Rehabilitative Ultrasound Imaging to Study the Gastrocnemius Muscles Morphology in Patients with Genu Varum and Valgum Deformities

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Abstract

Introduction: Genu varum and genu valgum deformities are highly prevalent in Iran. These deformities bring about changes in the structure and function of muscles around the knees. The aim of the present investigation was to study the structure of medial and lateral gastrocnemius muscles in patients with primary genu varum and genu valgum deformities and individuals with normal knee alignment, using rehabilitative ultrasound imaging. **Method and Materials: :** A Honda 2100 (Honda Co., Japan) real time ultrasound scanner was used in the current the study. The dominant legs of 18 women, 6 with genu varum (mean age: 22.00±1.78 years), 6 with genu valgum (mean age: 21.67±1.03 years), and 6 with normal alignment (mean age: 21.83±1.72 years) were examined. The morphological parameters like muscle thickness, pennation angle and fascicle length of medial and lateral gastrocnemius muscle were compared among groups. **Results:** In participants with genu varum, the medial gastrocnemius was thinner, closer and shorter in terms of muscle thickness, pennation angle, and fascicle lengths when compared to the lateral gastrocnemius ($P<0.05$). However, in participants with genu valgum, it was the other way around ($P<0.05$). In participants with normal alignment, there was no statistically significant difference between the medial and lateral gastrocnemius muscle structures. **Conclusions:** The rehabilitative ultrasound imaging is highly recommended for studying the structure of gastrocnemius muscle. The structural differences between medial and lateral gastrocnemius muscles may be due to the long term neuromuscular adaptation to knee joint alignment in both genu varum and genu valgum deformities.

Key words: Genu, Valgum, Varum, Rehabilitative, Ultrasound, Imaging

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Introduction

Genu varum is a kind of knee deformity in the frontal plane in which in standing position, when both medial malleoluse are in contact with each other, the knee joints fall apart while genu valgum is the opposite condition (1). These types of deformities are more or less prevalent in Iran (2-4). As a result of these deformities, the neuromuscular function and the control of the lower limbs as well as the structure and function of muscles around the knees will be affected (5-10). These changes may influence the ability of the muscles to deal with the forces exerted to the knee joint and may predispose the patients to the knee joint injuries.

The gastrocnemius muscle is one of the knee muscles responding to the forces exerted to the knee joint. It is one of the most important locomotor muscles of the body which has two medial and lateral parts (11). This muscle works synergistically with the quadriceps muscle to provide the stability of the knee joint (12). It also deals with varus and valgus external forces (the lateral gastrocnemius muscle against varus forces and the medial gastrocnemius muscle against valgus forces) (13). The structure and function of this muscle may change in genu varum and genu valgum deformities.

Muscle thickness, pennation angle, and fascicle length are regarded as the most important morphological parameters of an individual muscle (14). The thickness and pennation angle are two essential factors in force generation, while the muscle fascicle length is more related to the speed of contraction (15, 16).

The rehabilitative ultrasound imaging is a safe and noninvasive noninvasive method to determine the muscular structure. This method is currently common and popular for determining the muscular structure (14, 16, 17). The repeatability and accuracy of rehabilitative ultrasound imaging method to study the structure of the medial gastrocnemius has previously been tested (18).

The aim of the current study was to determine the structural changes in medial and lateral gastrocnemius muscles in patients with primary genu varum and genu valgum deformities using rehabilitative ultrasound imaging.

Materials and Methods

The present study was performed in 18 women (6 participants with genu varum, 6 with genu valgum, and 6 with normal knee alignment). The participants' characteristics are given in Table 1. Prior to the study, participants were informed about the study protocol and they signed the informed consent form. The study was approved by the Ethical Committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran.

The exclusion criteria were as follows: the presence of knee instability, any history of knee or ankle surgery, any history of musculoskeletal system injuries (tendon, ligament, and muscle) or immobility (casts, braces, *etc.*) of the lower limbs during the past six months, complaints about acute or chronic pain in the lower limbs, limping, complaints about frequent giving way (buckling), Having professional sport activities, all kinds of myopathies, and using muscle relaxants.

Identifying genu varum and genu valgum deformities

The weight and height were measured using routine measurement tools. In all the three groups, participants' dominant legs were the right legs which was identified by asking them to kick a ball. To measure the distance between medial malleoluses and the distance between medial femoral condyles, the participants were asked to stick their legs together without bending the knees while standing against the wall and their back, buttocks, and both heels touching the wall (19). The distances were measured using a caliper. Based on the distance measurements between medial malleoluses and the distance between medial femoral condyles, the participants were categorized into three groups: the genu varum group (the distance between medial condyles was more than 3 cm), the genu valgum group (the distance between medial malleoluses was more than 3 cm), and the normal group (the distance between medial condyles or medial malleoluses were less than 3 cm) (19).

