Forty-one long-distance runners aged 50 to 72 years were compared
with 41 matched community controls to examine associations of repetitive,
long-term physical impact (running) with osteoarthritis and osteoporosis.
Roentgenograms of hands, lateral lumbar spine, and knees were assessed
without knowledge of running status. A computed tomographic scan of the
first lumbar vertebra was performed to quantify bone mineral content.
Runners, both male and female, have approximately 40% more bone mineral
than matched controls. Female runners, but not male runners, appear to have
somewhat more sclerosis and spur formation in spine and weight-bearing
knee x-ray films, but not in hand x-ray films. There were no differences
between groups in joint space narrowing, crepitation, joint stability, or
symptomatic osteoarthritis. Running is associated with increased bone
mineral but not, in this cross-sectional study, with clinical osteoarthritis.

(JAMA 1986;255:1147-1151)

The relationship between exercise and health has been one of growing
interest and importance. Strong data link increased physical activity to
decreased risk of cardiovascular disease and assistance in weight
reduction, reduction of blood pressure, and improved mood. In part
because of these findings, running has become a national phenomenon of
importance, with nearly 15 million participating Americans, raising con-
cerns that this form of physical activity may accelerate the development of
osteoarthritis in the weight-bearing joints, leading to increased prevalence.
In general populations, the prevalence of osteoarthritis increases
with age. By roentgenogram, 86% of women and 78% of men over the age
of 65 years show evidence of osteoarthritis. Thus, questions have arisen for which there are few data.

Does aerobic running activity on hard
surfaces accelerate, slow, or have little effect on the development of osteoarthritis? Does such activity build
stronger bones and ligaments, which protect against osteoarthritis? Or are
we heading toward an era of healthy hearts but worn-out musculoskeletal
systems?

In January 1984, the Stanford (Calif) Arthritis Center began a prospective five-year longitudinal study
on the effect of running on the development of osteoarthritis, in running
and control subjects aged 50 to 72 years. This article presents initial
cross-sectional data on roentgenograms of knees, spine, and hands and
calcification (lumbar spine) in 41 runners and matched controls.

Subjects and Methods

Subjects

The 50-Plus Runners Association, with members from all over the United States, provided access to a large number of
long-distance runners. The Stanford Lipid Research Study, begun in 1972, provided access to a complete community sample,
consisting of the Stanford community. A study description was sent to and received by approximately 1,365 runners and controls,
of whom some 1,300 individuals responded with a postcard questionnaire indicating interest. The 1,250 who met age
(50 to 72 years), education (high school graduate or above), and language require-
ments (English primary language) were sent questionnaire materials and consent forms. The 539 50-Plus Runners Associa-
tion subjects and 422 controls returning these materials were enrolled in the study.

Protocol

All subjects provided extensive questionnaires on multiple variables
including exercise history (both past and present), musculoskeletal injuries, medical
history, Stanford Health Assessment Questionnaire, dietary history (especially
calcium and fat intake), and age of menopause and history of estrogen replacement
in women. An “intensive study” group was formed, without knowledge of responses,
from 98 subjects selected by living within 100 miles of Stanford and having a potent-
tial match in the opposite group. Subjects qualifying for intensive study included 41
50-Plus Runners and 57 community controls. We report results on 41 matched pairs, 18 female and 23 male, who could be
matched on age (within two years), sex, years of education (within two years), and
occupation (same census class from US Bureau of Census). These subjects under-
went rheumatologic examination, validation of previous questionnaire responses,
and x-ray films of hands (used as non-weight-bearing controls), lateral lumbar
spine, and weight-bearing knee joints. Forty subjects underwent computed tomo-
graphic (CT) scanning of the first lumbar vertebra for bone mineral content.

Radiological Measurements

X-ray films were scored by consensus by two readers blind to the exercise history of
the subject. Each x-ray film was scored for sclerosis, spur formation, and joint space
narrowing. Sclerosis and spur formation were scored 0 to 3 in increasing severity. The
medial and lateral joint space of the knee was marked and measured in millimeters.
The disk spaces in the lumbar spine were measured and the number of
narrowed disk spaces and severity of the narrowing tabulated. The distal inter-
phalangeal joint spaces were individually
evaluated and scored 0 to 3 for increased severity of joint space narrowing (or loss of cartilage space).

