Original article

The Study of the Cross-Sectional Areas of the Gluteal Muscles on Magnetic Resonance Images of the Weightlifting Athletes

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Abstract. M. gluteus maximus is the most important extensor and lateral rotator of the hip. It is often used to accelerate the body upward and forward from a position of hip flexion. Mm. glutei medius and minimus are referred to as small gluteal muscles. Both muscles are the most important abductors and medial rotators of the thigh. Their action stabilises the hip during standing and walking and prevents the tilting of the pelvis to the contralateral side while standing on one leg. This study aims to examine the cross-sectional areas of the gluteus maximus, gluteus medius and gluteus minimus muscles on magnetic resonance images of olympic style weightlifting athletes (male n = 15, age: 20.00±2.54, height: 1.73±0.54 m, weight: 78.70±14.96 kg; female n = 12, age: 20.75±1.49, height: 1.60±0.64 m, weight: 57.37±8.30 kg) and sedentary individuals (male n = 15, age: 19.9±2.15, height: 1.74±0.53 m, weight: 79±15 kg; female n = 12, age: 20.75±1.36, height: 1.60±0.058 m, weight: 56.68±7.64 kg). The cross-sectional areas of the gluteus maximus, gluteus medius and gluteus minimus muscles were assessed bilaterally using magnetic resonance imaging. It was observed that the cross-sectional areas of the right and left gluteus maximus of male weightlifting athletes were larger than those of sedentary males ($z(28)= 2.013$, $p< .05$, $z(28)= 1.991$, $p < .05$; respectively). Similarly, it was also found that that the cross-sectional areas of the right and left gluteus maximus of female weightlifting athletes were larger than those of sedentary females ($z(22)= 3.296$, $p< .001$, $z(22)= 3.726$, $p < .001$; respectively). No significant difference was observed for the cross-sectional areas of the gluteus medius and gluteus minimus muscles between the athlete and sedentary groups ($p>.05$). It might be stated that olympic style weightlifting trainings have a hypertrophic effect on the cross-sectional area of the gluteus maximus muscle of the athletes.

Key words: Olympic Style Weightlifting, MRI, CSA, Gluteal Muscles

Introduction

Since its introduction in Olympic Games, weightlifting is called Olympic style weightlifting (1). Olympic style weightlifting is lifting sport in which athletes perform by snatch and clean-and-jerk techniques (2). Weightlifting is a kind of sport which primarily requires lumbopelvic stability and dynamically uses all joints and striated muscles of the body (3-5). The gluteal muscles possess vital functions in standing, the stabilization of hip joint, ladder climbing, thigh and knee examination in lifting, sprinting, squatting, and climbing a steep hill (6-8). The gluteus maximus muscle (Gmax) originates at the iliac crest, sacrum, and coccyx, and inserts into the gluteal ridge at the postero-lateral femoral shaft below the greater trochanter (9,10). This muscle acts for the extension the hip joint, however, it can also act as adductor and lateral rotator of the lower limb and is active during locomotion (10, 8, 9). The mm. glutei medius (Gmed) and minimus

(Gmin) muscles are referred to as small gluteal muscles (7). Gmed attaches to the superior ilium and inserts into the lateral aspect of greater trochanter (11). Gmin arises from the external iliac fossa between the anterior and inferior gluteal lines and is covered almost completely by gluteus medius (12). Gmed and Gmin have been described as having essentially the same function, primarily abduction of the hip, with internal rotation and flexion being possible, depending on the position of the femur (13, 12, 7).

