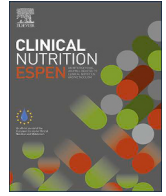




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Narrative Review

Breastfeeding and maternal exercise: A synergistic approach to improve cardiometabolic health



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SUMMARY

Background & aims: Breastfeeding is the optimal form of infant nutrition, conferring extensive benefits for both maternal and child health. Maternal physical activity likewise supports postpartum recovery, cardiometabolic health, and psychological well-being. Historical concerns have been raised about possible negative effects of exercise on breast milk composition, supply, and infant acceptance. This review synthesizes current evidence on the interplay between exercise and breastfeeding, with a focus on maternal and infant cardiometabolic health.

Methods: A structured literature search was conducted in PubMed and Scopus for the period January 2000–December 2024, using predefined keywords on breastfeeding, lactation, exercise, and maternal health. Eligible studies assessed maternal physical activity during lactation and reported outcomes on breast milk, maternal health, or infant development. Screening was performed independently by two reviewers following PRISMA guidelines.

Results: Moderate-intensity exercise (30–45 min per day) does not adversely affect milk volume, nutrient composition, or infant growth. Instead, it may enhance antioxidant levels in breast milk, improve lipid and hormonal profiles, and support maternal weight management. Transient lactate increases after strenuous exercise may alter milk taste, but normalize within an hour and have no clinical impact. Breastfeeding itself confers maternal cardiometabolic protection, lowering risks of hypertension, metabolic syndrome, and type 2 diabetes. Emerging data suggest maternal exercise during lactation may also influence infant metabolic programming, potentially reducing long-term risk of obesity and cardiovascular disease.

Conclusions: Maternal exercise and breastfeeding are not mutually exclusive but synergistic in promoting maternal and child health. Accumulated evidence indicates that moderate maternal exercise does not compromise breast milk supply or its capacity to meet infant nutritional needs.

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Importance: Healthcare providers should reassure postpartum women that moderate exercise is safe during lactation and encourage its integration into postpartum care. Future studies should explore high-intensity exercise, resistance training, and inter-individual variability to refine recommendations. © 2025 The Author(s). Published by Elsevier Ltd on behalf of European Society for Clinical Nutrition and Metabolism. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Breast milk is the optimal source of infant nutrition, providing macronutrients, immune factors, and bioactive compounds that support growth, development, and long-term health benefits such as reduced risks of infections, allergies, obesity, and diabetes [1–3]. Pregnancy and the postpartum period also represent critical windows for maternal cardiometabolic health, during which complications such as hypertensive disorders may emerge with long-term consequences [4,5]. These disorders are associated with acute complications and long-term cardiovascular consequences for women, and echocardiographic studies have demonstrated early cardiac organ damage in affected pregnancies, underscoring the need for prevention strategies [6,7]. In this context, maternal physical activity plays a pivotal role in recovery, weight management, and cardiovascular health [8] (see Fig. 1).

Concerns were historically raised that exercise might alter breast milk composition, volume, or taste [9–13]. Early reports suggested transient increases in milk lactate after strenuous activity, occasionally affecting infant acceptance [9,14]. However, subsequent randomized controlled trials and meta-analyses have consistently demonstrated that moderate maternal exercise does not compromise milk supply, nutrient content, or infant growth [11–13].

Despite these insights, important gaps remain. The mechanisms through which exercise influences breast milk composition, including hormonal shifts, metabolic changes, and immune pathways, are not fully understood [15]. Individual factors such as maternal diet, hydration, and fitness level may further modulate responses [16,17].

This review therefore synthesizes current knowledge on the relationship between maternal exercise and breast milk composition, focusing on macronutrients, immune factors, and bioactive compounds, and explores its potential role in infant metabolic programming and long-term cardiometabolic health [18].

