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Gastrocnemius Muscle Contraction and Its Role in Orthostatic Anti-Gravity Adjustment – The Effects of Body Mass Index

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Abstract

BACKGROUND: Obesity is a global concern with severe detrimental health and economic effect. Body mass index (BMI) is an inexpensive, non-invasive indicator for different diseases, and associated with abnormal weight.

AIM: The aim of the study was to investigate the relationship between BMI and the contraction of gastrocnemius muscle (GM) and its possible role in peripheral muscle pump activity and pathogenesis of orthostatic intolerance.

METHODS: One hundred and four volunteers (63 women and 41 men, mean age 39 ± 14 years) were divided into three subgroups according to their BMI values (with normal weight, overweight, and obesity). Changes in the transverse diameter and pennation angle of GM at rest and during maximal active plantar flexion (MAPF) were measured with multimodal ultrasound imaging. An active orthostatic test was performed and changes in systemic blood pressure and heart rate in supine position and active standing on the 1^{st}, 5^{th}, and 10^{th} min were monitored. The results were statistically processed with alternative, variational, and correlational analysis.

RESULTS: Patients with abnormal BMI were significantly older and had higher anthropometrical parameters compared to the subgroup with normal weight. They showed a significantly larger diameter and pennation angles at rest and during maximal active plantar flexion of GM bilaterally, which was more pronounced for the dominant right leg. However, the amount of changes in the GM diameter and pennation angles was similar in the different subgroups.

CONCLUSION: The study showed that BMI affects predominantly the initial values of GM parameters at rest and MAPF without influence on its antigravity contractility associated with active straightening.

Introduction

Obesity is a worldwide epidemic with constantly increasing prevalence among any ages. Apart from its severe social and economic consequences, it is known to be associated with various syndromes and diseases. Body mass index (BMI) is a commonly used parameter for measuring the degree of obesity. Although it is simplified and does not take into consideration the real body composition (fat or muscle), BMI correlates strongly with many metabolic conditions [1].

Using BMI as an indicator for obesity, the present study explores its impact on the structure and function of skeletal musculature with particular focus on the gastrocnemius muscles (GM) – a crucial component of the peripheral muscle pump responsible for the anti-gravitational redistribution of blood during orthostasis.

The aim of the study was to search for possible correlations between BMI and GM contraction, estimated by ultrasound imaging, during active stand-up in subjects with normal and abnormal weight.

Methods

Our study took place at the Clinic of Functional Diagnostics of the Nervous System of Military Medical Academy, Sofia, Bulgaria from February 2019 to January 2021. It was performed in compliance with the latest amendment of ethical requirements for medical research. An informed consent was provided to and signed by all participants.

The study included 104 volunteers selected from the hospital population. It was performed according to a standard protocol that has been used in our previous studies [2], [3], [4]. All investigated subjects were right-handed. They did not take any medication 24 h before the study.

The BMI was calculated in accordance to the standard formula (a person's height divided by the square of his weight measured in kg/m^2), accepted by the World Health Organization [5]. Based on these criteria, the patients were divided into three subgroups – with normal weight (BMI ≤ 24.9 kg/m^2), overweight (BMI 25–29.9 kg/m^2), and obese (BMI ≥ 30 kg/m^2).

Figure 1: Active orthostatic test. Blood pressure and heart rate were determined after 1, 5, and 10 min of rest and active standing

Age, sex, and various anthropometric parameters were determined such as height (cm), weight (kg), waist circumference (cm), thigh and lower leg circumference (cm), and chest circumference during inhalation and exhalation (cm). Additional information concerning the patients` comorbidities, past medical history, and medication intake was acquired.

An active orthostatic test was applied to all of the participants (Figure 1).

After 10 min of resting in a supine position, they were instructed to stand up actively and remain in a static position with tightly put together lower limbs without contraction of the musculature. After the test, the body was actively returned to a horizontal position for the same period of time. Changes in systemic hemodynamics – systolic (SBP), diastolic (DBP), and mean (MBP) blood pressure (mmHg), as well as heart rate (HR) were monitored using a monitor (Contec CMS8000) and recorded on the 1st, 5th, and 10th min during each position.

Myosonographic study was performed according to a standard protocol with the patient lying in prone position (Figure 2).

A multifrequency 5–12 MHz probe was used and located perpendicular to the muscle in its widest part [6]. The two heads of the gastrocnemius muscle were examined sequentially at rest and during maximal active plantar flexion (MAPF) (Figure 2). The following parameters were measured:

- Transverse diameter (cm) – the distance between the superficial and deep aponeurosis;
- Pennation angle (degrees) – the angle between muscle fibers and aponeurosis [7];

The results were statistically processed with alternative, variation, and correlational analysis.

