Health Benefits of Tennis

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Objective: The aim of the study was to explore the role of tennis in the promotion of health and prevention of disease. The focus of this study was on risk factors and diseases related to a sedentary lifestyle, including low fitness levels, obesity, hyperlipidemia, hypertension, diabetes mellitus, cardiovascular disease, and osteoporosis.
Methods: A literature search was undertaken to retrieve potentially relevant articles for the purpose of this paper. Structured computer searches of PubMed, Embase, and Cumulative Index to Nursing and Allied Health Literature (CINAHL) were undertaken, along with hand-searching of key journals and reference lists to locate relevant studies published up to March 2007. They had to be either cohort studies (of either a cross-sectional or longitudinal design), case-control studies or experimental studies.
Results: Twenty-four studies were identified that were related to physical fitness of tennis players, including seventeen on intensity of play and sixteen on maximum oxygen uptake of tennis players. Seventeen studies were found that investigated the relationship between tennis and (risk factors for) cardiovascular disease. Twenty-two studies were retrieved that examined the effect of tennis on bone health.
Conclusions: It was concluded that 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, a reduced risk for developing cardiovascular disease, and improved bone health.

Key words: health, prevention, risk factors, tennis

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 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 cardio-respiratory 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 nineties, exercise recommendations exhorted vigorous intensity exercise (e.g. 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 (e.g. brisk walking, cycling, 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 that 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 to what extent data are available indicating a direct relationship 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, i.e. low fitness levels, obesity, hypertension, hyperlipidemia, diabetes mellitus, cardiovascular disease, and osteoporosis.

Methods
A literature search was undertaken to retrieve potentially relevant articles for the purpose of this paper. 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 performed to identify additional relevant articles.

To be included in this review, studies had to meet the following criteria:
(1) They had to be cohort studies (of either a cross-sectional or longitudinal design), case-control studies or experimental studies published in English or German; and
(2) They had to contain data on the relationship between playing tennis and physical fitness, cardiovascular disease, obesity, hypertension, hyperlipidemia, 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 sixteen 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 relationship between tennis and risk factors for cardiovascular disease and included eight cross-sectional studies on cardiac size and/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 hyperlipidemia, two cross-sectional study on hypertension,[47,52] one longitudinal study on diabetes,[53] and one longitudinal study on cardiovascular morbidity and mortality.[62] Twenty-two studies (two of a longitudinal[63,64] and twenty of a cross-sectional design[65-85]) were retrieved that examined the effect of tennis on bone health.

Physical Fitness Levels

Table 1. Intensity of match play (mean±SD)

Reference*	Standard of player	ITN	Gender	N	Age (years)	Mean HR during play (bpm)	HRmax exercise test (bpm)	% HR max	Lactate (mmol.L^{-1})	Surface	VO_2 mean during play (ml.kg^{-1}.min^{-1})	VO_2max 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	n.r.	n.r.	1.41±0.63	Carpet	n.r.	n.r.
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	n.r.	Clay court	33±3	65±6
Christmass et al.[28]	State	3	m	7	24±2	n.r.	190±3	86 ± 1	5.86 ±[illegible]	Hard court	n.r.	53.4±1.8
Christmass et al.[29]	State	3	m	8	23±1	155	180±3	86		Hard court	n.r.	54.3±1.9
Reilly et al.[30]	Top club	4	m	8	23.4±3.1	146±19	191±11	76	n.r.	Wood	n.r.	53.2±7.3
Bergeron et al.[31]	University	4	m	10	20.3±2̃5	145±13	196±6	74	2.3±1.2	Clay	n.r.	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	n.r.	n.r.
Weber[24]	Competitive	4	m/f	18	23.8±3.6	148±10	n.r.	n.r.	2.11±0.77	Carpet	n.r.	n.r.
	Recreational	6-7	m/f	33	25.32.5	147±11	n.r.	n.r.	2.43±1.28	Carpet	n.r.	n.r.
	Beginners	9	m/f	16	25.8±3.0	135±19	n.r.	n.r.	1.92±0.56	Carpet	n.r.	n.r.
Morgans et al.[34]	Intermediate to advanced	2-4	m	17	31.4 ±7.3	154±17	188±11	82	n.r.	Hard court	n.r.	46.4±6.2
Eliott et al.[35]	College	4	m	8	20.3 ±1.3	153±3	192±11	79	n.r.	Hard court	n.r.	65.9±6.3
Docherty[36]	Low to high	4-9	m	42	25±5	150±10	n.r.	70	n.r.	Hard court	n.r.	n.r.
Kindermann et al.[37]	Well-trained	4-5	m	12	32.2±8.5	146±20	n.r.	n.r.	2.0±0.5	Unknown	n.r.	n.r.
Seliger et al.[38]	Top level	3	m	16	24.7±3.7	143	n.r.	n.r.	n.r.	Indoor court	27.3	n.r.
35 and over												
Ferrauti et al.[39]	National	2-3	m	6	47±5.4	142.5±12.7	n.r.	n.r.	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	n.r.	n.r.	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	n.r.	n.r.
Weber[24]	Competitive	4	m/f	12	50.4±4.9	154±15	n.r.	n.r.	2.82±0.92	Carpet	n.r.	n.r.
	Recreational	6-7	m/f	18	54.3±6.1	141±16	n.r.	n.r.	2.67±0.96	Carpet	n.r.	n.r.

