Effects of hormone replacement on growth hormone and prolactin exercise responses in postmenopausal women

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Kraemer, R. R., L. G. Johnson, R. Haltom, G. R. Kraemer, H. Gaines, M. Drapcho, T. Gimple, and V. Daniel Castracane. Effects of hormone replacement on growth hormone and prolactin exercise responses in postmenopausal women. J. Appl. Physiol. 84(2): 703–708, 1998.—Exercise elevates growth hormone (GH) and prolactin (PRL) blood concentrations in premenopausal women. Postmenopausal women taking hormone replacement therapy (HRT) maintain higher estrogen levels that could affect GH and PRL. The purpose of the study was to determine the effects of HRT on GH and PRL responses to treadmill exercise. Seventeen healthy women who were postmenopausal (naturally or surgically) or on oral HRT; 9 not on HRT (NHRT), completed 30 min of treadmill exercise at 79.16 ± 1.2% maximal O2 consumption (HRT group) and 80.19 ± 0.91% maximal O2 consumption (NHRT group). Blood samples were collected from an intravenous catheter during an exercise session and during a control session without exercise. GH and PRL concentrations were significantly higher in the exercise trial than in the nonexercise trial, whereas resting concentrations were similar for both trials. GH and PRL peaked at 10.8 ± 1.60 and 12.67 ± 2.58 ng/ml, respectively, for HRT subjects and at 4.90 ± 1.18 and 9.04 ± 2.17 ng/ml, respectively, for NHRT subjects. GH concentrations in the exercise trial were significantly higher for HRT than for NHRT subjects. This is the first study to demonstrate that HRT enhances treadmill-exercise-induced GH release and that similar PRL responses to treadmill exercise occur in postmenopausal women regardless of HRT status.

somatotropin; estrogen; menopause

IT HAS BEEN ESTABLISHED that hormonal changes induced by menopause accelerate the reduction of bone mineral density, elevating the risk of osteoporosis for affected women (4). Several treatments are recommended for osteoporosis, including calcium supplementation, exercise, and estrogen replacement therapy (9). Greater bone mineral density (or attenuation of its loss) from these treatments may be caused by mechanical loading of bone, nutrient status, or endocrine changes (23). Estrogen may have an effect on bone mineral density through calcium metabolism or by increasing levels of growth hormone (GH) (10, 23). The process of biological aging also includes a reduced capability for cellular protein synthesis, leading to a decline in muscle mass. It is known that aging is associated with decline in GH pulsatility, pulse amplitude, and insulin-like growth factor-I (IGF-I) concentrations, and it has been suggested that the decline in bone mineral density and muscle mass is associated with reduced GH release (29).

GH has been shown to increase in response to running exercise in eumenorrheic women (17). Low-volume resistive exercise also elicits a GH increase in eumenorrheic women during the luteal phase, but not during the follicular phase, of the menstrual cycle (19). Certain high-volume resistive exercise protocols elicit a GH response as well (21). There are only sparse data concerning GH responses to exercise in postmenopausal women. Exercise may stimulate a greater GH response for women receiving hormone replacement therapy (HRT) than for those not taking estrogen (NHRT). An increased GH response could have a beneficial effect on biological aging. The exercise-induced response may be especially evident for women who take oral estrogen rather than transdermal estrogen. The latter produces a tonic level of estradiol (E2) and does not pass through the liver in high concentrations but distributes E2 directly into the peripheral circulation (1). It has been shown that postmenopausal women receiving oral estrogen have significantly higher 24-h GH concentrations and pulse amplitudes than postmenopausal women taking transdermal estrogen (8, 27); however, treatment with oral and transdermal E2 that results in similar concentrations of circulating E2 increases GH concentrations to the same extent (8).

Prolactin (PRL) and GH share amino acid homologies, and the genes for PRL and GH have similar structure and organization; PRL receptors in humans are also stimulated by GH (28). Both PRL and GH levels have been shown to respond to exercise (6, 14, 17). The lactotrophic cells in the anterior pituitary are increased in size and number by estrogen (28); thus HRT may enhance PRL response to exercise in postmenopausal women. This is the first study to determine whether HRT affects GH and PRL responses to aerobic exercise in postmenopausal women.

