REVIEW

Health benefits of tennis

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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.

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The health benefits of exercise are well established. Research has shown that regular moderate physical activity has a beneficial effect on health[1] and is associated with a decreased risk of diabetes[2–4] and cardiovascular disease.[5–8] Regular exercise has a beneficial effect on cardiovascular risk factors through many mechanisms. It improves the plasma lipid profile,[9 10] reduces body weight,[11] lowers blood pressure,[9 12] increases insulin sensitivity,[13 14] and improves lung function,[15] cardiac function[16 17] and cardiorespiratory fitness.[16 17] In addition, exercise has a positive effect on bone health.[18]

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.[19 20] 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).[21 22] 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.[6]

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", "hyperlipidemia", "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 hyperlipidaemia, diabetes mellitus, and osteoporosis, or between playing tennis and the occurrence of health benefits in patients who suffer from these diseases.

The most important results of the identified studies were summarised and categorised according to the aforementioned categories. Studies on the prevention or treatment of sports injuries and literature reviews were excluded.

RESULTS

Our results in the PubMed, Embase, and CINAHL databases resulted in, respectively, 191, 179, and 382 potentially relevant papers. Papers were included when the content was felt to be appropriate by two independent reviewers. In case of disagreement, further discussion was undertaken to achieve consensus.

Twenty four studies (25 articles) were identified that contained data on physical fitness of tennis players.[23–47] Seventeen studies (18 articles) provided information on intensity of play,[23–40] and 16 studies contained data on maximum oxygen uptake of tennis players.[26–31, 34, 35, 39, 41–47] Seventeen studies[45, 47–62] were found that investigated the relation between tennis and risk factors for cardiovascular disease and included eight cross sectional studies on cardiac size or function,[54–61] four cross sectional studies on obesity,[45, 47, 50, 51] two cross sectional studies[47, 49] and one longitudinal study[48] on hyperlipidaemia, two cross sectional studies on hypertension,[47, 52] one longitudinal study on diabetes,[53] and one longitudinal study on cardiovascular morbidity and mortality.[62] Twenty two studies (two longitudinal[63, 64] and 20 cross sectional[65–85]) were retrieved that examined the effect of tennis on bone health.

Physical fitness levels

Exercise intensity

In 17 studies the intensity of match play was examined using heart rate recordings[23–39] or maximum oxygen uptake ($\dot{V}O_2$max), or both[23, 26, 27, 39, 40] during play (table 1). Mean (SD) heart rate during singles play ranged from 141 (16) to 182 (12) beats/minute, equating to 70–90% of maximum heart rate. Mean oxygen consumption during play ranged from 23.1 (3.1) to 40.3 (5.7) ml.kg^{-1}.min^{-1}, reflecting 50% to 80% of $\dot{V}O_2$max. Mean lactate levels during play were generally 2 to 3 mmol.l^{-1}; however, one investigator reported levels as high as 6 mmol.l^{-1}.[28] The results of these studies indicate that singles tennis play can be categorised as vigorous intensity exercise (>6 Mets).

Aerobic capacity

One longitudinal and 15 cross sectional studies on the $\dot{V}O_2$max of tennis players were identified (table 2).[26–31, 34, 35, 39, 41–47] The mean $\dot{V}O_2$max ranged from 35.5 (5.8) to 65.9 (6.3) ml.kg^{-1}.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.[86, 87]

In the one longitudinal study,[46] 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*[45] found below average body fat in 25 male (age 42 (6) years) and 25 female (age 39 (3) years) tennis players, with mean values of 16.3% and 20.3% for men and women. Schneider and Greenberg (n = 7248; 18–34 year old Americans),[50] showed that runners/joggers/fast walkers and tennis players were less likely to be obese, smoke, consume large quantities of alcohol, or drive without seat belts than those who participate in team sports and an aggregate of other sports.

Further evidence of an association between below average body fat and tennis was provided by Swank *et al*,[47] who found that elite male veteran tennis players had significantly less fat than an age matched active control group ($p \leqslant 0.05$). Both the younger veterans (aged 40 to 59) and the older veterans (over 60) were on average 3% leaner than the non-tennis-playing moderately active controls (17–20.5% *v* 21–25%, respectively).

