

REVIEW ARTICLE

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Techniques and Methods

Association of obesity with musculoskeletal health and functional mobility in females—a systematic review

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Obesity is a prevalent global health challenge with a significant yet unclear impact on musculoskeletal health, particularly among females. This systematic review aimed to unravel the association between obesity and musculoskeletal health, as well as functional mobility in women. A comprehensive literature search was conducted across PubMed, Scopus, Web of Science, and the Cochrane Library for articles published between January 2001 and December 2023. Studies were selected based on their examination of the relationship between overweight or obesity and musculoskeletal health (including bones, joints, and soft tissues) and/or functional mobility in adult females (age ≥ 19) within the general population. Studies focusing on selective populations, or involving subjects with other health conditions or work-related musculoskeletal issues, were excluded. The data collected revealed a direct impact of obesity on musculoskeletal health, gait, and functional mobility, especially among women. Markedly, there was a strong association between obesity and musculoskeletal pain, particularly lower back pain. Obesity significantly alters gait biomechanics, leading to increased plantar pressure, altered kinematic patterns, and higher energy expenditure during walking. Higher BMI was found to significantly impact mobility-related limitations. Data also revealed that obesity, especially with BMI levels above 35 kg/m², adversely affects weight-bearing tasks such as walking, stair climbing, and chair rise ability. The findings of this systematic review emphasize the need for targeted interventions to address obesity-related mobility challenges, gait alterations and musculoskeletal pain to allow independence and enhanced functional outcomes in the daily activities of individuals with obesity. Exploring gender differences in obesity towards better understanding of the effect of obesity on the musculoskeletal health and functional mobility of women is critical for devising female-specific mitigation measures and optimizing management and treatment modalities, including pharmacotherapy.

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INTRODUCTION

Prevalence

With more than two billion people (30% of the world's population) overweight or with obesity and an annual cost of \$2.1 trillion, obesity poses severe global health and economic problems [1]. According to new research by the McKinsey Global Institute (MGI), a devastating \$2.1 trillion, or 2.8 percent of global GDP is currently spent on obesity related health problems annually, but less than 1% on prevention [2]. Today, obesity comprises the 5th leading risk factor for mortality in the world (around 3.4 million annual deaths), as it significantly increases the risk for developing numerous chronic diseases including coronary heart disease (by over 50%), ischemic stroke (by 44%), type 2 diabetes (by 23%), as well as many cancers (up to 41%) [1–3]. The problem is expected to worsen, where almost half of the world's adult population is expected to be overweight or with obesity by 2030 [2]. The global trend of sustained growth in obesity prevalence indicates that the

current measures in the prevention, treatment, and management of the condition are largely ineffective. World Health Organization (WHO) 2016 data reveals that the UAE currently ranks fifth in the world in obesity, at a prevalence rate of 36% (33% males and 39% females) [1]. In other words, three in every ten Emirati males and almost four out of every ten females have obesity, with an economic burden amounting to \$6 billion/year in associated disease cost [2]. If we also include the percentage of overweight individuals, based on the most recent Global Burden of Disease report [1], more than 60% of men and 66% of women in the UAE are currently overweight or with obesity (average of 63% or more than double the global average of 30%). Furthermore, while the UAE slightly fares better than the US in adult obesity prevalence (US current rate is 38%), UAE children are 1.8 times more likely to have obesity than American children, indicating a dangerous future trend and prognosis as well as ineffective prediction tools and preventive/intervention strategies, particularly considering

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the very young median age of the population (30.3 years) [3]. This instigates huge health and economic challenges since obesity is an independent risk factor for both T2D and CVD, the major culprits for mortality and morbidity in the UAE [3].

The biomechanics of obesity

The biomechanical impact of obesity on the musculoskeletal system comprises a complex mechanical and biochemical interplay, typically resulting in a cascading vicious cycle of events leading to musculoskeletal dysfunction. The additional loading placed on the weight bearing joints (hip, knee, ankle), due to extra body weight, accelerates the wear of cartilage and increases the risk of joint pathology, including osteoarthritis. Excessive loading also compromises the structural integrity of these joints, resulting in a reduction of joint space, as well as formation of osteophytes and subchondral bone sclerosis. From a biochemical perspective, obesity results in systemic metabolic dysfunction due to secreted adipokines, including leptin, resistin, and adiponectin, associated with chronic low-grade inflammation. This pro-inflammatory state further exacerbates joint degradation and reduces the ability to regenerate cartilage, hence accelerating the progression of osteoarthritic changes and altering the joint biomechanics. Obesity-related metabolic syndrome and insulin resistance are also associated with joint pathology by enhancing oxidative stress and impairing chondrocyte function, leading to further breakdown of cartilage [4].

Mechanically, obesity poses a significant burden on the musculoskeletal system [5]. Individuals with higher waist circumference and body mass demonstrate difficulty in walking, balance, and maintaining strength and mobility while performing basic daily living activities. Individuals with obesity are reported to have greater musculoskeletal loading and higher, abnormally distributed joint loads, particularly on the lower extremity joints (hip, knee, ankle) during weight bearing tasks, such as walking and stair climbing [6, 7]. In their study on lower extremity joint forces in healthy weight, overweight, and individuals with obesity, Stanford et al. found a significant increase in absolute peak hip, knee, and ankle joint forces by 40%, 43%, and 48%, respectively, for the high-BMI versus normal group. This study also confirmed that body mass accounted for 70–80% of the variation in the peak compressive loads at the hip, knee, and ankle during gait, where the joint loads increased approximately linearly with the body mass [8]. A subject- and kinematics-specific musculoskeletal modeling approach was used by [9] to compare spinal loads between people with normal weight and people with obesity performing static two-handed load-reaching activities. Each model incorporated personalized muscle architectures, body mass distributions, and full-body kinematics for each subject and task. The results indicated that individuals with obesity experienced significantly larger (by ~38% in average) L5-S1 compression (2305 ± 468 N versus 1674 ± 337 N) and shear (508 ± 111 N versus 705 ± 150 N) loads during all reaching activities.

Obesity is also associated with structural changes in the musculoskeletal system, decreased range of motion and mobility, modification of the gait patterns and changes in the absolute and relative energy expenditures for a given activity [7]. There is growing evidence on the impact of obesity on skeletal muscle function, including impairment in oxidative capacity, abnormal muscle fiber organization, and interruption of the calcium cycle, inducing easy fatigue and an overall decline in contractile function [10]. Individuals with obesity are also reported to have reduced maximum muscle strength in the lower limb muscles (anti-gravity muscles) relative to their body mass as compared to individuals without obesity [11]. This results in the increased risk of developing osteoarthritis and various functional limitations, especially in the elderly, where high levels of adiposity and sarcopenia may impair agonist muscle activation. Obesity-related decline in function and physical performance are due, in part, to

compromised muscle strength, power, and endurance with several underlying mechanisms implicated, including alterations in myofibrillar protein function and cellular contractile properties, as well as morphological adaptations, such as shifts in fiber type composition and increased intramyocellular lipid content within skeletal muscle. Obesity is also associated with reducing skeletal muscle contractility in older adults. This potentially results in reduced function partly due to altered cellular (single fiber) and molecular (myosin-actin interactions) properties [12].

Moreover, obesity significantly leads to alterations in spinal biomechanics and kinematics of the pelvis, impacting postural balance, as well as the functional performance in a wide range of activities of daily living (ADLs). Increased loads on the pelvis and spine often disturb normal posture and gait patterns [13], leading to increased lumbar lordosis and waddling gait, characterized by excessive lateral pelvic tilt and trunk sway [14]. The increased mechanical load, muscle imbalances, gait alterations, and inflammatory state associated with obesity contribute to degenerative changes in the spine and pelvis, potentially leading to diminished functional mobility and chronic low back pain (CLBP)). Obesity has been associated with changes in spinal posture, and spinal as well as hip motion/kinematics in adults. This includes increased thoracic kyphosis but decreased spinal and hip mobility, except for thoracic lateral flexion [15].

Relative to the extensive literature available on many aspects of obesity, there is a scarcity of information pertaining to the functional musculoskeletal and biomechanical limitations imposed by the condition [5, 7]. Quantifying how obesity affects the biomechanics of locomotion and gait, muscle structure and function, as well as postural changes, provides insight into the relationship between metabolic and mechanical energetics, mechanical loading and the risk of musculoskeletal injury and allows for data-driven, informed intervention [6].

Obesity, mobility, and quality of life

Functional mobility (FM) is defined as a person's physiological ability to move independently and safely in diverse environments in order to accomplish functional tasks/activities and to effectively participate in the activities of daily living (ADL) at home, at work, and in the community [8]. One of the big challenges in obesity is the vicious circle created by the extra weight, where the increase of weight typically leads to less mobility, which yet results in more weight gained. Pataky et al. [9] argued that while significant advances in the understanding of the nature of obesity and its consequences on musculoskeletal health, gait and posture have been accomplished, the functional capacity of individuals with obesity as related daily physical activities remains elusive [9]. This was mainly attributed to the focus on one element of functional capacity (such as gait, endurance, or balance), rather than its multifaceted nature. The International Classification of Functioning and Disability (ICF) developed by WHO provides a global framework to describe the impact of health conditions, such as obesity, on functional living. In a review article by Forhan et al. [8], the compromised mobility experienced by persons with obesity was associated with reduced health-related quality of life (HRQoL) as compared to normal weight individuals. The various measures of quality of life and functional mobility used in the different articles consistently demonstrated an association between obesity, impairments of body functions and structures and personal and environmental factors which contributed to mobility disability. Busutil et al. [16] studied the effect of obesity on the HRQoL in Spain using Spanish National Health Survey data. They found that a BMI ≥ 35 reduced HRQoL even in the absence of chronic diseases. Obesity increased the probability of HRQoL problems in mobility (11.8%), self-care (2.2%), usual activities (4.3%) and pain/discomfort (7.4%). Furthermore, this study suggested that HRQoL in women was significantly worse than average.

