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The effects of exercise on breastmilk composition and supply: A critical literature review

Jewell McRoy
James Madison University

The Effects of Exercise on Breastmilk Composition and Supply: A Critical Literature Review

Jewell McRoy

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Committee Chair: Jeremy Akers

Committee Members:

Elizabeth Edwards

Jennifer Walsh

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Abstract

It is well established that breastfeeding provides dual benefits to both the mother and the infant and is the preferred method of providing nutrients to infants essential for growth and development. Participating in regular physical exercise is also well-supported by research to be beneficial to one's overall health and quality of life. Currently there are no physical activity guidelines developed for women who are postpartum and breastfeeding. An online database search was conducted; three articles met the inclusion criteria and were included within the review. Studies were included if there were direct measures of human breastmilk composition, supply/volume, and included a graded exercise component. Further research needs to be done to form physical activity guidelines for women who are postpartum (PP) and breastfeeding.

CHAPTER 1: Introduction

Introduction: The American Academy of Pediatrics (AAP) recommends infants be exclusively breastfed for the first six months, with continued breastfeeding alongside the introduction of complementary foods for at least one year of life (Eidelman & Schanler, 2012; Krol & Grossmann, 2018; Mahan & Raymond, 2017). Exclusively breastfeeding (EB) is defined as the infant only consumes human breastmilk as their main source of nutrients and fluid needed for growth and development. Currently, in the United States, the percentage of infants who are breastfed throughout the first six-months is 57.6%. Of that percentage of infants, only 24.9% are exclusively breastfed ("Breastfeeding Report Card", 2019). Both the mother and the infant, benefit from breastfeeding as it can result in reduced risk of developing a chronic disease, obesity, and improved insulin sensitivity (Mahan & Raymond, 2017; Truchet & Honvo-Houeto, 2017). While it has been heavily supported that breastfeeding enhances the mother's and infant's overall quality of life, there is limited research regarding the effects of exercise on human breastmilk composition and milk supply.

Participating in exercise is another area that provides similar health benefits for the mother to that of breastfeeding. There is conclusive evidence that participating in regular exercise improves cardiorespiratory fitness and overall quality of life. One might assume that since both breastfeeding and exercise are beneficial to one's health, participating in both could have additional health benefits over either in isolation. Unfortunately, there has been limited research completed examining the relationship between breastfeeding and exercise to determine if it is advantageous to exercise throughout breastfeeding. The majority of the research completed surrounding this topic dates back to the early 1990s-2000s. Recently there was a review published (2020), on the physical effects of exercise in lactating women that specifically assessed postnatal weight-loss, changes in body composition, and bone mineral density (BMD) (Meyer & Hong, 2020). This review emphasizes the majority of research surrounding the topic of breastfeeding and exercise, weight-loss, diet (Carey et. al., 2003), lactic acid (LA) (Wright et. al., 2002), and BMD in post-partum (PP) women (Lovelady et. al., 2009). Nevertheless, there is a paucity of evidence performed on how exercise affects a mother's breastmilk composition or supply. Currently, there are no reviews on this topic.

Background of the study: To establish the current literature available on how exercise intensity and duration affects human breastmilk composition and supply in breastfeeding mothers.

Statement of problem: It is unclear if performing exercise has a positive or negative effect on human breastmilk composition and supply. There is a large body of evidence that supports exercising while breastfeeding, however, there are currently no exercise guidelines set in place for women who are breastfeeding.

Statement of need: There is a need to develop physical activity guidelines for mothers who are breastfeeding.

Research question: How does exercise affect human breastmilk composition and supply?

Literature Review

Lactation:

Lactogenesis the process of developing the ability to secrete milk and involves the maturation of alveolar cells (Pillay & Davis, 2020). Lactogenesis occurs in two stages: secretory initiation (lactogenesis I) and secretory activation (lactogenesis II) (Pillay & Davis, 2020). Lactogenesis I begin during the second half of pregnancy, this stage is where the placenta supplies high levels of progesterone (Pillay & Davis, 2020). Whereas lactogenesis II, starts after the mother gives birth and the placenta is removed following delivery (Pillay & Davis, 2020). This cause a rapid drop in progesterone levels, along with an increase in prolactin, cortisol, and insulin all of which stimulates lactogenesis II to occur (Pillay & Davis, 2020).

Lactation is the production and secretion of breastmilk by the mammary glands (Pillay & Davis, 2020). To maintain lactation during the postpartum (PP) period, regular removal of breastmilk is needed (Pillay & Davis, 2020). The regular removal of breastmilk will signal the release of prolactin and oxytocin; the release of both of these hormones, along with the mammary gland receiving hormonal signals, are required for lactation to be successful (Pillay & Davis, 2020). Prolactin begins to increase during pregnancy and is responsible for inducing lactogenesis and is required for being able to maintain yielding breastmilk (Truchet & Honvo-Houeto, 2017). The concentrations of prolactin increase rapidly when the suckling of the nipple takes place (Pillay & Davis, 2020). As for oxytocin, its' main role is involved in the letdown of milk, forcing milk into the ducts and out through the nipple (Pillay & Davis, 2020; Truchet & Honvo-Houeto, 2017).

