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Review Paper

Biomechanical Characteristics of Non-steady -state and Transitional Movements in Obese Populations: A Systematic Review of Lower Extremity Mechanics

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ABSTRACT

Background: Obesity alters lower-extremity mechanics, increasing the risk of joint degeneration. While steady-state gait is well-documented, everyday transitional tasks are biomechanically demanding and under-synthesized in adults with obesity.

Objectives: This systematic review aimed to evaluate lower-extremity kinematics, kinetics, and postural stability during non-steady-state movements in this population.

Methods: Following preferred reporting items for systematic reviews and meta-analyses (PRISMA) and synthesis without meta-analysis guidelines (International Prospective Register of Systematic Reviews [PROSPERO]: CRD420261473990), PubMed, Scopus, and Web of Science were systematically searched up to June 2026. Eligible studies assessed biomechanical outcomes during sit-to-stand (STS) transfers, stair negotiation, gait initiation (GI), and obstacle crossing in overweight or obese adults compared to normal-weight (NW) controls. Methodological quality was evaluated using the modified Downs and Black checklist.

Results: Thirty-eight studies comprising 1,366 participants were included. During STS transfers, individuals with obesity exhibited restricted trunk flexion, which doubled absolute peak knee extension moments compared to controls (e.g. 0.74 vs 0.31 Nm/kg, $P<0.05$). GI and obstacle navigation revealed significant lateral postural vulnerability, characterized by wider mediolateral center-of-pressure excursions ($P=0.008$) and reduced anteroposterior stability ($P=0.008$), which significantly deteriorated under cognitive dual-tasking ($P=0.001$). During stair negotiation and high-impact locomotion, body-mass-normalized joint moments were frequently comparable to NW peers; however, absolute non-normalized forces were severely elevated (e.g. absolute knee extension moments reaching 145 Nm during ascent, $P<0.001$). To compensate, a "straighter knee" strategy was frequently adopted in early stance ($P<0.05$). Furthermore, disproportionate peak pressures under the midfoot (up to a 7.7-fold increase, $P<0.01$) indicated dynamic arch collapse.

Conclusion: Obesity necessitates fundamental neuromotor reorganization during transitional tasks. While compensatory strategies preserve immediate dynamic balance, they inadvertently concentrate destructive absolute mechanical overload on the distal joints, elevating the risk of osteoarthritis. Effective management requires multidisciplinary approaches combining weight reduction, targeted exercise, and biomechanical interventions.

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Introduction

Obesity imposes a substantial biomechanical load on the musculoskeletal system, which impairs physical functioning and limits daily activities [1]. This elevated body mass is associated with an increased risk of developing musculoskeletal disorders, particularly affecting the weight-bearing joints of the lower limbs and feet [2]. Chronic overloading of the skeleton during daily locomotion is explained by the added stress that excess weight places on the joints, which increases the rate of cartilage degeneration [3]. Altered lower-extremity mechanics and increased joint loading acting on weight-bearing joints contribute to the onset and progression of osteoarthritis [4]. Specifically, this pathomechanics involves a combination of increased absolute joint loading and altered lower-extremity movement patterns rather than elevated mass alone [5]. These altered biomechanics shift the contact position of the articular cartilage in weight-bearing joints toward infrequently loaded regions that cannot adapt to altered loading, which initiates cartilage degeneration prior to radiographic signs of osteoarthritis [5]. Long-term epidemiological evidence shows that a higher body mass index (BMI) is associated with progressive cartilage loss, joint space narrowing, and bilateral knee osteoarthritis, with mechanical pathogenesis acting as a primary driver [6, 7].

Biomechanical research on adult obesity has historically focused on steady-state overground walking at preferred or standardized walking speeds [8, 9]. However, everyday locomotion requires individuals to perform complex, non-steady-state, and transitional motor tasks [5]. These daily activities include rising from a chair, ascending and descending stairs, gait initiation (GI), and stepping over obstacles [10-12]. Rising from a chair is a highly frequent daily task, with adults executing the sit-to-stand (STS) movement 60-90 times per day on average [1, 12]. Stair negotiation represents another essential daily locomotion that is challenging because it has high demands on the musculoskeletal system to overcome or control gravity [4]. Similarly, the transition from static quiet standing to dynamic walking, known as GI, represents a common transient phase that is often associated with falls [11]. Obstacle crossing is another non-steady-state task that alters environmental constraints and requires rapid biomechanical adjustments [13].

Non-steady-state and transitional tasks are physically demanding for overweight and obese individuals because they require transferring or raising a larger body mass against gravity [2, 4]. During STS transition, obese individuals adopt an altered coordination strategy characterized by limited forward trunk flexion and backward movement of the feet [6, 14]. This strategy limits the torque at the hip joint but doubles the knee joint moment compared to normal-weight (NW) individuals, which creates a severe overload condition at the knee [2, 6]. Electromyographic measurements show that this movement is accompanied by altered muscle activation patterns, including higher tibialis anterior activity to stabilize the foot and increased quadriceps activity [15, 16]. Stair climbing is also highly demanding, requiring a greater joint range of motion, moments, forces, and power than level walking [8]. Individuals with obesity adjust to these demands by adopting slower walking velocities, longer stance phases, and larger absolute knee extension moments than lean individuals [8, 17]. Postural balance is compromised during these transitions because a higher center of mass shifts further from the base of support, requiring greater muscular stabilization [18]. During GI, individuals with obesity require longer bipedal standing phases and exhibit larger lateral center of pressure (COP) excursion and velocity during the unloading phase [11, 19]. When crossing obstacles, obese individuals show less efficient spatiotemporal parameters, including reduced step velocity, shorter single-limb support, and significantly longer double-limb support time to preserve equilibrium [13].

Despite the functional significance of these transitional movements, existing literature reviews have predominantly focused on pediatric and adolescent cohorts [1, 20]. Biomechanical findings from children and adolescents living with obesity cannot be directly translated to adult populations because of age-related differences in muscle strength, joint alignment, and joint degeneration [4, 17, 20]. Reviews that address adult populations often restrict their scope to steady-state level walking or include individuals with pre-existing joint pathology, which confounds the baseline effects of obesity on healthy joints [5]. Consequently, our understanding of lower-extremity kinematics and kinetics across various non-steady-state tasks in healthy adults remains fragmented [2, 4]. Although primary research studies on transitional tasks have recently emerged, the reported lower limb joint angles, moments, spatiotemporal adaptations, and postural stability parameters have not been systematically synthesized [4, 17].

Objectives

This systematic review aimed to synthesize lower-extremity kinematics, kinetics, and postural stability of obese adults across transitional movements, as these motor tasks represent the primary biomechanical challenges in daily activities [2, 5]. Specifically, this review evaluates how excess body mass alters movement coordination and joint loading during STS transitions, stair negotiation, GI, and obstacle crossing [4, 10-12]. We sought to answer the following specific research question: How do overweight and obesity in adults alter lower extremity joint angles, moments, powers, muscle activations, spatiotemporal parameters, and COP dynamics during STS transitions, stair negotiation, GI, and obstacle crossing compared to NW peers?

Materials and Methods

Study design and protocol registration

This systematic review was conducted and reported in strict accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) 2020 guidelines [21]. The review protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD420261473990. Given the anticipated methodological and statistical heterogeneity among the included studies, a quantitative meta-analysis was not feasible; thus, the results were narratively synthesized following the synthesis without meta-analysis reporting guidelines [22].

Eligibility criteria

The eligibility criteria for study inclusion were formulated based on the population, intervention/exposure, comparison, outcomes, study design framework. Eligible studies included healthy adults (≥18 years of age) classified as overweight or obese based on their BMI or body mass percentage. Studies involving pediatric populations, adolescents, or individuals with severe neurological disorders (e.g. stroke, Parkinson's disease, cerebral palsy), recent orthopedic surgeries, or severe lower-extremity trauma were strictly excluded. For the exposure and movement task criteria, studies were required to evaluate at least one non-steady-state or transitional movement. Eligible tasks included, but were not limited to, STS, stand-to-sit, GI, gait termination, turning, step ascent/descent, and obstacle crossing. Studies focusing exclusively on steady-state walking or completely static postures (e.g. quiet standing) without a transitional component were excluded. The comparison group consisted of NW or healthy-weight adult controls, although studies utilizing correlation analyses across different BMI categories were also deemed eligible. In terms of outcomes, studies had to provide explicit measurements of lower-extremity biomechanics. Eligible outcomes incorporated joint kinematics (e.g. joint angles, range of motion), joint kinetics (e.g. moments, torques, powers), ground reaction forces (GRF), COP dynamics, spatiotemporal parameters during transitions, and electromyography (EMG) of the lower limb muscles; conversely, studies assessing solely upper extremity mechanics were excluded. Finally, eligible study designs comprised original empirical and observational research, including cross-sectional, case-control, and baseline data from randomized controlled trials. Review articles, meta-analyses, case reports, editorials, and conference abstracts without full-text availability were excluded from this systematic review.