Obesity is also associated with a significant psychosocial burden, which ultimately impacts the quality of life. Many individuals with obesity, especially women, also struggle with issues related to mood, self-esteem, depression and anxiety, and body image. This emotional distress can impact successful treatment, including exercise and diet, significantly affecting mobility and health-related quality of life (HRQoL) [17, 18]. In their study on the psychological impact of obesity, Asharaf et al. [19] highlighted the intricate interactions among obesity, weight-related symptoms, HRQoL, and mental health, where they found significant correlations between obesity and fatigue, joint pain, and depression. These authors emphasized the need for tailored interventions, early prevention, and targeted management strategies for vulnerable subgroups to enhance the overall mobility, well-being and mental health of individuals with obesity. Another recent study by [20] shows that although their male participants had a higher degree of obesity, their self-esteem showed a higher level of confidence. Interestingly, in accordance with the degree of obesity, the males perceived their own body image, at a pre-obesity level, although in terms of the abdominal obesity degree, most males were below the threshold value of 90%.

Obesity has also been closely linked with multiple social and environmental determinants, including individual characteristics (e.g. sex, age, race, ethnicity, and socioeconomic status (SES)), environmental characteristics (e.g. living space and socio-cultural norms), and social hierarchy (e.g. social status/rank) influences [21]. In particular, socioeconomic disparities in obesity persist worldwide, where higher rates of obesity, and resulting lower functional mobility, are associated with low socioeconomic status individuals, as high calorie, energy dense food options are or perceived as more affordable. Additionally, environments experiencing deprivation, disorder, or high crime have been shown to be associated with higher odds of obesity, which may appear more frequently in low social status individuals [22].

Considering the high prevalence of obesity and consistent early onset, its devastating musculoskeletal health impact, and the significant effects on FM and HRQOL in females, this review focused on the association of obesity with musculoskeletal health and functional mobility in females. The remainder of the article is organized as follows: Section “Materials and methods” discusses the review approach, while Sections “Musculoskeletal health”, “Gait and function”, and “Functional mobility” provide the review results pertaining to musculoskeletal health, gait and function, and functional mobility among females, respectively. The economical burden of obesity/overweight is discussed in Section “Economic burden”. Sections “Clinical implications and future research directions” and “Limitations” highlight the clinical implications and limitations of this study, respectively, and finally,

Section “Conclusion and future work” offers the concluding remarks.

MATERIALS AND METHODS

Review design

This review was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol [23]. Motivated by the continuous worldwide increase in the prevalence of obesity and its impact on musculoskeletal system in association with gait and daily activities, and how the health span of females, from puberty to childbearing and through menopause, puts them at a unique risk for obesity, we systematically reviewed articles addressing the effect of overweight and/or obesity on the musculoskeletal health and mobility of female adults, which included observational studies of longitudinal and cross-sectional type, population and cohort-based studies, as well as reviews.

Search strategy

A systematic search of published articles between January 2001 to December 2023 was conducted using the databases of PubMed, Scopus, Web of Science, and Cochrane Library. According to the syntax rules of each database, the following keywords were logically combined to identify relevant studies addressing the effects of overweight/obesity on musculoskeletal biomechanics: *obes**, *overweight*, *excess weight*, *BMI*, *body mass index*, *weight gain*, *increased weight*, *bone health*, *bone mineral density*, *soft tissue*, *biomechanic**, *orthopedic**, *orthopaedic**, *low back pain*, *musculoskeletal pain*, *bone**, *feet*, *foot*, *hip*, *joint**, *injur**, *fracture**, *trauma**, *lesion**, *mobility*, *motion*, *movement*, and *walking*. Included studies were those focused on female adults representing a general population. The search was limited to articles published in English language only.

A sample search query applied in the PubMed database is given in Table 1. The search results were further analyzed using the VOSviewer, which constructs maps of the keywords (title and abstract) based on occurrence, as shown in Fig. 1 [24]. This depiction helps to understand the nature of the articles identified during the search process while using a combination of keywords as discussed above. The size of the label and area of the circle represent the total occurrences of the keywords (i.e. the relative relevance of that keyword/topic among the list of the search results).

Selection criteria

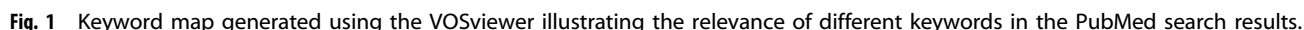
This systematic review included original, peer-reviewed scientific journals and conference articles which met the following criteria:

- The studies examining the relationship of overweight or obesity with musculoskeletal health, including bone, joint, and soft-tissues;

Table 1. A sample search query used in the PubMed database.

Keywords	overweight, excess weight, BMI, body mass index, obes*, weight gain, increased weight	bone health, soft tissue, musculoskeletal, biomechanic*, orthopedic*, orthopaedic*, low back pain, musculoskeletal pain, bone*, foot, feet, hip, joint*, injur*, fracture*, trauma*, lesion*	mobility, motion, movement, walking
Search query	(((“obes*”[Title] OR “overweight”[Title] OR “excess weight”[Title] OR “BMI”[Title] OR “body mass index”[Title] OR “weight gain”[Title] OR “increased weight”[Title]) AND (“bone health”[Title] OR “soft tissue”[Title] OR “Musculoskeletal”[Title] OR “biomechanic*”[Title] OR “orthopedic*”[Title] OR “orthopaedic*”[Title] OR “low back pain”[Title] OR “musculoskeletal pain”[MeSH Terms] OR “musculoskeletal pain”[Title] OR (“bone*”[Title] OR “feet”[Title] OR “foot”[Title] OR “hip”[Title] OR “joint*”[Title]) AND (“injur*”[Title] OR “fracture*”[Title] OR “trauma*”[Title] OR “lesion*”[Title])) OR (“mobility”[Title] OR “motion”[Title] OR “movement”[Title] OR “walking”[Title]) NOT “social mobility”[All Fields])) NOT (“child*”[Title] OR “teen*”[Title] OR “adolescen*”[Title] OR “youth”[Title] OR “pediatric*”[Title] OR “paediatric*”[Title] OR “juvenile”[Title]) AND (2001/1/1:2023/12/31[pdat])		

The same query was applied to other databases, with the syntax adapted to suit the requirements of each search engine.



- e.g., influence of obesity and muscle strength on mobility;
- Letters to editor and editorials, opinion pieces, conference summary, comment, short survey, and note;
- Non-English publication.

A PRISMA flow diagram illustrating the process of search and screening of articles is shown in Fig. 2.

The title and abstract of each article were initially screened by one author (DMM) and verified by the other author (KK) against the predefined inclusion and exclusion criteria. The full text of the potentially eligible records was obtained and reviewed to determine final inclusion by DMM, followed by verification by KK. Extracted information included author name and year of publication, study design and setting, participant age, sample size, sample BMI, co-variables, adjustment parameters, assessment/measurement protocol, data analysis protocol, and key findings (Tables 2 and 3). Inconsistencies and disagreements were resolved through discussion, and if consensus could not be reached, a third author (FAA) was consulted. This process ensured inter-rater reliability and minimized bias in data collection. Additionally, the reference lists of the included articles were scanned to identify additional publications of interest.