Finally, LaForest *et al*[51] studied recreational tennis players who had played twice a week for the previous ten years. Mean body fat percentage of the tennis players (aged 23 to 69 years) was significantly lower than the body fat of the age matched controls (20.4% *v* 23.9%, $p<0.05$).

Hyperlipidaemia

In a cross sectional study by Vodak *et al*,[49] 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) *v* 1.17 (0.31) mmol.l^{-1} ($p<0.001$); women, 1.72 (0.22) *v* 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*[48] 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 veteran players (11 men and 11 women aged 43 to 47 years) and compared these with 16 control subjects who continued their usual (tennis) habits. They found slight increases in HDL$_2$ cholesterol as well as small decreases in HDL$_3$ cholesterol, LDL cholesterol, and triglycerides. Despite the overall positive improvement of the lipid profile, the changes were not significantly different from the control group, possibly because of the limited number of subjects and the relatively short duration of the study.

Finally, Swank *et al*[47] studied 28 elite senior male tennis players (aged 40 to 60+ years) who had participated in tennis for an average of 21 years, and 18 moderately active age matched controls. There were no significant differences between tennis players and the control group for total cholesterol, LDL cholesterol, HDL cholesterol, total cholesterol/HDL cholesterol ratio and triglycerides. However, the tennis players in the 40 to 59 year old age group had an average HDL cholesterol of 0.21 mmol greater than an age matched control group. Furthermore, tennis players in the 60+ year old age group had an average HDL cholesterol 0.06 mmol greater than their age matched control group.

Hypertension

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

Table 1 Intensity of match play

Reference*	Standard of player	ITN	Sex	n	Age (years)	Mean HR during play (beats/min)	HR$_{max}$ exercise test (beats/min)	% HR max	Lactate (mmol.l^{-1})	Surface	$\dot{V}O_2$ mean during play (ml.kg^{-1}.min^{-1})	$\dot{V}O_2$max exercise test (ml.kg^{-1}.min^{-1})
Juniors												
Girard *et al*[23]	Club	6	M	7	15 (2)	182 (12)	201 (9)	90 (5)	2.36 (0.47)	Clay	40.3 (5.7)	50.3 (3.9)
			M	7	15 (2)	173 (17)	201 (9)	86 (6)	3.08 (1.12)	Hard court	35.9 (7.5)	50.3 (3.9)
Weber[24]	Competitive	4	M/F	18	12.6 (1.2)	172 (6)	nr	nr	1.41 (0.63)	Carpet	nr	nr
18–35 years												
Fernandez *et al*[40]	International	1–2	M	6					3.79 (2.03)	Clay	26.6 (3.3)	58.2 (2.2)
Novas *et al*[25]	State, national	3	F	6	18.3 (2.5)	146 (20)				Hard court		
Smekal *et al*[26]	Top league	3–4	M	20	26 (4)	151 (19)	193 (9)	78	2.07 (0.88)	Clay	29.1 (5.6)	57.3 (5.1)
Bernardi *et al*[27]	Intermediate	4–5	M	7	28.1 (3)	147 (9)	194 (5)	76	nr	Clay	33 (3)	65 (6)
Christmass *et al*[28]	State	3	M	7	24 (2)	nr	190 (3)	86 (1)	5.86 (1.33)	Hard court	nr	53.4 (1.8)
Christmass *et al*[29]	State	3	M	8	23 (1)	155	180 (3)	86		Hard court	nr	54.3 (1.9)
Reilly *et al*[30]	Top club	4	M	8	23.4 (3.1)	146 (19)	191 (11)	76	nr	Wood	nr	53.2 (7.3)
Bergeron *et al*[31]	University	4	M	10	20.3 (2.5)	145 (13)	196 (6)	74	2.3 (1.2)	Clay	nr	58.5 (9.4)
Therminarias *et al*[32,33]	Intermediate	4–5	F	9	21.2 (1.9)	157 (3)	190 (3)	82	1.76 (0.3)	Clay	nr	nr
Weber[24]	Competitive	4	M/F	18	23.8 (3.6)	148 (10)	nr	nr	2.11 (0.77)	Carpet	nr	nr
	Recreational	6–7	M/F	33	25.3 (2.5)	147 (11)	nr	nr	2.43 (1.28)	Carpet	nr	nr
	Beginners	9	M/F	16	25.8 (3.0)	135 (19)	nr	nr	1.92 (0.56)	Carpet	nr	nr
Morgans *et al*[34]	Intermediate to advanced	2–4	M	17	31.4 (7.3)	154 (17)	188 (11)	82	nr	Hard court	nr	46.4 (6.2)
Eliott *et al*[35]	College	4	M	8	20.3 (1.3)	153 (3)	192 (11)	79	nr	Hard court	nr	65.9 (6.3)
Docherty [36]	Low to high	4–9	M	42	25 (5)	150 (10)	nr	70	nr	Hard court	nr	nr
Kindermann *et al*[37]	Well trained	4–5	M	12	32.2 (8.5)	146 (20)	nr	nr	2.0 (0.5)	Unknown	nr	nr
Seliger *et al*[38]	Top level	3	M	16	24.7 (3.7)	143	nr	nr	nr	Indoor court	27.3	nr
35 years and over												
Ferrauti *et al*[39]	National	2–3	M	6	47 (5.4)	142.5 (12.7)	nr	nr	1.24 (0.37)	Clay	25.6 (2.8)	47.5 (4.3)
	National	2–3	F	6	47.2 (6.6)	141.5 (18.9)	nr	nr	1.67 (0.49)	Clay	23.1 (3.1)	41.4 (6.0)
Therminarias[32, 33]	Intermediate	4–5	F	10	46.5 (1.3)	156 (4)	175 (2)	89	1.79 (0.29)	Clay	nr	nr
Weber[24]	Competitive	4	M/F	12	50.4 (4.9)	154 (15)	nr	nr	2.82 (0.92)	Carpet	nr	nr
	Recreational	6–7	M/F	18	54.3 (6.1)	141 (16)	nr	nr	2.67 (0.96)	Carpet	nr	nr

