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Functional Training as a Therapeutic Strategy for Obesity: A Narrative Review of Physiological Adaptations, Biomechanical Outcomes, and Translational Implications

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Abstract

Background & Objectives: Obesity is a multifaceted and chronic disease characterized by profound metabolic dysregulation and significant biomechanical impairments, both of which compromise functional capacity and elevate the risk of comorbidities. This narrative review critically examines functional training (FT) as a comprehensive, multidimensional intervention for obesity management, emphasizing its physiological, biomechanical, and translational impacts. It aims to elucidate underlying mechanisms, synthesize current empirical evidence, and highlight clinical implications.

Materials & Methods: A thematic synthesis was conducted based on a systematic search of electronic databases up to April 2025. Eligible studies included randomized controlled trials, non-randomized controlled trials, and cohort studies involving adults classified as overweight or obese (BMI ≥ 25). These studies assessed the effects of FT on metabolic parameters, neuromuscular performance, and functional outcomes. The findings were organized into three analytical domains—physiological, biomechanical, and translational—guided by principles from systems physiology and movement science.

Results: FT has been shown to elicit marked enhancements in mitochondrial function, insulin sensitivity, and systemic inflammatory modulation (e.g., reductions in IL-6 and TNF-α, increases in adiponectin). From a biomechanical perspective, FT improves gait efficiency, postural stability, joint load distribution, and neuromuscular coordination. In comparison to traditional exercise modalities, FT confers distinct translational benefits, such as fall risk mitigation, injury prevention, and greater applicability in rehabilitation settings—particularly for individuals with sarcopenic obesity, musculoskeletal dysfunction, or cardiovascular comorbidities.

Conclusion: FT represents a powerful integrative strategy that bridges metabolic restoration and biomechanical resilience in the context of obesity therapy. Its integration into clinical rehabilitation pathways and public health initiatives is strongly supported by current evidence and should be prioritized. Future investigations should focus on protocol standardization, mechanistic randomized controlled trials, and longitudinal studies across heterogeneous populations to enable widespread clinical adoption.

Keywords: Obesity, Functional Training, Biomechanics, Metabolic Health, Public Health

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Introduction

Obesity remains one of the most pressing global public health challenges of the 21st century, with its prevalence steadily increasing across all age demographics. According to the World Health Organization, as of 2022, approximately 890 million adults—accounting for 16% of the global adult population—were classified as obese, reflecting a significant rise from 571 million in 2010. This accelerating trend is driven

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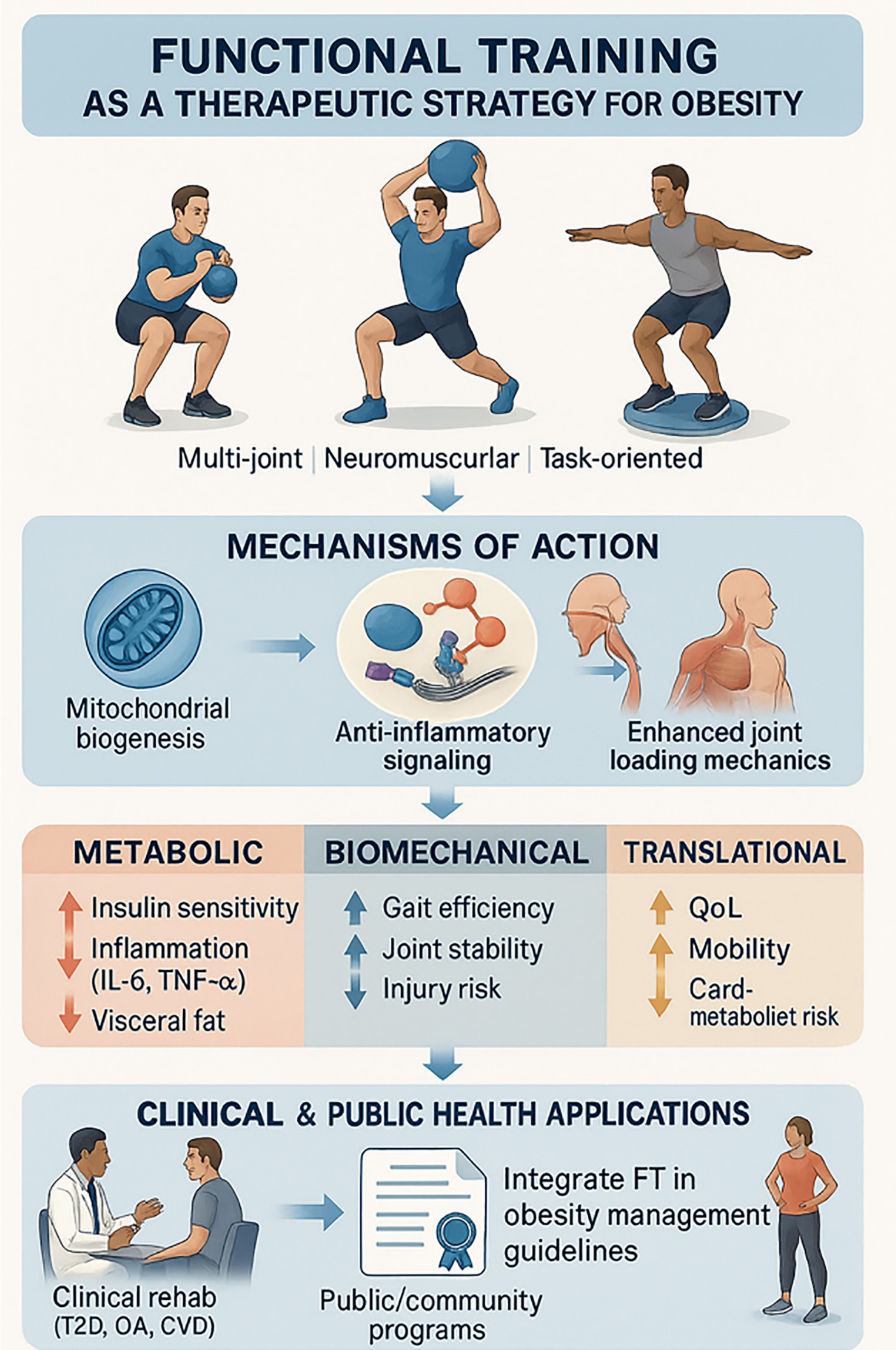
Graphical Abstract

"Functional Training for Obesity: Mechanistic Insights and Translational Outcomes"



This graphical abstract illustrates the therapeutic potential of functional training (FT) in the management of obesity, highlighting its multifaceted effects across physiological and biomechanical domains—from neuromuscular activation and anti-inflammatory signaling for enhanced joint function and improved metabolic regulation. Mechanistic pathways include mitochondrial biogenesis, optimized joint loading, and attenuation of systemic inflammation**.** Resultant outcomes encompass heightened insulin sensitivity, improved gait mechanics, and elevated quality of life. These findings strongly support the incorporation of FT into both clinical rehabilitation strategies and public health initiatives.

by excessive caloric intake, sedentary lifestyles in urban settings, socioeconomic inequalities, and environmental determinants (1). If current trajectories continue, it is projected that by 2030, more than 1.13 billion adults will be living with obesity, thereby exacerbating health, economic, and societal burdens on a global scale (2).

Obesity is no longer conceptualized merely as the result of caloric excess. Rather, it is now recognized as a complex, multifactorial disease shaped by intricate interactions among genetic predispositions, behavioral habits, endocrine imbalances, environmental exposures, and psychosocial pressures (3, 4). Genetic variants influencing adipose tissue distribution, appetite regulation, and insulin signaling pathways contribute to individual susceptibility, while behavioral components such as reduced physical activity and the frequent consumption of ultra-processed foods foster an obesogenic environment (5, 6). The excess mechanical load imposed by adiposity often leads to joint degeneration, altered gait patterns, and restricted mobility, thereby creating a self-perpetuating cycle of inactivity and further weight gain (7). Conventional obesity management strategies primarily emphasizing caloric restriction alongside aerobic or resistance exercise regimens have yielded mixed and frequently modest outcomes. While such interventions can achieve short-term weight loss, their long-term sustainability is often undermined by physiological adaptations, such as metabolic compensation, as well as by low adherence rates and limited enhancement of functional capacity (8). In addition, traditional exercise modalities frequently fail to target the biomechanical limitations and neuromuscular deficits that are prevalent in individuals with obesity (9).

Functional training (FT) has recently emerged as a promising and integrative approach within the field of exercise science. It is defined as a mode of training that involves multi-joint, neuromuscularly challenging, and task-specific movement patterns, with the objective of enhancing real-world performance and overall movement quality (10). In contrast to conventional resistance or endurance exercises, FT emphasizes dynamic postural stability, proprioceptive acuity, intermuscular coordination, and core integration (11). This multidimensional framework is uniquely positioned to simultaneously promote metabolic health and restore biomechanical function in individuals affected by obesity.

Despite its theoretical strengths, FT remains underrepresented in clinical obesity interventions. To date, only a limited number of randomized controlled trials have evaluated its comparative efficacy, and its adoption in routine practice remains minimal—likely due to limited clinician awareness, a lack of standardized protocols, and scarcity of longitudinal outcome data (12). Nonetheless, emerging evidence suggests that FT can concurrently improve insulin sensitivity, decrease visceral adiposity, and enhance motor control, thereby positioning it as a viable and comprehensive therapeutic strategy (13, 14).

This review aims to present a comprehensive, evidence-based narrative synthesis of the current literature concerning FT as a therapeutic modality for obesity. By systematically examining its physiological mechanisms, biomechanical outcomes, and translational potential, we posit that FT not only mitigates cardiometabolic risk but also facilitates the restoration of functional independence and improvement in quality of life. This dual-action capacity positions FT as a potentially transformative intervention in addressing obesity-related morbidity. Moreover, we identify critical gaps in the existing research landscape and propose targeted future directions essential for its successful integration into clinical and public health frameworks.