A good number of studies in literature examines the morphometry of the gluteal muscle. Sanchis-Moysi (14) studied the volume and degree of asymmetry of the gluteal muscles of tennis, soccer players and sedentary control individuals and stated that the volume of dominant and contralateral gluteal muscles of soccer players and sedentary individuals was similar, whereas the volume of non-dominant gluteal muscle of tennis players was larger than that of sedentary individuals. In another study on soccer players, Masuda (15) reported that they did not observe any significant differences between Gmax cross-sectional areas (CSA) in dominant and non-dominant leg of elite and non-elite soccer players. The fact that the Gmax CSA of athletes doing different types of sports is larger than the Gmax CSA of individuals that do not follow any specific training was found, however, it was stated that the Gmax CSA of endurance runners and swimmers and the Gmax CSA of control group had no significant difference Niinimäki (16). Modern pilates trainings followed by inactive and healthy women during 9 months had no elicit hypertrophic effect on the volume of lumbopelvic muscles and the researchers declared that the pilates exercises could have not been specific enough or the exercise intensity could have been too low to induce muscle hypertrophy in the lumbopelvic muscles (17). In their study, Amabile (18) expressed that the Gmax CSA of individuals with chronic low back pain is smaller than that of individuals with no pain. Moreover, the volume of Gmax, Gmin and piriformis muscles of individuals with low back with leg pain was found to be smaller than the volume of the same muscles of healthy individuals (19).

In literature, it was emphasized that asymmetric hypertrophy development will increase the possibility of chronic groin pain and low back pain (20, 21). It was reported that improper techniques, the repetition or asymmetric activities and different trainings during the season might cause not only asymmetric developments on the muscles, but also athletic injuries (22). In a study on tennis players, one of asymmetric types of sports, the researchers declared the gluteal muscles were asymmetrically hypertrophied in tennis players (14). In their study Masuda (15) examined the players of another asymmetric sport, soccer, and they reported there were no significant differences among the CSA sizes of the groups of thigh, hip and lumbar muscles on dominant and non-dominant leg. It was expressed that the volume of Gmax, Gmed and Gmin of individuals with hip osteoarthritis had atrophy and that asymmetric developments were observed in this group of muscles due to these atrophic developments (23).

In literature, no study is present on the morphometric characteristics (CSA, Volume) of Gmax, Gmed and Gmin muscles of athletes in olympic style weightlifting.

This study aims to compare the CSA of Gmax, Gmed and Gmin muscles on magnetic resonance images taken from the second and third sacral notch levels of athletes in olympic style weightlifting and sedentary individuals. We also aimed to investigate whether there exist asymmetric developments in these mentioned muscles. Our hypothesis was that athletes in olympic style weightlifting would have greater hypertrophy in their Gmax, Gmed and Gmin than sedentary individuals in our study.

Materials and Methods

Participants

This study included 4 groups of participants: asymptomatic male athletes (MW), female athletes (FW) in olympic style weightlifting, male (MCont) and female (FCont) sedentary individuals as control groups (Table 1). The study complies with the Declaration of Helsinki and the ethics committee of the University of Necmettin Erbakan, health sciences scientific research ethics committee approved the study protocol (dated 2021 and numbered 7). Each volunteer provided written informed consent.

Table 1. Physical characteristics of the participants and athletic history of the athletes (Mean± SD)

Variables	MW (n= 15)		MCont (n= 15)			FW (n= 12)		FCont (n= 12)		
	Mean	SD	Mean	SD	*p*	Mean	SD	Mean	SD	*p*
Age	20.00	2.54	19.9	2.15	.94	20.75	1.49	20.75	1.36	1.00
Height	1.73	0.54	1.74	0.53	.94	1.60	0.64	1.60	0.058	.87
Body weight	78.70	14.96	79	15	.96	57.37	8.30	56.68	7.64	.84
BMI	26.19	4.90	26.22	4.80	.98	22.31	2.08	22.22	2.46	.92
Athletic history	6.47	2	–	–	–	7.58	1.83	–	–	–

MW/FW: Male/Female athletes in olympic style weightlifting, **MCont/FCont:** Male/Female control groups, **BMI:** Body muscle mass index, Age in years, height in m, body weight in kg, BMI in kg/m^2, athletic history in years.

