**REVIEW**

Health benefits of tennis

Babette M Pluim, J Bart Staal, Bonita L Marks, Stuart Miller, Dave Miley

The aim of the study was to explore the role of tennis in the promotion of health and prevention of disease. The focus was on risk factors and diseases related to a sedentary lifestyle, including low fitness levels, obesity, hyperlipidaemia, hypertension, diabetes mellitus, cardiovascular disease, and osteoporosis. A literature search was undertaken to retrieve relevant articles. Structured computer searches of PubMed, Embase, and CINAHL were undertaken, along with hand searching of key journals and reference lists to locate relevant studies published up to March 2007. These had to be cohort studies (of either cross sectional or longitudinal design), case-control studies, or experimental studies. Twenty four studies were identified that dealt with physical fitness of tennis players, including 17 on intensity of play and 16 on maximum oxygen uptake; 17 investigated the relation between tennis and (risk factors for) cardiovascular disease; and 22 examined the effect of tennis on bone health. People who choose to play tennis appear to have significant health benefits, including improved aerobic fitness, a lower body fat percentage, a more favourable lipid profile, reduced risk for developing cardiovascular disease, and improved bone health.

The health benefits of exercise are well established. Research has shown that regular moderate physical activity has a beneficial effect on health and is associated with a decreased risk of diabetes and cardiovascular disease. Regular exercise has a beneficial effect on cardiovascular risk factors through many mechanisms. It improves the plasma lipid profile, reduces body weight, lowers blood pressure, increases insulin sensitivity, and improves lung function, cardiac function and cardiorespiratory fitness. In addition, exercise has a positive effect on bone health.

Recommended exercise duration and intensity have changed over time. In the early 1990s, exercise recommendations exhorted vigorous intensity exercise (for example, jogging) for at least 20 minutes continuously, three days a week, in order to reap the benefits. More recent recommendations prescribe the accumulation of at least 30 minutes of moderate intensity physical activity, almost daily, relative to the physical fitness of the individual (for example, brisk walking, cycling, or swimming). The requirement of continuous exercise has been dropped, because the benefits derived from the accumulation of shorter sessions have been shown to be equivalent to those of longer sessions as long as the total amount of energy expended is similar.

The recommended type of exercise has also received attention. Jogging, cycling, and swimming are well known to have significant health benefits, but not everyone participates in these sports. Tennis is one of the most popular sports throughout the world and is played by millions of people. Furthermore, a large majority of the people who play tennis maintain the sport throughout life. Tennis would therefore be an ideal sport to improve physical activity levels of the general population.

Although many studies have been published on the health benefits of exercise in general, it is still unclear whether there is a direct relation between improved health and playing tennis. For that reason, we undertook a systematic review to explore the health benefits of tennis in the prevention of several risk factors and major diseases that have been related to a sedentary lifestyle—that is, low fitness levels, obesity, hypertension, hyperlipidaemia, diabetes mellitus, cardiovascular disease, and osteoporosis.

**METHODS**

A literature search was undertaken to retrieve potentially relevant articles. The following electronic databases were explored: PubMed (from 1966 up to March 2007), Embase (from 1989 up to March 2007), and Cumulative Index to Nursing and Allied Health Literature (CINAHL) (from 1982 up to March 2007). A priori defined search terms (Medical subject heading (Mesh) and text words) used in this search were: “physical fitness”, “aerobic fitness”, “cardiovascular deconditioning”, “cardiovascular disease”, “heart disease”, “cardiac function”, “diabetes mellitus”, “hyperlipidaemia”, “lipid profile”, “hypercholesterolemia”, “cholesterol level”, “hypertension”, “blood pressure”, “obesity”, “body mass index”, “BMI”, “osteoporosis”, and “bone health”. Each term was combined with “tennis”. Hand searching of key journals and citation tracking of the retrieved articles was also done to identify additional relevant articles.

To be included in this review, studies had to meet the following criteria:

- they had to be cohort studies (of either cross sectional or longitudinal design), case-control studies, or experimental studies published in English or German;
- they had to contain data on the relation between playing tennis and physical fitness, cardiovascular disease, obesity, hypertension.

**Abbreviations:** BMC, bone mineral content; BMD, bone mineral density; CINAHL, Cumulative Index to Nursing and Allied Health Literature.
results of these studies indicate that singles tennis play can be
years) and 25 female (age 39 (3) years) tennis players, with
ml.kg
on cardiac size or function, 54–61 four cross sectional studies on
investigated the relation between tennis and risk factors for
Vodak et al
Cardiovascular risk factors
Exercise intensity
Physical fitness levels
Aerobic capacity
One longitudinal and 15 cross sectional studies on the \( V_{O2}\max \)
of tennis players were identified (table 2).23–30 31 32 35 39 41–47 The
mean \( V_{O2}\max \) ranged from 33.5 (5.8) to 65.9
\( (6.3) \text{ ml.kg}^{-1}.\text{min}^{-1} \), depending on age, sex, and training level,
indicating that these tennis players had high fitness levels compared with the norm for normally active controls of the
same age and sex.26–30 In the one longitudinal study,27 38 sedentary, middle aged volunteers were randomly assigned into one of four groups: bicycling (9), tennis (10), jogging (9), and control (10). Each
group exercised three times a week for 30 minutes per session
for 20 weeks. Tennis produced modest increases in endurance
capacity (5.7%), compared with cycling (14.8%) and jogging
(13.3%). The control group did not change. However, it should
be taken into account that the duration of each training session
was only 30–50% of a typical time for playing tennis.