Material and Methods

This narrative review was designed to provide a comprehensive and conceptually integrated synthesis of current evidence regarding the physiological and functional applications of functional training (FT) in obesity management. A narrative approach was deliberately chosen instead of a systematic or meta-analytic framework due to the heterogeneous nature of the available literature in terms of intervention modalities, outcome measures, population characteristics, and methodological quality. Existing studies on FT in obesity span a wide range of research designs, including randomized controlled trials, longitudinal observational studies, and conceptual reviews, many of which differ substantially in their protocols, durations, and assessment tools. Such heterogeneity precludes meaningful statistical aggregation or the type of uniform comparisons necessary for meta-analytic synthesis. Instead, a thematic and interpretive narrative synthesis allows for the nuanced integration of findings across domains, such as metabolic, biomechanical, and psychosocial outcomes, while preserving contextual richness and emphasizing translational relevance. This methodology also permits a critical examination of the conceptual foundations of FT, many of which remain under-theorized within quantitatively driven syntheses.

The search strategy was structured to ensure comprehensive and inclusive coverage of the topic. A systematic search was conducted across PubMed, Scopus, Web of Science, ScienceDirect, Cochrane Library, and EMBASE databases up to April 2025, using combinations of key terms such as “functional training,” “obesity,” “exercise therapy,” “biomechanics,” and “metabolic syndrome.” Searches were restricted to English-language publications or studies with English translations. No limitation was imposed on publication year to capture the evolution of the concept over time. To minimize publication bias, relevant grey literature—including doctoral dissertations, white papers, and clinical guidelines—was also reviewed if it offered empirical or conceptual insights. Reference lists of all included articles were manually examined to identify additional relevant sources.

Studies were included if they involved adult participants (≥18 years) with a body mass index (BMI) of 25 kg/m² or higher, regardless of comorbidities. Eligible study designs encompassed randomized controlled trials, non-randomized controlled trials, prospective cohort studies, cross-sectional analyses, and high-quality narrative or systematic reviews that provided mechanistic or translational insights. Studies were excluded if they focused exclusively on pediatric populations, pharmacological treatments in the absence of exercise, or non-functional exercise interventions. Only those studies that reported outcomes relevant to metabolic health (e.g., insulin sensitivity, lipid profiles), biomechanical function (e.g., gait, mobility, muscle strength), clinical endpoints (e.g., inflammation, cardiometabolic risk), or quality of life were retained for thematic synthesis.

Data extraction was performed manually and focused on population characteristics, intervention parameters, outcome variables, and reported findings. To ensure consistency and analytical depth, studies were categorized into three major thematic domains: (1) physiological outcomes, (2) biomechanical and neuromuscular adaptations, and (3) translational and clinical implications. The strength and quality of the evidence were assessed using the Oxford Centre for Evidence-Based Medicine (OCEBM) Levels of Evidence framework, which allows for flexible yet structured appraisal across diverse study types.

Although a formal quantitative risk-of-bias assessment was not applicable given the narrative format, commonly observed methodological limitations—including small sample sizes, short intervention durations, and inconsistent outcome measures—were systematically acknowledged to temper interpretative certainty. While the narrative synthesis enables a holistic understanding and conceptual clarity, it also

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introduces potential limitations, such as selection bias and subjectivity in interpretation. To mitigate these issues, a transparent reporting process was maintained throughout, with explicit justification of study selection criteria and synthesis methods. Furthermore, although the inclusion of diverse study designs enhances the scope of inference, it may compromise methodological homogeneity. These trade-offs were carefully weighed to produce a review that is both scientifically rigorous and clinically meaningful.

This methodological foundation sets the stage for a structured, thematically organized exploration of the ways in which FT may influence multiple dimensions of health in individuals with obesity. In the subsequent sections, we examine the physiological mechanisms underlying FT, its biomechanical and neuromuscular implications, and its translational potential for sustainable obesity management and functional rehabilitation.

Theoretical and Mechanistic Framework

FT is increasingly recognized as a multifaceted intervention capable of addressing the complex physiological and biomechanical impairments associated with obesity. Unlike conventional exercise modalities, which often isolate specific muscle groups, FT is characterized by integrated, task-specific movements that engage multiple physiological systems concurrently. This holistic model aligns with the principles of systems physiology, which emphasize the interdependence of bodily systems—including musculoskeletal, cardiovascular, endocrine, and nervous systems—in sustaining homeostasis and optimizing functional capacity.

From the systems physiology perspective, FT elicits adaptive responses across several interconnected domains. The musculoskeletal system benefits from enhanced muscular strength and joint stability, both of which are essential for supporting increased body mass and reducing the risk of obesity-related musculoskeletal disorders (15). Cardiovascular adaptations include improvements in cardiac output and vascular reactivity, which collectively enhance oxygen delivery and metabolic efficiency (16). The endocrine system responds to FT through increased insulin sensitivity and hormonal regulation, thereby contributing to better weight control and metabolic health (17). In parallel, the nervous system undergoes functional changes that support neuroplasticity—the brain's capacity to reorganize neural pathways—thereby improving motor coordination and cognitive function (18).

Neuroplasticity plays a pivotal role in the effectiveness of FT. Engaging in complex, coordinated movements stimulates motor cortex activity and associated neural circuits, leading to improvements in motor learning, coordination, and sensorimotor integration. These enhancements are particularly valuable for individuals with obesity, who often experience compromised motor function due to excess adiposity and prolonged physical inactivity. Research has demonstrated that exercise-induced neuroplasticity can lead to measurable improvements in balance, coordination, and overall motor performance (19). From a biomechanical standpoint, obesity imposes excessive stress on structural components of the body, leading to maladaptive movement patterns and heightened injury risk. The anterior displacement of the center of mass caused by increased fat mass affects posture and gait, prompting compensatory adjustments such as elevated joint torque and altered muscle recruitment strategies. These compensations can accelerate joint degeneration and contribute to chronic pain (20). FT addresses these biomechanical disruptions by prioritizing movement patterns that enhance proprioception, dynamic stability, and neuromuscular control, thereby improving the body's capacity to cope with abnormal loading and motion.

Additionally, obesity is frequently associated with kinetic chain dysfunctions, wherein the interrelated segments of the body fail to function synchronously, resulting in inefficient movement patterns and elevated susceptibility to injury. FT aims to restore optimal kinetic chain function by targeting core stability, enhancing flexibility, and promoting synchronized muscle activation. These adaptations contribute to improved biomechanical efficiency and reduced joint loading, which, in turn, mitigate the risk of musculoskeletal complications (21).

To conceptualize the dual therapeutic role of FT in obesity, a hypothetical integrative model can be proposed. Within this model, FT functions as a central intervention that concurrently targets both metabolic dysregulation and biomechanical dysfunction. On the metabolic axis, FT improves insulin sensitivity, lipid regulation, and inflammatory profiles, facilitating energy homeostasis and body weight reduction. On the biomechanical axis, FT strengthens musculoskeletal support structures, enhances movement quality, and augments neuromuscular control. The interaction between these domains forms a positive feedback loop, wherein gains in one area amplify improvements in the other. This synergy ultimately contributes to enhanced overall health outcomes and quality of life for individuals with obesity.

Physiological Adaptations to Functional Training

Metabolic Health and Cardiovascular Fitness

Obesity is characterized by a constellation of metabolic dysfunctions, including insulin resistance, chronic low-grade inflammation, impaired lipid metabolism, and mitochondrial dysfunction, all of which contribute to an elevated risk of cardiometabolic disease. FT, which emphasizes multi-joint, full-body dynamic movements performed at varying intensities, provides a physiologically potent stimulus capable of reversing many of these maladaptations. The beneficial metabolic effects of FT arise from its ability to enhance insulin signaling, stimulate mitochondrial biogenesis, increase lipid oxidation, and improve cardiovascular efficiency—mechanisms that are fundamental to the prevention and management of obesity-related complications. One of the primary adaptations to FT in individuals with obesity is enhanced mitochondrial biogenesis, the cellular process through which new mitochondria are synthesized. Given the mitochondrial dysfunction typically observed in obesity, FT-induced upregulation of peroxisome proliferator-activated receptor gamma coactivator-1α (PGC-1α) plays a pivotal role in restoring oxidative capacity in skeletal muscle (22). Studies have demonstrated that FT promotes more robust mitochondrial adaptations than traditional resistance training, owing to its high metabolic demands and concurrent recruitment of both aerobic and anaerobic energy systems (23). These adaptations are particularly critical in individuals with obesity, in whom diminished mitochondrial content and function have been associated with poor metabolic flexibility and elevated insulin resistance (24).

Moreover, FT has been shown to significantly improve insulin signaling pathways, thereby enhancing glucose uptake and glycemic control. Evidence indicates that the complex, high-effort movement patterns integral to FT increase the translocation of glucose transporter type 4 (GLUT4) to the muscle cell membrane, facilitating glucose clearance independent of insulin stimulation (25). This insulin-independent mechanism is particularly advantageous in insulin-resistant populations and, when sustained over time, contributes to improved insulin sensitivity and reductions in hemoglobin A1c levels (26).

Another critical cardiovascular adaptation observed with FT is the improvement in maximal oxygen uptake (VO_2max), a well-established predictor of cardiovascular morbidity and all-cause mortality. Unlike conventional aerobic exercise, which primarily targets endurance capacity, FT incorporates cardiovascular loading

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through circuit-based, high-intensity protocols that elevate heart rate and robustly engage the cardiorespiratory system (27). Meta-analytic findings suggest that FT programs combining resistance and aerobic elements significantly increase VO_2max in overweight and obese adults, thereby enhancing functional capacity and reducing cardiovascular risk (28).

Additionally, FT exerts favorable effects on vascular health by improving endothelial function and reducing arterial stiffness. These improvements are partially mediated by enhanced nitric oxide bioavailability and attenuation of pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6), both of which are elevated in obesity and contribute to endothelial dysfunction (29). FT has also been associated with improvements in heart rate variability and autonomic nervous system balance, reflecting a shift toward parasympathetic dominance—an adaptation believed to exert cardioprotective effects in individuals with obesity (30). Furthermore, lipid profile modulation constitutes another positive outcome of FT. Training interventions incorporating functional movement patterns have been shown to reduce serum triglycerides, elevate high-density lipoprotein cholesterol (HDL-C), and lower low-density lipoprotein cholesterol (LDL-C)—alterations that collectively diminish atherosclerotic burden and enhance cardiometabolic health (31). Taken together, the physiological adaptations elicited by FT—including enhanced mitochondrial function, improved insulin sensitivity, and increased cardiovascular capacity—offer a compelling rationale for its application as a therapeutic modality in obesity care. By addressing both cellular-level dysfunction and systemic physiological impairments, FT not only promotes metabolic health but also empowers individuals with obesity to regain functional autonomy and achieve sustained health resilience.