Information sources and search strategy

A comprehensive and systematic electronic literature search was conducted across three primary databases: PubMed, Scopus, and Web of Science (WOS). The search encompassed all literature published from the inception of each database to June 1, 2026. Additionally, Google Scholar was manually searched to identify relevant grey literature, unpublished studies, and to perform forward and backward citation tracking of the included articles. The search strategy combined Medical Subject Headings (MeSH) and free-text keywords related to obesity, transitional movements, and lower extremity biomechanics. Table 1 presents the exact search strings used for each database.

Selection process

All retrieved records from the initial search were exported to EndNote 21 reference management software (Clarivate Analytics, Philadelphia, PA, USA), where duplicate records were identified and removed automatically, followed by manual verification. The screening process was conducted in two distinct phases. First, two independent reviewers (Fariborz Imani and Ahmad Yazadnifar) screened the titles and abstracts of the remaining records against the predefined eligibility criteria. In the second phase, the full texts of potentially relevant articles were retrieved and independently evaluated by the same two reviewers. Any disagreements regarding study inclusion were resolved through discussion or, if necessary, by consulting a third senior reviewer (AmirAli Jafarnezhadgero) to reach a consensus.

Table 1. Complete search strategy for electronic databases

No.	Database	Search Query
1	PubMed	("Obesity"[Mesh] OR "Overweight"[Mesh] OR obesity[tiab] OR obese[tiab] OR overweight[tiab] OR "body mass index"[tiab] OR BMI[tiab]) AND ("transitional movement*"[tiab] OR "sit-to-stand"[tiab] OR "sit to stand"[tiab] OR "gait initiation"[tiab] OR cutting[tiab] OR turning[tiab] OR "step-descent"[tiab] OR "step descent"[tiab] OR "obstacle crossing"[tiab] OR "non-steady-state"[tiab] OR "non-steady-state"[tiab] OR acceleration[tiab] OR deceleration[tiab]) AND ("Lower Extremity"[Mesh] OR "Biomechanical Phenomena"[Mesh] OR biomechanic*[tiab] OR kinematic*[tiab] OR kinetic*[tiab] OR "lower limb*"[tiab] OR "lower extremity"[tiab] OR joint*[tiab] OR ankle[tiab] OR knee[tiab] OR hip[tiab])
2	Scopus	TITLE-ABS-KEY (obesity OR obese OR overweight OR "body mass index" OR BMI) AND TITLE-ABS-KEY ("transitional movement*" OR "sit-to-stand" OR "sit to stand" OR "gait initiation" OR cutting OR turning OR "step-descent" OR "step descent" OR "obstacle crossing" OR "non-steady-state" OR "non-steady-state" OR acceleration OR deceleration) AND TITLE-ABS-KEY(biomechanic* OR kinematic* OR kinetic* OR "lower limb*" OR "lower extremity" OR joint* OR ankle OR knee OR hip)
3	WOS	TS=(obesity OR obese OR overweight OR "body mass index" OR BMI) AND TS=("transitional movement*" OR "sit-to-stand" OR "sit to stand" OR "gait initiation" OR cutting OR turning OR "step-descent" OR "step descent" OR "obstacle crossing" OR "non-steady-state" OR "non-steady-state" OR acceleration OR deceleration) AND TS=(biomechanic* OR kinematic* OR kinetic* OR "lower limb*" OR "lower extremity" OR joint* OR ankle OR knee OR hip)

WOS: Web of science; MeSH: Medical subject headings.

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Data collection process and data items

Data were extracted by one reviewer (Fariborz Imani) using a standardized, pre-piloted Microsoft Excel spreadsheet, and the extracted data were thoroughly cross-checked for accuracy by a second reviewer (Mahrokh Dehghani or Elaheh Azadian). The following data items were extracted from each included study: study characteristics (author, publication year, and country), participant demographics (sample size, age, gender, BMI, or body mass categorization), movement task evaluated (e.g. STS, GI, and stair climbing), biomechanical assessment methods (e.g. 3D motion capture, force plates, and EMG), and the primary biomechanical outcomes (kinematics, kinetics, spatiotemporal parameters, and muscle activation patterns).

Study risk of bias assessment

The methodological quality and risk of bias of the included studies were independently assessed by two reviewers (Fariborz Imani and Ahmad Yazadnifar) using a modified version of the Downs and Black checklist [23]. This tool has been validated for assessing the quality of both randomized and non-randomized observational studies in biomechanics. To better suit the specific design of the included cross-sectional and observational biomechanical studies, the original 27-item checklist was modified to focus on the most relevant domains, including reporting quality, external validity, internal validity (bias and confounding), and statistical power. Discrepancies in quality scores were resolved via discussion or by the adjudication of a third reviewer (AmirAli Jafarnezhadgero).

Results

Study selection

A systematic literature search across electronic databases and grey literature yielded 3,818 records. Following the removal of 1,218 duplicate records, the titles and abstracts of 2,600 articles were screened, leading to the exclusion of 2,482 studies that did not meet the predefined criteria. The full texts of the remaining 118 articles were comprehensively evaluated. Ultimately, 80 articles were excluded for reasons, including the use of pediatric populations, surgical interventions, and a lack of transitional biomechanical outcomes. This process resulted in the final inclusion of 38 original studies for qualitative synthesis (Figure 1).

Methodological quality assessment

Methodological quality assessment using the modified Downs and Black checklist revealed a mean total score of 19.8 out of 27(73.5%) across the included studies. The overall quality grading categorized six studies (15.8%) as excellent, 24 studies (63.1%) as good, six studies (15.8%) as fair, and two studies (5.2%) as poor (Table 2). Reporting quality was consistently high, with a mean score of 8.8 out of 10. Internal validity for bias and confounding reached mean scores of 5.0 out of 7 and 4.8 out of 6, respectively, indicating adequate control of age and walking speed matching in most protocols. External validity was a primary limitation, scoring a mean of 1.2 out of 3 due to restricted sample demographics. Statistical power was rarely reported; only 6 out of the 38 studies explicitly detailed an a priori sample size calculation.