METHODS

Subjects. Seventeen women were recruited through newspaper advertisements. The women provided written consent for participation in the study. Eight untrained women were on oral HRT (5 naturally and 3 surgically postmenopausal; mean age 49.38 ± 3.10 (± SE) yr). Nine untrained women were NHRT subjects (7 naturally and 2 surgically postmenopausal, age 53.0 ± 2.98 yr). The HRT subjects were taking Ogen, Premarin, or Estratest daily. Criteria for participation in the study included 1) being in postmenopausal status, either natural or surgical (removal of both ovaries and uterus); 2) being able to complete 30 min of moderate treadmill exercise; 3) not having chronic illnesses, such as diabetes mellitus, liver or gallbladder disease, coronary heart disease, malignancy, anemia, or renal failure; and 4) not...
taking any medication that could alter hormone concentrations, e.g., β-blockers, glucocorticoids, diuretics, or other hormonal or hormone-mimetic medications. All subjects were deemed healthy through medical history screening and a graded-exercise test with a 12-lead electrocardiogram. Women were judged to be postmenopausal by 1) surgical removal of both ovaries and uterus, 2) absence of menses for at least 1 yr, and 3) baseline gonadotropin levels. The study was approved by the Southeastern Louisiana University Committee for the Use of Humans and Animals as Research Subjects and was completed in accordance with the Declaration of Helsinki.

Nutritional status. To verify that diet was similar for the HRT and NHRT groups, each subject completed a 3-day food record during the week before an experimental and a control trial. By using a computer program (Nutritionist IV-N², version 3; Salem, OR), food records were analyzed for 1) total kilocalorie intake, 2) percent of diet that was carbohydrate, fat, and protein, and 3) saturated and unsaturated fat intake. Subjects were asked to refrain from exercise or alcohol ingestion for 48 h before testing.

Session 1. Subjects completed a preexperimental session for determination of fitness level and to become familiarized with the treadmill. Skinfold thickness was assessed at four sites: 1) triceps, 2) abdomen, 3) suprailiac, and 4) thigh. Maximal O₂ uptake (V\textsubscript{O₂max}) was assessed on a treadmill with an automated system to measure O₂ consumption (V\textsubscript{O₂}). Every 30 s, an expiratory air volume was assessed with a heated pneumotach (series 3813; Hans Rudolph, Kansas City, MO) and pressure transducer (VRCD/HC-1; Consentis Technologies, Sandy, UT), and expired O\textsubscript{2} and CO\textsubscript{2} were analyzed (S-3/A/L and CD-4 analyzers; Ametek, Pittsburgh, PA). Equipment was interfaced (OUS/MC; Consentis Technologies) to a personal computer, and values were recorded every 30 s. Before each V\textsubscript{O₂max} determination, the O\textsubscript{2} and CO\textsubscript{2} gas analyzers were calibrated with gases of known composition. The treadmill protocol began at 2 miles/h (mph) and 2% grade until 3.5 mph was reached; thereafter, treadmill grade and every 2 min it was increased by 0.5 mph and 2%. Maximal O₂ uptake (V\textsubscript{O₂max}) was assessed with a 12-lead electrocardiogram. Women were deemed healthy through medical history screening and a colorimetric plasma lactate analysis (Sigma Chemical, St. Louis, MO). Whole blood was centrifuged, and serum was divided into aliquots and frozen (−20°C) for subsequent determination of GH, PRL, luteinizing hormone (LH), follicle-stimulating hormone (FSH), and E\textsubscript{2}. Hematocrit (microcapillary method) and hemoglobin values (Sigma Chemical) were used to determine plasma volume change (7) and to correct hormone levels for hemococoncentration shifts that could inherently elevate hormone levels (18).

