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Basic Science

Calf Muscle (Triceps Surae Complex) Thickness in an Adult Nigerian Population: An Imaging Based Normographic Study

Ogugua A Egwu[1*], Clinton O Njoku[2], Ukoha U Ukoha[3], Albert N Eteudo[2], Bright C Elem[2]

[1]Department of Anatomy, Federal University Ndufu-Alike Ikwo, Nigeria; [2]Department of Anatomy, Ebonyi State University, Abakaliki, Nigeria; [3]Department of Anatomy, Nnamdi Azikiwe University, Nnewi Campus, Nigeria

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***Correspondence:** Dr Ogugua Egwu, Department of Anatomy, Faculty of Basic Medical Sciences, Federal University, Ndufu-Alike Ikwo, P.M.B 1010 Abakaliki, Ebonyi State, Nigeria. E-mail- egwuoc@yahoo.com; egwuoc@gmail.com

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Abstract

Objective: The thickness of the triceps surae muscle complex was assessed by ultrasound in a young adult Nigerian population. Its relationship with some anthropometric variables and sexual dimorphism was also assessed.

Subjects and Methods: Sixty young adults (30 males and 30 females) between the ages of 19 and 30 years were recruited for the study. Anthropometric protocols for height, weight, foot length (FL) lower leg length (LLL) and mid calf circumference (MCC) were observed.

Results: Results show that the mean thickness of the calf muscle complex (CMT) was 81.65 ± 8.92 mm for all the subjects; 83.70 ± 8.73 mm for males; 79.95 ± 8.56 mm for females. The mean mid calf circumference (MCC) was 35.26 ± 2.61 cm for all subjects; 36.41 ± 3.56 cm for males; 34.10 ± 3.33 cm for females. Pearson's correlation coefficient showed that CMT correlated positively with height, weight, BMI and BSA in the sample subjects. However, such correlations were not observed among the male subjects. MCC also correlated with some anthropometric parameters (height, weight, BMI, BSA, FL) measured.

Conclusion: The findings from this study will form the bases for further research on relationships of the calf muscle complex. It also indicates that males have thicker Calf muscles and CMT has a positive relationship with height, weight, BMI and BSA especially among the female subjects.

Introduction

The skeletal muscle architecture is the primary determinant of muscle function [1, 2]. The knowledge of muscle architecture is of great practical importance in understanding the relationship between muscle structure, force and extension ability [3]. Muscle architecture has been mainly characterized by Fascicle length, Pennation angle and the thickness of the muscle [4-6].

Muscle thickness can be described as the distance between aponeurosis [5]. This muscle parameter is very important clinically in the assessment of atrophy and hypertrophy in neuromuscular diseases [7]; in the estimation of general muscle volume [8]; in the quantification of amyotrophic lateral sclerosis [9]; categorizing the intensity of relationship with activity levels in Cerebral Palsy [10] and in the monitoring of lean tissue mass.

Most assessments of muscles are done with the use of ultrasound since real-time sonography enables in vivo muscle scanning and offers an assurance for a realistic determination of changes in muscle architecture [6, 11]. In 1980, it was first discovered that diseased muscle showed a different ultrasound appearance compared to healthy muscles

[12]. Neuromuscular disorders, malignancies, infections and hematomas and ruptures of the musculoskeletal system can also be detected with ultrasound [13-16]. The sonographic appearance of muscles is fairly distinct and can easily be differentiated from surrounding structures such as subcutaneous fat, bone, nerves, and blood vessels [16]. Normal muscle is relatively black with low echo intensity [17].

The calf muscle (triceps surae complex) is connected to the foot through the Achilles tendon, and has three heads deriving from the two major masses of muscle. It has a superficial portion (the gastrocnemius) which gives off two heads attaching to the base of the femur directly above the knee and forming the superior boundaries of the popliteal fossa. The deep mass of muscle is the soleus and forms the remaining head, which attaches to the posteriosuperior region of the tibia. The aponeurosis of the three muscles joins to form Achilles tendon (Tendocalcaneus), which transmits loads generated by the calf muscle to the calcaneus [18]. This powerful muscular mass uses the lever provided by the calcaneal tuberosity, to elevate the heel and thus, depress the forefoot. The large size of gastrocnemius and soleus muscles is a human characteristic that is directly related to and is *sine qua non* to human bipedalic mechanism of motion. These muscles are strong and heavy because they lift, thrust, and accelerate the weight of the body when walking, running, jumping, or even standing on the toes. Their thickness as a musculotendinous unit has been reported to be influenced by factors like body stature, height, age, physical activities such as sports and by ethnic factors [18-20]. These relationships have not been explored in our sub-saharan African environment.