The values for bone mineral density of the vertebral body of L-1 were calculated from a CT scan with a single 10-mm slide through the center of the body using 80 kilovolts (peak), 300 mamp, and 2 s. A standardization phantom was placed under the patient, and the procedure and calculations were carried out as described by Genant et al.1 Scanner precision measurements made using a torso phantom yield a reproducibility of single-slice 80-kVp measurements of within 4%. Experience with repeated scans of a few individual patients (being studied for osteoporosis and not part of this project) shows variation of measurement of the phantom standards made at approximately six and 12 months compared with initial values to be less than 5%. This experience is similar to that reported by others.11,12 Although scan of a single vertebra does not furnish as much information as scans of multiple vertebrae, its use in the project involving healthy, volunteer subjects was chosen to limit patient exposure to radiation and reduce scanning time. The publications of Cann et al.,13 McBroon et al.,14 and Rosenthal et al.15 support usefulness of a single 80-kVp scan of L-1 in similar circumstances. We have relied on cadaver experiments conducted by others to support the accuracy of these procedures.11,12

For study of the 40 subjects undergoing CT scan, matched pairs were again constructed using the same criteria. This yielded eight male pairs. For women, additional matching criteria were included to take into account variables affecting bone density (age of menopause, years of estrogen replacement, and average calcium intake over ten years, reported as number of servings per week of calcium products over the previous ten years). With these added criteria, six matched female pairs were identified. Comparisons between runners and controls were based on matched pair data, using Student’s two-tailed t test.

Twenty-five control subjects were also or had been runners at some level; hence, data are provided comparing all runners and all nonrunners as well as comparing the 50-Plus Runners Association subjects with the community control subjects. In the tables, “runners” refers to all subjects who have ever run, “nonrunners” to all who have never run, “50+ Runners” to subjects recruited from the 50-Plus Runners Association, and “controls” to subjects recruited from the community control population.

RESULTS

A subset of 25 questionnaires was validated against physician interview, with good concordance. Correlation coefficients averaged close to 90%, and t test statistics failed to demonstrate any significant systematic differences.

Table 1 compares characteristics of the groups. The mean ages of the several groups were closely similar. After matching, groups were almost identical for age, and they were precisely matched for sex, occupation, and years of schooling. There was no significant comorbidity in either group. Weights were different; the mean weight of 50-Plus Runners was 66.4 kg, and matched controls were heavier at 72.7 kg. (Weights were higher in the all-runners group than in the 50-Plus Runners, since there were 10% more men in this group.) All subjects were white. Disability as measured by the Stanford Health Assessment Questionnaire was less in the runners. As expected, the exercise profiles show that the 50-Plus Runners exercised much more than controls and ran far more, and these differences are highly significant. Total average running mileage in the two final matched groups differed by a factor of 10. This difference in repetitive weight-bearing joint impact constitutes the major independent variable of this study.

The distal interphalangeal joints, included as non-weight-bearing control joints (Table 2), showed no significant differences between any of the runner and control comparison groups, in the 41 matched pairs or between female and male pairs for any variable, except for increased sclerosis (P<.05) in male controls. In general, the trends were for increased sclerosis, spur formation, and joint space narrowing in the controls. Statistical tests have been applied on the matched-pair analyses since this is methodologically most rigorous, but the means and SEs of the parent unmatched groups are shown as well.

Some differences in knee roentgenograms were observed (Table 3). Differences in sclerosis in the fema pairs were statistically significant (P<.05), being more marked in runners than in controls. This effect did not occur in men. Female runners showed more (P<.001) spur formation than matched controls. Perhaps the most noteworthy feature in osteoarthritis is joint space narrowing. There was increased width of the joint space in runners in both men and female pairs, but the difference was not statistically significant.

With lateral lumbar spine roentgenograms, the only statistically significant difference between groups was increased sclerosis in female runners, but not in male runners, compared with matched controls (Table 4). There was a tendency for increased spur formation in female runners, but not in male runners. Disk space narrowing, here represented on a scale where narrowing toward the higher number, showed no overall trend.

Runners had significantly higher (40%) bone density in both male and female groups (Table 5).

No differences in clinical signs of osteoarthritis, including neck crepitus, Heberden’s nodes, Schobert test, knee crepitus, or knee instability were observed.
Table 2.—Distal Interphalangeal Joint Roentgenograms (Mean Values)

<table>
<thead>
<tr>
<th></th>
<th>All Subjects</th>
<th>Matched Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Runners</td>
<td>Nonrunners</td>
</tr>
<tr>
<td>Sclerosis *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>6.9</td>
<td>8.8</td>
</tr>
<tr>
<td>SE</td>
<td>2.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Spur *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>9.2</td>
<td>9.4</td>
</tr>
<tr>
<td>SE</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Narrowing *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean score</td>
<td>6.7</td>
<td>7.4</td>
</tr>
<tr>
<td>SE</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

* See text for explanation.
† The SE of differences between matched pairs is listed in parentheses below the columns making up the pairs.
§ P < .05 (t test of matched pairs).

