IJAHSP
The Internet Journal of Allied Health Sciences and Practice
http://ijahsp.nova.edu
A Peer Reviewed Publication of the College of Allied Health & Nursing at Nova Southeastern University
Dedicated to allied health professional practice and education
http://ijahsp.nova.edu Vol. 6 No. 2 ISSN 1540-580X

Measurement Error Between a Goniometer and the NIH ImageJ Program for Measuring Quadriceps Angle

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CITATION: Roush, JR., Bustillo, K., Low, E. Measurement Error Between a Goniometer and the NIH ImageJ Program for Measuring Quadriceps Angle. *The Internet Journal of Allied Health Sciences and Practice*. April 2008, Volume 6 Number 2.

ABSTRACT
Purpose: Measurement error when determining the size of an angle is always an issue for clinicians. Computer assistance may help to decrease that error. The purpose of this study is to determine the amount of error when measuring Q-angles using a goniometer and the IMAGEJ program, a public domain program developed at the U.S. National Institutes of Health. **Methods:** Two investigators participated in data collection; one who is a licensed physical therapist who has over 25 years of clinical practice in orthopedic physical therapy and a second who is familiar and experienced with analyzing data using the National Institute of Health (NIH) IMAGEJ computer program. Quadriceps angles measured bilaterally for 30 subjects between the ages of 21 and 50 years were recorded. Interrater and intrarater reliability with standard error of the measurements were calculated. **Results:** The ICC (2,1) for measuring Q-angle with a goniometer was .96 (SEM =1.02°), while the ICC (2,1) for measuring Q-angle with the IMAGEJ program was .98 (SEM = 1.05°). The ICC (3,2) between measures obtained with a goniometer versus the IMAGEJ program was .89 (SEM = 2.06°). **Conclusions:** There is a high association between measures of Q-angle obtained with a goniometer compared to those obtained with computer-assistance using the IMAGEJ program. There may be a bias on the part of raters when measuring higher values of Q-angle. Further investigations should be conducted to examine the feasibility of increased use of IMAGEJ in measuring angles.

INTRODUCTION

Goniometry is the process of measuring angles created between two adjacent bones as well as angles between anatomical landmarks or structures.[1] Goniometers are the tools used to measure these angles.[2] Using goniometers to measure angles between anatomical landmarks has been found very reliable.[3]

The Q-angle has been defined as the angle formed by three anatomical landmarks: a line between the anterior superior iliac spine at the pelvis and the middle of the patella, a line between the middle of the tibial tuberosity, and the apex of the angle at the middle of the patella.[4] It has been used as a clinical measure of the alignment of the quadriceps femoris musculature relative to the underlying skeletal structures of the femur, tibia, and pelvis.[4]

The validity of measuring the Q-angle goniometrically versus radiographically has been debated. Schultz et al. found that intrarater reliability of Q-angle measurement using a goniometer ranged from .89 to .98.[8] Greene et al. compared goniometric measurements of Q-angles with radiographically-derived measurements and found the average intraclass correlation coefficient between the two ranged from 0.13-0.32.[5] Ilahi et al. found the interobserver and intraobserver variability of radiographic measurements of knee alignment was within four degrees 98% of the time.[6]

A potential source of error when measuring any joint angle on a human subject may be from the measurer. It may be easier and more error-free to photograph joint segments and structures from which angles can be calculated. Several computer programs are available to assist in the calculation of angles between anatomical landmarks or structures. One such program is the National Institutes of Health Image Program (IMAGEJ), a public domain image processing and analysis program developed at the U.S. National Institutes of Health.[9] This program calculates angles from three different points in a plane and can be used to calculate angles in human subject research between joint segments or other anatomical relationships. The clinician or researcher can photograph anatomical landmarks on a subject. The photograph can then be digitized and processed by IMAGEJ for variables such as distances, areas, or angles. Farber et al. believes computer angle measurement from digitized points on a radiograph is a valid and reliable method that may be necessary to make clinical decisions. The purpose of this study is to compare the amount of error when measuring Q-angles using a goniometer versus the IMAGEJ program.