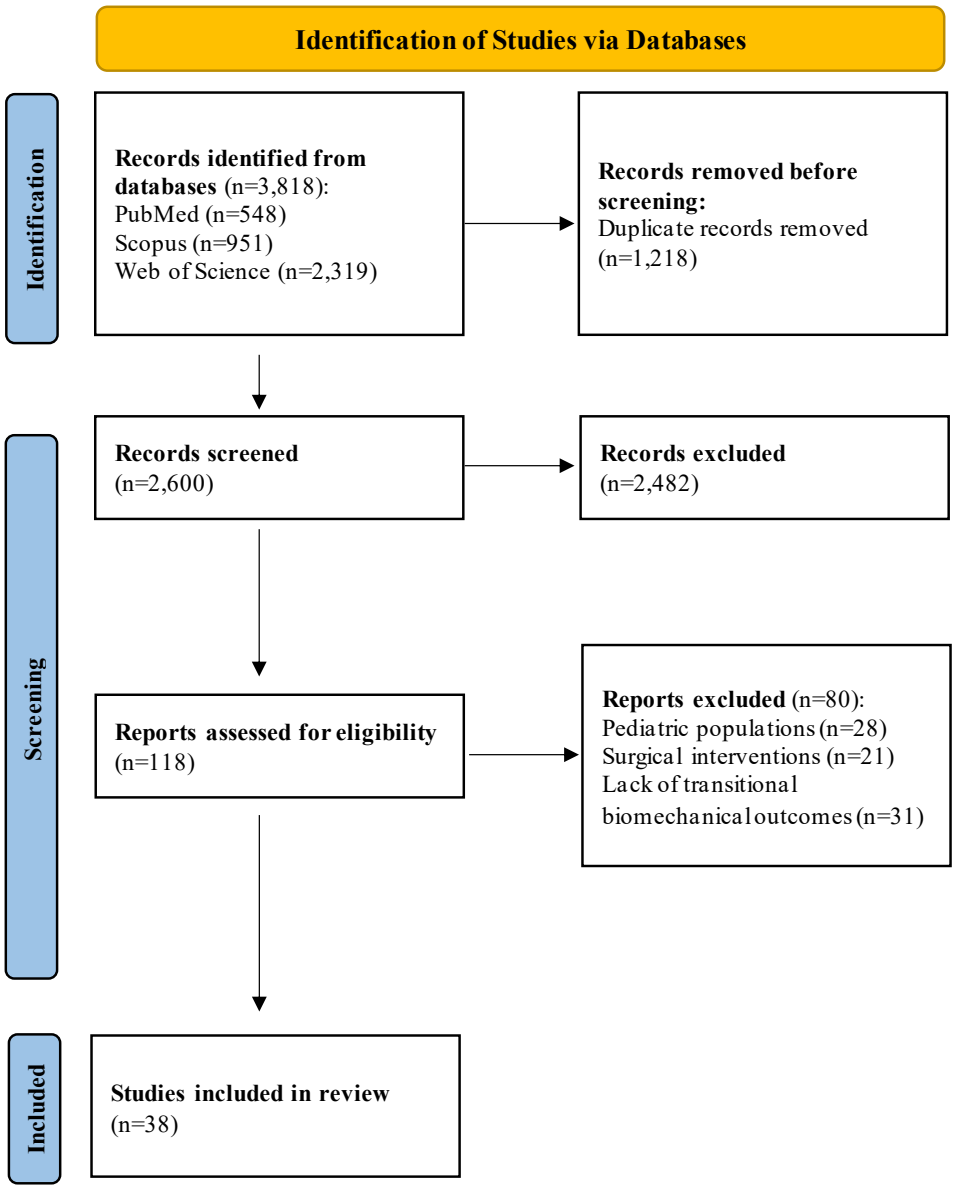


Figure 1. PRISMA flow diagram

Study characteristics

The 38 included studies analyzed diverse adult populations across varying geographical regions (e.g. USA, China, Italy, Iran, Australia, Canada, and Brazil). Cumulatively, these studies encompassed 1,366 participants, comprising both male and female cohorts. The participants' ages spanned a broad spectrum from 19 to 82 years, effectively capturing young adults, middle-aged individuals, and the elderly. Furthermore, the evaluated populations presented a wide range of BMI, from NW controls (approximately 18.5 kg/m²) up to individuals with severe class III obesity (reaching up to 54.7 kg/m²). The vast majority of studies employed a cross-sectional comparative design, evaluating lower extremity biomechanics in overweight or obese individuals against NW controls. Evaluated non-steady-state and transitional tasks included STS transfers, stair negotiation (ascent and descent), GI, obstacle crossing, and dynamic balance adjustments during overground and treadmill locomotion.

Biomechanical adaptations across transitional tasks

The synthesis of biomechanical data reveals specific kinematic and kinetic modifications adopted by obese individuals to manage excess body mass during movement transitions.

Sit-to-stand transitions

Executing an sit-to-stand (STS) transfer requires significant mechanical demands to raise the elevated body mass against gravity. Adults with obesity execute this transition using a distinct compensatory motor strategy characterized by limited forward trunk flexion [6]. This upright trunk posture reduces peak hip flexion moments (0.36 vs 0.60 Nm/kg, P<0.05) but severely overloads the distal joints, doubling the peak knee extension moment compared to NW peers (0.74 vs 0.31 Nm/kg, P<0.05) [14]. Repeated STS trials induce fatigue, forcing obese individuals to abandon lumbar protection and increase trunk flexion to reduce knee torque by 43% [14]. Kinematic adaptations also included a wider base of support and increased hip abduction up to 17.0 degrees (P=0.022), requiring significantly greater internal hip adductor torque to control lateral sway [24]. Functionally, this transition takes longer to complete, with lower vertical sacrum velocity (0.56 vs 0.67 m/s, P=0.018) and a reduced rate of force development [12, 15]. Muscle activation patterns demonstrate a 33% reduction in active vastus medialis and lateralis recruitment amplitude during lift-off (P<0.05), combined with reduced rectus femoris and erector spinae activation at lower chair heights (P<0.035) [15, 25].

Gait initiation and postural stability

Gait initiation (GI) exposes significant dynamic balance impairments in populations with elevated BMI. Anticipatory postural adjustments (APAs) in obese individuals present with significantly longer durations and larger lateral COP excursions [10]. During the dynamic unloading phase of initiation, lateral COP displacement amplitude and velocity increased significantly (P=0.008) [11]. Individuals with obesity utilize a prolonged bipedal standing phase (0.24 vs 0.19 s, P=0.002) and a slower anteroposterior COP velocity to limit forward progression and preserve equilibrium [10, 19]. The margin of stability in the anteroposterior direction decreased by 32.1% (P=0.008) [26]. The introduction of cognitive dual-tasking during GI exaggerates lateral instability, significantly increasing the mediolateral COP path length (P=0.001) without disproportionately deteriorating motor preparation times [19, 26]. Resistance training interventions uniquely improved mediolateral dynamic stability, reducing COP excursions by up to 21.4% (P=0.012) [27].

Stair negotiation mechanics

Stair climbing amplifies lower-limb joint loading, requiring specific kinematic and kinetic adjustments. Individuals with obesity ascend and descend stairs at significantly slower velocities (0.42 vs 0.49 m/s, P<0.05) with prolonged stance phases (64.3% vs 62.4%, P<0.05) while maintaining similar sagittal joint range of motion compared to NW controls [8, 17]. When normalized to body mass, peak knee flexion moments can be lower in obese individuals during ascent (0.57 vs 0.88 Nm/kg, P<0.05) [8]. However, absolute non-normalized forces demonstrate severe mechanical overload; peak knee extension moments reach 145 Nm during ascent and 125 Nm during descent (P<0.001), alongside elevated absolute vertical and mediolateral GRFs (P<0.001) [9, 17]. Increasing step width successfully reduces peak knee abduction moments during stair tasks (P<0.05) but introduces a trade-off by increasing knee extension moments during descent (P=0.024) [9].

Gait adaptations and obstacle crossing

Overground walking and high-impact locomotion evoked comprehensive spatiotemporal and kinetic modifications. Adults with obesity adopt a slower walking velocity, shorter step lengths, increased step widths, and prolonged double-limb support phases to shift the center of mass anteriorly and maintain sagittal stability [28, 29]. Kinematically, they exhibit reduced knee flexion in early stance (P<0.012), walking with a more extended knee to shift the mechanical burden to the ankle plantarflexors, where positive ankle work increases by 61% (P<0.000) [3, 30]. Coronal plane deviations were prominent, including increased pelvic drop (P=0.016), hip adduction (P<0.001), and rapid rearfoot eversion velocity (-198.7 vs -79.1 deg/s, P<0.01) [31, 32]. Slower walking speeds are an active risk-reduction strategy; reducing walking speed from 1.50 to 1.00 m/s drops absolute peak sagittal knee moments by 43% [33]. Incline walking at a slow pace further reduces early stance compressive tibiofemoral forces by 23% (P<0.001) [34].

Navigating obstacles heavily exposes these dynamic balance impairments. Crossing small to high obstacles significantly decreases step velocity and increases double-limb support time across all obstacle heights (P<0.01) [13]. During higher-impact locomotion, such as running, absolute plantar pressures increased up to 7.7-fold under the midfoot (P<0.01), indicating structural arch flattening [35, 36]. Runners with obesity dampen relative impact loading rates by decreasing vertical center of mass displacement (7.8 vs 9.1 cm, P=0.003) and increasing vertical stiffness (P=0.0001), relying on a hip-dominant neuromotor strategy that elevates hip extension and adduction moments (P<0.007) [37]. Localized fatigue during running further reduces ankle invertor strength, exacerbating hyper-pronation and elevating dynamic injury risk [36].