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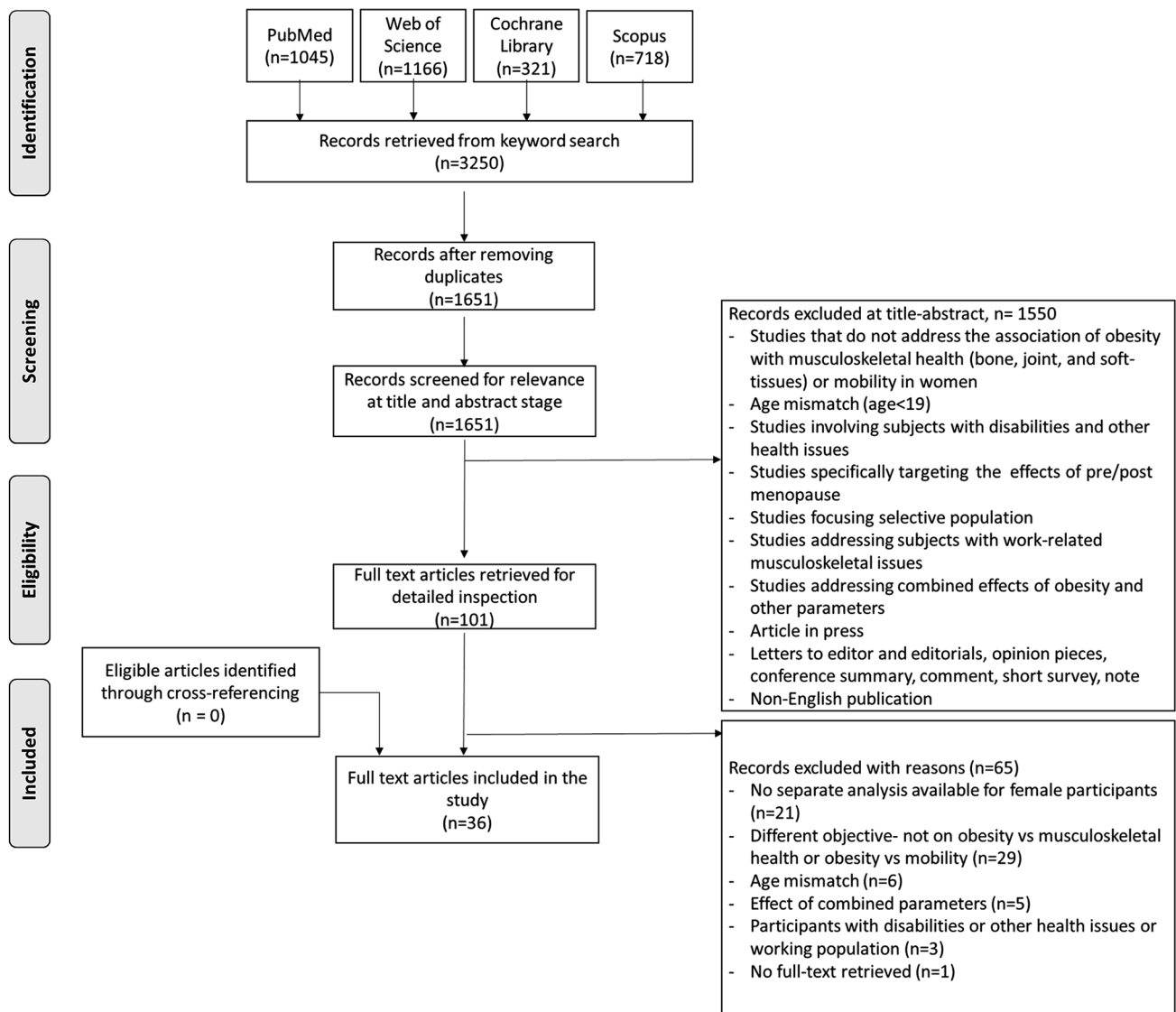


Fig. 2 Flowchart of the search and screening process based on PRISMA guidelines.

The data were then analyzed using descriptive methods, including tabulation of the study characteristics and summarization of outcomes. Key characteristics and results were compared with similar studies to draw concluding remarks and identify future research direction.

MUSCULOSKELETAL HEALTH

Based on the search criteria, a total of 20 articles, including reviews which examined the musculoskeletal consequences of obesity, were identified (Table 2). Although several factors are known to contribute to musculoskeletal issues, this study will particularly focus on the association of obesity with musculoskeletal health in females.

This section is divided into three subsections highlighting pain and fracture, gait, and functional mobility.

Pain and fracture

The risk of developing lower back pain (LBP) with increasing BMI has been well documented in the literature for decades. However, the link between musculoskeletal pain and weight-related factors remains controversial. An earlier study, involving 709 Japanese middle-aged (40–69 years) women, found a higher prevalence of

frequent shoulder pain at age 50, as well as an increased prevalence of frequent leg pain and difficulty of daily movements as a result of increased BMI [25]. On the other hand, data from U.A.E residents revealed only a moderate association of obesity with LBP [26]. This cross-sectional study analyzed interview questionnaire data of 374 females and 428 male residents of the U.A.E and identified that the prevalence of LBP in the population with obesity was higher among females (41.3%) than males (24.6%), further establishing the fact that obesity was moderately associated with LBP. In subsequent work, the authors reviewed 95 articles and the meta-analysis of 33 studies, and the results highlighted gender-specific observations on obesity and LBP. Based on the analysis of cross-sectional studies, both women with obesity and overweight exhibited an increased prevalence of back pain in the past 12 months. On the contrary, analyses from cohort studies revealed that obesity, but not overweight, was a risk factor for developing lower back pain in the past 12 months, among female subjects. Although men were at risk of developing lower back pain, the severity was less compared to women. A possible explanation for this gender-related difference could be the hormone-related obesity and associated changes in pain sensitivity, or difference in the proportion of mass distribution, or small sample size [27, 28].

Table 2. Studies on the association of obesity/overweight with musculoskeletal health.

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[25]	Study	40–69	709 Japanese women.	22.6 ± 2.7	Measured BMI, current smoking habits, frequency of pain, and difficulty of daily movements.	Age and current smoking.	Questionnaires.	Higher prevalence of frequent shoulder pain at age 50, and increased prevalence of frequent leg pain and difficulty with daily movements as a result of increased BMI.
[26]	Cross-sectional	25–65; 38.2 ± 10.5 (W)	802 (T), 374 (W)	27.8 ± 5.6 (W)	3 BMI groups: <25 (acceptable weight), 25–29.9 (people with overweight), and BMI > 30 (people with obesity); age, educational level, occupation, place of living, type of housing condition, and smoking habits.	None.	Face-to-face interview questionnaires.	LBP prevalence in individuals with obesity is higher among females (41.3%) than males (24.6%). Moderate association between BMI and obesity.
[68]	Cross-sectional (Finland)	24–39	2182 (T), 1172 (W)	24.5 ± 4.6 (W)	3 BMI classes: 25.0–29.9 kg/m ² (people with overweight), 30.0–34.9 kg/m ² (people with obesity), >35.0 kg/m ² (people with severe obesity); weight circumference, hip circumference, weight-to-hip ratio, socioeconomic factors, C-reactive protein, leptin, Adiponectin, smoking, and leisure time physical activity.	Age, socioeconomic status, and smoking.	Questionnaires.	Women with higher BMI, waist and hip circumference, waist-to-hip ratio, serum leptin levels, and C-reactive protein showed a higher prevalence of obesity.
[29]	Cross-sectional	38.3 ± 8.9 (people with obesity w/o LBP), 42.8 ± 11.9 (people with obesity with LBP), 31.9 ± 8.6 (people with normal weight)	37 (W) (13 people with obesity w/o LBP, 13 with LBP, 11 normal)	BMI 39.2 ± 3.6 kg/m ² (people with obesity w/o LBP), 41.9 ± 5.3 kg/m ² (people with obesity with LBP), 20.1 ± 1.2 kg/m ² (people with normal weight)	3 BMI groups: People with obesity without LBP, people with obesity with healthy subject, kinematic data of lateral bending and forward flexion.	N/A	6-camera optoelectronic motion analysis system.	Participants with obesity exhibited a reduced range of motion in the spine as a result of reduced mobility at pelvic and thoracic levels. Patients with obesity and cLBP showed increased lumbar lordosis. A higher degree of spine impairment was observed in subjects with cLBP compared to subjects with obesity but no cLBP.
[30]	Prospective cohort study (Norwegian county)	30–69 at baseline	25,450 (T), 14,048 (W)	<25 to ≥30	BMI groups: <25, 25–29.9, ≥30 (measured at clinical examination), presence/absence of cLBP, personal features (gender,	Age, education, work status, physical activity, smoking, blood pressure, and lipid levels.	Survey questionnaires and clinical consultation.	Women reported higher crude risk, and a higher crude recurrence of LBP than men across all age groups. Higher BMI values were associated with increased recurrence of LBP in both men and

Table 2. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[34]	Meta-analysis of prospective cohort study	Adults	3,126,313 (T)	≥28.0 kg/m ²	age, education, work status, physical activity, smoking habit), medical examination (blood pressure and lipid levels), and follow up after 11 years. BMI (normal weight group, group with obesity) and hip fracture.	Varied adjustment parameters across the selected studies, which included age, height, physical activity, diabetes mellitus, smoking, etc.	Data extracted from published cohort studies through systematic review of articles.	women. Recurrence of LBP was associated with increasing BMI among women after adjusting for age, but the association was weakened by further adjustment for confounding factors. Studies suggest that obesity significantly reduces the risk of hip fractures.
[36]	Cohort study (Norway)	50–79 at baseline; mean age 65.3	61,787 (T), 29,511 (W)	<22 to ≥30	4 BMI groups: (<22, 22–<25, 25–<30, and ≥30) (BMI measured Objectively); Hip fraction definition according to International Classification of Diseases, Ninth Revision (codes 820–820.9), and the International Classification of Diseases, Tenth Revision (codes S720–S722).	Age, marital status, height, smoking, degree of urbanization, and survey region.	Surveys and hip fracture data obtained electronically from hospitals.	Women with higher BMI (≥25) had a decreased risk of hip fracture compared with those with BMI <22 and 22–24.9. Inverse association between BMI and hip-fracture was linear among women aged 70–79. However, for the age group of 50–59 and 60–69, the hip fracture risk was highest for those with BMI <22, and the curved association levelled off at BMIs of 25 and above.
[35]	Cross-sectional and longitudinal	50 and above	56,002 (T), 51,313 (W)	<18.5 to ≥35	BMI groups: <18.5 kg/m ² (people with underweight), 18.5 to <25 kg/m ² (people with normal weight), 25 to <30 kg/m ² (people with overweight), ≥30 to <35 kg/m ² (people with class I obesity), ≥35 kg/m ² (people with class II obesity) using WHO standard, cross-sectional moment of inertia, cross-sectional area, femoral strength index, incident major osteoporotic fractures.	Age, prior fracture, parental hip fracture, rheumatoid arthritis, chronic obstructive pulmonary disease, alcohol abuse diagnosis, recent glucocorticoid use, and recent osteoporosis medication use.	Dual-energy X-ray absorptiometry (Lunar DPX prior to 2000; GE Lunar Prodigy after 2000) for bone mineral density, height and weight measured by stadiometer and floor scale in 82%, as well as by self-report in 18%, hospital records.	Association of increased BMI with a lower risk of major osteoporotic fractures and hip fracture in women. The protective association of BMI with MOF was largely explained by the higher bone mineral density, but partially for the association of BMI with hip fracture. This suggests that factors not associated with BMD, such as soft tissue thickness at the hip may have contributed to the lower risk of hip fracture among women.

