# A Girthometer for Accuracy and Reliability of Muscle Girth Measurements

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**Abstract**
The aim of this study is to provide a new innovative measuring tool to determine the reliability of measuring thigh and calf muscle girths. A total of eight healthy subjects were recruited in this study. The thigh and calf measurements were measured by using the Girthometer and standard measuring tape by three physiotherapists. The two measurement sites were evaluated for bilateral lower limbs: above the base of the patella and below the vertex of the patella. Reliability was assessed by calculating the interclass correlation coefficient (ICC), standard error of measurements (SEM) at 5% significance level. Compared to the Girthometer with a normal measuring tape, the proposed Girthometer results of ICC are much higher than the normal measuring tape. Thus, the reliability of the proposed Girthometer was better than the conventional type. The results revealed is significant over the standard measuring tape and the Girthometer is high in above and below knee measurement. In conclusion, based on the results obtained, the proposed Girthometer has proven that it is more reliable than the conventional method using a standard measuring tape. The null hypothesis was rejected yet the girthometer has more exceptional reliability among the competitors.
**Keywords** Muscle girth, thigh, calf, lower-extremity, reliability

## INTRODUCTION

Girth measurements are widely implemented in the clinical study. Reliable and valid measurements are important to meaningful clinical practice. Girths are circumference measures at the standard anatomical sites around the body and usually measured with tape measurement (Aitken, 1985). Girths are typically measured using flexible tapes. Numerous circumstances contribute to errors in girth measurement, including the degree to which the tape conforms to body shapes, the extent to which the tape compresses the skin, the precision with which the tape is perpendicular to the extended axle of the part or body segment and the error in locating the correct measurement site. Common clinical procedures often have not been subjected to rigorous analyses. Doing so would lead to justification for the use of frequently performed clinical measurements. In performing such steps, both validity and reliability should be considered, for even highly repeatable

measures are insignificant unless valid (Soderberg et al., 1996).

The earliest research to discuss the reliability of girth measurements were investigated by Cooperman, J. M. et al. (1990) and Harrelson, G. L. et al. (1998) for the inter- and intra-tester reliability and validity of girth measures. Measurements of thigh and calf girth following the knee damage and operation was evaluated and rehabilitation was advised (Ross, C. M., and Worrell, T. W 's (1998)). Maylia, E., et al. (1999) proved that the thigh girth measures precisely by utilizing a tape measure. However, the site area error can produce a notable influence on many girth measures (Daniell, N., et al. (2010).

Nicola, C. et al. (2016) showed the Hand-Held Lesser Scanner was more reliable than normal measuring tape in terms of circumference measurement (Karl, H.L. et al. (2000) and volume of the lower limb in normal weight and obese individuals. The reliability of ultrasound measurements of quadriceps muscle diameter in critically unhealthy subjects were investigated (Pardo E. et al. (2018)). Bakar Y. et al. (2017) presented that the lower limbs hand-operated girth measurement is a reliable way for clinical application. This study intended to define the interobserver and intra-observer reliability of manual girth measurement amidst various spectators and different measurement locations.

Fu, G. Q. et al. (2018) investigated the impact of rearfoot arrangement on static and dynamic postural balance in sports rehabilitation. Koo, T. K. and Li, M. Y. (2016) presented guidelines for choosing and recording intraclass correlation coefficients for reliability study.

Barde, M. P. and Barde, P. J. (2012) revealed the variability of data by the standard error or standard deviation (SD) of the mean. A peculiar knowledge and application of basic statistics (García, B. E. et. al. (2004), such as SD and SEM and their application enables better analysis, description, and transmission of data to all viewers.

Although there have been some researches that discuss problems linked with the standard measurements addressed in physiotherapy clientele (Potter & Rothstein, 1985; McClure et al., 1989; Lorentzon et al., 1989, Cooperman et al., 1990), a reflection of the literature established limited data on intra- or inter-therapist reliability of the girth measurement of body parts, either in a healthy community or in those individuals with diagnostic problems. Measurements of girth for edema, muscle mass or effusion are important to assess the subject's improvement in clinical trials.

Hence the objective of this study is to distinguish the cut off difference based on girth measurement using Girthometer and conventional method among test subjects. Furthermore, this study was carried out to ascertain the reliability of the innovative measuring tool. The importance of measurement of muscle girth for the patients and healthcare team are to be identified to contribute data associated with the anthropometric method that may improve current protocols and education programs.

## PROPOSED DESIGN

The primary aim of this design is to measure girths at several set distances from the criterion site to help quantify the effect site location has on various girth

measurements. The proposed design of the Girthometer is illustrated in Figure 1. The proposed Girthometer was designed using thermoplastic, plastic, ruler reading sticker, straps stretchy compression dressing straps and slap ruler in order to accomplish the required measurements.


**Figure 1:** Proposed Girthometer design

The measurement 1 component in Figure 1 is for stabilization purpose and mark reading of 5cm, 10cm and 15cm that allow the connector along with measurement 2. The two stretchy compression dressing straps were permanently fastened to thermoplastic strip at both intervals and a plastic connecter placed between the straps. The function of the stabilization straps 1 and 2 is to stabilize the measurement 1 in appropriate position at the thigh and calf. A small opening of the connector allows slap ruler to slip through and allows it to slide up and down the thermoplastic. The design is based on the human anatomical structure of the thigh and calf so that the Girthometer is applied and fit properly on the subject's lower limb. Thus, it can reduce mechanical error and zero error, so that a more precise reading could be obtained.

