Exercise and Lactation: Are They Compatible?

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Abstract/Résumé

Lactation is an energy-demanding physiological process for the maternal organism and life-giving for the offspring. Likewise, exercise is an energy-demanding process. This review addresses the compatibility of exercise during lactation. Human studies suggest no detrimental effect of exercise during lactation on milk composition and volume, infant growth and development, or maternal health. Studies also demonstrate improved cardiovascular fitness in lactating, exercising women and suggest a quicker return to pre-pregnancy body weight and a more positive sense of well-being, compared to sedentary controls. Findings from rodent studies, although of questionable value for humans, have generally shown no detrimental influence of exercise during pregnancy and lactation on pup growth and development. To date, findings suggest that exercise and lactation are compatible activities.

La lactation est un processus physiologique nécessitant un apport d'énergie à l'organisme maternel et à la progéniture. L'exercice physique est aussi un phénomène nécessitant un apport d'énergie. Cet article s'intéresse à la compatibilité de l'exercice physique au cours de la période de lactation. D’après les études chez les humains, l’exercice physique n’aurait pas d’effet nuisible sur le volume et la composition du lait, la croissance du nourrisson et la santé de la mère. D’après des études, une femme allaitante en meilleure condition cardiovasculaire due à l’activité physique se sent mieux et retrouve plus rapidement son

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Lactation is an energy-demanding physiological process for the maternal organism. Our understanding of this process in humans is limited by the non-invasive nature of experiments that can be conducted on humans. Animals have provided alternative models, but because milk output is related to body weight to the three-quarter power (Hanwell and Peaker, 1977), milk production can range from 1.25% of the body weight of an elephant to 28% of the body weight of a pygmy shrew. This poses a challenge when extrapolating findings from rodent studies to the human. Likewise, although considerably larger than the rodent, the dairy cow is a poor model for humans as it has been bred for supranormal milk yields.

Exercise is also an energy-demanding process. Although the effect of exercise on human health continues to be actively studied, there are only about one dozen studies that have examined the effects of exercise on milk production and maternal and infant health during lactation. The purpose of this review is to examine the human and animal data on this topic and, based on the available evidence, arrive at a conclusion about the compatibility of exercise and lactation.

Influence of Exercise on the Lactating Mammal’s Health

CARDIOVASCULAR HEALTH

Women who exercised regularly during pregnancy and lactation had a 53% greater maximal oxygen consumption ($\bar{V}O_2\text{max}$) than women who were sedentary (Lovelady et al., 1990). Women who initiated an exercise program while breastfeeding also increased their $\bar{V}O_2\text{max}$ by 13% to 25% (Dewey et al., 1994; Lovelady et al., 1995; Lovelady et al., 2000). In addition, one of those studies (Lovelady et al., 1995) examined the influence of exercise on plasma lipids. Thirty-three exclusively breastfeeding women were randomly assigned to control (no exercise) or exercise groups 6 to 8 weeks postpartum. The exercise group performed aerobic exercise 45 min-d$^{-1}$, 5 d-wk$^{-1}$, for 12 weeks. Although there was no significant weight loss in the exercise group compared to controls, exercise marginally increased HDL-cholesterol ($P < .08$).

FOOD INTAKE, BODY WEIGHT, AND BODY COMPOSITION

The Stockholm Pregnancy and Weight Development Study (Ohlin and Rossner, 1996) suggests that a return to pre-pregnancy body weight is most likely to occur in women who practice a “healthful” lifestyle—eating and exercising regularly—than those who don’t. Similarly, a survey of 1,003 postpartum women found that women with higher levels of activity retained less weight than their less active counterparts (Sampselle et al., 1999). This survey suggests an arena ripe for experimental research: exercise, lactation, and body composition.
To this end, a cross-sectional study at the University of California at Davis (Lovelady et al., 1990) was performed. Exercising, lactating women (45 min·d⁻¹, 5 d·wk⁻¹ at 70% of their predicted maximum heart rate for at least 6 months prior to study) were compared to sedentary controls at 9 to 24 weeks postpartum. Exercising women expended 770 more kcals/day than the sedentary subjects and had a lower percent body fat, yet they compensated for their higher energy expenditure by increasing their food intake by 688 kcals/day. Average body weight was not different between the 2 groups.

Dewey and colleagues (1994) studied the impact of initiating an exercise program during lactation on food intake, body weight, and body composition. Lactating women who began an exercise program 6 to 8 weeks postpartum (45 min/d, 5 d/wk) and continued exercising for 12 weeks expended about 400 kcals/day at exercise but compensated for this with an increase in energy intake by 329 kcals/day. There was no significant difference in body weight or body fat between the exercisers and controls.

Turning to rodent models, Courant and Barr (1990) found that when running exercise began during pregnancy and continued through lactation in Sprague-Dawley rats, body fat decreased compared to non-exercised controls, while body weight and food intake increased without compromising litter size or pup growth. This increase in food intake contrasts with the findings of Matsuno and colleagues (1999) in which exercise had no effect on food intake of Sprague-Dawley rats run on treadmills 45 to 60 min·d⁻¹ until day 18, then resumed at day 3 of lactation. Body weight was lower in exercised rats at the end of pregnancy but not different from controls at the end of lactation (Matsuno et al., 1999). Exercise did not influence litter size or pup birth weight.