Rehabilitative ultrasound imaging measurements

A Honda 2100 (Honda Co., Japan) real time ultrasound scanner with 7.5 MHz linear array probe (5 cm length) was used for the study. The participant was asked to lay in prone position on the bed as her ankles were out of the edge of the bed and her legs were quite relaxed. To define the place of probe, the 1/3 proximal way distance between tibial lateral condyle and the lateral malleolus was determined using a horizontal line (line A) on the skin (Figure 1).

After placing the probe horizontally on line A, the place between the bulks of the medial and the lateral gastrocnemius muscles was specified using a vertical line (line B) on the skin (Figure 2). The midway between lines B and the outermost and the innermost edge of the leg were specified using two vertical lines (lines C and D). Then, the probe of the device was placed longitudinally as its center met the intersection of line A and lines C or D. At last, the probe was slightly rotated to make a clear image.

From the ultrasonographic images, gastrocnemius muscle thickness was measured as the distance between superficial and deep aponeurosis in the middle of the image. The angle between clearly visible fascicle which, was nearest to the center of the image, and the deep aponeurosis was defined as gastrocnemius muscle pennation angle (Figure 3). The fascicle length was estimated using the equation: (thickness * (sinθ-1)) (20, 21). Then, all marks on the skin were cleared. Next, the participants were asked to sit for a while and again lie down in the same position and condition. All the procedures were repeated as described previously by the same examiner.

All parameters were measured on images, which were taken from both measurements, and the averages were used for data analysis. To test the reliability of ultrasonography measurements, all the procedures were repeated half an hour later.

Data analysis

The quantitative variables were described using mean and standard deviation. The Interclass Correlation Coefficient (ICC) was calculated for each measure of thickness, pennation angle, and fascicle length as an index of the reliability. The Kolmogorov-Smirnov test was used for examining the normal distribution of the variables and unpaired t-test was used for comparing the structural parameters of the medial and lateral gastrocnemius muscles in each group. In each statistical analysis the level of significance was set at $P < 0.05$.

Data was recorded and computed using SPSS software program for Windows, version 18 (SPSS Inc., Chicago, USA).

Table 1. The mean (SD) and range of subject's characteristics (*P*<0.05)

Group		Age(year)	Height (cm)	Weight (kg)	BMI (kg/m²)	Lower leg length (cm)	Intercondylar distance (cm)	Intermalleolar distance (cm)
Genu varum (n=6)	mean (SD)	22.00 (1.78)	165.50 (4.91)	52.66 (5.90)	19.17 (1.42)	44.25 (1.03)	4.91 (0.93)	0
	rang	19-24	158-171	45.50-62	18.20-22.00	42.5-45.0	4.05-6.65	0-0
Genu valgum (n=6)	mean (SD)	21.67 (1.03)	160.33 (3.02)	58.33 (5.53)	22.67 (1.88)	41.83 (0.66)	0	5.28 (0.85)
	rang	20-23	156-164	51.50-67	19.86-24.91	41.0-43.0	0-0	4.10-6.40
Normal (n=6)	mean (SD)	21.83 (1.72)	156.41 (6.31)	53.00 (5.83)	21.50 (1.65)	42.16 (2.06)	0.60 (0.71)	0
	rang	20-25	150-166	45-62	18.97-23.47	40.0-45.5	0-1.50	0-0

Table 2. The mean (SD) and range of Thickness, Pennation Angle and Fascicle Length of the medial and lateral gastrocnemius muscles (*P*<0.05)

Group		Thickness (mm)		Pennation angle (degree)		Fascicle length (mm)	
		Medial Gastrocnemius	Lateral Gastrocnemius	Medial Gastrocnemius	Lateral Gastrocnemius	Medial Gastrocnemius	Lateral Gastrocnemius
Genu varum (n=6)	mean (SD)	14.09 (1.47)	17.26 (2.46)	16.66 (3.18)	18.91 (3.29)	50.71 (11.15)	54.69 (12.45)
	rang	12.20-16.10	14.50-20.20	14.00-22.00	16.00-24.00	34.29-66.55	35.89-73.28
Genu valgum (n=6)	mean (SD)	16.95 (1.84)	11.27 (1.90)	20.83 (1.47)	15.16 (1.94)	47.65 (4.24)	43.16 (6.02)
	rang	14.25-20.00	7.57-12.50	19.00-23.00	13.00-18.00	42.35-53.39	33.65-48.89
Normal (n=6)	mean (SD)	14.96 (1.91)	14.11 (1.46)	17.75 (2.89)	17.00 (2.28)	49.44 (3.38)	48.45 (1.97)
	rang	13.50-18.60	12.00-15.60	14.50-22.00	14.00-19.00	44.73-53.97	46.07-51.77

Results

The mean, standard deviation, and range of the participants' characteristics are shown in table1.