Table 2. Summary of biomechanical outcomes across non-steady-state and transitional tasks

Authors (y)	Country, Design	Population (N, BMI, Task)	Biomechanical Outcomes (Kinematics, Kinetics, COP, EMG) vs Control	Key Conclusion
Adouni et al. 2024 [3]	Kuwait, Cross-sectional	n=60 (OB/OW/NW), BMI: 32.8 / 27.5 / 21.7 Task: Gait	Kin: ↑Hip add/ext rot, ↓Knee flex. Kinetic: ↑Hip/knee/ankle moments, ↑Abs vGRF (+50%). EMG: ↑quad, hamstrings, gastroc.	OB adults adopt a slower/wider gait; elevated joint moments and muscle activation reflect a strategy to distribute excess mass.
Almashaqbeh et al. 2015 [8]	Jordan, Cross-sectional	n=20 (OB/NW), BMI: 34.4 / 21.0 Task: Stair ascent	Kin: ↓speed, ↑stance phase %. =joint roms. kinetic: ↓peak knee flexion moment (normalized). =Hip/Ankle moments. Power: ↓peak ankle power.	Slower walking during stair ascent successfully reduces relative knee flexion moments to manage joint overload.
Bertocco et al. 2002 [6]	Italy, Cross-sectional	n=40 (OB/NW), BMI: 37.5 / 22.2 Task: STS	Kin: ↓forward trunk flex, ↑backward foot displacement. Kinetic: ↓Peak hip flex moment, ↑Peak knee ext moment (x2).	Restricting trunk flexion protects the lumbar spine but severely overloads the knee extensors.
Bollinger et al. 2019 [38]	USA, Relational	n=18 (OB only), BMI: 33.6 Task: STS	Kin: ↑BMI correlates with ↑stance width and ↑trunk flex velocity. ↓Knee extensor strength correlates with ↑initial/peak trunk flex angle.	BMI drives foot placement and velocity, while muscle weakness dictates the magnitude of trunk flexion.
Bollinger & Ransom 2020 [15]	USA, Cross-sectional	n=27 (OB/NW), BMI: 33.2 / 22.0 Task: STS	Kin: ↓Peak trunk flex angle, ↑total STS duration. EMG: ↓Vastus medialis/lateralis amplitude during lift-off. ↑Total integrated EMG.	Slower transitions compensate for reduced knee extensor burst intensity, driving up total muscular work.
Browning & Kram, 2007 [33]	USA, Cross-sectional	n=20 (OB/NW), BMI: 35.5 / 22.0 Task: Gait	Kin: =Sagittal angles. ↑Stance %, ↑Step width. Kinetic: ↑Abs GRFs, ↑Abs peak knee/hip moments. Speed effect: Slower speeds ↓GRFs and knee moments.	Higher absolute loads elevate OA risk; adopting slower walking speeds effectively mitigates peak joint loading.
Cau et al. 2014 [10]	Italy, Cross-sectional	n=35 (OB/NW), BMI: 43.0 / 21.2 Task: GI	Kin: ↑Duration of APAs. COP: ↑ML displacement and velocity. ↓AP velocity.	Wider and faster lateral COP shifts, along with reduced forward momentum, serve to preserve balance.
De Souza et al. 2005 [39]	B razil, Comparative	n=34 (OB vs Ref), BMI: 40.1 Task: Gait	Kin: ↓Speed, ↓Cadence, ↓Step length. ↑Support base, ↑Foot out-toeing (abduction).	Widespread kinematic impairments lead to a slower, wider gait to preserve dynamic stability under mass.
Desrochers et al. 2021 [13]	USA, Cross-sectional	n=34 (OB/NW), BMI: 40.9 / 23.7 Task: Obstacle crossing	Kin: ↓Speed, ↓Step length, ↑Step width, ↑DLS %. ↓FGA score (higher fall risk).	Navigating obstacles heavily exposes dynamic balance impairments, triggering a cautious, stance-heavy gait.
DeVita & Hortobágyi, 2003 [30]	USA, Cross-sectional	n=39 (OB/NW), BMI: 42.3 / 22.7 Task: Gait	Kin: ↑Hip ext, ↓knee flex (straighter leg), ↑ankle PF. Kinetic: ↓Knee torque (-46%), ↑Ankle torque (+89%).	A straighter knee posture shifts the mechanical burden from the knee to the ankle plantar flexors.
Galli et al. 2000 [14]	Italy, Cross-sectional	n=40 (OB/NW), BMI: 40.0 / 22.0 Task: STS	Kin: ↓Trunk flex (initial trial). Fatigue ↑trunk flex (10th trial). Kinetic: ↓Hip moment, ↑Knee moment.	Initial lumbar protection overloads the knee; fatigue forces a strategy shift back to trunk flexion.
Gao et al. 2019 [40]	China, Cross-sectional	n=53 (OB/OW/NW), BMI: >28 / 24-28 / <24 Task: Gait	Kin: ↓Peak COM velocity, ↑anterior COM position at toe-off. ↑DBATS score (poorer balance).	Slower COM velocity and anterior placement reflect a cautious strategy to prevent balance loss.
Haight et al. 2013 [34]	USA, Cross-sectional	n=19 (OB/NW), BMI: 35.0 / 22.1 Task: Gait (level/uphill)	Kin: ↓Knee flex (level). Kinetic: ↓Normalized TF force (level), ↓TF loading rate (uphill).	A straighter knee reduces relative compressive forces; uphill walking further protects joints.
Hills et al. 2001 [35]	Australia, Cross-sectional	n=70 (OB/NW), BMI: 38.8 / 24.2 Task: Standing/Gait	Kin: ↑Foot width. Kinetic: ↑Dynamic plantar pressures (up to 7.7-fold increase in midfoot).	Disproportionate midfoot loading indicates structural arch flattening and elevated foot discomfort risk.
Hirjaková et al. 2018 [11]	Slovakia, Cross-sectional	n=44 (OB/NW), BMI: 32.0 / 22.2 Task: GI	Kin: =Trunk (L5) kinematics. COP: ↑AP sway (quiet stance). ↑Lateral COP amplitude and velocity during unloading.	Increased lateral COP shift successfully stabilizes the trunk during dynamic transitional unloading.
Kim & Ju, 2021 [16]	Korea, Cross-sectional	n=26 (OB/NW), BMI: 30.5 / 20.3 Task: STS	EMG: ↓Rectus femoris and erector spinae activation at lower chair heights. =Tibialis anterior.	Reduced proximal muscle recruitment shifts reliance to distal ankle stabilization at demanding heights.
Kim et al. 2023 [25]	USA, Simulation	n=24 (OW/NW), BMI: 29.1 / 22.5 Task: Gait	Kin/Kinetics: =Joint angles and COM motion. Muscle Contrib: ↑Gastroc contribution to COM accel, ↓Vastus.	Equivalent COM motion is achieved via increased calf output and decreased quadriceps reliance.
Kong et al. 2024 [19]	China, Cross-sectional	n=36 (OB/OW/NW), BMI: 31.1 / 25.6 / 20.9 Task: GI (dual-task)	Kin: ↑Bipedal standing duration. COP: ↑Path length and ML amplitude. Dual-task exaggerated ML displacement.	Cognitive load exacerbates lateral instability and dynamic fall risk during GI.
Lai et al. 2008 [28]	Hong Kong, Cross-sectional	n=28 (OB/NW), BMI: 33.0 / 21.3 Task: Gait	Kin: ↓Speed, ↑DLS %. ↑hip/knee adduction, ↑Ankle eversion. Kinetic: =Sagittal moments.	Slower, wider gait manages sagittal loads but introduces prominent coronal-plane joint deviations.
Law et al. 2021 [4]	Canada, Cross-sectional	n=45 (OB/OW/NW), BMI: 33.3 / 27.4 / 22.1 Task: Stair ascent/ descent	Kin: =Peak joint angles. Kinetic: Ascent: ↑Hip flexor moment. Descent: ↑Knee extensor and ankle abductor moments.	Excess mass increases joint-specific kinetic demands without fundamentally altering movement kinematics.

