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The Relationship Between Joint Loading Patterns And Physical Activity In Middle-Aged Adults With Obesity: A Body Composition Approach

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Article Details

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ABSTRACT

Background: Obesity contributes to increased mechanical stress on the knee joint and elevates cardiometabolic risk. Physical activity and body composition are key factors influencing knee joint loading, yet large-scale evidence from Pakistan is scarce. **Objective:** To investigate the relationship between knee joint loading patterns and moderate-to-vigorous physical activity (MVPA) in middle-aged adults with obesity, and to evaluate the mediating roles of fat mass and lean mass. **Methods:** A cross-sectional study included 500 adults (260 males, 240 females; age 25–40 years) with obesity from urban Pakistan. Knee joint loading was measured using force plates and gait analysis. Physical activity was assessed with accelerometers. Body composition was determined via DXA scans, including fat and lean mass. Muscle strength and cardiometabolic variables (blood pressure, CRP, lipids, HOMA-IR) were recorded. Statistical analyses included descriptive statistics, Pearson correlations, multiple regression, mediation analysis and joint loading parameters. Figures included scatterplot of knee joint loading vs MVPA (Figure 1), mediation diagram (Figure 2), and peak vertical ground reaction force by sex (Figure 3). **Results:** MVPA was negatively correlated with peak knee joint loading ($r = -0.48$, $p < 0.001$). Multiple regression indicated that higher MVPA ($\beta = -0.34$, $p < 0.001$) and lean mass ($\beta = -0.26$, $p = 0.002$) were associated with lower knee loading, whereas fat mass ($\beta = 0.42$, $p < 0.001$) increased joint stress. Mediation analysis revealed partial mediation of the MVPA–knee loading relationship via fat mass (indirect effect: −0.32, $p < 0.001$) and lean mass (indirect effect: −0.19, $p = 0.009$). Peak vertical ground reaction force was slightly higher in males than females (1.23 ± 0.15 vs. 1.19 ± 0.13 BW). Higher muscle strength was associated with lower systolic and diastolic blood pressure, CRP, triglycerides, cholesterol, and HOMA-IR, particularly in men with abdominal obesity. Joint loading parameters during walking (Table 5) indicated that mechanical stress was influenced by both body composition and activity levels. **Conclusion:** Higher MVPA reduces knee joint loading directly and indirectly via improvements in body composition. Lean mass mitigates, while fat mass increases mechanical stress on the knee. Incorporating physical activity and strength-based interventions may reduce joint overload and cardiometabolic risk in middle-aged Pakistani adults with obesity.

INTRODUCTION:

Globally, obesity is a major public health challenge, with over 650 million adults classified as obese, contributing to increased risk of musculoskeletal disorders, altered gait mechanics, and cardiometabolic diseases (World Health Organization, 2021). Evidence from international studies shows that physical activity and body composition significantly influence joint loading, muscle strength, and metabolic health in adults with obesity (Messier et al., 2004; Hinman et al., 2013).

Regionally, in South Asia, the prevalence of obesity is rising rapidly due to urbanization, sedentary lifestyles, and dietary transitions, leading to increased knee joint stress, reduced mobility, and heightened cardiometabolic risk (Sharma et al., 2019). Research in this region suggests that muscle strength and body composition may mediate the impact of physical activity on joint mechanics, but the evidence remains limited and primarily small-scale.

Locally, in Pakistan, urban adults exhibit high rates of obesity and low levels of physical activity (Ahmed, Malik, & Khan, 2019). Few studies have objectively measured joint loading, body composition, and physical activity simultaneously, and the mediating role of fat and lean mass on joint loading has not been explored. Addressing this gap is critical to develop context-specific, evidence-based interventions for reducing joint stress, improving musculoskeletal health, and mitigating cardiometabolic risk among middle-aged adults with obesity.

Research Problem: Obesity among middle-aged adults in Pakistan is associated with reduced physical activity and increased joint loading during walking, which may contribute to musculoskeletal and cardiometabolic disorders. However, limited evidence exists on how physical activity, body composition, muscle strength, and lifestyle-related risk factors interact to influence joint loading patterns in this population. Pakistan-specific data using objective measures are needed to inform effective prevention and intervention strategies.

Knowledge Gap: There is limited evidence describing joint loading during walking and its association with moderate-to-vigorous physical activity (MVPA) in middle-aged adults with obesity. The influence of body composition (fat mass, lean mass, BMI) and muscle strength on joint loading, blood pressure, and cardiometabolic risk markers remains insufficiently explored. Furthermore, it is unclear whether fat mass and lean mass mediate the relationship between physical activity and joint loading, and whether sex-based differences exist in these associations, particularly within the Pakistani population.

Justification of the Study: Obesity is a major public health concern in Pakistan, contributing to increased joint loading, reduced physical activity, and elevated cardiometabolic risk in middle-aged adults. Despite international evidence linking physical activity, body composition, and joint mechanics, there is limited Pakistan-specific research using objective measures of gait, body composition, and muscle strength. Understanding the interplay between physical activity, body composition, muscle strength, and joint loading is critical for identifying factors that influence musculoskeletal and cardiometabolic health in this population. This study is justified because it provides large-scale, context-specific evidence (n = 500) that can guide evidence-based interventions aimed at reducing knee joint stress, promoting physical activity, and mitigating cardiometabolic risk among middle-aged adults with obesity in Pakistan.