2. Methods

A structured literature search was conducted in PubMed and Scopus from January 2000 to December 2024 using predefined keywords related to breastfeeding, lactation, exercise, and maternal health. Search terms included "breastfeeding and exercise," "breast milk composition," and "postpartum physical activity." A total of 780 records were identified (PubMed, n = 412; Scopus, n = 368). After removal of 132 duplicates, 648 records remained for title and abstract screening. Of these, 512 were excluded as not relevant. The full texts of 136 articles were assessed, and 87 were excluded for lack of breastfeeding outcomes, inadequate description of exercise exposure, or insufficient

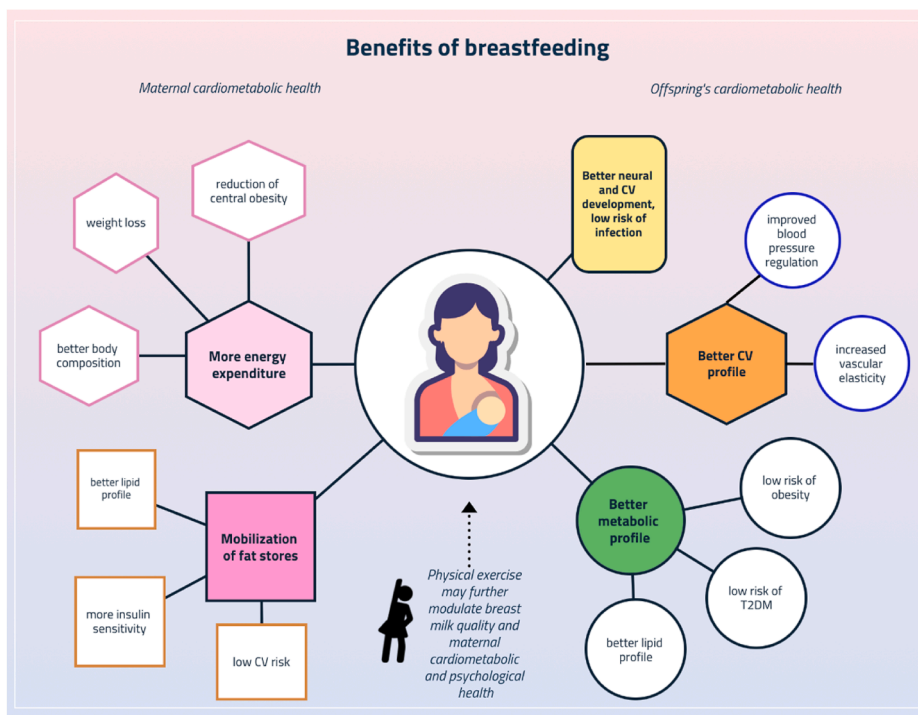


Fig. 1.

methodological quality. Finally, 49 studies were included in this review. Screening and selection were performed independently by two reviewers, with disagreements resolved by consensus. To ensure transparency and completeness of reporting, we followed the PRISMA guidelines, and a detailed flow chart of the selection process is provided in the Supplemental Materials (Fig. S1).

Although we conducted a structured search across multiple databases, a formal systematic review was not feasible. The available studies were highly heterogeneous in design, populations, and reported outcomes, and often lacked sex-disaggregated data. These limitations precluded the use of standardized quality assessment tools and the conduct of a meta-analysis. Therefore, we synthesized the evidence as a narrative review, which permits a broader and more integrative discussion of the topic.

3. Mechanistic insights

Maternal exercise influences breastfeeding through multiple physiological and biochemical mechanisms. These include classical pathways such as hormonal regulation, lactate metabolism, energy balance, and immune modulation, as well as emerging mechanisms involving exerkines, fatty acid composition, and the milk miRNome.

3.1. Hormonal regulation of lactation

Physical activity induces transient changes in maternal hormonal profiles, particularly prolactin, cortisol, insulin, and thyroid hormones, which play central roles in milk synthesis and secretion. Early clinical studies demonstrated that moderate aerobic exercise does not suppress prolactin secretion or impair milk production, confirming that exercise within physiological limits is compatible with successful lactation [10,11]. By contrast, vigorous or prolonged exercise may transiently elevate cortisol, raising theoretical concerns about interference with the milk ejection reflex, although such effects remain unproven.