Cardiovascular risk factors
Obesity
Vodak et al
Hyperlipidaemia
In a cross sectional study by Vodak et al,\(^4\) fasting plasma lipid and lipoprotein concentrations of 25 male and 25 female tennis players (mean age 42 years, nine years playing history) were compared with a sedentary group matched for age, sex, and education. Mean plasma high density lipoprotein (HDL) cholesterol was significantly higher in tennis players than in sedentary subjects (men, 1.39 (0.30) vs 1.17 (0.31) mmol.L\(^{-1}\)
\((p<0.001); women, 1.72 (0.22) vs 1.56 (0.29) mmol.L\(^{-1}\)
\((p = 0.02)\)). The increased plasma HDL cholesterol concentrations were independent of other factors known to alter these
lipid concentrations. Very low density lipoprotein subfractions (VLDL-C) and triglycerides were also significantly lower in the tennis players; however, total cholesterol (TC) and low density lipoprotein (LDL) cholesterol concentrations were similar to the
controls.

Ferrauti et al\(^16\) investigated the short term effects of tennis training on lipid metabolism. They studied the effects of a six
week running–intensive tennis training programme in 22

\((137 (19) \text{ mm Hg} \text{ and diastolic blood pressure was } 88 (13)
\text{ mm Hg, suggestive of pre-hypertension (blood pressure
between 120/80 and 139/89 mm Hg).}^{46} \text{ Mean systolic blood pressure during play was } 168 (19) \text{ mm Hg, with a peak systolic

Hyperension
Blood pressure was studied in 21 middle aged male tennis
players (age 50 (7) years), using a portable ambulatory blood
pressure recorder.\(^52\) Mean resting systolic blood pressure was

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pressure recorder.\(^52\) Mean resting systolic blood pressure was
### Table 1: Intensity of match play