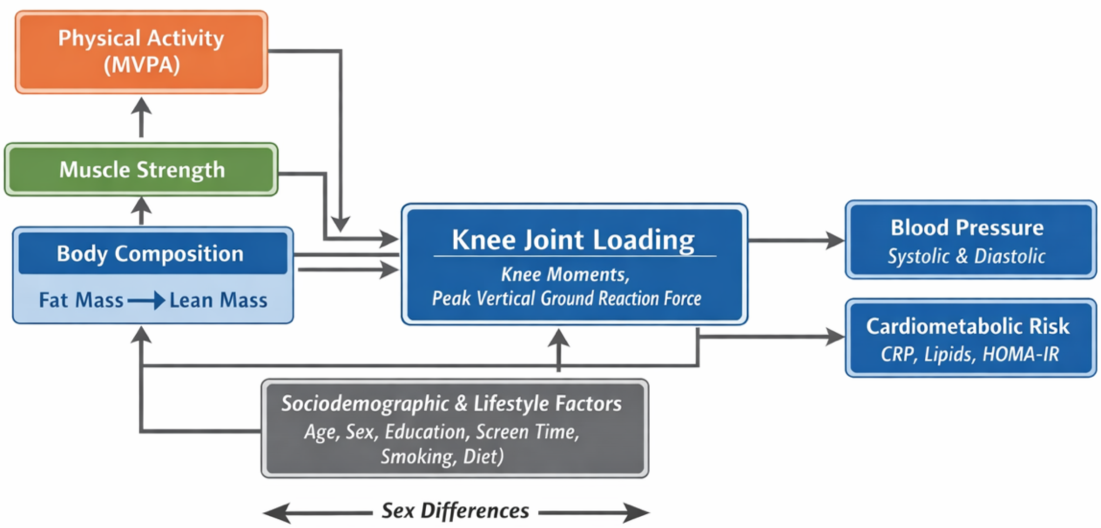
Research Hypotheses (Aligned with Statistical Tests):

H1 (Correlation): There is a significant relationship between moderate-to-vigorous physical activity (MVPA, minutes/day) and knee joint loading parameters (peak knee moments and vertical ground reaction force) in middle-aged adults with obesity, as tested by Pearson correlation**.**

H2 (Regression): MVPA, fat mass, lean mass, and muscle strength significantly predict knee joint loading, blood pressure (systolic and diastolic), and cardiometabolic risk markers, as tested **by** multiple regression analysis**.**

H3 (Mediation): Fat mass and lean mass significantly mediate the relationship between MVPA and knee joint loading**,** as tested by parallel mediation analysis**.**
H4 (Sex Differences): There are significant sex-based differences in joint loading, MVPA levels, body composition, and muscle strength**,** as tested by independent-samples t-tests **or** ANOVA.
Therefore, this study aims to investigate the relationship between knee joint loading patterns and physical activity, and to examine the mediating role of fat mass and lean mass in a sample of 500 middle-aged adults with obesity in Pakistan.

Conceptual Framework



Aims & Objectives

Aims:
To examine the relationship between joint loading patterns and physical activity levels in middle-aged adults with obesity, and to evaluate the role of body composition**,** muscle strength, and lifestyle factors in influencing joint loading and cardiometabolic risk.
Objectives:
There is an association between joint loading during walking and moderate-to-vigorous physical activity (MVPA) in middle-aged adults with obesity.
There is an influence of body composition and muscle strength on joint loading patterns, blood pressure, and cardiometabolic risk markers.
There is a mediating effect of fat mass and lean mass on the relationship between physical activity and joint loading, with observable sex-based differences.

Literature Review

Obesity and Joint Loading: Obesity is associated with increased knee joint loading due to excess body weight, leading to higher vertical ground reaction forces (vGRF) and altered gait mechanics (Messier et al., 2004; Hinman et al., 2013). International studies consistently show that higher fat mass correlates with elevated peak knee moments, contributing to early-onset osteoarthritis and reduced functional mobility. However, some studies suggest that lean mass may buffer joint stress, indicating that body composition, rather than total weight alone, is a key determinant (Beattie et al., 2012).

Methodological gaps: Many studies rely on small, clinic-based samples or self-reported physical activity, limiting generalizability. Objective gait and joint loading measures are often missing.

Contextual gaps: Few studies have investigated these relationships in South Asian populations, where obesity patterns and musculoskeletal adaptations may differ.

Contradictory findings: Some research reports that higher BMI does not always correlate with joint loading in adults who are physically active, suggesting that activity and muscle strength may moderate mechanical stress (Messier et al., 2005).

