Original article

Determine the kinematics and kinetics parameters associated with bilateral gait patterns among healthy, overweight, and obese adults

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Abstract. *Background and aim:* Biomechanical analysis of gait is important to obtain information regarding the lower limb impairments and dysfunction during locomotion. This study aimed to determine the potential difference among healthy, overweight, and obese participants and their impact on gait parameters by observing the kinematic and kinetics parameters. *Methods:* A cross-sectional study was conducted with forty (15 healthy, 12 overweight, 13 obese) male participants. All participants were non-smokers, and their physical activity level was 7000±2142 steps per day. Participants anthropometric characteristics were age: 21.57±1.46 years; height: 173.63±6.43 cm, body mass: 86.15±23.36 kg., body mass index (BMI): 28.57±7.68 kg/m^2, body fat: 29.93±9.44%. A bioelectrical impedance device was used to determine participants' body composition and health status. A portable pressure sensor mat (Walkway) from Tekscan was used to measure bilateral gait parameters kinematically and kinetically. A one-way analysis of variance was used to determine the differences between groups. *Results:* Significant differences were found between healthy, overweight, and obese participants for different bilateral gait's kinematic and kinetic parameters such as cadence, gait velocity, step time, step length, step velocity, step width, stride time, stride length, stride velocity, maximum force, maximum peak pressure, active propulsion, and passive propulsion except for impulse at .05 level of significance. *Conclusions*: The finding shows that gait's kinematics and kinetics parameters were affected by the BMI status. Current research suggests that increased body weight interferes with normal musculoskeletal function via a range of kinematic and kinetic deficits. More research is required to understand the structural and functional restrictions imposed by overweight and obese individuals. (www.actabiomedica.it)

Key words: Walking, Locomotion, Biomechanics, Motion analysis, Body Traits.

Introduction

Gait analysis is a method for identifying impairment and functional limitations that contribute to a disability during locomotion (1). Kinematics and kinetics analysis of gait is a part of physical examination that can help to determine essential evidence on the functional capability of human beings while evaluating disability. Evidence shows that a better understanding of normal gait may be useful in interpreting abnormal findings (2). Healthy participants have been used to produce normative data that can be used as a reference when assessing abnormal and/or pathological gait parameters (3). The ability to walk is one of the most important factors in determining individuals' quality of life and health status (4). State of health has been shown to affect gait kinematics and kinetics significantly.

Gait analyses provide essential information on the functional capability of humans while evaluating disabilities. Overweight and obese people are more likely to develop ankle and foot problems due to the additional mechanical stress of carrying excess weight. They may have musculoskeletal disorders such as arthritis, plantar fasciitis, bursitis, and tibia vara, leading to gait impairment (5). Research has found that excess weight is associated with slow walking speed and predicts the development of mobility impairment (6). Excess body weight places a biomechanical strain on the knee and hip joints, leading to joint degeneration and walking impairment (7). Xu and Xue (8) reported that obese individuals had reduced functional ability compared to individuals with normal weight. Obese people showed differences in foot structure (9), plantar pressure (10), and foot mechanics when compared to healthy people (11). Scientific evidence showed that moderate body weight loss benefits knee pain and joint mobility for osteoarthritis patients (12). The spatiotemporal parameters (cadence, stance, stride length, walking speed, and swing phase duration) differences have been reported between obese and healthy subjects in the previous studies (13).

Understanding the impact of body types on the gait parameters is important to get insight into the gait pattern's muscle strength, imbalance, and biomechanical asymmetries. Understanding the factors that may affect the ability to walk in healthy, overweight, and obese people may identify preventive and rehabilitative measures. This study aimed to determine the potential difference among healthy, overweight, and obese participants and their impact on gait parameters by observing the kinematic and kinetics parameters.

Methodology

Design and setting

This was a cross-sectional study conducted at the department of physical therapy in IAU, Dammam. Imam Abdulrahman Bin Faisal University's institutional review board committee fully approved all the procedures (IRB-2022-03-111) and was conducted according to the Declaration of Helsinki 2013. The study participants comprised three groups: healthy, overweight, and obese.