## METHODOLOGY

### Parameters

A muscle wasting questionnaire consisting thirteen questions was used to obtain the subject's details and to rate the subject's health conditions. Muscle wasting questionnaire is a tool that allow the therapist to obtain the general information of the patient at the same time allow the patient to gain the knowledge toward muscle wasting or muscle atrophy before starting to measure the girth measurements of the lower limbs.

The satisfaction survey contains five questions. The purpose of this survey is to evaluate the satisfaction of the patients towards the Girthometer. The patients rate on the likert scale from 1 to 5, with 1 being strongly disagree, 2 being disagree, 3 being neutral, 4 being agree and 5 being strongly agree. Addition comments toward the device was open for the patient to help the researcher in improving the current innovation.

The study was conducted in the therapists' house in Sungai Petani, Kedah, Malaysia. The subjects were selected within our family members without any breaching the social distancing norms due to the current Covid-19 pandemic situation. All the subjects had

undergone a detailed assessment by student physiotherapists to match the inclusion criteria and exclusion criteria in the study. The study was undergone for 9 months from December 2019 to August 2020. Data collection was held on for two months, from May 2020 to July 2020.

For inclusion criteria, around eight healthy subjects of both gender aged from 14 to 66 years old with a normal body size. For exclusion criteria, individual that is obese (BMI ≥30), children under age of 14, having lower limb fracture, deformity of knee, severe ill patient (Malignancy) or patient on external fixation.

**Procedure**

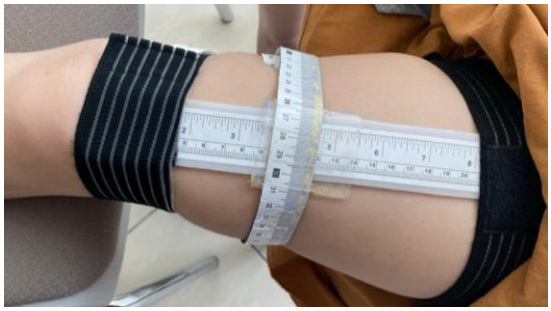
Eight subjects (3Male; 5Female) volunteered for the study was selected within our family members without breaching the social distancing norms due to the covid-19 pandemic situation. Prior to subjects' examination, a brief introduction was given about our innovation such as the advantages of the innovation, demonstrated the application of the system on subject, the concern form and the subjects' rights. The subject was notified that there were two kinds of examinations done on the patient, one with a standard measuring tape and another with the proposed Girthometer.

All eight subjects volunteered for girth measurements of both lower limbs. So, a total of sixteen lower limbs, at the following locations of 10 cm and 5 cm inferior to the knee joint line and at 5cm, 10cm and 15cm superior to the knee joint line are measured. All subjects were in supine lying with the knee position in relaxed full extension and all proclaimed this position as comfortable. Ensure the subject wear fitted clothing or no clothing around the measure area. Make sure the body is slackened for all the measurements. Two investigations were undertaken on 6 sites each lower limbs by using standard measuring tape and Girthometer.

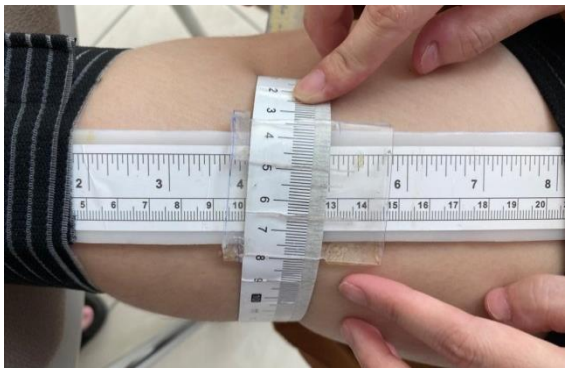
**Procedure for Thigh measurement**

While the patient is lying in supine position, by using standard tape, the girths circumference is measured for both lower limbs at the locations 5cm, 10cm and 15 cm from superior the apex of the patella. The positions sites are marked for each measurement using a pen on the subject's skin surface. The tape is passed and wraps around the body part with the landmark above the tape line. The girths are measured with the tape perpendicular to the portion of the bone or body segment. Three repetition measurements were taken from each site for accuracy and minimized zero error.

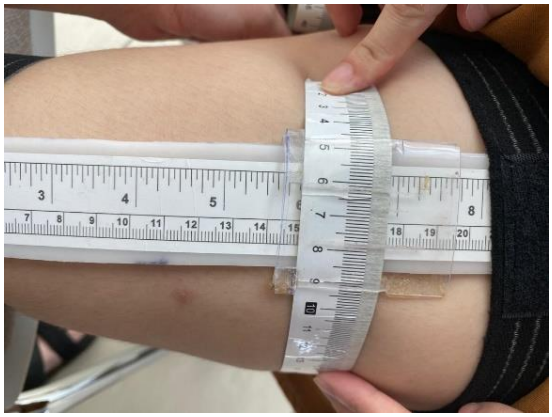
Being the subject lying in supine position, place the base line of the proposed girthometer above the base of the patella and secure the two Velcro straps that is located on the proximal and distal end of the Girthometer (Figure 2a). Adjust the slap ruler to the level 5cm, 10cm (Figure 2b) and 15 cm (Figure 2c) marked on the Girthometer by sliding up or down the measurement 2 strap and record the reading. Three repetition measurements are taken from each site for accuracy and minimized zero error.



