Brief Report

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Iranian Journal of Diabetes and Obesity (IJDO)

Effects of Fatigue on Knee Joint Muscle Co-Contraction During Walking in Adults with Obesity and Pronated Feet

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Abstract

Objective: The objective of this research was to examine the impact of fatigue on directed and general muscular co-contraction of knee joint in individuals with both obesity and pronated feet during walking.

Materials and Methods: The study involved 15 adults' male with both obesity and pronated feet and 16 healthy age-matched controls. The G*power software, version 3.1.9.7, was used to estimate the required sample size. This indicated that 15 participants per group were needed to achieve 80% statistical power at a 0.05 significance level. This study was performed during the before and after fatigue protocol. Directed and general muscular co-contraction of knee joint were recorded during barefoot walking (~ 1.2 m/s) at constant speed.

Results: The findings showed significant main effects of "Group" for direct co-contraction Flexor and Extensor (P= 0.029, η2= 0.155) and Medio and Lateral (P= 0.031, η2= 0.151) of knee joint during loading phase. Significantly greater direct co-contraction Flexor and Extensor muscles of knee joint during loading phase in the obesity/pronated feet compared with the healthy group was found. Also, significantly lower direct co-contraction Medio and Lateral muscles of knee joint during loading phase in the obesity/pronated feet compared with the healthy group was observed.

Conclusion: The results demonstrated that individuals with both obesity and pronated foot demonstrate different direct and general muscular co-contraction of knee joint during walking compared with the healthy group.

Keywords: Obesity, Co-contraction, Gait, Pronated feet, Fatigue

QR Code:

Citation: Fakhri Mirzanagh E, Jafarnezhadgero A, Dehghani M, Rezazadeh F, Enteshari-Moghadam A. Effects of Fatigue on Knee Joint Muscle Co-Contraction During Walking in Adults with Obesity and Pronated Feet. , Iran J Diabetes Obes.. 2026; 18 (4) :315-320

URL: http://ijdo.ssu.ac.ir/article-1-1085-en.html

10.18502/ijdo.v18i4.23245

Article info:

Received: 25 November 2025
Revised: 17 May 2026
Accepted: 23 September 2026

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[DOI: 10.18502/ijdo.v18i4.23245]

Introduction

The previous studies reported that obesity rate has increase dramatically and this situation is a major concern in public health (1). Relative between obesity, body weight distribution and the biomechanical components of walking is necessary for preventing another chronic disease to managing of healthy life in individuals with obesity.

Understanding underlying mechanisms that change biomechanical components during walking in individuals with obesity could be used for detecting rehabilitation protocols. We aimed to investigate the impact of fatigue on directed and general muscular co-contraction of knee joint in individuals with both obesity and pronated during walking. We hypothesized that fatigue would increase knee muscle co-contraction in individuals with obesity and pronated feet compared with healthy controls.

Material and methods

Participants

Thirty-one adults were categorized into 2 groups (Table 1). The G*power software, version 3.1.9.7, was used to estimate the required sample size. This indicated that 15 participants per group were needed to achieve 80% statistical power at a 0.05 significance level. The healthy group was include NN; individual with normal BMI (e.g., 20≤ BMI <25 kg/m^2) and normal foot (e. g., 4< navicular drop<10 mm, foot posture index between 0 and 6) and second group was include OP; individual with both obesity (e.g., 35≥ BMI ≥ 30kg/m^2) and PF (e.g., navicular drop> 10 mm, 12≥ foot posture index> 10) (2).

Participants were instructed from of Ardabil city that invited to this study by platforms such as telegram, WhatsApp and et al. last researches demonstrated that relationship sedentary and obesity in different individuals (3). Because, we invited individuals with sedentary in present study. Therefore participants must <5000 steps/day during activity (4,5).

Fatigue protocol

Fatigue protocol was performed on a treadmill (Omega GT, USA) set at zero incline. Participants began by walking at a speed of six kilometer/hours, with the speed increasing by 1 kilometer/hours every 2 minutes. The Borg Rating of Perceived Exertion (RPE) scale (6–20) was used to identify the point of fatigue (4). When participants reported an RPE score of 13 or higher, the treadmill speed was held constant to initiate steady-state running. During this phase, RPE scores were recorded every 30 seconds. The fatigue protocol concluded after 2 minutes of steady-state running at an RPE greater than 17 or upon reaching 80% of the participant's estimated maximum heart rate (6).