3.2. Lactate metabolism and breast milk taste

High-intensity exercise increases circulating lactate, and some diffuses into breast milk. This may transiently alter its taste, though the effect is short-lived. The clinical implications are further detailed in Section 4.2.3.

3.3. Energy balance and nutrient partitioning

Lactation requires substantial energy, and exercise further increases maternal expenditure, enhancing mobilization of fat stores accumulated during pregnancy. This dual demand contributes to improved lipid and glucose regulation [19,20]. Bopp et al. further demonstrated that maternal exercise was associated with favorable changes in breast milk fatty acid composition, without compromising volume or nutrient content [21]. Controlled trials demonstrate that moderate exercise without caloric restriction does not compromise milk volume or macronutrient composition [22], underscoring its safety in the postpartum period. The detailed clinical implications for maternal metabolism are described in Section 4.2.1.

3.4. Immune modulation

Exercise exerts immunological effects through cytokines, stress hormones, and signaling molecules known as exerkines [23]. Some reports suggest that strenuous exercise may transiently lower secretory IgA concentrations in breast milk [24], whereas moderate activity does not appear to negatively affect immune factors [25]. These findings raise the possibility that maternal physical activity could influence the immunological composition of breast milk, with downstream consequences for infant immune development.

3.5. Exerkines and metabolomics

Physical activity stimulates the release of myokines, adipokines, and other circulating mediators, collectively termed exerkines [26]. Some of these molecules, including adiponectin and leptin, are present in breast milk and contribute to infant appetite regulation and glucose metabolism [27]. Recent human evidence supports this concept: Lu et al. reported that maternal exercise during lactation beneficially influenced breast milk composition and infant metabolic outcomes, while Taki et al. demonstrated that physical activity shapes the breast milk metabolome, further supporting its role in offspring metabolic programming [28,29].

3.6. Emerging mechanisms: fatty acid composition and milk miRNome

Beyond these classical mechanisms, maternal exercise may also modulate the lipid profile and epigenetic content of breast milk. Bopp et al. showed that postpartum exercise is associated with favorable changes in breast milk fatty acid composition, without compromising nutrient content. In experimental models [21]. Quiclet et al. demonstrated that maternal training modifies breast milk fatty acid pathways and improves offspring glucose homeostasis, while Harris et al. reported exercise-induced increases in milk oligosaccharides that enhanced metabolic health in mouse offspring [30,31]. Together, these findings suggest that maternal activity may generate a healthier fatty acid and metabolite phenotype in breast milk.

A second emerging pathway is the regulation of the milk microRNA profile, or *miRNome* [32]. MicroRNAs are small non-coding RNAs carried in milk extracellular vesicles that regulate gene expression and may influence immune maturation, metabolic processes, and neurodevelopment in the infant. Animal studies support this concept: Ribeiro et al. showed that maternal physical activity alters mammary gland gene expression, including miRNA pathways, while Moser et al. highlighted the role of maternal environment in shaping offspring development through epigenetic regulators [33,34].

More recently, Holm et al. confirmed in humans that maternal physical activity modulates specific breast milk metabolites with potential implications for infant cardiometabolic health [35]. These mechanisms suggest that maternal exercise exerts its effects on lactation and infant health through overlapping pathways, including hormonal regulation, energy balance, lactate metabolism, immune modulation, exerkines, lipid metabolism, and epigenetic factors. While most evidence indicates safety and potential benefits of moderate exercise during lactation, further mechanistic studies, particularly in the fields of metabolomics and the milk miRNome, are needed to fully elucidate these pathways.

4. Benefits of breastfeeding on cardiovascular health

4.1. Benefits for infants and children

Breastfeeding provides optimal nutrition for infants, with a composition uniquely adapted to support growth, development, and immune protection. It reduces the incidence of infectious diseases such as respiratory tract infections and diarrhea, while also conferring protection against chronic conditions including allergies, asthma, obesity, and type 2 diabetes later in life. A meta-analysis of 25 studies found that breastfed infants had a 22 % lower risk of obesity and a 24 % lower risk of type 2 diabetes in adulthood [1,18].