(a)



(b)



(c)

**Figure 2:** (a) Place Girthometer base on right above the apex or on top of the patella (b) marking on measurement 2 with sliding up connectors to 10cm and (c) 15cm

**Procedure for Calf measurement**

By using standard tape, the girths circumference of the calf was taken of the involved and uninvolved legs at 5cm and 10cm below the vertex of the patella. Landmarks are marked for each measurement. The tape is passed around the body part with the landmark above the tape line. The girths are measured with the tape perpendicular to the length of the bone or body segment. Three repetition measurements are taken from each site for accuracy and minimized zero error.

By using proposed Girthometer, place the base line below the vertex of the patella and secure the two Velcro straps located on the proximal and distal end of the Girthometer (Figure 3). Adjust the slap ruler to the level 5cm and 10cm marked on the Girthometer by sliding up or down the measurement 2 strap and record the reading.

**Figure 3:** Method of reading markings on measurement 2

### Statistical tools

The IBM SPSS Statistic version 21 was used for data analysis. All variables present as mean ± standard deviation. Data were entered into a statistical software program for the calculation of mean, ICCs and p-value and BA plots for both the limbs for all five locations of the measurement and by comparing both Girthometer and standard measuring tape.

## ANALYSIS AND INTERPRETATION

### Data Presentation

The results from the data collections are analyzed by using SPSS. Based on the analysis, the three therapists have participated in the study. The total number of healthy subjects that has participated in the study is eight (Table 1). Among the eight subjects, there are 3 healthy male subjects and 5 healthy female subjects. The percentage of the male healthy subject is 37.5% while the percentage of the female healthy subject is 62.5% as shown in Table 1. The mean age of the healthy subjects is 44.12 and the standard deviation (SD) for the age of the healthy subjects is 17.7. The total number of measurements for thigh and calf is 240 for both conventional method (standard measuring tape / normal tape) and proposed Girthometer. The percentage of measurement for conventional method is 50% and the Girthometer is 50%. The total number of conventional measurements for the above knee is 144 and below knee is 96. The percentage of the conventional measurement is 60% for the above knee and 40% for the below knee. The total number of Girthometer measurements for the above knee is 144, while the total number of Girthometer measurements for the below knee is 96. The percentage of the Girthometer measurements is 60% for the above knee and 40% for the below knee.

**Table 1:** Baseline Data of Study Samples

| | **Mean (SD)** | **Frequency** | **Percentage (%)** |
|---|---|---|---|
| Gender | | | |
| Male | | 3 | 37.5 |
| Female | | 5 | 62.5 |
| Number of measurements | | | |
| Conventional method | | 240 | 50 |
| Girthometer | | 240 | 50 |
| Conventional measurements | | | |
| Above knee | | 144 | 60 |
| Below knee | | 96 | 40 |
| Girthometer measurements | | | |
| Above knee | | 144 | 60 |
| Below knee | | 96 | 40 |
| Age | 44.13 (17.7) | | |

**Table 2:** Comparison of conventional and proposed girthometer: Intra-class Correlations of Above Knee Measurement

| Device/ Variable | Measurement 1 Mean (SD) | Measurement 2 Mean (SD) | Measurement 3 Mean (SD) | ICC [2,1] (95%CI) | SEM | p |
|---|---|---|---|---|---|---|
| Normal Tape | | | | | | |
| 5cm above knee left | 36.438(2.492) | 36.450(2.429) | 36.387(2.482) | 0.999 (0.997-1.000) | 0.078 | 0.000 |
| 10cm above knee left | 39.975(2.748) | 40.025(2.753) | 40.025(2.713) | 0.998 (0.993-1.000) | 0.122 | 0.000 |
| 15cm above knee left | 44.250(2.287) | 44.200(2.235) | 44.225(2.195) | 0.998 (0.994-1.000) | 0.100 | 0.000 |
| 5cm above knee right | 36.437(2.664) | 36.350(2.608) | 36.400(2.597) | 0.999 (0.996-1.000) | 0.083 | 0.000 |
| 10cm above knee right | 40.137(2.331) | 40.137(2.331) | 40.100(2.256) | 0.999 (0.996-1.000) | 0.073 | 0.000 |
| 15cm above knee right | 44.325(2.462) | 44.237(2.569) | 44.312(2.448) | 0.994 (0.981-0.999) | 0.193 | 0.000 |
| Girthometer | | | | | | |
| 5cm above knee left | 36.437(2.516) | 36.450(2.491) | 36.450(2.525) | 1.000 (1.000-1.000) | 0.000 | 0.000 |
| 10cm above knee left | 40.050(2.768) | 40.050(2.768) | 40.025(2.722) | 1.000 (0.999-1.000) | 0.000 | 0.000 |
| 15cm above knee left | 44.225(2.207) | 44.225(2.207) | 44.225(2.172) | 1.000 (0.999-1.000) | 0.000 | 0.000 |
| 5cm above knee right | 36.400(2.644) | 36.387(2.640) | 36.400(2.644) | 1.000 (1.000-1.000) | 0.000 | 0.000 |
| 10cm above knee right | 40.137(2.300) | 40.150(2.308) | 40.137(2.300) | 1.000 (0.999-1.000) | 0.000 | 0.000 |
| 15cm above knee right | 44.350(2.460) | 44.362(2.453) | 44.362(2.484) | 1.000 (1.000-1.000) | 0.000 | 0.000 |