Hormonal and Inflammatory Regulation

Obesity is now widely acknowledged not only as a disorder of caloric excess but also as a condition underpinned by profound neuroendocrine dysregulation and persistent low-grade inflammation. Through its systemic physiological demands and high degree of metabolic complexity, FT has emerged as a non-pharmacological strategy capable of modulating hormonal secretion and suppressing pro-inflammatory signaling pathways. These adaptations are essential in mitigating comorbidities commonly associated with obesity, including insulin resistance, metabolic syndrome, and atherosclerosis. Among the principal endocrine targets of FT is cortisol, a glucocorticoid hormone implicated in adipogenesis and visceral fat deposition when chronically elevated. Individuals with obesity often present with dysregulated hypothalamic-pituitary-adrenal (HPA) axis activity, resulting in sustained cortisol hypersecretion and associated metabolic disturbances. FT has been shown to normalize both basal and stress-responsive cortisol levels, especially when compared with high-volume endurance training, which may exacerbate cortisol secretion (32). A randomized trial by Paoli et al. (2021) demonstrated that circuit-based FT significantly reduced morning salivary cortisol and improved stress resilience among overweight adults (33). These effects are likely mediated through FT-induced recalibration of autonomic balance, promoting parasympathetic dominance and attenuating stress-related cortisol release.

In parallel, adipokines such as adiponectin and leptin play central roles in metabolic regulation. Adiponectin, an anti-inflammatory and insulin-sensitizing hormone, is typically suppressed in obesity, whereas leptin levels are elevated, reflecting a state of leptin resistance—an established marker of metabolic dysregulation. Studies consistently show that FT enhances circulating adiponectin while concurrently reducing leptin concentrations, thereby restoring endocrine sensitivity (34). These hormonal adjustments are believed to result from concurrent improvements in body composition, enhanced skeletal muscle glucose uptake, and reductions in systemic inflammation (35). The anti-inflammatory potential of FT is particularly evident in its effects on cytokine profiles. Obesity-related inflammation is characterized by elevated levels of TNF-α and IL-6, both of which are implicated in the pathophysiology of insulin resistance and vascular dysfunction. Although acute elevations in IL-6 during exercise—originating from contracting skeletal muscle—are considered beneficial, chronically elevated basal IL-6 and TNF-α levels are harmful and must be attenuated. FT, particularly when delivered in circuit or interval-based formats, has been shown to significantly reduce basal concentrations of these cytokines, thereby decreasing systemic inflammatory load (36).

These effects are partly attributable to increased production of anti-inflammatory cytokines, such as interleukin-10 (IL-10), and a shift in macrophage phenotype from M1 (pro-inflammatory) to M2 (anti-inflammatory) profiles (37). In a 2022 systematic review, Monteiro et al. reported that multi-modal FT interventions in overweight populations significantly improved inflammatory biomarkers after 8 to 12 weeks of training, independent of body weight changes (38). These results highlight the immunomodulatory properties of FT, distinct from those achieved through caloric restriction or pharmacologic therapies. Emerging evidence also suggests that FT enhances endocrine function at the skeletal muscle level by stimulating the release of myokines such as irisin and brain-derived neurotrophic factor (BDNF), both of which exert anti-inflammatory and neuroprotective effects (39). This muscle–adipose tissue crosstalk has been proposed as a novel therapeutic axis in obesity, positioning FT at the core of a metabolo-immunological reprogramming model.

In summary, FT elicits a broad spectrum of endocrine and immunological adaptations. By reducing cortisol levels, increasing adiponectin concentrations, decreasing leptin resistance, and modulating inflammatory cytokine expression, FT offers a robust and holistic strategy for reversing hormonal and inflammatory dysregulation in individuals with obesity. These physiological improvements not only enhance metabolic regulation but also bolster resilience against obesity-related complications, including type 2 diabetes, cardiovascular disease, and immune dysfunction.

Energetic Efficiency and Body Composition

One of the most consequential sequelae of obesity is the disruption of energy homeostasis, accompanied by adverse alterations in body composition, including excessive adipose accumulation, loss of lean tissue, and diminished metabolic flexibility. FT, which involves multi-joint, high-variability movements performed at moderate to high intensities, offers a distinctive advantage in enhancing energetic efficiency and improving body composition through multiple synergistic mechanisms.

A central pathway through which FT augments energy expenditure is the phenomenon of excess post-exercise oxygen consumption (EPOC). EPOC reflects the elevated oxygen uptake following physical activity, indicative of the body's ongoing efforts to restore homeostasis and replenish energy substrates. Multiple studies have demonstrated that FT protocols—particularly those utilizing circuit or interval formats with minimal rest intervals—elicit significantly greater EPOC responses than traditional steady-state exercise (40). For instance, a randomized trial conducted by Smith et al. (2022) revealed that a 12-week FT program induced a prolonged EPOC response lasting up to 38 hours post-exercise, thereby contributing to a substantial increase in weekly total energy expenditure among overweight adults (41). This sustained post-exercise metabolic elevation plays a critical role in facilitating a prolonged negative energy balance, which is essential for the reduction of adipose tissue.

Equally important is the improvement in resting metabolic rate (RMR), another favorable adaptation associated with FT. Unlike some calorie-restricted diets or aerobic training modalities that may inadvertently depress RMR, FT has been shown to maintain or even elevate it by promoting the retention and augmentation of lean body mass (42). This preservation is of particular relevance given that lean tissue represents the most metabolically active component of body composition, accounting for a substantial portion of total daily energy expenditure. In a comparative study by Novaes et al. (2021), individuals participating in a high-intensity FT protocol exhibited a 5.3% increase in RMR, in contrast to those in an aerobic training (AT) cohort who showed no statistically significant change (43).

The efficacy of FT in enhancing body composition has been consistently substantiated through dual-energy X-ray absorptiometry (DEXA), the gold-standard imaging modality for quantifying fat mass, lean tissue, and visceral adiposity. DEXA-derived data from recent trials indicate that FT leads to significant reductions in total and trunk fat mass while concurrently preserving or increasing skeletal muscle mass, even in the absence of substantial weight loss (44). Such recompositional shifts are especially advantageous in the context of obesity management, as they confer greater metabolic benefits than simple weight reduction accompanied by lean mass loss.

Moreover, FT enhances intramuscular mitochondrial density and promotes lipid oxidation, thereby improving substrate utilization during both activity and rest. This metabolic shift toward preferential fat oxidation has been attributed to the upregulation of key mitochondrial enzymes, including carnitine palmitoyltransferase-1 (CPT-1) and β-hydroxyacyl-CoA dehydrogenase, following consistent FT engagement (45). As a result, individuals who adhere to FT regimens demonstrate improved metabolic flexibility, defined as the capacity to efficiently switch between carbohydrate and fat substrates based on energy demands—a capability frequently impaired in those with obesity (46).

An additional and often underappreciated benefit of FT lies in its enhancement of muscle quality, which encompasses not only the quantity of muscle mass but also its contractile efficiency and metabolic functionality. Improvements in muscle quality—as evaluated through resistance-specific power output and electromyographic activity—have been positively associated with increased thermogenesis and heightened insulin sensitivity, both of which further support favorable shifts in body composition (47).

In sum, FT facilitates a comprehensive reconfiguration of the metabolic phenotype in individuals with obesity. Through sustained EPOC, increased RMR, preservation of lean mass, enhanced fat oxidation, and improved muscle quality, FT presents a robust framework for reestablishing energetic homeostasis and reversing the metabolic liabilities associated with excess adiposity.

The integrated physiological effects of FT in individuals with obesity are conceptually illustrated in Figure 1, which depicts the multi-level adaptations across metabolic, endocrine, and compositional domains. This figure provides a hierarchical model beginning with FT stimuli characterized by high-intensity, multi-joint, and neuromuscularly demanding movements. These inputs lead to three principal domains of adaptation: (A) metabolic and cardiovascular improvements (e.g., enhanced mitochondrial biogenesis, increased insulin sensitivity, improved VO_2max); (B) hormonal and inflammatory modulation (e.g., reduced cortisol levels, improved adipokine and cytokine profiles); and (C) enhancements in energetic efficiency and body composition (e.g., increased lean mass, elevated resting metabolic rate, reduced fat mass).

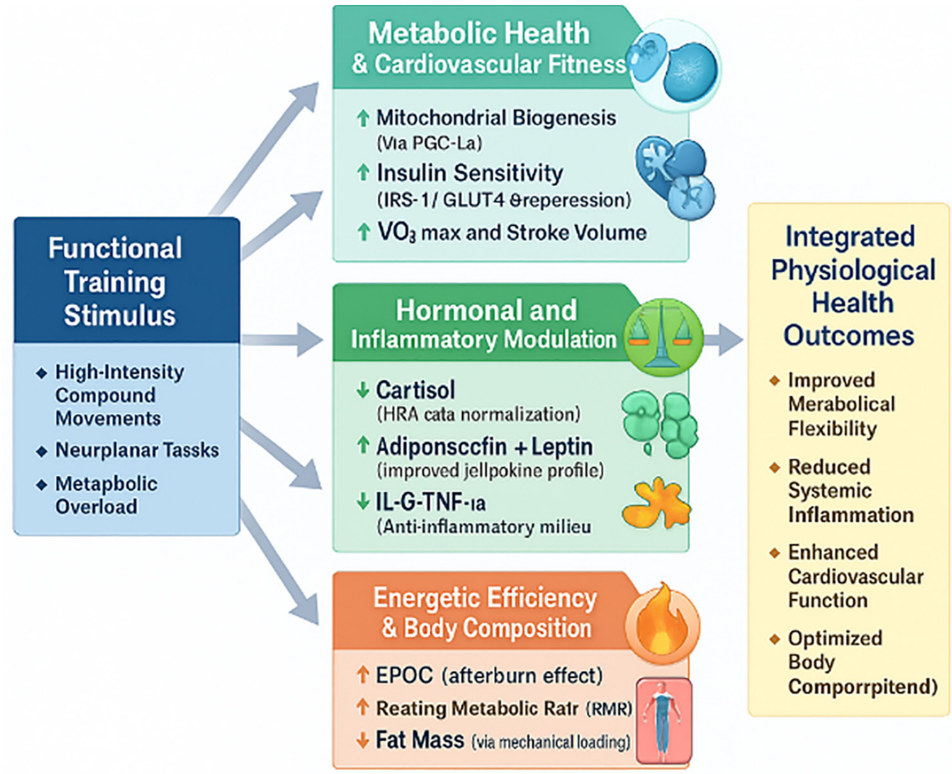

Figure 1. Hierarchical Model of Key Physiological Adaptations to Functional Training in Individuals with obesity

Together, these adaptations converge to improve metabolic flexibility, reduce systemic inflammation, and mitigate the risk of obesity-related comorbidities.