The stance phase of walking was divided into three sub-phases for analysis: loading (0–20%), mid-stance (20–50%), and push-off (50–100%) (7). To normalize EMG data, MVIC was measured for each muscle (8). Also, directed flexor–extensor co-contraction was calculated using the normalized EMG activity of the knee flexor muscle (semitendinosus) and the knee extensor muscles (rectus femoris, vastus medialis, and vastus lateralis). Medio–lateral directed co-contraction was calculated using the normalized EMG activity of the vastus medialis and vastus lateralis muscles.

1-Agonist of average activity muscles/ Antagonist of average activity muscles

Directional co-contraction (mean antagonist muscle activity <mean agonist muscle activity)

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Directional co-contraction (mean antagonist muscle activity>mean agonist muscle activity)

Statistical analysis

Data normality was assessed using the Shapiro–Wilk test. Homogeneity of variances between groups was examined using Levene's test. The assumption of sphericity for the within-subject factor was assessed using

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[DOI: 10.18502/ijdo.v18i4.23245]

Mauchly's test, and when violated, the Greenhouse–Geisser correction was applied. For each dependent variable, a separate two-way mixed-design analysis of variance (mixed ANOVA) was performed. Group (healthy vs. obesity/pronated feet) was treated as the between-subject factor, whereas Fatigue (pre-fatigue vs. post-fatigue) was treated as the within-subject repeated-measures factor. The analysis evaluated the main effects of Group and Fatigue, as well as the Group × Fatigue interaction. Statistical significance was set at $P< 0.05$. Effect sizes were reported as partial eta squared (ηp^2), interpreted as small (0.01), medium (0.06), and large (0.14) according to Lakens, 2013 (9). The significance value was $P< 0.05$. All analysis were done by SPSS 26.

Ethical considerations

This study received ethical approval from the Research Ethics Committee of the University of Mohaghegh Ardabili confirmed this study (IR.UMA.REC.1403.062).

Results

Anthropometric features of two groups were showed in Table 1.

. Significant effects of "Group" for directed co-contraction Flexor and Extensor ($P= 0.029$, $\eta^2=0.155$) and Medio and Lateral ($P= 0.031$, $\eta^2=0.151$) of knee joint during loading phase. Greater directed muscular co-contraction Flexor and Extensor of knee joint during loading phase in the obesity/pronated feet compared with the healthy group was observed.

Significantly lower directed muscular co-contraction Medio and Lateral of knee joint during loading phase in the individuals with obesity/pronated feet compared with the healthy group were found (Table 2).

Significant effects of "Fatigue" were found for general and directed co-contraction of knee joint at mid-stance ($P> 0.05$) (Table 3).

Significant effects of "Group" for directed co-contraction Flexor and Extensor ($P= 0.012$, $\eta^2= 0.197$) and Vastus medialis and Vastus lateralis ($P= 0.010$, $\eta^2= 0.210$) of knee joint during mid-stance were observed. Significantly greater directed muscular co-contraction Flexor and Extensor of knee joint during mid-stance phase in the obesity/pronated feet compared with the healthy group were observed. Significantly lower directed muscular co-contraction Vastus medialis and Vastus lateralis of knee joint at mid-stance in the obesity/pronated feet compared with the healthy group were observed.

Significant effects of "Fatigue and groups" for general muscular co-contraction ($P= 0.032$, $\eta^2= 0.149$) of knee joint during mid-stance were observed. Significantly lower general muscular co-contraction of knee joint during mid-stance phase in the obesity/pronated feet group (but not in the healthy group) after fatigue compared before fatigue were observed (Table 3).

Significant effects of "Fatigue" for direct muscular co-contraction Vastus medialis and Vastus lateralis ($P= 0.047$, $\eta^2= 0.129$) of knee joint during push-off phase. Significantly lower directed muscular co-contraction Vastus medialis and Vastus lateralis of knee joint during push-off phase at after fatigue compared with before fatigue were observed (Table 4).

Conclusion

Obesity combined with pronated feet appears to alter selected patterns of knee muscle co-contraction during walking, particularly during loading and mid-stance phases. These neuromuscular adaptations may represent compensatory strategies to enhance knee joint stability during walking, although they may also increase joint loading. Future studies incorporating objective measures of localized muscle fatigue and lower-limb kinematics are warranted to further clarify the underlying mechanisms.

Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

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[DOI: 10.18502/ijdo.v18i4.23245]

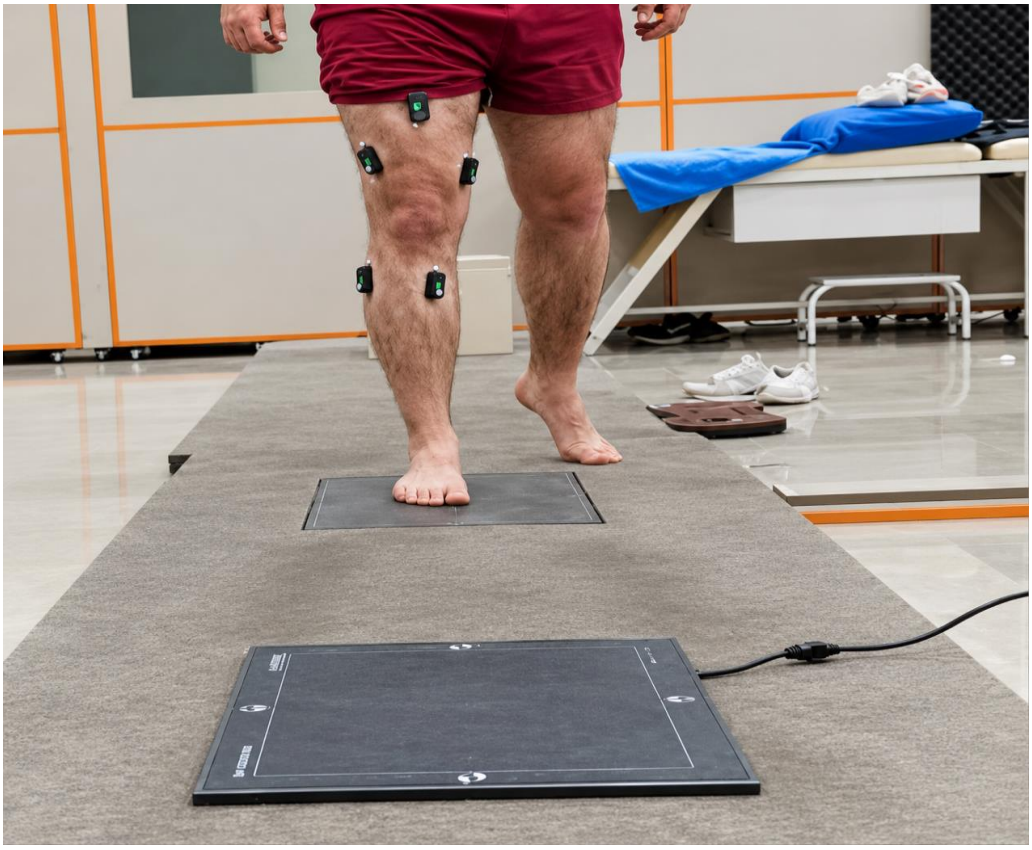


Figure 1: Recording of electrical activity of lower limb muscles

Table 1. Anthropometric features in two groups

Group	Normal weight/normal foot group	Obesity/pronated foot group	*P*-value
Height (m)	1.77 (± 0.24)	1.79 (± 0.04)	0.106
Mass (kg)	76.94(± 5.35)	117.61 (± 16.69)	< 0.001*
Body mass index (kg/m^2)	24.61 (± 1.18)	35.92 (± 4.23)	< 0.001*
Age (year)	23.40 (± 0.82)	23.86 (± 0.91)	0.154

Notes:* symbol indicates the significance of the variables

Table 2. Knee muscular co-contraction at loading phase

Muscles	Healthy group		Obesity/pronated feet		Fatigue P (η^2)	Group P (η^2)	Group× Fatigue interaction P (η^2)
	Pre	Post	Pre	Post			
General Co-Contraction (Loading phase)	39.85 (± 17.81)	40.37 (± 19.53)	43.08 (± 32.82)	35.61 (± 15.54)	(0.016) 0.500	(0.001) 0.904	(0.021) 0.439
Directed Co-Contraction (Flexor/Extenso)	0.67(± 0.20)	0.64 (± 0.28)	0.78 (± 0.15)	0.81 (± 0.12)	(0.001) 0.872	(0.155) 0.029*	(0.025) 0.398
Directed Co-Contraction (Medio/Lateral)	0.66 (± 0.22)	0.65 (± 0.32)	0.33 (± 0.41)	0.43 (± 0.48)	(0.015) 0.505	(0.151) 0.031*	(0.024) 0.405
Directed Co-Contraction (Vastus medialis / Vastus lateralis)	-0.17 (± 0.61)	-0.19 (± 0.60)	0.26 (± 0.18)	-0.12 (± 0.92)	(0.021) 0.435	(0.072) 0.143	(0.019) 0.464

Notes:* symbol indicates the significance of the variables

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Table 3. Knee muscular co-contraction at mid stance phase