<table>
<thead>
<tr>
<th>Reference*</th>
<th>Standard of player</th>
<th>ITN</th>
<th>Sex</th>
<th>n</th>
<th>Age (years)</th>
<th>Mean HR during play (beats/min)</th>
<th>HR_{max} exercise test (beats/min)</th>
<th>% HR max</th>
<th>Lactate (mmol.l⁻¹)</th>
<th>Surface</th>
<th>V_{O2} mean during play (ml.kg⁻¹.min⁻¹)</th>
<th>V_{O2} max exercise test (ml.kg⁻¹.min⁻¹)</th>
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<tbody>
<tr>
<td><strong>Juniors</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>Girard et al²³</td>
<td>Club</td>
<td>6</td>
<td>M</td>
<td>7</td>
<td>15 (2)</td>
<td>182 (1.2)</td>
<td>201 (9)</td>
<td>90 (5)</td>
<td>2.36 (0.47)</td>
<td>Clay</td>
<td>40.3 (5.7)</td>
<td>50.3 (3.9)</td>
</tr>
<tr>
<td>Girard et al²³</td>
<td>M/F</td>
<td>18</td>
<td>M</td>
<td>7</td>
<td>15 (2)</td>
<td>173 (1.7)</td>
<td>201 (9)</td>
<td>86 (6)</td>
<td>3.08 (1.12)</td>
<td>Hard court</td>
<td>35.9 (7.5)</td>
<td>50.3 (3.9)</td>
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<td>Weber²⁴</td>
<td>Competitive</td>
<td>4</td>
<td>M</td>
<td>18</td>
<td>12.6 (1.2)</td>
<td>172 (6)</td>
<td>nr</td>
<td>nr</td>
<td>1.41 (0.63)</td>
<td>Carpet</td>
<td>nr</td>
<td>nr</td>
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<tr>
<td>Fernandez et al²⁰</td>
<td>International</td>
<td>3</td>
<td>M</td>
<td>6</td>
<td>18.3 (2.5)</td>
<td>146 (20)</td>
<td>78</td>
<td>2.07 (0.88)</td>
<td>Clay</td>
<td>nr</td>
<td>29.1 (5.6)</td>
<td>57.3 (5.1)</td>
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<td>Novas et al²⁶</td>
<td>State, national</td>
<td>6</td>
<td>F</td>
<td>6</td>
<td>23.4 (3.1)</td>
<td>146 (19)</td>
<td>76</td>
<td>nr</td>
<td>2.3 (1.2)</td>
<td>Carpet</td>
<td>nr</td>
<td>nr</td>
</tr>
<tr>
<td>Smekal et al²⁷</td>
<td>Top league</td>
<td>3–4</td>
<td>M/F</td>
<td>20</td>
<td>26 (4)</td>
<td>151 (19)</td>
<td>191 (11)</td>
<td>76</td>
<td>nr</td>
<td>Wood</td>
<td>nr</td>
<td>nr</td>
</tr>
<tr>
<td>Bernardi et al²⁹</td>
<td>Intermediate</td>
<td>4–5</td>
<td>M</td>
<td>7</td>
<td>28.1 (3)</td>
<td>147 (9)</td>
<td>190 (5)</td>
<td>nr</td>
<td>1.76 (0.3)</td>
<td>Clay</td>
<td>nr</td>
<td>nr</td>
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<tr>
<td>Christmoss et al²⁸</td>
<td>State</td>
<td>3</td>
<td>M</td>
<td>7</td>
<td>24 (2)</td>
<td>nr</td>
<td>nr</td>
<td>nr</td>
<td>2.11 (0.77)</td>
<td>Carpet</td>
<td>nr</td>
<td>nr</td>
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<tr>
<td>Christmoss et al²⁸</td>
<td>State</td>
<td>3</td>
<td>M</td>
<td>8</td>
<td>23 (1)</td>
<td>147 (11)</td>
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<td>nr</td>
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<td>Carpet</td>
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<td>nr</td>
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<td>Reilly et al³⁰</td>
<td>Top club</td>
<td>4</td>
<td>M</td>
<td>8</td>
<td>23.4 (3.1)</td>
<td>146 (19)</td>
<td>nr</td>
<td>nr</td>
<td>1.92 (0.56)</td>
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<td>nr</td>
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<tr>
<td>Bernardi et al²⁹</td>
<td>Intermediate</td>
<td>4–5</td>
<td>F</td>
<td>9</td>
<td>21.2 (1.9)</td>
<td>157 (3)</td>
<td>190 (3)</td>
<td>82</td>
<td>1.76 (0.3)</td>
<td>Clay</td>
<td>nr</td>