Biomechanical and Neuromuscular Outcomes

Movement Economy and Gait Kinetics

Obesity is closely associated with deranged locomotor biomechanics, including impaired movement economy, altered gait dynamics, and heightened joint loading, all of which contribute to diminished mobility, increased injury risk, and reduced quality of life. FT, which prioritizes movement efficiency, neuromuscular coordination, and postural control, has emerged as a compelling intervention to address these biomechanical impairments.

Movement economy, defined as the energy cost of locomotion at a submaximal intensity, is notably impaired in individuals with obesity. This inefficiency stems from excess body mass, maladaptive gait compensations, and inadequate muscular coordination (48). Evidence indicates that FT enhances movement economy by reinforcing core stability, refining proprioceptive acuity, and synchronizing muscle recruitment patterns. For example, Marques et al. (2023) conducted a randomized controlled study in which obese participants completed 16 weeks of FT and exhibited significant reductions in oxygen cost during submaximal treadmill walking, thereby demonstrating improved biomechanical efficiency (49).

Changes in gait kinetics and kinematics, particularly stride length, ground reaction forces (GRF), and joint angles—are also critical in the context of obesity. Individuals with obesity typically exhibit shorter stride lengths, wider stance widths, and increased mediolateral instability as compensatory adaptations to excess mass and reduced joint mobility (50). Such adaptations can result in abnormal joint-loading patterns and elevated shear forces at weight-bearing joints, accelerating degeneration and functional decline (51). In addition to kinematic alterations, kinetic parameters such as peak vertical GRF (vGRF), loading rates, and joint moments are central to understanding gait inefficiencies in obesity (50). Individuals with obesity often demonstrate elevated vGRF and increased anterior–posterior braking forces during the stance phase, which exacerbate joint loading and diminish shockabsorption capacity. FT interventions have been shown to reduce peak vGRF, enhance force attenuation, and achieve more physiologically balanced joint moment distributions—particularly at the knee and ankle—thus promoting improved kinetic chain synergy and muscular control while alleviating stress on joints (50, 51).

FT appears to mitigate maladaptive gait patterns by facilitating neuromuscular reeducation and reinforcing kinetic chain integration. Postintervention assessments utilizing threedimensional gait analysis have shown increased stride length, improved step symmetry, and reduced peak vGRF following FT programs (52). These enhancements are particularly significant because aberrant GRF profiles in obese individuals are linked to elevated plantar pressure, impaired balance, and increased risk of musculoskeletal injury. Moreover, FT induces favorable adaptations in joint kinematics, especially in the sagittal and frontal planes. Studies using motioncapture and forceplate analysis have documented increased hip and knee flexion throughout both stance and swing phases following FT, suggesting improved joint mobility and muscular engagement (53). These adaptations contribute to enhanced dynamic stability and smoother gait mechanics, while concurrently relieving dependence on passive structures such as ligaments and joint capsules—thereby reducing injury susceptibility.

The neuromuscular adaptations underlying these biomechanical improvements are thought to arise from FT's multifaceted stimuli, which combine balance challenges, closedchain exercises, and eccentric control drills. Through these modalities, FT promotes enhanced activation of deep stabilizing musculature—such as the gluteus medius, transversus abdominis, and multifidus—muscles that are often underactive in individuals with obesity (54). Increased recruitment of these stabilizers correlates strongly with superior movement control, postural alignment, and propulsion efficiency during gait and functional tasks (55).

Finally, FT may confer protective effects against future declines in mobility. By targeting both central neuromuscular control and peripheral biomechanical alignment, FT has the potential not only to restore functional capacity but also to prevent progression toward severe musculoskeletal conditions such as osteoarthritis (OA) and tendinopathy (56). In summary, FT promotes a comprehensive enhancement of movement economy and gait kinetics in individuals with obesity. These adaptations manifest as reduced energy expenditure during movement, normalized stride parameters, optimized GRF characteristics, and improved joint kinematics—together demonstrating that FT is more than a metabolic intervention; it is a biomechanical corrective strategy essential for longterm functional independence.

Neuromuscular Coordination and Balance

Obesity compromises not only metabolic and cardiovascular health but also significantly impairs neuromuscular coordination and balance control, leading to increased fall risk, movement inefficiency, and reduced functional independence. These impairments stem from a combination of excess body mass, disrupted proprioceptive feedback, diminished relative muscle strength, and suboptimal motor unit recruitment patterns (57, 58). FT, by emphasizing integrated movement patterns, balance challenges, and neuromuscular engagement, has demonstrated superior efficacy in enhancing coordination and balance compared to conventional exercise modalities.

Electromyographic (EMG) assessments consistently reveal altered muscle activation patterns in individuals with obesity, often characterized by delayed onset of stabilizing muscles and prolonged cocontraction in the trunk and lower extremities (59). These abnormalities impair anticipatory postural adjustments (APAs) and reactive control during destabilizing tasks. FT programs that incorporate unstable surfaces, dynamic resistance, and multiplanar drills have been shown to improve motor unit recruitment timing and synergistic muscle activation. For instance, Chang et al. (2022) reported that obese adults who engaged in 12 weeks of FT demonstrated significantly earlier activation of the gluteus medius and erector spinae muscles during dynamic balance tests, alongside reduced antagonist coactivation, as measured using surface EMG (60). In terms of postural control, obese individuals often present with larger centerofpressure excursions, increased sway velocity, and reduced limits of stability—indicators of impaired sensorimotor integration and delayed neuromuscular responses (61). These deficiencies reflect central nervous system processing delays and peripheral sensory deficits rather than biomechanical issues alone. FT appears to address both domains by augmenting proprioceptive input, refining sensorimotor integration, and facilitating adaptive neuromuscular responses.

Randomized controlled trials have demonstrated that FT significantly enhances both static and dynamic balance in obese individuals. A recent metaanalysis revealed that functional balance training substantially reduced sway area and velocity during eyesclosed stance and improved reach distance in the Ybalance test, indicating enhanced postural stability and dynamic control (62). These improvements have been attributed to heightened activation of core stabilizers such as the transversus abdominis and multifidus, along with more efficient hip and ankle strategies in response to perturbations (63). Furthermore, FT improves intermuscular coordination by promoting more equitable force distribution across muscle groups during complex tasks. This reorganization reduces localized muscular fatigue, prevents compensatory movement patterns, and supports more fluid and stable execution of daily activities such as stair climbing, lifting, and directional changes (64). Neuroplastic adaptations induced by FT—including enhanced corticospinal excitability and improved motor planning—have been documented in functional MRI (Magnetic Resonance Imaging) studies of obese individuals participating in balanceintensive interventions (65). Importantly, FT fosters taskspecific motor learning, so improvements in neuromuscular coordination transfer to realworld function. Programs incorporating reactive stepping, unilateral loading, rotational movements, and agility drills yield measurable gains in fall resilience and gait adaptability (66). These benefits possess profound translational relevance, particularly for older obese adults at elevated risk for falls and mobility-related disability.

In conclusion, FT provides a robust foundation for improving neuromuscular coordination and balance in individuals with obesity. Marked by EMGconfirmed enhancements in activation timing, reductions in centerofpressure displacement, and refinements in intermuscular synergy, FT restores postural control, fosters functional confidence, and supports autonomous activity.

Musculoskeletal Load and Injury Prevention

Obesity imposes substantial mechanical and physiological strain on the musculoskeletal system, leading to increased joint loading, aberrant gait mechanics, and a heightened risk of degenerative joint disease and musculoskeletal injury. This augmented biomechanical stress contributes to the onset and progression of OA, chronic low back pain, and an elevated susceptibility to falls, particularly among older adults and those with long-standing obesity (67, 68). FT, through its integrative and neuromechanically informed framework, offers a distinct therapeutic pathway for redistributing joint loads, enhancing musculoskeletal resilience, and mitigating injury risk in obese populations. Excess body mass significantly increases compressive and shear forces on weight-bearing joints, particularly the knees, hips, and lumbar spine. During ambulation, each step taken by an individual with obesity can impose forces equivalent to three to six times their body weight on the knee joint (69). This repetitive mechanical overload expedites articular cartilage degeneration and accelerates the development of OA. Whereas conventional linear resistance training may fall short in addressing these loads within functional contexts, FT employs multi-planar, closed kinetic chain movements that emphasize dynamic stability and proprioceptive integration, resulting in more even mechanical load distribution across joints and surrounding tissues (70).

Moreover, FT enhances biomechanical alignment and optimizes movement efficiency, thereby reducing maladaptive compensations frequently observed in individuals with obesity. Studies utilizing three-dimensional motion analysis have demonstrated that FT effectively corrects postural aberrations such as excessive trunk inclination, dynamic knee valgus, and anterior pelvic tilt—all of which are strongly associated with increased injury risk (71). A randomized controlled trial conducted by Nguyen et al. (2022) found that a 10-week FT program significantly reduced the knee adduction moment (KAM) during walking, a biomechanical marker closely linked to medial knee OA progression (72). The connection between obesity and OA is not solely mechanical; it also encompasses chronic low-grade systemic inflammation and metabolic dysregulation (73). FT addresses both aspects by promoting efficient biomechanical patterns and eliciting anti-inflammatory effects through consistent moderate-to-vigorous physical activity. FT programs that prioritize neuromuscular control, eccentric loading, and precise joint alignment—such as modified squats, lateral lunges, and hip-dominant hinging—have been shown to improve joint mechanics conducive to cartilage preservation and alleviate OA-related discomfort (74).

Chronic low back pain (CLBP) is another widespread musculoskeletal disorder exacerbated by obesity-induced postural imbalances, decreased core stability, and increased lumbar compressive forces. FT protocols that target deep spinal stabilizers, including the transversus abdominis, multifidus, and diaphragm, have demonstrated superior efficacy over general exercise programs in alleviating CLBP symptoms in overweight populations (75). EMG-based investigations further support this finding, showing that FT enhances both the timing and amplitude of deep core muscle activation, thereby reducing spinal shear forces and improving intersegmental control (76). Obesity is also an independent risk factor for falls, especially among older adults, due to impairments in proprioception, delayed neuromuscular response, and compromised postural control (77). Falls in this demographic are not only more prevalent but also more likely to result in serious injury, such as fractures and extended recovery periods. FT mitigates fall risk by improving lower-limb muscle power, neuromuscular reactivity, and postural stabilization, all of which are essential components of fall resistance. In a 2023 longitudinal study by Evers et al., FT was shown to significantly reduce fall incidence among obese older women compared to a standard walking group, with improvements mediated by enhanced ankle proprioception, refined hip strategy execution, and improved trunk stabilization during perturbation-based tasks (78).