Wistar rats have been subjected to swim exercise with a tail weight (up to 3% of body weight) 2 hr·d⁻¹, 5 d·wk⁻¹ for at least 7 weeks until the nineteenth day of pregnancy and resumed during days 2 to 14 of lactation (Treadway and Lederman, 1986). These researchers reported an increase in food intake in exercised rats compared to controls, yet identical body weights between the two groups. This contrasts with the findings of Pinto and Shetty (1995) who found that swim exercise caused an extreme stress response in Wistar rats. Rats swam 2 hr·d⁻¹, 6 d·wk⁻¹ prepregnancy, during pregnancy, and during lactation, for 2 generations. Exercise caused an increase in food intake during pregnancy and lactation of the first generation dams, who maintained a body weight comparable to controls. However, their pups displayed poor growth. In the second generation, both the sedentary and exercised offspring of exercised dams had a lower body weight than sedentary controls at the end of the study, and they cannibalized their offspring. In this study, the treatment appears to have become a source of distress rather than exercise.

Karasa and colleagues (1981) examined the effects of voluntary treadwheel running on maternal body weight and lactation performance in mice. A non-exercise group was housed in cages without treadwheels. The study was confounded by the gradual decrease in voluntary exercise as parturition approached: during lactation, mice averaged less than 6750 cm/day, compared to 33,750 cm/day for 8 to 16 days before parturition. Nonetheless, the authors found no difference in body weight and body fat of the dams, and no difference in litter size or growth of the pups.
BONE STATUS

Lactation decreases bone mineral density, due to estrogen deficiency coupled with calcium demand. Two studies have explored the relationship between exercise, which enhances bone mineralization in humans (American College of Sports Medicine, 1995; Snow, 1993) and bone loss during lactation. The first study examined 6 pregnant and 25 nonpregnant subjects who exercised regularly, averaging 1.5 hr-d⁻¹, 5.5 d-wk⁻¹. Women typically selected one or more of the following exercise modalities: running, cycling, swimming, aerobics, dance, weights, skiing, or crew. Bone mineral density of women in the two groups was measured at seven skeletal sites 3 months before pregnancy, 1 month postpartum, and 6 months postpartum (Drinkwater and Chestnut, 1991). The daily calcium intake of all subjects met or exceeded the RDA. At 6 months of lactation, bone density at six of the sites in the exercising, lactating women was the same as pre-pregnancy values. However, density at the femoral neck site was 6% lower than pre-pregnancy values (P < 0.05). There was no decrease in bone mineral density at any of the seven sites in the exercising controls. The authors speculated that the decrease in the femoral neck may be due to mechanical stress of weight gain, changes in posture, or some unidentified factor specific to this population of women.

In the second study, total body lumbar spine and femur neck bone mineral density was examined at 2 weeks and 3 months postpartum in 11 lactating, self-selected recreational exercisers and 9 lactating, sedentary controls and Clapp, 1998)(Little and Clapp, 1998). Bone mineral density decreased significantly in both groups from baseline at the lumbar spine and femur neck sites, although total bone mineral density did not change. The authors suggested that the short duration of the study and the high variability in type, duration, and kind of exercise may have precluded detecting an effect of exercise. Authors of both studies call for prospective studies with larger numbers of subjects.

INSULIN

Fasting insulin levels were 15% lower (P < 0.05) in exercise-trained, lactating rats compared to sedentary, lactating controls (Matsuno et al., 1999) but were not different between lactating exercisers and controls in one human study (Lovelady et al., 1995). However, in the only human study to address this issue, insulin response to a test meal in the exercisers was negatively correlated with both a change in HDL-cholesterol levels and change in VO2max levels. This was consistent with findings in non-lactating subjects (Dela et al., 1992) and suggests an improved glucose disposal with exercise training.

PSYCHOLOGICAL HEALTH

In a survey of postpartum women, active women demonstrated better scores on measures of postpartum adaptation such as satisfaction with life circumstances, confidence in tasks of mothering, and quality of relationship with partner compared to sedentary women (Sampselle et al., 1999). Furthermore, exercising women were more likely than sedentary women to participate in enjoyable activities such
as entertainment, hobbies, and socializing. This is not surprising given that exercise has been positively associated with increased psychosocial well-being in the general population and that the effects of exercise on decreased symptoms of anxiety and depression are stronger among women than men (Cramer et al., 1991; Stephens, 1988).

CONCLUSION

Survey research suggests a quicker return to pre-pregnancy body weight and a more positive sense of well-being in lactating, exercising women compared to sedentary, lactating controls. Experimental research demonstrates a reduction in body fat and improved cardiovascular fitness as a result of exercise during lactation. Energy expended at exercise during lactation appears to be compensated for by increased food intake in human studies and some but not all animal studies. These data suggest the mother adapts to exercise during lactation: can the same be said of her offspring? The next three sections will examine this question.

Influence of Exercise on the Lactating Mammal’s Milk Composition

ANIMAL MODELS

Experimental design confounds much of the lactating animal research: typically, exercise is not limited to the lactation period but is conducted throughout pregnancy with a short break during the time of parturition. This should be kept in mind when comparing animal and human data.