Male and female weightlifting athletes that train regularly for three hours, five days a week and have actively participated in national and international tournaments within the last two years were included in the study. The groups of sedentary individuals were people that never trained. All athletes and trainers were asked whether they used to do any specific exercise to strengthen their Gmax, Gmed and Gmin before or after the trainings and they declared that they had no specific exercise to strengthen their Gmax, Gmed and Gmin. All participants, athletes and sedentary individuals, were asked to answer which foot they dominantly use in daily life, and we noted that they all preferred right foot dominantly. Anthropometric measurements were taken according to conventional criteria and measurement procedures (24). Body weight and height were measured to the nearest 0.1 kg and 0.5 cm, respectively. Body mass index (BMI) was calculated using the formula: BMI kg/m^2. Demographic data, including age, height, body weight, BMI, athletic history was recorded for each participant and the obtained data is shown in Table 1. All participants in the study were physically examined by a medical doctor (B.I). All participants of the study had no physical symptoms or signs of low back problem. For both groups, the exclusion criteria were as follows: aged under 18, having a history of diagnoses that can cause low back pain or muscle atrophy, including: central nervous system disorders, other chronic pain syndromes, connective tissue or rheumatoid disorders, lifetime history of spinal or pelvic fractures. Finally, the sedentary individuals doing sports or fitness trainings to strengthen their hip muscles for the last three months were excluded.

Protocols of MRI and MRI Evaluation

For the abdominal magnetic resonance imaging (MRI) of the participants, a 1.5 Tesla device was used (Magnetom Avanto; Siemens Healthcare Erlangen, Germany). The participants were asked to take supine position and lay their legs completely for MRI process. 4-channel phase lined body coils were placed on abdominal area. The imaging was conducted from the proximal ending of the 12th thoracic vertebrae to the distal border of the trochanter minor of femur. From the related area, we got axial images primarily (T1 parameters: TE: 10, TR:1150, interslice thickness: 5 mm, interslice distance: 5 mm, Matrix: 320*160, FOV: 206*330, NEX: 2) and then we got some sagittal and coronal images for radiological evaluation. Imaging process was ended following the record of MR images in the form of DICOM into CD-ROM.

The MR images were evaluated by a radiology expert (M.Y). In the CD-ROM executed in personal computers, the axial interslice images including related images of the muscle were specified. These images were transformed into JPEG format and saved in personal files of each participant. By using a graphic tablet (UclogicLapazz A4 professional design tablet, Japan), we determined the limits of the related muscle with the

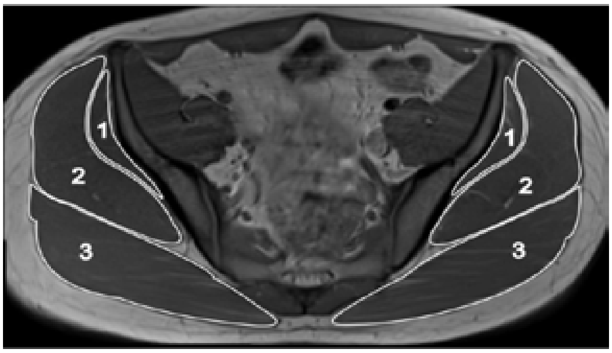

Figure. 1. Axial section of the lower part of the body (above the hip joint; intermuscular borders are drawn). (1) m. gluteus minimus; (2) m. gluteus medius; (3) m. gluteus maximus.

limits of surrounding tissue over the images and saved (19, 23) (Figure 1).

CSA Calculation of gluteal muscles

Over the images taken from between the second and third sacral notch of the participants, we measured the CSA of the gluteal muscles. The axial images, whose limits to surrounding tissues were determined previously, were executed in ImageJ software (Version 1.36b, http://rsb.info. nih.gov/ij). After the required synchronization steps, area measurement scales of each point, representing 36 mm^2 for male groups and 25 mm^2 for female groups, were randomly gridded on the axial images. Points corresponding to Gmax, Gmed, Gmin (right and left separately) were counted (See Figure 2). The process was repeated for three times and the mean number of points was found. The resulting figure was multiplied by its representing area and the cross-sectional area of Gmax, Gmed and Gmin was calculated as shown in Table 2.