METHODS

Subjects

The study was approved as safe for human subjects by the Institutional Review Board of A.T. Still University of Health Sciences - Mesa, Arizona campus where the data collection was conducted. Informed consent from the subjects was obtained prior to data collection. A convenience sample of 30 subjects between the ages of 21 and 50 years old were recruited as volunteers to participate. There were no other inclusion or exclusion criteria other than the willingness to participate. Subjects were assigned a random number to identify their data.

Investigators

Two investigators participated in data collection. The first investigator was a licensed physical therapist that has over 25 years of clinical practice in orthopedic physical therapy and was a Certified Orthopedic Specialist (OCS) with the American Physical Therapy Association. This investigator's role was to measure the Q-angle of the subject, to place identifying marks over the anatomical landmarks of the subject, and photograph the subject. The second investigator was a licensed physical therapist who has over 20 years of clinical practice in physical therapy. This investigator was familiar and experienced with analyzing data using the National Institute of Health (NIH) IMAGEJ computer program. Each investigator was blinded to the data gathered by the other until the time of data analysis.

Procedure

Subjects were asked to stand on a tiled floor with their shoes and socks off and both feet in a neutral position. To prevent posturing, subjects were asked to take five steps in place. Using the landmarks of the ASIS, the mid-patella, and tibial tuberosity, three measurements of the Q-angle were taken with a standard goniometer for each lower extremity. Three strips of white tape were applied on each subject at the sites of the ASIS, the mid-patella, and tibial tuberosity of both lower extremities. The investigator then marked the center of the landmark with a black, permanent marking pen (Figure 1).

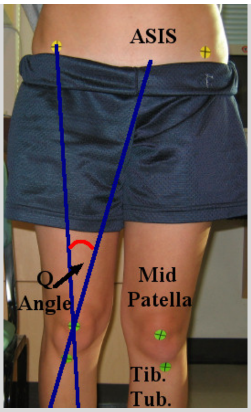

Figure 1.
Placement of markers for measurement of Q-angles

A Canon Digital EOS digital camera (Canon USA Inc., Lake Success, NY) was placed 5 feet from subject's feet and centered at mid-thigh. A level was used to ensure horizontal alignment of the lens both superiorly and inferiorly to the middle of the subject's thigh. The camera was also aligned medially and laterally to a line midline between the subject's thighs.

Data Analysis

A total of six trials were conducted; three trials for each thigh. One investigator used a goniometer to determine the Q-angle, and the other investigator used the NIH IMAGEJ program. Means, standard deviations, and coefficients of variation were calculated for the Q-angle for both tools. Interclass correlation coefficients (ICC) and standard errors of measurement were calculated for data collected by both investigators. A coefficient of variation for method error was calculated between the data measured with the goniometer and the data measured with the NIH IMAGEJ program, and a t-test was used to determine the significance of the coefficient. An alpha level of .05 was used as the level of significance. Intraclass correlation coefficients and standard errors of measurement were calculated between measures acquired using a goniometer and the NIH Image program.

Bland-Altman plots were calculated to determine any bias by the investigators in data collection.[10] Two measurers were used in the analysis. First, an array was developed of the difference between the measurers. Next, an array was developed of the average of the measurers. A plot was constructed of the differences as a function of the average for the data. Visual analysis was used to determine the consistency of the measures. If the plotted line deviated from the x-axis of the analysis (which in this case has a magnitude of zero), then there was potential for bias on the part of measurers. Within the development of the Bland-Altman plots, 2nd degree polynomials were calculated to determine a trend line of the data. A coefficient of determination was also calculated to determine the fit of the trend line. All calculations were performed using the SPSS 14.0 statistical package and Microsoft's Excel program.