The World Health Organization (WHO) and leading pediatric societies recommend exclusive breastfeeding for the first six months of life, recognizing it as the gold standard of infant nutrition that significantly lowers infant mortality and promotes lifelong health [36].

4.1.1. Essential fatty acids and lipid metabolism

One of the most compelling long-term benefits of breastfeeding is its impact on cardiometabolic health. Breast milk contains essential fatty acids (EFAs), including omega-3 and omega-6 fatty acids, which serve as precursors for long-chain polyunsaturated fatty acids (LCPUFAs) such as docosahexaenoic acid (DHA) and arachidonic acid. These nutrients are fundamental for neural and cardiovascular development [37]. Cholesterol in breast milk supports cell membrane and steroid hormone synthesis and plays a role in early lipid metabolism programming. Studies consistently show that breastfed infants have lower total cholesterol and LDL levels in adulthood, suggesting protection against dyslipidemia and cardiovascular disease (CVD) [38–40].

4.1.2. Adipokines and metabolic regulation

Breast milk also contains bioactive adipokines, notably leptin and adiponectin, which regulate appetite, energy balance, and glucose metabolism. Leptin acts centrally to regulate hunger and fat distribution, while adiponectin enhances insulin sensitivity and exerts anti-inflammatory effects [27,41]. These hormones influence infant metabolic programming, reducing the risk of metabolic syndrome and type 2 diabetes. Higher leptin levels in breast milk have been associated with improved weight regulation during childhood, a key determinant of cardiovascular risk [42,43].

4.1.3. Cardiovascular health markers

Cardiovascular benefits of breastfeeding are reflected in blood pressure and vascular function. The CHILD (Canadian Healthy Infant Longitudinal Development) cohort demonstrated that any breastfeeding, regardless of exclusivity or duration, was associated with lower blood pressure at 3 years of age [44]. Breastfed infants also show improved arterial compliance and vascular elasticity; markers strongly linked to reduced lifetime cardiovascular risk [45]. These effects are thought to be mediated, at least in part, by the anti-inflammatory and antioxidant properties of breast milk. Breastfed infants are exposed to protective mediators such as cytokines, lactoferrin, and glutathione, which modulate systemic inflammation [46,47]. Lactation is associated with reduced maternal levels of pro-inflammatory cytokines (IL-6, TNF- α , CRP) and enhanced production of anti-inflammatory mediators like IL-10, a profile that may attenuate systemic inflammation and protect vascular integrity [48–51].

4.1.4. Obesity prevention

Given the global burden of obesity, estimated to affect more than 200 million children worldwide and contribute to 2.8 million

deaths annually, the protective role of breastfeeding against excess weight gain is particularly [52,53]. Childhood obesity dramatically increases the risk of diabetes, hypertension, dyslipidemia, and CVD, underscoring the importance of early interventions such as breastfeeding to promote healthier metabolic trajectories [19,20,54,55].

4.1.5. Maternal contributions

Finally, breastfeeding aids in mobilization of fat stores accumulated during pregnancy, improving lipid metabolism and reducing maternal [19,20,56]. This contributes not only to maternal cardiometabolic recovery but also to a breast milk profile that supports favorable metabolic programming in the infant [57,58].