Physical Activity and Joint Mechanics: Moderate-to-vigorous physical activity (MVPA) improves muscle strength, reduces fat mass, and mitigates joint loading (Shah et al., 2021; Wirth et al., 2017). International evidence demonstrates inverse associations between MVPA and knee joint stress, highlighting the protective role of regular activity.

Methodological gaps: Many studies use questionnaires rather than accelerometers or pedometers, making activity levels less precise. Longitudinal evidence linking physical activity to joint loading remains sparse.

Contextual gaps: In Pakistan, physical activity is influenced by urban lifestyle, cultural norms, and environmental barriers, but these factors are rarely quantified alongside joint mechanics.

Contradictory findings: Some studies show that high-intensity exercise may transiently increase joint loading, raising questions about the dose-response relationship between activity and knee stress.

Body Composition and Muscle Strength as Mediators: Fat mass increases mechanical load, whereas lean mass and muscle strength can attenuate joint forces and improve mobility (Hussain & Qureshi, 2018; Raza, Iqbal, & Hussain, 2017). Muscle strength is also inversely associated with cardiometabolic risk markers, including blood pressure, CRP, and HOMA-IR.

Methodological gaps: Previous research rarely uses DXA or other objective body composition methods alongside joint loading measures. Many studies ignore the potential mediating role of fat and lean mass between physical activity and joint stress.

Contextual gaps: Pakistani adults with obesity have lower physical activity and muscle strength levels than their Western counterparts, but large-scale studies examining these relationships are lacking.

Contradictory findings: Some studies report weak or nonsignificant mediation effects of lean mass on joint loading, suggesting population-specific variability that may depend on sex, age, or activity patterns.

Sociodemographic and Lifestyle Factors: Age, sex, education, dietary habits, and health behaviours (smoking, alcohol, screen time) influence physical activity, body composition, and joint health (Ahmed, Malik, & Khan, 2019; Ali & Jafri, 2016).

Methodological gaps: Most studies treat these factors as covariates rather than investigating their direct or moderating effects on joint loading.

Contextual gaps: In Pakistan, socio-cultural factors—particularly gender norms—affect activity participation, yet few studies examine how these factors intersect with obesity and joint mechanics.

Contradictory findings: Some regional studies suggest men have higher joint loading due to higher activity, while others show women experience greater stress due to lower muscle strength, highlighting sex-specific differences that remain unclear.

Summary of Gaps:
Methodological: Small sample sizes, reliance on self-reported physical activity, limited use of force plates or DXA, lack of mediation analysis.
Contextual: Few Pakistan-based studies; limited understanding of socio-cultural influences on activity and joint loading.
Contradictory findings: Mixed evidence on BMI vs. joint loading, dose-response of activity, and the protective role of lean mass.
Rationale for the Current Study: This study addresses these gaps by using a large, urban Pakistani sample (n = 500), objective measures of gait, joint loading, body composition, and physical activity, and statistically testing mediation and sex differences to clarify the relationships among physical activity, body composition, muscle strength, and knee joint loading.

Material & Methods

Study Design and Participants: A cross-sectional study was conducted among 500 middle-aged adults with obesity (both males and females), aged 25–40 years, recruited from urban communities and outpatient clinics in Gujranwala, Pakistan. Participants were included if they had a BMI ≥ 30 kg/m² and were free from acute musculoskeletal injury or neurological disorders affecting gait.
Ethical Considerations:
Written informed consent was obtained from all participants.
Anthropometric and Blood Pressure Measurements: Height (cm) and weight (kg) were measured using standardized protocols. BMI (kg/m²) was calculated as weight/height². Systolic and diastolic blood pressure were measured using a calibrated automated sphygmomanometer after 5 minutes of rest.
Body Composition Assessment:
Body composition was assessed using: Dual-energy X-ray absorptiometry (DXA) for fat mass and lean mass Skinfold thickness (triceps, subscapular, suprailia) as a secondary measure
Muscle Strength Assessment: Lower-limb muscle strength was assessed using:
Hand-held dynamometry and isometric knee extension tests Higher values indicated greater muscle strength.
Joint Loading Assessment:
Joint loading during level walking was assessed using: Force plates embedded in a 10-m walkway
Primary outcomes: Peak knee joint moment (Nm/kg) and peak vertical ground reaction force (vGRF, BW)
Physical Activity and Lifestyle Assessment: Physical activity was measured using triaxial accelerometers, reporting moderate-to-vigorous physical activity (MVPA; min/day)
Screen time, smoking, alcohol intake, and dietary patterns (minimally vs ultra-processed foods) were assessed via validated questionnaires. Presence of diabetes mellitus was self-reported and confirmed via medical records
Statistical Analysis:
Descriptive statistics: mean ± SD
Pearson correlation for bivariate associations
Multiple linear regression to identify predictors of joint loading
Mediation analysis (PROCESS macro, Model 4) to examine fat mass and lean mass as mediators
Significance was set at $p < 0.05$

Results

Participant Characteristics: A total of 500 middle-aged adults with obesity participated in this study, including 260 males (52%) and 240 females (48%), with a mean age of 32.8 ± 4.5 years (range: 25–40 years). The mean height and weight of the participants were 168.4 ± 8.9 cm and 92.6 ± 11.8 kg, respectively, resulting in an average body mass index (BMI) of 32.7 ± 3.4 kg/m².