Lactate and hemoglobin were analyzed spectrophotometrically (Sigma Chemical). Hematocrit was determined by using a microhematocrit method. GH, PRL, LH, FSH, and E\textsubscript{2} were analyzed by using a chemiluminescent enzymatic immunoassay (IMMULITE; Diagnostic Products, Los Angeles, CA). All hormone serum samples from each subject were determined in the same assay to avoid interassay variability. Intra-assay coefficients of variation for GH, PRL, LH, FSH, and E\textsubscript{2} were all <5.0%. Interassay coefficients of variation for GH, PRL, LH, FSH, and E\textsubscript{2} were <10%. E\textsubscript{2} interassay coefficients of variation for middle and high control pools were <10% and for the low control pool was 14.51%.

Statistics. The data were analyzed by using two different statistical approaches. First, to examine the total response of GH and PRL to exercise and estrogen replacement, we computed an integrated area under the curves (AUC) for GH and PRL response by using a trapezoidal method after subtracting averaged baseline hormone concentration for each subject. AUC is a summary statistic often used in endurance research (e.g., Ref. 19) that allows the cumulative effect of a stimulus on an endocrine parameter to be examined. Independent t-tests were used to determine whether hormone concentrations differed between the HRT and NHRT groups.

### Table 1. Descriptive characteristics of subjects

<table>
<thead>
<tr>
<th>Group</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>BMI, wt/h²</th>
<th>Sum of Skinfolds, mm</th>
<th>V\textsubscript{O₂max}, ml·kg⁻¹·min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRT</td>
<td>162.71 ± 1.35</td>
<td>64.72 ± 4.31</td>
<td>24.26 ± 1.03</td>
<td>88.25 ± 9.95</td>
<td>29.37 ± 1.35</td>
</tr>
<tr>
<td>NHRT</td>
<td>164.82 ± 1.37</td>
<td>70.40 ± 5.19</td>
<td>25.94 ± 1.98</td>
<td>86.11 ± 11.17</td>
<td>23.79 ± 2.79</td>
</tr>
</tbody>
</table>

Values are means ± SE for 8 subjects in hormone replacement therapy (HRT) group and 9 subjects in non-HRT (NHRT) group. BMI, body mass index; wt, weight; ht, height; V\textsubscript{O₂max}, maximal O₂ consumption.
results. These were one-tailed analyses, as we expected GH and PRL to be higher in the HRT group than in the NHRT group. To ascertain whether AUC for GH and PRL differed between experimental (exercise) and control trials, dependent t-tests were conducted. These were also one-tailed analyses, because we expected GH and PRL to be higher during the exercise trial than during the control trial.

Second, to examine the GH and PRL response to exercise and HRT replacement at specific time points, a 2 × 2 × 10 (trial × group × time point) repeated-measures analysis of variance (ANOVA) was conducted. Significance levels reported reflect Geisser-Greenhouse degrees of freedom adjustments.

Potential confounding variables that could also influence GH and PRL include diet and fitness level. To verify that diet was similar between groups and trials for total kilocalories, percent carbohydrate, percent fat, and percent protein, an independent t-test was conducted. To account for the proportion of GH increase that could be caused by fitness level, we analyzed AUC values by using an analysis of covariance (ANCOVA) with \( VO_{2\text{max}} \) as the covariate. To verify that E2 and PRL included diet and fitness level. To verify that diet was higher in the HRT group than in the NHRT group. These were one-tailed analyses, because we expected E2 to be higher in the HRT group and FSH to be lower in the HRT group than in the NHRT group. The alpha level was set at \( P < 0.05 \).

**Results**

Time period \(-40\) and \(-10\) hematocrit and hemoglobin concentrations were within the normal range for resting values. Plasma volume shifts did not exceed 7.4% between any two time points during the exercise trial. Age, height, weight, BMI, \( VO_{2\text{max}} \), and sum of skinfolds were not significantly different between HRT and NHRT groups. Lactate peaked at \( 5.79 \pm 0.80 \) mM (+15) for HRT subjects and at \( 4.60 \pm 0.65 \) mM for NHRT subjects (R0). Resting and peak lactate values were not significantly different between the HRT and NHRT groups during exercise.