Table 3.—Knee Joint Roentgenograms (Mean Values)

<table>
<thead>
<tr>
<th></th>
<th>All Subjects</th>
<th>Matched Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Runners</td>
<td>Nonrunners</td>
</tr>
<tr>
<td>Sclerosis *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>5.9</td>
<td>5.2</td>
</tr>
<tr>
<td>SE</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Spur *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>7.3</td>
<td>5.7</td>
</tr>
<tr>
<td>SE</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Narrowing *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean score</td>
<td>7.0</td>
<td>6.9</td>
</tr>
<tr>
<td>SE</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

* See text for explanation.
† The SE of differences between matched pairs is listed in parentheses below the columns making up the pairs.
§ P < .001 (t test of matched pairs).

bility, were found. Runners were slightly more likely (P = .04) to have Bouchard's nodes.

COMMENT

Osteoarthritis is defined on roentgenogram by osteophyte formation, sclerosis of subchondral bone, cyst formation, and joint space narrowing.15 There are known inconsistencies between findings on x-ray films and clinical symptoms, with only 25% to 30% of subjects with osteoarthritis by roentgenogram being clinically symptomatic.16 Overall, we found few differences except in bone density, which was strongly associated with running in both sexes. Female runners tended to show more sclerosis and spur formation in knees and spine, but the cartilage width in the knees and spine, measured as joint space narrowing, was not different in the two groups. We cannot exclude the possibility that increased bone density resulted in increased ability to "read" sclerosis and new bone formation (spurs) in the running group. Previous studies of runners and osteoarthritis have shown that the incidence of roentgenographic evidence of osteoarthritis of the hip is lower in former athletes (mean age, 56 years) who have run for an average of 21 years than in a sedentary control group.7 In a study of 299 subjects with roentgenographic evidence of hip osteoarthritis, only 10% had ever taken part in any form of sport.16 On the other hand, in a study of 20 runners with knee pain, six had osteoarthritis by roentgenogram; trauma to the knee or underlying deformity (ligamentous laxity, genu varum, history of severe trauma) was found to be significantly associated with degenerative changes.17 Ballet dancers are reported to have roentgenographic evidence of osteophytes without joint space narrowing at the first metatarsal phalangeal joint, but only rarely to have symptoms.18

One theory of the development of osteoarthritis is that joints "wear out" by repetitive impulse loading.19 This impulse loading results in trabecular microfracture, then bone remodeling and sclerosis, and stiffened bone. This rigidity increases stress on articular cartilage, with subsequent cartilage breakdown and joint degeneration. It has been observed that total paralysis severely reduces intra-articular stress and appears to spare joints from further degeneration.
Other authors suggest that it requires both impulse loading and a mechanical derangement to the joint to result in osteoarthritis. A careful review by Hadler emphasizes that the postulated relationship of osteoarthritis and heavy work rests on almost entirely anecdotal evidence.

Female runners in this study tended to show more subchondral bone formation (sclerosis) and osteophytes (spurs). If these findings are valid, then female runners could be developing microfractures and bone remodeling, with the osteophytes representing an attempt to build and spread the load per unit area, as hypothesized by Radin et al. The absence of joint space narrowing in runners compared with the control group, even after running of these extreme distances, might suggest that bone remodeling is successful in protecting the joint cartilage. Nilsson and Hernborg, on the other hand, have suggested that osteophytes are more a function of aging than of osteoarthritis, and in a 17-year prospective study determined that osteophytes increased in size at a faster rate in patients who had subsequently developed clinical osteoarthritis.

Running was associated with markedly increased bone density of the first lumbar vertebrae in our subjects. Trabecular bone density has been linked to vertebral fracture in postmenopausal women. Others previously have demonstrated that exercise can prevent involutional bone loss. Smith and colleagues studied 18 women in a nursing home with a mean age of 81 years and demonstrated an increase in bone mineral content in the group that was exercising and the group supplemented with calcium compared with sedentary controls. Aloia et al., in a cross-sectional study of marathon runners, reported that the usual decrease in total body calcium and total body potassium concentrations with increasing age was not present in marathon runners.

Krolner et al. studied 31 women (mean age, 61 years) with previous Colles' fracture of the forearm and found the exercise group had an increase in lumbar spine bone mineral content compared with that of a control group over an eight-month period. Forearm bone density was found to be independent of exercise in this study. Amenorrrhea observed in premenopausal female athletes running even more extreme distances may be accompanied by a decrease in mineral density of the lumbar vertebrae. We have no information on menstrual history before menopause in our subjects and cannot comment on this effect; if it occurred, it appears to have been more than compensated by the positive effects of weight-bearing exercise on bone density.