* First author and reference number; SD indicates standard deviation; ITN indicates International Tennis Number; m indicates male; f indicates female; N indicates number of subjects; n.r. indicates not reported.

Exercise intensity

In 17 studies the intensity of match play was examined using heart rate recordings [23-39] and/or maximum oxygen uptake (VO_2max)[23,26,27,39,40] during play (Table 1). Mean heart rate during singles play ranged from 141±16 to 182±12 beats per minute (bpm), equating to 70 to 90% of maximum heart rate. Mean oxygen consumption during play ranged from 23.1±3.1 $ml \cdot kg^{-1} \cdot min^{-1}$ to 40.3±5.7 $ml \cdot kg^{-1} \cdot min^{-1}$, reflecting 50% to 80% of VO_2 max. Mean lactate levels during play were generally 2 to 3 $mmol \cdot L^{-1}$, however one investigator reported levels as high as 6 $mmol \cdot L^{-1}$.[28] The results of these studies indicate that singles tennis play can be categorised as vigorous-intensity exercise (>6 Mets).

Table 2. Maximum oxygen uptake of tennis players of various levels of play (mean±SD)

Reference*	Level of play, country	ITN	Gender	N	Age (years)	VO_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
Christmas 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

Aerobic capacity

One longitudinal and 15 cross-sectional studies on the VO_2 max of tennis players were identified (Table 2).[26-31,34,35,39,41-47] The mean VO_2 max ranged from 35.5±5.8 $ml \cdot kg^{-1} \cdot min^{-1}$ to 65.9±6.3 $ml \cdot kg^{-1} \cdot min^{-1}$, depending on age, gender and training level, indicating that these tennis players had high fitness levels, compared to norm values for normally active controls of the same age and gender.[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 to 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 (42±6yrs) and 25 female (39±3yr) tennis players, with mean values of 16.3% and 20.3% for males and females.

Schneider et al. (n = 7,248; 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 demonstrated 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 40-59) and the older veterans (over 60) were on average 3% leaner than the non-tennis-playing moderately active controls (17–20.5% vs. 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 vs. 23.9%, $p<0.05$).

Hyperlipidemia

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 to a sedentary group matched for age, sex and education. Mean plasma HDL-cholesterol levels were significantly higher in tennis players than in sedentary subjects (males 53.8±11.7 vs. 45.1±11.9 mg/100ml, [$p<0.001$], females 66.4±8.4 vs. 60.1±11.1 mg/100ml, [$p=0.02$]). 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 LDL-C 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 males and 11 females, aged 43 to 47 years old) 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, which may have been due to 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 40-60+ 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 40-59 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 (50±7 yr), using a portable ambulatory blood pressure recorder.[52] Mean resting systolic blood pressure was 137±19 mmHg and diastolic blood pressure was 88±13 mmHg, suggestive of pre-hypertension (blood pressure between 120/80 and 139/89 mm Hg).[88] Mean systolic blood pressure during play was 168±19 mmHg, with a peak systolic blood pressure of 198±30 mmHg. Mean diastolic blood pressure during play decreased to 82±16 mmHg.

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 (40-59 yrs: systolic blood pressure (SBP) = 121±10 vs. 124±14 mmHg, diastolic blood pressure (DBP) = 78±10 vs. 79±10 mmHg, 60+ yrs: SBP = 136±10 vs.135±14, DBP 82±7 vs. 81±7 mmHg).