GH. GH levels peaked at R0 at \( 10.8 \pm 1.60 \) and \( 4.90 \pm 1.18 \) ng/ml for for HRT and NHRT, respectively (Fig. 1). The results of t-tests comparing AUC for GH levels in HRT and NHRT groups revealed that both exercise trials were significantly higher than control trials, and AUC for GH levels in the HRT group was significantly higher than that for NHRT in the exercise trial (Table 2).

The repeated-measures ANOVA revealed a significant main effect for trial \( [F(1, 30) = 16.82; P < 0.01] \) and group \( [F(1, 30) = 5.82; P < 0.05] \), as well as for several significant interactions, including trial × group × time \( [F(9, 270) = 2.85; P < 0.05] \). Further investigation of this interaction by using the Newman-Keuls test revealed significant differences between groups were localized at four time points: +15, R0, R10, and R20. At these times, GH levels were higher during the exercise trial than during the control trial for both HRT and NHRT groups, and the concentrations during exercise were higher for the HRT group than for the NHRT group (Fig. 1).

PRL. PRL peaked at \( 12.67 \pm 2.58 \) ng/ml (R0) for HRT subjects and at \( 9.04 \pm 2.17 \) ng/ml (R10) for the NHRT group (Fig. 2). The t-test results indicated AUC values

**Table 2. Area-under-the-curve concentrations for growth hormone and prolactin**

<table>
<thead>
<tr>
<th>Hormone</th>
<th>AUC HRT</th>
<th>AUC NHRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth hormone, ng/ml</td>
<td>290.37 ± 70.39*†</td>
<td>-96.40 ± 55.60</td>
</tr>
<tr>
<td>Prolactin, ng/ml</td>
<td>237.12 ± 138.51*</td>
<td>-203.14 ± 62.01</td>
</tr>
<tr>
<td>Growth hormone mean adjusted for ( VO_{2\text{max}} ), ng/ml</td>
<td>286.72 ± 70.39</td>
<td>56.70 ± 47.69</td>
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</tbody>
</table>

*Values are means ± SE for 8 subjects in HRT group and 9 subjects in NHRT group. AUC, area under the curve. *P < 0.05 vs. control; †P < 0.05 vs. NHRT.
for PRL in the HRT and NHRT groups during exercise were significantly higher than those in control trials, but not significantly different from each other (Table 2).

The ANOVA comparing PRL concentrations at different time points revealed a significant main effect for trial \([F(1, 28) = 4.26; P < 0.05]\) and time \([F(9, 252) = 4.03; P < 0.01]\). However, both main effects were superseded by a significant trial \(\times\) time interaction \([F(9, 252) = 6.18; P < 0.01]\). A Newman-Keuls test was used to further investigate these findings; it revealed that PRL was significantly higher during the exercise trial than during the control trial at R0, R10, R20, R35, and R50.

Potential confounding variables. Mean FSH, LH, and E2 concentrations were within the normal range, as established by our laboratory, for postmenopausal women on HRT and NHRT (Table 3). As expected, E2 was significantly higher in the HRT group, and FSH was significantly higher in the NHRT group. One potential variable influencing GH responses to exercise is fitness level of the subjects. The results of an ANCOVA, using \(V_{\text{O2max}}\) as the covariate and AUC for GH as the dependent measure, revealed a significantly higher AUC for GH for the HRT group \([F(1, 28) = 6.18; P < 0.01]\). A Newman-Keuls test was used to further investigate these findings; it revealed that PRL was significantly higher during the exercise trial than during the control trial at R0, R10, R20, R35, and R50.