Breastfeeding:

Breastmilk that is produced as a result of lactation is comprised of an abundance of nutrients, hormones, and immunoglobulins that are vital for infant growth and development (Donovan, 2017; Erick, 2018; Institute of Medicine (US) Committee on Nutritional Status During Pregnancy and Lactation, 1991; Mahan & Raymond, 2017). Exclusively breastfeeding (EB) is defined as only providing the infant with breastmilk and no other form of feeding. EB is undeniably the preferred method of feeding; the current recommendations set by the Academy of Nutrition and Dietetics (AND), American Academy of Pediatrics (AAP), Centers for Disease Control and Prevention (CDC), and the World Health Organization (WHO) is to EB the infant throughout the first six-months of life (Eidelman & Schanler, 2012; Krol & Grossmann, 2018; Mahan & Raymond, 2017). Human breastmilk is composed of numerous nutrients that provide the infant with immune protection, energy vital for infant growth and development, and reduces the risk of inflammatory diseases (George et al., 2018; Le Doare et al., 2018).

Benefits of Breastfeeding for Infants:

Within the first six months of life, the infant's immune system is drastically low making him/her susceptible to various infections, viruses, and/or diseases. Human breastmilk can help infants build up their immune system with the mother's antibodies that have protective effects against infections and inflammatory diseases. The inflammatory diseases from which human breastmilk can offer protection to infants from include asthma, allergies, obesity, and diabetes (types 1 and 2) (George et al., 2018; Mahan & Raymond, 2017; Truchet & Honvo-Houeto, 2017). The longer a mother lactate and continue to breastfeed, the longer they can continue to provide essential nutrients and immunities needed for their infant (Mahan & Raymond, 2017; Truchet & Honvo-Houeto, 2017; Zielinska et. al., 2017). Other benefits of breastfeeding include decreasing the infant's risk of diarrhea, malocclusion, decreased incidences of bacteremia, developing celiac disease, along with decreased severity of respiratory tract infection, an sudden infant death syndrome (SID) (Mahan & Raymond, 2017; Truchet & Honvo-Houeto, 2017).

Benefits of Breastfeeding for Mothers:

Breastfeeding is not only beneficial to the infant but is beneficial to the mother as well. Lactation can have reversal effects on insulin resistance, hyperlipidemia, and visceral fat accumulation (Jackson & Nazar, 2006). Research reflects that a longer duration of breastfeeding is associated with lowering the risk of mothers later developing breast cancer, ovarian cancer, hypertension, and type II diabetes (Jackson & Nazar, 2006; MacMillan Uribe & Olson, 2019). Some benefits for breastfeeding mothers include promoting rapid uterine involution, decreasing the risk of postmenopausal hip fracture and osteoporosis, and promoting weight loss or quicker return to prenatal weight (Mahan & Raymond, 2017).

Factors Affecting Breastmilk Supply and Composition:

Several factors can alter human breastmilk supply and/or composition. One substantial factor that varies from mother to mother is the length of gestation; some women deliver preterm while others carry until full-term (Institute of Medicine (US) Committee on Nutritional Status During Pregnancy and Lactation, 1991). Mode of delivery plays into the effect of when mothers move from lactogenesis I and II. Milk production can be affected if a mother goes into labor before full gestation is reached. A factor that can negatively affect human breastmilk supply is stress and anxiety. Both are perceived to influence milk production by inhibiting the milk-ejection reflex (Lactation et al., 1991, p. 88). Smoking while breastfeeding is associated with reduced production of milk and shorter lactation periods have been observed in smoking mothers who are breastfeeding (Napierala et al., 2016, p. 323). Nicotine reduces the level of prolactin present within the mother's blood (Napierala et al., 2016, p. 323). Prolactin is essential for normal lactogenesis, it stimulates the growth of the mammary glands promoting lactation. Another hormone that is affected by the presence of nicotine is oxytocin. Oxytocin is responsible for stimulating the contractions of the myoepithelial cells which results in milk ejection (Pham et al., 2020, p. 554). A mother's nutritional intake plays an enormous role in both milk composition and milk synthesis. Breastfeeding is a physically demanding process that results in expending energy. If mothers do not maintain a well-balanced diet with regular intake it affects the mother's milk supply (Pham et al., 2020, p. 555). Exercise prior to delivery during pregnancy is another factor that could influence human breastmilk composition. Aparicio et al (2018), investigated the influence of exercising during pregnancy on colostrum and mature human breastmilk inflammatory markers. Results of this study displayed that the concurrent exercise program promoted a less proinflammatory profile, particularly the colostrum, within human breastmilk (Aparicio et al., 2018).

Benefits of Regular Exercise:

In recent years, researchers have started investigating the effects exercise plays on women who are breastfeeding specifically how and/or if exercise affects the composition of human breastmilk and supply. The literature is conclusive that participating in regular exercise is beneficial and contributes to overall health status and life expectancy. Previous studies have revealed that exercise is linked to preventing heart disease, strokes, high blood pressure; along with reducing the risk of developing type II diabetes, and promoting good bone health and psychological wellbeing (Carey & Quinn, 2003; Control, National Research Council (US) Subcommittee on Nutrition and Diarrheal Diseases & National Research Council (US) Subcommittee on Diet, Physical Activity, 1992; Mortensen & Kam, 2012; Nguyen et al., 2019). However, two questions remain to be answered: 1) Does exercise during breastfeeding provide any specific benefits to women during this timeframe, and 2) Will exercising during breastfeeding hinder milk supply and/or alter composition in ways that are harmful to the infant?