Diabetes Mellitus

Nessler[53] performed a longitudinal study of 12 patients (7 men, mean age 62±4yrs and 5 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 insulin levels (10.3±3.8 μE/ml vs. 13.9±5.7 μE/ml, $p=0.026$) and c-peptide production (3.5±1.0 vs. 4.7±1.4, $p=0.001$). The mean glucose concentration (mean of 12 participants measured before and after 12 training sessions) dropped 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 gender.[54,55,59,60,61] Systolic and diastolic function were within normal limits.[56,57,61]

Morbidity and mortality
Houston et al.[62] studied 1,019 male students between 1948 to 1964. After a standard physical exam, 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 higher 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]: 0.35-0.89) in the high-ability group and 0.67 (95% CI: 0.47-0.96) in the low-ability group, compared with the no-ability group. A primary factor for this beneficial health profile may be due to the fact that tennis was the sport that was played most frequently through midlife. Half of the tennis players were still participating in the sport in midlife, compared to only one quarter of those whom reported playing golf, and none whom 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 compared to controls, and exercise induced bone gain was greater in young than in old starters. Table 3 contains more specific information regarding the effect of tennis on bone health.

Table 3. Characteristics and results of included studies on the effect of playing tennis on indicators of bone health.

Reference*	Study design	Study population	Method	Main results
Ducher[85]	Cross-sectional	Twenty-eight young (22 boys, 6 girls, 11.6±1.4yrs) and 47 adult tennis players (23 men, 24 women, 22.3±2.7yrs), and 70 age-matched controls (12 children [12.2±1.6yrs] and 58 adults [23.3±3.2yrs]).	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% versus +15.6%; third-distal radius +6.9% versus +13.3%).
Ducher[82]	Cross-sectional	Fifty-two tennis players (24.2±5.8yrs), 16.2±6.1yrs 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[83]	Cross-sectional	Twenty regional-level tennis players (10 men and 10 women, 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 sub-cortical 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 parameters did not correlate with those in bone parameters.
Ducher[84]	Cross-sectional	Fifty-seven regional-level tennis players (33 men and 24 women). 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% vs. 11.7±6.8%; third-distal radius:5.0±4.8% vs. 8.4±6.2%).
Sanchis-Moysi et al.[66]	Cross-sectional	Ten female postmenopausal tennis players (60±5yrs) and 12 postmenopausal controls (63±7yrs). Tennis players started at 31±9yrs and had been playing for 27±7yrs, at least 3 h per week.	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]	Cross-sectional	Seventeen male tennis players (55□2yrs), 9 female tennis players (61□1yrs), 15 male (56□3yrs) and 20 female (62□2yrs) control subjects. Mean tennis participation was 27□7yrs, 3 h per week.	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 compared with controls (p<0.05).
Kontulainen et al.[80]	Cross-sectional	36 young female Finnish tennis/squash players (22±8yrs, mean starting age 11±2yrs), and 28 older female players (39±11yrs, mean starting age 26±8yrs), and 27 controls (29±10yrs).	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]	Cross-sectional	92 middle-aged female tennis players (46±5yrs) who initiated training after bone had matured (mean starting age 36±3yrs).	pQCT	Endocortical area (0.278±0.094 cm^2 vs. 0.300±0.106 cm^2), periosteal area (1.007±0.14 cm^2 vs. 1.061±0.15 cm^2), BMC (0.141±0.017 g vs. 0.147±0.017 g), moment of inertia (1598±413 mm^4 vs. 1744±460 mm^4), section modulus (219±41 mm^3 vs. 233±44 mm^3), and SSI (352±66 mm^3 vs. 376±71 mm^3) of dominant midradius were significantly (p<0.01) smaller compared to the non-dominant radius. BMD of trabecular bone (0.383±0.060 g/cm^3 vs. 0.363±0.070 g/cm^3, p<0.05) and whole bone (0.756±0.115 g/cm^3 vs. 0.656±0.120 g/cm^3, p<0.01) at the dominant distal radius were significantly greater compared to the non-dominant radius.
Kontulainen et al.[64]	Prospective cohort study; 5-yr follow-up	36 young female Finnish tennis/squash players (22±8yrs, mean starting age 11±2yrs), and 28 older female players (39±11yrs, mean starting age 26±8yrs), and 27 controls (29±10yrs). Young starters reduced training from 4.7±2.7 to 1.4±1.3 times a week; old starters from 4.0±1.4 to 2.0±1.4 times a week.	DXA	Bone gain was 1.3-2.2 times greater in favour of young starters: The difference in BMC of humeral shaft in dominant vs. non-dominant arm was 22±8.4% in young starters vs. 10±3.8% in old starters at follow-up.
Haapasalo et al.[67]	Cross-sectional	12 male former Finnish national-level tennis players (30□5yrs) 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]	Prospective cohort study; 4-yr follow-up	13 male former competitive tennis players (26±5yrs) who started their career at a mean age of 11yrs and 13 controls (26±6yrs). The players had all retired from top-tennis before (mean 2.3±0.6yrs) 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% vs. 1.4% and 1996 18.4% vs. 0.5%), humeral shaft (1992 25.2% vs. 4.7% and 1996 25.9% vs. 4.5%), radial shaft (1992 13.9% vs. 1.8% and 1996 14.2% vs. 2.1%), and distal radius (1992 13.2% vs. 2.0% and 1996 13.2% vs. 2.3%).
Ashizawa et al.[69]	Cross-sectional	Forearms of 16 competitive tennis players (10 women) and 12 healthy controls (7 women) aged 18-24yrs were scanned at mid and distal site of the radius.	pQCT	Players exhibited 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 compared with the non-playing arm. In controls, side-to-side differences in these parameters 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 that measured for the non-playing arm. In controls, significant side-to-side differences were not found in any measured parameters.
Haapasalo et al.[70]	Cross-sectional	Ninety-one 7- to 17-year-old female tennis players and 58 healthy female 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 became obvious until Tanner stage III (mean age 12.6yrs). In the lumbar spine differences were not found until Tanner stage IV (mean age 13.5yrs, 0.97±0.13 g/cm^2 vs. 0.89±0.09 g/cm^2, p<0.05) and Tanner stage V (mean age 15.5yrs, 1.08±0.105 g/cm^2 vs. 0.96±0.134 g/cm^2, p<0.05).
Calbet et al.[71]	Cross-sectional	Nine male professional tennis players (26□6yrs) and 17 non-active male subjects (24□3yrs).	DXA	Total mass (4977±908 g vs. 4220±632 g, lean mass (3772±500 g vs. 3246±421 g, p<0.001, and BMC (229±43.5 g vs. 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 compared to controls in the lumbar spine (1.25±0.29 g/cm^2 vs. 1.09 ±0.12 g/cm^2, p=0.09) and in the trochanteric region (0.94±0.11g/cm^2 vs. 0.80±0.07 g/cm^2, p<0.001).