4.2. Benefits for the mothers

Breastfeeding reduces maternal cardiovascular risk by promoting a healthier cardiometabolic profile, including lower rates of hypertension, diabetes CVD, and later in life [59]. (Table 1) A recent meta-analysis of over one million women demonstrated that mothers who breastfed had significantly lower risks of CVD, coronary heart disease, stroke, and fatal cardiovascular events compared with those who never breastfed [59]. In this random-effects meta-analysis, the pooled multivariable-adjusted hazard ratios comparing parous women who ever breastfed to those who never breastfed were 0.89 for CVD (95 % CI, 0.83–0.95; $I^2 = 79.4 %$), 0.86 for coronary heart disease (95 % CI, 0.78–0.95; $I^2 = 79.7 %$), 0.88 for stroke (95 % CI, 0.79–0.99; $I^2 = 79.6 %$), and 0.83 for fatal CVD (95 % CI, 0.76–0.92; $I^2 = 47.7 %$) [59]. These findings highlight the long-term protective role of lactation on maternal cardiovascular health. It supports postpartum recovery, enhances metabolic regulation, and provides long-term protection against CVD.

4.2.1. Maternal metabolism: energy expenditure, fat mobilization, and cardiometabolic health

Beyond energy balance, breastfeeding promotes the mobilization of fat stores accumulated during pregnancy, particularly visceral adipose tissue, which is closely associated with insulin resistance and cardiometabolic risk [19,60]. Breastfeeding is a metabolically demanding process, requiring approximately 500 additional kilocalories per day to support milk production [61]. This elevated energy expenditure contributes to postpartum weight loss and helps mothers return more effectively to their pre-pregnancy weight compared with non-lactating women [61,62]. Excess postpartum weight retention is a well-documented risk factor for CVD, as it is associated with increased adiposity, systemic inflammation, and dyslipidemia [63,64]. Recent longitudinal studies further indicate that inadequate postpartum weight loss predicts higher lifetime cardiometabolic risk, linking central obesity to adverse cardiovascular outcomes [63]. Exclusive breastfeeding for at least six months amplifies these protective effects, with evidence of healthier waist-to-hip ratios and reduced risk of metabolic syndrome and related cardiovascular conditions [65,66].

A group of 678 women enrolled in the Pregnancy Outcomes and Community Health (POUCH) cohort also participated in the POUCHmoms Study 7–15 years after delivery. Multivariable linear regression models and propensity scores were used to assess the relationship between WC measured at follow-up and self-reported history of breastfeeding duration of >6 months versus ≤ 6 months. After a mean follow-up period of 11.0 (standard deviation = 1.4) years, breastfeeding was significantly associated with smaller WC. A threshold effect was detected for women who reported breastfeeding >6 months; their adjusted mean WC was 3.5 cm (95 %

Table 1
Benefits of breastfeeding.

Category	Benefit	Key Points
Infant health	Nutrition	Optimal source of nutrients
	Protection	↓ infections, ↓ asthma, ↓ obesity, ↓ type 1 diabetes, ↓ SIDS
	Antibodies	Colostrum rich in IgA and other antibodies
	Immune support	Maternal antibodies protect respiratory & GI tract
Maternal health	Convenience	Always available, no preparation needed
	Cancer risk	↓ breast and ovarian cancer
	Metabolic health	↓ type 2 diabetes, ↓ hypertension
General	Mental health	↓ risk of postpartum depression
	Exclusive breastfeeding	Recommended for first 6 months; continue with complementary foods ≥12 months

confidence interval [CI]: -5.7 to -1.2) smaller compared with women who breastfed ≤ 6 months. The use of two propensity score approaches, weighted and matched, produced similar results; adjusted mean WC difference was -3.6 cm (95 % CI: -5.6 to -1.6) and -3.1 cm (95 % CI: -5.5 to -0.7), respectively [66].

Furthermore, by supporting fat redistribution and reducing central obesity, lactation facilitates improvements in maternal body composition and metabolic health [19]. Epidemiological studies indicate that women who breastfeed exhibit more favorable lipid profiles, with lower triglycerides and LDL cholesterol and higher HDL cholesterol [63]. In addition, lactation has been linked to reduced postpartum weight retention, healthier waist-to-hip ratios, and a lower risk of developing metabolic syndrome [63]. These metabolic benefits extend to long-term health, as persistent excess weight after pregnancy is a well-documented predictor of CVD [63]. Breastfeeding enhances maternal glucose homeostasis by improving insulin sensitivity and reducing circulating glucose levels during the postpartum period [67]. In women with a history of gestational diabetes, sustained lactation has been linked to a substantially lower incidence of type 2 diabetes in long-term follow-up cohorts [68]. These findings highlight breastfeeding as a simple, natural intervention that can mitigate one of the most important metabolic complications of pregnancy [68]. Taken together, the increased energetic cost of milk production and the mobilization of maternal fat reserves represent key mechanisms through which breastfeeding supports postpartum weight regulation and reduces cardiometabolic risk [68].