Table 3. Baseline (−10) growth hormone, prolactin, gonadotropin, and estradiol concentrations

<table>
<thead>
<tr>
<th>Group</th>
<th>GH, ng/ml</th>
<th>PRL, ng/ml</th>
<th>FSH, mIU/ml</th>
<th>LH, mIU/ml</th>
<th>E2, pg/ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRT</td>
<td>1.43 ± 0.39</td>
<td>7.14 ± 0.90</td>
<td>32.19 ± 6.13</td>
<td>24.76 ± 4.04</td>
<td>102.11 ± 45.26</td>
</tr>
<tr>
<td>NHRT</td>
<td>2.51 ± 1.05</td>
<td>6.04 ± 0.33</td>
<td>58.07 ± 10.76</td>
<td>24.89 ± 2.94</td>
<td>26.64 ± 4.02</td>
</tr>
</tbody>
</table>

Values are means ± SE for 8 HRT subjects and 9 NHRT subjects. GH, growth hormone; PRL, prolactin; FSH, follicle-stimulating hormone; LH, luteinizing hormone; E2, estradiol.

We have demonstrated that GH responses to treadmill exercise are higher in postmenopausal women receiving HRT than in those not on HRT. However, in response to treadmill exercise, PRL increases in postmenopausal women regardless of their estrogen status. Our research design controlled for GH pulsatility by using a control trial and short intervals between blood sampling. This is the first study to document effects of HRT in postmenopausal women on their GH and PRL responses to a well-quantified exercise bout.

Circulating GH and IGF-I concentrations have been shown to decline with age in women of reproductive age and postmenopausal women (27). The age-related decline in GH pulses may be explained partially by an increase in somatostatin tone, because the administration of agents that inhibit somatostatin release, i.e., cholinergic agonists and arginine, have been demonstrated to increase GH release in older persons (23, 29). There is evidence that GH and IGF-I facilitate anabolic functions of bone formation and protein synthesis in muscle (2). The data from our investigation underscore the importance of incorporating exercise into the lifestyle of postmenopausal women, whether on or off estrogen replacement, to reduce catabolic effects associated with aging.

Evidence suggests that oral estrogen administration to postmenopausal women elicits an increase in GH-pulse height, individual GH-pulse amplitude, and incremental GH-pulse amplitude (8, 26). Although both oral and transdermal HRT have been shown to increase blood levels of GH, neither has been shown to com-

Table 4. Average daily kilocalorie intake, carbohydrate intake, fat intake, protein intake, and polyunsaturated/saturated fat ratio

<table>
<thead>
<tr>
<th>Group</th>
<th>Average Daily Intake, kcal</th>
<th>Carbohydrate Intake, g</th>
<th>Fat Intake, g</th>
<th>Protein Intake, g</th>
<th>Polyunsaturated/Saturated Fat Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRT</td>
<td>1,910.25 ± 105.94</td>
<td>267.43 ± 25.22</td>
<td>60.62 ± 5.01</td>
<td>79.65 ± 12.11</td>
<td>0.65 ± 0.13</td>
</tr>
<tr>
<td></td>
<td>(55.31)</td>
<td>(57.12)</td>
<td>(28.21)</td>
<td>(16.47)</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1,758.75 ± 259.63</td>
<td>257.50 ± 40.17</td>
<td>56.55 ± 10.22</td>
<td>66.03 ± 6.35</td>
<td>0.76 ± 0.10</td>
</tr>
<tr>
<td></td>
<td>(57.12)</td>
<td>(28.23)</td>
<td>(14.65)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NHRT</td>
<td>1,815.22 ± 142.15</td>
<td>254.20 ± 15.22</td>
<td>55.17 ± 8.07</td>
<td>81.27 ± 14.55</td>
<td>0.74 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>(55.31)</td>
<td>(27.01)</td>
<td>(17.68)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1,834.22 ± 179.26</td>
<td>242.34 ± 25.99</td>
<td>62.08 ± 8.57</td>
<td>85.25 ± 14.87</td>
<td>0.56 ± 0.04</td>
</tr>
<tr>
<td></td>
<td>(51.86)</td>
<td>(29.89)</td>
<td>(18.24)</td>
<td></td>
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</tr>
</tbody>
</table>

Values are means ± SE for 8 subjects in HRT group and 9 subjects in NHRT group. Nos. in parentheses, %total intake.
pletely reverse age-related reductions (2). Mechanisms suggested for the E2 effect on increased GH include the expression of E2 and somatostatin receptors in the hypothalamus by GH-releasing hormone neurons (24) and reduced IGF-I negative feedback effect on GH secretion (1, 8). We have previously shown that exercise-induced increases in GH do not result in short-term increases in IGF-I concentrations (20); therefore, we did not measure IGF-I values in the present study.