Results

Clinical characteristics of the BMI Subgroups

All subjects had normal mental and physical development, but had various underlying disease and risk factors for orthostatic intolerance (arterial hypertension, diabetes mellitus Type II, lower limb varicose veins, mitral valve prolapse, etc.). All of them were with right dominant limbs. Their clinical characteristics are presented in Table 1.

Obese patients were significantly older than the control and overweight subgroups. All patients with abnormal BMI had significantly higher anthropometric parameters including calf and chest circumferences.

Active orthostatic test

The subjects with overweight and obese patients had significantly higher SBP, DBP, and MBP during all orthostatic positions. According to our study, obesity does not seem to have a significant impact on heart rate (Table 2).

The patients with increased BMI had a lower rate of orthostatic intolerance in comparison to the healthy subjects – 22.5% and 35.9% accordingly, more pronounced during the 1st min of active standing.

Myosonographic examination

Compared to controls, all patients with increased BMI had significantly higher diameters for both lateral and medial heads of the GM at rest and during MAPF. The anatomical pennation angles of the

Table 1: Clinical characteristics of the BMI subgroups (n = 104)

Group	n	Age (years)	Height (cm)	Weight (kg)	(BMI) (kg/m^2)	Leg length (cm)	Circumference (cm)			
							calf L	calf R	chest in	chest ex
Normal	64	38 ± 14	169 ± 7	63 ± 7	22 ± 2	78 ± 4	35 ± 2	35 ± 2	91 ± 7	87 ± 7
Overweight	28	38 ± 12	175 ± 10**	84 ± 9***	27 ± 1***	82 ± 7**	38 ± 2***	39 ± 2***	105 ± 7***	100 ± 7***
Obese	12	53 ± 13***	169 ± 11	95 ± 17***	33 ± 4***	79 ± 6	42 ± 4***	43 ± 4***	110 ± 9***	106 ± 9***

*p < 0.05, **p < 0.01, ***p < 0.001 - Significant differences between the group with normal and abnormal BMI.

lateral heads at rest and during MAPF for both sides were significantly larger. However, the absolute differences in the values of the diameters and pennation angles between the two states (at rest and during MAPF) were similar both groups (Table 3).

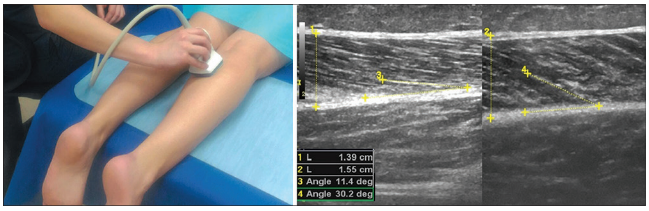

Figure 2: Ultrasound B-mode imaging of gastrocnemius muscle with measurement of the pennation angle and transverse diameter at rest and during maximal active plantar flexion

The integrative function of the muscle pump, represented by a summation of the values for the lateral and medial heads for the right, left, and both sides (Table 4), is showed to be stronger in overweight and obese patients, in favor of the dominant right leg.

Table 2: Hemodynamic parameters at rest and during active orthostatic test of the groups

