefits of using a standing position for measurement of pennation angle have not been discussed. This method could potentially remove restrictions that are normally involved in the supinated position for subjects with disabilities or injuries, and allow the exploration of further research on the subject matter.

Pennation angle can be measured manually through the surface of a dissected muscle using a goniometer or through an automatic method in vivo using an imaging technique such as an ultrasound (Infantolio). Muscle imaging was used in (Hodges, P.W., Pengel, L.H.M., Herbert, R.D. Gandevia, and S.C., 2003) to show that ultrasonography could properly estimate muscle activity. They measured architectural parameters which included: pennation angle, fascicle lengths and muscle thickness. Ultrasonography is used to understand biological and bioelectrical characteristics of muscles. It can be used for sonomygraphy (SMG) which is a technique that can quantify the real time change of muscles under different contractions, angles and motions (Zhou et al., 2015) or to take static images which then can be further analyzed. An ultrasound is a proper non-invasive real time imaging for muscle structure (Zhou et al., 2015). The static images taken by the ultrasound can be analyzed to detect the fascicles and aponeuroses for calculating the pennation angle.

Previous studies have addressed the correlation between pennation angle and muscle force production, but in those studies the pennation angle was not taken in a mechanically loaded position. The purpose of this project is to determine the reliability of pennation angle measurements while in a standing position.

Methods

Participants

Sixteen young adult female participants ranging from 19 to 25 years of age volunteered for the study. The mean ages of the participants was 21.8 with a standard deviation of 1.6. The mean weight was 73.3 kg with a standard deviation of 18.8 kg, and mean height was 166.4 cm with a standard deviation of 6.2 cm. The participants were recruited from the university population and were considered to be recreationally active. The study protocol was approved by the local university ethics board and informed consent was obtained prior to testing.

Materials

Participants used the Biodex Unweighing System (Biodex Medical Systems, Shirley, New York) for support as they stood along tape that marked 15 degrees abduction and adduction positions. The ultrasound images of the gastrocnemius muscles were taken with the Terason t3000™ Ultrasound System (Terason t3000™, Chicago, Illinois). Aquasonic 100 Ultrasound Gel (Aquasonic 100, Clinton Township MI) was used on the probe of the ultrasound. ImageJ software (U. S. National Institutes of Health, Bethesda, Maryland) was used to detect the fascicles and aponeuroses for calculating the pennation angle. This data was saved in an Excel spreadsheet (Microsoft, Redmond, Washington) and statistically analyzed.

Procedures

The primary investigator, was trained by an ultrasound technician to properly operate the Terason ultrasound machine and the ImageJ software. In addition 15 degree adduction/ abduction positions, images were also taken in the laying supine positon and standing neutral. The ultrasound images of laying supine position and standing in neutral, were measured by two researchers to test reliability.

This allowed for the pennation angle images to be used for comparison to test the reliability of this method of measurement. Prior to any data collection, participants were given the conformed consent form and made aware of the purpose and risks associated with this research.

For the laying supine position, participants were directed to remove shoes, with feet hanging off the table, lay flat as possible on their stomach for 20 minutes. A measurement, in centimeters, was collected from the popliteal line to the lateral malleolus. Of that measurement, 30 percent of that value was marked as the site of image collection. The gastrocnemius muscle was then palpated to locate the middle of the muscle heads and the location was be marked with a permanent marker for reference during the ultrasound imaging. When correctly located, the ultrasound image displayed a clear view of the muscle fascicle and the deep aponeurosis. Three images were collected for both medial and lateral heads of right gastrocnemius. These images were saved and transferred to the ImageJ software.

Once the laying supine measurements were collected, the participants were instructed to stand in neutral position on a platform of the Biodex Unweighing System. To prevent the loss of balance, a bar for hand placement was provided to stabilize the stance. To ensure that the participant would not plantar flex, a mat underneath the machine was used for reference. The participants were instructed to contract the muscle to record an accurate image of the pennation angle in a mechanically loaded position. After three images of both medial and lateral heads of right gastrocnemius were collected, the participant was instructed to position themselves on the 15 degree abduction tape marking foot placement, and then 15 degree adduction. After a minimum of 24 hour separation, images were retaken in every position, totaling 72 ultrasound images per participant.