Table 2. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[31]	New analysis of a previous cross-sectional study	40–59	6079 (W)	24.4	BMI groups; <18.5 kg/m ² (low body weight), 18.5 to 24.9 kg/m ² (normal weight), BMI 25.0 to 29.9 kg/m ² (overweight), ≥30.0 kg/m ² (obesity), abdominal perimeter, age, personal study level, smoking, alcohol consumption, physical activity, parity, having a stable partner, natural or surgical menopause, anxiety and depressive symptoms, use of hormonal or alternative therapies for menopausal symptoms, oral contraceptive use, and past history of chronic diseases.	N/A	Questionnaires.	Women with low BMI had a decreased risk of musculoskeletal pain, overweight women had a higher risk, and women with obesity had the highest risk compared to those of normal weight. Obesity is a significant risk factor for musculoskeletal pain in middle-aged women.
[37]	Cohort study (Korea)	59.9 ± 7.4 years	288,058 (T), 6079 (W)	24.1 ± 3.0	7 BMI groups: <18.5, 18.5–20.9, 21–22.9, 23–24.9, 25–27.4, 27.5–29.9, ≥30, age, sex, smoking habit, alcohol use, physical activity, income status, comorbidity, and medication use.	Age, sex, smoking status, alcohol consumption, physical activity, beneficiary income status, oral steroid use, hormone replacement therapy use, and prevalent osteoporosis, comorbid diabetes, hypertension, rheumatoid arthritis, ischemic stroke, myocardial infarction, heart failure, liver cirrhosis, and chronic kidney disease.	Objectively measured BMI, fasting serum glucose assessed using enzymatic methods, Smoking history, alcohol use, and physical activity reported via a questionnaire.	Overweight group exhibited the lowest risk of hip fracture. An inverse association between BMI and hip fracture was observed in women with a BMI <25 kg/m ² . Among women with BMI ≥ 25, a 5% increase in BMI was associated with a 26% increase in hip fracture risk.

Table 2. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[54]	Experimental study	19–48; mean 33.11	132 (T), 50 (W)	Mean BMI 26.31 ± 2.75	Anthropometric measures of obesity (weight, body mass index, waist circumference, hip circumference, and waist-hip ratio) and degree of pain intensity.	N/A	Height and weight measured by stadiometer and waist and hip circumferences measured using flexible tapes. Intensity of pain was rated using visual analog scales.	No association was found between the anthropometric indices of obesity and the degree of pain intensity in patients with chronic non-specific low back pain.
[53]	Observational analytic study with cross sectional	50–60 (54.08 ± 4.00)	12 (W)	BMI 31.52 ± 3.83 (26.4 to 36.9)	BMI, age, height, weight, Lumbar axis, and pain intensity on Visual Analog Scale.	N/A	Lumbosacral photography, visual analog scale for pain intensity reading.	No significant association was found between BMI and low back pain. A significant association was observed between BMI and the lumbosacral axis.
[69]	Cross-sectional study	≥ 70	14,155 (T), 7680 (W)	27.9 ± 4.5 (T)	Pain data, BMI, age, living arrangement, years of education and depressive symptoms.	Age and depression.	Self-reported pain data, objectively measured height and weight, questionnaires, and depressive symptoms assessed via the Center for Epidemiologic Studies Depression Scale.	Overweight female participants had 50% higher odds of reporting moderate to severe LBP compared to healthy counterparts at baseline, after adjusting for age and depression. Male and female subjects with obesity had more than twice the odds of reporting moderate to severe LBP compared to healthy individuals at baseline BMI.
[32]	Cross-sectional study	Age > 18; 46.28 ± 10.59 (W)	466 (T), 342 (W)	Participants mean BMI 42.77 ± 5.64; 42.52 ± 10.51 (W)	BMI ≥ 35 kg/m ² with comorbidities or ≥ 40 kg/m ² without comorbidities, personal feature (gender, age and body mass index), and pain intensity in seven anatomical region.	N/A	Pain intensity assessed using a numeric rating scale ranging from 0 to 10.	A higher prevalence of MSK pain was observed in women compared to men (95% vs. 77.4%). Pain intensity was also higher among females. A moderate positive correlation between BMI and numeric rating scale scores was found in women for the shoulder ($p = 0.010$), knee ($p = 0.042$), and ankle ($p = 0.024$). No Significant associations were found for other regions in either men or women.
[55]	Prospective population based cohort (UK)	45–64	938 (W)	25.51 ± 4.15 (at baseline, year 1), 27.80 ± 4.90 (end of follow up, year 20)	BMI groups: People with slight overweight, lower upper overweight to obesity, lower obesity, upper obesity, and two groups of people with normal weight; musculoskeletal pain, age, current	Age, menopause status, the number of live births, smoking habits, alcohol drinking, physical activity, oral contraceptive pill use, hormone	Medical examinations.	Women with BMI 27–34 were more likely to experience musculoskeletal pain and those with BMI above 40 had a higher risk of all-cause and cardiovascular mortality.

Table 2. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[58]	Cross-sectional study	18–32 and 45–88	141 postmenopausal and 118 young women	27.1 ± 5.3 postmenopausal and 22.4 ± 4.5	menopause status, physical activity, use of oral contraceptive pill or hormone replacement therapy, use of analgesic medication, history of hysterectomy, cancer, orthopedic operations, other major illness, and any fractures in last 10 years.	replacement therapy use, analgesic use, hysterectomy, cancer, fractures, orthopedic operations, and other major illness.	Bio-electrical impedance analyzer, calcaneal quantitative ultrasound, hand dynamometer, and modified short physical performance battery test.	Higher prevalence of low muscle mass was observed among young participants compared to older adults. Older adults had a higher prevalence of obesity and low bone density compared to younger counterparts.
[56]	Cross-sectional study	25–65	443 (W)	≤18.5 kg/m ² to ≥30 kg/m ²	BMI, height, weight, and musculoskeletal pain.	None.	Objectively measured height and weight, questionnaire.	Increased risk of upper and lower back pain was observed among women with obesity and overweight.
[57]	Analytical cross-sectional study	53.0 median	19,716 (T), 10,282 (W)	≤18.5 kg/m ² to ≥30 kg/m ²	Age, sex, BMI, chronic low back pain, and physical activity.	Sex, age, physical occupational demands, and recreational physical activity.	Self-reported BMI and Questionnaire.	Obesity increased the odds of chronic low back pain (cLBP) by 1.719 times, and being female increased the odds by 1.683 times.

T total participants, W women participants.

Table 3. A summary of the key research findings from the identified articles.

Article	Key findings
[25]	Increased BMI was associated with a higher prevalence of frequent shoulder pain, leg pain, and difficulty in performing daily movements.
[26, 30]	Higher prevalence of LBP was observed in females with obesity compared to their male counterparts.
[29]	Obesity was linked to a reduced range of motion in the spine.
[34–36]	Increased BMI was associated with a lower risk of major osteoporotic fractures and hip fractures in women.
[31]	Obesity has been identified as a risk factor for musculoskeletal pain in middle-aged women.
[37]	An inverse association was reported between BMI and hip fracture in women with a BMI < 25 kg/m ² . However, in women with a BMI ≥ 25 kg/m ² , increased BMI was associated with an increased risk of hip fracture.
[53, 54]	No significant association between BMI and low back pain was reported.
[57, 69]	Increased BMI was associated with a higher incidence of LBP.
[32, 55, 56]	Increased BMI was associated with a higher risk of MSK pain.
[43]	Subjects with obesity showed higher metabolic cost, greater relative aerobic effort while walking at preferred speed compared to normal subjects. No difference in the gross energetic cost per distance of walking.
[44]	Women with obesity had a higher net metabolic rate.
[42]	Individuals with obesity exhibited reduced trunk flexion, increased base of support width, thoracic and thoracolumbar motion restrictions, and significant postural adaptations with increased hip joint moment during standing tasks.
[41]	Subjects with obesity exhibited altered standing posture, limited spinal range of motion, larger Initial pelvic tilt angle, limited thoracic movement, particularly in forward flexion and lateral bending.
[39]	Increased BMI was associated with an increased plantar pressure at certain foot regions.
[46]	Both individuals with obesity and individuals without obesity showed an increased knee extensor moment and decreased hip extensor moments after 30 min walking session, but no changes in knee and hip adduction moments. The association between joint moments and BMI was weak.
[38]	Significant between-group differences were found in peak pressure, pressure impulse, and contact pressure for most foot regions, except the second through fifth toes and first metatarsal.
[40]	Normal BMI had faster gait velocity, shorter percentage of gait cycle spent in stance and larger percentage in swing than those in the higher BMI classes.
[45]	Women with obesity walk with a greater relative effort, which was attributed to obesity related increases in joint torques than strength.
[47]	Women in the underweight, overweight, and obesity group were at the highest risk of developing functional limitations, with no association found between muscle mass and functional limitations.
[48–50, 52]	Obesity was associated with an increased risk of walking disability.
[51]	Higher prevalence rate for women than men for both mobility and ADL disability across 5 different research sites.