Based on their functional roles, as a musculotendinous unit, in the mechanics of human bipedalism and their significance in the clinical assessment of muscle wasting in children, adolescents and adults [21-23]; in the occurrence of overuse injuries of the foot [24], it is absolutely necessary to document a nomographic data of their thickness, to serve as a good guidepost to the further understanding of their biomechanics especially, in a Sub-Saharan African population where studies on the structural disposition of muscles are absolutely lacking. The study will also form a possible basis for description of racial/ethnic differences as was described by Ishida et al [25] between Japanese and Americans; and sexual dimorphism. It will also establish the relationship, in our Sub-Saharan environment, between Calf muscle thickness and some important anthropometric parameters associated with physique, growth and physical development and activity.

This study is therefore, conducted to investigate the thickness of calf muscle among young healthy Adults (within an active age group) using ultrasound. The thickness of these muscles will possibly be a pointer to the functional status of the muscle; its use among young adults and its role in force generation during human propulsion.

Subjects and Methods

Study design

This study is designed to use ultrasound in measuring the thickness of calf muscle.

Participants

The sampling method is that of a convenient purposive nature. Sixty healthy subjects (30 males and 30 females) were used for this study. They were selected from a pool of students in the College of Health Science, Ebonyi State University, Abakaliki, South-east Nigeria. All subjects were physically active, not previously taken part in regular weight training (weight lifting). None had any subjective clinical evidence of musculoskeletal injury or any orthopaedic abnormality. They were informed to avoid any rigorous exercise (e,g, running, cycling, etc) two weeks before the study as this has been found to cause an increase in muscle thickness [26]. Oral interview with the subjects revealed that they were all Igbos with mono-ethnic parenthood of Igbos of South-east Nigeria. They were between the ages of 19 and 30.

Study Area

Abakaliki is the capital city of Ebonyi state, which is a mainland south-eastern state of Nigeria, inhabited and populated primarily by Igbos of the south eastern, Nigeria. It lies approximately within longitude$7^{O}30^{1}$ and $7^{O}30^{1}$E and latitude $5^{O}40^{1}$ and $6^{O}45^{1}$N.it has a landmass of about 5,935 square kilometers. The population of Ebonyi state according to National Population Commission held on 21st march, 2006 is 2,176,947 peoples with males having 1,064,156 and females 1,112,791. Agriculture in the major economic base of the state with about 80% of the population actively engaged. Abakaliki is the leading producer of rice in southeast Nigeria. Massive production of yams, potatoes, maize, beans, cassava, etc is also done in the state. Indigenes living in the riverine areas are also actively engaged in fish farming.

Study Centre

The study centre was at life scan ultrasound centre, Felix Memorial Hospital, 7 Hilltop road, Abakaliki, Ebonyi State, Southeast, Nigeria. This Life scan ultrasound centre receives patients from within Abakaliki metropolis and beyond. Their patients are mostly obstetric patients and individual with soft tissue pathology, including all form of abdominal pathologies. The centre receives patients from all private hospitals in Abakaliki metropolis, Ogoja metropolis, Afikpo metropolis and beyond and those not accommodated in the Federal Teaching Hospital, Abakaliki, Ebonyi state, Southeast, Nigeria.

Brightness mode (B-mode) ultrasound system (Siemens Sonoline SL-1, version 2000) was used to objectively measure calf muscle thickness with 7.5MHz linear transducer.

Scanning Protocol

To ensure reproducibility of result, a standardized protocol was developed. The subjects were asked to lie down in a prone position with ankle extending beyond the examination couch. Each ankle was held at 90^0 to the horizontal plane (Fig. 1a and b) which, was measured with the goniometer. This position is chosen to facilitate contact between the probe and the muscle and to avoid anisotropic effect, which can occur if the muscle is not taut [19, 27].