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.

Table 2 Maximum oxygen uptake of tennis players of various levels of play

Reference*	Level of play, country	ITN	Sex	n	Age (years)	$\dot{V}O_2max$ (ml.kg^{-1}.min^{-1})
Juniors						
Buti *et al*[41]	State squad, Australia	3	M	8	11.7	56.3 (6.5)
			F	8	11.7	52.6 (8.2)
Carlson *et al*[42]	Elite junior, Australia	2–3	M	6	16.8	60.3 (6.4)
			F	6	14.6	52.3 (7.5)
Powers, *et al*[43]	High school, USA	4–5	F	10	15.8 (0.4)	48 (2.1)
18–35 years						
Smekal *et al*[26]	Top league, Austria	3–4	M	20	26 (4)	57.3 (5.1)
Bernardi *et al*[27]	Intermediate, Italy	4–5	M	7	28.1 (3)	65 (6)
Christmass *et al*[28]	State level, Australia	3	M	7	24 (2)	53.4 (1.8)
Kraemer *et al*[44]	College, Div I and III, USA	3–5	F	38	20 (2)	47.6 (4.4)
Christmass *et al*[29]	State level, Australia	3	M	8	23 (1)	54.3 (1.9)
Reilly *et al*[30]	Top club, UK	4	M	8	23.4 (3.1)	53.2 (7.3)
Bergeron *et al*[31]	University, Div I, USA	3–4	M	10	20.3 (2.5)	58.5 (9.4)
Morgans *et al*[34]	Intermediate to advanced, USA		M	17	31.4 (7.3)	46.4 (6.2)
Elliott *et al*[35]	College level, Australia	3–4	M	8	20.3 (1.3)	65.9 (6.3)
Wilmore *et al*[46]	Beginners, USA	9–10	M	9	29 (6.6)	44.4 (7.5)
35 years and over						
Ferrauti *et al*[39]	Nationally ranked, Germany	2–3	M	6	47 (5.4)	47.5 (4.3)
			F	6	47.2 (6.6)	41.4 (6.0)
Vodak *et al*[45]	Recreational, USA	6–8	M	25	39 (3)	50.2 (5.7)
		6–8	F	25	42 (6)	44.2 (5.4)
Swank *et al*[47]	Elite, USA	3–4	M	13	40–59	48.7 (11.7)
		4–5	M	15	>60	35.3 (5.8)