A cross-sectional study which examined the young Finnish population of ages ranging from 24 to 39 for the association of various weight-related factors (BMI, waist circumference, hip circumference, waist-to-hip ratio), adipokins, and C-reactive protein with LBP further ascertained that obesity is associated with LBP in women, but not in men. Among the various weight-related factors assessed, waist circumference was the highest risk factor for LBP in women. The effect of obesity and low back pain on the kinematics of trunk motion was also examined in [29]. This study was conducted on a small sample size of 37 women (13 subjects with obesity without LBP, 13 subjects with obesity with non-specific chronic LBP, and 11 normal subjects with no history of musculoskeletal issues), and the kinematics, including lateral bending (frontal plane) and forward flexion (sagittal plane) data were acquired. The subjects with obesity and chronic low back pain (cLBP) were characterized by a reduced range of motion of the spine as a result of impaired mobility, as well as increased lumbar lordosis as compared to individuals with obesity and no cLBP.

The thoracic range of motion was also found to be significantly lower in both the subjects with obesity without cLBP and the subjects with obesity with cLBP groups compared to the normal group, whereas the lumbar range of motion remained the same across the three sub-groups. Heuch et al. examined data from 2 surveys (HUNT 2 study and HUNT 3) conducted approximately 11 years apart in a Norwegian county further highlighted the risk of developing chronic LBP (cLBP) in relation to obesity [30]. This

11-year follow-up study, which examined data from 14,048 females, aged 30–69 years old found that crude risk, as well as crude recurrence of cLBP were higher among women than men in all age groups. The association between increasing BMI and recurrence of cLBP was noticeable among women after adjusting for age, while further adjustment for confounding factors weakened this association. Logistic regression analysis after adjusting for age also revealed a positive association of BMI with the risk of cLBP among women. Studies have further confirmed that obesity is a risk factor for musculoskeletal pain among women [31, 32]. In [31], data from 6079 middle-aged [33–52] Latin-American women revealed that women with low BMI (<18.5) showed non-significant lower risk, while women with overweight and obesity exhibited an increased risk of musculoskeletal pain. Rosa et al. reported similar findings in their cross-sectional study that examined a total of 466 middle-aged individuals (with 342 females) with severe obesity (BMI ≥ 35 kg/m² with comorbidities or ≥ 40 kg/m² without comorbidities). Prevalence of pain was reported by 95% of women (compared to 77.4% for men) with 57.8% reporting severe pain. A moderate positive correlation between BMI and pain at the shoulder ($p = 0.010$), knee ($p = 0.042$), and ankle ($p = 0.024$) joints was also recorded. This study further emphasizes that female gender and obesity were significant factors associated with the prevalence and intensity of MSK pain. A higher prevalence of moderate to severe LBP was also reported among community-dwelling older female Australians than males (18% vs. 11%) and being overweight or with obesity

was a risk factor among females in developing LBP. Overweight female participants had 50% higher odds of reporting moderate to severe LBP as compared to healthy counterparts at baseline when adjusted for age and depression. Both males with obesity and females with obesity had more than twice the odds of reporting moderate to severe LBP compared to healthy subjects at baseline BMI. On the other hand, Handini et al. also found no correlation between increased BMI and LBP [53]. However, the study included only 12 female participants, and the findings may be influenced by the small sample size. Hussein et al. reported no association of pain intensity among patients with non-specific cLBP with the anthropometric measures of obesity, such as weight, BMI, waist circumference, hip circumference, waist-hip ratio [54]. The study included 132 participants in total, with 50 female participants. This study suggests that obesity may lead to the onset of LBP, however, the effect of obesity in worsening the pain intensity may be limited. It is worth noting that the conflicting findings in these studies may be attributed to the study design, including the population size, characteristics of the participants, and the confounding factors. For instance, Handini et al.'s study included only 12 female participants, which limits the generalizability of the results. In contrast, Hussein et al. considered a larger sample of 132 participants (50 females), providing more robust evidence. However, neither study explicitly reported the confounding factors considered, thus making it difficult to generalize the findings.

Another study has also highlighted the association of increased musculoskeletal pain among women with BMI 27–34, and an increased all-course and cardiovascular mortality among those with a BMI higher than 40 kg/m² [55]. In [56] and [57], obesity and overweight were found to be associated with lower back pain. Another recent study has reported higher prevalence of low-muscle mass among younger females (aged 18–32 years) in comparison to older adults, aged 45–88 years old. Besides, higher prevalence of obesity, as well as low bone density was observed among older females compared to the younger population [58]. Additionally, the association of obesity with MSK was explored in the review articles by Wearing et al. and Anandacoomarasamy et al. [33, 59].

Besides musculoskeletal pain, the complex relationship between obesity and fracture was also explored by several researchers [34–37]. In a meta-analysis of a prospective cohort study, Tang et al. concluded that obesity in adults is significantly associated with a decreased risk of developing a hip fracture. Shen et al. also reported the association of increased BMI with a lower risk of major osteoporotic fractures and hip fractures in women [35]. This protective association of BMI with major osteoporotic fractures was largely explained by higher bone mineral density (BMD), but mostly in association with hip fractures. It was suggested that factors not associated with BMD, such as cushioning soft tissue thickness at the hip, may have contributed to the lower risk of hip fractures among women. A cohort study by Sogaard et al. suggested that women with higher BMI (≥ 25 kg/m²) had a decreased risk of hip fracture as compared with those with BMI < 22 and 22–24.9 kg/m². The inverse association between BMI and hip fracture was linear in women in the age group of 70–79. However, for the age group of 50–59 and 60–69, the hip fracture risk was highest for those with BMI < 22 kg/m², and the nonlinear association leveled off at BMIs 25 kg/m² and above [36]. Kim et al. suggest that the association of BMI and hip fracture may depend upon ethnicity, as they observed that obesity was associated with an increased risk of hip fracture in women in particular, while overweight was associated with a lowest risk [37].

GAIT AND FUNCTION

Walking, or gait is a fundamental movement pattern, which results from an extremely complex interplay between the musculoskeletal

system and central nervous system. It has been well-documented that obesity poses significant challenges to the normal walking of subjects with overweight or obesity as they need to carry the excess body weight or body fat over the long term. Changes in the biomechanics of walking can be observed as alterations in foot plantar pressure, kinematics, kinetics, as well as spatiotemporal parameters. This review included 9 articles that focus on the association of obesity with gait (see Table 4).

In a gait study on Czech females [38], the authors investigated the effects of BMI on the absolute and relative plantar pressure parameters during walking in women with different BMI levels. It involved 163 Czech women with age ranging from 45 to 65 years (mean $\pm$ SD of age, 57.4 $\pm$ 5.3 years and BMI, 27.0 $\pm$ 5.3 kg/m²) representing three BMI groups (normal weight: < 24.9 , overweight: < 29.9 , and obesity: < 34.9).

The BMI was objectively measured using a digital medical scale with a stadiometer (InBody BSM370; BioSpace, Seoul, South Korea) and gait analysis was performed by means of a Footscan pressure measurement system (RSscan International, Olen, Belgium). The analyzed pressure data included absolute peak pressure, contact percentage, absolute pressure impulse, and relative pressure impulse derived from ten-foot regions (first toe, second through fifth toes, first metatarsal, second metatarsal, third metatarsal, fourth metatarsal, fifth metatarsal, midfoot, medial heel, and lateral heel). A statistically significant between-group difference in the mean peak pressure values and absolute pressure impulse was observed in all foot regions except for second through fifth toes ($p > 0.05$). Similarly, the contact pressure demonstrated a significant between-group difference for the metatarsal regions and midfoot. In addition, relative pressure impulse reported a significant between-group difference for all foot regions except for the second through fifth toes and the first metatarsal. It can be concluded that increased body mass contributed to a higher peak pressure and total load on the foot during overground walking in women. In addition, pressure increase in the lateral forefoot and midfoot was also noticed. On the other hand, Jung et al. examined the effects of BMI on the plantar pressure while crossing an obstacle [39]. Twenty-seven middle-aged females who participated in a study were grouped into four according to their BMI, such as normal (age 52.80 $\pm$ 2.58 years and BMI 21.90 $\pm$ 0.68 kg/m²), overweight (age 48.37 $\pm$ 6.30 years and BMI 24.51 $\pm$ 0.95 kg/m²), slight obesity (age 50.85 $\pm$ 6.01 years and BMI 27.61 $\pm$ 1.8 kg/m²), moderate obesity (age 48.28 $\pm$ 5.05 years and BMI 39.13 $\pm$ 13.93 kg/m²). The results showed that during walking over obstacles of 10 cm height or above, an increase in BMI caused a significant increase in the plantar pressure in specific foot regions. Further, walking over obstacles of 20 cm, an increased plantar pressure was observed in all groups, including the normal-weight group.