Note: SD; Standard deviation; ICC: Intra-class correlation; SEM; Standard error of measurement

**Table 3:** Comparison of conventional method and proposed Girthometer: Intra-class Correlations of Below Knee Measurements

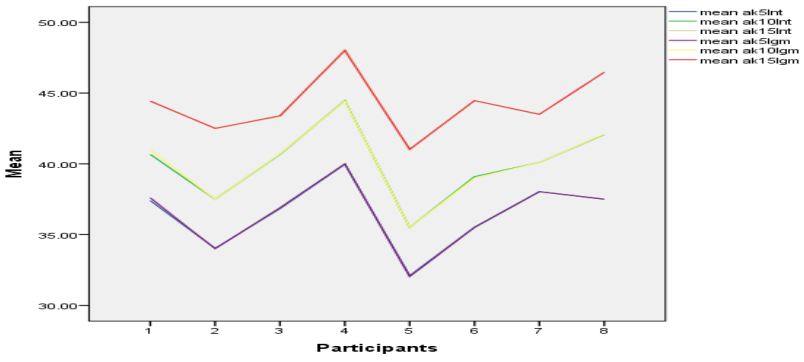
| Device/ Variable | Measurement 1 Mean (SD) | Measurement 2 Mean (SD) | Measurement 3 Mean (SD) | ICC [2,1] (95%CI) | SEM | p |
|---|---|---|---|---|---|---|
| Conventional method 5cm below knee | 31.837(2.033) | 31.875(1.998) | 31.900(2.053) | 0.998 (0.995-1.000) | 0.091 0.085 | 0.000 0.000 |

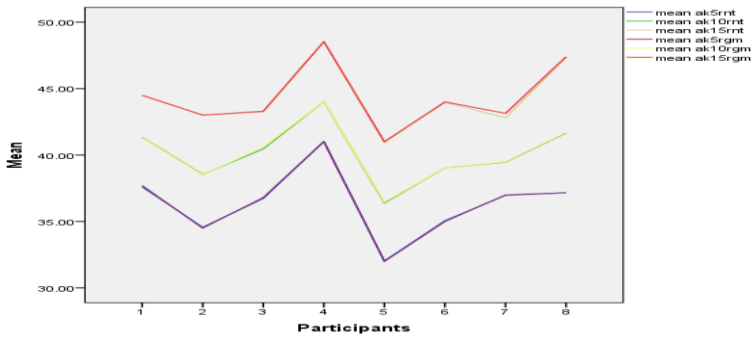
| | | | | | | |
|---|---|---|---|---|---|---|
| left | 33.212(2.6 | 33.225(2.6 | 33.175(2.7 | 0.999 (0.998- | 0.062 | 0.000 |
| 10cm below | 87) | 62) | 02) | 1.000) | 0.084 | 0.000 |
| knee left | 31.612(1.9 | 31.600(1.9 | 31.575(1.9 | 0.999 (0.996- | | |
| 5cm below knee | 53) | 73) | 30) | 1.000) | | |
| right | 33.187(2.6 | 33.175(2.6 | 33.137(2.6 | 0.999 (0.998- | | |
| 10cm below | 59) | 47) | 94) | 1.000) | | |
| knee right | | | | | | |
| Girthometer | | | | | | |
| 5cm below knee | 31.862(2.0 | 32.000(2.2 | 31.987(2.2 | 0.990 (0.968- | 0.217 | 0.000 |
| left | 23) | 25) | 62) | 0.998) | 0.000 | 0.000 |
| 10cm below | 33.187(2.6 | 33.162(2.6 | 33.187(2.6 | 1,000 (0.999- | 0.000 | 0.000 |
| knee left | 94) | 83) | 99) | 1.000) | 0.000 | 0.000 |
| 5cm below knee | 31.612(1.9 | 31.637(1.9 | 31.600(1.9 | 1.000 (0.999- | | |
| right | 94) | 64) | 88) | 1.000) | | |
| 10cm below | 33.162(2.6 | 33.175(2.6 | 33.175(2.6 | 1.000 (0.999- | | |
| knee right | 40) | 86) | 63) | 1.000) | | |

Note: SD; Standard deviation; ICC: Intra-class correlation; SEM; Standard error of measurement

Note: ak5lnt: above knee 5cm left normal tape; ak10lnt: above knee 10cm left normal tape; ak15lnt: above knee 15cm left normal tape; ak5lgm: above knee 5cm left girthometer; ak10lgm: above knee 10cm left girthometer; ak15lgm: above knee 15cm left girthometer