The results of the present study demonstrated a high intra-rater reliability for rehabilitative ultrasound imaging of gastrocnemius muscle thickness (ICC=0.98), pennation angle (ICC=0.97), and fascicle length (ICC=0.95) measurements.

In patients with genu varum, the medial gastrocnemius muscle had significantly smaller thickness (*P*<0.001), closer pennation angle (*P*=0.001), and shorter fascicles (*P*<0.01) than those of the lateral gastrocnemius muscle. However, in patients with genu valgum, the medial gastrocnemius muscle had significantly greater thickness (*P*<0.001), wider pennation angle (*P*<0.001), and longer fascicles (*P*<0.05) than those for the lateral gastrocnemius muscle. In normal participants, there was no statistically significant difference between thickness, pennation angle, and fascicle length of the medial gastrocnemius when compared with those of the lateral gastrocnemius. The means, standard deviations, and ranges of thickness, pennation angle, and fascicle length of the medial and lateral gastrocnemius muscles in participants with genu varum and genu valgum and normal participants are shown in table 2.

Discussion

The thickness, pennation angle, and fascicle length of human skeletal muscles are important factors in determining the strength of muscles (14, 16). A thicker muscle, in comparison to thinner one, may produce more force. The greater pennation angle may also produce more muscle force when compared to smaller pennation angle (22, 23). The length of the fascicle may also influence the speed of muscle contraction (23).

In the current study, the structure of gastrocnemius muscle was measured and compared among three groups of normal participants, patients with genu varum, and patients with genu valgum deformities using rehabilitative ultrasound imaging. It was revealed that in healthy normal participants, there was no significant difference between structures of the medial and lateral gastrocnemius muscles, while in patients with genu varum, the medial gastrocnemius muscle had smaller thickness, closer pennation angle, and shorter fascicles compared with those in the lateral gastrocnemius muscle. It was also detected that, the medial gastrocnemius muscle had greater thickness, greater pennation angle, and longer fascicles than those of the lateral gastrocnemius muscle in patients with genu valgum. Therefore, in patients with genu varum deformities, medial gastrocnemius muscle may be weaker than the lateral gastrocnemius muscle, and in patients with genu valgum, lateral gastrocnemius muscle may be weaker than the medial gastrocnemius muscle.

It can be argued that a part of those changes may refer to unequal activities of these muscles during normal activities. Meaning that during daily activities, the amount of varus and valgus force exerted to the knee joint may be altered in genu varum and genu valgum deformities, respectively (24). Then, the medial gastrocnemius and the lateral gastrocnemius muscle react differently against valgus and varus forces exerted to the knee (13). This may result in hypertrophy of the muscle, which is accompanied by the changes in the thickness, pennation angle, and even fascicle length of the muscle (25). The results of the current study may suggest that the increased activities of the

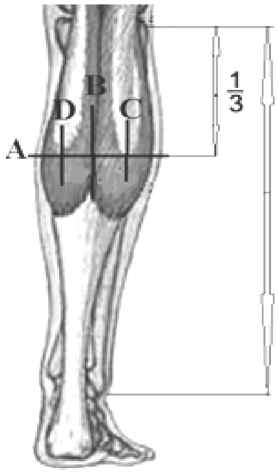

Figure 1. Locations of sonographic scanning sites. *A:* The horizontal line on the 1/3 proximal way distance between tibial lateral condyle and the end of lateral malleolus; *B:* The vertical line on the place between the bulks of the medial and the lateral gastrocnemius muscles; *C:* The vertical line on midway between line B and outermost edge of the leg; *D:* The vertical line on midway between line B and innermost edge of the leg.