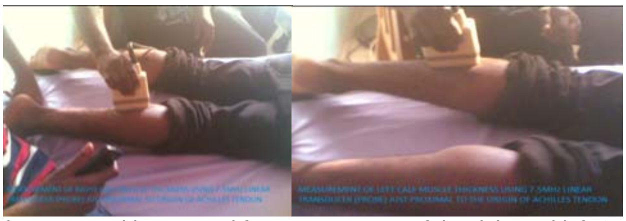

Figure 1a and b: Protocol for measurement of the right and left Calf muscle thickness (CMT).

The feet were rested against the wall to maintain a constant angle. Longitudinal views of the calf muscles were obtained with the transducer placed in sagittal plane. The measurements were taken at point where the calf muscle was seen to be thickest, just proximal to the Achilles tendon origin. At this point, the medial (the larger mass) and lateral heads of gastrocnemus had formed a common aponeurosis and has received the fibres of the soleus (a point 1/3 of the distance from the popliteal crease to the calcaneal tubercle). These measurements were taken twice for the two legs and the average deduced.

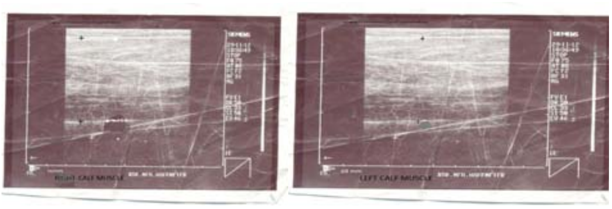

Figure 2a and b: Sonographs for the Right and Left CMT.

Anthropometric Measurements

Anthropometric parameters such as Age, Height, length of the leg, mid-calf circumference, weight were all measured on both sides of each subject.

Length of Lower Leg (LLL)

The length of the each lower leg was measured on both legs as the distance between the inferior border of the lateral malleolus and the popliteal crease using a measuring tape.

Figure 3: Protocol for measuring Lower leg length.

Mid-Calf Circumference (MCC)

The mid-calf circumference was measured at the point of the largest circumference which was located at 70% of the distance between the inferior border of the lateral malleolus (inferiorly) and the popliteal crease (superiorly) using a non-stretchable measuring tape.

Length of the Foot (FL)

The length of the foot was measured as the distance between the tip of the skin covering the calcaneal tuberosity (posteriorly) and the apex of either the big/great toe (1st toe) or the second toe depending on the longer toe.

Weight

The body weight was measured using a bathroom scale. This scale was at the zero scale reading before measuring each subject. The subjects wore a very light clothing to ensure as much accuracy as possible.

Height

Height was measured using a Stadiometer. The subjects stood erect and their heads were made to be parallel to the Frankfort plane to ensure accuracy.

Body Mass Index (BMI) and Body Surface Area (BSA)

BMI was derived using the formula weight/(height)^2 while BSA was derived using the equation derived by Du and Du Bois [28], thus BSA= (Weight $^{0.425}$ X Height $^{0.725}$) 0.007184.

Data Analysis

All the data collected for each subject were compiled in a Microsoft excel spread sheet. For statistical analysis, the statistical package for social sciences (SPSS) version 18 was used. The means, standard deviation and correlations were calculated. Mean values of the various measured parameters were expressed with their standard deviations. These parameters were correlated with each other using bivariant Pearson correlation with significance levels determined at p <0.05 and p < 0.01.

Ethical Approval

In line with Belmont report of 1979 where respect for persons, beneficence and justice are recommended in every research involving human subjects, ethical approval was obtained from the Research Committee of the Faculty of Basic Medical Sciences, Ebonyi State University, Abakalilki, Southeast, Nigeria.

Results

Table 1 displayed the mean with standard deviation (mean ± SD) of the calf muscle thickness for all the subjects. The mean calf muscle thickness was 81.65 ± 8.92 mm (range 55-100 mm). It also shows that the average age and height of the subjects are 23.90 ± 3.02 and 1.69 ± 0.09 m respectively.

Table 1: Descriptive Statistics of all variables for the overall subjects.