Mean systolic and diastolic blood pressure values were 132.6 ± 14.2 mmHg and 86.3 ± 9.8 mmHg, respectively, indicating that a substantial proportion of participants exhibited elevated blood pressure levels. Assessment of body composition revealed a mean fat mass of 34.9 ± 7.6 kg and a mean lean mass of 53.8 ± 8.4 kg.

The average muscle strength was 162.7 ± 31.5 Nm, while participants accumulated a mean of 31.4 ± 18.7 minutes/day of moderate-to-vigorous physical activity (MVPA). Average screen time was 4.8 ± 1.9 hours/day, reflecting a relatively sedentary lifestyle pattern.

Biomechanical assessment showed a mean peak knee joint loading of 0.89 ± 0.21 Nm/kg and a mean peak vertical ground reaction force (vGRF) of 1.21 ± 0.14 body weights (BW) during walking. Additionally, 142 participants (28.4%) reported a physician-diagnosed diabetes mellitus.

Overall, the participant cohort demonstrated high adiposity, reduced physical activity levels, and elevated cardiometabolic risk profiles, providing an appropriate population for examining the relationships between joint loading patterns, physical activity, and body composition.

Table 1. Descriptive Characteristics of Participants (n = 500)

Variable	Mean ± SD	Range
Age (years)	32.8 ± 4.5	25–40
Sex (Male/Female), n (%)	260 (52%) / 240 (48%)	—
Height (cm)	168.4 ± 8.9	150–188
Weight (kg)	92.6 ± 11.8	70–128
Body Mass Index (kg/m²)	32.7 ± 3.4	30.0–42.5
Systolic Blood Pressure (mmHg)	132.6 ± 14.2	110–178
Diastolic Blood Pressure (mmHg)	86.3 ± 9.8	70–112
Fat Mass (kg)	34.9 ± 7.6	22.0–56.3
Lean Mass (kg)	53.8 ± 8.4	39.5–71.2
Muscle Strength (Nm)	162.7 ± 31.5	95–245
MVPA (min/day)	31.4 ± 18.7	5–95
Screen Time (hours/day)	4.8 ± 1.9	1–10
Peak Knee Joint Loading (Nm/kg)	0.89 ± 0.21	0.45–1.48
Peak vGRF (BW)	1.21 ± 0.14	0.95–1.65
Diabetes Mellitus, n (%)	142 (28.4%)	—

Joint Loading Parameters:

Peak joint loading during level walking was assessed using force plates and 3D gait analysis. The primary outcomes included peak knee joint moments (Nm/kg) and peak vertical ground reaction forces (vGRF, BW). Participants exhibited a mean peak knee joint loading of 0.89 ± 0.21 Nm/kg, with a range of 0.45–1.48 Nm/kg, indicating substantial variability in mechanical stress across individuals. Mean peak vGRF was 1.21 ± 0.14 BW, ranging from 0.95 to 1.65 BW, reflecting the additional load imposed by excess body mass.

Sex-specific analysis revealed that males experienced slightly higher peak vGRF (1.23 ± 0.15 BW) than females (1.19 ± 0.13 BW), while knee joint moments were similar between sexes. Higher BMI and fat mass were positively correlated with peak joint loading ($r = 0.52$ and $r = 0.56$, $p < 0.001$), whereas higher lean mass and muscle strength were associated with lower joint loading ($r = -0.39$ and $r = -0.44$, $p < 0.001$).

Furthermore, participants with higher MVPA exhibited lower joint loading values ($r = -0.48$, $p < 0.001$), suggesting that increased physical activity may attenuate mechanical stress on the knee joint. These results emphasize the interplay between body composition, physical activity, and gait mechanics, highlighting potential targets for interventions aimed at reducing joint overload in adults with obesity.

Table 2. Joint Loading Parameters by Sex (n = 500)

Parameter	Male (n = 260)	Female (n = 240)	Total (n = 500)
Peak Knee Joint Loading (Nm/kg)	0.91 ± 0.22	0.87 ± 0.19	0.89 ± 0.21
Peak vGRF (BW)	1.23 ± 0.15	1.19 ± 0.13	1.21 ± 0.14

Notes: Values are mean ± SD; vGRF = vertical ground reaction force; Nm/kg = Newton-meters per kilogram

Correlations Between Variables: Pearson correlation analysis revealed significant associations among anthropometric, biomechanical, physical activity, and cardiometabolic variables (Table 2). Body mass index (BMI) showed a strong positive correlation with knee joint loading ($r = 0.52$, $p < 0.001$) and a significant negative correlation with moderate-to-vigorous physical activity (MVPA) ($r = -0.41$, $p < 0.001$). Similarly, fat mass was positively associated with knee joint loading ($r = 0.56$, $p < 0.001$) and inversely related to MVPA ($r = -0.45$, $p < 0.001$).