Authors (y)	Country, Design	Population (N, BMI, Task)	Biomechanical Outcomes (Kinematics, Kinetics, COP, EMG) vs Control	Key Conclusion
Lerner et al. 2014 [31]	USA, Simulation	n=19 (OB/NW), BMI: 35.0 / 22.1 Task: Gait	Kin: ↑Knee ext, ↑pelvic drop. Muscle force: ↑Peak gluteus medius and soleus, ↓vastus force.	Straighter knee protects vasti; however, increased pelvic drop elevates hip abductor (GMED) fatigue risk.
Leutzinger et al. 2024 [17]	USA, Cross-sectional	n=30 (OB/NW), BMI: 33.3 / 22.0 Task: Stair ascent/ descent	Kin: =Joint angles. Kinetic: =Normalized moments. ↑Absolute peak knee extension moments.	Despite equivalent kinematics, high absolute knee moments subject the joint to chronic mechanical overload.
Li et al. 2025 [41]	China, Cross-sectional	n=40 (OW/NW/UW), BMI: 26.7 / 21.1 / 18.0 Task: STS	Kin: ↑Knee-ankle proximal coordination. Kinetic: ↑Pelvis and thigh power (energy flow).	OW individuals rely on knee drive and increased pelvic power to compensate for insufficient hip drive.
Liu & Yang, 2017 [29]	China, Cross-sectional	n=44 (OB/NW), BMI: 35.1 / 21.7 Task: Gait	Kin: ↓Speed, ↑Step width, ↑DLS %. ↑Anterior COM at touchdown. =Sagittal stability.	Cautious spatiotemporal adaptations and anterior COM shift successfully preserve dynamic sagittal stability.
Messier et al. 1994 [32]	USA, Cross-sectional	n=29 (OB/NW), BMI: 41.1 / 20.8 Task: Gait	Kin: ↑Touchdown inversion, ↑eversion ROM and velocity, ↑forefoot abduction (out-toeing).	Excessive rearfoot eversion and out-toeing mechanically elevate the risk of lower limb overuse injuries.
Naderi et al. 2020 [36]	Iran, Cross-sectional	n=75 (OB/OW/NW), BMI: 31.5 / 25.9 / 22.3 Task: Running	Kin: ↑Contact time, ↑Dynamic arch index. Kinetic: ↑Peak pressure and impulse in midfoot/ heel.	Fatigue reduces ankle strength, exacerbating hyper-pronation and midfoot loading in runners with OB.
Qu et al. 2021 [26]	China, Cross-sectional	n=28 (OW/NW), BMI: 26.4 / 19.6 Task: GI (Dual-Task)	Kin: ↑Step execution time. COP: ↓AP margin of stability (MOS). Cognitive task slowed execution equally.	OW individuals exhibit reduced AP stability; cognitive load slows execution without excess destabilization.
Russell et al. 2010 [42]	USA, Cross-sectional	n=20 (OB/NW), BMI: 33.1 / 22.6 Task: Gait	Kin: ↓Preferred speed. Kinetic: ↑Impact shock. Shorter stride ↓Knee adduction impulse but =Peak impact.	Shorter strides reduce knee adduction impulses but fail to mitigate damaging peak impact shocks.
Sangkarit et al. 2025 [18]	Thailand, Cross-sectional	n=60 (OB/OW/NW), BMI: 34.1 / 27.1 / 22.1 Task: Single-Leg STS	COP: ↑Path Length, ↑AP and ML Sway. The dynamic test was more sensitive than the static test.	Heightened COP sway exposes subclinical unilateral balance deficits and elevated fall risk.
Schmid et al. 2013 [12]	Switzerland, Cross-sectional	n=36 (OB/NW), BMI: >30 / 23.9 Task: 5xSTS	Kin: ↓Sacrum velocity, ↑Total time. Kinetic: ↓Normalized peak force, ↓Rate of force development.	Slower transition performance is driven by deficits in rapid force generation rather than execution fatigue.
Segal et al. 2009 [7]	USA, Cross-sectional	n=59 (OB/NW), BMI: 35.7 / 22.8 Task: Gait	Kinetic: ↑Abs peak knee adduction moment (EKAM). =Normalized EKAM.	Absolute body weight (not regional fat distribution) primarily drives elevated medial knee loading.
Valizadeh-orang et al. 2022 [43]	Iran, Cross-over	n=15 (OW flat-feet), BMI: 28.2 Task: Running (shoes)	EMG: Motion control shoes ↑Vasti co-contraction (loading) and ↑ML knee co-contraction (push-off).	Motion control shoes optimize dynamic knee stability via altered muscle co-contraction strategies.
Veras et al. 2020 [44]	Portugal, Cross-sectional	n=64 (OB/NW), BMI: 32.3 (range) Task: Gait	Kinetic: ↑Peak accelerations, GRFs, and loading rates. Developed accurate predictive equations.	Accelerometry can accurately predict GRFs and loading rates, offering a non-laboratory clinical monitoring tool.
Vincent et al. 2020 [37]	USA, Case-control	n=54 (OB/NW), BMI: 32.5 / 22.6 Task: Running	Kin: ↓Vertical COM, ↑stride width/stance. Kinetic: ↑Abs GRF, ↓normalized GRF. ↑Hip moments.	A hip-dominant strategy and increased vertical stiffness successfully dampen relative impact loading rates.
Wu et al. 2012 [45]	USA, Cross-sectional	n=12 (OB/NW), BMI: 34.8 / 25.4 Task: TUG	Kin: ↓Peak AP trunk accel, ↑time to peak ext velocity, ↑DLS %. =Total TUG time.	Obese elderly show subclinical mobility impairments during postural transitions despite overall normal times.
Yocum et al. 2018 [9]	USA, Cross-sectional	n=24 (OB/NW), BMI: 32.7 / 22.5 Task: Stairs and gait	Kinetic: ↑Abs GRFs and knee ext moments. Wide step ↓Knee abduction moment but ↑knee ext moment.	Wide stepping reduces medial loading but introduces a trade-off by increasing extension demands.
Zemková et al. 2017 [27]	Slovakia, RCT	n=25 (OW/OB only), BMI: 31-32 Task: Step initiation	Kin: Training ↓step execution time. COP: Resistance training ↓ML COP excursion.	Training improves step speed; resistance training uniquely improves mediolateral dynamic stability.
Zhao et al. 2026 [24]	China, Cross-sectional	n=20 (OW/NW), BMI: 26.9 / 20.9 Task: STS	Kin: ↓Max hip flex, ↑hip abd and ext rot. Kinetic: ↑Internal adduction/abduction hip torque.	A wider base of support manages balance but elevates functional loads and torque on the hip joint.

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Abbreviations: APA: Anticipatory postural adjustment; OB: Obese; OW: Overweight; NW: Normal weight; UW: Underweight; BMI: Body mass index; STS: Sit-to-stand; GI: Gait initiation; TUG: Timed up and go; Kin: Kinematics; COM: Center of mass; COP: Center of pressure; GRF: Ground reaction force; DLS: Double-limb support; AP: Anteroposterior; ML: Mediolateral; ROM: Range of motion; EMG: Electromyography; TF: Tibiofemoral; FGA: Functional gait assessment; DBATS: Dynamic balance ability test scale; Abs: Absolute; ↑: Significantly increased; ↓: Significantly decreased; =: Indicates no significant difference.

Table 3. Methodological quality assessment of included studies using the modified Downs and Black checklist

Authors (y)	Reporting	External Validity	Internal Validity: Bias	Internal Validity: Confounding	Power	Total Score	Overall Quality
Adouni et al. 2024 [3]	9	1	5	5	0	20	Good
Almashaqbeh et al. 2015 [8]	9	1	5	5	0	20	Good
Bertocco et al. 2002 [6]	7	1	3	2	0	13	Poor
Bollinger et al. 2019 [38]	8	1	4	4	0	17	Fair
Bollinger & Ransom 2020 [15]	9	1	5	5	0	20	Good
Browning & Kram, 2007 [33]	9	1	5	5	0	20	Good
De Souza et al. 2005 [39]	9	1	5	5	0	20	Good
Desrochers et al. 2021 [13]	7	1	3	1	0	12	Poor
DeVita & Hortobágyi, 2003 [30]	8	1	4	4	0	17	Fair
DeVita & Hortobágyi, 2003 [30]	9	1	5	4	0	19	Fair
Galli et al. 2000 [14]	8	1	4	2	0	15	Fair
Gao et al. 2019 [40]	8	1	5	4	0	18	Fair
Haight et al. 2013 [34]	9	1	5	5	0	20	Good
Hills et al. 2001 [35]	9	1	5	5	0	20	Good
Hirjaková et al. 2018 [11]	9	1	5	5	0	20	Good
Kim & Ju, 2021 [16]	9	1	5	5	0	20	Good
Kim et al. 2023 [25]	9	2	6	6	1	24	Excellent
Kong et al. 2024 [19]	9	1	5	5	0	20	Good
Lai et al. 2008 [28]	9	1	5	5	0	20	Good
Law et al. 2021 [4]	9	1	5	5	0	20	Good
Lerner et al. 2014 [31]	9	1	5	5	0	20	Good
Leutzinger et al. 2024 [17]	9	1	5	5	0	20	Good
Li et al. 2025 [41]	9	1	5	4	0	19	Fair
Liu & Yang, 2017 [29]	9	1	5	5	0	20	Good
Messier et al. 1994 [32]	9	1	5	5	0	20	Good
Naderi et al. 2020 [36]	9	2	6	6	1	24	Excellent
Qu et al. 2021 [26]	9	1	5	5	0	20	Good
Russell et al. 2010 [42]	9	1	5	5	0	20	Good
Sangkarit et al. 2025 [18]	9	2	6	6	1	24	Excellent
Schmid et al. 2013 [12]	9	1	5	5	0	20	Good
Segal et al. 2009 [7]	9	2	6	6	1	24	Excellent
Valizadehorang et al. 2022 [43]	9	2	6	6	1	24	Excellent

Authors (y)	Reporting	External Validity	Internal Validity: Bias	Internal Validity: Confounding	Power	Total Score	Overall Quality
Veras et al. 2020 [44]	9	1	5	5	0	20	Good
Vincent et al. 2020 [37]	9	1	5	5	0	20	Good
Wu et al. 2012 [45]	9	1	5	5	0	20	Good
Yocum et al. 2018 [9]	9	2	6	6	1	24	Excellent
Zemková et al. 2017 [27]	9	1	5	5	0	20	Good
Zhao et al. 2026 [24]	9	1	5	5	0	20	Good
Mean score	8.8	1.2	5.0	4.8	0.2	19.8 (73.5%)	Good

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Note: Maximum possible scores for each domain: reporting (10), external validity (3), internal validity – bias (7), internal validity – confounding (6), and power (1; awarded only if an a priori sample size calculation was explicitly reported). Maximum total score: 27. Overall quality grading: excellent (24–27), good (20–23), fair (15–19), and poor (<14).