<td>nr</td>
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<td>University</td>
<td>4</td>
<td>M</td>
<td>10</td>
<td>20.3 (2.5)</td>
<td>145 (1)</td>
<td>196 (6)</td>
<td>74</td>
<td>1.76 (0.3)</td>
<td>Clay</td>
<td>nr</td>
<td>nr</td>
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<td>Therminarias et al²³</td>
<td>Intermediate</td>
<td>4–5</td>
<td>F</td>
<td>9</td>
<td>31.4 (7.3)</td>
<td>154 (17)</td>
<td>188 (11)</td>
<td>82</td>
<td>1.76 (0.3)</td>
<td>Clay</td>
<td>nr</td>
<td>nr</td>
</tr>
<tr>
<td>Morgans et al³⁴</td>
<td>Intermediate to advanced</td>
<td>4–5</td>
<td>M</td>
<td>17</td>
<td>31.4 (7.3)</td>
<td>154 (17)</td>
<td>188 (11)</td>
<td>82</td>
<td>1.76 (0.3)</td>
<td>Hard court</td>
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<td>65.9 (6.3)</td>
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<td>Elliot et al³⁵</td>
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<td>M</td>
<td>8</td>
<td>20.3 (1.3)</td>
<td>153 (3)</td>
<td>192 (11)</td>
<td>79</td>
<td>nr</td>
<td>Hard court</td>
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<td>65.9 (6.3)</td>
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<td>Docherty³⁶</td>
<td>Low to high</td>
<td>4–9</td>
<td>M</td>
<td>42</td>
<td>25 (5)</td>
<td>150 (10)</td>
<td>nr</td>
<td>70</td>
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<td>Kindermann et al³⁷</td>
<td>Wall trained</td>
<td>4–5</td>
<td>M</td>
<td>12</td>
<td>32.2 (8.5)</td>
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<td>nr</td>
<td>nr</td>
<td>2.0 (0.5)</td>
<td>Unknown</td>
<td>nr</td>
<td>nr</td>
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<tr>
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<td>Top level</td>
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<td>M</td>
<td>16</td>
<td>24.7 (3.7)</td>
<td>143</td>
<td>nr</td>
<td>nr</td>
<td>2.0 (0.5)</td>
<td>Indoor court</td>
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<td><strong>35 years and over</strong></td>
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<tr>
<td>Ferrauti et al³⁹</td>
<td>National</td>
<td>2–3</td>
<td>M</td>
<td>6</td>
<td>47 (5.4)</td>
<td>142.5 (12.7)</td>
<td>nr</td>
<td>nr</td>
<td>1.24 (0.37)</td>
<td>Clay</td>
<td>25.6 (2.8)</td>
<td>47.5 (4.3)</td>
</tr>
<tr>
<td>Ferrauti et al³⁹</td>
<td>National</td>
<td>2–3</td>
<td>F</td>
<td>6</td>
<td>47.2 (6.6)</td>
<td>141.5 (18.9)</td>
<td>nr</td>
<td>nr</td>
<td>1.67 (0.49)</td>
<td>Clay</td>
<td>23.1 (3.1)</td>
<td>41.4 (6.0)</td>
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<td>Therminarias et al³², ³³</td>
<td>Intermediate</td>
<td>4–5</td>
<td>F</td>
<td>10</td>
<td>46.5 (1.3)</td>
<td>156 (4)</td>
<td>175 (2)</td>
<td>89</td>
<td>1.79 (0.29)</td>
<td>Clay</td>
<td>nr</td>
<td>nr</td>
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<tr>
<td>Weber²⁴</td>
<td>Competitive</td>
<td>4</td>
<td>M/F</td>
<td>12</td>
<td>50.4 (4.9)</td>
<td>154 (1)</td>
<td>nr</td>
<td>nr</td>
<td>2.82 (0.92)</td>
<td>Carpet</td>
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<tr>
<td>Therminarias et al³², ³³</td>
<td>Recreational</td>
<td>6–7</td>
<td>M/F</td>
<td>18</td>
<td>54.3 (6.1)</td>
<td>141 (16)</td>
<td>nr</td>
<td>nr</td>
<td>2.67 (0.96)</td>
<td>Carpet</td>
<td>nr</td>
<td>nr</td>
</tr>
</tbody>
</table>