Furthermore, the incorporation of reactive and agility-based components within FT regimens has been linked to gains in muscle-tendon stiffness, intermuscular coordination, and landing mechanics, each of which contributes to overall musculoskeletal robustness and reduces

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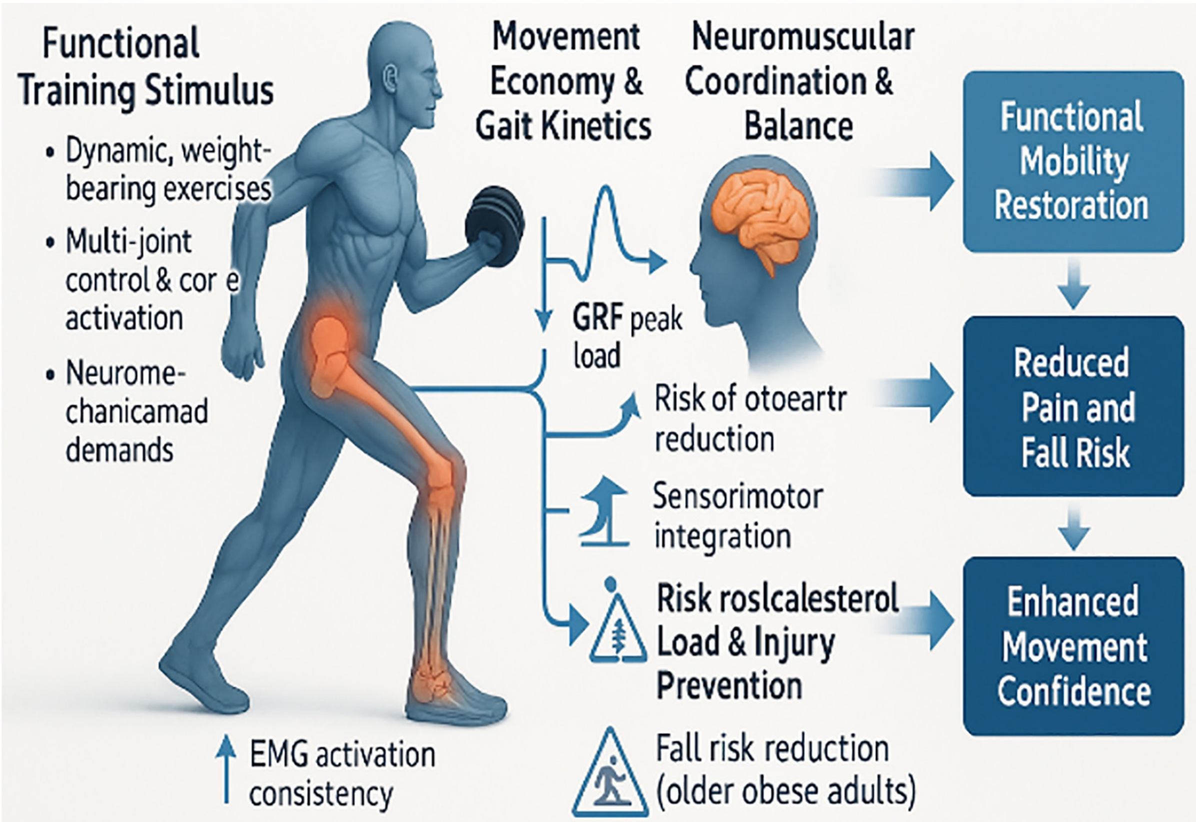

Figure 2. Biomechanical and Neuromuscular Adaptations to Functional Training in Individuals with Obesity

the likelihood of injury (79). From a translational perspective, reducing musculoskeletal load through FT not only improves biomechanical function but also promotes long-term adherence to physical activity by decreasing pain, limiting injury incidence, and improving movement efficiency. FT represents a low-risk, high-reward intervention model that can be individualized based on joint integrity, mobility status, and comorbidity profile, rendering it especially applicable in clinical settings for populations with obesity (80).

As outlined in Figure 2, FT induces a spectrum of biomechanical and neuromuscular adaptations particularly pertinent to individuals with obesity. These include enhanced gait mechanics, EMG-demonstrated improvements in motor control, and significant reductions in joint loading—factors that collectively diminish injury risk and enhance long-term physical functionality. The figure presents a conceptual model organized into three primary domains: (1) Movement Economy and Gait Kinetics, encompassing enhancements in stride length, ground reaction forces (GRF), and joint kinematics; (2) Neuromuscular Coordination and Balance, highlighting optimized EMG activation patterns and superior postural regulation; and (3) Musculoskeletal Load and Injury Prevention, focusing on reductions in joint stress and key risk factors associated with OA, back pain, and falls. Together, these adaptations contribute to improved locomotor efficiency and decreased mechanical burden during both daily activities and structured exercise.

To synthesize the key physiological and biomechanical adaptations outlined in Sections 5 and 6, Table 1 provides a concise summary of the primary mechanistic pathways and their associated functional outcomes resulting from FT interventions in individuals with obesity.

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Table 1. Summary of Key Mechanisms and Functional Effects of Functional Training in Obesity

Domain	Key Mechanisms	Primary Functional Outcomes
Metabolic Efficiency	↑ AMPK activation, ↑ GLUT4 translocation, ↑ mitochondrial biogenesis (via PGC-1α)	Improved insulin sensitivity, ↑ VO_2max, enhanced substrate utilization
Hormonal & Inflammatory Profile	↓ Cortisol, ↓ TNF-α, ↓ IL-6, ↑ Adiponectin	Reduced systemic inflammation, improved hormonal balance, better metabolic flexibility
Cardiorespiratory Function	↑ Stroke volume, ↑ parasympathetic tone, ↓ resting HR	Improved heart rate variability, ↑ cardiorespiratory fitness, reduced CVD risk
Gait and Movement Economy	↑ Stride symmetry, ↓ GRF peaks, ↑ joint ROM and control	Improved walking efficiency, reduced fatigue, better locomotor stability
Neuromuscular Coordination	↑ EMG synchronization, ↑ proprioceptive acuity, ↑ motor unit recruitment	Enhanced balance, reduced fall risk, better agility and dynamic postural control
Musculoskeletal Load Management	↓ Joint loading forces, ↑ trunk and core control, ↓ lumbar shear stress	Reduced risk of OA and back pain, improved musculoskeletal resilience
Translational Functionality	↑ Functional movement patterns (e.g., squatting, pushing, carrying)	Enhanced ADL capacity, workplace tolerance, and quality of life in obese individuals
Anthropometric Outcomes	↓ fat mass (via ↑ lipolysis), ↓ waist circumference, ↑ lean mass retention	Reduced BMI and body fat %, improved body composition, ↓ WHR

This integrative summary offers a clear translational framework that connects cellular-level adaptations (e.g., mitochondrial biogenesis, hormonal regulation) with system-level enhancements (e.g., improved gait efficiency, reduced joint loading), thereby increasing the practical relevance of these findings for both clinicians and exercise professionals.

Comparative Effectiveness of FT vs. Conventional Training

FT vs. Resistance/Aerobic/HIIT in Obesity

FT vs. Resistance Training (RT): FT and traditional resistance training (RT) both contribute meaningfully to obesity management, yet they diverge in their biomechanical emphasis, neuromuscular demands, and degree of functional transfer to daily activities. RT primarily induces hypertrophy, elevates basal metabolic rate, and enhances muscular strength through isolated, often machine-based, linear movement patterns (81). In contrast, FT employs integrated, multi-joint, and multiplanar exercises that mimic real-world motor demands, thereby enhancing not only strength but also neuromotor coordination, dynamic balance, and functional mobility (82). Evidence suggests that although RT significantly improves lean body mass and resting energy expenditure, FT yields superior outcomes in mobility, postural stability, and movement quality among individuals with obesity (83). In a randomized controlled trial (RCT) conducted by Zhang et al., obese women who participated in 12 weeks of FT demonstrated greater improvements in Functional Movement Screen (FMS) scores compared to those following a traditional RT program, despite similar reductions in BMI and body fat percentage (84). From a cardiometabolic perspective, both FT and RT improve insulin sensitivity and lipid profiles; however, FT may exert more pronounced anti-inflammatory effects, likely due to its neuromuscular activation strategies that enhance peripheral vasodilation and endothelial function (85).

FT vs. Aerobic Training (AT): AT has long been regarded as the standard intervention for weight reduction, primarily due to its high caloric expenditure and well-established cardiovascular benefits. However, AT may fail to address the neuromuscular deficits, postural imbalances, and motor inefficiencies commonly observed in individuals with obesity. FT addresses these limitations while maintaining a moderate-to-high metabolic cost (86). In a comparative trial by Lorenzo-Luaces et al., 16 weeks of FT produced equivalent reductions in body mass and waist circumference as moderate-intensity continuous AT, yet resulted in significantly greater gains in core stability, gait efficiency, and self-reported physical function among obese older adults (87). Moreover, while AT primarily enhances mitochondrial density and fat oxidation, FT also improves functional independence—an especially valuable outcome for aging or morbidly obese populations (88). This makes FT particularly advantageous for individuals experiencing musculoskeletal discomfort or limited tolerance for traditional aerobic modalities.

FT vs. High-Intensity Interval Training (HIIT): HIIT has garnered attention for its rapid metabolic benefits, including increased VO_2max, enhanced insulin sensitivity, and elevated fat oxidation. Nevertheless, its demanding intensity often limits feasibility and adherence, particularly in untrained or obese individuals. FT presents a viable alternative by incorporating high-effort, low-impact circuits that simulate HIIT's metabolic effects while preserving joint integrity and improving movement proficiency (89). In a controlled study by Calderon-Celle et al., FT circuits and HIIT cycling were compared in sedentary obese adults. Both protocols significantly reduced visceral adiposity and improved VO_2max; however, only FT improved movement competency and flexibility, as evidenced by gains in Y-balance and sit-and-reach performance (90). This suggests that FT offers broader functional enhancements, even when total energy expenditure is matched. Notably, FT has been associated with lower perceived exertion and higher enjoyment scores than HIIT, factors which may enhance long-term adherence (91). Furthermore, FT permits auto-regulation of intensity via bodyweight scaling, rendering it accessible and adaptable across diverse obesity phenotypes.