Position	min	Group	n	SBP	DBP	MBP	HR
Supine							
	1	Normal	64	115.9 ± 14.4	68.7 ± 9	84.5 ± 10.3	71.4 ± 9.4
		Overweight	28	127.0 ± 11.4***	74.6 ± 7.8***	92.1 ± 8.1***	73.7 ± 10.3
		Obese	12	139.1 ± 11.1***	81.6 ± 4.4***	100.8 ± 6.0***	72.5 ± 9.3
	5	Normal	64	111.7 ± 14.1	67.4 ± 8.3	82.2 ± 9.6	69.4 ± 9.1
		Overweight	28	123.6 ± 11.9***	73.7 ± 8.2***	90.3 ± 8.4***	71.9 ± 10.4
		Obese	12	134.3 ± 11.4***	79.5 ± 5.1***	97.8 ± 6.5***	71.5 ± 9.5
	10	Normal	64	110.9 ± 13.8	65.6 ± 8.3	80.7 ± 9.5	68.5 ± 8.9
		Overweight	28	122.4 ± 12.2***	72.3 ± 8.5***	88.9 ± 8.7***	71.1 ± 11.0
		Obese	12	134.7 ± 11.7***	79.3 ± 4.6***	97.7 ± 6.3***	70.9 ± 10.0
Active standing							
	1	Normal	64	120.2 ± 13.8	75.2 ± 9.1	90.2 ± 9.9	83.3 ± 13.1
		Overweight	28	131.2 ± 14.2***	82.9 ± 10.3***	98.9 ± 10.9***	84.3 ± 13.5
		Obese	12	133.8 ± 18.2	84.8 ± 9.0	101.1 ± 11.1	79.3 ± 11.9*
	5	Normal	64	116.3 ± 13.9	75.8 ± 9.7	89.3 ± 10.3	88.1 ± 12.5
		Overweight	28	127.0 ± 13.7***	83.0 ± 10.2***	97.7 ± 10.8***	86.5 ± 10.9
		Obese	12	133.1 ± 15.8**	83.0 ± 10.3**	99.7 ± 11.5	79.2 ± 12.9*
	10	Normal	64	114.9 ± 14.6	75.5 ± 10.4	88.6 ± 11.1	88.8 ± 12.8
		Overweight	28	126.0 ± 11.5***	82.9 ± 10.3***	97.3 ± 9.8***	86.5 ± 10.2
		Obese	12	131.7 ± 11.7***	79.4 ± 8.2*	96.8 ± 8.2**	70.8 ± 9.6*
Supine							
	1	Normal	64	111.2 ± 13.9	66.3 ± 8.7	81.3 ± 9.7	70.8 ± 9.7
		Overweight	28	120.4 ± 11.0***	72.0 ± 7.4***	88.2 ± 7.7***	71.7 ± 13.3
		Obese	12	131.7 ± 11.7***	79.4 ± 8.2***	96.8 ± 8.2***	70.8 ± 9.6
	5	Normal	64	111.6 ± 14.4	65.3 ± 9.4	80.8 ± 10.3	66.4 ± 8.9
		Overweight	28	121.2 ± 12.9***	71.0 ± 7.7***	87.7 ± 8.1***	69.2 ± 11.3
		Obese	12	129.5 ± 11.8 ***	77.3 ± 9.7***	94.7 ± 9.0***	70.8 ± 8.5
	10	Normal	64	110.4 ± 13.6	65.6 ± 8.5	80.6 ± 9.7	65.0 ± 9.2
		Overweight	28	119.8 ± 11.7***	71.6 ± 9.9**	87.7 ± 9.6***	68.0 ± 11.4
		Obese	12	127.8 ± 10.9***	76.3 ± 8.7***	93.5 ± 8.6***	69.3 ± 10.9

SBP: Systolic blood pressure, DBP: Diastolic blood pressure, MBP: Mean blood pressure; HR: Heart rate. *p < 0.05, **p < 0.01, ***p < 0.001 - Significant differences between the patients with normal and abnormal BMI.

Discussion

It is known that the properties of a muscle depend on its structural features and material composition [8]. By changing both the macroscopic and microscopic structure, obesity is linked to various morphological and functional changes in the musculoskeletal system of the lower limbs [9].

It has been found that obese patients have hypertrophy of muscle fibers, increased pennation angle, and cross-sectional area of the lower limb muscles (especially in those with anti-gravity function) [10], [11]. Some authors considered these findings a form of adaptation to excess mass loading [11], [12], [13].

Other investigators link obesity to muscle tissue changes and associated with worsening of muscle quality and loss of performance. Some of the suggested pathophysiological mechanisms behind this phenomenon have been reviewed:

- Increased levels of fibrotic tissue [9] probably due to altered macrophage activity leading to the higher levels of proinflammatory cytokines (primarily transforming growth factor β) which, in turn, induce excess intramuscular collagen deposition [14], [15].
- Intramuscular fat accumulation (both intramyocellular and extramyocellular) causing higher stiffness of the muscle and the aponeurosis [8].
- Different muscle fiber type and distribution – A discrete transition to fast switch IIb fibers was reported [16].
- Changes of the structural properties of Achilles tendon decreasing its adaptability to exercise [17].
- Hypertrophy of the muscle fibers and increased pennation angle, significantly more pronounced in the young obese population [11].

All these mechanisms seem to be associated with the efficacy of the peripheral muscle pump and its role in the orthostatic adjustment.

Table 3: Myosonographic parameters of gastrocnemius muscle at rest and during maximal active plantar flexion