Gill et al. assessed how different levels of obesity (Class I obesity: ≥ 30 to < 35 kg/m², Class II obesity: ≥ 35 to < 40 kg/m², and Class III obesity: > 40 kg/m²) affect flat ground walking and obstacle crossing in adults through experiments involving 13 normal weight, 18 overweight/Class I, 16 Class II, and 20 Class III female adults with obesity [40]. They reported that the normal BMI group had faster gait velocity, lower variability in the velocity, shorter percentage of the gait cycle spent in stance and longer percentage in swing, as compared to those in the higher BMI classes. Class I showed faster velocity and less variability in velocity than Class II and Class III individuals. Notably, no differences were observed in the velocities between Class II and Class III. These findings suggest that increases in the classes of obesity contribute to remarkable changes in the walking patterns and lead to limited participation in challenging activities.

Obesity has also been associated with a different standing posture and altered trunk movement [41]. The standing posture in females with obesity was characterized by limitations in forward

Table 4. Studies on the association of obesity/overweight with gait and function.

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement Methods	Key Findings
[43]	Study	25.5 ± 6.9 (with obesity), 26.6 ± 5.5 (with normal weight)	20 women; 10 women with obesity, and 10 women with normal weight	34.1 ± 3.2 (with obesity), 20.4 ± 2.1 (with normal weight)	Height, body mass, lean body mass, percent body fat, VO2max, standing VO2, and preferred walking speed, metabolic rate, energy cost per distance, and relative aerobic effort.	None.	Treadmill (Track Master 425; Full Vision, Inc., Newton, KS), whole body DXA scanner (DPXIQ; Lunar Corp., Madison, WI), 12-lead electrocardiogram, and open circuit respirometry (CardIO2/CP; Gas Exchange System; Med-Graphics, St. Paul, MN).	Subjects with obesity showed 11% higher metabolic cost when averaged across different walking speeds; greater relative aerobic effort while walking at preferred speed, and a similar preferred walking speed compared to normal subjects. No difference in the gross energetic cost per distance (Joules per kilogram per meter) of walking.
[44]	Study	25.3 ± 7.3 (with obesity); 26.6 ± 5.5 (with normal weight)	39 (T), 19 (W)	33.8 ± 3.3 (women with obesity), 20.4 ± 2.1 (women with normal weight), 33.5 ± 2.1 (men with obesity), 22.3 ± 1.9 (men with normal weight)	Waist-to-hip ratio, percent body fat, lean body mass, metabolic rate, segment measurements and composition, VO2 max, preferred walking speed.	None.	Composition using a whole body DEXA scanner (DPXIQ; Lunar Corp., Madison, WI) and open-circuit respirometry system (CardIO2/CP, Med Graphics, St. Paul, MN).	The net metabolic rate of women with obesity was 10% higher than that of men with obesity and normal-weight women, and 20% higher than that of normal-weight men.
[42]	Cross-sectional comparison	44.5 ± 10.3 (with obesity), 44.2 ± 10.1 (normal)	20 women; 10 with obesity, 10 with normal weight	38.9 ± 6.6 (with obesity), 21.7 ± 1.5 (with normal weight)	Thoracic and pelvic segment displacement (deg), mediolateral width of the base of support (cm), hip joint and thoracolumbar spine range of motion (deg), during seated and standing forward flexion; thoracic and pelvic segment angular displacement (deg), hip joint and thoracolumbar spine angular displacement (deg), hip-to-bench distance (cm) and hip joint moment during the simulated standing work task.	None.	A single camera motion analysis system (Peak Motus).	Seated and standing posture: Reduced trunk forward flexion motion and increased mediolateral width of the base of support in subjects with obesity. No changes in pelvic segment displacement and hip joint range of motion. Motion restrictions were observed in the thoracic segment and thoracolumbar spine range of motion. Standing work task: Significant postural adaptations and increased hip joint moment.

Table 4. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement Methods	Key Findings
[41]	Study	38.4 ± 10.2 (with obesity), 30.2 ± 6.8 (with normal weight)	20 women; 10 with obesity, 10 with normal weight	38.7 ± 3.5 (with obesity), 19.9 ± 0.8 (healthy)	Three movements of the trunk: forward flexion, bilateral bending, and rotation.	None.	A 6-camera optoelectronic motion analysis system (Vicon 460, Oxford Metrics Group, Oxford, UK).	Subjects with obesity were characterized by a different standing posture, limited spinal range of motion, larger pelvic tilt angle in the initial position, and a limited thoracic movement. Obesity affects thoracic movement during forward flexion and lateral bending.
[39]	Study	48.37 ± 6.30 (overweight); 50.85 ± 6.01 (slight obesity); 48.28 ± 5.05 (moderate obesity); 52.80 ± 2.58 (normal)	27 women	24.51 ± 0.95 (overweight), 27.61 ± 1.8 (slight obesity), 39.13 ± 13.93 (moderate obesity), 21.90 ± 0.68 (normal)	Peak plantar pressure in 7 foot regions.	None.	Height & Weight: JEXIN (Korea) & DS-102Inbody 4.0 (Biospace, Korea); Gait analysis using FootMat System (Tekscan, USA).	Increased BMI resulted in higher plantar pressure in certain foot regions while crossing an obstacle of 10 cm or above.
[46]	Study	37.7 ± 4.8 (with obesity), (38.1 ± 4.5 (with normal weight)	10 women with obesity and 10 women with normal weight	36.1 ± 4.2 (with obesity), 22.6 ± 2.3 (with normal weight)	None.	BMI, hip and waist Circumference, hip and knee moment, and VO2max.	30-min walking trial on treadmill; GAITRite mat, force plates, and Optotrak motion analysis system for measuring spatiotemporal, kinetic, and kinematic gait data; VO2 max was calculated using Ebbeling protocol.	Both individuals with obesity and those without obesity experienced increased knee extensor moments after a 30-min walking session. Hip extensor moments decreased for both groups. No changes in knee and hip adduction moments. A weak association was observed between hip/knee moments with BMI.
[38]	Study	45–65 (57.4 ± 5.3)	163 women; 39 with obesity, 59 with overweight, 65 with normal weight	27.06 ± 5.3	Plantar pressure parameters (PPPs) in 10 foot regions: contact percentage, absolute pressure impulse, relative pressure impulse, and absolute peak pressure.	None.	BMI: digital medical scale with a stadiometer (InBody BSM370; Biospace, Seoul, South Korea); Gait analysis: Footscan pressure measurement system (RSscan International, Olen, Belgium).	Mean peak pressure values and absolute pressure impulse: Significant between-group differences for all foot regions except for the second through fifth toes; Contact pressure: Significant between-group difference for the metatarsal regions and midfoot; Relative pressure impulse: significant between-group difference for all foot regions except for the second through fifth toes and first metatarsal.

Table 4. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement Methods	Key Findings
[40]	Study	36.16 ± 12.76 (class I BMI), 41.17 ± 5.89 (class II BMI), 42.72 ± 11.43 (class III BMI), 38.20 ± 7.04 (normal)	67 women; 13 normal, 18 class I BMI, 16 class II BMI, 20 class III	29.36 ± 3.19 (overweight/-class I), 37.78 ± 1.42 (class II), 44.31 ± 4.24 (class III), 22.56 ± 1.61 (normal BMI)	Velocity, percent of the gait cycle spent in swing, and percent of the gait cycles spent in stance.	None.	Pressure-sensitive gait carpet (Protokinetics, LLC, Peekskill, NY, USA).	Normal BMI had faster gait velocity, a shorter percentage of gait cycle spent in stance, and a larger percentage in swing compared to those in higher BMI classes. No difference in velocities between class II and class III BMI group. Normal BMI had lower variability in velocities compared to all other groups. Class I had lower variability in velocity compared to class II and class III.
[45]	Study	18–30 young, 65–80 older	39 women; 10 (young, healthy), 10 (young, obese), 10 (older, healthy), 10 (older, obese), 9 (older, people with obesity)	22.5 ± 1.8 (young, healthy), 33.7 ± 2.9 (young, with obesity), 22.7 ± 3.0 (older, healthy), 32.5 ± 2.0 (older, with obesity)	Knee, hip, and ankle strength, ground reaction forces, segmental kinematics, and torques at joints.	None.	Force plate (Model 9090; Bertec Corporation, Columbus, OH), dynamometer (System 3; Biodex Medical Systems, Inc., Shirley, NY), a six-camera motion capture system (MX-T10; Vicon Motion Systems Inc., Los Angeles, CA).	Women with obesity walk with a greater relative effort, which was attributed to obesity-related increases in joint torques rather than strength.

7 total participants, 10 women participants.

flexion and a larger pelvic tilt in the initial position, similar to a pattern that is often observed in women at later stages of pregnancy. The forward translation of the center of mass may have been compensated by adopting a higher pelvic tilt, which eventually led to non-specific or even specific low back pain [41]. In addition, changes in the thoracic movement during forward flexion and lateral bending were also reported. In support of these claims, Gilleard and Smith found that increased BMI was associated with restricted trunk forward motion both in sitting and standing posture [42]. A possible explanation could be the adjacent positioning of the anterior thigh and the abdominal tissue resulting in limited forward flexion motion while seated, and the decreased stability causing difficulties while standing. No significant differences in pelvic segment displacement and hip joint range of motion between the groups were observed during seated and standing flexion. Although not significant, the mediolateral width of the base of support increased with the increase in BMI. Further movement restrictions were observed in thoracic segment and thoracolumbar spine range of motion. Moreover, subjects with obesity exhibited an altered posture accompanied by an increase in the hip joint moment during standing work tasks. Several of the postural adaptations perceived in the obesity group were comparable with those seen during the progression of pregnancy.