During lactation, bone mineral density (BMD) is naturally lost as a result from breastfeeding. However, performing exercise promotes protective properties on preserving BMD, especially in women who are breastfeeding. Lovelady et. al. (2009), investigated the effect of exercise training on the loss of BMD during lactation and based on results, the exercise group lost significantly less lumbar spine BMD than the control group which did not participate in any exercise training (Lovelady et al., 2009). There were no significant differences in total body and hip-bone mineral density between the two groups. Similarly, Colleran et al. (2019), examined the effects of exercise during early lactation on BMD during the first year of PP, found that participating in a 16-week resistance and aerobic exercise intervention resulted in less loss of BMD in the lumbar spine within the first 20-weeks PP (Colleran et al., 2019). The exercise group also resulted in higher lumbar spine BMD levels at 1-year PP compared to the control group who did not exercise during the 16-week intervention (Colleran et al., 2019). Therefore, it appears that exercising while breastfeeding can help attenuate losses in BMD during breastfeeding.

A topic that is constantly being investigated is lactic acid (LA) levels found within human breastmilk following exercise. LA is thought to change the composition of human breastmilk and affect infant acceptance (Duffey, 1996). Given that LA is produced during exercise, studies have investigated the effects of exercise on LA concentration in human breastmilk, and subsequent infant acceptance of breastmilk, to determine whether exercise should be recommended while breastfeeding. A study conducted by Wallace et al. (1994), assessed LA concentrations following maximal graded exercise in breastfeeding women. Upon completion of the maximal graded exercise test, there was a significant increase in LA concentrations between pre-exercise and post-exercise (0.64 ± 0.18 mM and 2.88 ± 0.80 mM) (Wallace et al., 1994). Even though LA concentrations were increased following the graded exercise, this study failed to assess infant acceptance of human breastmilk following maximal exercise.

A study by Wright et. al. (2002), looked at infant acceptance of human breastmilk after three 30-minute bouts of exercise at different intensities (maximal, moderate, and a resting control) (Wright et al., 2002). LA was significantly increased 1-hour after the maximal exercise test when compared to the pre-test values. However, infant acceptance did not change 1-hour after the maximal exercise, indicating that LA levels did not affect infant acceptance (Wright et al., 2002). Based on this studies findings, LA does not appear to be an area of concern for women participating in moderate to vigorous exercise while EB.

The majority of the research surrounding breastfeeding and exercise focuses on BMD and LA concentrations in human breastmilk. There is limited research on how exercise impacts other aspects of human breastmilk composition and supply. The effects of exercise on breastmilk composition and supply were first questioned in the early 1990s. Lovelady et al. (1990), conducted a control trial study with EB women looking at whether or not vigorous exercise affects lactation performance. Subjects were required to provide a 3-day food record (FR), physical activity log, milk volume (assessed through test weighing), and 24-h milk samples (Lovelady et al., 1990). The exercising group was required to perform a $VO_{2\,max}$ test on a treadmill until they had reached exhaustion. The data collected from the study resulted in no difference between the exercising group and the control group (non-exercising) in plasma hormones or milk energy, lipid, protein, or lactose content (Lovelady et al., 1990). The exercise group had higher $VO_{2\,max}$ scores, milk volume (839 vs 776 g/d) and the milk samples were more energy dense (538 vs 494 kcal/d), ultimately resulting in no adverse effect of performing vigorous exercise in milk supply or composition (Lovelady et al., 1990). This study supports the claim that vigorous exercise may be beneficial to overall milk supply and calorie content in the human breastmilk following exercise.

Following this study, Dewey et al (1994), conducted a randomized control study to assess the effects of moderate exercise on human breastmilk composition and supply. The participants were six to eight weeks PP and were randomly assigned to either the exercise group (EG) or the control group (CG). Participants in the EG performed moderate intensity workout of 45 minutes/day, 5 days/week, for 12 weeks (Dewey et al., 1994). The findings of this study displayed a significant increase, by 25%, in aerobic capacity in the EG. Human breastmilk composition (lipid, protein, lactose concentrations, and energy density) did not differ between groups except for protein concentrations (Dewey et al., 1994). Protein concentrations were significantly higher in the EG than the CG, however, the rate of decline was similar between both groups (P = 0.80) (Dewey et al., 1994). Higher protein concentrations could have serious ramifications in the infant's growth and development. Research has shown that infant formula has higher concentrations of protein compared to human breastmilk (~2.2 g/100 kcal versus ~1.5 g/100 kcal) and has been associated with extra weight gain in infants; increased circulating amino acids stimulating the secretion of insulin and insulin-like growth factor (IGF-1) (Tang, 2018). In addition to weight gain in infancy, formula fed infants are 20% more at risk of being overweight or obese later in life (Martin et al., 2016; Tang, 2018). Human breastmilk supply, referred to as milk volume in the article, had a lower output of energy in breastmilk samples of the EG when expressed in kcal/day. However, it did not have a lower output when adjusted for BW of the infants (kcal/kg/day) (Dewey et al., 1994).

Carey et al (1997) observed human breastmilk composition after performing an aerobic exercise of different intensities (Carey et al., 1997). Participants were required to complete, at random, four different intensity trials: 100% $VO_{2\ max}$, 75%, 50%, and a control session (quietly sitting for 30 minutes-no exercise). The results of this study revealed that human breastmilk LA levels were significantly elevated at 0, 30, 60, and 90 minutes post-exercise after maximal testing compared to the control trial, however it was not observed at 75% or 50% of $VO_{2\ max}$ (Carey et al., 1997). When accounting for human breastmilk volume, otherwise referred to as supply in this study, there was no significant difference at any of the time points before and after all intensities (Carey et al., 1997). The overall conclusion was that under extreme exercise conditions with maximal intensity, LA within human breastmilk increases significantly.