	Mean	Std. Deviation	N
Age	23.90	3.02	60
Height (m)	1.69	.09	60
Weight (Kg)	65.37	10.56	60
BMI Kg/m^2	22.76	2.72	60
BSA	1.75	.18	60
MCC (cm)	35.26	3.61	60
LLL (cm)	42.57	3.19	60
FL (cm)	26.27	1.80	60
CMT (mm)	81.65	8.92	60

Table 2 also displayed the mean with standard deviation (mean ± SD) of all the anthropometrics for the male subjects. The mean age (n=30) was 24.2 ± 3.21 (range 19-32), Height (n=30) was 1.57 ± 0.068 m (range 1.57-1.89 m), mean weight (n=30) was 70.97 ± 9.031 kg (range 48-88 kg), mean BMI (n=30) was 22.8 ± 2.301 kg/m^2 (range 19.38-26.61 kg/m^2), mean BSA (n=30) was 1.86 ± 0.143 m^2 (range 1.45 ± 2.11 m^2), mean LLL (n=30) was 44.16 ± 3.11 cm (range 38-51 cm), mean MCC (n=30) was 36.41 ± 3.56 cm (range 29.75-51 cm), and the mean FL (n=30) was 27.46± 1.68 cm (range 23.35-31.3 cm).

Table 2: Descriptive Statistics of all variables for the male subjects.

	Mean	Std. Deviation	N
AGE	24.20	3.21	30
HEIGHT	1.75	.07	30
WEIGHT	70.97	9.03	30
BMI	22.80	2.30	30
BSA	1.86	.14	30
LLL	44.16	3.11	30
MCC	36.41	3.56	30
FL	27.46	1.68	30
CMT	83.70	8.73	30

Table 3 also shows the mean ± standard deviation (mean ± SD) of the CMT and the other anthropometric parameters measured in the female subjects. The mean age (n=30) was 23.6 ± 2.84 (range 19-30), mean height was 1.62 ± 0.05 m (range 1.54-1.72 m), mean weight was 61.07 ± 10.12 kg (range 47-85 kg), mean BMI was 22.71 ± 3.13 kg/m^2 (range 17.26-29.17 kg/m^2), mean BSA was 1.64 ± 0.14 m^2 (range 1.47 ± 1.88 m^2), mean LLL was 40.64 ± 3.24 cm (range 29-44 cm), mean MCC was 34.1 ± 3.33 cm (range 29.85-42 cm), and the mean FL was 25.08 ± 0.92 cm (range 23.35-26.7 cm).

Table 3: Descriptive Statistics of different variables for females subjects.

	Mean	Std. Deviation	N
AGE	23.60	2.83	30
HEIGHT (m)	1.62	.05	30
WEIGHT (Kg)	61.07	10.12	30
BMI	22.71	3.13	30
BSA	1.63	.14	30
LLL (cm)	40.64	3.24	30
MCC cm)	34.10	3.33	30
FL(cm)	25.08	.92	30
CMT (mm)	79.95	8.56	30

Table 4 highlights some of the significant correlations seen between variables- both anthropometric and sonographic parameters. The CMT expresses some significant correlation with the height of the subjects (r=0.033), weight (r=0.004), BMI (r=0.023), BSA (r=0.004) and MCC (r=0.000). The MCC also correlated with height (r=0.000), weight (r=0.000), BMI (r=0.000), BSA (r=0.000), LLL (r=0.022) and FL (r=0.000)

Table 4: Pearson's correlation coefficients between CMT and the Anthropometric Variables for all subjects.

	Age	Height	Weight	BMI	BSA	MCC	LLL	FL
MCC	0.190	0.550**	0.767**	0.556**	0.753**	1.000	0.295*	0.475**
	0.146	0.000	0.000	0.000	0.000		0.022	0.000
CMT	0.164	0.276*	0.365**	0.293*	0.368**	0.508**	0.072	0.124
	0.210	0.033	0.004	0.023	0.004	0.000	0.582	0.345

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

Table 5 shows that the CMT in the males did not show any significant correlation with all the anthropometric variables measured. However, the MCC showed some significant degree of correlation with height, weight, BMI and BSA (r=0.005; 0.000; 0.004 and 0.000 respectively).

Table 5: Pearson's correlation coefficients between CMT and the Anthropometric Variables for male subjects.

