Physical exercise as prophylaxis against involutional vertebral bone loss: a controlled trial

BJØRN KRØLNER, BIRTE TOFT, STIG PORS NIELSEN AND ERIK TØNDEVOLD
Department of Medicine F, Department of Rheumatology, Department of Clinical Physiology and Department of Orthopaedic Surgery, Frederiksborg County Hospital, Hillerød, Denmark

(Received 4 January/8 October 1982; accepted 23 November 1982)

Summary
1. The skeletal effects of physical training were studied in a controlled trial involving 31 healthy women (aged 50–73 years) with previous Colles’ fracture of the forearm. The bone mineral content of the lumbar spine and both distal forearms was measured by dual-photon (183Gd) absorptiometry.
2. The participants were allocated to either a physical exercise group or a control group. The former group followed a standardized exercise programme, exercising for 1 h twice weekly during 8 months.
3. Twenty-seven women completed the study. Lumbar spine bone mineral content of the exercise group increased by 3.5%, whereas that of the control group decreased by 2.7%. The rate of bone loss in the control group equalled that of age-matched normal women.
4. The changes in forearm bone mineral content appeared to be independent of the exercise. The bone mineral content of the previously fractured forearm remained nearly unchanged. The bone mineral content of the uninjured forearm decreased on average by 3.5%.
5. The data suggest that physical exercise can inhibit or reverse the involutional bone loss from the lumbar vertebrae in normal women. Physical exercise may prevent spinal osteoporosis.

Key words: bone mineral content, fractures, osteoporosis, physical exercise, prophylaxis, spine.

Introduction
The crush fractures of spinal osteoporosis are incurable. A rational treatment of osteoporosis implies prevention of the bone loss that leads to structural deterioration of the vertebral bodies [1]. Physical activity is a major determinant of bone remodelling and bone mass [2], and physical exercise has been suggested as a possible prophylactic against involutional bone loss and osteoporosis [3, 4].

The main purpose of the present study was to investigate whether physical exercise could prevent the involutional bone loss from the lumbar vertebrae in healthy women.

Material and methods
Patients
Thirty-one otherwise healthy women (aged 50–73 years) with previous fractures of the distal forearm (Colles’ fracture) consented to participate in this prospective trial in accordance with the Helsinki II Declaration. The patients comprised about half the middle-aged women treated for Colles’ fracture in the emergency ward of the hospital during 1979 [4]. The risk of future vertebral compression fractures in those patients was considered to be somewhat higher than the risk in age-matched normal woman [4, 5]. The times elapsing after the forearm injury were 9–21 months. The study was conducted from September 1980 till May 1981.

Protocol
The participants were allocated to either a physical exercise group (n = 16) or a control group (n = 15). Randomization was impractic-
able owing to difficulties of patient transport. Those living close to the hospital were included in the exercise group. Those living far from the hospital were controls. Table 1 shows the initial values of relevant biological variables in the two groups.

The patients were maintained on their usual diets. Calcium supplements were not given. All medical treatment (hypnotics, analgesics, diuretics) was continued. Three women were still premenopausal or perimenopausal (all in the control group). Three received oestrogens (two in the exercise group, one in the control group). Oestrogen had been administered for more than 5 years in each case.

Exercise programme

The women in the exercise group exercised for 1 h twice weekly during 8 months under the supervision of an experienced physiotherapist. The training load was considered to be moderate for that age group. The programme included: (1) walking exercises, (2) running exercises, (3) exercises in standing, (4) exercises in sitting, (5) exercises in lying, (6) exercises on all fours and (7) ball games.

Each training period was initiated with warming-up exercises for 5 min. Any sparing of the fractured arm was omitted, but the training programme did not focus on training of the forearms separately. The women were encouraged to continue exercising at home. An amplified version of the exercise programme is available from the authors on request.

Compliance to the trial

Three women left the exercise group during the first 2 months, the reasons being lack of time, fatigue and backache respectively. The last of the three showed symptoms and signs of a prolapsed intervertebral disc. One woman had a peri-tendinitis of short duration. No other medical complications related to the exercising were observed. The rate of attendance at the single training periods ranged from 39 to 100% (mean 73%) in the 13 women who completed the entire exercise programme. One woman left the control group for personal reasons.