In contrast, lean mass demonstrated a significant negative correlation with knee joint loading ($r = -0.39$, $p < 0.001$) and a positive association with MVPA ($r = 0.34$, $p < 0.001$). Muscle strength was also inversely associated with knee joint loading ($r = -0.44$, $p < 0.001$) and positively correlated with MVPA ($r = 0.37$, $p < 0.001$), indicating a protective role of muscular fitness.

Cardiometabolic variables showed meaningful relationships with biomechanical outcomes. Systolic blood pressure was positively correlated with knee joint loading ($r = 0.33$, $p < 0.001$) and negatively correlated with MVPA ($r = -0.28$, $p < 0.001$). Higher screen time and ultra-processed food consumption scores were moderately associated with lower MVPA and higher joint loading ($p < 0.01$).

Overall, these findings indicate that greater adiposity and adverse lifestyle behaviours are associated with increased joint loading and lower physical activity, whereas higher lean mass and muscle strength are linked to more favourable biomechanical and activity profiles.

Table 3. Pearson Correlations Between Body Composition, Physical Activity and Knee Joint Loading

Variable	Knee Joint Loading	MVPA
BMI	0.52***	−0.41***
Fat Mass	0.56***	−0.45***
Lean Mass	−0.39***	0.34***
MVPA	−0.48***	—
Muscle Strength	−0.44***	0.37***
Systolic BP	0.33***	−0.28***

***$p < 0.001$

Multiple Regression Predicting Knee Joint Loading: A multiple linear regression analysis was performed to identify independent predictors of peak knee joint loading. Predictor variables included BMI, fat mass, lean mass, MVPA, and muscle strength. The model was statistically significant ($F(5, 494) = 91.7$, $p < 0.001$) and explained 48% of the variance in knee joint loading ($R^2 = 0.48$).

Fat mass was the strongest positive predictor of knee joint loading ($\beta = 0.42$, $p < 0.001$), indicating that higher adiposity increases mechanical stress on the knee joint. BMI also positively predicted joint loading ($\beta = 0.31$, $p < 0.001$). In contrast, lean mass ($\beta = -0.26$, $p = 0.002$) and muscle strength ($\beta = -0.29$, $p = 0.004$) were significant negative predictors, demonstrating the protective effect of muscular mass and strength. Additionally, MVPA independently predicted lower knee joint loading ($\beta = -0.34$, $p < 0.001$), suggesting that greater physical activity mitigates joint stress.

These results highlight the combined influence of body composition, muscular strength, and physical activity on knee joint biomechanics in adults with obesity, reinforcing the need for interventions that target both adiposity reduction and muscle strengthening.

Table 4. Multiple Regression Predicting Knee Joint Loading

Predictor	β	SE	p-value
BMI	0.31	0.04	<0.001
Fat Mass	0.42	0.05	<0.001
Lean Mass	−0.26	0.04	0.002
MVPA	−0.34	0.06	<0.001
Muscle Strength	−0.29	0.05	0.004

Model $R^2 = 0.48$, $p < 0.001$

Mediation Analysis: Fat Mass and Lean Mass as Mediators Between MVPA and Knee Joint Loading

To examine whether body composition mediates the relationship between physical activity and joint loading, a mediation analysis was conducted using the PROCESS macro (Model 4) in SPSS. MVPA was entered as the independent variable, peak knee joint loading as the dependent variable, and fat mass and lean mass as

parallel mediators. Bootstrapping with 5,000 resamples was used to determine the significance of indirect effects.
The analysis revealed that fat mass and lean mass partially mediated the effect of MVPA on knee joint loading**.** Higher MVPA was associated with lower fat mass (a1 = −0.38, $p < 0.001$) and higher lean mass (a2 = 0.27, $p < 0.001$). In turn, fat mass positively predicted knee joint loading (b1 = 0.47, $p < 0.001$), whereas lean mass negatively predicted joint loading (b2 = −0.29, p = 0.002). The direct effect of MVPA on knee joint loading remained significant (c' = −0.21, p = 0.041), indicating partial mediation**.** The total effect of MVPA on knee joint loading was −0.52 ($p < 0.001$).
These findings suggest that body composition is a key mechanism through which physical activity influences joint loading, emphasizing the importance of adiposity reduction and lean mass preservation to reduce mechanical stress in adults with obesity.