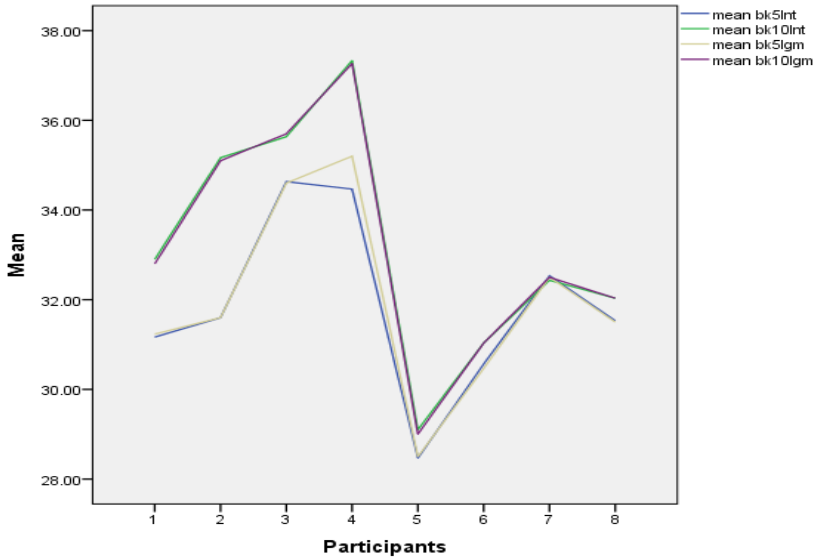
(a)



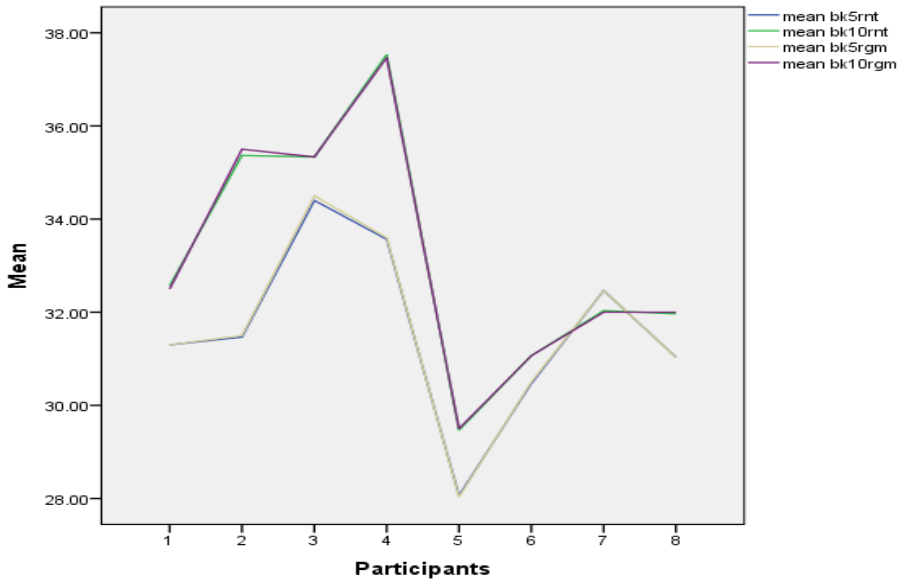



Note: ak5rnt: above knee 5cm right normal tape; ak10rnt: above knee 10cm right normal tape; ak15rnt: above knee 15cm right normal tape; ak5rgm: above knee 5cm right girthometer; ak10rgm: above knee 10cm right girthometer; ak15rgm: above knee 15cm right girthometer

(b)




Note: bk5lnt: below knee 5cm left normal tape; bk10lnt: below knee 10cm left normal tape; bk5lgm: below knee 5cm left girthometer; bk10lgm: below knee 10cm left girthometer(c)




Note: bk5rnt: below knee 5cm right normal tape; bk10rnt: below knee 10cm right normal tape; bk5rgm: below knee 5cm right girthometer; bk10rgm: below knee 10cm right girthometer

(d)

**Figure 4:** Comparison of conventional method and proposed Girthometer: Mean Measurements (a) Above Left Knee (b) Above Right Knee (c) Below Left Knee (d) Below Right knee

**Table 4:** Users Feedback on the Use of proposed Girthometer

| | **Mean±SD** | **Frequency** | **Percentage (%)** |
|---|---|---|---|
| Gender | | | |
| Male | | 2 | 25.0 |
| Female | | 6 | 75.0 |
| Satisfaction | 4.25±0.46 | | |
| Strongly disagree | | 0 | 0 |
| Disagree | | 0 | 0 |
| Neutral | | 0 | 0 |
| Agree | | 6 | 75.0 |
| Strongly agree | | 2 | 25.0 |
| Comfort | 4.13±0.64 | | |
| Strongly disagree | | 0 | 0 |
| Disagree | | 0 | 0 |
| Neutral | | 1 | 12.5 |
| Agree | | 5 | 62.5 |
| Strongly agree | | 2 | 25.0 |
| Time saving | 4.25±0.46 | | |
| Strongly disagree | | 0 | 0 |
| Disagree | | 0 | 0 |
| Neutral | | 0 | 0 |
| Agree | | 6 | 75.0 |
| Strongly agree | | 2 | 25.0 |
| High quality | 3.88±0.35 | | |
| Strongly disagree | | 0 | 0 |
| Disagree | | 0 | 0 |
| Neutral | | 1 | 12.5 |
| Agree | | 7 | 87.5 |
| Strongly agree | | 0 | 0 |