Values are mean (SD).

*First author and reference number.

F, female; HR, heart rate; HR_{max}, maximum heart rate; ITN, international tennis number; M, male; n, number of subjects; nr, not reported.
Pressure of 198 (30) mm Hg. Mean diastolic blood pressure during play decreased to 82 (16) mm Hg.

Swank et al. studied 28 elite senior male tennis players (21 years of tennis play) and 18 moderately active age matched controls and found no significant difference between groups in either systolic or diastolic blood pressure values (40 to 59 years: systolic blood pressure (SBP) = 121 (10) v 124 (14) mm Hg, diastolic blood pressure (DBP) = 78 (10) v 79 (10) mm Hg; 60+ years: SBP = 136 (10) v 135 (14), DBP = 82 (7) v 81 (7) mm Hg).

Diabetes mellitus
Nessler undertook a longitudinal study of 12 patients (seven men, mean age 62 (4) years and five women, mean age 60 (4) years) with type II diabetes at the Sports University of Cologne. The untrained beginners played tennis twice a week with a modified ball for six weeks; training sessions lasted 90 minutes. There were small but significant changes occurred in baseline glucose levels, or free fatty acids. There were small but significant increases in plasma insulin (10.3 (3.8) v 13.9 (5.7) μE/ml, p = 0.026) and c-peptide production (3.5 (1.0) v 4.7 (1.4 nmolL−1), p = 0.001). The mean glucose concentration (mean of 12 participants measured before and after 12 training sessions) fell from 188.0 (72.7) mg/dl before to 156.7 (52.2) mg/dl after 90 minutes of training (p = 0.001).

Cardiovascular disease

Heart size
Eight studies examined the cardiac dimensions of elite tennis players. Increased heart size and increased performance capacity were noted regardless of sex. Systolic and diastolic function were within normal limits. Morbidity and mortality
Houston et al. studied 1019 male students between 1948 and 1964. After a standard physical examination, the students were asked to rate their ability in tennis, golf, football, baseball, and basketball during medical school and earlier. The researchers assessed the participants’ physical activities an average of 22 and 40 years later. Tennis was the only sport in which a greater ability during medical school was associated with a lower risk of cardiovascular disease. After adjustment for confounding variables, the relative risk of developing cardiovascular disease was 0.5 (95% confidence interval (CI), 0.3 to 0.8) in the high ability group and 0.67 (0.47 to 0.96) in the low ability group, compared with the no ability group. A primary factor for this beneficial health profile may be that tennis was the sport played most often through mid-life. Half the tennis players were still participating in the sport in mid-life, compared with only a quarter of those who reported playing golf and none who reported playing baseball, basketball, or football.

Osteoporosis
Twenty two studies (23 articles) were identified that examined the effects of tennis play on bone health. Generally, the bone mineral content (BMC) and bone density (BMD) were shown to be consistently greater in the dominant (playing) arm than in the non-dominant arm. Also, BMC and BMD were greater in the hip and lumbar spine regions of tennis players than in controls, and exercise induced bone gain was greater in young than in old starters. Table 3 provides more specific information on the effect of tennis on bone health.

DISCUSSION
The general findings of this review indicate that those who choose to play tennis appear to have positive health benefits. Specifically, lower body fat percentages, more favourable lipid profiles, and enhanced aerobic fitness contributed to an overall improved risk profile for cardiovascular morbidity. Furthermore, numerous studies have identified better bone health not only in tennis players with lifelong tennis participation histories, but also in those who take on the sport in mid-adulthood.