Statistical Analyses

From the analyses through Kolmogorov-Smirnov and Shapiro-Wilk, we observed that values related to age and BMI variables do not comply with the data of normality. However, due to the low number of participants, Mann-Whitney U method was used for non-parametrical analyses for the comparison of the

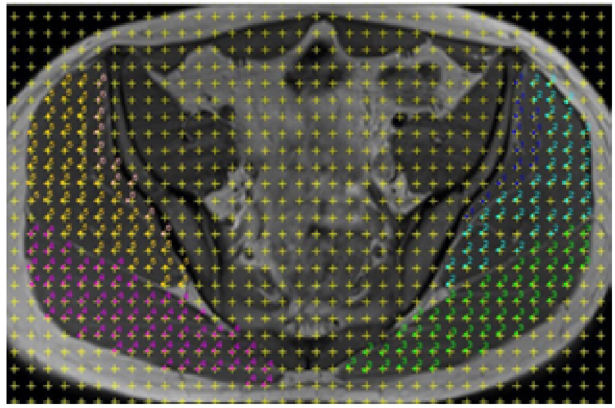

Figure. 2. The gridding process on MR images executed in ImageJ software and the determination of points corresponding to right-left gluteal muscles (m. gluteus minimus, m. gluteus medius, m. gluteus maximus). The image was taken from between the second and third sacral notch.

groups and Wilcoxon analysis was used for intragroup comparison. Prior to main analyses, descriptive statistics regarding demographic variables were studied. The mean rank differences in the CSA of right and left Gmax, Gmed and Gmin of athlete and control groups were found using Mann Whitney-U analysis. In addition, the mean rank differences in the CSA of right and left Gmax, Gmed and Gmin of male and female athletes and male and female sedentary individuals were also found by Mann Whitney-U analysis. Then, the mean rank differences in the CSA of right and left Gmax, Gmed and Gmin of the participants in the study group were specified by Wilcoxon analysis. Statistical significance rate was set at $p < .05$ for all analysis. All statistical procedures were conducted using the SPSS 25 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.).

Results

The mean CSA calculations of Gmax, Gmed and Gmin of male and female athletes along with sedentary individuals are shown in Table 2.

Table 3 shows the CSA measurements of the right left Gmax, Gmed and Gmin of the athletes in olympic style weightlifting and control groups.

Table 2. The mean CSA calculations of Gmax, Gmed and Gmin of athlete and sedentary groups[a]. (Mean± SD)

	MW (n = 15)		MCont (n = 15)		FW (n = 12)		FCont (n = 12)	
Muscles	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Right Gmax	44.64	9.72	38.39	8.07	34.91	4.90	25.55	4.82
Left Gmax	43.99	8.19	38.24	6.73	35.41	5.19	26.03	3.68
Right Gmed	33.14	5.68	32.58	4.93	26.12	4.53	22.36	3.80
Left Gmed	32.90	5.78	32.46	4.93	26.59	4.39	22.02	4.33
Right Gmin	11.05	2.57	11.25	2.23	6.64	1.88	5.35	1.11
Left Gmin	10.14	2.06	11.19	2.52	6.50	1.49	5.48	1.12

Gmax: gluteus maximus, **Gmed:** gluteus medius, **Gmin:** gluteus minimus, **MW/FW:** Male/Female athletes in olympic style weight-lifting, **MCont/FCont:** Male/Female control groups, [a]Values are expressed in cm^2.

Table 3. The comparison of the CSA of the mentioned muscles between study and control groups.