Discussion

This systematic review aimed to synthesize biomechanical adaptations of the lower extremities during non-steady-state and transitional movements in populations with obesity. Analyzing data from 38 original studies encompassing 1,366 participants aged 19-82 years, the findings highlight a distinct biomechanical trade-off. Individuals living with obesity frequently demonstrate alterations in lower-extremity kinematics and coordination strategies as a means to maintain postural balance and compensate for relative neuromuscular weakness [1, 30]. These kinematic adjustments, such as slower transition speeds, widened bases of support, and restricted joint excursions, appear to serve as protective mechanisms to mitigate instantaneous balance loss [26, 29]. However, these adaptive strategies inadvertently result in severe absolute mechanical overload on distal joints, particularly at the knee and ankle [9]. While body-mass-normalized joint loading may appear comparable to NW counterparts, persistent exposure to elevated absolute, non-normalized joint forces and moments may accelerate cartilage degeneration and heighten the risk of musculoskeletal pathology over time [2, 5].

Compensatory strategies and joint overload in sit-to-stand transfers

During sit-to-stand (STS) transfer, adults with obesity exhibit specific neuromotor adaptations to manage the translocation of excess body mass. Healthy-weight individuals typically utilize a fully forward trunk-bending strategy that generates substantial forward momentum at the hip and reduces the necessary knee extension torque. In contrast, obese individuals often limit forward trunk flexion during the initial phase of rising. This restricted movement is suggested to be an active compensation to protect the lumbar spine from excessive loading and associated lower back pain [6, 14]. While this restricted trunk flexion successfully limits lower back torque, it increases the distance from the body's center of mass to the knee joint center. Consequently, this adaptation is associated with approximately double peak knee joint moments compared to NW controls [6].

These high knee joint moments represent a significant mechanical demand superimposed on relative quadriceps weakness. Although individuals with obesity often possess higher absolute muscular strength, their knee extensor strength and power normalized to total body mass are significantly reduced compared to NW peers [12]. This functional weakness is reflected in electromyographic analyses, which reveal reduced mean quadriceps activation amplitudes during the active rising phase of STS transfer, despite an overall increase in total muscle work driven by prolonged transition durations [15, 16]. Interestingly, as fatigue increases over repeated STS repetitions, obese individuals tend to abandon the protective spinal strategy and increase trunk flexion to assist the weakened quadriceps in completing the rise, thereby transferring the mechanical burden back to the lumbar structures [14]. To maintain dynamic stability and overcome physical obstruction from abdominal fat, overweight individuals also utilize a wider stance and increased hip abduction during the initial phase of STS, requiring larger hip adductor torque to control lateral sway as the body rises [24, 38].

Postural vulnerability during gait initiation and obstacle navigation

Postural transition tasks, such as gait initiation (GI) and obstacle crossing, represent periods of high balance vulnerability in obese individuals. GI requires the central nervous system to destabilize a quiet bipedal posture and transfer body weight laterally to a single-leg support phase [10, 11]. Obese individuals demonstrate prolonged bipedal standing phases and extended APA durations, suggesting a more conservative strategy to plan and execute weight transfer [19, 26]. Despite these extended preparation times, individuals with obesity exhibit significantly wider COP excursions and larger peak-to-peak sway amplitudes, particularly in the mediolateral direction [10, 18]. This lateral instability is closely associated with an elevated activation requirement of hip abductors, such as the gluteus medius, to stabilize the pelvis during single-limb support [19, 31].

Lateral postural vulnerability is further compounded when dynamic movements are performed under cognitive dual-task conditions. Postural control draws on finite central cognitive resources. When a secondary executive task is introduced, competition for these resources increases dynamic fall risks [26]. Under dual-task constraints, young adults with obesity display significantly greater mediolateral COP displacement amplitudes and prolonged preparation phases, indicating that the motor strategies required to manage lateral balance become less effective under cognitive load [19]. Furthermore, when encountering external constraints such as stepping over obstacles, individuals with obesity walk more slowly and demonstrate less efficient spatiotemporal parameters than NW controls [13].

The mechanical burden of locomotion: stairs, walking, and high-impact tasks

The mechanical loading experienced during continuous locomotion is heavily influenced by body mass. Biomechanical studies of stair negotiation, level walking, and running frequently demonstrate that lower-extremity joint moments normalized to body mass do not differ significantly between obese individuals and NW controls [4, 17, 37]. However, this equivalence in normalized metrics can lead to the misleading assumption that joint tissue stress is similar across body sizes. In reality, the absolute, non-normalized joint moments and GRF are significantly elevated in populations with obesity [9, 33]. For example, during stair climbing, absolute knee extension moments can be up to 90% higher in obese individuals, exposing the articular cartilage and subchondral bone to chronic mechanical overload [17].

To mitigate these high joint loads, obese individuals adopt a characteristic “straighter knee” strategy during the early stance phase of level walking and running [30, 31]. By walking with a more extended knee joint, obese individuals align the resultant GRF vector more closely with the joint center. This kinematic shift reduces the required quadriceps muscle force and the corresponding early stance tibiofemoral compressive force [30, 34]. Additionally, runners with obesity exhibit a 15% reduction in vertical center-of-mass displacement and increased vertical stiffness to dampen vertical GRF and loading rates, although this is accompanied by a substantial increase in joint loading at the hip [37]. While the straighter knee strategy may protect the quadriceps from early fatigue, walking with restricted knee flexion reduces the joint’s natural shock-absorption capacity, which is associated with elevated absolute joint loading during weight acceptance and stair negotiation [9, 34].

Structural foot adaptations and the role of footwear interventions

The feet of obese individuals undergo substantial structural and functional adaptations to support elevated systemic loads. Repetitive carrying of excess body weight is associated with dynamic arch collapse, subtalar hyperpronation, and structural flatfootedness [32, 35]. Plantar pressure analyses during standing and walking reveal that obesity is associated with significantly larger contact areas and higher peak pressures and force impulses beneath the metatarsal heads, medial heel, and particularly the midfoot longitudinal arch [35, 36]. The disproportionately elevated peak pressures under the midfoot reflect progressive flattening of the longitudinal foot arch, which may impair the shock-distributing capacity of the foot during dynamic transitions [46]. During walking and running, obese individuals demonstrate significantly larger rearfoot eversion ranges of motion, faster peak eversion velocities, and pronounced out-toeing (forefoot abduction) [32].

These aberrant foot mechanics highlight a clear clinical need for targeted footwear and orthotic interventions to protect the distal joints from excessive mechanical stress. Surface electromyographic and kinetic evaluations indicate that the use of motion-control shoes can significantly increase vasti co-contraction during loading and mediolateral knee co-contraction during push-off in individuals with flat feet, which may enhance dynamic joint stability in the frontal plane [43]. Additionally, during prolonged running, local muscular fatigue of the foot invertors and plantar flexors impairs the active control of foot rollover, resulting in increased dynamic arch index

sways and higher plantar pressures under the midfoot [36]. In these fatigue-prone conditions, motion-control running shoes and supportive medial arch orthoses may be recommended to limit excessive rearfoot eversion, redistribute plantar pressures, and lower the risk of overuse injuries during weight-bearing exercise.

Clinical implications: osteoarthritis risk and multidisciplinary interventions

The chronic biomechanical deviations observed in populations with obesity are strongly linked to the development and progression of medial compartment knee osteoarthritis. The combination of elevated absolute knee extension moments and increased knee adduction moments during walking and stair negotiation concentrates compressive forces on the medial tibiofemoral cartilage [7, 9]. Similarly, excessive rearfoot eversion and dynamic arch collapse alter the ascending kinetic chain, which may further increase knee joint malalignment and shear stress on the articular surface [2]. These elevated mechanical loads are primary predictors of joint degeneration, and when combined with prolonged low-grade systemic inflammation associated with obesity, they may accelerate the breakdown of joint tissue [3, 5].