	Age	Height	Weight	BMI	BSA	MCC	LLL	FL
MCC	0.193	0.499**	0.721**	0.508**	0.692**	1.000	0.077	0.363
	0.306	0.005	0.000	0.004	0.000		0.684	0.056
CMT	0.048	0.046	0.052	0.136	0.046	0.273	0.324	0.179
	0.800	0.808	0.784	0.473	0.811	0.144	0.080	0.345

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

Table 6 shows that the CMT of females correlates with height (r=0.008), weight (r=0.000), BMI (r=0.000) and BSA (r=0.000). The MCC also correlates with all anthropometric variables measured except the LLL (r=0.012).

Table 6: Pearson's correlation coefficients between CMT and the Anthropometric Variables for female subjects.

	Age	Height	Weight	BMI	BSA	MCC	LLL	FL
MCC	0.136	0.472**	0.698**	0.657**	0.802**	1.000	0.451*	0.432*
	0.473	0.008	0.000	0.000	0.000		0.012	0.017
CMT	0.286	0.302(*)	0.427*	0.418*	0.571**	0.432*	0.122	0.248
	0.125	0.032	0.019	0.022	0.001	0.017	0.522	0.186

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

Table 7 shows that there is no significant difference between the CMT of male and female subjects when t-test is used to compare their means (P=0.103). However, the MCC and BSA of male subjects are significantly higher than those of the females (P=0.008; P=0.000 respectively).

Table 7: Paired difference (T-test) between some parameters in the males and females.

	Mean	Standard deviation	Standard error in mean	t-value	Df	p-value
CMT	3.75	12.21	2.23	1.68	29	0.103
MCC	2.31	4.42	0.81	2.86	29	0.008*
BSA	0.218	0.17	0.03	6.92	29	0.000*
BMI	0.09	3.65	0.67	0.13	29	0.898

*P<0.05 as Significant.

Discussion

Muscle thickness can be described as the cross-sectional diameter of the belly that extends from aponeurosis to aponeurosis. Its characterization as part of muscle architecture cannot be overemphasized because of its role in the comparative assessment of gross morphology of muscles.

This study has shown that the calf muscle thickness was 81.65 ± 8.92 mm (range 55-100 mm) for all the subjects. This is the first set of data being reported from a Sub-Saharan African population. These values are higher than the values (≈ 60 mm) reported by Maganaris et al [5] in a Caucasian environment. This difference could be attributed to racial differences in the disposition of Muscle structure as reported by Ishida et al [25], who described muscle architectural (thickness) differences between Japanese and American female subjects. Even though Maganaris et al [5] did not establish a relationship with the stature/physique of the individuals, it is possible that the results were tied to the physique of the subjects because Pearson's correlation coefficient revealed a significant positive relationship between CMT and some anthropometric variables like height, weight, BMI, BSA and MCC of all subjects (See Table 4). This relationship could be an extension of the correlations described by Koivunen-nieman et al [19] between the tendinous segment (Tendocalcaneus) of the musculotendinous complex and some anthropometric parameters like height etc.

There was no correlation between CMT and age among the entire subjects (see Table 4). This is because the subjects' age range was quite narrow and did not allow for age and ageing of the subjects to influence the structural disposition of the musculotendinous complex. However, we believe that the relatively large values obtained for CMT were because the age bracket of the subjects represents the point of maximum muscle development and could be attributed to age associated degree of physical activity. MCC was not also affected by age. The MCC is a representation of the thickness of the subcutaneous adipose tissue, the triceps surae complex, extensor muscles and the tibia and fibula diameters. It correlated with all anthropometric parameters for all the subjects (See Table 4). It therefore implies that MCC is an important variable in the morphological description of stature, weight, LLL, FL and by extension, the BMI and BSA. Hence, it is an important parameter in anthropometric assessment- both in nutritional and physical activity related assessments.