Tenforde et al (2015) completed an observational study with long distance runners during pregnancy and breastfeeding. Out of 110 participants there was 84.1% of breastfeeding mothers who regularly ran and reported that running has no effect on their ability to breastfeed (Tenforde et al., 2015). A correlation was observed in breastfeeding women who ran were less likely to report experiencing PP depression than those who did not run while breastfeeding (6.7% versus 23.5%, P=0.051) (Tenforde et al., 2015). Exercise could be beneficial with preventing and treating PP depression in mother's who are breastfeeding.

CHAPTER 2: Methodology

Search Strategy:

An online search using PubMed, SPORTDiscus, and CINAHL was conducted searching articles published from 1990-2020, by using the following keywords to locate articles used within this review: breastfeeding, lactation, human breastmilk composition, breastmilk volume, breastmilk supply, exercise, and physical activity. For a study to be included in this review it must have met the following criteria: measurement of human breastmilk composition and/or milk supply and include an exercise protocol.

Studies were included in the review if there were direct measures of human breastmilk composition, supply/milk volume, and included a graded exercise component. Publications were excluded if they focused on the following: diet and exercise on postpartum weight-loss, not original research, or exercise related to bone mineral density and lactation.

Initial search for PubMed articles included 79 results, in which 20 articles were discarded because they were not human studies, and only six articles were included in the review because they met the inclusion criteria (further explained in the following subsection). In the CINAHL Plus search, there were initially 14 results and six met the criteria, three of the six articles were the same ones found in PubMed. The review of SPORTDiscus with full text yielded seven results, which none met the criteria.

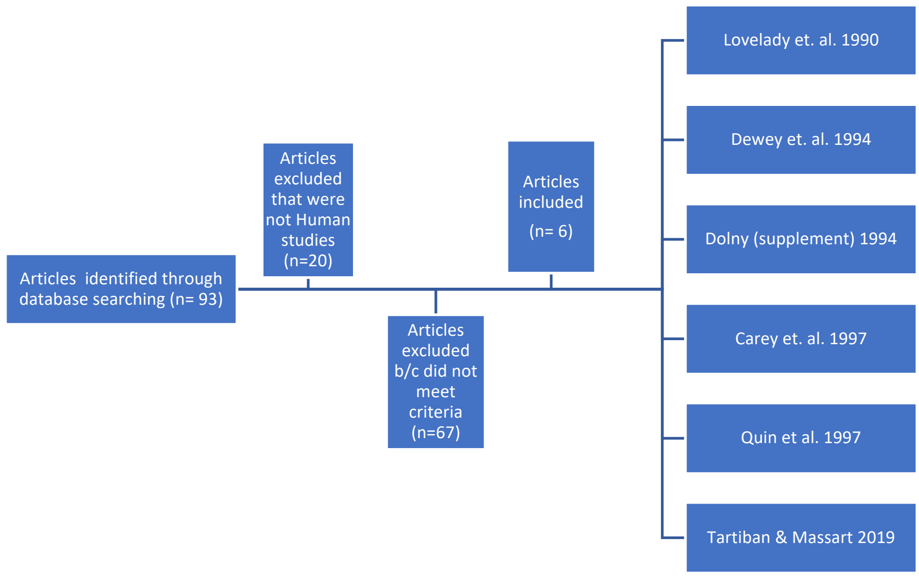

Figure 1. Diagram of online database engine search of articles included in review.

The table below is a brief overview of the articles included in the review (Table 1).

Table 1. Summary of studies included in review.

Study	**Number Participants**	**Brief Methodology**	**Results**
Lovelady et al (1990)	EG= 8 CG= 8 Infants were 9-24 wk old and EBF	All participants completed a 3-d FR, performed test-weighing (BM supply), and collected BM samples for 24 hr	There was no difference between the groups for breastmilk composition. EG tended to have higher milk volume (839 v. 776 g/d) and energy output in BM (538 v. 494 kcal/d). Vigorous exercise had no adverse effect on lactation performance.
Dewey et al (1994) RCT	EG= 18 CG= 15 6-8 wk PP Planned to EBF for at least 20 weeks	Participants were randomly assigned to either EG or CG (EG: 5 d/wk, 45 min/d for 12 wk; CG: did not engage in aerobic exercise more than 1d/wk) BM samples were	EG significantly improved aerobic capacity by 25%. BM composition did not differ except in protein concentration in EG was significantly higher at the final measure.