	Mean Rank				Mean Rank			
Muscles	**MW (n = 15)**	**MCont (n = 15)**	***z***	***p***	**FW (n = 12)**	**FCont (n = 12)**	***z***	***p***
Right Gmax	18.73	12.27	-2.013*	**.045**	17.25	7.75	-3.296***	**.000**
Left Gmax	18.70	12.30	-1.991*	**.045**	17.88	7.13	-3.726***	**.000**
Right Gmed	15.07	15.93	-.270	.806	15.21	9.79	-1.881	.060
Left Gmed	15.03	15.97	-.291	.775	15.33	9.67	-1.965	.052
Right Gmin	14.73	16.27	-.478	.653	15.13	9.88	-1.825	.068
Left Gmin	13.50	17.50	-1.251	.217	15.29	9.71	-1.939	.052

Gmax: gluteus maximus, **Gmed:** gluteus medius, **Gmin:** gluteus minimus, **MW/FW:** Male/Female athletes in olympic style weight-lifting, **MCont/FCont:** Male/Female control groups ***** $p < .05$, ****** $p < .01$, ******* $p < .001$.

From the findings, the mean rank of the CSA of right and left Gmax of MW was observed to be higher than that of MCont (z (28) = 2.013, $p < .05$, z (28) = 1.991, $p < .05$, respectively). Similarly, the mean rank of the CSA of right and left Gmax of FW was higher than that of FCont (z (22) = 3.296, $p < .001$, z (22) = 3.726, $p < .001$, respectively).

Table 4 illustrates the size differences of the CSA of right-left Gmax, Gmed and Gmin of MW and FW besides MCont and FCont. From the obtained results, it was observed that the mean rank CSA of right-left Gmax, Gmed and Gmin of MW was higher than that of FW (z(25)= -2,686, $p < .01$, z(25)= -2,904, $p < .001$, z(25)= -3,346, $p < .001$, z(25)= -3,005, $p < .01$, z(25)= -3,933, $p < .01$, z(25)= -4,109, $p < .001$, respectively). Similarly, the mean rank CSA of right-left Gmax of MCont was observed to be higher than that of FCont (z (25) = -3,736, $p < .001$, z (25) = -4,055, $p < .001$, z (25) = -4,398, $p < .001$, z (25) = -4,051, $p < .001$, z (25) = -3,981, $p < .001$, z (25) = -4,351, $p < .001$, respectively).

In the study, we conducted several Wilcoxon analyses to compare the CSA of right and left Gmax, Gmed, Gmin of the groups. The results show that there exists no asymmetric difference in the CSA of right and left Gmax, Gmed and Gmin of both male and female groups ($p > .05$) (Table 5).

Discussion

The aim of this study is to examine the CSA of Gmax, Gmed and Gmin of athletes in olympic style

Table 4. The CSA comparison of right-left Gmax, Gmed and Gmin of male and female groups.

	Mean Rank				Mean Rank			
Muscles	**MW (n = 15)**	**FW (n = 12)**	*z*	*p*	**MCont (n = 15)**	**FCont (n = 12)**	*z*	*p*
Right Gmax	17.67	9.42	-2.686**	**.007**	19.10	7.63	-3.736***	**.000**
Left Gmax	17.97	9.04	-2.904***	**.000**	19.53	7.08	-4.055***	**.000**
Right Gmed	18.57	8.29	-3.346***	**.000**	19.53	7.08	-4.398***	**.000**
Left Gmed	18.10	8.88	-3.005**	**.003**	19.43	7.21	-4.051***	**.000**
Right Gmin	19.37	7.29	-3.933**	**.002**	20.00	6.50	-3.981***	**.000**
Left Gmin	19.60	7.00	-4.109***	**.000**	19.93	6.58	-4.351***	**.000**

Gmax: gluteus maximus, **Gmed:** gluteus medius, **Gmin:** gluteus minimus, **MW/FW:** Male/Female athletes in olympic style weight-lifting, **MCont/FCont:** Male/Female control groups * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 5. The comparison of the CSA of right and left Gmax, Gmed, Gmin of the groups