Sample size

The sample size was calculated using G*Power 3.1.9.4 based on kinematics data from a previous study (13) with the following combination: two tail F tests for difference among three independent means; effect size of 0.40; alpha level (α) of 0.05; power (1- β) of 80%; and allocation ratio N2/N1 of 1. The sample size calculation resulted in 12 participants in each group. An extra 10% was added in case of dropout, resulting in 40 participants.

Participants

A total of forty (15 healthy, 12 overweight, 13 obese) male participants participated in this study (age: 21.57±1.46 years; height: 173. 63±6.43 cm, body mass; 86.15±23.36 kg., BMI 28.57±7.68, body fat: 29.93±9.44%, mass of body fat: 27.68±16.18 kg, and total body water: 41.33±6.86 L). No leg discrepancy was found in any of the participants. All the participants were non-smokers, and their physical activity level was 7000±2142 steps per day. None of the participants had any pathological conditions, as they declared.

Tools

Stadiometer: Stadiometer (Detecto 8430S USA) was used to measure the participants' height.

Body Composition Analyzer: Bioelectrical impedance device (ioi-353, Jawon Medical, South Korea) was used to determine participants' body composition and health status.

Takscan's Walkway: The standard resolution portable pressure sensor mat (Walkway) from Tekscan (South Boston, US) was used to measure bilateral gait's kinematic and kinetic parameters. The device provides objective, quantifiable, visualized plantar pressure distribution and vertical force data that help to get insight into muscle, strength imbalance, and biomechanical asymmetries to understand movement. The Walkway was used with an application to capture and evaluate dynamic foot functions at a sampling frequency of 100Hz.

Procedure

Each test was conducted in the morning under the supervision of a researcher. All the necessary information regarding the test was verbally explained to the participants. Participants also signed informed consent before the actual test. Initially, the anthropometric characteristics of participants were measured in the indoor laboratory setting. Standing height and weight were measured by the using stadio-cum-weighing scale. Leg length was measured by using a measuring tape. BMI was calculated as body weight (kg) divided by squared height (m^2). Body fat percentage, the mass of body fat, and total body water were determined by using a bioelectrical impedance analyzer. The kinematics and kinetics parameters were measured using the Tekscan Walkway pressure sensor mat (Tekscan, South Boston, US). The Walkway was used on the zero level in an indoor setting. The participant was asked to walk barefoot freely in the hall. The researcher observed the participant walking normally; they asked him to be walked on the device and research record the walking data in the device. Three trials were recorded, and an average of three trials was used for analysis. The data were recorded in software and later extracted for statistical analysis.

Statistical analysis

Prior to analysis, the data were examined for missing data, outliers, and normality. Shapiro-Wilk and Levene's tests confirmed the normality of distribution and homogeneity of variances. Descriptive and inferential statistics were provided as means and standard deviation (SD). One-way analysis of variance was used to determine the differences between healthy, overweight, and obese participants for gait's kinematics and kinetics parameters. The level of significance was set at P :< .05 and confidence of interval 95%. All the statistical analyses were done by IBM SPSS program version 26 for Windows.

Results

A total of 40 participants were selected to conduct this study. Fifteen participants were healthy, twelve were overweight, and thirteen were obese. All the participants did not have similar anthropometric characteristics (p>.05). The descriptive results for each kinematic and kinetic parameter on the gait (means and standard deviations) for the three groups (healthy, overweight, and obese) were presented in tables 1 and 2. All the kinematics and kinetics parameters of all groups were analyzed using a one-way variance (ANOVA) test.