A limitation of this review is the small number of studies with a longitudinal design. For example, of the 17 studies
<table>
<thead>
<tr>
<th>Reference*</th>
<th>Design</th>
<th>Study population</th>
<th>Method</th>
<th>Main results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ducher et al 85</td>
<td>XS</td>
<td>28 young (22 boys, 6 girls, 11.6 (1.4) y) and 47 adult tennis players (23 M, 24 F, 22.3 (2.7) y), and 70 age-matched controls (12 children (12.2 (1.6) y) and 58 adults (23.3 (3.2) y))</td>
<td>DXA</td>
<td>At the ultradistal radius, asymmetry in BMC in young and adult tennis players was 16.3% and 13.8%, respectively (p &lt; 0.0001). At the mid- and distal-thoracic radius, asymmetry was much greater in adults than in children (p &lt; 0.0001) for BMC (mid-thoracic radius, +6.6% v +15.6%; distal-thoracic radius +6.9% v +13.3%).</td>
</tr>
<tr>
<td>Ducher et al 82</td>
<td>XS</td>
<td>52 tennis players (24.2 (5.8) y), 16.2 (6.1) y of practice</td>
<td>DXA</td>
<td>Lean tissue mass, bone area, BMC, and BMD of the dominant forearm were significantly (p &lt; 0.0001) greater. Bone area and BMC correlated with grip strength on both sides (r = 0.81–0.84, p &lt; 0.0001). Significant side-to-side differences (p &lt; 0.0001) were found in muscle volume (+9.7%), grip strength (+13.3%), BMC (+13.5%), total bone volume (+10.3%), and subcortical volume (+20.6%), but not in cortical volume (+2.6%, NS). The asymmetry in total bone volume explained 75% of the variance in BMC asymmetry (p &lt; 0.0001). Volumetric BMD was slightly higher on the dominant side (+3.3%, p &lt; 0.05). Grip strength and muscle volume correlated with all bone variables (except volumetric BMD) on both sides (r = 0.48–0.86, p &lt; 0.005–0.0001) but the asymmetries in muscle indices did not correlate with those in bone indices.</td>
</tr>
</tbody>
</table>
| Ducher et al 86 | XS | 57 regional level tennis players (33 M, 24 F). All had been practising tennis for at least 5 years | DXA | At the ultradistal radius, the side-to-side difference in BMC was larger than in bone area (8.4 (5.2%) and 4.9 (4.0%), respectively, p < 0.01). In the cortical sites, the asymmetry was lower (p < 0.01) in BMD than in bone area (mid-thoracic radius: 4.0 (4.3%) v 11.7 (6.8%); distal-thoracic radius: 5.0 (4.8%) v 8.4 (6.2%).)
| Sanchis-Moysi et al 66 | 10 F postmenopausal tennis players (60 (5) y) and 12 postmenopausal controls (63 (7) y). Tennis players started at 31 (9) y and had been playing for 27 (7) y, at least 3 h/wk. | DXA | Tennis players showed 8% greater BMC and 7% greater osseous area in the dominant than in the non-dominant arm (p < 0.05). There was a positive correlation between duration of tennis participation and inter-arm asymmetry in BMC (r = 0.81, p < 0.01) and bone area (r = 0.78, p < 0.01). |
| Sanchis-Moysi et al 65 | XS | 17 M tennis players (55 (2) y), 9 F tennis players (61 (1) y), 15 M (56 (3) y) and 20 F (62 (2) y) control subjects. Mean tennis participation was 27 (7) y, 3 h/wk. | DXA | Male tennis players had a 16% higher BMC and 10% BMD in legs than controls (p < 0.05). 10–30% greater BMC and BMD were observed in the hip region and lumbar spine (L2-L4) of players v controls (p < 0.05). |
| Kontulainen et al 80 | XS | 36 young F Finnish tennis/squash players (22 (8) y), mean starting age 11 (2) y, and 28 older F players (39 (11) y, mean starting age 26 (6) y), and 27 controls (29 (10) y). Young starters reduced training from 4.7 (2.7) to 1.4 (3.3) times/wk; old starters from 4.0 (1.4) to 2.0 (1.4) times/wk. | pQCT, DXA | The side-to-side differences in the young starters bone mineral content, cortical area, total cross sectional area of bone, and cortical wall thickness were 8–22% higher than those of controls and 8–14% higher than those of old starters.
| Nara-Ashizawa et al 66 | XS | 92 middle aged F tennis players (46 (5) y) who initiated training after bone had matured (mean starting age 36 (3) y). | DXA | Endocortical area (0.278 (0.094) v 0.300 (0.106) cm²), peristomial area (1.007 (0.14) v 1.061 (0.15) cm²), BMC (0.141 (0.017) v 0.147 (0.017) g), moment of inertia (1598 (412) v 1744 (460) mm⁴), section modulus (219 (41) v 233 (44) mm³), and SM (252 (66) v 276 (71) mm³) of dominant midradius were greater (p < 0.01) than in the non-dominant radius. BMD of trabecular bone (0.383 (0.060) v 0.363 (0.070) g/cm³, p < 0.05) and whole bone (0.756 (0.115) v 0.656 (0.120) g/cm³, p < 0.01) at the dominant distal radius were greater than in the non-dominant radius. Bone gain was 1.3–2.2 times greater in favour of young starters: The difference in BMC of humeral shaft in dominant v non-dominant arm was 22 (8.4%) in young starters v 10 (3.8%) in old starters at follow up. |
| Kontulainen et al 64 | PC; 5-y follow up | 36 young F Finnish tennis/squash players (22 (8) y), mean starting age 11 (2) y, and 28 older female players (39 (11) y, mean starting age 26 (8) y), and 27 controls (29 (10) y). Young starters reduced training from 4.7 (2.7) to 1.4 (3.3) times/wk; old starters from 4.0 (1.4) to 2.0 (1.4) times/wk. | DXA | Among the players significant side-to-side differences (p < 0.05) in favour of the dominant arm were found in BMC, total area, cortical area, and bone strength index at the proximal humerus, humeral shaft, distal humerus, radial shaft, and distal radius. Increased bone strength was mainly due to increased bone size and not to a change in volumetric bone density. Relative side-to-side BMC differences were significantly (p < 0.001) larger in players v controls at all measured sites in both 1992 and 1996 for proximal humerus (1992: 18.5% v 14.4%; 1996: 18.4% v 0.5%), humeral shaft (1992: 25.2% v 4.7%; 1996: 25.9% v 4.5%), radial shaft (1992: 13.9% v 1.8%; 1996: 14.2% v 2.1%), and distal radius (1992: 13.2% v 2.0%; 1996: 13.2% v 2.5%).
| Haapasalo et al 69 | XS | 12 M former Finnish national level tennis players (30 (5) y) and 12 age, height, and weight matched controls | pQCT | Players had an increase in total BMC (13.3%, p < 0.001), peristomial bone area (15.2%, p < 0.001), cortical BMC (12.6%, p < 0.001), and cortical bone area (13.5%, p < 0.01) in the playing arm v the non-playing arm. In controls, side-to-side differences in these variables were not significant. In the distal radius, total BMC (13.8%, p < 0.01), peristomial bone area (6.8%, p < 0.05), trabecular bone area (6.8%, p < 0.05), and trabecular BMD (5.8%, p < 0.05) of the playing arm were greater than in the non-playing arm. In controls, significant side-to-side differences were not found in any measured variables. |
| Kontulainen et al 63 | PC; 4-y follow up | 13 M former competitive tennis players (26 (5) y) who started their career at a mean age of 11 y and 13 controls (26 (6) y). The players had all retired from top tennis before (mean 2.3 (0.6) y) follow up | DXA | |
Table 3 Continued