Groups			**n**	**Mean Rank**	**Sum of Ranks**	*z*	*p*
MW	Left Gmax Right Gmax	Negative Ranks	7	9.57	67.00	−.398	.691
		Positive Ranks	8	6.63	53.00		
		Ties	0				
	Left Gmed Right Gmed	Negative Ranks	6	9.92	59.50	−.441	.659
		Positive Ranks	8	5.69	45.50		
		Ties	1				
	Left Gmin Right Gmin	Negative Ranks	10	9.25	92.50	-1.850	.064
		Positive Ranks	5	5.50	27.50		
		Ties	0				
MCont	Left Gmax Right Gmax	Negative Ranks	8	7.50	60.00	.000	1.000
		Positive Ranks	7	8.57	60.00		
		Ties	0				
	Left Gmed Right Gmed	Negative Ranks	5	8.40	42.00	−.245	.806
		Positive Ranks	8	6.13	49.00		
		Ties	2				
	Left Gmin Right Gmin	Negative Ranks	7	6.86	48.00	−.175	.861
		Positive Ranks	6	7.17	43.00		
		Ties	2				
FW	Left Gmax Right Gmax	Negative Ranks	5	6.00	30.00	−.707	.479
		Positive Ranks	7	6.86	48.00		
		Ties	0				
	Left Gmed Right Gmed	Negative Ranks	5	4.90	24.50	−.756	.449
		Positive Ranks	6	6.92	41.50		
		Ties	1				
	Left Gmin Right Gmin	Negative Ranks	7	6.07	42.50	−.275	.783
		Positive Ranks	5	7.10	35.50		
		Ties	0				

Groups			n	Mean Rank	Sum of Ranks	z	p
FCont	Left Gmax Right Gmax	Negative Ranks	6	4.58	27.50	−.489	.624
		Positive Ranks	5	7.70	38.50		
		Ties	1				
	Left Gmed Right Gmed	Negative Ranks	6	7.25	43.50	−.934	.350
		Positive Ranks	5	4.50	22.50		
		Ties	1				
	Left Gmin Right Gmin	Negative Ranks	4	4.88	19.50	−.819	.413
		Positive Ranks	6	5.92	35.50		
		Ties	2				

Gmax: gluteus maximus, **Gmed:** gluteus medius, **Gmin:** gluteus minimus, **MW/FW:** Male/Female athletes in olympic style weightlifting, **MCont/FCont:** Male/Female control groups**.**