Table 1 showed significant differences between health, overweight, and obese participants for different bilateral gait kinematic parameters. The cadence of healthy participants was 114.35±4.95 steps per minute, overweight 102.98±2.73 steps per minute, and obese 93.82±8.06 steps per minute. Obese participants were slowest than overweight and healthy participants. The gait velocity was better in healthy participants (94.67±14.21) than in overweight (112.47±2.2) and obese (126.03±9.09). Healthy participants have taken lesser time to take a step (94.67±14.21) than overweight (112.47±2.2) and obese (126.03±9.09) participants. There were significant difference for cadence (steps/min) (F=45.56, P:<.05), gait velocity (cm/sec) (F=33.15, P:<.05), step time (sec) (F=26.43, P:<.05), step length (cm) (F=52.35, P:<.05), step velocity (cm/sec) (F=45.87, P:<.05), step width (cm) (F=51.93, P:<.05), stride time (sec) (F=13.85, P:<.05), stride length (cm) (F=17.69, P:<.05), stride velocity (cm/sec) (F=23.17, P:<.05) for left foot. While the left foot also showed significant differences for step time (sec) (F=31.25, P:<.05), step length (cm) (F=11.74, P:<.05), step velocity (cm/sec) (F=37.48, P:<.05), step width (cm) (F=48.35, P:<.05), stride time (sec) (F=9.90, P:<.05), stride length (cm) (F=9.79, P:<.05), stride velocity (cm/sec) (F=9.36, P:<.05) for left foot.

Table 2 showed significant differences between healthy, overweight, and obese participants for different bilateral gait kinetic parameters. The average maximum force of healthy participants was 86.91±12.93 kg, overweight 114.53±3.79 kg, and obese 145.64±17.24 kg for the left foot. The average maximum force for the left

Table 1. Kinematics comparison of bilateral gait's parameters among healthy, overweight, and obese participants.

Variables		Healthy	Overweight	Obese	F	Sig.
Cadence (steps/min)		114.35±4.95	102.98±2.73	93.82±8.06	45.56	< 0.001
Gait Velocity (cm/sec)		94.67±14.21	112.47±2.2	126.03±9.09	33.15	< 0.001
Step Time (sec)	**R**	0.53±0.02	0.58±0.02	0.64±0.07	< 0.001	< 0.001
	L	0.52±0.03	0.58±0.01	0.65±0.07	31.25	< 0.001
Step Length (cm)	**R**	71.29±4.25	64.27±1.74	55.66±5.13	52.35	< 0.001
	L	69.25±3.06	62.88±1.47	52.21±15.98	11.74	< 0.001
Step Velocity (cm/sec)	**R**	131.13±8.78	115.75±3.16	94.44±14.16	45.87	< 0.001
	L	130.1±8.8	112.58±2.6	95.21±15.09	37.48	< 0.001
Step Width (cm)	**R**	5.1±2.42	8.67±0.59	11.95±1.61	51.93	< 0.001
	L	5.25±2.48	8.82±0.48	12.14±1.79	48.35	< 0.001
Stride Time (sec)	**R**	1.30±0.19	1.17±0.01	1.06±0.08	13.85	< 0.001
	L	1.37±0.19	1.25±0.02	1.15±0.11	9.90	< 0.001
Stride Length (cm)	**R**	133.64±5.32	122.62±0.47	109.35±18.03	17.69	< 0.001
	L	132.49±9.88	123.41±0.03	112.92±17.49	9.79	< 0.001
Stride Velocity (cm/sec)	**R**	121.7±6.21	108.78±1.8	95.69±15.29	23.17	< 0.001
	L	120.35±12.38	110±1.25	101.11±15.25	9.36	< 0.001

Table 2. Kinetics comparison of bilateral gait's parameters among healthy, overweight, and obese participants.

Variables		Healthy	Overweight	Obese	F	Sig.
Max Force (kg)	**R**	86.91±12.93	114.53±3.79	145.64±17.24	73.26	< 0.001
	L	81.31±9.06	102.3±3.94	132.68±18.73	61.70	< 0.001
Impulse (kg*sec)	**R**	42.33±4.68	58.75±4.43	79.62±8.46	129.70	< 0.001
	L	37.83±5.3	54.18±6	82.99±11.95	1.30	0.286
Max Peak Pressure (N/cm2)	**R**	37.33±5.74	46±2.13	57.77±6.55	52.56	< 0.001
	L	30.27±5.13	42.33±1.83	53.92±4.05	119.97	< 0.001
Active Propulsion (sec)	**R**	0.08±0.03	0.11±0.01	0.22±0.08	51.58	< 0.001
	L	0.10±0.05	0.12±0.05	0.25±0.22	5.32	0.009
Passive Propulsion (sec)	**R**	0.17±0.04	0.15±0.02	0.10±0.02	14.67	< 0.001
	L	0.17±0.03	0.13±0.01	0.11±0.01	28.66	< 0.001