The ImageJ software was used to calculate the pennation angle of the images collected through ultrasound. To ensure an accurate measurement reading, a reference measure was used. The ultrasound image was synced to the imageJ software to provide an identical measurement scale. To calibrate the scale, the straight edge tool was selected and a line was drawn from one end of the reference measure to the other and then analyzed. Once calibrated, using the angle tool, a line was drawn along the muscle fascicle and was then connected to the deep aponeurosis. This provided the measurements of pennation angle. These measurements placed into Microsoft Excel and categorized by the participant, position, and the day on which they participated.

Results

Reliability

Prior to collection of pennation angle using ultrasound with adduction and abduction, an interclass correlation (ICC) calculation for reliability had to be performed. This data was analyzed for laying in the prone position and standing in neutral position. Ultrasound images of the medial and lateral head of the right gastrocnemius muscle were measured in six different positions, on both days, with a total of 72 images per person.

Table 1.1. Intra-reader, between days, and between readers within each day. Pennation angle measurement reliability. Includes both lateral and medial heads of the gastrocnemius muscle for both laying down and standing in neutral position.

	Between Days		Between Readers	
	Reader 1	Reader 2	Day 1	Day 2
Mean	10.9	11.0	11.0	10.9
SD	1.8	1.7	1.7	1.7
SE	0.1	0.1	0.1	0.1
ICC	0.91	0.95	0.98	0.96

Table 1.2. Mean, standard deviation, and standard error of between days reliability test for both laying and standing position lateral head of the gastrocnemius muscle.

	Laying	Neutral
Reliability	0.80	0.87
Mean	9.4	9.5
SD	0.9	0.9
SE	0.1	0.1

Table 1.3. Mean, standard deviation, and standard error of between days reliability test for both laying and standing position medial head of the gastrocnemius muscle

	Laying	Neutral
Reliability	0.68	0.71
Mean	12.6	12.3
SD	0.7	0.8
SE	0.1	0.1

For laying in the prone position, the mean and standard deviations from the reliability of pennation angles were 9.4 ± 0.9 laterally and 12.6 ± 0.7 medially. For standing in the neutral position, the mean and standard deviation from the reliability of pennation angles were 9.5 ± 0.9 laterally and 12.3 ± 0.8 medially.

Adduction and Abduction

The pennation angle measurements from 15 degree adduction and 15 abduction. The use of Cohen's d for calculations can be seen below.

Table 2.1. P-value of one-tailed paired t-test:

	N-AB	N-AD	AD-AB
Medial	0.188	0.000	0.001
Lateral	0.054	0.464	0.058

Table 2.2. Effect size for the tests.

	N-AB	N-AD	AD-AB
Medial	0.121	0.321	0.413
Lateral	0.163	0.010	0.181

Table 2.3. Mean, standard deviation, standard error of the lateral pennation angle values from neutral, 15 degree abduction, and 15 degree adduction.

	Mean	SD	SE
Neutral	9.4	0.9	0.1
15 degree adduction	9.4	0.8	0.1
15 degree abduction	9.2	0.8	0.1

Table 2.4. Mean, standard deviation, standard error of the medial pennation angle values from neutral, 15 degree abduction, and 15 degree adduction.

	Mean	SD	SE
Neutral	12.3	0.9	0.1
15 degree adduction	12.6	1.0	0.1

15 degree abduction	12.2	1.1	0.1

For the 15 degree adduction position, the mean and standard deviation were 9.4 ± 0.8 laterally, and 12.6 ± 1.0 medially. For the 15 degree abduction position, the mean and standard deviation were 9.2 ± 0.8 laterally, and 12.2 ± 1.1 medially.