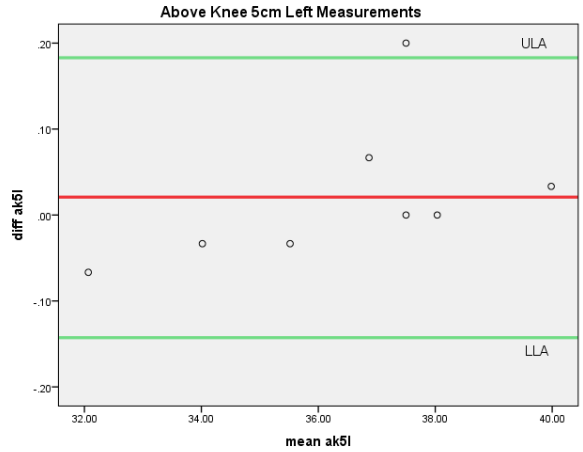
Note: SD: Standard deviation

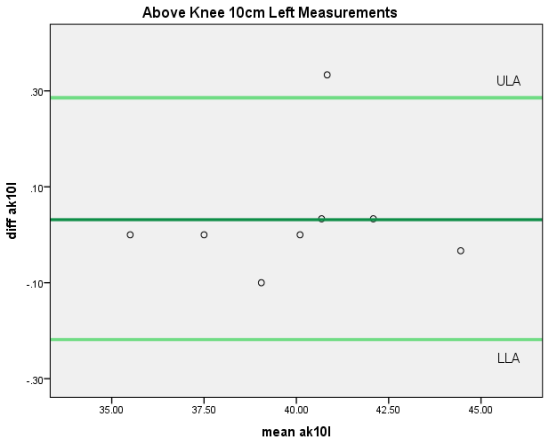
**Table 5:** Results of Clients' Feedback on proposed Girthometer Based on Reference Value

| | **Mean±SD** | **SEM** | **Mean difference** | **95% CI of the difference** | | **t(df)** | **p[a]** |
|---|---|---|---|---|---|---|---|
| | | | | **Lower** | **Upper** | | |
| Satisfaction | 4.25±0.46 | 0.16 | 0.2500 | -0.1370 | 0.6370 | 1.528(7) | 0.170 |
| Comfort | 4.13±0.64 | 0.23 | 0.1250 | -0.4108 | 0.6608 | 0.552(7) | 0.598 |
| Time saving | 4.25±0.46 | 0.16 | 0.2500 | | | 1.583(7) | 0.170 |

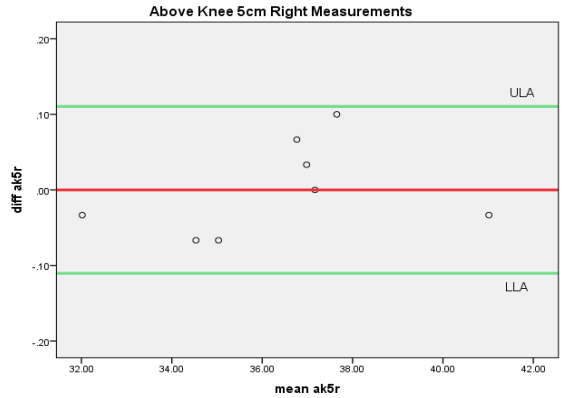
| | | | | | | |
|---|---|---|---|---|---|---|
| Highly quality | 3.88±0.35 | 0.13 | -0.1250 | -0.1370<br>0.6370<br>-0.4206 | -1.000(7) | 0.351<br>0.1706 |

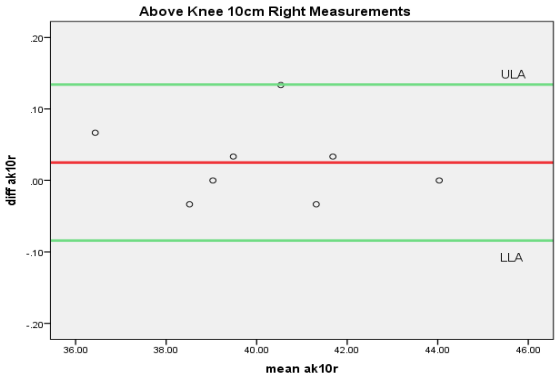
Note: SD: Standard deviation; SEM: Standard error mean; CI: Confidence interval; df: Degree of freedom; [a]: one sample t test based on test value of 4



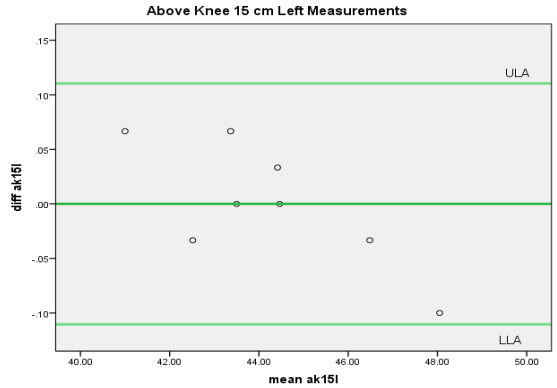



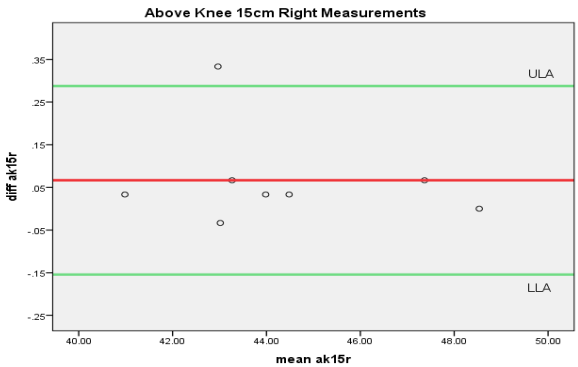

(a) (b)