foot of healthy participants was 81.31±9.06 kg, overweight 102.3±3.94 kg, and obese 132.68±18.73 kg. Obese participants had more force than overweight and healthy participants. The impulse was better in healthy participants 42.33±4.68 than in overweight 58.75±4.43 and obese 79.62±8.46 kg*sec for the right foot. In healthy participants, the impulse for the left foot was 37.83±5.3, overweight 54.18±6, and obese 82.99±11.95 kg*sec. Healthy participants' average maximum peak pressure was 37.33±5.74 N/cm^2, overweight 46±2.13 N/cm^2, obese 57.77±6.55 N/cm^2 for the right foot. The average maximum force for the left foot of healthy participants was 30.27±5.13 N/cm^2, overweight 42.33±1.83 N/cm^2, and obese 53.92±4.05 N/cm^2. The statistically significant differences for maximum force were (F=73.26, p=0.000) for the right foot and (F=61.70, P:0.000); the impulse for the right foot showed a significant difference (F=129.70, P:0.000), while the left foot showed insignificant statistical difference (F=1.30, P:0.286). The maximum peak pressure for the right foot was significant (F=52.56, P:0.000) and the left foot (F=119.97, P:0.000) for healthy, overweight, and obese participants.

Discussion

Based on the study in the literature, there was sufficient information to define differences in gait parameters in obese participants for various reasons. Gait analysis may also reveal possible issues with the persistence of weight distribution. It provides information to develop evidence-based deficit-specific or general gait retraining techniques for overweight and obese individuals.

In our study, we divided all the participants into three groups depending on the BMI level as healthy, overweight, and obese. The result of this study consisted of general gait kinematics parameters (Cadence, Gait Velocity, Step Time, Step Length, Step Velocity, Step Width, Stride Time, Stride Length, Stride Velocity) and kinetics parameters (Max Force, Impulse, and Max Peak Pressure) for right and left foot. The data analysis showed statistically significant differences in kinematics and kinetics parameters of gait among healthy, overweight, and obese participants for the right and left foot. Participants from the obese category group walked slowly compared to overweight and healthy participants. The gait velocity, cadence, step, and stride velocity were higher in healthy participants than in obese and overweight participants. Step length and stride length were more in healthy participants than overweight and obese participants, whereas step width was wider in overweight and obese than in healthy participants. Step time and stride time were more obese and overweight than healthy participants.

Concerning the kinematics parameters of gait, the current research finding on cadence agreed with the literature that reported a significant difference between obese and healthy participants (14). An earlier study revealed that overweight participants took longer stance time than healthy participants while both walked at their preferred speed (15,16). Dufek and colleagues (17) investigated walking characteristics in adolescents. They reported that overweight participants have a significantly slower walking velocity and greater stance width than their healthy counterparts. The literature suggests that obese and overweight individuals walk with shorter steps, shorter stride lengths, and wider step widths than healthy or normal participants while walking at a self-selected speed (18). Another finding was consistent with earlier reports that increased body mass was associated with shorter step length, step width, and stride length (16,19). Our findings suggest that obese and overweight participants do not preserve a normal gait pattern as healthy participants due to an increase in overall adiposity.

Gait velocity, step velocity, and stride velocity certainly play a crucial role in defining the kinematics of gait in healthy, overweight, and obese participants and can be considered the main cause for the step length, width, and stride length. Concerning the kinematical parameters, the literature recommends that obese and overweight participants have shorter step lengths, stride lengths, and wider step widths than healthy participants (20). However, these findings may be directly due to the effect of gait velocity, step and stride velocity. The slow walking speed/velocity is thought to be the deterioration of the control function in the extension of the double support phase, single-leg supporting phase, and decrease in stride length (21). A study was conducted on the gait pattern between normal-weight and obese participants. They found that obese participants walked with significantly greater step width. The researchers proposed that the obese group participants had wider step widths due to excessive adipose tissue between the thighs, providing a larger support base while walking (15,22). Our findings contradict the findings of Rosso et al. (23), which showed no significant difference between healthy and overweight participants for walking speed, step width, stride length, step length, and cadence. The reason might be the number of participants and the instrument used in the experiments.