The principal methodological problem with cross-sectional studies of exercise and osteoarthritis is that of possible self-selection of subjects. It is possible that runners are more likely to be resistant to osteoarthritis, that nonrunners do not run because of early osteoarthritis, or that runners experiencing joint pain on running stop running for that reason. In

Table 4.—Lumbar Spine Roentgenograms (Mean Values)

<table>
<thead>
<tr>
<th></th>
<th>All Subjects</th>
<th>Matched Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Runners (n=65)</td>
<td>Nonrunners (n=33)</td>
</tr>
<tr>
<td>Sclerosis* Mean</td>
<td>4.2</td>
<td>3.4</td>
</tr>
<tr>
<td>SE†</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Spur* Mean</td>
<td>6.4</td>
<td>5.3</td>
</tr>
<tr>
<td>SE†</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Narrowing* Mean</td>
<td>7.0</td>
<td>6.9</td>
</tr>
<tr>
<td>SE†</td>
<td>0.2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*See text for explanation.  †The SE of differences between matched pairs is listed in parentheses below the columns making up the pairs.  ‡P<.05 (t test of matched pairs).

Table 5.—Lumbar Spine Bone Mineralization (Mean Standardized Values)*

<table>
<thead>
<tr>
<th></th>
<th>All Subjects</th>
<th>Matched Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50+ Runners (n=20)</td>
<td>Controls (n=23)</td>
</tr>
<tr>
<td>Actual scores Mean</td>
<td>129.4</td>
<td>105.6</td>
</tr>
<tr>
<td>SE†</td>
<td>6.4</td>
<td>6.0</td>
</tr>
</tbody>
</table>

*Computed tomographic scan for L-1 bone minerals.  †The SE of differences between matched pairs is listed in parentheses below the columns making up the pairs.  ‡P<.001 (t test of matched pairs).  §§P<.05 (t test of matched pairs).
this study, we attempted to minimize this potential bias by using (1) a study group that runs a great deal more than the controls and should exaggerate any differences, (2) healthy community controls unlikely to have early osteoarthritis, (3) careful matching for potentially confounding variables, and (4) use of radiologic and CT scan variables for which self-selection would seem unlikely. Both case and control groups are generally presymptomatic with regard to osteoarthritis, and are being studied prospectively from this point.

Additionally, since over one third of community controls had run at some point, it was possible to inspect the data for evidence of self-selection. Of the 25 community control group subjects who were or had been runners, 12 were not currently running. Eleven subjects stopped running for reasons clearly not associated with musculoskeletal pain. One man stopped running, after having run only a total of 50 miles in his life, because of knee pain; on examination, he had a torn cartilage of uncertain origin. Hence, we cannot at present find evidence for substantial self-selection. Prospective longitudinal studies of these same populations are under way to confirm this observation.

The role of body weight as a potential confounding variable deserves comment. Obesity has been associated with an increased prevalence of osteoarthritis of the knee.12 Aerobic exercise is associated with control of body weight, and might even protect against development of osteoarthritis through the mechanism of weight control. In this study, while the runners were leaner, the controls were not obese and did not have excess weight of the magnitude associated with increased osteoarthritis of the knee. We could find no association between body weight and joint space narrowing in the knee in our subjects. Indeed, with sclerosis and spur formation, there was actually a slight negative correlation with increased weight. Hence, we do not believe that weight differences affected these results.

Failure to find a difference with small numbers of patients does not necessarily mean that there is no difference, especially if the power of the study is insufficient to detect a difference. In general, numbers are sufficient in this study for detection of a 50% difference between groups with 80% power. Clinically, the most meaningful measurement in this study is the joint space width of the knee, measured objectively in millimeters (Table 3). Here, observed differences actually favored the runners in all groups, rendering it very unlikely that larger numbers would in fact show an association between running and knee joint space narrowing.

Our data support the role of exercise in the retardation of bone loss with aging in an area of high trabecular bone. For women, weight-bearing exercise, in addition to estrogen and calcium therapy, may retard the phenomenon of bone loss with aging. These cross-sectional data do not suggest an increase in clinical osteoarthritis or in radiologic cartilage loss in runners, even when extreme running distances are involved. Running appears, in general from these data, not to predispose to development of osteoarthritis.

We thank Sarah Carpenter for statistical and literature assistance, Ginny Wielgus and Rebecca Pecich for clerical assistance, Dee Simpson from Stanford Arthritis Center for technical assistance, and the Stanford Heart Disease Prevention Program, William Haskell, PhD, and Nathan Maccoby, PhD, for access to the Lipid Research Project participants.

References