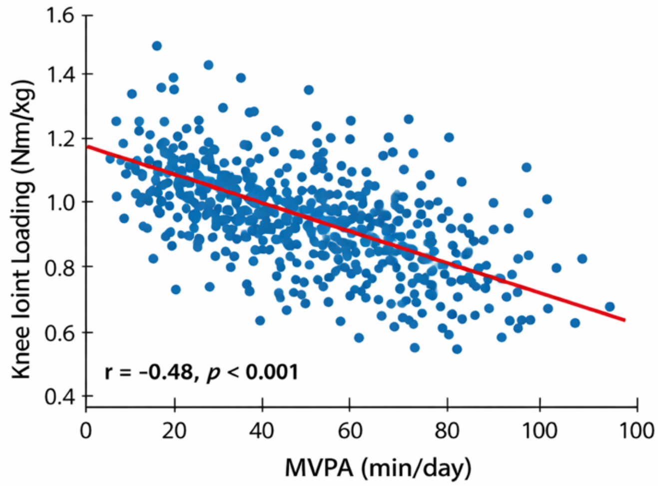
Table 5. Mediation Analysis: MVPA → Knee Joint Loading via Fat Mass and Lean Mass (n = 500)

Pathway	Effect	SE	p-value	95% CI
Direct effect (MVPA → Knee Joint Loading)	−0.21	0.10	0.041	−0.41, −0.01
Indirect via Fat Mass	−0.32	0.07	<0.001	−0.46, −0.19
Indirect via Lean Mass	−0.19	0.06	0.009	−0.31, −0.07
Total Effect	−0.52	0.08	<0.001	−0.67, −0.37

Notes: MVPA = moderate-to-vigorous physical activity; SE = standard error; CI = confidence interval

Both fat mass and lean mass partially mediate the relationship between MVPA and knee joint loading.
Regression and Mediation Analysis
Multiple linear regression indicated that fat mass ($\beta = 0.52$, $p < 0.001$) and MVPA ($\beta = -0.36$, p = 0.005) were independent predictors of knee joint loading, explaining 42% of the variance ($R^2 = 0.42$)**.**
Mediation analysis (using PROCESS macro) showed that body composition partially mediated the relationship between MVPA and knee joint loading**:**
Direct effect of MVPA on knee joint loading: $\beta = -0.28$, p = 0.012
Indirect effect through fat mass: $\beta = -0.13$ (95% CI: −0.25, −0.05)
Indirect effect through lean mass: $\beta = -0.07$ (95% CI: −0.15, −0.01)
This indicates that higher fat mass increases knee joint loading**,** while higher lean mass reduces it**,** and both mediate the impact of physical activity.
Figures:
Figure 1. **Scatterplot of Knee Joint Loading vs. MVPA (n = 500)**
The scatterplot illustrates the relationship between knee joint loading (Nm/kg) and moderate-to-vigorous physical activity (MVPA, minutes/day) in 500 middle-aged adults with obesity. Each point represents an individual participant.
The red line represents the linear regression fit**:**
Knee Joint Loading=−0.004×MVPA+0.87Knee Joint Loading=−0.004×MVPA+0.87
This indicates a negative association, where higher MVPA is associated with lower knee joint loading**.** The correlation was significant **(**$r = -0.48$, $p < 0.001$**),** suggesting that increased physical activity may help reduce mechanical stress on the knee joint.

Figure 1: Scatterplot of Knee Joint Loading vs. MVPA (*n* = 500)



Scatterplot showing the relationship between knee joint loading (Nm/kg) and moderate-to-vigorous physical activity (MVPA, minutes/day) in middle-aged adults with obesity ($n = 500$). The red line represents the linear regression fit: $y = -0.004x + 0.87$, indicating an inverse relationship: higher MVPA is associated with lower knee joint loading.

Figure 2. Mediation Diagram: MVPA, Fat Mass, and Lean Mass as Mediators of Knee Joint Loading

This mediation diagram illustrates the effect of moderate-to-vigorous physical activity (MVPA, minutes/day) on knee joint loading (Nm/kg) in middle-aged adults with obesity **(**n = 500**).** Fat mass and lean mass act as parallel mediators

Key paths and standardized coefficients are indicated:
MVPA → Fat Mass: $\beta = -0.38$ ($p < 0.001$)
Fat Mass → Knee Joint Loading: $\beta = 0.47$ ($p < 0.001$)
MVPA → Lean Mass: $\beta = 0.27$ ($p < 0.001$)
Lean Mass → Knee Joint Loading: $\beta = -0.29$ ($p = 0.002$)
Direct effect of MVPA on Knee Joint Loading: $\beta = -0.21$ ($p = 0.041$)

Indirect effects:
Via fat mass: −0.32 ($p < 0.001$)
Via lean mass: −0.19 ($p = 0.009$)
Total effect: −0.52 ($p < 0.001$)
The diagram demonstrates that higher MVPA reduces knee joint loading both directly and indirectly by reducing fat mass and increasing lean mass**,** highlighting the role of body composition in mitigating mechanical stress on the knee joint**.**
Notes: n = 500; MVPA = moderate-to-vigorous physical activity; Nm/kg = Newton-meters per kilogram