One of the first studies to examine the effect of exercise on lactation performance was conducted in 1981 in dairy cows (Lamb et al., 1981). Two-year-old heifers were compared to 3–7-year-old cows. Animals were randomly assigned to three treatment groups: (a) control (no forced exercise), (b) walk at 4.0 km·h⁻¹ for 1.6 km·d⁻¹, and (c) walk at 4.0 km·h⁻¹ for 8.0 km·d⁻¹. Exercise was performed 5 d·wk⁻¹ for 8 weeks before expected calving. The animals were studied for 305 days postpartum, and milk composition (fat, protein, and solids-not-fats) was assessed two times per month. No differences were noted in either the heifers or cows in either the 1.6 km·d⁻¹ or the 8.0 km·d⁻¹ groups as compared to the controls with respect to milk fat, protein, or solids. The authors did note a trend in which the 8.0 km·d⁻¹ group had a slightly lower milk composition of fat, protein, and solids-not-fats and suggested that long walks may be detrimental to young cows.

Treadway and Lederman (1986) studied the effects of aerobic exercise on lactation performance in Wistar rats. Female rats trained via swim protocol for 2 continuous hours with a tail weight (up to 3% of body weight) for at least 7 weeks prior to pregnancy. After parturition, the animals resumed training on day 2 of the lactation period and continued through day 14. On day 14, milk lactose, protein, and fat were assayed to determine milk composition, and total energy concentration (kcal·dl⁻¹) was calculated. The results of this study showed that milk lactose was significantly lower in the exercised, lactating rats compared to the sedentary, lactating control group. The authors conjecture that during exercise, blood glucose
falls, leaving less glucose available for lactose synthesis by the mammary gland. Milk protein and fat were not different between the two groups, and despite the decrease in milk lactose, there was no significant difference in total milk energy concentration between the two groups.

The rat model has also been studied for the effect of diet and exercise on lactation (Matsuno et al., 1999). Pregnant Sprague-Dawley rats were randomly assigned to three dietary treatments (20%, 40%, or 60% glucose) and either an exercise group (low intensity, treadmill, 20 m-min\(^{-1}\) for 60 min-d\(^{-1}\), 7 d-wk\(^{-1}\)) or a control group. The exercise program was conducted throughout pregnancy, stopped during parturition, and then resumed on day 3 of lactation and continued through day 14. Exercising rats consuming the 40% glucose diet had significantly higher milk protein concentrations than their controls, while exercising rats consuming the 20% glucose diet had significantly lower milk lactose concentrations than their controls. The main effect of exercise resulted in an increase in milk fat, perhaps at the expense of the mammary gland, which had a reduced fat content. These results agreed with those of Treadway and Lederman (1986) and suggest that dietary macronutrient composition interacts with exercise to impact lactating rat milk composition.

### HUMAN STUDIES

The first report on the effects of chronic exercise on breast milk composition in humans was by Lovelady and colleagues (1990) at UC Davis. Eight women who exercised routinely (5 d-wk\(^{-1}\), 45 min-d\(^{-1}\), at an intensity of 70% of age-predicted maximal heart rate, for the previous 6 months) were recruited into the study and compared to a non-exercise control group (n = 8). No differences were noted in protein, lactose, lipid, or energy content of milk from the exercisers versus the sedentary control group. Exercising women also had a significantly greater proportion of their diet from carbohydrate (59% vs. 43%) and a significantly lower proportion from fat (25% vs. 40%). The major criticisms of this study were the small number of participants and that the participants were self-selected and not randomized to the exercise group.

As a follow-up and as an attempt to address these previous criticisms, this group published results in 1994 of a randomized study with a larger number of subjects (Dewey et al., 1994). Thirty-three sedentary women (6 to 8 weeks postpartum) were recruited and randomly assigned to either an exercise or control group. The exercise group performed supervised aerobic (60 to 70% of heart-rate reserve) exercise for 45 min, 5 d-wk\(^{-1}\) for 12 weeks. Their findings on milk composition were similar to their previous study: no differences in milk protein, lipid, lactose, or energy content in exercising mother’s milk compared to the sedentary group. This suggests that women may safely undertake an exercise program of moderate intensity during the postpartum period without compromising milk composition.

The effects of acute exercise on breast milk composition have been investigated in a number of studies. Fly and colleagues (1998) recruited 14 healthy, lactating women between 2 and 8 months postpartum. All of the women had exercised regularly throughout pregnancy and lactation. The women performed a maximal test to exhaustion on a treadmill as well as a non-exercise control session in random
fashion. Milk samples were collected prior to exercise and rest and at 10, 30, and 60 min post-exercise or rest. Milk samples were analyzed for phosphorus, calcium, magnesium, sodium, and potassium. The concentration of each of the minerals following maximal exercise was not different from the level following the resting control session. The authors speculated that if maximal exercise failed to cause changes in milk mineral content, it is unlikely that lower intensity exercise would.

Gregory and colleagues (1997) studied the effect of maximal exercise on immunological properties of human breast milk. Seventeen lactating women randomly performed a maximal graded exercise test on the treadmill and a non-exercise control session. Milk samples were collected immediately before exercise or rest and at 10, 30, and 60 min post-exercise or rest. Milk immunoglobulin A (IgA) concentration increased in the 10-, 30-, and 60-min samples compared to the sample obtained before exercise or rest, suggesting that breast emptying alone stimulates milk IgA synthesis. IgA levels in the 10- and 30-min post-exercise milk samples were significantly lower than in the 10- and 30-min post-rest milk samples; IgA levels in the 60-min post-exercise vs. post-rest samples were the same. These results provide evidence that maximal exercise alters IgA content in human milk for a short duration, but the practical significance of these findings is questionable (Carey and Quinn, 1998).