Discussion

The purpose of this study was to show the reliability of measuring pennation angle while in a neutral standing position, and to see any differences between 15 degree adduction/abduction standing positions. This study expected to see results of pennation angle measurements to be less than 2 degrees apart, showing that the measurement technique is indeed reliable and can be used by other researchers in this field.

For both reliability tests, laying supine and standing neutral, Cicchetti (1994) gives the following guidelines for interpretation for ICC inter-rater agreement measures: poor: ICC < 0.40; fair: 0.40 <= ICC<= 0.59; good: 0.60 <= ICC <= 0.74; and excellent: 0.75 <= ICC <= 1.00. According to Table 1.1 the pennation angle measurements of laying in the prone position and standing in the neutral position were reliable both between days and between readers. For Tables (1.2 and 1.3), data only from one reader for the pennation angle measurement reliability tests for both medial and lateral heads of the right gastrocnemius muscle for laying supine and standing position were analyzed. There is a minimal mean pennation angle degree difference between laying down and standing neutral positions. However, it displays a pronounced difference between the medial and lateral head pennation angle degree when at the same position.

For the 15 degree adduction and abduction positions Cohen’s d= (M2-M1)/SD_{pooled} can be used to analyze data. It was suggested that d=0.2 be considered a ‘small’ effect size, 0.5 represents a ‘medium’ effect size, and 0.8 a ‘large’ effect size. According to Table 2.1, only the adduction displayed a ‘small’ effect size. For abduction interrelated with adduction, and alone, an observable difference was not accomplished. Tables 2.3 and 2.4, once again display the mean angle difference between medial and lateral heads of right gastrocnemius muscle. According to both Table 2.3 and 2.4, lateral head of right gastrocnemius displays smaller mean angle values than medial.

Possible errors in this research study include that the participants were not provided instructions prior or between the measurement days. Exercise or other activities such as stretching or injury might have slightly altered the muscle fascicles or deep aponeuroses.
This study successfully displayed that the ultrasound does show reliable pennation angle measurements of the medial and lateral heads of the gastrocnemius muscle while in a standing neutral position. Ability to measure the pennation angle while in a mechanically loaded position will allow studies of pennation angle with the muscle contracted and in motion. This will allow for further studied involving stretching and muscle power production. A possible continuation of this research could include examining the vast difference behind pennation angle values for lateral and medial heads of the gastrocnemius.

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Appendix A

Purpose, Limitations, Delimitations, Assumptions

Purpose

The purpose of this research study was to display that pennation angle measurements of the gastrocnemius muscle using ultrasound, while the participant is in an upright position, are reliable. In this position the muscle is mechanically loaded.

Limitations

- Sample size of only 16 participants, made it difficult to find significant relationships from the data. This sample size is not a representative distribution of the population.
- Lack of prior research studies on this topic. Research has been completed with the pennation angles only examined while participant is laying down.
- Measure used to collect the data. The angles used to examine adduction and abduction could have been too small to notice any difference.

Delimitations

- Participants were all full-time students enrolled at Georgia Southern University.
- The participants were all female ages 19 to 25.

Assumptions

- The ultrasound is a reliable tool for pennation angle measurement collection.

Appendix B

Literature Review

Muscle architecture has been typically studies using cadavers, with the use of a goniometer but vivo is an option as well. Vivo uses imaging techniques such as ultrasounds. Ultrasounds generate a two-dimensional image of a slice through the muscle. Ultrasonography has allowed for reliable measures at rest, and during static and dynamic contractions (Stevens et. al., 2014). This approach assumes that a single cross-section of a muscle is reflective of the entire muscle. Typically multiple measures of the pennation angle can be demonstrated within one ultrasound image (Infantolino, et. al., 2014). This helps to explain one limitation to ultrasound imaging in pennation angle measurements.