Values are mean (SD).
*First author and reference number.
F, female; ITN, international tennis number; M, male; n, number of subjects; $\dot{V}O_2max$, maximum oxygen consumption.

pressure of 198 (30) mm Hg. Mean diastolic blood pressure during play decreased to 82 (16) mm Hg.

Swank *et al*[47] 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[53] 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. No significant changes occurred in baseline glucose levels, HbA1c concentration, triglyceride levels, LDL, HDL, and total cholesterol 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 nmol.l^{-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.[54–61] Increased heart size and increased performance capacity were noted regardless of sex.[54 55 59–61] Systolic and diastolic function were within normal limits.[56 57 61]

Morbidity and mortality

Houston *et al*[62] 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 0.56 (95% confidence interval (CI), 0.35 to 0.89) 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)[63–85] 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 3 Characteristics and results of included studies on the effect of playing tennis on indicators of bone health

Reference*	Design	Study population	Method	Main results
Ducher *et al*[85]	XS	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))	DXA	At the ultradistal radius, asymmetry in BMC in young and adult tennis players was 16.35% and 13.8%, respectively ($p<0.0001$). At the mid- and third-distal radius, asymmetry was much greater in adults than in children ($p<0.0001$) for BMC (mid-distal radius, +6.6% *v* +15.6%; third-distal radius +6.9% *v* +13.3%).
Ducher *et al*[82]	XS	52 tennis players (24.2 (5.8) y), 16.2 (6.1) y of practice	DXA	Lean tissue mass, bone area, BMC, and BMD of the dominant forearm were significantly ($p<0.0001$) greater. Bone area and BMC correlated with grip strength on both sides ($r=0.81$–0.84, $p<0.0001$).
Ducher *et al*[83]	XS	20 regional level tennis players (10 M; 10 F, mean age 23.1 (4.7) years, with 14.3 (3.4) years of playing)	DXA	Significant side-to-side differences ($p<0.0001$) 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 ($p<0.0001$). Volumetric BMD was slightly higher on the dominant side (+3.3%, $p<0.05$). Grip strength and muscle volume correlated with all bone variables (except volumetric BMD) on both sides ($r=0.48$–0.86, $p<0.05$–0.0001) but the asymmetries in muscle indices did not correlate with those in bone indices.
Ducher *et al*[84]	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 BMD was larger than in bone area (8.4 (5.2)% and 4.9 (4.0)%, respectively, $p<0.01$). In he cortical sites, the asymmetry was lower ($p<0.01$) in BMD than in bone area (mid-distal radius: 4.0 (4.3)% *v* 11.7 (6.8)%; third-distal radius: 5.0 (4.8)% *v* 8.4 (6.2)%).
Sanchis-Moysi *et al*[66]	XS	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 arm 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 tennis 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 (8) y), and 27 controls (29 (10) y)	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*[68]	XS	92 middle aged F tennis players (46 (5) y) who initiated training after bone had matured (mean starting age 36 (3) y)	pQCT	Endocortical area (0.278 (0.094) *v* 0.300 (0.106) cm^2), periosteal area (1.007 (0.14) *v* 1.061 (0.15) cm^2), BMC (0.141 (0.017) *v* 0.147 (0.017) g), moment of inertia (1598 (413) *v* 1744 (460) mm^4), section modulus (219 (41) *v* 233 (44) mm^3), and SSI (352 (66) *v* 376 (71) mm^3) 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/cm^3, $p<0.05$) and whole bone (0.756 (0.115) *v* 0.656 (0.120) g/cm^3, $p<0.01$) at the dominant distal radius were greater than in the non-dominant radius.
Kontulainen *et al*[64]	PCS; 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 (1.3) times/wk; old starters from 4.0 (1.4) to 2.0 (1.4) times/wk	DXA	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.
Haapasalo *et al*[67]	XS	12 M former Finnish national level tennis players (30 (5) y) and 12 age, height, and weight matched controls	pQCT	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.
Kontulainen *et al*[63]	PCS; 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	Relative side-to-side BMC differences were significantly ($p<0.001$) larger in players than in controls at all measured sites in both 1992 and 1996 for proximal humerus (1992: 18.5% *v* 1.4%; 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* 2.3%).
Ashizawa *et al*[69]	XS	Forearms of 16 competitive tennis players (10 F) and 12 healthy controls (7 F) aged 18–24 y were scanned at mid and distal site of the radius	pQCT	Players had an increase in total BMC (13.3%, $p<0.001$), periosteal 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%, $p<0.01$), periosteal bone area (6.8%, $p<0.05$), total BMD (6.8, $p<0.01$), 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.