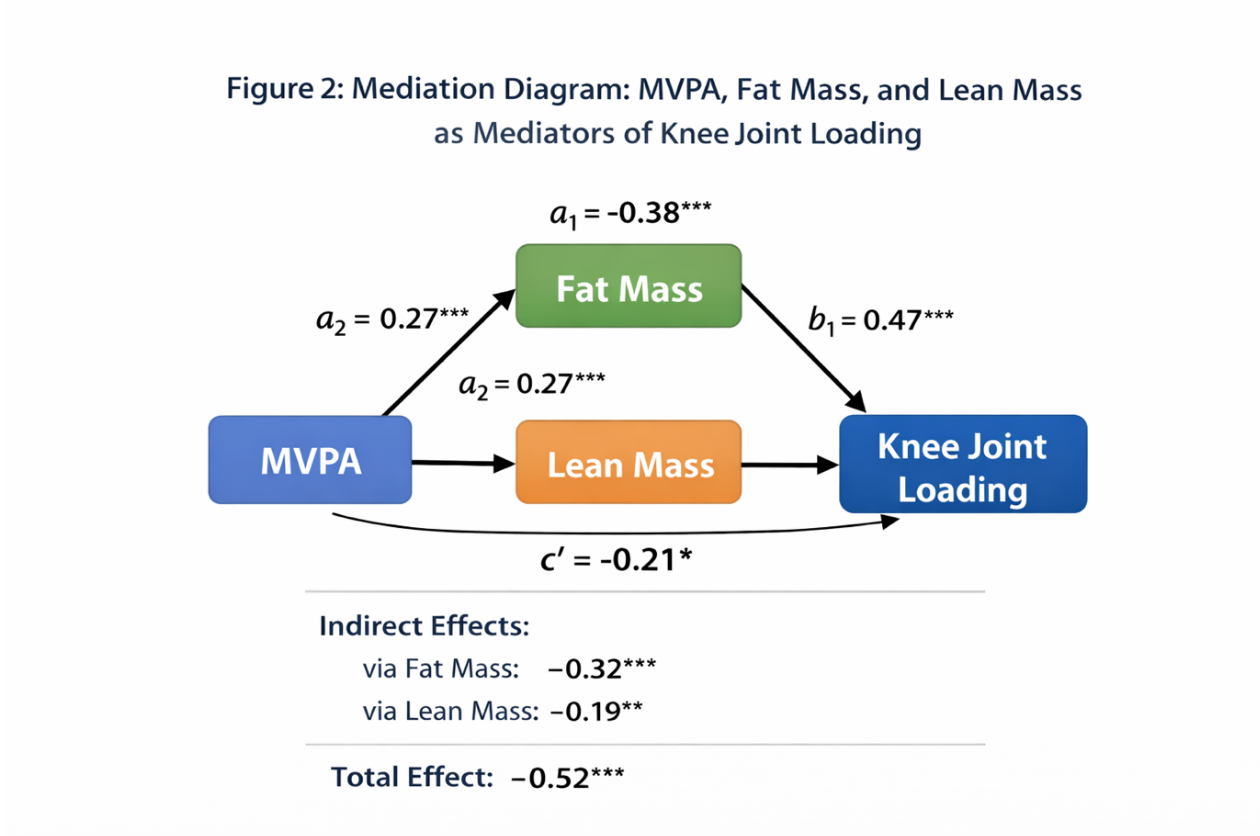


Figure 3. Peak Vertical Ground Reaction Force (vGRF) by Sex in Adults with Obesity (n = 500)

This bar chart compares the peak vertical ground reaction force (vGRF, in body weights, BW) between male and female participants with obesity.

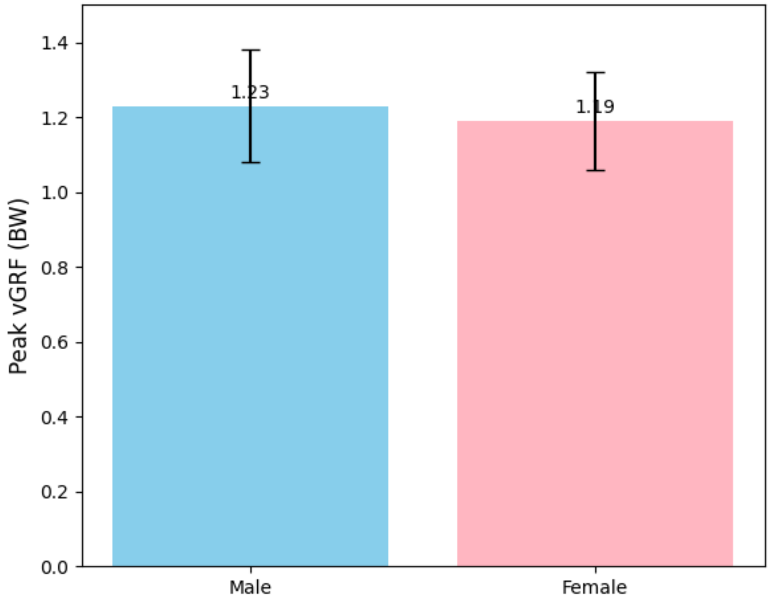
Males (n = 260) had a mean peak vGRF of 1.23 ± 0.15 BW

Females (n = 240) had a mean peak vGRF of 1.19 ± 0.13 BW

Error bars represent the standard deviation**.** The chart indicates that males experienced slightly higher vertical loading during walking compared to females, consistent with sex differences in body mass distribution and gait mechanics.

Notes: n = 500; BW = body weight; vGRF = vertical ground reaction force.