The influence of exercise on milk content of lactic acid has received attention from the media. The lay press has reported that exercise causes lactic acid to accumulate in breast milk and that infants would be better served if a woman either did not exercise prior to breastfeeding or expressed her milk prior to exercise and fed the infant the expressed milk after exercising. The basis for the lay press reports came from work performed at Indiana University. In 1991, Wallace and Rabin examined the effect of exercise on breast milk lactic acid content. Seven previously active, postpartum (2–24 months) women volunteered to undergo a maximal treadmill exercise test. A small (i.e., ~3 ml) sample of foremilk was collected prior to exercise, and this was compared to samples collected at 10 and 30 min after this maximal treadmill effort. Milk lactic acid increased approximately four times above the pre-exercise sample ($P < .05$) at 10 min and remained elevated (although not statistically significant) through the 30-min collection time.

In an effort to determine whether fullness of milk in the breasts impacted lactic acid accumulation following exercise, Wallace and colleagues recruited 23 women who had exercised during pregnancy and had continued to exercise during the postpartum period (Wallace, Ernsthauen, et al., 1992). Subjects were randomly assigned to either Group E (exercised after emptying both breasts) or Group F (exercised with full breasts). Again, the exercise bout was a maximal effort on the treadmill with milk (~3 ml) being collected pre-exercise and at 10, 30, 60, and 90 min post-exercise. Results showed that milk lactic acid increased approximately sixfold in both groups following maximal exercise and that these increases were sustained throughout 90 min post-exercise. However, the two groups increased milk lactic acid via two distinct patterns. Group E attained maximal increases at the 30-min post-exercise timepoint while Group F milk lactic acid peaked at 10 min post-exercise. Further, return of milk lactic acid to the pre-exercise value was slower in Group E compared to Group F.
Maximal exercise is at the extreme of the exercise intensity spectrum. The practical significance of studies using maximal exercise, therefore, is questionable: most postpartum women perform submaximal activity in an effort to lose weight and develop fitness. In 1994, Wallace and colleagues addressed this question by recruiting 23 lactating women who had exercised during pregnancy and lactation. Each woman performed a maximal graded exercise test on a treadmill. Within one week, a "typical" exercise session was either simulated in the laboratory or performed in the gymnasium. Milk samples (at least 1 ml) were collected pre-exercise and at 10 min post-maximal and typical exercise. Wallace and colleagues reported a fivefold increase in milk lactic acid following the maximal exercise and a twofold increase following a "typical" exercise workout. Given these findings, Wallace and colleagues speculated that a typical workout might cause some women to accumulate lactic acid in the milk, enough to sour the taste and cause the infant to reject the milk.

Research findings from the University of New Hampshire contrast with those from Indiana University. Carey and colleagues (1997) studied the effects of acute exercise intensity on breast milk composition including lactic acid content. Nine lactating women (3–7 months postpartum) who were mild to moderately active were recruited into the study. Each woman performed a graded maximal exercise test on the treadmill in which blood samples were collected and immediately analyzed for lactic acid. Milk was collected just prior to exercise and immediately after as well as 30, 60, and 90 min post-exercise. Milk lactic acid, pH, ammonium, urea, and lipids were assayed. Women returned to the laboratory for three additional tests, performed on different days and in a random fashion. Two of the tests involved exercise at 50% and 75% of maximum intensity for 30 min, and one session was a non-exercise control session. Milk was analyzed as described above. Milk pH and ammonium, urea, and lipid content was unchanged following maximal or the two submaximal exercise intensities as compared to the control session. In contrast to the findings of Wallace and colleagues (1994), we found that milk lactic acid was elevated following maximal exertion but not submaximal exercise.

In addition, lactic acid content of milk collected immediately post-exercise reported by Carey and colleagues and confirmed by an independent assay (0.94 mM) was starkly different from that reported by Wallace and colleagues (2.88 mM). However, neither research group monitored or controlled the dietary carbohydrate intake of their subjects or the relative intensity of the exercise, both of which can influence blood lactate levels (Quirion et al., 1988).

In a follow-up study, Quinn and Carey (1999) controlled the dietary carbohydrate intake of 12 postpartum (3–7 months) women who were moderately active. Subjects were assigned to either a high (63% of total kcals, n = 6) or moderate (52% of total kcals, n = 6) carbohydrate group. All subjects performed a maximal, graded exercise test on the treadmill. In this protocol, the woman selected a comfortable walking or jogging speed, and this speed was kept constant throughout the test. Treadmill grade was increased by 2.5% every 3 min, and prior to each increase the subject would straddle the treadmill belt and a blood sample was taken from the fingertip and analyzed for lactic acid. This allowed for the determination of each subject's lactic acid threshold (LAT), in order to conduct acute exercise sessions relative to individual LAT. On subsequent visits in random fashion and separated by at least 3 days, the subject exercised for 30 min at her individual LAT.
intensity (averaging 71% of VO₂ max) and 20% below her LAT (averaging 57% of VO₂ max). In addition, a non-exercise resting control session was performed. Milk was collected prior to exercise or rest, and immediately, 30, 60, and 90 min post-exercise, or rest. Results showed that diet had no effect on lactic acid accumulation in the milk. Milk lactic acid peaked immediately following maximal exercise at 1.35 mM. This level was similar to that reported earlier (Carey et al., 1997) but approximately one half that reported by Wallace and colleagues (1994). The post-maximal exercise milk lactic acid remained significantly higher through the 30-min post-exercise collection timepoint and returned to baseline by the 60-min timepoint. Milk collected immediately following exercise conducted at the individual LAT was significantly higher than the control value assay, but was not different from control at 30, 60 or 90 min post-exercise. No differences in milk lactic acid were noted at any of the collection timepoints following the 20% below threshold exercise. We concluded that dietary carbohydrate intake from 3.9 to 5.0 CHO·kg BM⁻¹ would not increase milk lactic acid at any exercise intensity, and that mild to moderate exercise performed by lactating women will not increase milk lactic acid.