		collected from one breast for 24 hours and test weighing was done before and after each feeding at 6-8 weeks (baseline), 12-14 weeks (midpoint), and 18-20 (end) weeks.	
Dolny (Supplement) (1994)	N= 13 (EG= 7) (CG=6) 4-6 mos. PP N=7 of which had been exercising for > 3x/wk for at least 6 wks	Evaluated for $VO_{2\ max}$. BM samples collected for 4 consecutive days- no training in either group during this time. Performed 2 separate sessions- subjects exercised for either 30 or 60 mins at 65% of $VO_{2\ max}$. BM samples were collected 15, 60, and 180 mins post exercise. Samples were analyzed for lactose, total protein, urea N, total lipid, lactate, and pH. Blood samples were collected as well, prior to exercise and 15 mins post exercise	Total protein, total lipid, lactate, and pH in BM samples were unchanged following exercise in both groups and both exercise durations. Blood glucose and BM lactose were lower ($P < 0.05$) in EG vs CG in post 60 min session. Urea N was greater ($P <0.05$) in EG vs CG in 15 min post exercise blood sample and 180 mins in BM sample following each session. BM measurements remained fairly stable regardless of training status or duration of exercise
Carey et al (1997)	N=9 3-7 mos. PP, EBF, mild-to-moderately active	Performed 4 separate graded exercise sessions at a random order: 100% max, 75% max, 50% max, and a control session (30 mins of sitting and no exercise) BM samples were collected immediately post-	LA was significantly elevated in BM up to 90 minutes following 100% max. Not observed following either, 75% max or 50% max. LA was significantly elevated in the blood up to 60 minutes following 100% max. No

		exercise and every 30 mins up to 90 mins post-exercise along with fingersticks	significant differences in milk pH or volume at any time points before and after 50%, 75%, and 100% intensity compared to the same points in the control session. The same goes for milk urea and milk lipid.
Quinn and Carey (1999) RCT	N= 12 (High CHO diet= 6) (Moderate CHO= 6) 3-7 mos PP, EBF (> 80% of feedings via breast), mild to moderately active 2-6x/wk	Participants performed a maximal treadmill test to determine LAT and $VO_{2\ max}$. BM samples were collected 30 mins and immediately pre-exercise, immediately post-exercise, 30, 60, and 90 mins post-exercise. Blood samples were also collected (via fingerstick) at the same time points just right before BM samples were collected. Following maximal testing, participants reported to the lab 3 additional times to perform 2 30-min exercise bouts (conducted at LAT and LAT-20) as well as a control session (sitting quietly for 30-mins)	Milk LA was significantly higher immediately following maximal exercise in both groups and following LAT exercise bout when compared to control sessions. Not observed following LAT-20 exercise bout for either group. Elevated milk LA continued in the 30-mins collection point following maximal exercise only. No significant effect of dietary treatment on milk or blood LA at any of the collection points.
Tartiban and Massart (2019) RCT	N= 28 sedentary prior to study 6-8 wks PP	10 wks- EG performed aerobic exercises at 60% HRR for 3x/wk for	IgA concentrations were significantly increased in the EG at both 60% and 70% of

	(EG= 14) (CG= 14)	the first 5 weeks; continued same exercises but at 70% HRR for 3x/wk for the remaining 5 wks. CG did not participate in any exercises	HRR. IgA concentration were significantly higher at 70% HRR compared to 60% HRR. Increase in body density and aerobic fitness were also observed in this study, supporting no contradiction with lactation performance and exercise.

Key: exercise group (EG), control group (CG), randomized control trial (RCT), postpartum (PP), breastmilk (BM), exclusively breastfeeding (EBF), heart rate reserve (HRR), lactic acid threshold (LAT), and 20% below the LAT (LAT-20).

CHAPTER 3: MANUSCRIPT

Abstract

It is well established that breastfeeding provides dual benefits to both the mother and the infant and is the preferred method of providing nutrients to infants essential for growth and development. Participating in regular physical exercise is also well-supported by research to be beneficial to one's overall health and quality of life. Currently there are no physical activity guidelines developed for women who are postpartum and breastfeeding. An online database search was conducted; three articles met the inclusion criteria and were included within the review. Studies were included if there were direct measures of human breastmilk composition, supply/volume, and included a graded exercise component. Further research needs to be done to form physical activity guidelines for women who are postpartum (PP) and breastfeeding.

Introduction

Research heavily supports the benefits associated with participating in regular physical activity. Physical activity has been linked with decreasing the risk of type II diabetes and preventing heart disease, strokes, high blood, etc. (Carey & Quinn, 2003; Mortensen & Kam, 2012). Similar to these benefits achieved through physical activity, the same benefits have been observed in women breastfeeding and infants who were breastfed. However, there is a current gap in research regarding the relationship between exercising and breastfeeding. While a large body of research supports exercising while breastfeeding, currently there are no physical activity guidelines or recommendations set in place for this specific population. It is crucial to understand how exercise can affect human breastmilk composition and supply at different intensities and durations to develop safe guidelines that improve the overall quality of life for the mother/baby dyad.

Methodology

An online search using PubMed, SPORTDiscus, and CINAHL was conducted searching articles published from 1990-2020, by using the following keywords to locate articles used within this review: breastfeeding, lactation, human breastmilk composition, human breastmilk volume/supply, exercise, and physical activity. For a study to be included in this review, it must have met the following criteria: human study, measurement of human breastmilk composition and/or milk supply, and exercise testing and/or training protocol. Studies were included in the review if there were direct measures of human breastmilk composition, supply/milk volume, and an exercise component. Publications were excluded if they focused on the following: diet and exercise on postpartum weight-loss, not original research, or exercise related to bone mineral density and lactation.

Initial search for PubMed articles resulted in 79 articles, in which 20 articles were excluded due to not being human studies, and three articles matched the inclusion criteria and were included in the review (further explained in following subsection). CINAHL Plus search, initially yielded 14 results and three met the criteria, these were the same articles that were found in PubMed. SPORTDiscus with full text results included 7 articles, none of which met the criteria.