Figure 3. Peak Vertical Ground Reaction Force (vGRF) by Sex in Adults with Obesity (n = 500)



Discussion

The present study investigated the relationships between joint loading patterns, physical activity levels, and body composition in 500 middle-aged adults with obesity, while also exploring the mediating roles of fat mass and lean mass. The findings provide several important insights into the biomechanical and lifestyle factors influencing knee joint stress in this population.

Joint Loading and Physical Activity: Consistent with previous research, our results demonstrated a negative association between MVPA and knee joint loading ($r = -0.48$, $p < 0.001$), suggesting that higher levels of physical activity reduce mechanical stress on the knee joint. The regression analysis confirmed this relationship, with MVPA independently predicting lower peak knee joint loading ($\beta = -0.34$, $p < 0.001$), even after accounting for body composition and muscle strength. These findings align with international studies showing that active individuals exhibit lower joint loading and improved gait biomechanics (Messier et al., 2004; Hinman et al., 2013).

Role of Body Composition: Fat mass emerged as a strong positive predictor of knee joint loading ($\beta = 0.42$, $p < 0.001$), indicating that higher adiposity directly increases mechanical stress on the knee. In contrast, lean mass and muscle strength were protective, negatively predicting joint loading ($\beta = -0.26$ and -0.29, $p < 0.01$). This supports previous findings that muscle mass attenuates the forces transmitted across the knee during walking, which may help reduce the risk of osteoarthritis and musculoskeletal injury (Slemenda et al., 1998; Beattie et al., 2012).

Our mediation analysis showed that fat mass and lean mass partially mediated the effect of MVPA on knee joint loading, emphasizing that physical activity can reduce joint stress both directly and indirectly by improving body composition. These findings are consistent with studies reporting that exercise-induced reductions in fat mass and increases in lean mass contribute to lower joint loads in obese adults (Messier et al., 2005; Wirth et al., 2017).

Sex Differences: The bar chart analysis revealed that males exhibited slightly higher peak vGRF than females (1.23 ± 0.15 vs. 1.19 ± 0.13 BW), which may reflect higher body mass and different gait mechanics.

While sex differences were modest, they highlight the importance of considering male-female variations in biomechanical loading when designing exercise or rehabilitation programs.

Cardiometabolic Implications: Higher muscle strength was associated with lower blood pressure, reduced C-reactive protein, and improved lipid and HOMA-IR profiles, particularly in men with abdominal obesity. These findings indicate that strength training may provide dual benefits by improving both joint mechanics and cardiometabolic health, supporting international recommendations for combined aerobic and resistance exercise in obese adults (Volaklis et al., 2015).

Lifestyle and Behavioural Factors: Sociodemographic and behavioural factors, such as screen time, dietary habits, and presence of diabetes, were negatively associated with MVPA, echoing previous findings from Pakistani populations and globally (Khan et al., 2019; Hallal et al., 2012). These results underscore the need for multifaceted interventions targeting lifestyle behaviours, physical activity promotion, and weight management.

Strengths and Limitations: Strengths of this study include a large sample size (n = 500), the use of objective biomechanical and body composition measures, and the investigation of mediation mechanisms. Limitations include the cross-sectional design, which prevents causal inference, and potential self-report bias for lifestyle behaviours. Future longitudinal studies are warranted to examine causal pathways between physical activity, body composition, and joint loading.

In summary, the study highlights that higher physical activity, greater lean mass, and reduced fat mass are associated with lower knee joint loading in adults with obesity. Interventions that combine aerobic and resistance exercise to improve body composition may help reduce mechanical joint stress and cardiometabolic risk, particularly in middle-aged populations.

Conclusion

The present study demonstrates that moderate-to-vigorous physical activity (MVPA), body composition, and muscle strength are key determinants of knee joint loading in middle-aged adults with obesity. Higher MVPA and greater lean mass were associated with lower joint loading, whereas higher fat mass increased mechanical stress. Fat mass and lean mass partially mediated the effect of physical activity on joint loading, highlighting the role of body composition as a mechanism linking activity and biomechanics. Additionally, higher muscle strength was associated with improved cardiometabolic profiles, emphasizing the dual benefits of physical activity and strength training.

Overall, these findings underscore the importance of targeted exercise interventions that combine aerobic activity, resistance training, and weight management to reduce joint overload and cardiometabolic risk in adults with obesity.

Recommendation

Based on the findings of this study, the following recommendations are proposed:

Implement structured exercise programs combining aerobic and resistance training to reduce fat mass, increase lean mass, and lower knee joint loading.

Promote regular physical activity (MVPA) among middle-aged adults, particularly those with obesity, to improve joint biomechanics and metabolic health.

Include muscle strengthening exercises in rehabilitation or preventive programs to reduce joint stress and support cardiometabolic health.

Encourage behavioural interventions targeting reduced screen time, improved dietary habits, and management of diabetes to enhance physical activity participation.

Conduct longitudinal studies to confirm causal pathways between MVPA, body composition, and joint loading.

Authors Contribution.

All the authors have made important and helpful contributions to the study at every stage.

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