Systematic comparisons highlight the unique benefits of each modality. In a meta-analysis of 48 RCTs involving obese participants, combined AT and RT (CT) resulted in the greatest fat mass reductions, whereas FT was most effective for improving quality of life, coordination, and reducing fall risk (92). Additionally, a multi-arm RCT by Rodrigues et al. showed that FT combined with AT led to greater reductions in waist-to-hip ratio and systemic inflammation than either modality alone (93). Another trial by Bittencourt et al. found that obese adolescents assigned to FT outperformed those in a HIIT group in functional capacity and adherence over a 20-week period, despite both groups exhibiting similar reductions in BMI (94). The dose-response characteristics of FT remain less defined than those of RT or HIIT; however, emerging evidence suggests a nonlinear adaptation profile, in which training frequency and movement complexity—rather than total volume—determine efficacy (95). For instance, a study by Oliveira et al. revealed that obese adults who trained with FT four times per week achieved significantly greater improvements in body composition and insulin sensitivity compared to those training twice weekly, even when total training duration was equivalent (96). Moreover, neuromuscular adaptations associated with FT—such as enhanced proprioception and motor control—appear to plateau at excessively high volumes, emphasizing the need for progressive periodization and complexity over duration alone (97).

Individualization remains a critical determinant of FT's success. FT allows for scalable movement pattern design and real-time proprioceptive integration, both of which optimize central nervous system adaptation and support long-term functional gains in obese populations (98). To consolidate current clinical evidence, Table 2 summarizes randomized controlled trials (RCTs) directly comparing FT with RT, AT, and HIIT in obese populations.

Table 2. Summary of Randomized Controlled Trials Comparing Functional Training (FT) with Conventional Training Modalities in Obese Individuals

Study (Author, Year)	Population (n, Age, BMI)	Intervention	Comparator	Duration	Main Outcomes	FT Superiority/ Equivalence
Silva et al., 2022 (99)	n=40, adults, BMI>30	FT (multi-joint, unstable) 3x/wk	Traditional RT 3x/wk	12 wk	↓ body fat %, ↑ VO_2max, ↑ functionality	Superiority in VO_2max and movement quality
Chen et al., 2023 (100)	n=60, middle-aged women	FT (circuit, whole-body) + diet	Aerobic treadmill	10 wk	↓ fat mass, ↑ insulin sensitivity	Equivalenc, better adherence in FT
Garcia et al., 2021 (101)	n=50, obese young males	FT vs. HIIT (matched volume)	HIIT (bike, intervals)	8 wk	↓ visceral fat, ↑ metabolic flexibility	FT slightly superior in motor skills
Kim et al., 2022 (102)	n=70, obese adults	FT (with proprioceptive tools)	Combined RT + AT	16 wk	↑ muscular endurance, ↑ balance, ↑ QOL	FT showed more improvemes in balance & QOL
Maaloul et al., 2024 (103)	n=64, inactive women with obesity	FT (HIFT) + Time-Restricted Eating (TRE)	HIFT only, TRE only	12 wk	↓ body weight, ↓ waist circumference, ↑ lipid and glucose profiles	Superiorityin combined FT+TRE group
Cao et al., 2024 (104)	n=45, young adults with overweight/ obesity	Functional HIIT (HIIT-F)	Running HIIT (HIIT-R)	12 wk	↑ lean mass, ↑ muscular strength, ↑ VO_2max	HIIT-F superior in muscular fitness
Morze et al., 2021 (105)	n=4774, adults with obesity	FT vs. RT vs. AT vs. HIIT	Various	≥6 mo	↓ BW, BMI, WC, FM, ↑ FFM	FT comparableto AT and superior to RT in FFM

Across a wide array of study designs, FT was found to deliver comparable or superior outcomes in fat loss, cardiorespiratory fitness, muscular strength, and psychosocial well-being. These findings underscore that FT is not merely an equivalent alternative to conventional training but rather a uniquely adaptive and engaging intervention, particularly well-suited for obese individuals when functional mobility and quality of life are prioritized. The collective data emphasize the translational value of FT in contemporary obesity management.

Functional Training Combined with Other Modalities

FT is increasingly recognized as a critical component of multimodal strategies for managing obesity. However, given the multifactorial etiology of obesity—including metabolic dysregulation, sedentary behavior, emotional eating, and psychosocial stress—relying solely on exercise-based approaches may constrain therapeutic efficacy. Emerging evidence supports the integration of FT with adjunctive interventions such as nutritional counseling and cognitive-behavioral therapy (CBT), producing synergistic benefits that promote sustainable weight loss, enhanced physical function, and improved psychological resilience. In a 2024 randomized controlled trial, Maaloul et al. evaluated the efficacy of combining time-restricted eating (TRE) with high-intensity FT (HIFT) in sedentary women with obesity. The combined intervention produced significantly greater reductions in body weight, waist circumference, fasting glucose, and lipid levels than either modality alone, underscoring the potentiating effect of simultaneous metabolic and neuromuscular stimuli on cardiometabolic outcomes (106). Similarly, Wang et al. examined a hybrid intervention incorporating functional strength training and aerobic exercise in obese adolescents. The program resulted in superior reductions in fat mass and greater improvements in cardiorespiratory fitness and movement competency compared to traditional RT, highlighting FT's capacity to restore biomechanical functionality in younger populations (107). Nechalová et al. extended this line of inquiry by demonstrating that combining caloric restriction with strength training and HIIT not only improved glycemic responses but also altered gut microbiota composition in individuals with obesity. These findings suggest that multimodal interventions may influence host metabolism through gut–muscle–brain signaling pathways beyond anthropometric changes (108).

Another promising strategy involves merging behavioral modification techniques with FT protocols. For example, Christensen et al. implemented a workplace intervention integrating diet, structured physical activity (including FT components), and CBT. The intervention yielded significant reductions in body weight and systolic blood pressure, along with improved work-related physical capacity and adherence to health-promoting behaviors, thereby demonstrating FT's applicability in real-world occupational contexts (109). Moreover, the advent of digital health technologies offers novel opportunities to deliver integrated interventions. In a 2023 trial, a mobile application delivering FT routines alongside personalized nutritional feedback and CBT modules led to clinically meaningful reductions in BMI and depressive symptoms over 16 weeks, with high adherence rates in obese adults (110). Such digitally enabled multimodal programs may offer scalable, cost-effective alternatives to traditional care, particularly in underserved or remote populations. The synergistic benefits of combining FT with complementary interventions are attributable to their collective impact on physiological and behavioral systems. FT enhances neuromuscular function, energy expenditure, and movement proficiency; dietary strategies optimize caloric intake, macronutrient composition, and metabolic regulation; and CBT facilitates cognitive restructuring, emotional control, and sustainable lifestyle change. These domains converge on shared biological pathways, including modulation of inflammation, hormonal balance (e.g., leptin, ghrelin, cortisol), and neuroplasticity. For instance, FT promotes the release of brain-derived neurotrophic factor (BDNF), while CBT improves prefrontal–limbic network connectivity—both contributing to improved mood, self-efficacy, and long-term exercise adherence (111). The translational value of such integrative approaches lies in their ability to address the complexity of obesity across interconnected domains—physiological, behavioral, nutritional, and environmental. Consequently, FT should be conceptualized not as an isolated intervention but rather as a central pillar within individualized, multidisciplinary obesity treatment frameworks.

Clinical, Public Health, and Translational Implications

FT in Clinical Rehabilitation and Chronic Disease Management

FT, with its emphasis on multi-joint, functional movement patterns and neuromuscular integration, has emerged as a clinically effective modality not only for obesity reduction but also for managing obesity-related chronic diseases. Given that obesity is a shared risk factor across a broad spectrum of metabolic and musculoskeletal conditions—including type 2 diabetes (T2D), non-alcoholic fatty liver disease (NAFLD), cardiovascular disease (CVD), and orthopedic disorders—FT offers a flexible and multidimensional platform well-suited for incorporation into clinical rehabilitation protocols.

Type 2 Diabetes (T2D): The global burden of T2D continues to rise in parallel with obesity prevalence. Insulin resistance in skeletal muscle and impaired glucose uptake are core features of T2D pathophysiology, and exercise regimens targeting these mechanisms are central to disease management. FT, by combining AT, RT, and balance elements, has demonstrated superior efficacy in enhancing insulin sensitivity, optimizing glycemic control, and increasing translocation of glucose transporter type 4 (GLUT-4). In a recent randomized trial, Nunes et al. found that a 12-week FT program led to significant reductions in HbA1c and fasting plasma glucose in middle-aged adults with T2D, outperforming conventional walking-based interventions in both metabolic regulation and perceived physical function (112). Similarly, Lopes et al. observed improved postprandial glycemic profiles and reductions in HOMA-IR following high-intensity FT in individuals with insulin resistance, supporting its potential as a targeted glucose-modulating therapy (113).

Non-Alcoholic Fatty Liver Disease (NAFLD): NAFLD, often regarded as the hepatic manifestation of metabolic syndrome, is now the most prevalent form of chronic liver disease and closely correlated with visceral adiposity. Although weight loss remains the cornerstone of treatment, recent findings suggest that FT may exert hepatoprotective effects via improved intrahepatic lipid metabolism and mitochondrial function. In a pilot study, García-Peña et al. reported that a 16-week FT protocol significantly reduced hepatic steatosis and liver stiffness—as assessed via transient elastography—in obese individuals with NAFLD, even in the absence of substantial weight loss (114). These findings suggest that FT may elicit hepatic adaptations via activation of AMPK (activated protein kinase) and SIRT1 (Sirtuin 1) signaling pathways, thereby extending its benefits beyond traditional energy balance models.