Table 3 Continued

Reference*	Design	Study population	Method	Main results
Haapasalo *et al*[70]	XS	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 lumber spine were compared between the players and controls	DXA	In players, BMD inter-arm differences were significant ($p<0.05$ to <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) *v* 0.89 (0.09) g/cm^2, $p<0.05$) and Tanner stage V (mean age 15.5 y, 1.08 (0.105) *v* 0.96 (0.134) g/cm^2, $p<0.05$).
Calbet *et al*[71]	XS	9 M professional tennis players (26 (6) y) and 17 non-active M subjects (24 (3) y)	DXA	Total mass (4977 (908) *v* 4220 (632) g, lean mass (3772 (500) *v* 3246 (421) g, $p<0.001$, and BMC (229 (43.5) *v* 194 (33) g) were greater in the dominant arm of tennis players than in controls (all $p<0.05$). BMD was increased in tennis players *v* controls in the lumbar spine (1.25 (0.29) *v* 1.09 (0.12) g/cm^2, $p=0.09$) and in the trochanteric region (0.94 (0.11) *v* 0.80 (0.07) g/cm^2, $p<0.001$).
Haapasalo *et al*[72]	XS	17 young competitive M tennis players (25 (5) y), 30 young F players (19 (3) y), 20 older F players (43 (5) y), 16 M controls (25 (5) y), 25 young F controls (21 (3) y), and 16 older F (39 (6) y). Starting age, M 10 (3) y, young F 9 (2) y, older F 29 (6) y	DXA	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 (range +5.8% to +22.5%), cortical wall thickness (range +6.9% to +45.2%), cross sectional moment of inertia (range +7.8% to +26.4%), and section modulus (range +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%).
Etherington *et al*[73]	XS	16 former tennis players (aged 40–65 y), 67 former middle and long distance runners and 585 age matched controls	DXA	Tennis players had greater BMD than runners (lumbar spine 12% (95% CI, 5.7 to 18.2), $p=0.0004$, femoral neck 6.5% (–0.2 to 13.2), $p=0.066$). Athletes had greater BMD than controls (lumbar spine 8.7% (5.4 to 12.0), $p<0.001$ and femoral neck 12.1% (9.0 to 15.3), $p<0001$). BMD of tennis players' forearms were greater than their non-dominant forearms.
Tsuji *et al*[74]	XS	10 M college wrestlers (20 (1) y), 16 female college basketball players (20 (1) y), and 12 F college tennis players (21 (1) y)	DXA	A significant and positive relation was found between mid-radial (0.48 (0.07) g/cm^2) BMD and grip strength (31.2 (4.1) kg) in the dominant forearm of tennis players ($r=0.43$, $p<0.05$). There was a significant difference between mid-radial BMD in the dominant (range 0.63–0.87 g/cm^2) and non-dominant arm (range 0.52–0.57 g/cm^2, $p<0.05$).
Kannus *et al*[75]	XS	105 F Finnish national level tennis/squash players (28 (11) y) and 50 controls (27 (9) y). Players were divided into starting groups according to the biological age (y before or after menarche) at which their playing careers began	DXA	The players had a larger ($p<0.001$) side-to-side difference in BMC for proximal humerus (1.42 (1.33) *v* 0.41 (1.08) g), humeral shaft (2.77 (2.20) *v* 0.57 (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.
Kannus *et al*[76]	XS	20 top level M Finnish tennis players (25 (5) y), and 20 controls (26 (5) y)	DXA	Relative side-to-side differences in BMD and BMC were significantly increased in players *v* controls for humeral shaft (BMD 0.29 (0.09) *v* 0.03 (0.10) g/cm^2, BMC 6.41 (0.28) *v* 1.06 (0.33) g, $p<0.001$), and proximal humerus (BMD 0.12 (0.08) *v* 0.01 (0.10) g/cm^2, BMC 2.38 (1.8) *v* 0.28 (1.7) g, $p<0.001$).
Krahl *et al*[77, 78]	XS	20 highly ranked professional tennis players (12 M, 8 F, 20.1 (4.5) y), and 12 controls (7 M, 5 F, 23.1 (4.7) y)	*x* ray	Relative side-to-side differences were significantly increased in tennis players *v* controls for ulnar diameter (2.1 *v* 0.02 mm, $p<0.01$), ulnar length (8 *v* 0.17 mm, $p<0.01$), second metacarpal diameter (0.9 *v* 0.0 mm, $p<0.01$), and second metacarpal length (2.7 *v* 0 mm, $p<0.01$).
Jacobson *et al*[79]	XS	11 college tennis players, 23 swimmers, and 86 older athletic F aged 23 to 75 y and age matched non-athletic controls.	Single and dual photon densitrometry	Lumbar spine density was increased in tennis players *v* swimmers and controls (1.51 (37) *v* 1.39 (27) and 1.36 (49) g/cm^2, $p<0.02$). Metatarsal density was increased in tennis players *v* swimmers and controls (626 (26) *v* 565 (14) and 512 (13) g/cm^2, $p<0.001$). BMC of dominant arm of tennis players 16% higher than in non-dominant arm; in controls $\leqslant 3\%$ ($p<0.001$). Differences between controls and athletic women were highest in oldest age groups.
Huddleston[81]	XS	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	Transmission scanning with a low energy *x*-ray beam	Bone mass of the radius of the playing arm (mean, 1.37 g/cm) was greater than that of the non-playing arm (mean, 1.23 g/cm) in all but one person. The quantity of BM present in the playing arms of the tennis population was greater than that of the dominant arm on non-athletes.