RESULTS

Descriptive statistics for the subjects can be found in Table 1. The three measures of Q-angle using the goniometer and using the NIH IMAGEJ program were averaged to provide an overall mean and standard deviation for the descriptive data. Q-angle measures taken with a goniometer ranged from 0° to 22° for females and from 0° to 28° for males. Q-angles measured using the NIH IMAGEJ program ranged from 4° to 20° for females and from 0° to 16° for males. The data using the NIH IMAGEJ program was normalized to zero to insure an easier comparison with the data measured with a goniometer. The reliability statistics for the data can be found in Table 2. A coefficient of variation is a measure of variability for a data set and can be used to compare two or more distributions. A coefficient of 0% is an indication of little variation in the data. The coefficient of variation between measures using the goniometer and the NIH IMAGEJ program differed by 7.75%, which was found to be insignificant ($t = 0.43$; $df = 59$; $CV = 2.0$).

TABLE 1. Means and Standard Deviations of Descriptive Statistics

		Age	Height	Weight	Q-Angle with Goniometer	Q-Angle with NIH program
Males	Mean	32.81	71.19	200.25	10.68	9.75
(n=32)	Standard Deviation	5.52	2.57	33.14	5.52	4.44
Females	Mean	26.46	67.07	150.86	15.58	19.06
(n=28)	Standard Deviation	5.39	3.76	50.82	3.6	5.55

The results of the ICC (2,1) to determine the degree of consistency of the measures derived from the goniometer and the measures derived from the IMAGEJ program exceeded .90, which indicated high agreement. The results of the ICC (3,2) to determine the agreement between measures from goniometer and measures from the IMAGEJ program was .89 (95% CI = .83 - .93), which was also considered high.

TABLE 2. Reliability Statistics

	Overall Mean	Overall SD	Coefficient of Variation	ICC	95%CI	SEM
Measures with Goniometer	12.97	5.37	41.41%	.96	.94 - .98	1.02
Measures with NIH	14.09	6.93	49.16%	.98	.97 - .99	1.05
For all Measures	13.53	6.22	45.93%	.89	.83 - .93	2.06

A Bland-Altman plot of all the data can be found in Figure 2. Analysis of the data has suggested a bias may be occurring in measurements taken using the goniometer. A second-degree polynomial was fit to the data. The results indicated that with goniometric measurements, as the Q-angle increased, the measurer was biased to record a measure that was less than that measured when using the NIH IMAGEJ program. Bland-Altman plots with second degree polynomials were developed for females and males separately. The bias was observed more in females. For males, measurements recorded were higher when using the goniometer than when using the NIH IMAGEJ program.

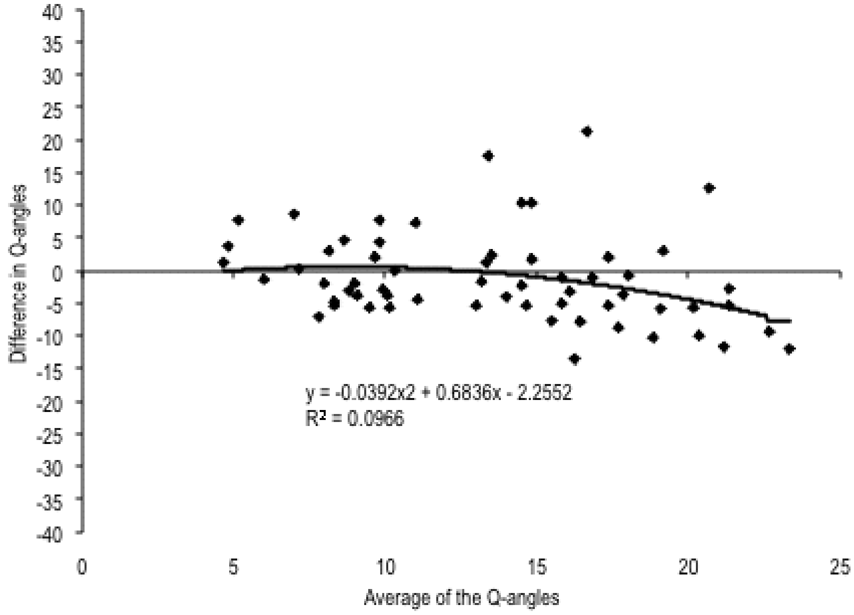

FIGURE 2. Bland-Altman analysis of diferences between measured Q-angles as a function of the mean of the measured Q-angles.