(c) (d)



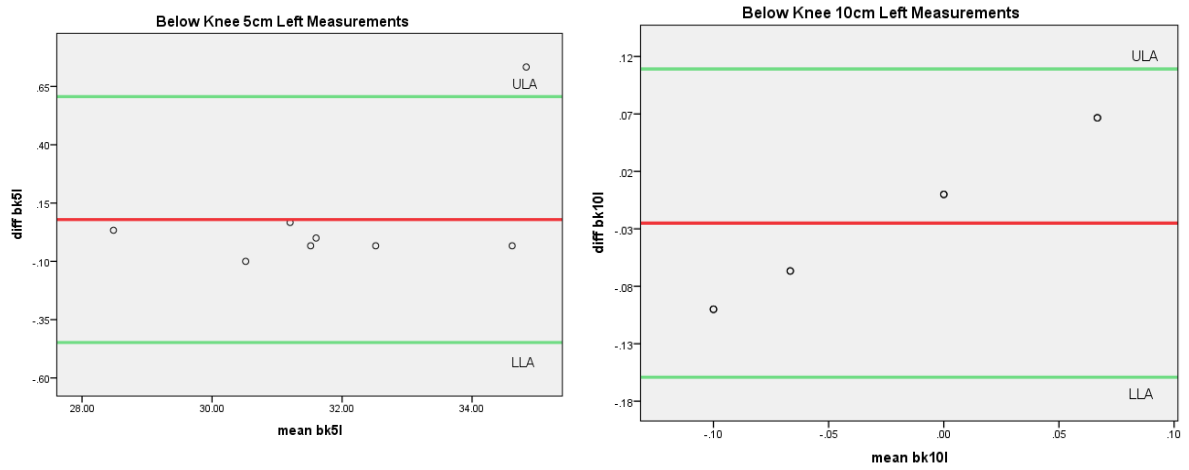




(e) (f)

Note: ak5l: Above knee 5cm left; diff ak5l: Difference above knee 5cm left; ak10l: Above knee 10cm left; diff ak10l: Difference above knee 10cm left; Note:

ak5r: Above knee 5cm right; diff ak5r: Difference above knee 5cm right; ak10r: Above knee 10cm right; diff ak10r: Difference above knee 10cm right; ak15l: Above knee 15cm left; diff ak15l: Difference above knee 15cm left ak15r: Above knee 15cm right; diff ak15r: Difference above knee 15cm right; LLA: Lower limit of agreement; ULA: Upper limit of agreement.

**Figure 5:** Comparison of conventional method and proposed Girthometer: Bland-Altman Plot for Above Knee Left (a) 5cm (b) 10cm (e)15cm, Above Knee Right (c) 5cm (d) 10cm (f)15cm Measurements




(a) (b)

(c) (d)

Note: bk5l: Below knee 5cm left; diff bk5l: Difference below knee 5cm right; LLA: Lower limit of agreement; ULA: Upper limit of agreement.

Bk10r: Below knee 10cm right; diff bk10r: Difference below knee 10cm right

**Figure 6:** Comparison of conventional method and proposed Girthometer: Bland-Altman Plot for Below Knee Left (a) 5cm (b) 10cm, Below Knee Right (c) 5cm (d) 10cm Measurements

## Data Interpretation / Results

A two-way random model is used in this study to evaluate the reliability of the Girthometer. Standard deviation (SD), Intra-class correlation (ICC) and Standard error of measurement (SEM) are used to test the

reliability for the above knee measurement and below knee measurement between normal tape and Girthometer. ICC is defined as "absolute agreement" and "consistency". The higher the ICC value, the high the reliability of the Girthometer.

ICC is calculated as in equation (1):

$$\frac{MS_R - MS_E}{MS_R + (k-1)MS_E + \frac{k}{n}(MS_C - MS_E)} \quad (1)$$

SEM is the standard error of mean of random samples drawn from the original population. It is an estimate of variability of possible values of means of samples as shown in equation (2). Its main function is to help construct confidence intervals (CI).

$$SEM = \frac{SD}{\sqrt{n}}. \quad (2)$$

$$s = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}} \quad (3)$$

SD is a dispersion of individual observations about the mean,

The comparative results in Tables 2 and 3 indicates that the proposed Girthometer result of ICC is much higher than the normal measuring tape (ICC > 0.9, P<0.05). This proves that the reliability of the proposed Girthometer is better than the conventional type. P-value is significant, P = 0 for both normal tape and Girthometer at the site of above-knee measurement. Thus, it proved that the result is significant over the standard measuring tape and the Girthometer is high in above and below knee measurement.

To further strengthen the findings of the agreement in the reliability between the Girthometer and normal measuring tape, the line graph was employed in the study rather than the block spot as shown in Figures 4 and 5.

In Table 2, the mean value obtained 5 cm above the left knee for both standard measuring tape and Girthometer is between 36.387 until 36.450. The mean value obtained 10 cm above the left knee for both standard measuring tape and Girthometer is between 39.975 until 40.025. The mean value obtained 15 cm above the left knee for both standard measuring tape and Girthometer is between 44.200 until 44.250. The mean value for three measurements for each site is significance similar and almost equal.