The degree of correlation was totally different in both sexes. In the female subjects, the CMT showed meaningful correlation with anthropometric variables like height, weight, BMI, BSA and MCC (See Table 6) while in the male; there was virtually no statistical relationship between CMT and other anthropometric variables. This disparity could be attributed to the possibility that in females, the listed anthropometric variables have more influence on the structural disposition of the tricep surae complex while such influence is not perceived in the males possibly because of the masculinity of exercises they are exposed to in their day to day living. Chow et al [29] earlier described gender variability in the gastrocnemus and Soleus complex and Miller et al [30]; Kanehisha et al [31] and Kanehisa et al [32] described sexual differences in the size, length and degree of force generation indicating sexual dimorphism and by extension, sexual variability in the myoanthropometric relations.

Results also showed that males had thicker Calf muscle complex than their female counterparts even though the difference was not significant (see Table 7). The difference can simply be explained on the basis of masculinity in the post-pubertal development of male subjects as opposed to post-pubertal feminization in the females. This possible sexual difference has also been reported by Kanehisha et al [32] for abdominal muscles and the findings in this study are in consonance with their report. Accordingly, the MCC of males was significantly higher than those of females (See Table 7). This significant difference could also be attributed to post-pubertal testosterone induced masculinisation that leads to more massive bones and larger intra-compartmental connective tissues, which contribute to the actual value of MCC.

This study has established a normographic base for the assessment of triceps surae complex in vivo. Being the first of its kind in musculoskeletal biology in this part of the world, it has created an insight into the structural disposition of the musculotendinous unit in an African population. It has also highlighted some of the relationships existing between muscles and human physique, anthropometric categorization and sex. Through this study, reconstructive and restorative procedures in degenerative compartment syndromes of the posterior compartment of the leg can be done using locally generated data and myoanthropometric relationships. The study will form the basis of other studies on the triceps surae complex in relation to its biomechanical properties in sports and occupational medicine.

In conclusion, males have a higher CMT than females even though it is not significant. CMT correlates positively with the weight, height, BMI and BSA of the subjects and this could be a pointer to the effect of stature, physique and some anthropometric variables on the structural disposition of the human triceps surae complex.

References

1. Fukunaga T, Kantakami Y, Kuno S, Funato K, Fukashiro S. Muscle architecture and function in humans. J Biomech. 1997;30(5):457-463.

2. Aagaard P, Andersen JL, Dyhre-Poulsen P, Leffers AM, Wagner A, Magnusson SP, Halkjaer-Kristen J, Simonsen EB. A mechanism for increased contractile strength of human pinnate muscle in response to strength training: Changes in muscle architecture. J Physiol. 2001;534(2):613-623.

3. Lieber RL, Friden J. Clinical significance of skeletal muscle architecture. ClinOrthopRelat Res. 2001;383:140-151.

4. Fukunaga T, Ichinose Y, Ito M, Kawakami Y, Fukunaga J. Determination of fascicle length and pennation in a contracting human muscle *in* vivo. J Appl Physiol. 1997;82(1):354-358.

5. Maganaris CN, Baltzopoulos V, Sargeant AJ. *Invivo* measurement of triceps surae complex architecture in man: Implication of muscle function. J Physiol. 1998;2: 603-614.

6. Rutherford OM, Jones DA. Measurement of fibre pennation using ultrasound in the human quadriceps *in vivo*.Eur J Appl Physiol. 1992;65(5):433-437.

7. Heckmatt JZ, Pier N. Dubowitz V. Assessment of quadriceps femoris muscle atrophy and hypertrophy in neuromuscular disease in children. J Clin Ultrasound. 1988;16 (3): 177-181.

8. Miyatani M, Kanehisa H, Ito M, Kawakami Y, Fukunaga T. The accuracy of volume estimates using ultrasound muscle thickness measurements in different muscle groups. Euro J Appl Physiology. 2004;91(2-3):264-272

9. Lee CD, Song Y, Peltier AC, Jarquin-Valdivia AA, Donofrio PD. Muscle ultrasound quantifies the rate of reduction of muscle thickness in amyotrophic lateral sclerosis. Muscle & Nerve. 2010; 42(5): 814–819.

10. Moreau NG, Simpson KN, Teefey SA, Damiano DL. Muscle Architecture Predicts Maximum Strength and Is Related to Activity Levels in Cerebral Palsy. Phys Ther. 2010;90(11): 1619–1630.

11. Narici MV. Human skeletal muscle architecture studied *invivo* by non-invasive imaging techniques: Functional significance and applications. J Electromyogr Kinesiol. 1999;9;97-103.