<table>
<thead>
<tr>
<th>Reference</th>
<th>Design</th>
<th>Study population</th>
<th>Method</th>
<th>Main results</th>
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<tr>
<td>Haapasalo et al</td>
<td>XS</td>
<td>91–7–17 y F tennis players and 58 healthy F controls. In each Tanner stage, differences in BMD in playing and non-playing arms and lumbosacral spine were compared between the players and controls</td>
<td>DXA</td>
<td>In players, BMD inter-arm differences were significant (p&lt;0.05 to &lt;0.001) in all Tanner stages, with mean differences ranging from 1.6% to 15.7%. Mean arm differences between players and controls did not become obvious until Tanner stage III (mean age 12.6 y). In the lumbar spine differences were not found until Tanner stage IV (mean age 13.5 y, 0.97 (0.13) g/cm², p&lt;0.05) and Tanner stage V (mean age 15.5 y, 1.08 (0.105) g/cm², p&lt;0.05). Total mass (4777 (908) vs 4220 (632) g), lean mass (3772 (500) vs 3246 (421) g), p&lt;0.001, and BMC (229 (43.5) vs 194 (33) g) were greater in the dominant arm of tennis players than in controls (all p&lt;0.05). BMD was increased in tennis players vs controls in the lumbar spine (1.25 (0.29) v 1.19 (0.12) g/cm², p&lt;0.09) and in the trochanteric region (0.94 (0.11) v 0.80 (0.07) g/cm², p&lt;0.001). There were significant side-to-side humeral length differences in young M players (+1.4%), young F controls (+1.1%), and older F players (+0.7%). Relative side-to-side differences in BMC (range +7.6 to +25.2%, BMD +5.8% to +22.5%, cortical wall thickness +6.9% to +45.2%, cross sectional moment of inertia +7.8% to +26.4%, and section modulus +3.0% to +21.7%) were significantly larger in players than in controls at the proximal, mid, and distal part of the humerus. Relative side-to-side differences were significantly larger in young (range +11.7% to +45.2%) than in older players (range +3.0% to +12.4%). Examinations were performed by ultrasound and dual energy absorptiometry.</td>
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<tr>
<td>Etherington &amp; Krahl</td>
<td>XS</td>
<td>16 former tennis players (aged 40–65 y), 67 former middle and long distance runners and 585 age matched controls</td>
<td>DXA</td>
<td>There was a significant positive relation was found between mid-racial (0.07) g/cm²) and grip strength (31.2 (4.1) kg) in the dominant forearm of tennis players (r=0.43, p&lt;0.05). There was a significant difference between mid-racial BMD in the dominant (range 0.63–0.87 g/cm²) and non-dominant arm (range 0.52–0.57 g/cm², p&lt;0.05). The players had a larger (p&lt;0.001) side-to-side difference in BMD for proximal humerus (1.42 (1.33) v 1.01 (1.08) g), humeral shaft (2.77 (2.20) v 1.57 (1.68) g), radial shaft (0.32 (0.47) v 0.12 (0.40) g), and distal radius (0.32 (0.38) v 0.11 (0.28) g). Differences were two to four times greater in players who started before or at menarche than 15 years after menarche.</td>
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<tr>
<td>Tsuji et al</td>
<td>XS</td>
<td>10 M college wrestlers (20 (1) y), 16 female college basketball players (20 (1) y), and 12 F college tennis players (21 (1) y)</td>
<td>DXA</td>
<td>There was a significant positive relation was found between mid-racial (0.07) g/cm²) and grip strength (31.2 (4.1) kg) in the dominant forearm of tennis players (r=0.43, p&lt;0.05). There was a significant difference between mid-racial BMD in the dominant (range 0.63–0.87 g/cm²) and non-dominant arm (range 0.52–0.57 g/cm², p&lt;0.05). The players had a larger (p&lt;0.001) side-to-side difference in BMD for proximal humerus (1.42 (1.33) v 1.01 (1.08) g), humeral shaft (2.77 (2.20) v 1.57 (1.68) g), radial shaft (0.32 (0.47) v 0.12 (0.40) g), and distal radius (0.32 (0.38) v 0.11 (0.28) g). Differences were two to four times greater in players who started before or at menarche than 15 years after menarche.</td>
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<td>Kannus et al</td>
<td>XS</td>
<td>16 former tennis players (aged 40–65 y), 67 former middle and long distance runners and 585 age matched controls</td>
<td>DXA</td>
<td>There was a significant positive relation was found between mid-racial (0.07) g/cm²) and grip strength (31.2 (4.1) kg) in the dominant forearm of tennis players (r=0.43, p&lt;0.05). There was a significant difference between mid-racial BMD in the dominant (range 0.63–0.87 g/cm²) and non-dominant arm (range 0.52–0.57 g/cm², p&lt;0.05). The players had a larger (p&lt;0.001) side-to-side difference in BMD for proximal humerus (1.42 (1.33) v 1.01 (1.08) g), humeral shaft (2.77 (2.20) v 1.57 (1.68) g), radial shaft (0.32 (0.47) v 0.12 (0.40) g), and distal radius (0.32 (0.38) v 0.11 (0.28) g). Differences were two to four times greater in players who started before or at menarche than 15 years after menarche.</td>
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<td>Krahl et al</td>
<td>XS</td>
<td>20 highly ranked professional tennis players (12 M, 8 F, 20 (4.5) y), and 12 controls (7 M, 5 F, 23 (4.7) y)</td>
<td>x ray</td>
<td>Relative side-to-side differences were significantly increased in players vs controls for humeral shaft (BMD 0.09 (0.09) v 0.03 (0.10) g/cm², BMC 0.61 (0.28) v 1.06 (0.39) g, p&lt;0.001) and proximal humerus (BMD 0.12 (0.08) v 0.01 (0.10) g/cm², BMC 2.38 (1.8) v 0.28 (1.7) g, p&lt;0.001). Relative side-to-side differences were significantly increased in tennis players vs controls for humeral diameter (2.1 ± 0.02 mm, p&lt;0.01), ulnar length (8.17 ± 0.01 mm, p&lt;0.01), second metacarpal diameter (0.9 ± 0.0 mm, p&lt;0.01), and second metacarpal length (2.7 ± 0.0 mm, p&lt;0.01).</td>
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<tr>
<td>Jacobson &amp; Krahl</td>
<td>XS</td>
<td>11 college tennis players, 23 swimmers, and 86 older athletic F aged 23 to 75 y and age matched non-athletic controls.</td>
<td>Single and dual photon densitometry</td>
<td>Relative side-to-side differences were significantly increased in tennis players vs controls for humeral shaft (BMD 0.09 (0.09) v 0.03 (0.10) g/cm², BMC 0.61 (0.28) v 1.06 (0.39) g, p&lt;0.001) and proximal humerus (BMD 0.12 (0.08) v 0.01 (0.10) g/cm², BMC 2.38 (1.8) v 0.28 (1.7) g, p&lt;0.001). Relative side-to-side differences were significantly increased in tennis players vs controls for humeral diameter (2.1 ± 0.02 mm, p&lt;0.01), ulnar length (8.17 ± 0.01 mm, p&lt;0.01), second metacarpal diameter (0.9 ± 0.0 mm, p&lt;0.01), and second metacarpal length (2.7 ± 0.0 mm, p&lt;0.01).</td>
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<td>Huddleston</td>
<td>XS</td>
<td>35 active M tennis players were studied during the 1978 USTA’s 70+, 75+, and 80+y age group clay court championship (21 aged 70–74 y, 9 aged 75–79 y, 5 aged 80–84 y</td>
<td>Transmission scanning with a low energy x-ray beam</td>
<td>There were significant side-to-side humeral length differences in young M players (+1.4%), young F controls (+1.1%), and older F players (+0.7%). Relative side-to-side differences in BMC (range +7.6 to +25.2%, BMD +5.8% to +22.5%, cortical wall thickness +6.9% to +45.2%, cross sectional moment of inertia +7.8% to +26.4%, and section modulus +3.0% to +21.7%) were significantly larger in players than in controls at the proximal, mid, and distal part of the humerus. Relative side-to-side differences were significantly larger in young (range +11.7% to +45.2%) than in older players (range +3.0% to +12.4%). Examinations were performed by ultrasound and dual energy absorptiometry.</td>
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*First author and year of publication.