In Table 3, the mean value obtained 5 cm above the right knee for both standard measuring tape and Girthometer is between 36.350 until 36.437. Mean value obtained 10 cm above the right knee for both standard measuring tape and Girthometer is between 40.100 until 40.150. The mean value obtained 15 cm above the right knee for both standard measuring tape and Girthometer is between 44.312 until 44.362. The mean value for three measurements for each site is significance similar and almost equal.

In Table 3, the mean value obtained 5 cm below the left knee for both standard measuring tape and Girthometer is between 31.837 until 32.000. The mean value obtained 10 cm below the left knee for both standard measuring tape and Girthometer is between 33.175 until 33.212. The mean value for three measurements for each site is significance similar and almost equal. In Table 3, the mean value obtained 5 cm below the right knee for both standard measuring tape and Girthometer is between 31.575 until 31.637. The mean value

obtained 10 cm below the right knee for both standard measuring tape and Girthometer is between 33.137 until 33.187. The mean value for three measurements for each site is significance similar and almost equal.

In Table 4, the mean value obtained for satisfactory of Girthometer is 4.25±0.46. The mean value obtained for comfort value of Girthometer is 4.13±0.64. The mean value obtained for time saving application is 4.13±0.64. The mean value obtained for determination quality of Girthometer is 3.88±0.35. In Table 4, the mean difference obtained for satisfactory of Girthometer is 0.2500 and the degree of freedom is 1.528(7) and $p^a$ value is 0.170. The mean difference obtained for comfort value of Girthometer is 0.1250 and the degree of freedom is 0.552(7) and $p^a$ value is 0.598. The mean difference obtained for time saving application is 0.2500 and the degree of freedom is 1.583(7) and $p^a$ value is 0.170. The mean difference obtained for determination quality of Girthometer is -0.1250 and the degree of freedom is -1.000(7) and $p^a$ value is 0.351.

To further strengthen the findings of the agreement in the reliability between the Girthometer and normal measuring tape, the Bland-Altman Plot was employed in the study. In the Bland-Altman Plot in Figure 6, the x-axis indicated the mean of two measurements and the y-axis indicated the difference between Normal Tape and Girthometer.

## DISCUSSION

In this study, eight healthy participants were recruited to test the proposed Girthometer. Although a few sample studies were involved, the number of measurements taken was high. There are 144 repetitions of measurements for above-knee by using both Girthometer and standard measuring tape. 96 repetitions of measurements for bellow knee by using both Girthometer and standard measuring tape. This is because there are 3 girth measurement sites for each thigh and 2 girth measurement sites for calf muscles.

Two-way random effects, absolute agreement, single rater/measurement ICC (2,1) is applied in this research. According to table 2 and table 3, the ICC result over the Girthometer readings is relatively higher than the standard measuring tape.

SEM was emphasized in this study because it is mainly to estimate of the variability of Girthometer measurement and to estimate the variability of possible values of means of samples. As mean values are considered for calculation of SEM, it is expected to prove the variability in the values of the sample mean in the Girthometer than in the standard measuring tape. This shows that SEM is a measure of the precision with which sample mean $\bar{X}$ estimates the population means $\mu$. The precision increases as the repetition of measurements increases.

In statistics, the p-value is the likelihood of achieving outcomes as extreme as the perceived results of a statistical hypothesis test. A smaller p-value indicates that there is more substantial evidence in support of the alternative hypothesis. According to table 2 and table 3, the P values are all equal to zero on both sides above and below knee readings. Thus, it indicates that the results are significant.

Bland and Altman advocated the application of a graphical approach to outline the difference scores of two measurements versus the average for respectively individual and clarified that if the

innovative approach corresponds adequately well with the conventional. It gives a concept of recognition that performs a significant part in method correlation studies. The display of the ninety-five percent frontiers of identification is for visual inspection of how strongly the two methods of measures match. The more diminutive the range between these two limits the more reliable the agreement is. Thus, Figures 4, 5 and 6 has proven that the result is significant and reliable as the range between the two limits is less.

The distribution of mean between above and below knee showed smaller gap of differences. As the comparison between the difference of mean and upper limit of agreement and difference of mean and lower limit of agreement are significant. Results obtained are uniformly distributed between upper limit of agreement and lower limit of agreement. Thus, it showed that Girthometer has excellent agreement in measuring the thigh and calf muscles. Hence, the use of Girthometer appear to be an accurate and acceptable device in thigh and calf muscles girth measurement.

## CONCLUSION

In conclusion, based on the results obtained, the Girthometer has proven that it is more reliable than the conventional method as known as a standard measuring tape. The null hypothesis is rejected. The proposed Girthometer conserves time for taking patient's thigh and calf muscle girth measurement and without marking on patient's skin during clinical assessment compare with conventional method. Thus, it increases patient satisfaction toward the girth measurement process. The new innovative measuring tool can minimize the measurement errors which commonly made by practitioner. Girthometer can improve the reliability of thigh and calf muscle girth measurement. The differences in appearance and applying the method of the proposed Girthometer and the standard measuring tape or the measurement tools available in the market, yet the Girthometer has more exceptional reliability among the competitors.

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