Another important quantitative indicator of efficient walking is the energy expenditure. In general, the gross energy cost per distance forms a U-shaped curve when plotted against walking speed, and individuals typically prefer to walk at a speed that minimizes the energy required to walk a given distance. It has been observed that the metabolic rate for walking at a given speed is 0 to 33% higher in individuals with obesity as compared to their normal counterparts [43, 44]. Based on experimental trials involving 20 adult women (10 subjects with obesity and 10 normal-weight), Browning and Kram confirmed that women with obesity presented 11% higher metabolic cost when averaged across different walking speeds, greater relative aerobic effort while walking at preferred speed as compared to normal subjects [43]. In a subsequent study, these authors assessed the metabolic rates, energy cost per distance of walking vs. speed relationships, as well as the preferred walking speed of both women and men with obesity in relation to normal-weights. In addition, the effect of the adipose tissue distribution on the metabolic walking cost was also examined. They suggested both gender- and obesity-driven differences in the net metabolic rate, where women with obesity showed 10% higher net metabolic rate as compared to men with obesity and normal-weight women, and 20% higher rate as compared to normal-weight men [44]. The preferred walking speed was similar across the groups and was close to the speed that minimizes the energy cost per distance. However, they were unable to report conclusive results on the effects of the thigh or body mass distribution on the net metabolic rate. Another study [45] found that women with obesity walk with a greater relative effort, which can mostly be attributed to obesity-related increases in joint torques. In [46], the authors assessed changes in gait after a 30-min walking session. Ten women with obesity and ten normal-weight women participated in this study. They found a weak association between the hip/knee moments with BMI.

In summary, gait abnormalities in individuals with obesity are often reflected in reduced walking speed, step length, cadence, and swing time, increased stance phase and double-limb support time, a greater magnitude and rate of rearfoot eversion, reduced hip, knee, and ankle range of motion, and higher plantar pressure, ground reaction forces, and loads at knee [38–40].

FUNCTIONAL MOBILITY

Increasingly used as an outcome in MSK rehabilitation assessment and numerous clinical studies, functional mobility remains poorly

defined and non-standardized. The current definition is subjective and falls under the general umbrella of a person's physiological ability to move independently and safely in a variety of environments to accomplish functional activities for daily living. Various qualitative and quantitative tools have been proposed over the years, including the International Classification of Functioning and Disability (ICF) from WHO, the Functional Mobility Scale (FMS), the Gillette, and the Functional Assessment Questionnaire Scale. Higher BMI has been reported to have a significant association with functional mobility-related limitations in both men and women. An older study [47] examined the association of different body composition indices, including muscle mass, percentage of body fat, and BMI, with functional limitations in a representative U.S. sample. This cross-sectional study involved 1391 men and 1526 women, aged 70 years or above, with a mean BMI of 26.4 and 26.4 kg/m², respectively. They were grouped into five BMI classes, such as underweight (BMI < 18.5), normal-weight (BMI 18.5–24.99), overweight (BMI 25–29.99), class I obesity (BMI 30–34.99), and class II obesity (BMI ≥ 35). A questionnaire consisting of five mobility-related items (difficulty walking a quarter mile; difficulty walking up 10 steps without resting; difficulty carrying something as heavy as 10 pounds; difficulty stooping, crouching or kneeling; and difficulty standing up from an armless chair) were used to assess functional limitations. Statistical analyses revealed that women in the underweight, overweight, and obesity groups were significantly more likely to experience mobility limitations than those in the normal-weight group. Besides, no association between muscle mass and functional limitations were reported.

Researchers have also focused on the association of past or present obesity, as well as long-term weight loss, with functional limitations. Stenholm et al. explored the influence of early or late onset of obesity and obesity duration on walking limitations among middle-aged and older populations [48]. In a retrospective longitudinal study based on a representative sample of a Finnish population aged 50–99 years, statistical analysis revealed that subjects with obesity since the age of 30 (age and gender adjusted odds ratio (OR) 8.97, 95% confidence interval (CI), 3.06–26.29), 40 (OR 6.01, 95% CI, 2.55–14.14), and 50 (OR 4.33, 95% CI, 2.59–7.23) years had a higher risk of walking limitations as compared to individuals without obesity. Also, subjects with obesity ever since the ages of 30 and 40 years old had the highest prevalence of walking limitations (57% and 49%). This study found no association between neither age and obesity duration, nor between gender and obesity duration. Another similar study [49] assessed the association of overweight/obesity in young, middle, and late adulthood, and its cumulative effect over the adult life course, in which, participants aged 70–79 years at baseline were assessed over 7 years of follow-up recording their functional mobility (difficulty walking 1/4 mile or climbing 10 steps) semi-annually. BMI was calculated using recalled height at ages 25 and 50 years, and measured height at ages 70–79 years. This study further underlined the fact that overweight/obesity at young, middle, and late adulthood were associated with increased risk of incident mobility limitations in both men (1.6 fold higher) and women (2.8 fold higher) in late adulthood as compared to normal weight. Importantly, walking disability was more common in women with obesity than men with obesity. In [50], the authors explored how BMI and body composition (both total and segmental) affect functional capacity according to gender and obesity grade, by measuring the distance traveled during a 6 min Walk Test (6MWT). Six min Walk Distance (6MWD) was positively correlated with fat free mass (FFM), fat free mass of upper limb, and fat free mass of lower limb, and negatively with BMI, fat mass, fat mass of upper limb, and fat mass of lower limb among female participants. Several studies also investigated the association of functional mobility with different obesity measures. For example, Santarem et al. highlighted that total and segmental fat free mass

or FFM associated better with walking performance than BMI. De Souza et al. reported higher prevalence rate of mobility (21.7% to 66.0%) and activities of daily living (ADL) (20.4% to 43.9%) disability among women than men [51]. On the other hand, gender-combined analyses revealed that higher values of waist circumferences are significantly associated with mobility disability, even for a short duration (4 years). Association of higher BMI levels with increased mobility limitations were also underscored by [52], where data from 2865 Black, 1846 Hispanic, and 9721 White middle-aged and older women were analyzed to draw conclusions. Refer to Table 5 for the details of the review outcomes.

In conclusion, although the exact definition of functional mobility varied among studies, the majority have consistently reported that a higher BMI, particularly above 35 kg/m², adversely affects weight bearing tasks, including walking, stair climbing, and chair rise ability. Compared to men with obesity, women were found to have an increased risk of developing functional mobility limitations. This trend has been witnessed in both middle-aged and older population. Moreover, as most of the studies suggest, BMI and waist circumference could better predict the onset of mobility impairments [60].

ECONOMICAL BURDEN

In the last few decades, obesity has become a growing concern worldwide, reaching pandemic proportions [61]. Whilst overweight and obesity were generally considered the problems of high-income countries, recent trends reveal that low and middle-income countries are also witnessing an upsurge. Economic growth, urbanization and global free trade are some of the factors resulting in a global upsurge in the prevalence of obesity. It has also been reported that the prevalence of obesity tends to be higher among the wealthy in low-income countries and the economically disadvantaged in high-income countries [62]. These differences can be explained by various reasons, including increased food affordability with rising income, dietary shifts towards more Westernized eating patterns, and the adoption of sedentary lifestyles and occupations among wealthier individuals. However, in societies with higher income levels, there is a prevailing social stigma surrounding obesity, in addition to access to healthy diets, healthcare, education, and weight loss-promoting activities, which further amplifies the disparities in obesity rates [63].

Within the UAE, the current economic boom is steered by swift urbanization and increased inundation of expatriate workforce. This shift in economic climate is witnessed by rapid changes in lifestyle leading to a more modern, fast-paced and technology driven way of life. Combination of these factors has led to a reduction in domestic as well as occupational or leisure-driven physical activity in addition to the consumption of unhealthier, calorie-dense, prepackaged food choices. The aforementioned factors explain a sudden surge in obesity and related disorders in the country. In fact, the prevalence of obesity and overweight has doubled in the UAE between 1989 and 2017 [64]. As per the Central Intelligence Agency World Factbook, the prevalence rate of obesity in the UAE is 31.7% and the countries in the GCC region are ranked among the top 40 in the world for high prevalence of obesity and cardiometabolic disorders [65].

The high prevalence rate of obesity has a significant direct economic impact for individuals as well as the entire nation. This is evidenced by the direct healthcare care costs associated with the treatment of obesity and its related disorders. There is a significant correlation between individuals living with obesity and the use of at-home health care services, increased number of hospital visits, a surge in prescribed medications and a higher hospital admission rate with surgical and non-surgical treatments than individuals with optimum BMI. They also incur a higher cost of care and longer hospital stays [66]. There are also indirect costs that

increase the economic burden resulting from lost or reduced productivity and human capital, especially arising from complications of obesity such as musculoskeletal disorders. Studies worldwide have shown that individuals with obesity have a higher rate of absenteeism from work than individuals without obesity, and work at less than full capacity when present at work [67].