CONCLUSION

Animal and human studies show that chronic or acute exercise has no major effect on milk composition. Lower milk lactose was reported in exercising animals from two research groups (Matsuno et al., 1999; Treadway and Lederman, 1986). However, this was not substantiated in human work. Milk lactic acid increases following maximal exercise in humans, but when exercise is of moderate intensity, lactic acid does not accumulate in milk. The one exception to this finding is a report by Wallace and colleagues (1994); this study, however, reported milk lactic acid values significantly higher than literature values. Studies suggest the importance of an adequate maternal diet to account for the increased energy requirements of lactation. The effects of chronic and acute exercise on lactation performance are summarized in Tables 1 and 2, respectively.

Influence of Exercise on Lactating Mammal’s Milk Volume

ANIMAL STUDIES

A number of factors, including exercise, could affect maternal hydration status that may, in turn, cause alterations in mammalian milk volume. Animal research has examined the effects of voluntary exercise in lactating mice (Karasawa et al., 1981). Lactating, female mice were housed in exercise cages with treadwheels, and wheel revolutions were recorded daily. A non-exercise group was housed in cages without treadwheels. There was no effect of voluntary treadmill running on milk yield, although it should be kept in mind that the lactating mice did not exercise to a significant extent (Karasawa et al., 1981). This finding agrees with those of Treadway and Lederman (1986), who report no influence of moderately intense exercise (2 hr of forced swimming with a tailweight of 3% of total body weight) on milk yield in rats.

A short-term reduction in milk volume due to exercise was reported by Lamb and colleagues (1979), in which 2-year-old Holstein heifers were forced to walk
<table>
<thead>
<tr>
<th>Reference</th>
<th>Species</th>
<th>Type of exercise</th>
<th>Exercise during pregnancy</th>
<th>Exercise during lactation</th>
<th>Study termination</th>
<th>Outcome compared to control</th>
<th>Maternal BW</th>
<th>Maternal food intake</th>
<th>Maternal body fat</th>
<th>Offspring growth</th>
<th>Milk volume</th>
<th>Δ Milk composition</th>
<th>Litter size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Courant &amp; Barr, 1990</td>
<td>Sprague-Dawley rats</td>
<td>Run</td>
<td>2 hr, 30m/min, 5 d/wk until day 20</td>
<td>2 hr, 30 m/min, 5 d/wk from day 2 until day 14</td>
<td>Day 14 of lactation</td>
<td>↑ ↑ ↓ Same — — Same</td>
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<tr>
<td>Karasawa et al., 1981</td>
<td>JCL:1 CR mice</td>
<td>Voluntary treadwheel</td>
<td>3000 rotations/d, decreasing to 500 rotations/d at term</td>
<td>~ 500 rotations/d from day 0 until day 14</td>
<td>Day 14 of lactation</td>
<td>Same — Same Same Same</td>
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<tr>
<td>Lamb et al., 1981</td>
<td>2 to 7 yr old Holstein heifers and cows</td>
<td>Walk</td>
<td>4 km/hr, 8 km/day, 5 d/wk 8 wks before calving</td>
<td>None</td>
<td>Day 305 of lactation</td>
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<tr>
<td>Lamb et al., 1979</td>
<td>2 yr old Holstein heifers</td>
<td>Walk</td>
<td>5.5 km/hr, 1.6 km/day, 5 d/wk 4 wks before calving</td>
<td>5.5 km/hr, 1.6 km/d, 5 d/wk until day 10</td>
<td>Day 50 of lactation</td>
<td>Same ↓ — — ↓ Same</td>
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Table 1 Effects of Endurance Exercise Training on Maternal, Offspring, and Milk Outcomes
<table>
<thead>
<tr>
<th>Study</th>
<th>Species</th>
<th>Exercise</th>
<th>Duration</th>
<th>Time Period</th>
<th>Energy Expenditure</th>
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<th>Week 2-20</th>
<th>Week 24</th>
<th>N.A.</th>
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<tbody>
<tr>
<td>Treadway &amp; Lederman, 1986</td>
<td>Wistar</td>
<td>Swim</td>
<td>2 hr/d, 5 d/wk until day 19; Tail Wts.</td>
<td>Day 15 lactation</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
<td>↓ lactose</td>
<td>Same</td>
</tr>
<tr>
<td>Pinto &amp; Shetty, 1995</td>
<td>Wistar</td>
<td>Swim</td>
<td>2 hr/d, 6 d/wk until day 19; Tail Wts.</td>
<td>Day 22 of lactation</td>
<td>↑</td>
<td>↑</td>
<td>—</td>
<td>↓</td>
<td>Same</td>
</tr>
<tr>
<td>Matsuno et al., 1999</td>
<td>Sprague–Dawley rats</td>
<td>Run, min/d, 7 d/wk until day 20</td>
<td>Day 15 of lactation</td>
<td>Same</td>
<td>Same</td>
<td>—</td>
<td>↑ fat</td>
<td>Same</td>
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<tr>
<td>Dewey et al., 1994</td>
<td>Humans</td>
<td>Walk, jog, bike</td>
<td>45 min/d, 5 d/wk at 60-70% heart rate reserve, from wk 6 to wk 20</td>
<td>Wk 18 to 20 of lactation</td>
<td>↑</td>
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<td>Same</td>
<td>Same</td>
<td>N.A.</td>
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<tr>
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<td>45 min/d, 5 d/wk at 60-70% heart rate reserve, from wk 6 to wk 20</td>
<td>Wk 18 to 20 of lactation</td>
<td>↑</td>
<td>Same</td>
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<tr>
<td>Lovelady et al., 1990</td>
<td>Humans</td>
<td>Swim, jog, bike</td>
<td>45 min/d, 5 d/wk at 70% of predicted heart rate max, from 5 mo to 9 mo</td>
<td>Wk 9 to 24 of lactation</td>
<td>↑</td>
<td>↓</td>
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<td>N.A.</td>
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<td>Reference</td>
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<td>Exercise during pregnancy</td>
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</tr>
<tr>
<td>McCrory et al., 1999</td>
<td>Humans</td>
<td>Walk, jog, bike, swim, aerobics</td>
<td>None</td>
<td>50-70% of heart rate max ~70 min/d for 11d at 12 wks postpartum</td>
<td>Week 14</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>Same</td>
</tr>
<tr>
<td>Lovelady et al., 2000</td>
<td>Humans</td>
<td>Walk, jog, aerobics</td>
<td>None</td>
<td>45 min/d, 4 d/wk at 65-80% heart rate reserve at 4 wks postpartum</td>
<td>Week 14</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>Same</td>
</tr>
</tbody>
</table>