To address these pathological mechanisms, therapeutic strategies should combine biomechanical correction with multidisciplinary weight loss and exercise interventions. Direct biomechanical manipulations, such as instructing patients to adopt a wider step width, have been shown to reduce knee abduction moments and medial compartment loading, though they may introduce a trade-off by increasing hip and knee extension moments [9]. In addition, walking with a 15% shortened stride length increases the metabolic cost of locomotion while simultaneously reducing the knee adduction angular impulse over the course of the stride [42]. However, biomechanical modifications alone are insufficient to fully protect the lower joints. Comprehensive interventions that combine supervised diet-induced weight loss with structured physical training are essential to reduce the absolute mass loading the skeleton while restoring the relative strength and neuromuscular control of the lower limbs [27]. Specifically, integrating resistance training has been shown to improve mediolateral dynamic stability during step execution, while aerobic conditioning selectively enhances rapid distal motor performance, thereby potentially reducing both dynamic fall risk and joint pathology [27].

Methodological limitations and future directions

The current literature on transitional and non-steady-state biomechanics in obesity has several methodological limitations that restrict the generalizability of the findings. Systematic appraisals using the modified Downs and Black checklist (Table 3) revealed that while the majority of studies demonstrated high reporting quality (mean score: 8.8/10), they consistently exhibited poor external validity. Most investigations recruited highly specific, healthy, young, or relatively active cohorts under laboratory conditions, which may not adequately represent the broader, more sedentary, or older populations living with obesity who are at the greatest risk of dynamic instability and joint degeneration [17, 29]. Furthermore, there is a pervasive lack of a priori power calculations across these studies; only 6 out of 38 studies explicitly detailed their sample size calculations. This often results in small sample sizes that are frequently underpowered to detect sex-specific biomechanical strategies or subtle kinetic interactions [38, 42].

Additionally, reliance on cross-sectional comparative designs prevents the establishment of clear causal relationships between elevated body mass, altered neuromotor coordination, and long-term joint pathology [2, 5]. It remains unclear whether the biomechanical deviations observed are primary compensatory responses to excess mass or secondary adaptations to subclinical, undiagnosed joint pain or structural damage [12]. Future research should prioritize longitudinal prospective designs that track cohorts across different life stages and physical activity levels to document the onset of joint degeneration. Future studies must also incorporate a priori power calculations to ensure adequate sample sizes, stratify participants by obesity class, and evaluate the biomechanical effects of common clinical interventions, such as handrail use during stair negotiation or personalized orthotics, to optimize rehabilitation protocols [10, 17].

Conclusion

Obesity necessitates a fundamental neuromotor reorganization of the lower extremity kinetic chain during transitional and non-steady-state movements to preserve dynamic balance and manage the substantial mechanical demands of excess body mass. To compensate for relative muscular weakness and protect the lumbar spine, obese individuals adopt conservative, cautious strategies, such as restricted trunk flexion during sitting transfers, prolonged double-support times during GI, and a straighter knee posture during walking and running. While these kinematic adjustments are associated

with immediate postural stability, they inadvertently redirect and concentrate high, non-normalized absolute joint forces and moments on the distal joints of the knee and ankle. Consequently, this mechanical overload elevates the risk of medial compartment knee osteoarthritis, chronic joint degeneration, and progressive mobility limitations. Therefore, the clinical management of obesity cannot rely solely on weight reduction or biomechanical corrections in isolation. Effective long-term prevention of musculoskeletal pathology and dynamic instability requires a multidisciplinary approach that combines dietary weight loss with targeted resistance and aerobic exercise, thereby reducing absolute joint loads while restoring neuromuscular coordination, joint stability, and relative lower-limb strength required for safe functional transitions.

Ethical Considerations

Compliance with ethical guidelines

The review protocol was prospectively registered in PROSPERO (Code: CRD420261473990).

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Authors' contributions

Conceptualization and project administration: Fariborz Imani, AmirAli Jafarnezhadgero, and Mahrokh Dehghani; Methodology: Fariborz Imani, AmirAli Jafarnezhadgero, Mahrokh Dehghani, and Elaheh Azadian; Data curation, formal analysis, investigation, software, and writing the original draft: Fariborz Imani, Elaheh Azadian, and Ahmad Yazadnifar; Funding acquisition: AmirAli Jafarnezhadgero; Resources and supervision: AmirAli Jafarnezhadgero and Mahrokh Dehghani; Validation: AmirAli Jafarnezhadgero, Mahrokh Dehghani, Elaheh Azadian, and Ahmad Yazadnifar; Visualization, review, editing and final approval: All authors.

Conflict of interest

The authors declared no conflict of interest.

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References

[1] Hills AP, Hennig EM, Byrne NM, Steele JR. The biomechanics of adiposity--structural and functional limitations of obesity and implications for movement. Obes Rev. 2002; 3(1):35-43. [DOI:10.1046/j.1467-789X.2002.00054.x] [PMID]

[2] Wearing SC, Hennig EM, Byrne NM, Steele JR, Hills AP. The biomechanics of restricted movement in adult obesity. Obes Rev. 2006; 7(1):13-24. [DOI:10.1111/j.1467-789X.2006.00215.x] [PMID]

[3] Adouni M, Alkhatib F, Hajji R, Faisal TR. Effects of overweight and obesity on lower limb walking characteristics from joint kinematics to muscle activations. Gait Posture. 2024; 113:337-44. [DOI:10.1016/j.gaitpost.2024.06.024] [PMID]

[4] Law NH, Li JX, Law NY, Varin D, Lamontagne M. Effects of body mass and sex on kinematics and kinetics of the lower extremity during stair ascent and descent in older adults. Sports Med Health Sci. 2021; 3(3):165-70. [DOI:10.1016/j.smhs.2021.06.001] [PMID]

[5] Runhaar J, Koes BW, Clockaerts S, Bierma-Zeinstra SM. A systematic review on changed biomechanics of lower extremities in obese individuals: A possible role in development of osteoarthritis. Obes Rev. 2011; 12(12):1071-82. [DOI:10.1111/j.1467-789X.2011.00916.x] [PMID]

[6] Bertocco P, Baccalaro G, Montesano A, Vismara L, Parisio C, Galli M. The analysis of sit-to-stand movement in obese and normal subjects: Biomechanic evaluations and postural changes between groups. Eur Medicophys. 2002; 38(3):131-7. [Link]

[7] Segal NA, Yack HJ, Khole P. Weight, rather than obesity distribution, explains peak external knee adduction moment during level gait. Am J Phys Med Rehabil. 2009; 88(3):180-8; quiz 189-91, 246. [DOI:10.1097/PHM.0b013e318198b51b] [PMID]

[8] Almashaqbeh S, Al-Sheikh B, Abas W, Abu Osman NA. Lower Extremities Biomechanics of Regular Stair Climbing: Slim Versus Obese. Biomed Eng Appl Basis Commun. 2015; 27(4):1550036. [DOI:10.4015/S1016237215500362]

[9] Yocum D, Weinhandl JT, Fairbrother JT, Zhang S. Wide step width reduces knee abduction moment of obese adults during stair negotiation. J Biomech. 2018; 75:138-46. [DOI:10.1016/j.jbiomech.2018.05.002] [PMID]

[10] Cau N, Cimolin V, Galli M, Precilios H, Tacchini E, Santovito C, et al. Center of pressure displacements during gait initiation in individuals with obesity.J Neuroeng Rehabil. 2014; 11:82. [DOI:10.1186/1743-0003-11-82] [PMID]

[11] Hirjaková Z, Šuttová K, Kimijanová J, Bzdúšková D, Hlavačka F. Postural changes during quiet stance and gait initiation in slightly obese adults. Physiol Res. 2018; 67(6):985-92. [DOI:10.33549/physiolres.933870] [PMID]

[12] Schmid S, Armand S, Pataky Z, Golay A, Allet L. The relationship between different body mass index categories and chair rise performance in adult women. J Appl Biomech. 2013; 29(6):705-11. [DOI:10.1123/jab.29.6.705] [PMID]

[13] Desrochers PC, Kim D, Keegan L, Gill SV. Association between the Functional Gait Assessment and spatiotemporal gait parameters in individuals with obesity compared to normal weight controls: A proof-of-concept study. J Musculoskelet Neuronal Interact. 2021; 21(3):335-42. [PMID]

[14] Galli M, Crivellini M, Sibella F, Montesano A, Bertocco P, Parisio C. Sit-to-stand movement analysis in obese subjects. Int J Obes Relat Metab Disord. 2000; 24(11):1488-92. [DOI:10.1038/sj.ijo.0801409] [PMID]