BMI type	n	Diameter (cm)			Anatomical pennation angle (o)		
		At rest	MAPF	Δ	At rest	MAPF	Δ
Left lateral head							
Normal	64	1.19 ± 0.20	1.50 ± 0.26	0.31 ± 0.17	14.6 ± 3.7	25.7 ± 5.8	11.1 ± 6.1
Over	28	1.33 ± 0.25**	1.68 ± 0.29**	0.35 ± 0.21	16.3 ± 4.4*	29.6 ± 6.2**	13.4 ± 5.7*
Obese	12	1.38 ± 0.27*	1.67 ± 0.29*	0.30 ± 0.08	16.8 ± 2.9*	29.6 ± 6.6*	12.8 ± 5.8
Left medial head							
Normal	64	1.52 ± 0.17	1.77 ± 0.22	0.25 ± 0.17	18.7 ± 3.9	38.7 ± 7.5	19.9 ± 7.1
Over	28	1.68 ± 0.28**	1.92 ± 0.32**	0.24 ± 0.19	19.7 ± 5.5	40.3 ± 9.2	20.6 ± 7.6
Obese	12	1.48 ± 0.18	1.70 ± 0.18	0.22 ± 0.08	19.5 ± 4.4	41.9 ± 7.6	22.4 ± 7.1
Right lateral head							
Normal	64	1.21 ± 0.21	1.60 ± 0.25	0.39 ± 0.17	14.4 ± 3.5	26.9 ± 7.2	12.5 ± 6.2
Over	28	1.47 ± 0.24***	1.79 ± 0.24***	0.32 ± 0.21	16.4 ± 3.8**	30.4 ± 8.9*	13.7 ± 7.9
Obese	12	1.44 ± 0.35*	1.78 ± 0.34	0.34 ± 0.15	15.9 ± 3.4	30.4 ± 4.7*	14.5 ± 7.2
Right medial head							
Normal	64	1.52 ± 0.20	1.78 ± 0.21	0.26 ± 0.15	18.34 ± 3.57	37.1 ± 8.9	18.8 ± 7.9
Over	28	1.78 ± 0.29***	2.01 ± 0.32***	0.24 ± 0.13	20.41 ± 6.09*	39.5 ± 8.5	19.1 ± 7.9
Obese	12	1.66 ± 0.28	1.90 ± 0.28	0.24 ± 0.22	17.81 ± 3.42	36.6 ± 7.5	18.8 ± 7.6

MAPF: Maximal active plantar flexion, Over: Overweight, Δ: Absolute difference. *p < 0.05, **p < 0.01, ***p < 0.001 - Significant differences between the patients with normal and those with abnormal BMI.

Obesity is also known to influence on systemic hemodynamics. It is an indisputable fact that fat is associated with high blood pressure mainly due to activation of the renin-angiotensin-aldosterone system and increased sympathetic nervous system activity [18]. The role of obesity in orthostatic autoregulation in particular, however, is controversial and has not been well established.

Table 4: Summation of the myosonographic parameters of gastrocnemius muscle at rest and during maximal active plantar flexion

Myosonographic Parameters		Normal BMI 18.5–24.9 kg/m^2 (n = 64)	Overweight 25–29.9 kg/m^2 (n = 28)	Obese>30 kg/m^2 (n = 12)
Left leg				
Diameter (cm)	Rest	2.72 ± 0.29	3.01 ± 0.46**	2.86 ± 0.43
	MAPF	3.28 ± 0.38	3.60 ± 0.49**	3.37 ± 0.44
Angle (degree)	Rest	33.38 ± 5.67	35.97 ± 8.54	36.29 ± 5.33*
	MAPF	64.44 ± 10.20	69.94 ± 13.4*	71.53 ± 10.16*
Right leg				
Diameter (cm)	Rest	2.73 ± 0.33	3.24 ± 0.43***	3.10 ± 0.58*
	MAPF	3.38 ± 0.37	3.80 ± 0.49***	3.67 ± 0.59*
Angle (degree)	Rest	32.75 ± 5.04	36.83 ± 8.45**	33.67 ± 4.04*
	MAPF	64.00 ± 13.30	69.63 ± 14.49*	66.97 ± 9.62
All				
Diameter (cm)	Rest	5.44 ± 0.56	6.25 ± 0.85***	5.95 ± 0.85*
	MAPF	6.65 ± 0.65	7.41 ± 0.88***	7.05 ± 0.97
Angle (degree)	Rest	66.13 ± 9.00	72.80 ± 16.21*	69.96 ± 6.97
	MAPF	128.44 ± 19.58	139.57 ± 24.36*	138.49 ± 18.11*

MAPF: Maximal active plantar flexion. *p < 0.05, **p < 0.01, ***p < 0.001 - Significant differences between the patients with normal and abnormal BMI.

According to Moloney *et al*. [19], higher BMI has protective role in orthostatic hypotension since in overweight and obese groups the drop of systolic blood pressure during tilt testing was significantly lower than in underweight patients. It has been found that the lower BMI predisposes to orthostatic intolerance, caused by down-regulation of the sympatic and up-regulation of the parasympatic nervous system [20].

Conversely, in the research of Lee *et al*. [21], reduced orthostatic tolerance in obese patients was reported.

Conclusion

Our study shows the higher values of the anatomical pennation angles and diameters in overweight and obese patients which probably represent a form of adaptation to the chronic mass loading. However, the similar absolute differences in the muscle dimensions reveal a universal pattern of action of the peripheral muscle pump (represented by GM contraction) considered a form of adaptation.

From clinical and hemodynamic point of view, in our study, the BMI influenced mainly the anthropometric parameters and the systemic blood pressure in subjects with increased BMI. The percentage of people demonstrating any symptoms of orthostatic intolerance was lower among the overweight and obese patients, showing that the higher BMI probably could have a protective role against orthostatic intolerance.

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