4.2.2. Maternal exercise and lactation performance

Early clinical studies demonstrated that moderate to vigorous physical activity during lactation does not impair milk production, composition, or infant growth. In their seminal trial, Lovelady et al. found no adverse effects of exercise on lactation hormones or milk composition, and milk yield was slightly higher in exercising women compared with sedentary controls [10]. Exercising women exhibited greater VO_{2max} (46.4 vs 30.3 mL $kg^{-1} \cdot min^{-1}$), lower body fat (21.7 % vs 27.9 %), increased energy expenditure (3169 vs 2398 kcal/day), and higher caloric intake (2739 vs 2051 kcal/day). Despite such differences, neither plasma concentration of prolactin, cortisol, insulin and FT3 nor milk composition changed. Further, exercising women yielded a slightly higher amount of milk (839 vs 776 g/day) and delivered greater amount of energy output in milk (538 vs 494 kcal/day). The study concluded that vigorous exercise does not adversely affect lactation performance. These findings were corroborated by Dewey et al., who reported in a randomized trial that aerobic exercise four to five times per week did not alter milk volume or nutrient content [10]. The MILKSHAKE trial, the first randomized controlled study to comprehensively profile breast milk, showed that endurance training modifies a wide array of metabolites, cytokines, hormones, and microRNAs without adverse effects on infant growth [69].

Similarly, Holm et al. demonstrated stability of milk insulin concentrations following acute moderate- or high-intensity exercise [35], and Moholdt et al. reported preliminary evidence of favorable shifts in bioactive milk components in response to supervised training during lactation [69]. A recent narrative review has further hypothesized that maternal physical activity may influence milk composition in ways that reduce offspring obesity risk, though these findings remain preliminary [70].

4.2.3. Lactate accumulation and breast milk taste

As outlined in Section 3.2, lactate metabolism represents one of the main mechanisms through which exercise may influence breastfeeding. The role of lactate in breast milk after exercise has been investigated extensively. High-intensity activity increases lactate accumulation in muscle and circulation, and some of this diffuses into breast milk. Early work by Wallace et al. documented a rise in lactic acid concentration after maximal exercise, accompanied by reduced infant acceptance of milk, likely due to altered taste [9,10]. However, later studies reported no negative effect of maternal exercise on infant feeding [71], and confirmed that lactate accumulation is intensity-dependent and short-lived. Zhang et al. showed that levels can rise four-to six-fold within 10 min of moderate-to-vigorous exercise, but return to baseline within 30–60 min, with no lasting impact on breastfeeding performance or infant growth [72]. Together, these findings indicate that lactate changes are transient, dose-related, and not clinically significant.

4.2.4. Potential risks and conflicting findings

Although the vast majority of studies report neutral or beneficial effects of exercise and breastfeeding, some evidence suggests that minor reductions in milk volume may occur when exercise is combined with caloric restriction. Additional potential concerns include maternal dehydration and energy deficits, which could negatively impact milk supply. Future research should examine the influence of resistance training and high-intensity exercise on lactation outcomes to further refine recommendations.

5. Exercise as a biological modulator: implications for lactation and maternal health

Regular physical activity is widely recognized as a powerful biological modulator, acting across multiple organ systems to influence hormonal regulation, energy balance, immune function, and metabolic pathways. In the context of lactation, these adaptations may affect both maternal recovery and breast milk composition, thereby shaping infant growth and long-term cardiometabolic health. Unlike pharmacological therapies, which typically target single pathways, exercise induces systemic effects, anti-inflammatory, metabolic, and vascular, that act synergistically to improve health outcomes (Table 2).