*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; pQTC, peripheral quantitative computer tomography; wk, week; XS, cross sectional study; y, years.

examining tennis and cardiovascular risk factors, only two had a longitudinal design (six week follow up). Similarly, of the 22 studies on bone health, only two had a longitudinal design. But to their credit, follow up was much longer (four and five years).

A second limitation, that of selection bias, may also have occurred in the studies reviewed, given that those who are healthy may be more inclined to play tennis (and continue lifelong participation) in comparison with others who may have health problems and deem tennis inappropriate for them. The type of person who is able to and does play tennis may self select for more positive health outcomes, as playing tennis is generally associated with a higher socioeconomic status.[89] Furthermore, most of the studies included failed to adjust appropriately for confounding variables when studying the relation between tennis and health indices.

Despite these limitations, there remains an indication of positive health benefits associated with regular tennis participation. This conclusion concurs with those of other well designed studies investigating the general impact of exercise on various health indices.

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).[90]

This review shows that tennis is associated with increased plasma HDL cholesterol.[47–49] Even though more than 200 risk factors for coronary heart disease have now been identified, the single most powerful predictor is hyperlipidaemia.[91] 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.[92]

The results of the study by Vodak *et al*[49] indicate that blood pressure response during tennis play is comparable to the response to an acute bout of moderate intensity dynamic exercise.[93] 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.[63 65–85] 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.[94]

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).[20–22] 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 $\dot{V}O_2$max. Moderate intensity activities are those done at a relative intensity of 40% to 60% of $\dot{V}O_2$max (60–75% of maximum heart rate), whereas vigorous intensity activities are those done at a relative intensity of >60% of $\dot{V}O_2$max (>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.[86 87]

In doubles play, heart rate and $\dot{V}O_2$ 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 $\dot{V}O_2$max 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*,[62] 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.

What is already know 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.

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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