Haapasalo et al.[72]	Cross-sectional	Seventeen young competitive male tennis players (25□5yrs), 30 young female players (19□3yrs), 20 older female players (43□5yrs), 16 male controls (25□5yrs), 25 young female controls, (21±3yrs) and 16 older women (39□6yrs). Starting age male players 10□3yrs, young females 9□2yrs, older females 29□6yrs.	DXA	There were significant side-to-side humeral length differences in young male players (+1.4%), young female controls (+1.1%) and older female 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]	Cross-sectional	16 former tennis players (aged 40-65yrs), 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%, 95% CI –0.2 to 13.2, p=0.066). Athletes had greater BMD than controls (lumbar spine 8.7%, 95% CI 5.4 to 12.0, p<0.001 and femoral neck 12.1%, 95% CI 9.0 to 15.3, p<0001). BMD of tennis players forearms were greater than their non-dominant forearms.
Tsuji et al.[74]	Cross-sectional	10 male college wrestlers (20□1yrs), 16 female college basketball players(20□1yrs), and 12 female college tennis players (21□1yrs).	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]	Cross-sectional	105 female Finnish national-level tennis/squash players (28□11yrs) and 50 controls (27□9yrs). Players were divided into starting groups according to the biological age (years before or after menarche) at which their playing careers began.	DXA	The players had a significantly (p<0.001) larger side-to-side difference in BMC for proximal humerus (1.42±1.33 g vs. 0.41±1.08 g), humeral shaft (2.77±2.20 g vs. 0.57±1.68 g), radial shaft (0.32±0.47 g vs. 0.12±0.40 g), and distal radius (0.32±0.38 g vs. 0.11±0.28 g). Difference were two to four times greater in players who started before or at menarche than 15 years after menarche.
Kannus et al.[76]	Cross-sectional	Twenty top-level male Finnish tennis players (25□5yrs), and 20 controls (26□5yrs).	DXA	Relative side-to-side differences in BMD and BMC were significantly increased in players compared to controls for humeral shaft (BMD 0.29±0.09 g/cm^2 vs. 0.03±0.10 g/cm^2, BMC 6.41±0.28 g vs. 1.06±0.33 g, p<0.001) and proximal humerus (BMD 0.12±0.08 vs. 0.01±0.10 g/cm^2, BMC 2.38±1.8 vs. 0.28±1.7 g, p<0.001).