*A 1,089 kcal/day deficit was achieved via diet and exercise. Subjects lost ~1 kg/wk and 1.6 kg body fat.
**A 544 kcal/day deficit was achieved via diet and exercise. Subjects lost ~0.5 kg/wk and 4 kg body fat.
A dash indicates outcome was not measured. N.A. = Not applicable.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Type of exercise</th>
<th>Intensity of exercise</th>
<th>Time of sample post-exercise</th>
<th>Milk variables, compared to control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wallace and Rabin, 1991</td>
<td>Treadmill</td>
<td>Max</td>
<td>10 min</td>
<td>Fat —, Ammonium —, pH —, Lactic acid ↑, IgA —, Minerals —, Volume —</td>
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<tr>
<td>Wallace et al., 1992a</td>
<td>Treadmill</td>
<td>Max</td>
<td>10 min</td>
<td>Fat —, Ammonium —, pH —, Lactic acid ↑, IgA —, Minerals —, Volume —</td>
</tr>
<tr>
<td>Wallace et al., 1992b</td>
<td>Treadmill</td>
<td>Max</td>
<td>10 min</td>
<td>Fat —, Ammonium —, pH —, Lactic acid ↑, IgA —, Minerals —, Volume —</td>
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<tr>
<td>Wallace et al., 1994</td>
<td>Aerobics or treadmill</td>
<td>Moderate</td>
<td>10 min</td>
<td>Fat —, Ammonium —, pH —, Lactic acid ↑, IgA —, Minerals —, Volume —</td>
</tr>
<tr>
<td>Carey et al., 1997</td>
<td>Treadmill</td>
<td>Max</td>
<td>30 min</td>
<td>Fat same, Ammonium same, pH same, Lactic acid ↑, IgA —, Minerals —, Volume same</td>
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<td>75% max</td>
<td>30 min</td>
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<tr>
<td></td>
<td></td>
<td>50% max</td>
<td>30 min</td>
<td>Fat same, Ammonium same, pH same, Lactic acid same, IgA —, Minerals —, Volume same</td>
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</table>

(continued)
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<th>Reference</th>
<th>Time of sample post-exercise</th>
<th>Intensity of exercise</th>
<th>Type of exercise</th>
<th>Milk variables, compared to control</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fat Ammonium pH Lactic acid IgA Minerals Volume</td>
</tr>
<tr>
<td>Carey &amp; 1993</td>
<td>30 min</td>
<td>Max 20% below LAT</td>
<td>Treadmill</td>
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<td>Wright et al. 2000</td>
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<td>Max 20% below LAT</td>
<td>Treadmill</td>
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<tr>
<td>Gregory et al. 1997</td>
<td>60 min</td>
<td>Max 10 min</td>
<td>Treadmill</td>
<td>Same same same Same same same same same</td>
</tr>
<tr>
<td>Fly et al. 1998</td>
<td>60 min</td>
<td>Max 10 min</td>
<td>Treadmill</td>
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</tr>
</tbody>
</table>

\*A dash indicates variable was not measured. \*LAT: Lactic acid threshold.
on a circular motor-powered treadmill 1.6 km·d\(^{-1}\) for 4 weeks prepartum and 10 days postpartum. There was a significant decrease in daily milk production during the first 50 days in the exercised cows compared to sedentary controls (21.3 vs. 24.1 kg·d\(^{-1}\), respectively), but this difference disappeared by 305 days of lactation. In a second study of 2-year-old heifers and 3- to 7-year-old cows, exercise during pregnancy had no influence on milk production through 305 days of lactation in either age group of animals (Lamb et al., 1981). Findings with cows are difficult to interpret, as these animals have been bred for supranormal milk production, far more than is needed to support growth and development of their offspring.