Methods

A standard bicycle ergometer test was utilized for prediction of the maximal oxygen uptake during work. Changes in the systolic blood pressure–pulse rate product at submaximal work load were used as a measure of the conditioning effect of the exercise programme. Maximal oxygen uptake and blood pressure–pulse rate product were not calculated in two patients treated for mild hypertension (one in each group), one treated for atrial fibrillation (in the control group) and one with knee complaints (in the control group).

Bone mineral content of the lumbar spine and both distal forearms was measured by dual-photon (153Gd) absorptiometry as previously described [4, 6, 7]. Lumbar bone mineral content was expressed as the total mineral mass of the second, third and fourth lumbar vertebrae in arbitrary units (dimension: mass). Forearm bone

<table>
<thead>
<tr>
<th>Variable</th>
<th>Physical exercise (n = 16)</th>
<th>Controls (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>61</td>
<td>6</td>
</tr>
<tr>
<td>Years after the menopause</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Time after the forearm injury (months)</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>161</td>
<td>7</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>59</td>
<td>7</td>
</tr>
<tr>
<td>Maximal oxygen uptake (l/min)</td>
<td>2.3</td>
<td>1.0</td>
</tr>
<tr>
<td>10^-2 BPP (mmHg beats)</td>
<td>255.4</td>
<td>58.6</td>
</tr>
<tr>
<td>Lumbar spine BMC (units)</td>
<td>38.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Forearm BMC (units/cm)</td>
<td>1.20</td>
<td>0.25</td>
</tr>
<tr>
<td>Serum calcium (normalized) (mmol/l)</td>
<td>2.32</td>
<td>0.06</td>
</tr>
<tr>
<td>Serum phosphate (mmol/l)</td>
<td>0.97</td>
<td>0.15</td>
</tr>
<tr>
<td>Serum alkaline phosphatase (units/l)*</td>
<td>182</td>
<td>58</td>
</tr>
<tr>
<td>Serum albumin (mmol/l)</td>
<td>0.72</td>
<td>0.04</td>
</tr>
</tbody>
</table>

* Laboratory normal range: 80–275 units/l.
Prevention of bone loss by exercise

mineral content was expressed as the average mineral density of a 1.0 cm segment of both distal forearms in units/cm (dimension: mass per unit length). The forearm measuring site was at least 1.5 cm proximal to the fracture line of the previous Colles' fracture, and callus was not measured.

Serum concentrations of calcium, inorganic phosphate, total alkaline phosphatase and albumin were determined by routine methods. All serum samples were kept deep-frozen and analysed during 1 day. Serum calcium concentration was normalized to a serum albumin concentration of 0.70 mmol/l.

The variables were determined before the beginning of the trial and after 4 and 8 months.

Statistical evaluation

Student's t-test for paired and unpaired samples was used for comparison. P values less than 0.05 were considered significant. Calculations were based on differences between initial and 8 months' values.

Results are given as means ± SEM.

Results

The exercise group and the control group were comparable with regard to age, duration of menopause, time elapsing after the forearm injury, physical performance capacity and mineral metabolism before the beginning of the trial (Table 1).

The training programme was an obvious social success. The exercise group showed an 11.3% decrease in the blood pressure-pulse rate product at submaximal work load after 8 months (P < 0.01), whereas the control group showed a non-significant decrease of 4.7%.

Effects on bone mineral content are summarized in Figs. 1 and 2. The mean change in lumbar bone mineral content in the exercise group was an increase of 1.3 ± 0.6 units or 3.5 ± 1.6% (not significant, N.S.; P = 0.07) compared with a decrease of 1.2 ± 0.5 units or 2.7 ± 1.3% (P < 0.05) in the control group (Fig. 1). The difference between these changes was highly significant (2.5 ± 0.8 units, P < 0.005).

The spinal bone mineral loss in the control group equalled that of 32 age-matched normal women [7].

Forearm bone mineral content remained practically unchanged in the exercise group, whereas a reduction of 0.05 ± 0.02 unit/cm or 3.7 ± 1.8% (P < 0.05) was seen in the control group (Fig. 1). The difference between the groups was not statistically significant (P = 0.12).

Analyses of bone mineral content of the uninjured and the fractured forearm separately indicated a pattern of differential bone mineral changes, independent of physical exercise (Fig. 2). When the data of both groups of women (n = 27) were pooled the uninjured forearm showed a mean decrease of 0.05 ± 0.02 unit/cm or 3.5 ± 1.6% (P < 0.01), whereas the fractured forearm showed a mean increase of 0.01 ± 0.02 unit/cm or 1.8 ± 1.7% (N.S.).