Cardiovascular Disease (CVD): Owing to the well-established relationship between obesity and CVD—including hypertension, atherosclerosis, and heart failure—there is growing interest in FT as a cardioprotective intervention. Unlike steady-state AT, FT incorporates dynamic, whole-body movements that engage both central and peripheral cardiovascular mechanisms, enhancing cardiac output, endothelial function, and autonomic regulation. A 2023 meta-analysis by Ruiz-Montero et al. found that FT significantly improved VO_2max, heart rate variability, and systolic blood pressure in obese individuals at risk for CVD, surpassing the benefits observed in traditional resistance-based programs (115). Importantly, the inherently enjoyable and functionally relevant nature of FT may promote greater long-term adherence—a crucial factor in the success of preventive cardiovascular strategies.

Orthopedic and Musculoskeletal Comorbidities: Obesity substantially increases mechanical loading on joints, particularly the knees, hips, and lumbar spine, which elevates the risk of OA, chronic low back pain, and movement dysfunction. When appropriately individualized, FT can counteract these effects by improving joint alignment, enhancing proprioceptive acuity, and retraining neuromuscular control. In a study by Carvalho et al., FT improved gait kinematics, lower-limb strength asymmetry, and pain tolerance in obese adults with early-stage knee OA (116). Another comparative trial found that FT yielded greater improvements in postural balance and core stability among obese adults with chronic low back pain than standard physiotherapy, suggesting its utility as a biomechanically intelligent alternative (117). These findings support the role of FT in restoring optimal movement mechanics and reducing mechanical stress in individuals with obesity-related orthopedic conditions.

Community and Home-Based FT Programs

As obesity continues to exert a profound strain on public health systems worldwide, there is growing emphasis on interventions that are scalable, cost-effective, and widely accessible. FT, with its inherent adaptability and focus on real-life movements, presents a distinct opportunity to extend structured exercise beyond clinical and fitness settings into community and home environments. This decentralized approach is well aligned with contemporary models of preventive healthcare, in which sustainability, feasibility, and adherence are prioritized.

Feasibility and Accessibility: A principal advantage of FT lies in its exceptional versatility. Because functional exercises typically require minimal equipment and are easily modifiable to suit confined spaces, they are particularly well suited to home and community contexts. Research has demonstrated that FT can be effectively implemented using bodyweight, resistance bands, common household items, or portable equipment such as kettlebells and medicine balls, thereby removing many of the logistical obstacles that often hinder participation (118). For example, a pragmatic randomized controlled trial conducted by McLaughlin et al. evaluated a 12-week community-based FT program delivered at local recreation centers in economically disadvantaged neighborhoods. The intervention not only produced improvements in BMI and waist circumference but also yielded high retention (86%) and session attendance (mean: 87%) rates (119). These findings underscore FT's minimal infrastructure demands and its potential for widespread dissemination, particularly in resource-limited settings.

Adherence and Engagement: Sustained adherence is among the most critical factors influencing the long-term efficacy of exercise in obesity management. Conventional exercise programs frequently experience high dropout rates, often attributed to monotony, lack of variety, or perceived difficulty. In contrast, FT integrates diverse, gamified, and functionally meaningful tasks that enhance both engagement and long-term compliance. Recent qualitative research by D'Addario et al. found that participants enrolled in a home-based FT intervention for overweight adults reported significantly greater enjoyment, a heightened sense of purpose, and increased self-efficacy compared to counterparts engaged in traditional aerobic regimens (120). Furthermore, because FT incorporates movements that closely replicate everyday tasks—such as squatting, pushing, lifting, and stepping—it enhances perceived relevance, a well-established mediator of adherence (121). From a behavioral psychology perspective, FT aligns effectively with Self-Determination Theory (SDT), fostering autonomy (through customization), competence (via functional skill development), and relatedness (particularly in group-based formats), all of which are positively associated with intrinsic motivation and sustained participation (122).

Low-Cost and Scalable Implementation Models: The escalating economic burden of obesity-related comorbidities highlights the urgency of identifying interventions that are both affordable and scalable. Community-based FT programs offer a compelling solution, as they demand minimal professional supervision and infrastructure. Several municipalities and public health agencies have begun incorporating FT into their population health frameworks due to its cost-effectiveness. For instance, the "MoveWell" initiative in New Zealand employed certified trainers to deliver free FT classes in public parks and community centers across both urban and rural areas. A 2022 program evaluation revealed significant reductions in obesity prevalence and metabolic syndrome indicators in participating districts over a 12-month period (123). Similarly, digital and remote delivery methods—such as mobile applications, video conferencing platforms, and wearable feedback systems—have seen rapid expansion. A 2023 meta-analysis by Leung et al. confirmed that app-guided FT interventions produced comparable improvements in body composition, muscular strength, and functional capacity relative to in-person programs, while offering lower implementation costs and broader accessibility (124). Importantly, these delivery models accommodate individuals facing barriers such as mobility impairments, social anxiety, or limited time availability, thereby addressing the diverse obstacles that often impede physical activity among individuals with obesity.

Special Populations and Health Equity: Community- and home-based FT interventions are particularly advantageous for populations traditionally underserved by structured fitness programs, including older adults, women with caregiving responsibilities, and individuals from marginalized ethnic groups. Customized FT protocols that respect cultural values, individual functional capacity, and day-to-day constraints can help close health equity gaps and support inclusive public health initiatives (125). A recent clinical trial involving Hispanic women with obesity demonstrated that culturally adapted, home-based FT—delivered through WhatsApp video messaging—substantially increased physical activity levels and reduced depressive symptoms, with adherence rates exceeding 90% over a 16-week period (126). Such culturally sensitive approaches offer strong support for expanding FT beyond Western-centric models into broader global health strategies.

FT in Special Populations

Women: FT provides a personalized approach tailored to the distinct physiological and biomechanical characteristics of women, particularly those affected by obesity. Hormonal fluctuations, especially during menopause, are associated with increased adiposity and loss of muscle mass. FT, which emphasizes compound and functional movements, can attenuate these effects by enhancing muscular strength and elevating metabolic rate. Recent empirical studies have shown that resistance-based FT programs significantly improve both body composition and functional performance in older women with sarcopenic obesity, thereby enhancing mobility and reducing fall risk (127).

Older Adults: The aging process is typically accompanied by a progressive decline in muscle mass and strength, which undermines functional autonomy. FT programs that prioritize balance, coordination, and muscular strength offer considerable benefits for older adults. Evidence indicates that multicomponent training (MCT) interventions incorporating FT elements improve muscular hypertrophy, strength, gait efficiency, postural balance, and cardiorespiratory fitness in elderly populations. Moreover, resistance-based FT regimens have consistently produced meaningful improvements in body composition and physical functioning among older adults with sarcopenic obesity (128).

Sarcopenic Obesity: Sarcopenic obesity—a condition characterized by the coexistence of reduced muscle mass and excessive adiposity—presents a serious risk for physical decline and metabolic dysregulation. FT, particularly in the form of RT, has emerged as an effective countermeasure to mitigate the deleterious consequences of this dual condition. Meta-analyses have confirmed that RT enhances physical performance and reduces body fat percentage in older adults with sarcopenic obesity. Additionally, targeted resistance exercise programs have demonstrated efficacy in improving both body composition and functional capabilities, especially among older women in this high-risk group (129).

FT in National Physical Activity Guidelines

Although traditionally underrepresented in national physical activity guidelines, FT has increasingly been recognized as a viable approach to addressing the multifaceted challenges of obesity, owing to its physiological, biomechanical, and behavioral advantages. As governments and public health authorities confront the escalating prevalence of obesity and its associated comorbidities, incorporating FT into national guidelines presents a scalable, accessible, and adaptable solution that aligns with the core principles of population health promotion, disease prevention, and healthy aging.

Historically, physical activity recommendations issued by authoritative bodies such as the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), and national health agencies have predominantly emphasized aerobic exercise and traditional RT. However, recent shifts indicate a paradigm change toward more inclusive models that prioritize functional capacity, mobility, and the performance of real-world tasks—principles that form the foundation of FT methodologies. For instance, the WHO's 2020 *Guidelines on Physical Activity and Sedentary Behaviour* advocate multicomponent physical activity for older adults, explicitly recommending exercises that improve functional balance and muscular strength to prevent falls and support independent living (130). Similarly, the U.S. Department of Health and Human Services' Physical Activity Guidelines for Americans (2nd edition) endorse muscle-strengthening activities targeting major muscle groups that facilitate everyday movement—objectives that are inherently fulfilled through FT protocols (131).

In the context of obesity, both national and international strategies are progressively incorporating FT principles into disease-specific guidelines. These recommendations increasingly emphasize exercises that enhance movement efficiency, core stability, and neuromuscular control—components particularly pertinent to populations in which obesity compromises biomechanical function. The Canadian *24-Hour Movement Guidelines*, for example, underscore the importance of integrating strength- and balance-enhancing activities throughout the week, especially for individuals managing chronic conditions such as obesity or type 2 diabetes (132). Notably, functional modalities (e.g., squatting, pushing, pulling) not only improve proficiency in activities of daily living but also tend to yield higher adherence due to their dynamic and varied characteristics (133).

Incorporating FT into public health strategies can extend the reach and inclusivity of national guidelines, especially among underserved and at-risk populations. By emphasizing movement quality and its relevance to everyday life, FT serves as an effective bridge between clinical rehabilitation and community-based health promotion. Countries such as Australia and New Zealand have begun implementing policy models that prioritize functional fitness across the lifespan, acknowledging its role in preserving autonomy and reducing healthcare expenditures associated with obesity-related disability (134). In parallel, the European Union's *EU Physical Activity Guidelines* and the *Health-Enhancing Physical Activity (HEPA) Europe* framework increasingly advocate for the integration of functional movement training into school curricula, workplace wellness initiatives, and clinical rehabilitation programs, thereby reinforcing the translational value of FT in public health (135). These efforts are consistent with broader planetary health goals, which promote physical literacy and lifelong movement competence from early childhood through older adulthood.

Despite the conceptual alignment, the widespread integration of FT into national physical activity guidelines presents several challenges. These include the need for protocol standardization, the training and accreditation of fitness professionals, and the development of robust mechanisms for monitoring efficacy in large-scale populations. Moreover, existing surveillance metrics (e.g., MET-minutes) may insufficiently capture the physiological and functional benefits conferred by non-linear and task-specific movement patterns. Future iterations of national guidelines should aim to explicitly define and incorporate FT modalities, supported by empirically validated frameworks to ensure consistency in implementation and outcome assessment. To facilitate policy adoption, interdisciplinary collaboration among exercise scientists, healthcare providers, policymakers, and public health professionals is essential. The development of culturally adaptive FT models and their integration into primary care pathways for obesity prevention and treatment could significantly expand both the reach and effectiveness of these interventions at the population level.

