The Impact of Body Mass Index on Joint Kinematics and Muscle Activations During Walking

Malek Adouni[1, 2], Fadi Al-khatib[3], Raouf Hajji[4], Tanvir R. Faisal [5]

[1]Biomedical and Instruments Engineering Program, Abdullah Al Salem University, Kuwait; [2]Department of Physical Medicine and Rehabilitation, Northwestern University, Chicago, IL, USA; [3]Department of Mechanical Engineering, Australian University, Kuwait; [4]Department of Internal Medicine University of Sousse, Tunisia. ;[5]Department of Mechanical Engineering, University of Louisiana at Lafayette, USA.

Disclosures: M. Adouni: None; F. Al-Khatib: None; Raouf Hajji: None; Tanvir R. Faisal: None.

INTRODUCTION: Obesity is strongly linked to various health conditions, notably knee osteoarthritis, due to the extra stress that excess body weight places on joints, accelerating cartilage wear [1]. In the United States, obesity has dramatically increased, with over 40% of adults now considered obese [2]. This surge is significant because obesity is a leading factor in disability, particularly due to osteoarthritis and rheumatism [1]. Research has demonstrated that individuals with knee osteoarthritis walk differently than those without, showing altered knee biomechanics, such as reduced flexion and increased adduction. These biomechanical patterns overlap with those seen in obese individuals, suggesting a connection between obesity and exacerbated joint issues. However, studies have sometimes provided contradictory findings, potentially due to methodological limitations, including early-stage osteoarthritis participants being inadvertently included, and a focus on sagittal plane movements without considering other planes or muscle activations [3]. To address these gaps, the current research investigates the lower limb biomechanics of individuals with different body weights during walking, hypothesizing that unhealthy-weight individuals will show distinct muscle activation and movement patterns that could lead to increased joint stress. The study categorizes participants by Body Mass Index (BMI) and conducts gait analysis to offer a comprehensive view of the biomechanical effects of obesity on joint health, a critical aspect in the ongoing fight against obesity-related disabilities.

METHODS: In this research, 60 age-matched, physically stable males with no knee pain history or lower limb surgeries were recruited through university outreach and gave informed consent under ethical guidelines. Participants were sorted into three BMI-based groups as per WHO standards: under 25 (healthy weight), 25-30 (overweight), and over 30 (obese). Using Philips Medical Systems' X-ray equipment, knee images were taken and analyzed to exclude osteoarthritis-obesity links [4]. Gait was analyzed via AMTI force platforms and an 8-camera optoelectronic system at 120 Hz, tracking 27 markers on key body points. Walking trials were smoothed with Butterworth filters. Kinematics and kinetics were assessed using inverse dynamics, focusing on lower limb joint moments based on inertial properties, with algorithms in Matlab. EMG preamplifiers recorded muscle activity, processed as per Besier et al.,[5] aligned with motion data at 2400 Hz. Statistical tests evaluated gait disparities across BMI groups, seeking $p<0.05$ significance in temporal-distance variables, kinematics, kinetics, and muscle activations throughout the stance cycle.

RESULTS: Stride analysis comparing obese, overweight, and healthy weight individuals revealed marked differences primarily among obese participants. The obese group, walking at self-selected speeds, showed a 20% longer stride time, a 16% lower average velocity, and an 8% decrease in cadence compared to their healthy counterparts. Spatially, their stride length was 7% shorter with a 13% wider step width. Overweight individuals displayed a significant decline in mean velocity and stride length, but other parameters were similar to the healthy weight group. In joint angle dynamics, obese participants had greater hip flexion in the initial stance, with increased hip extension in the latter phase, higher hip adduction and external rotation throughout, and altered knee and ankle rotations. These changes mirrored joint moments (fig.1a), with obese individuals exhibiting higher hip flexor and extensor moments, increased knee flexion, adduction, and internal moments, and pronounced ankle dorsiflexion and internal rotation moments during late stance. Ground reaction forces also peaked in the obese group, particularly in the vertical component, with up to a 50% increase. Electromyographic analysis (fig. 1b) showed that the BMI changes affected muscle activity: the vastus medialis was more active during early to midstance, lateral hamstring activation was higher in the obese and overweight groups, while the lateral gastrocnemius showed increased activation during late stance in the obese group. These findings underscore the significant biomechanical impact of obesity on gait parameters, with some notable differences also observed in the overweight population.

DISCUSSION: This study explored the biomechanical impact of Body Mass Index (BMI) on gait, examining 3D joint motions, moments, ground reaction forces, and muscle activations in healthy, overweight, and obese cohorts. Results revealed that higher BMIs increase the biomechanical load on joints during walking. Key findings included increased hip flexion angle in obese participants during early stance, with a unique pattern of change across cohorts, aligning with established literature [6-7]. Obese individuals also showed greater hip adduction and sustained external rotations, suggesting weakened hip abductors due to higher loads, which affects gait stability. Significantly, obese participants displayed increased knee flexion moments early in the stance phase, with lower flexion angles, indicating a more upright walking pattern and suggesting neuromuscular adaptations to distribute increased ground reaction forces. These adaptations, however, lead to greater knee loading, raising osteoarthritis risk due to abnormal knee joint loading. Stride analysis showed that obese individuals have longer ground contact times and shorter, slower steps, akin to pregnant women and loaded servicemen, which affects joint loads. Diverging from some past studies, our research found that obesity alters muscle activation patterns during gait, particularly in the gastrocnemius and quadriceps, possibly as a compensatory strategy for joint stability. This study, while insightful, has limitations including a lower average BMI in the obese cohort and potential skin movement artifacts in data collection. The findings contribute to understanding gait biomechanics in obesity, aiding in developing targeted osteoarthritis treatments for various BMI categories.

SIGNIFICANCE: Our findings represent a comprehensive picture that contributes to the understanding of how excess weight and obesity influence joint biomechanics, highlighting the associated risk of joint osteoarthritis. **REFERENCES:** [1] Andersen, R., 2003 Hum Kin. [2] NIH NIDDKD., 2021 [3] DeVita et al., 2003, J Biom. [4] Hu, F., 2008 Oxf Univ. [5] Besier, T.F., et al.,2009, J Biom, 42(7): p. 898-905. [6] Amiri, P., et al., 2015 J of Electro and Kines 25(6): p. 951- 958. [7] Yocum, D., et al., (2018), J Bio, 7(3): p. 239-50.

Figure. 1

a) Joints Moments (Nm/Kg) **b) Muscle Activation (EMG signals)(%)**