weightlifting and sedentary individuals. It was found in our study that the CSA of Gmax of athletes was larger than that of sedentary individuals. However, we found no statistically significant difference in the CSA of Gmed and Gmin of the groups. In literature, there is a good number of studies that investigates the morphometry of Gmax, Gmed and Gmin of athletes from different types of sports (15, 16), of individuals with low back pain (18, 19), of sedentary individuals (17) and of elders (25). In their study on the examination of the CSA of dominant, non-dominant leg quadriceps, hamstring, adductor, Gmax, abductor and iliopsoas muscles of above-average (national students' team) and average level soccer players, Masuda (15) reported that no difference was observed in the CSA of the muscle groups of two groups of the players. Moreover, the researchers also stated that the CSA of Gmax, Gmed and Gmin was strongly correlated with hip abductor strength and no significant relationship between the CSA of the Gmax and hip extensor strength was present. Niinimäki (16) studied the relations between Gmax muscle size and muscle strength and body size of female athletes from different types of sports and they reported that the size of the Gmax was significantly larger in high impact (volleyball players and high jumpers), odd impact (soccer and squash players) and high magnitude (powerlifters) loading groups, compared to the control group. However, there were no differences in the CSA of Gmax in individuals engaged in repetitive impact (endurance runners) or repetitive non-impact (swimmers) loadings compared to the control group. The same researchers also underlined the fact that the reason for the absence of the CSA of Gmax differences between endurance runners along with swimmers and control groups might be because endurance runners do not need rapid and powerful movements and swimmers do not require large muscles. Furthermore, they also found a relation between larger muscles and greater isometric and dynamic muscle strength regardless of loading type in athletic activities. In another study on the volume of Gmax, Gmed and Gmin muscles of swimmers, non-swimmers and controls, the researchers declared that they found no significant differences in the volume of the gluteal muscles of the groups (26). Another study in literature studied the volume and degree of asymmetry of iliopsoas and gluteal muscles of tennis, soccer players and sedentary individuals and the authors observed that soccer and non-active control individuals had similar gluteal muscles volumes in both sides (for the dominant and contralateral). In addition, they also mentioned that the volume of non-dominant gluteal muscles was 20% greater in tennis players than in sedentary individuals, whilst tennis players and sedentary individuals had similar volumes of dominant gluteal muscles (14). Amabile (18) observed the CSA of Gmax of individuals with and with no low back pain and they explained that the CSA of Gmax of individuals with chronic low back pain was significantly smaller than the control group and that the existing atrophy of the CSA of Gmax of individuals with chronic low back pain might be correlated with low back pain. In a study on the volume of pelvic muscles of healthy individuals with individuals with low back with leg pain, Skorupska (19) reported that the patients with low back with leg pain had a smaller volume for all pelvic muscles (Gmax, Gmin, m. piriformis) for the symptomatic side, both left and right (except for Gmed) and that the atrophy found in the volume of m. piriformis, Gmin and Gmax probably have some diagnostic value for individuals with low back with leg pain. Zacharias (23) studied the volume and force parameters of Gmax, Gmed and Gmin muscles of healthy individuals and individuals with hip osteoarthritis. The researchers declared that the volume of Gmax, Gmed and Gmin muscles of the individuals with hip osteoarthritis decreases and this atrophy adversely affects the hip abduction and internal rotation strength parameters of these individuals. Another study in literature focused on the CSA of hip muscles on MR images of elder male and female individuals. The study results showed that the CSA of Gmax, obturator externus, gemelli, quadratus femoris, priformis, sartorius and iliopsoas muscles of male groups were larger than those of female elders (25). The same researchers also reported that the CSA of most hip muscles (except gluteus maximus and gemelli) were positively associated with leg strength.

In our study, it was observed that the CSA of gluteal muscles of male groups including both athletes and sedentary individuals is larger than that of female individuals. We consider that the reason for the difference is due to gender. It was observed in our study that the CSA of right and left Gmax of MW is significantly larger than that of MCont, similarly, the CSA of right and left Gmax of FW is also significantly larger than that of FCont. Therefore, the findings of this study confirm our hypothesis that Gmax hypertrophy would be greater in athletes in olympic style weightlifting. The studies of sports medicine define that only some certain types can help to increase muscle size and strength. Furthermore, in literature it's stated that there is more to the relationship between muscle activation and the great requirement for larger muscles (27-35). Weightlifting is a sport that includes trainings to single lift of maximal weight and requires high explosive forces. That's why, we also consider that the difference in the CSA of Gmax between weightlifting athletes and sedentary individuals might also correlated with these intensive weightlifting trainings. Gmax is a strong flexor of thigh in flexion (36) and it functions to accelerate the body upward and forward from a position of hip flexion ranging from 45° to 60° (6). In weightlifting, Gmax endures really heavy loadings during snatch and clean-and-jerk and from the start position to finish lifting steps (thigh flexion), after the bar blockage from the squat position to lift upward (thigh in flexion). As a result of these extreme loads, we also consider that Gmax might be hypertrophied, and thus, this might be another reason for the difference in the CSA of Gmax between athlete and control groups.

In our study, we did not observe any difference between the CSA of right and left Gmed and Gmin of MW and MCont, similarly, we again did not observe any difference between the CSA of right and left Gmed and Gmin of FW and FCont. Therefore, the findings of our study do not confirm our hypothesis that Gmed and Gmin hypertrophy would be greater in athletes in olympic style weightlifting. In literature, Gmed and Gmin are referred to be the most important abductors and medial rotators of the thigh (7). In weightlifting, during the blockage of the lift in snatch and rising the lift to the shoulders during clean, foot might be abducted slightly. During lifting steps, due to the technical requirement in weightlifting, there exists no movement that requires medial rotation. Thus, we consider that Gmed and Gmin are not heavily loaded during these techniques and depending on that we estimate the absence of difference in the CSA of Gmed and Gmin between the athlete and control groups exists.