12. Heckmatt JZ, Pier N. Dubowitz V. Measurement of quadriceps muscles thickness and subcutaneous tissue thickness in normal children by real-time ultrasound imaging. J Clin Ultrasound. 1988;16 (3): 171-176.

13. Campbell SE, Adler R, Sofka CM. Ultrasound of muscle abnormalities. Ultrasound Q. 2005;21(2):87-94.

14. Fornage BD. The cause for ultrasound of muscles and tendons. Semin musculoskelet Radiol. 2002;4:375-391.

15. Hashimoto BE, Kramer DJ, Wiitala L. Application of musculoskeletal. Sonography.J Clin ultrasound. 1999;.27:793-299.

16. Peetrons P. Ultrasound of muscles. Eur Radiol. 2002;12:35-43.

17. Sigrid P. Skeletal muscle ultrasound. European Translational Journal Myology. 2010;1(4):145-155.

18. Egwu OA, Anibeze CIP, Akpuaka FC, Udo BE. Activity related differences in the thickness of Achilles tendon among four different occupational groups in nigeria: an ultrasound based study. Bangladesh Journal of Medical Science. 2012;11(02):103-111.

19. Koivunen-nieman T, Parkkola K. Anatomy of Achilles tendon (tendocalcaneous) with respect to tendon thickness measurements. Surgical and Radiologic Anatomy. 1995;17:263-268.

20. Bjordal JM, Demmink JH, Ljunggren AE. Tendon thickness and depth from skin for spraspinatus, common wrist and finger extensors, patellar and Achilles tendons: Ultrasonography study of healthy subjects. Physiotherapy. 2003;89(6):375-385.

21. Scholten RR, Pillen S, Verrips A, Zwarts MJ. Quantitative ultrasonography of skeletal muscles in children: Normal values. Muscle & Nerve. 2003;27(6):693–698.

22. Ohata K, Tsuboyama T, Ichihashi N and Minami S. Measurement of Muscle Thickness as Quantitative Muscle Evaluation for Adults with Severe Cerebral Palsy. Physical Therapy. 2006;86(9):1231-1239.

23. Legerlotz K, Smith HK, Hing WA. Variation and reliability of ultrasonographic quantification of the architecture of the medial gastrocnemius muscle in young children. Clinical Physiology and Functional Imaging. 2010;30(3):198–205.

24. Werd MB. Achilles tendon.Sports injuries: A review of classification and treatment. Journal of the American Podiatric Medical Association. 2007;97(1):37-48.

25. Ishida Y, Kanehisa H, Fukunaga T, Pollock ML. A comparison of fat and muscle thickness in Japanese and American women. The Annals of Physiological Anthropology = Seiri Jinruigaku Kenkyukai Kaishi. 1992;11(1):29-35.

26. Ying M, Emmye Y, Bran L, Winnie L, Mandy L, Tsoi CW. Sonographic evaluation of the size of Achilles tendon: The effect of exercise and dominance of the ankle. Ultrasound in Medicine and Biology. 2003;29(5):637-642.

27. Dong Q, Fessell D. Achilles tendon ultrasound technique. American Journal of Roetgenology. 2005;193:W173.

28. Du Bois D, Du Bois EF. A formula to estimate the approximate body surface area if height and weight be known. Archives of Internal Med. 1916;17:863-871.

29. Chow RS, Medri MK, Martin DC, Leekam RN, Agur AM, McKee NH. Sonographic studies of human soleus and gastrocnemius muscle architecture: gender variability. Eur J Appl Physiol. 2000;82: 236-244.

30. Miller AEJ, MacDougall JD, Tarnopolsky MA, Sale DG. Gender differences in strength and muscle fibre characteristics. Eur J Appl Physiol. 1993;66: 254-262.

31. Kanehisa H, Ikegawa S, Tsunoda N, Fukunaga T. Strength and cross-sectional area of knee extensor muscles in children. Eur J Appl Physiol. 1994;68: 402-405.

32. Kanehisa H, Miyatani M, Azuma K, Kuno S, Fukunaga T. Influences of age and sex on abdominal muscle and subcutaneous fat thickness. Euro Journ of Applied Physiol. 2004;91(5-6):534-537.