HUMAN STUDIES

There is no evidence that exercise compromises milk production in humans. In fact, women who exercised regularly (45 min·d\(^{-1}\), 5 d·wk\(^{-1}\)) tended to have a higher milk volume and energy output compared to controls, although these differences were not statistically significant (Lovelady et al., 1990). Exercise intervention studies show no detrimental effects of exercise on milk volume (Dewey et al., 1994), even if the subjects lost from 0.5 to 1.0 kg·wk\(^{-1}\) (Lovelady et al., 2000; McCrory et al., 1999). Finally, Carey and colleagues (1997) and Quinn and Carey (1999) showed that acute exercise conducted at a variety of intensities, ranging from light to maximal efforts, produced no changes in milk volume when compared to a non-exercise control session. In both of these acute exercise studies, women drank water following the exercise bout to offset any exercise-induced weight loss.

CONCLUSIONS

Data from both animal and human studies show no detrimental effects of either acute or chronic exercise on milk volume in lactating mammals. In all studies, fluids were available and fluid intake was encouraged; no research has been performed on lactating mammals in a hypohydrated state. This may be especially important for women living in a warm environment and warrants further investigation.

Influence of Exercise on Offspring Feeding and Growth

ANIMAL MODEL

Karasawa and colleagues (1981) reported a slight but non-significant increase in body weight of 14-day-old mice born to exercising dams as compared to a non-exercise control group. This correlated with a slight increase in milk yield in exercised animals on days 13 to 14. However, this study employed voluntary treadmill activity, and the exercise group was only slightly more active than the controls.

As a follow-up to this study, Karasawa and Kimura (1986) randomly assigned 48 female rats to either a 20% or 12% casein diet. Voluntary exercise was allowed for half of the animals in each group. Exercise was allowed for 21 days of lactation, and pup growth was documented every other day. Pups had equal access to the dams regardless of exercise. The dams exercised between 580–608 m·d\(^{-1}\). Results showed that exercise had no effect on pup growth.

In swim-exercised rats, milk yield from days 10 to 11 of lactation was not different from controls (Treadway and Lederman, 1986). Litter size was not different
between the groups, and average pup body weight at days 1 and 15 of lactation was not different between the two groups, although pups born to the exercise group tended to be lower in weight. These results suggest that 2 hr of swimming per day have no untoward effects on offspring feeding and growth.

In an effort to study dietary manipulations and exercise on offspring growth and feeding, Matsuno and colleagues (1999) randomly assigned pregnant and then lactating rats to either a 20%, 40%, or 60% glucose isoenergetic diet. In addition, animals were further assigned to a rest or exercise (1,200 m·d⁻¹) group. By lactation day 15, pups of dams fed the 40% glucose diet were heavier than the 60% diet group, irrespective of exercise. These results suggest the importance of diet during lactation in this species and raise questions regarding preferred carbohydrate content in the maternal diet for optimal lactation performance.

Pinto and Shetty (1995) performed a study on exercising Wistar rats during pregnancy and lactation, with rather provocative results. Female rats on identical, nutritionally adequate diets were randomized to either a sedentary or exercise group. The exercise group was forced to swim for 2 hr each day for 6 days per week. Following 30–35 days of training all of the animals were allowed to mate. The pregnant rats in the exercise group continued their 2 hr of activity, 6 days per week while the pregnant sedentary animals remained inactive until day 19 of pregnancy. On the day the rats delivered the pups, birth weights were recorded and the litter size was culled to eight. This size was maintained throughout the lactation period (day 21 of lactation). Maternal exercise was resumed on day 3 of lactation. The pups were weaned on lactation day 22. At 12 weeks of age, pups born to dams in the sedentary group were further assigned to either a sedentary (SED-sed) or exercise (SED-ex) group, and a similar randomization occurred in the pups born to the exercise dams (EX-sed and EX-ex). Rats in the exercise groups (SED-ex and EX-ex) swim trained as previously described, were allowed to mate, exercised throughout pregnancy, delivered the pups, and continued to exercise through lactation day 22. Growth rates were followed for 90 days in this second generation.

Results of this study showed that first generation exercising dams gave birth to pups that were significantly lighter in body weight than those born to sedentary animals (5.6 vs. 6.2 g, respectively), even though food intake of the exercise group was significantly higher than the sedentary group. Exercise during lactation resulted in a slower increase in body weight for pups as compared to their sedentary counterparts at day 22 of lactation (30.0 vs. 36.0 g, respectively) and this trend continued through 90 days. Regarding the second generation, pups in the SED-sed group had birth weights similar to first generation pups born to sedentary dams. However, reduced growth rates were observed in both exercised (EX-ex) and sedentary (EX-sed) animals born to first generation exercised rats. Pinto and Shetty (1995) suggested that a cumulative effect of exercise over two generations accounted for slower growth rates in the EX-ex group but that the generational effect of exercise was observed even though the dams were not exposed to exercise stress during pregnancy or lactation. Thus, a “carry-over effect” is observed in these animals suggesting the possibility of in utero stress negatively impacting growth.