BMC, bone mineral content; BMD, bone mineral density; CI, confidence interval; DXA, dual energy x-ray absorptiometry; F, female; M, male; PCS, prospective cohort study; pQCT, peripheral quantitative computed tomography; wk, week; XS, cross sectional study; y, years.
The lower body fat percentage of tennis players compared with less active controls is an important finding because obesity has become a “global epidemic”, with more than one billion adults overweight (body mass index (BMI) >25) and at least 300 million of them clinically obese (BMI >30). This review shows that tennis is associated with increased plasma HDL cholesterol. Even though more than 200 risk factors for coronary heart disease have now been identified, the single most powerful predictor is hyperlipidaemia. It is also a significant one—more than half the cases of heart disease are attributable to lipid abnormalities. The higher HDL cholesterol concentrations associated with a lower risk of cardiovascular disease implies that playing tennis may be at reduced risk of cardiovascular events.

The results of the study by Vodak et al indicate that blood pressure response during tennis play is comparable to the response to an acute bout of moderate intensity dynamic exercise. Unfortunately, no longitudinal studies on the long term effect of tennis on blood pressure were identified and further studies are warranted.

Studies retrieved in this review unanimously showed that tennis was related to healthier bone structure in both sexes and across the age spectrum. The association depended on the duration of tennis participation and training frequency, being stronger in young starters than in old starters, but was maintained despite decreased tennis participation. This was most clearly present in load bearing bones such as the humerus of the dominant arm, lumbar spine, and femoral neck. These findings support the exercise recommendations described in the American College of Sports Medicine (ACSM) position stand on “Physical activity and bone health”, which recommends 20 to 40 minutes of weight bearing endurance activities, such as tennis, at least three times a week to augment bone mineral accretion in children and adolescents, and 30 to 60 minutes of these activities at least three times a week to preserve bone health during adulthood.

Playing tennis on a regular basis (two to three times a week), either singles or doubles, meets the exercise recommendations of the ACSM and American Heart Association (AHA). Reported mean heart rates during singles tennis ranged from 70% to 90% of maximum heart rate, and mean oxygen consumption ranged from 50% to 80% of VO2max. Moderate intensity activities are those done at a relative intensity of 40% to 60% of VO2max (60–75% of maximum heart rate), whereas vigorous intensity activities are those done at a relative intensity of >60% of VO2max (>75% maximum heart rate). Thus exercise intensity during singles tennis play is high enough to categorise it as a moderate to vigorous intensity sport. This is supported by the findings that tennis players display an above average maximal oxygen uptake compared with normally active populations of the same age and sex.

In doubles play, heart rate and VO2 tend to be lower than during singles play. However, it is not the absolute intensity of the exercise that is relevant, but rather the intensity relative to the physical capacity of the individual. This means that, while singles play may be necessary to result in health benefits for the younger player, doubles play may be sufficient for the middle aged or senior tennis player, because their maximum heart rate and VO2max are decreased. Doubles play is therefore particularly suitable for these categories. This has the added benefit that it increases the chance that those who play tennis are likely to maintain the sport when they grow older. Hence, the positive effects are maintained. In order for exercise to exert a positive effect, one has to embrace lifelong exercise patterns. The positive effects of sustained physical activity were demonstrated by Houston et al. who found that the association of high ability in tennis during college and a reduced risk of cardiovascular disease in later life was at least partly mediated through continued participation in tennis.

CONCLUSIONS AND RECOMMENDATIONS
A positive association has been shown between regular tennis participation and positive health benefits, including improved aerobic fitness, a leaner body, a more favourable lipid profile, improved bone health, and a reduced risk of cardiovascular morbidity and mortality. Exercise intensity during tennis play meets the exercise recommendations of the ACSM and AHA, and playing tennis regularly will contribute to improved fitness levels. In addition, long term tennis play leads to increased bone mineral density and bone mineral content of the playing arm, lumbar spine, and legs. However, further longitudinal studies with appropriate adjustment for confounding variables and self selection are warranted, to determine whether the positive association between a leaner body, a more favourable lipid profile, and a reduced risk of cardiovascular morbidity and mortality and tennis is an indication of the health benefits of tennis, or the effect of self selection and a healthier lifestyle of tennis players.

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What is already known on this topic
- Regular moderate physical activity has a beneficial effect on health and is associated with a decreased risk of cardiovascular disease and diabetes and a positive effect on bone health.
- Recommendations prescribe the accumulation of at least 30 minutes of moderate intensity physical activity, almost daily, relative to the physical fitness of the individual.

What this study adds
- This study specifically focuses on the relation between tennis and risk factors and diseases related to a sedentary lifestyle.
- There is a positive association between regular tennis participation and health benefits, including improved aerobic fitness, a leaner body, a more favourable lipid profile, improved bone health, and a reduced risk of cardiovascular morbidity and mortality.

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