![Figure 1](image-url)

**Fig. 1.** Lumbar spine (a) and forearm (b) bone mineral contents (BMC) before and during exercising. •——•, Exercise group; ○···○, control group. Values are given as the mean deviation (± SEM) from the values before the beginning of the trial (September). **Significantly different from the control group (P < 0.01).
The difference obtained between the changes in the bone mineral content of the uninjured and the fractured forearm (0.07 ± 0.03 unit/cm) approximated to the mean differences of 0.10 ± 0.02 unit/cm between bone mineral contents of the uninjured and the fractured forearm in the patients before the trial (i.e. the fracture-related bone loss [4]).

All biochemical variables remained unchanged during the study.

The results were not changed if the premenopausal women and the women receiving oestrogens were excluded.

Discussion

The etiology of primary (involutional) osteoporosis is multifactorial [8, 9]. Oestrogen deficiency is considered as one main cause of net bone resorption in postmenopausal women [10], other possible factors being insufficient dietary calcium intake [11], impaired renal conversion of 25-hydroxycholecalciferol into 1,25-dihydroxycholecalciferol (leading to diminished intestinal calcium absorption) [12, 13] and osteoblast failure [14]. The influence of altered mechanical loading of the skeleton in aging women might be an additional factor of great importance [1, 4]. Skeletal muscle mass and muscle strength decline with increasing age [15] and involutional bone loss might reflect an adaptive response to decreased physical activity. The bone loss that occurs after immobilization [16] and the apparent bone mass gain of athletes [17] need no emphasis.

It follows from the hypothesis that decreasing mechanical stimulation with increasing age is an important pathogenetic factor in osteoporosis, that the involutional bone loss might be reversed by physical training [1]. The present trial supports this hypothesis. Our results suggest that physical exercise can inhibit the involutional bone loss from the axial skeleton in middle-aged women and lead to net gain in axial bone mass.

The effects of exercise on forearm bone mineral content were not significant. This might be due to a differential exercise response in trabecular and cortical bone. Nevertheless, the groups studied were too small to exclude the possibility of parallel changes in the axial and the appendicular skeleton, and forearm exercises being more rigorous than in the present training programme might be beneficial.

Smith et al. [18] have demonstrated a 2% increase in forearm bone mineral content of aged women after a programme of physical exercise for 3 years. Aloia et al. [3] found a similar effect on total body calcium in normal women immediately after the menopause.

It is a matter of controversy whether the bone loss that follows Colles' fractures in adults is reversible [19, 20]. Our previous cross-sectional...
results [4] suggested total reversal of the fracture-related bone loss within 3 years after the injury. The present longitudinal study confirms this finding. However, it appears that the reversal is due to acceleration of the normal involutional bone loss in the uninjured forearm rather than net bone mass gain in the fractured limb. It is as yet unclear whether the systematic decrease in bone mineral content seen in January (Figs. 1 and 2) indicates a midwinter diminution of bone mineralization or bone mass [21].

Administration of oestrogens or calcium supplements to normal postmenopausal women tends to inhibit or partly reverse the involutional bone loss [22–26], whereas administration of vitamin D metabolites [27] and fluorides [28] might prevent bone loss in a subgroup of older women with obvious spinal osteoporosis. These agents are associated with significant risks, however, and treatment will be tentative since it remains to be established that the susceptibility to vertebral fractures is lowered by the therapy [25, 26]. Physical exercise appears to be an appropriate alternative. The medical side-effects of physical exercise are less serious, and exercising may in addition strengthen the musculo-ligamental support of the spine and improve the general physical performance and well-being.

Motivation for long-term prophylaxis is essential for successful prevention of spinal osteoporosis. The social aspects of exercising in groups could be an effective way to encourage middle-aged women to take exercise necessary to decrease the risk of vertebral fractures. Further studies are needed to establish the long-term effects and side-effects of physical exercise on the involutional bone loss in different parts of the skeleton.

Acknowledgments
The exercise programme was kindly conducted by Mrs K. Ibsen and Mrs N. Mercier, leading physiotherapists. The technical assistance of Mrs A. Hytholm is acknowledged. The study was supported by a grant from Nordisk Gjenforsikrings Selskabs Jubileumsfond.

References