Krahl et al.[77,78]	Cross-sectional	20 highly ranked professional tennis players (12 males, 8 females, 20.1±4.5yrs), and 12 controls (7 males, 5 females, 23.1±4.7yrs)	X-ray	Relative side-to-side differences were significantly increased in tennis players compared to controls for ulnar diameter (2.1 vs. 0.02 mm, $p<0.01$), ulnar length (8 vs. 0.17 mm, $p<0.01$), second metacarpal diameter (0.9 vs. 0.0 mm, $p<0.01$) and second metacarpal length (2.7 vs. 0 mm, $p<0.01$).
Jacobson et al.[79]	Cross-sectional	Eleven college tennis players, 23 swimmers, and 86 older athletic women from 23 to 75 years of age and age-matched non-athletic controls.	Single photon densitometry	Lumbar spine density was increased in tennis players compared to swimmers and controls (1.51±37 g/cm^2 vs. 1.39±27 g/cm^2 and 1.36±49 g/cm^2, $p<0.02$). Metatarsal density was increased in tennis players compared to swimmers and controls (626±26 g/cm^2 vs. 565±14 g/cm^2 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 ≤ 3% ($p<0.001$). Differences between controls and athletic women were highest in oldest age groups.
Huddleston[81]	Cross-sectional	Thirty-five active male tennis players were studied during the 1978 USTA's 70-,75- and 80-year age group clay court championship (21 were aged 70 to 74 yrs, 9 were aged 75 to 79 yrs, and 5 were aged 80 to 84 yrs.		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 indicates bone mineral content; BMD indicates bone mineral density; DXA indicates dual-energy x-ray absorptiometry; pQTC indicates peripheral quantitative computer tomography; 95% CI indicates 95% confidence interval.

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 middle-adulthood.

A limitation of this review is the low number of studies with a longitudinal design. For example, of the seventeen studies examining tennis and cardiovascular risk factors, only two had a longitudinal design (i.e. 6-week follow ups). Similarly, of the twenty-two 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 to 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 included studies failed to appropriately adjust for confounding variables when studying the relationship between tennis and health parameters.

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 parameters.

The lower body fat percentage of tennis players compared to less active controls is an important finding because obesity has become a 'global epidemic', with more than 1 billion adults overweight (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 levels.[47-49] Even though more than 200 risk factors for coronary heart disease have now been identified, the single most powerful predictor of coronary heart diseases is hyperlipidemia.[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 reduced risk of cardiovascular disease implies that playing tennis may reduce the risk of cardiovascular events.[92]

The results of the study by Vodak et al.[52] 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 genders 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 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 ACSM Position Stand on "Physical Activity and Bone Health", who recommend 20-40 minutes of weight-bearing endurance activities, such as tennis, at least three times per week to augment bone mineral accrual in children and adolescents, and 30-60 minutes of these activities at least three times per 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 American College of Sports Medicine (ACSM) and American Heart Association (AHA).[20-22] Reported mean heart rates during singles tennis ranged from 70-90% of maximum heart rate, and mean oxygen consumption ranged from 50-80% of VO_2 max. Moderate intensity activities are those performed at a relative intensity of 40-60% of VO_2 max (60-75% of maximum heart rate, whereas vigorous-intensity activities are those performed at a relative intensity of >60% of VO_2max (>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 to normally active populations of the same age and sex.[86,87]

In doubles play, heart rate and VO_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 VO_2max 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 shown by Houston et al.[62], who demonstrated 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 life-style 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 relationship between tennis and risk factors and diseases related to a sedentary lifestyle.
- There is a positive association 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.