Table 2
Health benefits of physical activity.

Health Benefit	Description
Weight management	Helps achieve and maintain a healthy weight, preventing obesity, which is a risk factor for many cancers.
Heart health	Strengthens the heart, improves circulation, lowers high blood pressure, cholesterol, and triglyceride levels, reducing the risk of heart disease.
Blood glucose control	Lowers blood glucose and insulin levels, reducing the risk of metabolic syndrome and type 2 diabetes.
Chronic disease management	Helps reduce pain and improve function in adults with arthritis and disabilities.
Cancer risk reduction	Lowers the risk of colon, breast, uterine, bladder, esophageal, kidney, stomach, and lung cancer by stimulating the immune system and reducing inflammation.
Mental health and mood	Helps manage stress, anxiety, and reduces the risk of depression.
Bone and muscle strength	Builds strong bones in kids and teens, slows bone density loss with age, and maintains muscle mass and strength.
Fall and injury prevention	Improves balance and muscle strength, reducing the risk of falls in older adults.
Better sleep	Improves sleep quality and duration.
Smoking cessation support	Aids in quitting smoking by reducing cravings and withdrawal symptoms.
Sexual health improvement	Enhances sexual health and well-being.
Increased longevity	Boosts overall health, increasing life expectancy.
Cognitive function	Helps maintain sharp thinking, learning, and judgment skills as you age.

5.1. Pregnancy and postpartum benefits

Prenatal physical activity contributes to healthier pregnancies, with lower risks of gestational diabetes, hypertension, and excessive weight gain [73]. In the postpartum period, exercise supports maternal weight management and cardiometabolic recovery, while also being associated with longer breastfeeding duration [74–77]. Importantly, moderate-intensity activity has been shown to be safe during lactation, without compromising milk volume, composition, or infant growth [22].

5.2. Immunological and hormonal adaptations

The effects of exercise on the immune properties of breast milk remain an emerging area of research. Strenuous exercise can transiently reduce sIgA levels in breast milk, but these changes normalize within 1 h and are unlikely to have clinical significance [24]. Moderate exercise, by contrast, exerts minimal impact on stress hormones such as cortisol and is associated with favorable immune modulation. Notably, lactating women may exhibit a blunted stress-hormone response to intense exercise compared with non-lactating women, suggesting a protective neurohormonal adaptation during lactation [78]. These findings indicate that moderate physical activity during lactation is safe and may even contribute to more balanced immune and hormonal profiles in mothers.

5.3. Postpartum weight and metabolic health

As outlined in Section 4.2.1, lactation increases maternal energy expenditure and promotes mobilization of fat stores, thereby facilitating postpartum weight regulation and healthier body composition. When combined with moderate physical activity, these effects are amplified, leading to improved waist-to-hip ratios and reduced risk of obesity and metabolic syndrome [65,66].

In addition, lactation combined with exercise promotes favorable lipid and glucose metabolism, with increased insulin sensitivity and reduced fasting glucose, especially beneficial in women with a history of gestational diabetes. Longitudinal studies further indicate that inadequate postpartum weight loss predicts adverse cardiometabolic outcomes, whereas women who breastfeed for longer durations demonstrate lower lifetime risks of type 2 diabetes and CVD [67,68]. A recent systematic review and meta-analysis of 46 studies confirmed that postpartum physical activity improves maternal cardiometabolic outcomes, including blood pressure and diabetes risk, without negatively affecting breast milk production, nutritional content, or infant growth [79]. These

findings reinforce that moderate, sustained exercise can be safely integrated into postpartum care to enhance maternal recovery and support breastfeeding. Exclusive breastfeeding for at least six months provides additional protection, with consistent evidence of reduced risk of metabolic syndrome and related cardiovascular conditions [65,66].