Clinical Translation and Practical Applications

FT represents a promising translational conduit between exercise science and pragmatic obesity management. In contrast to conventional RT or AT, FT prioritizes multi-planar, task-specific movements that emulate real-world physical demands, thereby enhancing both physiological resilience and biomechanical adaptability. This renders FT particularly suitable for individuals with obesity, who frequently encounter challenges such as restricted mobility, joint discomfort, and elevated fall risk. From a clinical perspective, functional exercises contribute to improved movement economy, postural alignment, and neuromuscular coordination—all of which directly influence quality of life and mitigate the risk of obesity-related comorbidities, including OA and chronic lower back pain.

Rehabilitation specialists and exercise physiologists can customize FT interventions to address specific impairments, such as balance deficits or abnormal gait mechanics, utilizing modalities like unstable surfaces, dynamic resistance tools, and proprioceptive stimuli. Importantly, the adaptability of FT protocols allows for their implementation across a wide range of clinical and community-based settings, from outpatient rehabilitation facilities to population-level wellness programs. When combined with nutritional counseling and behavioral support, these programs may yield synergistic benefits, particularly for individuals presenting with complex biopsychosocial profiles. In this capacity, FT extends beyond traditional fitness objectives to function as a core therapeutic strategy in comprehensive obesity care.

Functional Training Principles in Obesity Management:

To bridge the gap between theoretical constructs and clinical application, Table 3 provides a synthesis of evidence-based FT protocols specifically designed for individuals with obesity. This table outlines critical parameters—such as frequency, intensity, modality, and progression strategies—drawn from recent clinical and applied studies. It serves as a practical framework for exercise professionals seeking to implement safe, effective, and adaptive FT programs within the context of obesity management. To enhance the translational impact of this review, Table 3 presents a set of empirically grounded recommendations tailored to the needs of fitness practitioners and exercise physiologists. These guidelines, derived from aggregated findings in the current literature, have been adapted to optimize safety, promote effectiveness, and encourage long-term adherence in individuals with obesity (136-141).

A dedicated section entitled “Key Takeaways for Clinicians and Exercise Practitioners” has been introduced to consolidate the practical implications of the present findings. This section distills the core insights from the existing literature into actionable guidance, thereby enabling professionals in clinical and fitness settings to implement FT protocols effectively within obesity management strategies.

Key Takeaways for Clinicians and Exercise Practitioners:

- Functional training is not merely a performance-enhancing approach; rather, it constitutes a clinically relevant intervention for addressing obesity through integrative physiological and biomechanical adaptations.
- Evidence of improved insulin sensitivity, lipid profiles, and inflammatory markers underscores its substantial cardiometabolic benefits, particularly among middle-aged and older adults.

Table 3. Evidence-Based Functional Training Protocols for Obesity: Practical Guidelines for Implementation

Component	Recommended Parameters	Rationale
Training Goals	Fat loss, improved mobility, enhanced functional capacity	Targets core deficits in obese individuals
Session Frequency	3–5 sessions/week	Ensures metabolic stimulus without overtraining
Session Duration	45–60 minutes	Balances energy expenditure with adherence
Exercise Types	Multi-joint, functional movements (e.g., squats, lunges, carries, rotation patterns)	Engages large muscle groups, promotes calorie burn
Intensity	Moderate to high (60–85% HRmax) or RPE 6–8	Stimulates metabolic response while maintaining safety
Progression Strategy	Increase complexity and load every 2–3 weeks	Promotes adaptation, avoids plateau
Warm-up / Cool-down	5–10 min dynamic warm-up; 5–10 min active recovery/stretching	Injury prevention and recovery enhancement
Balance & Coordination	Include unstable surfaces or dual-task exercises 2x/week	Improves neuromuscular efficiency and fall prevention
Core Integration	Include anti-rotation, planks, dead bugs, etc. in every session	Reduces back pain risk, improves trunk stability
Monitoring Tools	HR monitor, RPE scale, movement screening (e.g., FMS)	Enhances safety and individualization
Population Specific Tips	For elderly: reduce volume, prioritize stability; For youth: emphasize motor skill learning	Tailors interventions for safety and engagement in diverse populations

Enhancements in movement efficiency, neuromuscular coordination, and reduced joint loading contribute to improved functional mobility and a decreased risk of injury.

• FT protocols should be individualized, progressive, and multicomponent, emphasizing core stability, balance, and task-oriented movements.

• Combined interventions—such as those incorporating nutritional guidance and behavioral counseling—are likely to augment the overall effectiveness of FT in individuals with obesity.

• Routine assessment of body composition, postural control, and patient-reported outcomes is critical for evaluating functional progress and guiding program modifications.

• Functionally oriented protocols may confer disproportionate benefits to specific subpopulations, including postmenopausal women and older adults, due to the compounding effects of age-related physiological decline.

Innovation and Future Directions

Technological Integration

The integration of emerging technologies into FT frameworks marks a pivotal advancement in the therapeutic management of obesity. Among the most transformative tools are wearable devices—such as smartwatches and fitness trackers—which enable real-time monitoring of physiological parameters including heart rate, energy expenditure, and step count. These technologies facilitate self-monitoring and promote behavioral accountability, both of which are critical for sustained weight loss and long-term behavioral change.

A meta-analysis by Brickwood et al. (2024) demonstrated that wearable devices are associated with statistically significant reductions in both BMI and fat mass in overweight and obese populations (142). Additionally, motion capture systems have augmented the clinical utility of FT by providing precise biomechanical analyses. Both marker-based and markerless technologies have been employed to evaluate postural control, joint kinematics, and compensatory movement patterns—data that are essential for tailoring FT interventions to individuals with obesity, who frequently exhibit altered gait mechanics and aberrant joint loading (143). The provision of real-time feedback facilitates immediate correction, thereby enhancing exercise quality and mitigating injury risk. Furthermore, artificial intelligence (AI)-driven exercise applications now possess the capacity to personalize FT regimens by dynamically adjusting training variables—such as intensity, volume, and rest intervals—based on wearable data, self-reports, and user performance. Such platforms have demonstrated superior adherence rates and greater user satisfaction compared to static exercise programs (144). Virtual reality (VR) and augmented reality (AR) applications are also being explored for their potential to enhance engagement, particularly in populations with low intrinsic motivation toward physical activity (145).

Research Gaps

Despite the technological promise, several research gaps persist within the FT–obesity literature. A principal limitation is the absence of standardized FT protocols across studies. Current investigations exhibit considerable variability in intervention design, encompassing discrepancies in session duration, training frequency, intensity modulation, exercise complexity, and progression criteria. This heterogeneity compromises both the comparability of outcomes and the external validity of findings.

Moreover, many studies are constrained by short intervention durations and modest sample sizes. There is a notable scarcity of longitudinal, ecologically valid trials examining the chronic adaptations to FT, particularly in diverse populations burdened with obesity-related comorbidities such as type 2 diabetes or sarcopenic obesity. Additionally, limited research exists on the durability of FT-induced benefits, such as weight maintenance, metabolic resilience, and psychosocial well-being, over extended timeframes. Another underexplored area concerns the interaction between technology use and exercise behavior. Although digital tools can improve adherence, their influence on intrinsic motivation, autonomy, and sustained compliance remains inadequately understood. Issues of accessibility and affordability further complicate implementation, especially within socioeconomically disadvantaged populations.

Future Directions

While the current narrative review highlights the multifaceted physiological and biomechanical benefits of FT for individuals with obesity, future research must address several critical knowledge gaps. First, longitudinal RCTs are urgently needed to compare FT modalities directly with traditional RT or AT, focusing on long-term adherence, functional performance, and metabolic outcomes. Second, integrative intervention models that combine FT with dietary modifications, psychological support, and behavioral therapies remain underdeveloped. These multimodal approaches may produce synergistic effects, particularly among individuals with complex obesity-related challenges such as emotional eating, mood disorders, or low exercise motivation. Third, technological innovations—including AI-driven platforms and motion analysis tools—hold substantial promise for optimizing load progression, movement precision, and injury prevention. These technologies may be particularly beneficial when customizing interventions for subgroups such as postmenopausal women, adolescents, or elderly individuals.

Finally, future investigations should examine the neurocognitive and psychosocial implications of FT. Given its task-specific, cognitively engaging nature, FT may enhance executive function, emotional regulation, and overall quality of life to a greater extent than conventional exercise modalities. Collectively, these research priorities underscore the necessity of a multidisciplinary approach to translating the theoretical and empirical potential of FT into scalable, real-world applications.

Conclusion

FT constitutes a robust, multidimensional therapeutic strategy for obesity management, targeting not only weight reduction but also broader physiological, biomechanical, and psychosocial health outcomes. This review underscores that FT interventions—defined by their emphasis on neuromuscular control, movement efficiency, and functional relevance—can yield meaningful improvements in body composition, cardiovascular risk factors, metabolic regulation, and musculoskeletal function in individuals with obesity. Moreover, the inherently adaptable and engaging nature of FT promotes long-term adherence and enhances psychological well-being, both of which are critical for sustainable lifestyle change. Unlike traditional exercise modalities that prioritize isolated physiological adaptations, FT uniquely integrates core stability, proprioceptive engagement, and multi-joint coordination—characteristics that are especially aligned with the functional impairments common in obese populations. Given its dual-action profile and minimal reliance on specialized equipment, FT is well-suited for integration into both clinical rehabilitation settings and public health initiatives. Within clinical contexts, FT can be embedded into comprehensive obesity management programs alongside nutritional therapy, behavioral interventions, and pharmacotherapy. In essence, FT extends beyond conventional exercise to function as a rehabilitative and preventive framework that addresses both the mechanical and metabolic dimensions of obesity. While the existing literature affirms its efficacy, large-scale, rigorously controlled trials comparing FT with established exercise modalities remain a critical unmet need. Future research should aim to refine protocol parameters for different obesity phenotypes, explore dose-response relationships, and evaluate long-term outcomes across diverse populations.

In summary, FT should be recognized as a viable, integrative component of individualized obesity treatment strategies. It bridges the divide between rehabilitation, performance enhancement, and chronic disease prevention. This review offers clinicians, exercise practitioners, and researchers a consolidated foundation for evidence-based implementation and outlines key avenues for future inquiry in this evolving field.

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Conflict of Interest

The authors declare no conflict of interest.

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