[15] Bollinger LM, Ransom AL. The Association of Obesity With Quadriceps Activation During Sit-to-Stand. Phys Ther. 2020; 100(12):2134-43. [DOI:10.1093/ptj/pzaa170] [PMID]

[16] Kim SH, Ju SK. Comparison of muscle activity during sit-to-stand movement at different chair heights between obese and normal-weight subjects. J Exerc Rehabil. 2021; 17(1):39-44. [DOI:10.12965/jer.2040800.400] [PMID]

[17] Leutzinger TJ, Kingston DC, Dinkel DM, Wellsandt E, Knarr BA. Differences in knee joint moments between individuals who are living with obesity and those of a healthy weight when negotiating stairs. Knee. 2024; 49:217-25. [DOI:10.1016/j.knee.2024.07.006] [PMID]

[18] Sangkarit N, Tapanya W, Amput P, Muangchuen C, Seeta P, Paleeta W. Assessment of balance in overweight and obese young adults: Utilizing centre of pressure displacement variables in the single leg sit-to-stand test. Int J Adolesc Youth. 2025; 30(1):2470188. [DOI:10.1080/02673843.2025.2470188]

[19] Kong L, Zhang Z, Bao J, Zhu X, Tan Y, Xia X, et al. Influences of cognitive load on center of pressure trajectory of young male adults with excess weight during gait initiation. Front Bioeng Biotechnol. 2024; 11:1297068. [DOI:10.3389/fbioe.2023.1297068] [PMID]

[20] Steinberg N, Nemet D, Pantanowitz M, Eliakim A. Gait Pattern, Impact to the Skeleton and Postural Balance in Overweight and Obese Children: A Review. Sports (Basel). 2018; 6(3):75. [DOI:10.3390/sports6030075] [PMID]

[21] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 2021; 372:n71. [DOI:10.1136/bmj.n71] [PMID]

[22] Campbell M, McKenzie JE, Sowden A, Katikireddi SV, Brennan SE, Ellis S, et al. Synthesis without meta-analysis (SWiM) in systematic reviews: Reporting guideline. BMJ. 2020; 368:l6890. [DOI:10.1136/bmj.l6890] [PMID]

[23] Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health. 1998; 52(6):377-84. [DOI:10.1136/jech.52.6.377] [PMID]

[24] Zhao G, Ma F, Li L. An Analysis of Hip and Knee Joint Movement Characteristics in Overweight Individuals During Sit-to-Stand Transfers-Based on Statistical Parametric Mapping: An Exploratory Study. Life. 2026; 16(3):515. [DOI:10.3390/life16030515] [PMID]

[25] Kim HK, Lu SH, Lu TW, Chou LS. Contribution of lower extremity muscles to center of mass acceleration during walking: Effect of body weight. J Biomech. 2023; 146:111398. [DOI:10.1016/j.jbiomech.2022.111398] [PMID]

[26] Qu X, Hu X, Tao D. Gait initiation differences between overweight and normal weight individuals. Ergonomics. 2021; 64(8):995-1001. [DOI:10.1080/00140139.2021.1896788] [PMID]

[27] Zemková E, Kyselovičová O, Jeleň M, Kováčiková Z, Ollé G, Štefániková G, et al. The effect of 3 months aerobic and resistance training on step initiation speed and foot tapping frequency in the overweight and obese. Sport Sci Health. 2017; 13(2):331-9. [DOI:10.1007/s11332-017-0362-9]

[28] Lai PP, Leung AK, Li AN, Zhang M. Three-dimensional gait analysis of obese adults. Clin Biomech (Bristol). 2008; 23(Suppl 1):S2-6. [DOI:10.1016/j.clinbiomech.2008.02.004] [PMID]

[29] Liu ZQ, Yang F. Obesity May Not Induce Dynamic Stability Disadvantage during Overground Walking among Young Adults. PLoS One. 2017; 12(1):e0169766. [DOI:10.1371/journal.pone.0169766] [PMID]

[30] DeVita P, Hortobágyi T. Obesity is not associated with increased knee joint torque and power during level walking. J Biomech. 2003; 36(9):1355-62. [DOI:10.1016/S0021-9290(03)00119-2] [PMID]

[31] Lerner ZF, Board WJ, Browning RC. Effects of obesity on lower extremity muscle function during walking at two speeds. Gait Posture. 2014; 39(3):978-84. [DOI:10.1016/j.gaitpost.2013.12.020] [PMID]

[32] Messier SP, Davies AB, Moore DT, Davis SE, Pack RJ, Kazmar SC. Severe obesity: Effects on foot mechanics during walking. Foot Ankle Int. 1994; 15(1):29-34. [DOI:10.1177/107110079401500106] [PMID]

[33] Browning RC, Kram R. Effects of obesity on the biomechanics of walking at different speeds. Med Sci Sports Exerc. 2007; 39(9):1632-41. [DOI:10.1249/mss.0b013e318076b54b] [PMID]

[34] Haight DJ, Lerner ZF, Board WJ, Browning RC. A comparison of slow, uphill and fast, level walking on lower extremity biomechanics and tibiofemoral joint loading in obese and nonobese adults. J Orthop Res. 2014; 32(2):324-30. [DOI:10.1002/jor.22497] [PMID]

[35] Hills AP, Hennig EM, McDonald M, Bar-Or O. Plantar pressure differences between obese and non-obese adults: A biomechanical analysis. Int J Obes Relat Metab Disord. 2001; 25(11):1674-9. [DOI:10.1038/sj.ijo.0801785] [PMID]

[36] Naderi A, Baloochi R, Rostami KD, Fourchet F, Degens H. Obesity and foot muscle strength are associated with high dynamic plantar pressure during running. Foot (Edinb). 2020; 44:101683. [DOI:10.1016/j.foot.2020.101683] [PMID]

[37] Vincent HK, Kilgore JE 3rd, Chen C, Bruner M, Horodyski M, Vincent KR. Impact of Body Mass Index on Biomechanics of Recreational Runners. PM R. 2020; 12(11):1106-12. [DOI:10.1002/pmrj.12335] [PMID]

[38] Bollinger LM, Walaszek MC, Seay RF, Ransom AL. Knee extensor torque and BMI differently relate to sit-to-stand strategies in obesity. Clin Biomech (Bristol). 2019; 62:28-33. [DOI:10.1016/j.clinbiomech.2019.01.002] [PMID]

[39] de Souza SA, Faintuch J, Valezi AC, Sant' Anna AF, Gama-Rodrigues JJ, de Batista Fonseca IC, et al. Gait cinematic analysis in morbidly obese patients. Obes Surg. 2005; 15(9):1238-42. [DOI:10.1381/096089205774512627] [PMID]

[40] Gao X, Wang L, Shen F, Ma Y, Fan Y, Niu H. Dynamic walking stability of elderly people with various BMIs. Gait Posture. 2019; 68:168-73. [DOI:10.1016/j.gaitpost.2018.11.027] [PMID]

[41] Li L, Liu X, Liu Y. Coordination Patterns and Energy Flow Analysis in Sit-to-Stand Transitions Among Individuals with Different Body Mass Indexes. Life (Basel). 2025; 15(3):464. [DOI:10.3390/life15030464] [PMID]

[42] Russell EM, Braun B, Hamill J. Does stride length influence metabolic cost and biomechanical risk factors for knee osteoarthritis in obese women? Clin Biomech (Bristol). 2010; 25(5):438-43. [DOI:10.1016/j.clinbiomech.2010.01.016] [PMID]

[43] Valizadehorang A, Jafarnezhadgero A, Alihosseini S. [The Effects of Motion Control Shoes on Knee Joint Co-Contraction in Overweight Individuals With Flat Feet (Persian)]. Sci J Rehabil Med. 2022; 10(6):1182-93. [DOI:10.32598/SJRM.10.6.5]

[44] Veras L, Diniz-Sousa F, Boppre G, Devezas V, Santos-Sousa H, Preto J, et al. Accelerometer-based prediction of skeletal mechanical loading during walking in normal weight to severely obese subjects. Osteoporos Int. 2020; 31(7):1239-50. [DOI:10.1007/s00198-020-05295-2] [PMID]

[45] Wu X, Yeoh HT, Soangra R, Lockhart TE. Investigation into the Functional Mobility Difference between Obese and Non-Obese Elderly. Proc Hum Factors Ergon Soc Annu Meet. 2012; 56(1):1814-6. [DOI:10.1177/1071181312561365]

[46] Piri E, Jafarnezhadgero AA. [A review of running mechanics in obese or overweight individuals (Persian)]. J Sport Biomech. 2023; 9(1):16-31. [DOI:10.61186/JSportBiomech.9.1.16]

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