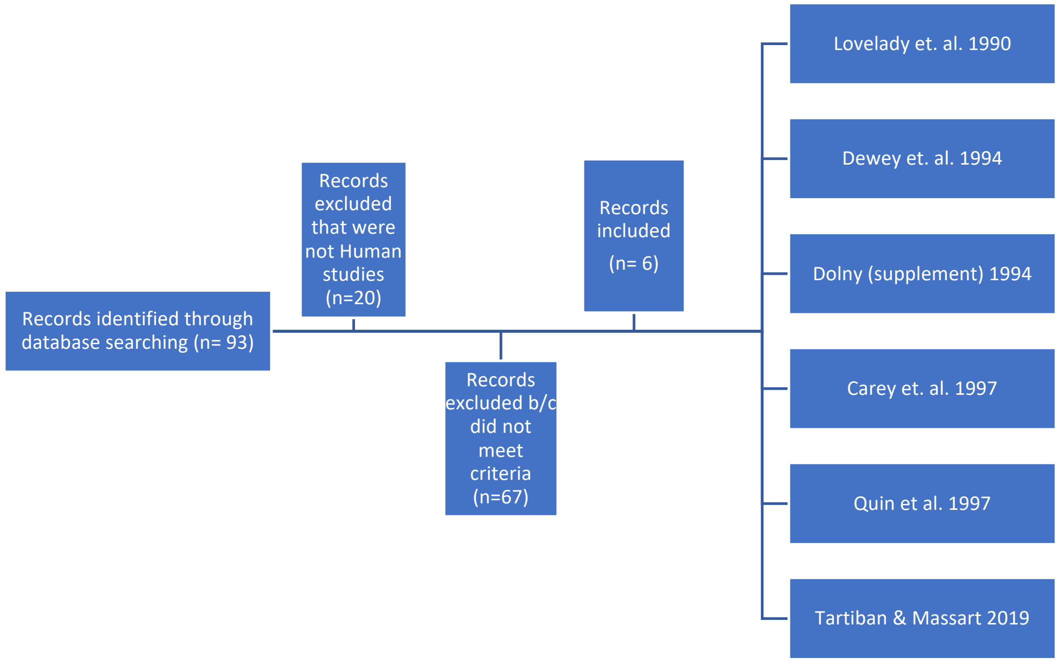

Figure 1. Diagram of online database engine search of articles included in review.

Table 1 provides a brief overview of each article included in the review.

Table 1. Summary of studies included in review.

Study	**Number Participants**	**Brief Methodology**	**Results**
Lovelady et al (1990)	EG= 8 CG= 8 Infants were 9-24 wk old and EBF	All participants completed a 3-d FR, performed test-weighing (BM supply), and collected BM samples for 24 hr	There was no difference between the groups for breastmilk composition. EG tended to have higher milk volume (839 v. 776 g/d) and energy output in BM (538 v. 494 kcal/d). Vigorous exercise had no adverse effect on lactation performance.
Dewey et al (1994) RCT	EG= 18 CG= 15 6-8 wk PP Planned to EBF for at least 20 weeks	Participants were randomly assigned to either EG or CG (EG: 5 d/wk, 45 min/d for 12 wk; CG: did not engage in aerobic exercise	EG significantly improved aerobic capacity by 25%. BM composition did not differ except in protein concentration in EG was

		more than 1d/wk) BM samples were collected from one breast for 24 hours and test weighing was done before and after each feeding at 6-8 weeks (baseline), 12-14 weeks (midpoint), and 18-20 (end) weeks.	significantly higher at the final measure.
Dolny (Supplement) (1994)	N= 13 (EG= 7) (CG=6) 4-6 mos. PP N=7 of which had been exercising for > 3x/wk for at least 6 wks	Evaluated for $VO_{2\ max}$. BM samples collected for 4 consecutive days- no training in either group during this time. Performed 2 separate sessions- subjects exercised for either 30 or 60 mins at 65% of $VO_{2\ max}$. BM samples were collected 15, 60, and 180 mins post exercise. Samples were analyzed for lactose, total protein, urea N, total lipid, lactate, and pH. Blood samples were collected as well, prior to exercise and 15 mins post exercise	Total protein, total lipid, lactate, and pH in BM samples were unchanged following exercise in both groups and both exercise durations. Blood glucose and BM lactose were lower ($P < 0.05$) in EG vs CG in post 60 min session. Urea N was greater ($P <0.05$) in EG vs CG in 15 min post exercise blood sample and 180 mins in BM sample following each session. BM measurements remained fairly stable regardless of training status or duration of exercise
Carey et al (1997)	N=9 3-7 mos. PP, EBF, mild-to-moderately active	Performed 4 separate graded exercise sessions at a random order: 100% max, 75% max, 50% max, and a control session (30 mins of sitting and no exercise)	LA was significantly elevated in BM up to 90 minutes following 100% max. Not observed following either, 75% max or 50% max. LA was significantly elevated in the blood up to 60