CLINICAL IMPLICATIONS AND FUTURE RESEARCH DIRECTIONS

The findings from this literature review address several gaps in our current understanding of the impact of obesity on musculoskeletal health and mobility in women, offering valuable clinical insights. Healthcare professionals may need to recognize that obesity has dual health implications, affecting both metabolic and musculoskeletal systems. The scientific evidence demonstrates that women with BMI values above 35 kg/m² experience elevated musculoskeletal pain mainly in their lower back thus requiring regular pain evaluations and prompt intervention strategies. Treatment plans should include hormonal factors and body composition analysis because the literature shows gender-specific musculoskeletal effects of obesity. The documented changes in gait patterns and mobility impairments require healthcare professionals to implement functional mobility assessments together with personalized physical therapy in their clinical practice. Weight reduction combined with muscle strengthening and biomechanical correction interventions will help reduce pain while enhancing both gait efficiency and overall mobility. The protective effects of obesity on certain fractures need to be evaluated against its negative effects on physical function. Medical professionals should implement a combined approach of weight management and physical rehabilitation with psychosocial support to improve musculoskeletal health and maintain independence in women who have obesity.

Future studies should focus on investigating the short- and the long-term effects of structured weight-loss interventions, exercise, and physiotherapy on mobility and pain management in women with obesity. Exploring the efficacy of these interventions in women with varying degrees of obesity will provide key insights into the management of their mobility and pain over time. Longitudinal studies will also help understand the long-term effects of obesity on musculoskeletal health in women. Based on the results of this review, future studies should track changes in gait, musculoskeletal health, and functional mobility over a period of time, in order to more comprehensively assess the effect of obesity on musculoskeletal health.

LIMITATIONS

Identifying suitable studies has proven challenging due to several limitations, including a scarcity of studies that independently compare the effects of obesity on male and female populations separately and limited research has specifically focused on female participants in the examination of the impact of obesity on musculoskeletal health, gait, and functional mobility.

CONCLUSION AND FUTURE WORK

In conclusion, the comprehensive analysis of the literature reveals a clear and multifaceted impact of obesity on musculoskeletal health, gait, and functional mobility, particularly among women. The association between obesity and musculoskeletal pain, particularly lower back pain, is well-documented, with numerous studies highlighting increased prevalence and severity of pain in women with obesity. Gender-specific differences further suggest that hormonal factors and body mass distribution may play critical roles in these associations. While obesity is linked to an increased risk of musculoskeletal pain and reduced functional mobility, it

Table 5. Studies on the association of obesity/overweight with functional mobility.

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[47]	Cross-sectional, population representative sample	≥70; 77.3 ± 2.2 (W)	2917 (T), 1526 (W)	26.4 ± 0.18 (W)	BMI classes: <18.5 (underweight), 18.5–24.99 (normal weight), 25–29.99 (overweight), 30–34.99 (class I obesity), ≥ 35 (class II obesity); muscle mass, percentage of body fat, functional limitations.	Age, education, ethnicity, and chronic illness or disease, smoking history, and estrogen replacement therapy.	Electronic scale, stadiometer, Holtain calipers, Valhalla Scientific Body Composition Analyzer 1990B (Biodynamics Corporation, Seattle, WA).	Women in the underweight, overweight, and obesity groups were at the highest risk of developing functional limitations. No association was found between muscle mass and functional limitations.
[48]	Retrospective longitudinal study	55–99 (mean 68)	3392 (T), 2055 (W)	Without obesity (<30 kg/m ²) and with obesity (≥30 kg/m ²)	Obesity history, sociodemographic and health factors, and obesity-related diseases.	Age, gender, medical covariates, and smoking and alcohol use.	Walking speed test and self-reported walking disability (walking disability was defined as walking speed <1.2 m/s or difficulty walking 0.5 km); Data from health interview and health check-up; weight and height measured during health checkups; recalled height at 20 years, and weight at 20, 30, 40, and 50 years.	Walking disability was more common among women than men. Having obesity at the age of 30, 40, or 50 increased the risk of walking disability by 4 times compared to individuals without obesity.
[49]	Data from a prospective cohort study	70–79	2845 (T), 1441 (W)	Normal weight (<25.0 kg/m ²), overweight (25.0–29.9 kg/m ²), and with obesity (30.0 kg/m ²)	BMI history and mobility limitations.	Demographic characteristics, smoking, drinking, physical activity, and prevalent health condition.	Recalled and measured height and weight.	Overweight/obesity at young, middle, and late adulthood were associated with and increased risk of incident mobility limitations in both men (1.6 fold higher) and women (2.8 fold higher) in late adulthood, compared to normal weight.

Table 5. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[50]	Study	18–60 (40.5 ± 9.6 (W))	90 (T), 69 (W)	Mean BMI (women: 47.6 ± 5.4, men: 48.2 ± 4.9), People with sever obesity (40–49.9 kg/m ²) and super obesity (50–60 kg/m ²)	Forced vital capacity (FVC), forced expiratory volume in one second (FEV1), FEV1/FVC ratio, and mean forced expiratory flow between 25 and 75% of the volume of FVC (FEF 25–75%); fat mass (FM), fat free mass (FFM), fat free mass of upper limbs (FFM_UL), fat free mass of trunk (FFM_TR), fat free mass of lower limbs (FFM_LL), fat mass of upper limbs (FM_UL), fat mass of trunk (FM_TR) and fat mass of lower limbs (FM_LL); basal heart rate (HR), oxy-hemoglobin saturation, fatigue and dyspnea scores (Borg scale) and arterial blood pressure.	N/A	Spirometry test, anthropometric measurements, body mass composition, and 6 MWT.	6MWD was positively correlated with FFM, FFM_UL and FFM_LL, and negatively with BMI, FM, FM_UL and FM_LL among female participants.
[52]	N/A	50 and above	2865 Black, 1846 Hispanic, and 9721 White women	Mean BMI 29.1 (Black), 28.2 (Hispanic), 26.7 (White)	BMI: self-reported values, Mobility: calculated as ordinal measure (score 0–5), 5 questions about walking difficulties, personal (demographic, economic, and health), activity, and environmental.	N/A	Survey	Higher BMI is positively associated with mobility limitations among middle-aged and older Black, Hispanic, and White women.

Table 5. continued

Article	Design	Age	Sample size	Sample BMI (kg/m ²)	Co-variables	Adjustment parameters	Measurement methods	Key findings
[51]	Longitudinal observational study	64–74 older adults; 68.7 ± 2.6 (W)	1104 (T); Free of mobility disability	N/A	Abdominal obesity; waist circumference ≥ 88 cm (for women) and ≥ 102 cm (for men); Mobility disability: difficulty in walking 400 m or climbing a flight of stairs without resting; ADL disability: difficulty in performing at least one of 5 mobility-related ADL.	Depression, gait speed, handgrip strength, health behaviors, comorbidity, socioeconomic variables and research site.	Gait speed assessment using 4 or 3 m walking, handgrip strength measurement using handheld dynamometer (Jamar Hydraulic Hand Dynamometer®), CESD for depression assessment and Self-reported score on MATW for physical activity.	Higher prevalence rates were observed for women compared to men for both mobility (21.7% to 66.0%) and ADL disability (20.4% to 43.9%) across five different research sites. Higher values of waist circumference were significantly associated with mobility disability in a 4-year follow-up (sex-combined analysis).

7 total participants, W women participants.

appears to have a protective effect against certain types of fractures, likely due to higher bone mineral density and cushioning from soft tissues. The variability in findings across different studies indicates the need for more targeted research to fully understand the complex interplay between obesity and musculoskeletal health in women. Addressing obesity through effective interventions could potentially mitigate its adverse effects on musculoskeletal health, improving the quality of life for many women.

The reviewed literature also highlights the substantial impact of obesity on gait and functional mobility in females. Obesity significantly alters walking biomechanics, leading to increased plantar pressure, altered kinematic patterns, and higher energy expenditure during walking. These changes result in slower walking speeds, reduced range of motion, and greater physical effort required for movement. The studies consistently demonstrate that higher BMI levels are associated with greater deviations from normal gait patterns, contributing to increased risk of musculoskeletal issues and decreased functional mobility. Addressing obesity through targeted interventions is crucial for improving gait efficiency and reducing the risk of mobility-related health problems in females with obesity.

Additionally, the review of literature on functional mobility underscores the significant impact of higher BMI on mobility-related limitations, particularly in women. Despite variations in the definition of functional mobility, studies consistently show that obesity, especially with BMI levels above 35 kg/m², adversely affects weight-bearing tasks such as walking, stair climbing, and chair rise ability. Women are more susceptible to mobility limitations compared to men, with walking disability being notably prevalent. The findings emphasize that both BMI and waist circumference are reliable predictors of mobility impairments, highlighting the need for targeted interventions to address obesity-related mobility challenges, thereby improving the overall quality of life and independence in daily activities for individuals with obesity.

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AUTHOR CONTRIBUTIONS

DMM, FAA, and KK conceived the idea. DMM, FAA, and KK formulated the objective for this review. DMM designed the search strategy, conducted abstract screening and full text review, extracted the data, and drafted the manuscript. KK, FAA, and NK contributed to writing the manuscript. KK, FAA, and NK provided significant guidance on the content of the manuscript, overall supervision, and critical feedback. All authors contributed to the manuscript revision and approved the final version of the manuscript.

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COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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