Dawson-Hughes et al. (5) reported a slightly higher GH response to light exercise in postmenopausal women treated for 2 wk with ethynyl E2. The exercise intensity was not well quantified (walking at ~1 mph as determined by a pedometer) and appeared to be considerably lower than that used in the present study. It has been shown that the mode and intensity of exercise affect the GH response (17–19, 21). We have previously documented elevated GH concentrations in young women in response to treadmill running (17) and to resistive exercise during the luteal phase of the menstrual cycle (19). One mechanism explaining enhanced exercise-induced increases in GH increases via E2 includes increased pituitary sensitization leading to increased release of GH-releasing hormone (19), which could explain the observations from the present study. Another mechanism, hemoconcentration, was ruled out as an explanation for increased GH and PRL levels in the present study, because peak percent increases in GH and PRL were well above the greatest percent PV reduction that would have caused increased hormonal concentrations.

It has been shown that PRL secretion is increased by E2 through 1) increasing baseline secretion, 2) increasing release of thyroid-releasing hormone, and 3) reducing the effects of dopamine agonists on inhibition of PRL secretion (25). PRL responses to exercise have been observed in eumenorrheic runners, but the PRL responses were absent in amenorrheic runners (22), and those findings were suggested to be caused by extreme ovarian suppression. Our data, however, suggest that treadmill exercise at ~80% of V̇O_2max increases PRL concentrations in postmenopausal women, regardless of their HRT status.

Keizer et al. (16) showed that PRL rises in trained and untrained eumenorrheic women when they are exercised to exhaustion (above lactate threshold). Because lactate levels were increased during exercise in the present study, it would appear that lactate threshold was exceeded and produced a PRL response even in the NHRT postmenopausal women.

For a number of reasons, we do not think there was a difference in physical exertion between the HRT and NHRT groups. First, the percentages of V̇O_2max maintained by the NHRT and HRT groups were similar. Second, lactate concentrations in the HRT and NHRT groups were not significantly different at rest or peak exercise. Third, the rating of perceived exertion reported for the NHRT group was similar to that of the HRT group during exercise (5.10 for HRT group vs. 5.30 for NHRT group on the 10-point Borg scale). Fourth, the percent of maximum heart rate maintained by both groups during exercise was not significantly different (90.23 vs. 89.49% for HRT vs. NHRT group, respectively; P > 0.05).

It has previously been shown that higher fitness levels are associated with greater GH response to exercise (3). Not only was V̇O_2max similar between groups, (P > 0.05), but even with the variance accounted for by V̇O_2max removed in an ANCOVA analysis, the GH concentrations were still significantly and substantially higher in the HRT group compared with the NHRT group. Moreover, no significant relationship between fitness level and GH response (AUC) was found.

Diet may also affect GH concentrations (12); however, it is unlikely that diet affected the results of the present study. Food records indicated that the diets of subjects in the HRT and NHRT groups were not significantly different in total caloric intake as well as in percent carbohydrate, fat, and protein; moreover, the nutrient composition and caloric values were close to recommended daily allowance values.

The exercise response of other hormones may also be affected by HRT. For example, we have recently documented an enhanced exercise response of the adrenal hormones dehydroepiandrosterone and cortisol in the same subjects who participated in the present study (15). Future investigations are needed to examine exercise responses and adaptations of hormones affected by E2.

In summary, this is the first study to demonstrate an augmented response of GH to treadmill exercise by postmenopausal women on HRT and similar PRL responses in postmenopausal women regardless of HRT or NHRT status. The effect of HRT and exercise may serve to enhance the obvious health benefits produced by HRT or by exercise alone.

The authors are grateful to the women who participated as subjects in this study. We especially thank Dr. Edward P. Hebert for advice and help with statistical analyses. We also wish to thank Diagnostic Products Corporation, Los Angeles, CA, for their contribution of radioimmunoassay materials.

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