		BM samples were collected immediately post-exercise and every 30 mins up to 90 mins post-exercise along with fingersticks	minutes following 100% max. No significant differences in milk pH or volume at any time points before and after 50%, 75%, and 100% intensity compared to the same points in the control session. The same goes for milk urea and milk lipid.
Quinn and Carey (1997) RCT	N= 12 (High CHO diet= 6) (Moderate CHO= 6) 3-7 mos PP, EBF (> 80% of feedings via breast), mild to moderately active 2-6x/wk	Participants performed a maximal treadmill test to determine LAT and $VO_{2\ max}$. BM samples were collected 30 mins and immediately pre-exercise, immediately post-exercise, 30, 60, and 90 mins post-exercise. Blood samples were also collected (via fingerstick) at the same time points just right before BM samples were collected. Following maximal testing, participants reported to the lab 3 additional times to perform 2 30-min exercise bouts (conducted at LAT and LAT-20) as well as a control session (sitting quietly for 30-mins)	Milk LA was significantly higher immediately following maximal exercise in both groups and following LAT exercise bout when compared to control sessions. Not observed following LAT-20 exercise bout for either group. Elevated milk LA continued in the 30-mins collection point following maximal exercise only. No significant effect of dietary treatment on milk or blood LA at any of the collection points.
Tartiban and Massart	N= 28	10 wks- EG performed aerobic	IgA concentrations were significantly

(2019) RCT	sedentary prior to study 6-8 wks PP (EG= 14) (CG= 14)	exercises at 60% HRR for 3x/wk for the first 5 weeks; continued same exercises but at 70% HRR for 3x/wk for the remaining 5 wks. CG did not participate in any exercises	increased in the EG at both 60% and 70% of HRR. IgA concentration were significantly higher at 70% HRR compared to 60% HRR. Increase in body density and aerobic fitness were also observed in this study, supporting no contradiction with lactation performance and exercise.

Key: exercise group (EG), control group (CG), randomized control trial (RCT), postpartum (PP), breastmilk (BM), exclusively breastfeeding (EBF), heart rate reserve (HRR), lactic acid threshold (LAT), and 20% below the LAT (LAT-20).

Discussion

There is contradicting research when it comes to whether or not PP mothers should participate in exercise while breastfeeding. Exercise provides many benefits to a mother's health, including improving cardiorespiratory fitness, insulin sensitivity, reduces loss of bone mineral density (BMD), and reducing risk for obesity (Bane, 2015). However, breastfeeding and exercise are both physically demanding and raises the question if it will alter human breastmilk composition and/or supply. Within the last 20 years, there has been insufficient research completed on the relationship between exercising and breastfeeding. The few studies that were performed, have inconsistencies making this concept unknown still to this day.

Exercise's effect on human breastmilk composition and supply was first brought to question in the early 1990's. Lovelady et al. (1990) conducted a control trial study with

EB women, looking at whether or not vigorous exercise affects lactation performance. Participants were recruited based on if they fit the criteria for either the exercise or control group. EG criteria recruited participants who were engaged in an aerobic exercise program at an intensity of 70% of their predicted maximal heartrate (HR) for $\geq$ 45 minutes per day, 5 days per week and had been exercising for $\geq$ six months before the study. As for the CG, participants were recruited if they refrained from vigorous exercise > one day per week during six months before the study. Participants of the study were required to provide a three-day food record (FR), physical activity log, milk volume (via test weighing infants before and after each feed), and 24-hour milk samples (Lovelady et al., 1990). The EG performed a $VO_{2\ max}$ test on a treadmill until they had reached exhaustion. Data obtained from this study resulted in no difference between the EG and the CG in the following: plasma hormones or milk energy, lipid, protein, or lactose content (Lovelady et al., 1990). EG had higher $VO_{2\ max}$ scores, milk volume (839 vs 776 g/d), and milk samples were more nutritionally dense (538 vs 494 kcal/d) none of which were significantly different- resulting in no adverse effects in human breastmilk composition or milk supply after completing a strenuous aerobic workout (Lovelady et al., 1990). Results from this study support the claim that vigorous exercise could be beneficial to overall milk supply/volume and calorie content in human breastmilk following exercise.

Dewey et al.'s (1994) study, observed the effects of moderate aerobic exercise on women's breastmilk composition and supply. This study differs from Lovelady et al.'s (1990) because it was a randomized control trial and there was a significant improvement in VO_2 for the EG (Dewey et al., 1994). EG participants were required to perform a moderate intensity workout for 45 minutes per day, 5 days per week, for 12 weeks (Dewey et al., 1994). The findings of this study displayed there was no difference between human breastmilk composition (lipids, protein, lactose concentrations, and energy density) for either group. However, there was a significant increase (25%) in aerobic capacity within the EG. Alongside the improvements in VO_2, there were significantly higher protein concentrations in the EG's breastmilk at the final measurement compared to the CG, nonetheless, both groups rate of decline was similar ($P= 0.80$) (Dewey et al., 1994). Research supports high protein concentrations, studied mostly within infant formulas (IF), is directly associated with rapid weight gain, risk factor for obesity later in life, altered kidney size and function, and insulin resistance (IR) (Patro-Gołąb et al., 2016; Oropeza-Ceja et al., 2018). High protein intake, regardless of caloric amount, affects kidney size and function due to the high renal workloads as a response to high levels of protein present (Oropeza-Ceja et al., 2018). Infants fed with IF also had higher concentrations of insulin and insulin-like growth factor (IGF-1) compared to infants who consumed human breastmilk (Patro- Gołąb et al., 2016). The correlation between protein present in IF and the adverse effects it has on infants leads to question, if mother's breastmilk has a higher concentration of protein as a byproduct of performing exercise, will breastfed infants experience similar adverse effects?