A study conducted by (Zhou et. al., 2015), proposed an automatic measurement of pennation angle and fascicle length. In order to save time from manually analyzing the images collected through an ultrasound, a machine that would detect line-like structures could be used to locate the fascicles and aponeuroses for calculating the pennation angle. Multiple studies have been conducted with interest in pennation angle. A study by the Centre Hospitalier Universitaire de Saint Etienne, 2015) analyzed the effects of muscle spastic on pennation angle. Pennation angles influence contractile force and velocity during dynamic actions and therefor has been used in studies by biomechanists and muscle physiologists. A study by (Stresser et. al., 2013) displayed the use of pennation angle in studying muscle strength among young and elderly patients.

Most pennation angle studies, such as (McMahon, 2015) have been conducted with the participant in a pronated position. In this position, the ultrasound is used to detect images of relaxed muscle belly. This study displayed that there was no significant difference for within-image, between-image and between session data. This displays the ability to gather reliable measures of medial gastrocnemius while at rest between separate days using an ultrasound.

The most accurate way to measure pennation is when the image plane intersects the aponeurosis perpendicularly. Typically there is some degree of misalignment which results in overestimation of the angle. According to (Bolsterlee et. al., 2016), misalignment is likely to greater for ultrasound images obtained in dynamic or active conditions. This helps to explain why generally pennation angle has been studied in prone position with the muscle relaxed.

References:

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Appendix C

COLLEGE OF HEALTH AND HUMAN SCIENCES

DEPARTMENT OF HEALTH AND KINESIOLOGY

INFORMED CONSENT

Title of Project: Reliability of pennation angle measured using ultrasound with upright position

Georgia Southern undergraduate students Molly McLaughlin and Diana Tyler will be working with Dr. Li Li for this research. The purpose of this research is to prove that itis possible to measure the pennation angle of a person's gastrocnemius muscle while standing in the upright position. Thirty participants will be recruited and tested at one of the scheduled times. Once you arrive you will be put into one of two different groups Molly will be measuring the pennation angles of your gastrocnemius from three different ankle joint angles. Diana will measure this at three different feet abduction angles. You will then be asked to come back at another time and have the measurements taken for the second time. Each meeting time will take no longer than thirty minutes.

There are minor risks that could occur with this research. While unlikely, it is possible you may lose balance and fall during the ultrasound procedure. To minimize this risk, we will have you hold onto the vertical stabilizing poll while testing. There could also be the possibility of having a reaction to ingredients in the ultrasound gel. To make sure this does not happen, all participants will be screened prior to testing to make sure they are not allergic to any of those ingredients. Due to this, please agree to the following statement: "l understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. I also understand that 1 am not waiving any rights that I may have against the University for injury resulting from negligence of the University or investigators.

The benefits to participants include helping to get involved in research which in many majors at Georgia Southern in beneficial to have. It may also be good if you have an interest in one day becoming an ultrasound technician because it can give you more background information on it. The benefits to society include helping the future of using ultrasound machines to measure pennation angles, making it much more functional. It will become much more convenient to ultrasound technicians if their patients can stand during procedures.

You should be aware that "Deidentified or coded data from this study will be placed in a publically available repository for study validation and further research. You will not be identified by name in the data set or any reports using information obtained from this study, and your confidentiality as a participant in this study will remain confidential. Subsequent uses of records and data will be subject to standard data use policies which protect the anonymity of individuals and institutions." You have the right to ask questions and have those questions answered. If you have questions about this study, please contact the researcher named above or the researcher's faculty advisor, whose contact information is located at the end of the informed consent. For questions concerning your rights as a research participant, contact Georgia Southern University Office of Research Services and Sponsored Programs at 912-478-0843.

As student participants, there will be no compensation for volunteering in this research study. You do not have to participate in this research; you may end your participation at any time by telling the person in charge, and you do not have to answer any questions you do not want to answer. There will be no penalty for deciding not to participate in this research study. You may withdraw without penalty or retribution. You must be 18 years of age or older to consent to participate in this research study. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date.

You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number **H16388.**

________________________________ __________________

Participant Signature Date