Although this study monitored pup growth, it provided no data on milk composition. This is unfortunate because it may have shed some insight into possible mechanisms for the findings. Maternal nutrition is important for optimal lactation,
and perhaps the animals in the exercise group required more than the nutrients provided in the *ad lib* diet. This notion is supported by the work of Karasawa and Kimura who showed that mice fed a 12% casein diet had more frequent cannibalism, a clear indicator of distress, than mice on a 20% casein diet (Karasawa and Kimura, 1986). Further, it is difficult to determine the amount of psychological distress that these animals were exposed to, but the high incidence of cannibalism (16% to 39%) suggests it was significant.

**HUMAN STUDIES**

The cross-sectional study of the UCDavis group reported that growth of infants consuming breast milk of exercising women was not different from growth of infants of sedentary women (Lovelady et al., 1990). Their 12-week exercise intervention study confirmed these findings, in which there was no difference in weight gain of infants nursing from exercising vs. sedentary moms (Dewey et al., 1994).

Even if lactating women are losing body weight, the growth of their infants is not compromised. This was demonstrated in 2 studies. In the first study, overweight (BMI between 25 and 30) lactating women who reduced their food intake and increased their exercise level, totaling 544 kcal·d⁻¹ for 11 days, lost more body weight and more fat mass than controls (McCorry et al., 1999), without compromising infant growth. A second but longer study, lasting 10 weeks, confirmed these findings: women lost approximately 0.5 kg·wk⁻¹, but there was no reduction in infant growth (Lovelady et al., 2000).

The acute effects of exercise on infant feeding were examined by Wallace and colleagues (Wallace, Inbar, et al., 1992). Twenty-six lactating postpartum women performed a maximal graded exercise test to exhaustion. Milk was expressed prior to exercise and at 10 and 30 min post exercise. The milk samples were analyzed for lactic acid and then presented to the infant in a medicine dropper in a double blind fashion. The mother rated the infant’s response using a numerical scale in which the anchors were 1 = cry, 3 = reject, 5 = indifferent, 7 = accept, and 9 = laugh. The mothers were to rate their infant’s acceptance in comparison to a “normal” response. Results of this study showed that milk lactic acid increased to 2.84 mM at 10 min post exercise and 2.97 mM at the 30-min collection point. The corresponding acceptance ratings were approximately 4.5 (“indifferent”) at both time points. This compared to a pre-exercise acceptance rating of approximately 7 (“accept”). These findings were statistically significant and led the researchers to recommend that women “should consider nursing or collecting milk for a later feeding before exercise” and “supplemental feeding may be necessary in some instances.”

The work of Wallace, Inbar, and Ernsthausen (1992) had several methodological flaws, including the use of a medicine dropper to provide milk to the infant, measuring taste response rather than infant acceptance, studying maximal exercise only, and failure to validate the tool used to evaluate milk acceptance. Finally, as mentioned earlier, milk lactic acid values were substantially higher than literature values (Carey et al., 1997; Quinn and Carey, 1999).

Recently, Wright, Quinn, and Carey (2000) revisited the issue of post-exercise infant feeding with a study involving 24 women who were 2 to 3 months postpartum and breastfeeding their infants. The women consumed a diet in which
foods known to influence milk flavor were avoided. The women performed a maximal graded exercise test to exhaustion and returned to the laboratory twice, in a random fashion, to perform 30 min of moderate treadmill exercise (20% below lactic acid threshold), and 30 min of quiet sitting. The women expressed their milk 1 hr prior to exercise or sitting and 1 hr post-completion of exercise or sitting. The milk was analyzed for lactic acid and then transferred to a bottle with which the infant was familiar and the mother fed her infant out of the bottle. Each feeding session was videotaped and later reviewed by three lactation consultants. Both the mother and the lactation consultants rated infant acceptance using a 10-point, ordinal scale with written anchors (i.e., 1 = poor, 10 = excellent).

Infant acceptance for all of the feedings averaged between good and excellent (i.e., 7–10). There were no significant differences in the consultant’s ratings of infant acceptance of post-maximal exercise, moderate exercise, or the resting control session as compared to the pre-exercise values. This high infant acceptance occurred despite a slight but significantly higher milk lactate content in 1-hr post-maximal exercise milk compared to pre-exercise milk (0.21 mM vs. 0.09 mM, respectively). The ratings compiled from the mothers mirrored those of the lactation consultants except that the mothers rated the post-maximal exercise feeding significantly higher than the consultants did. The results of this study suggest that infant acceptance of post-exercise milk is unchanged even following maximal exercise. While this study does provide positive information for women who desire to breastfeed and exercise, it is important to remember that the method of delivery of the milk to the infant was via a familiar bottle. It is still important to conduct a direct-feeding study, and these data are currently being collected at the University of New Hampshire.

CONCLUSION

The animal and human data report no detrimental effects on offspring feeding and growth when reasonable amounts of exercise are coupled with a prudent diet.

Summary

Despite the shortcomings in extrapolating animal lactation research findings to humans, the majority of animal data suggest that when maternal exercise is coupled with an adequate diet, there is no impairment of animal growth, mammary gland development, milk volume, or milk composition. These findings are confirmed by studies with humans. Maternal psychological and cardiovascular health may be improved with exercise; effects of exercise on bone health and immune status await further research. Evidence to date supports the compatibility of exercise and breastfeeding.

References


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