Muscles	Healthy group		Obesity/pronated feet		Fatigue P (η^2)	Group P (η^2)	Group× Fatigue interaction P (η^2)
	Pre	Post	Pre	Post			
General Co-Contraction (Loading phase)	27.19 (± 11.81)	31.53 (± 15.73)	37.33 (± 23.09)	26.23 (± 15.60)	(0.033) 0.332	(0.008) 0.635	(0.149) 0.032*
Direct Co-Contraction (Flexor/Extenso)	0.52 (± 0.36)	0.60 (± 0.45)	0.84 (± 0.12)	0.78 (± 0.14)	(0.000) 0.924	(0.197) 0.012*	(0.045) 0.253
Direct Co-Contraction (Medio/Lateral)	0.52 (± 0.32)	0.48 (± 0.45)	0.26 (± 0.11)	0.20 (± 0.17)	(0.007) 0.655	(0.091) 0.098	(0.000) 0.967
Direct Co-Contraction (Vastus medialis/ Vastus lateralis)	0.42 (± 0.43)	0.20 (± 0.18)	0.21 (± 0.13)	-0.13 (± 0.50)	(0.118) 0.058	(0.210) 0.010*	(0.008) 0.642

Notes:* symbol indicates the significance of the variables

Table 4. Knee muscular co-contraction at push off phase

Muscles	Healthy group		Obesity/pronated feet		Fatigue P (η^2)	Group P (η^2)	Group× Fatigue interaction P (η^2)
	Pre	Post	Pre	Post			
General Co-Contraction (Loading phase)	26.27 (± 13.57)	24.87 (± 10.42)	30.36 (± 18.47)	21.99 (± 8.87)	(0.089) 0.103	(0.001) 0.874	(0.047) 0.240
Direct Co-Contraction (Flexor/Extensor)	0.63 (± 0.25)	0.64 (± 0.35)	0.82 (± 0.18)	0.74 (± 0.18)	(0.011) 0.577	(0.122) 0.054	(0.440) 0.021*
Direct Co-Contraction (Medio/Lateral)	0.48 (± 0.42)	0.58 (± 0.31)	0.26 (± 0.16)	0.38 (± 0.36)	(0.079) 0.126	(0.111) 0.067	(0.001) 0.898

Notes:* symbol indicates the significance of the variables

Funding

None.

Conflict of Interest

The authors declared no conflict of interest.

Authors' contributions

Conceptualization: EFM and AJG. Data Collection and Laboratory Analysis: CH.AS.

Data Collection and Laboratory Analysis: FR and EFM. Writing – Original Draft Preparation: EFM and FR. Writing – Review and Editing: EFM and AEM. Supervision: AJG and EFM. All authors read and approved the final manuscript.

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[DOI: 10.18502/ijdo.v18i4.23245]

References

1. Sun M, Sun H. Recent prevalence and trends of obesity and metabolic dysfunction-associated steatotic liver disease (MASLD) among US adolescents: 1999 to 2020. Pediatric obesity. 2025;20(5):e70003.
2. Piri E, Jafarnezhadgero A, Dehghani M, Dionisio VC. Response to fatigue protocol on running ground reaction forces in individuals with anterior cruciate ligament reconstruction and pronated feet: a cross-sectional observational study. BMC Musculoskeletal Disorders. 2026;27:501.
3. Sukatemin S, Muhalla HI, Muarrofah M, Utari DA, Fitriani VY. Sedentary lifestyle and the threat of obesity among young people. The Journal of Academic Science. 2025;2(1):232-40.
4. Pescatello LS, editor. ACSM's guidelines for exercise testing and prescription. Lippincott Williams & Wilkins; 2014.
5. Wang Y, Guo X, Liu L, Xie M, Lam WK. Effects of Tai-chi and running exercises on cardiorespiratory fitness and biomarkers in sedentary middle-aged males: A 24-week supervised training study. Biology. 2022;11(3):375.
6. Koblbauer IF, van Schooten KS, Verhagen EA, van Dieën JH. Kinematic changes during running-induced fatigue and relations with core endurance in novice runners. Journal of science and medicine in sport. 2014;17(4):419-24.
7. Jafarnezhadgero AA, Alizadeh R, Mirzanag EF, Dionisio VC. Could the anterior cruciate ligament reconstruction and pronated feet affect the plantar pressure variables and muscular activity during running? A comparative study. Journal of Bodywork and Movement Therapies. 2024;40:986-91.
8. Farahpour N, Jafarnezhadgero A, Allard P, Majlesi M. Muscle activity and kinetics of lower limbs during walking in pronated feet individuals with and without low back pain. Journal of Electromyography and Kinesiology. 2018;39:35-41.
9. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Frontiers in psychology. 2013;4:863.

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