Mode of delivery may influence postpartum recovery, hormonal responses, and lactogenesis. Women who deliver vaginally typically experience earlier lactation onset and faster hormonal normalization, whereas cesarean delivery may be associated with delayed milk production and slower recovery. Moderate-intensity exercise should therefore be individualized based on delivery mode and physical recovery. Once adequate healing is achieved, postpartum exercise is safe and may facilitate physical and psychological recovery, improve circulation, and reduce inflammation after cesarean section. However, data comparing cardiometabolic and lactation-related outcomes between delivery modes remain limited, underscoring the need for further research [80–83]. These insights are consistent with the broader concept of primordial cardiometabolic prevention, recently highlighted by Fogacci and colleagues underscoring how early-life exposures such as breastfeeding and maternal lifestyle behaviors can shape long-term cardiovascular trajectories [84].

6. Practical recommendations for postpartum women

To help postpartum women incorporate safe physical activity into their routines, several evidence-based recommendations should be considered. Moderate-intensity aerobic activity, such as brisk walking, cycling, or swimming, is preferred and is advised at least 150 min per week for women without contraindications, according to ACOG (Committee Opinion No. 804) [85]. Resistance training may provide benefits, but further human studies are needed to clarify its effect on lactation. To minimize potential taste alterations in breast milk, infants may best be breastfed before exercising or after a sufficient post-exercise interval, since maximal exercise has been shown to increase lactic acid and reduce infant acceptance at 10–30 min post-exercise [9]. Maternal hydration and a well-balanced diet are important to support both milk production and exercise performance; trials of moderate aerobic activity indicate that milk volume and macronutrient composition remain stable under those conditions [13,86]. Despite these recommendations, several gaps in research remain undressed. Further studies are needed to investigate the effects of high-intensity interval training (HIIT) on breast milk composition, as well as the potential role of maternal exercise in shaping the breast milk microbiota and its impact on infant gut health. In

addition, long-term prospective studies should explore whether maternal exercise during lactation influences epigenetic programming in breastfed infants.

For example, Holmen et al. found that high-intensity exercise increases breast milk adiponectin, but comprehensive profiling of macronutrients, micronutrients, or microbiota after HIIT is lacking [87]. Similarly, studies such as Ajeeb et al. [88] and Bianco et al. [89] show that maternal diet and lifestyle are associated with the human milk microbiome and infant gut colonization, but experimental data isolating the effect of maternal exercise are almost nonexistent. More recently, epigenetic studies suggest a possible role of physical activity on DNA methylation: Panagiotidou et al. [90] demonstrated associations of maternal physical activity during pregnancy with offspring DNA methylation, and the MANOE study [91] identified differences in methylation of obesity-related genes by breastfeeding duration, but whether maternal exercise during lactation itself modulates epigenetic programming remains unexplored.

7. Conclusions

Breastfeeding and maternal physical activity are complementary strategies that promote maternal and child cardiometabolic health. Current evidence shows that moderate exercise during lactation is safe, does not impair milk supply or composition, and may even enhance breast milk's bioactive profile. By improving maternal energy balance, immune function, and metabolic recovery, exercise may also contribute to favorable infant programming.

Despite encouraging data, most studies remain small and heterogeneous. Larger, mechanistic trials are needed to clarify the impact of different exercise modalities and intensities on lactation outcomes and long-term child health. Integrating safe, sustainable physical activity into postpartum care represents a practical and cost-effective opportunity to improve health trajectories for both mothers and their children.

Authors contribution

Conceptualization GC, MP, AVM; Methodology GC, GS, VB, FM; Writing - Original draft preparation GC, MP, GS, VB, CM, SG, JM, AVM; Software GC, CM, MP; Validation AVM; Writing - Reviewing and Editing: all authors; Supervision GC, SS, SG, JLM, MP, AVM.

Declaration of generative AI and AI-assisted technologies in the writing process

Authors disclose the use of AI and AI-assisted technologies in the writing process.

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Conflict of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.clnesp.2025.10.029>.

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