The gait's kinetic parameters (Maximum force, impulse, and Maximum peak pressure) showed statistically significant differences among healthy, overweight, and obese participants for the right and left feet except for the impulse of the left foot. The participants from the obese category group showed a higher level of maximum force, impulse, and maximum peak pressure than overweight and obese participants.

Furthermore, it has been revealed that healthy, overweight, and obese participants bear more weight on their right foot than on the left.

Excess body weight is a mechanical load on the lower extremity joints that leads to restricted movements. While mechanical load reaches a certain level, it may overwhelm the appearance of deficits in the neuromuscular system. However, when performing a walk for a distance, excess body weight induces a large mechanical load and acts as a primary perturbation. Thus, excess body weight is likely to be more associated with abnormal gait patterns (24). An individual's gait pattern is affected by several factors that result from both cognitive and mechanical organization (25,26). A study applying a prediction method by Lelas et al. (27) reported that most of the gait parameters changed due to increased gait speed. Predictability was better for kinetic parameters than kinematics. The kinetic variables were affected to a lesser extent than kinematic ones because the difference was observed only at a fast speed. At the same time, the ground reaction force did not change in any speed comparison. In healthy participants, only the propulsive force increased at a fast speed, while the vertical force decreased at a slow speed, as per the findings of an earlier study (28). In the overweight and obese participants, maximum force and maximum peak pressure have been seen.

During normal human gait, the participants' weight is subjected to repetitive impact loading. It was clear that these repetitive high-frequency impulse loads at hill strikes (29). A study comparing non-obese and obese individuals found that during level walking, the planter pressure increased with obesity (10). Birtane and Tuna (30) observed that the peak plantar pressures increased with the increase in BMI. Hills et al. (10) identify the planter pressure distribution patterns between obese and non-obese adults as they do the biomechanical analysis. They found that body weight was a major factor in the magnitude of pressure under the feet of obese adults. The was also a positive relationship between peak pressure and body mass; as body mass increases, the number of strides decreases and healthy weight participants have higher peak planter pressure and greater muscle forces (31,32). These differences may explain the increased peak pressures during walking due to the above-suggested kinematic and kinetic parameters.

Gait velocities differ between types of participants. The participants' choice of walking velocity was more reproducible for the type of participant and may allow some form of compensation for increasing pressure. If peak pressures alone were used, asking participants to walk at a standard velocity would be reasonable to exclude compensation, which might also alter the gait pattern. Some researchers have proposed that walking at a slower velocity may also be an expression of a compensatory strategy aimed at minimizing the magnitude of forces acting on the joints of the lower extremities, thus reducing the risk of musculoskeletal diseases.

There were a few limitations to this study. Firstly, the sample size of this study was quite small, and a large sample size might be used in future investigations. This will help researchers better to understand an important aspect of normal and pathological gait. Secondly, the participants for this study were young male adults only. Earlier studies recruited obese participants with any musculoskeletal disorder and elderly participants. Thirdly, limited kinetic data were collected in this study, and more kinetic parameters could be included in a future study to provide valuable information. Another limitation was the heterogeneity of participants in terms of healthy, overweight, and obese participants, which makes comparison with data in the literature more difficult. Finally, it was important to highlight that the walking pattern was determined using a pressure mat that determines the planter pressure and associated variables in this study.

Conclusion

After analyzing the gait parameters between healthy, overweight, and obese participants, the result shows that the kinematics and kinetics parameters of gait were affected by the status of their BMI. Current research suggests that increased body weight interferes with normal musculoskeletal function via a range of kinematic and kinetic deficits. Walking abnormalities should be carefully analyzed and considered to minimize overload and subsequent musculoskeletal deformities, extending the rehabilitation process and possibly even having harmful consequences. More research is needed to properly identify the structural and functional constraints imposed by overweight and obesity.

Conflicts of interest: The author declares that he has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

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