Carey et al. observed human breastmilk composition following different aerobic exercise intensities (Carey et al., 1997). One aspect that was observed in this study was LA present in human breastmilk following exercise at 100%, 75%, and 50% maximal intensity. There were significantly elevated levels of LA in human breastmilk following 100% maximum intensity up until 90 minutes post-exercise, and it was not significant at

75% or 50% of maximal intensity (Carey et al., 1997). Human breastmilk supply was not affected significantly before or after any of the interventions, in addition to it did not affect the babies breastfeeding. Quinn and Carey (1999) examined if exercise intensity or diet influenced LA accumulation within human breastmilk. Participants were randomly assigned to either a high carbohydrate (CHO) or a moderate CHO diet, both groups completed a control session, maximal exercise test on the treadmill until exhaustion was met, and two additional 30-minute bouts of exercises based off lactic acid threshold (LAT) obtained from the maximal test. Human breastmilk samples and blood samples were obtained 30-minutes pre-exercise, immediately pre-exercise, immediately post exercise, 30, 60, and 90-minutes post exercise (Quinn &Carey, 1999). Milk LA was significantly elevated in both groups, high CHO and moderate CHO, immediately and 30-minutes post maximal test (Quinn & Carey, 1999). In addition, milk LA was significantly elevated following the LAT bout in both groups immediately post exercise. No elevations were observed after LAT-20 bout in either group (Quinn &Carey, 1999). There is a correlation between LA and exercise intensity within breastfeeding women, however this correlation is not entirely understood. There is a lack of research surrounding LA present within human breastmilk, it remains unknown if LA could be harmful to the infant if consumed on a regular basis or if it can affect overall composition of human breastmilk and supply.

Zourladani et al (2014) conducted a randomized control trial to evaluate the effect exercise (aerobic (low-impact dance), resistance, and stretching exercises) plays in lactating women's physical fitness, lipidemic profile, and hormone levels (Zourladani et al., 2014). EG participated in 50-60 minutes of aerobic, resistance, and stretching exercises three days per week for twelve-weeks; CG did not participate in any exercises. The EG significantly differed from the CG following the twelve-week intervention in: VO2 max, muscular endurance of upper extremities, abdominal muscular endurance, flexibility, and body fat. However, the EG did not have any significant changes to lipid profile or lactation-associated hormone levels (Zourladani et al., 2014). Although this study did not directly measure human breastmilk composition, it is important to note the hormone prolactin was assessed which has a direct effect on human breastmilk production. The EG displayed an increase in prolactin level from baseline to follow-up (P= 0.006) after completing the twelve-week intervention (Zourladani et al., 2014).

In a later study by Tartiban and Massart (2019), the relationship between exercise and secretory immunoglobulin A (IgA) concentrations within human breastmilk were examined. Participants were sedentary prior to study and randomized into either EG or CG. EG participants performed aerobic exercises over a ten-week duration; the first five weeks participants exercised at 60% heart rate reserve (HRR) three times per week and the second five weeks participants exercised at 70% HRR three times per week (Tartiban & Massart, 2019). CG did not participant in any exercises throughout the ten weeks. Results of this study displayed that the exercise group had significant increases in IgA compared to the CG, in addition to increased body density and aerobic fitness (Tartiban & Massart, 2019). It is important to highlight that there was an additional increase seen in IgA from 60% HRR to 70% HRR (29.9 ± 9.3 versus 40.4 ± 11.6) (Tartiban & Massart, 2019). IgA provides advantageous effects to the infant's immune system, providing the infant with the ability to fight off infectious organisms and prevents the organism from colonizing within the infant's intestine (Tartiban & Massart, 2019).

The limited research surrounding exercising and breastfeeding has left many questions unanswered. It is unclear if/how performing exercise impacts human breastmilk composition and supply. There are no current recommendations set forth for breastfeeding PP women who wish to participate in regular exercise. Based on the current research available, human breastmilk composition and supply may be altered as a result of the mode of exercise (Wallace et al., 1994), exercise intensity (Carey et al., 1997; Quinn & Carey, 1997; Wright et al., 2002; Tartiban & Massart, 2019), and/or the duration of the exercise (Lovelady et al., 1990 & Dewey et al., 1994). All studies consisted of a different exercise prescription protocols; however, the most significant findings were present following maximal intensity. Lovelady et al (1990) EG had a higher milk volume than then CG following maximal exercise. Dewey et al (1994) EG aerobic capacity increased by 25% and had higher protein concentrations after completing a 12-week moderate intensity intervention. Carey et al (1997) had significantly elevated LA concentration up to 90-minutes following 100% graded max test. Whereas Zourladani et al (2014), observed a significant increase in $V0_{2\ max}$ without any significant changes occurring in participant’s lipid profile and lactation-associated hormones after completing a low intensity workout. Tartiban and Massart (2019) observed significant increases in IgA at 60% HRR, but even higher levels of IgA after 70% HRR.

The limited amount of current research available agrees that low-to-moderate intensities are safe to perform without significantly affecting human breastmilk composition or supply (Lovelady et al., 1990; Carey et al., 1997; Quinn & Carey,1997; Wright et al., 2002). If performing regular vigorous exercise does alter a mother's composition of breastmilk this could directly affect an infant's growth and development. It is imperative that further research be conducted to better understand the relationship between breastfeeding and physical exercise; in hopes of developing physical activity guidelines for mothers who are breastfeeding to ensure the health and safety of both mother and infant.

Conclusion

Based off current research, human breastmilk composition and supply are affected as a result of moderate to vigorous exercise. The articles within this review consists of different methodologies and report different findings. It is recommended that further research be done to develop a better understanding of how exercise affects human breastmilk composition and supply, in addition to developing physical activity guidelines for this population.

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