DISCUSSION

The IMAGEJ program is a calculator that has the ability to perform many different functions, one of which is to calculate angles from three different points.[9] It was developed at the U.S. National Institutes of Health and is readily available on their website. It should be considered a gold standard when calculating many different functions, including angles in biological or kinesiological research.

Measurement of the Q-angle can be influenced by many different factors such as patella alta, patella baja, and patellar tilting.[11] The most common instrument used for measuring the Q-angle is a standard goniometer.[4] However, the standard error of the measurement of the Q-angle is 2.4 degrees.[12] This error would equate to an increase or decrease of the lateral force of the quadriceps by 2.9 kilograms (6.3 pounds) for an individual whose quadriceps muscles are generating 68 kilograms (150 pounds) of force. Such a large error may be significant in clinical decision-making. Therefore, alternatives to using a standard goniometer need to be considered.

The Q-angle has been commonly measured with the subject lying in supine and the quadriceps relaxed.[6] However, it is becoming more popular to position the subject in a more functional position such as standing.[13-16] The Q-angles of the subjects in this study were measured in the standing position. The only difference was the subjects were instructed to take five steps in place to decrease the potential of posturing on the part of the subject.

Most of the research that compares computer-assisted measures with goniometric measures has addressed measuring errors of Cobb angles for subjects with scoliosis. Shea et al. found a measurement error of 2.6 degrees for computer-assisted measurement 3.3 degrees for manual measurement.[17] They concluded that advantages to computer-assisted measurement is rapid comparison between radiographs, decreased measurement error due to variability in goniometers, and decreased error by the measurer when using a goniometer. Clinicians who routinely measure Q-angle are confronted with similar issues. A technique of assessing Q-angles using digital photography was described in the paper, which allows the clinician to have a permanent visual record of a patient's knee.

The major confounding variable that accounts for error in the measurement of Q-angle is the palpation of the anatomical landmarks (the center of the anterior superior iliac spine, the center of the patella and the center of the tibial tuberosity.)[18] An error in identifying the center of any of these landmarks can lead to substantial error in the calculation of the Q-angle. France and Nester stated that an error up to 5 mm in palpation of the proper center of the landmark could lead to 5-degree error in the Q-angle calculation.[18] France and Nester also felt that the main points of palpation error were the tibial tuberosity and the center of the patella. In our study, we felt the main point of palpation error was over the anterior superior iliac spine because of the amount of adipose tissue over this region.[18] This was especially true for subjects with higher body mass indexes.

This study was of one experienced clinician with many years of experience measuring Q-angles with a goniometer. The results of the Bland-Altman analysis were unexpected as examiner bias was revealed in measuring the Q-angle with a goniometer. A review of the literature has revealed that no similar findings have been reported. We have no explanation of why the bias was found. Although only one experienced clinician evaluated the Q-angles in this study, many clinicians understand the overall ramifications of an increased Q-angle in terms of the lateral force on the patella. Generally, clinicians are unable to influence any internal change in the knee complex to decrease the lateral force. The bias issue needs to be examined in a larger sample, as we suspect the bias may be more common.

The Q-angle was chosen for this study as it is relatively easy to measure and there is variability in measures between different individuals. However, it should be noted that the issue of measurement error occurs in all joints or body segments. The IMAGEJ program is a calculator that finds the angle between three points on a plane and therefore is less prone to measurement error.

CONCLUSIONS
There is a high association between measures of Q-angle obtained with a goniometer compared to those obtained with computer-assistance using the IMAGEJ program. The IMAGEJ program is easy to obtain, easy to use, and allows for more permanent digital documentation of the results of Q-angle measurements by the clinician.

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