Athletes participating in sports requiring repetitive and powerful unilateral trunk rotations develop sport-specific bilateral differences in the volume of the lumbopelvic muscles (37, 38, 14, 39). Side-to-side asymmetries in the volume of this musculature may predispose to pathological conditions such as low back pain or hip osteoarthritis (40,41). Zacharias (23) examined the volume of the gluteal muscles of healthy individuals and individuals with hip osteoarthritis and stated that they observed atrophy in Gmax, Gmed and

Gmin of individuals with hip osteoarthritis, so they reported asymmetry in these muscle groups due to the atrophic developments. In their study focusing on asymmetric sports, tennis and soccer, Sanchis-Moysi (14) studied players and stated that gluteal muscles are asymmetrically hypertrophied in tennis players, whereas, in the evaluation of dominant and conralateral gluteal muscles they expressed that those had no asymmetry. On the examination of the CSA of Gmax of individuals with low back pain, Amabile (18) declared that the atrophy in the CSA of Gmax of these individuals is significantly larger than those with no low back pain, however, they also informed that they did not observe any asymmetric development in the CSA of right and left Gmax of both groups. In their study on the CSA of thigh, hip and lumbar muscles of soccer players, the researchers announced that no asymmetric development exists in the CSA of dominant and non-dominant leg sides (except knee flexor muscle) (15).

In our study, we found symmetry on the CSA of right-left Gmax, Gmed and Gmin of MW and FW. Olympic style weightlifting is a symmetrical sport when dominant hand and foot use is considered (apart from the second period of clean-and-jerk) (42). Although the weightlifting athletes in our study dominantly use their right foot, we found no asymmetry in the CSA of Gmax, Gmed and Gmin of the groups and we consider that this is probably because weightlifting is a symmetrical sport. Nonetheless, from the point of view that asymmetric developments might cause health problems in athletes, we consider that radiological imaging of these areas periodically might be beneficial to prevent potential developments in the future.

There are some limitations of this study. The main limitation is the small number of participants, which is highly common to studies on elite athletes. Another limitation is that the athletes in our study were asymptomatic. Future studies on the CSA changes in gluteal area might benefit from adding athletes with symptoms and including power and strength parameters of these muscles.

Our study proved that the CSA of Gmax of male and female athletes is larger than that of sedentary individuals. However, the CSA of Gmed and Gmin of athletes and sedentary individuals was not statistically different. It was expressed in literature that a positive correlation lies between muscular strength of the gluteus muscles and muscle volume along with cross-sectional area (43). Similarly, Niinimäki (16) reported that larger muscle size is positively correlated with muscle strength, regardless of loading type. and other researchers such as Blanpied (44); Bolgla; Uhl (45); Ekstrom (46); Ayotte (47) and Distefano (48) reported that specific exercises (for a high level: lateral step-up; quadruped with contralateral arm and leg lift; forward step-up; unilateral bridge; transverse lunge; wall squat; side-lying hip abduction; pelvic drop and single-limb deadlift, for a higher level: (single-limb squat and side-bridge to neutral spine position) are relatively beneficial for the activation of Gmed and Gmin. As a conclusion of these insights, we believe that the implementation of such exercises with weightlifting athletes might both affect their performance and lower the risk of injury in this area. Moreover, as asymmetric developments might cause health problems in athletes, we consider periodical radiological imaging might be beneficial to prevent potential developments in the future.

Consequently, in weightlifting, it might be stated that exercises and trainings followed by weightlifting athletes might have a hypertrophic effect on the cross-sectional area of the gluteus muscles. In addition, the findings of our study may be of great importance for coaches and clinicians to design specific training and injury prevention programs.

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