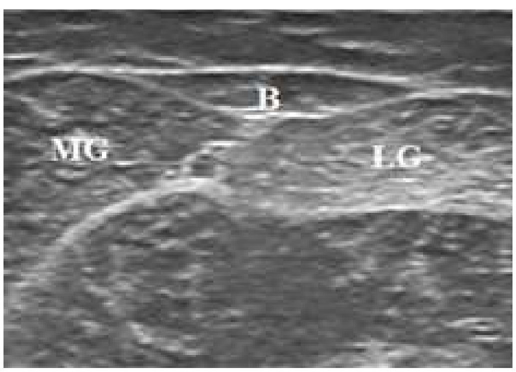

Figure 2. Image obtained from placing the ultrasound probe on line A to detect the place between the medial and the lateral gastrocnemius bulks. MG=Medial Gastrocnemius; LG=Lateral Gastrocnemius; B=the place between the bulks of the medial and the lateral gastrocnemius muscles.

lateral gastrocnemius muscle in genu varum and the increased activities of the medial gastrocnemius muscle in genu valgum may make them undergo hyperactivity, and consequently, increase their thickness and pennation angle. Furthermore, with inward deviation of lower leg in genu varum, the lateral gastrocnemius muscle lies in a more stretched status compared with the medial gastrocnemius muscle, and the reverse happens in genu valgum deformity. Muscles which are shortened for a long period of time are more exposed to atrophy than those which are stretched (26). Thus, the lesser thickness, pennation angle, and fascicle length of the medial gastrocnemius than the lateral gastrocnemius muscle in genu varum deformity and the lateral gastrocnemius than the medial gastrocnemius muscle in genu valgum deformity may be due to the more shortening status of these muscles.

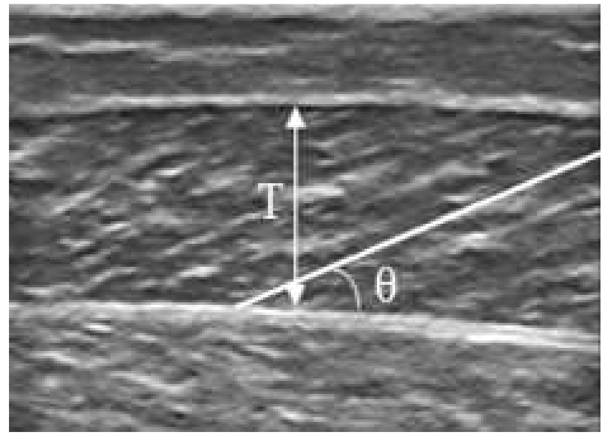

Figure 3. Image obtained from placing the ultrasound probe on line C to detect the thickness and pennation angle of lateral gastrocnemius. T=Thickness θ=Pennation angle

Moreover, the structural difference between the medial and lateral gastrocnemius muscles may be influenced by the changes which are occurred in the length of knee capsuloligamentous structures. The role of capsuloligamentous mechanoreceptors is very important to provide afferent information to central nervous system; they contribute to the dynamic stability of a joint. Changes in the length of capsuloligamentous structures bring about changes to the threshold of those receptors. Abnormal afferent may reduce the excitability of gamma motor neurons and inhibit the muscle kinetic response, and consequently, make them atrophic (27).

In this respect, the increase in muscular activity due to the increased external forces exerted to the knee joint, the changes in direction of limbs and consequently the changes in muscle length, as well as the changes in signals of afferent neurons from the proprioceptive receptors may contribute to this muscular asymmetry. The asymmetry between medial and lateral gastrocnemius muscles may disturb patients' gait. Gheluwe and colleagues (2005) stated that subtalar pronation and supination moment would increase during the propulsion phases of walking in genu varum and genu valgum, respectively (28). Accordingly, in propulsion phase the gastrocnemius muscle has the highest activity. Perhaps, the increase in subtalar pronation and supination moments during the propulsion phases of walking, respectively in genu varum and genu valgum, could be due to the fact that in patients with genu varum, medial gastrocnemius muscle has less strength compared with that in the lateral gastrocnemius muscle. Therefore, the lateral gastrocnemius muscle may be weaker than medial gastrocnemius muscle in patients with genu valgum deformity.

Conclusion

In the present study, the rehabilitative ultrasound imaging appeared as an objective and valuable method in determining the structural changes in medial and lateral gastrocnemius muscles in patients with genu varum and genu valgum compared with those in the normal participants. The present study revealed that in patients with genu varum deformity, the medial gastrocnemius muscles were thinner, closer, and shorter compared with those of the lateral gastrocnemius muscles. While in patients with genu valgum deformity, the medial gastrocnemius muscles were thicker, wider and longer compared with those of the lateral gastrocnemius muscle. Therefore, it is recommended to consider the structural differences of these muscles while designing a proper exercise therapy programs for patients with genu varum and valgum deformities. The method is also

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All authors made substantial contributions to conception, design, acquisition, analysis and interpretation of data.

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