Blood pressure and hypertension in athletes: a systematic review

H M Berge,[1] C B Isern,[2] E Berge[3]

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[1]Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, Oslo, Norway
[2]Faculty of Medicine, University of Oslo, Oslo, Norway
[3]Department of Cardiology, Oslo University Hospital, Ullevål, Oslo, Norway

Correspondence to
Dr H M Berge, Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, Sognsveien 220, PO Box 4014 Ullevål stadion, Oslo NO-0806 Norway; hilde.moseby.berge@nih.no

HMB and CBI contributed equally.

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ABSTRACT

Objective Hypertension is reported to be the most prevalent risk factor for cardiovascular disease in elite athletes. We aimed to review blood pressure (BP) and prevalence of hypertension in different elite athletes, and study whether there was an association between high BP and left ventricular hypertrophy (LVH).
Methods A systematic review of studies reporting BP in athletes using search strategies developed for PubMed and EMBASE, including only studies with ≥100 participants. We collected data on BP, prevalence of hypertension, LVH and methods of BP measurement.
Results Of 3723 records identified, 51 met the inclusion criteria. These included men and women (n=138 390), aged mostly between 18 and 40 years, from varied sports disciplines. Mean systolic BP varied from 109±11 to 138±7 mm Hg and mean diastolic BP from 57±12 to 92±10 mm Hg. Strength-trained athletes had higher BP than endurance-trained athletes (131.3 ±5.3/77.3±1.4 vs 118.6±2.8/71.8±1.2 mm Hg, $p<0.05$), and there was a trend towards a higher BP in athletes training ≥10 h compared with others (121.8 ±3.8/73.8±2.5 vs 117.6±3.3/66.8±6.9, p=0.058), but overall there was no significant difference in BP between athletes and controls. The prevalence of hypertension varied from 0% to 83%. Some studies showed an association between high BP and LVH. Measurement methods were poorly standardised.
Conclusions BP and prevalence of hypertension in athletes varied considerably partly because of variations in methodology, but type and intensity of training may contribute towards higher BP. High BP may be associated with LVH.

What this study adds?

- There was no evidence that blood pressure (BP) was lower in athletes than in controls. A number of studies showed a higher BP in athletes. The prevalence of hypertension in athletes could not be determined reliably because of different definitions of hypertension and poorly standardised methods of BP measurement.
- A positive linear association between high BP and left ventricular hypertrophy was observed in athletes, but confounding factors may have played a role.
- Future studies should be designed to determine more precisely the prevalence, determinants and prognostic significance of hypertension in athletes.

INTRODUCTION

In Western countries, the prevalence of hypertension has been reported as 14.4% and 21.2% in men aged 20–29 and 30–39 years, respectively, and as 6.2% and 9.9% in women in the same age group.[1] High blood pressure (BP) at a young age predicts cardiovascular mortality and morbidity decades later.[2 3]

High BP is the most common abnormal finding during preparticipation cardiac screening of athletes.[4–8] The prognostic significance of high BP in athletes is unknown, but still athletes with BP <160/100 mm Hg are given the license to continue with sport participation if they have no signs of end organ damage, such as pathological left ventricular hypertrophy.[9] Increased left ventricular mass is considered as subclinical organ damage in people with hypertension.[10 11] As several studies have demonstrated increased left ventricular mass and increased left atrium size in athletes,[12] it is possible that high BP may be a contributing factor[13 14] that may also link to the increased risk of atrial fibrillation in endurance athletes.[15–17] Hence, there is increasing interest in BP in athletes.[14 18 19] BP measurement during preparticipation screening of athletes should be performed according to 'best clinical care',[20] as outlined in the European Society of Cardiology's guidelines, with hypertension defined as systolic BP (SBP) ≥140 mm Hg and/or diastolic BP (DBP) ≥90 mm Hg after repeated measurements.[21] We aimed to review BP and prevalence of hypertension in different athletes, and study the association between increasing BP and left ventricular hypertrophy.

METHODS

Literature search

We performed a systematic review of studies reporting BP in athletes by using a comprehensive search strategy developed for PubMed and EMBASE (see online supplementary material). The medical subject headings and text words were: 'Athlete', 'Sport and Professional', 'Exercise Test' and 'Sudden Death', combined with 'Blood Pressure' or 'Hypertension'. The electronic search was restricted to studies published before 6 April 2014. In addition, we manually searched reference lists of reviews and original study articles, and our own archive.

Inclusion and exclusion criteria

We searched for studies of athletes that reported BP or prevalence of hypertension, using the studies' own definitions of hypertension. We included studies of ≥100 athletes, with mean or median age between 18 and 40 years, of any epidemiological design (with or without follow-up, and with or

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without controls), and reported in English language. We excluded studies that were only presented as conference abstracts. If there were more than one publication from the same group, we used the record with most participants, or the newest, if the number of participants were the same. When in doubt, we contacted the corresponding authors.

Outcome variables

The primary outcome variable was BP or prevalence of hypertension in different categories of athletes (defined by gender, ethnicity, sports discipline or level of athletic activity). Secondary outcome variables were (1) method for measurement of BP and (2) association between BP and left ventricular hypertrophy (determined by left ventricular mass or relative wall thickness on echocardiography or by voltage criteria on ECG).

Extraction of data

All data were extracted by one reviewer (CBI) and checked by another reviewer (HMB), using a standardised data extraction sheet.

Statistical analysis

Differences between subgroups of athletes were analysed using t tests for continuous variables. Data are presented as mean with SD. A $p<0.05$ was considered statistically significant and all tests were two-tailed. The statistical analyses were conducted using SPSS (PASW Statistics 21; IBM Corporation 2013, Armonk, New York, USA).

RESULTS

Study selection

The searches retrieved a total of 4433 records (figure 1). After addition of studies from other sources and removal of duplicates, 3723 records remained. Screening of titles and abstracts excluded 2896 and 361, respectively. Another 404 studies did not meet the inclusion criteria, 9 were duplicate reports, and 2 studies were not available. The remaining 51 studies were included in the review.

Study characteristics

Table 1 shows characteristics of the 51 studies, including a total of 138 390 athletes, with a median number of 434 athletes (range 100[22]–42 386 athletes[23]). Sixteen studies included non-athletes as controls and the median number of controls was 176 (range 26–9997). The mean or median age of the athletes in all studies was between 18 and 40 years, and about half of the studies had participants within this range only; however, several studies included participants with an age outside this range. Twenty studies included males only and across the 31 studies of both genders, 72.5% were males.

Most studies (28) included athletes from different sports disciplines, but 16 included athletes from only one discipline, eg, soccer (4),[13 24–26] American football (3),[27–29] triathlon (2)[30 31] and long distance running (2);[16 32] other studies classified sports disciplines as either endurance sports, strength sports or a mixture of the two (table 1). The athletes' level of competition was described in 50 studies and ranged from participation in amateur sport to the Olympic Games. Hours of training per week or previous years of vigorous training were given in 24 studies, and ranged from 4 to 28 h a week and from 2 to 30 years, respectively.

BP in athletes

Table 2 shows BP and prevalence of hypertension in the same studies. Among the 34 studies that reported BP, two-thirds had BP in the prehypertensive range (SBP ≥120–139 and/or DBP ≥80–89 mm Hg).[33] Mean SBP varied from 109±11 mm Hg (intercollegiate female college athletes (mean age 20 years))[34] to

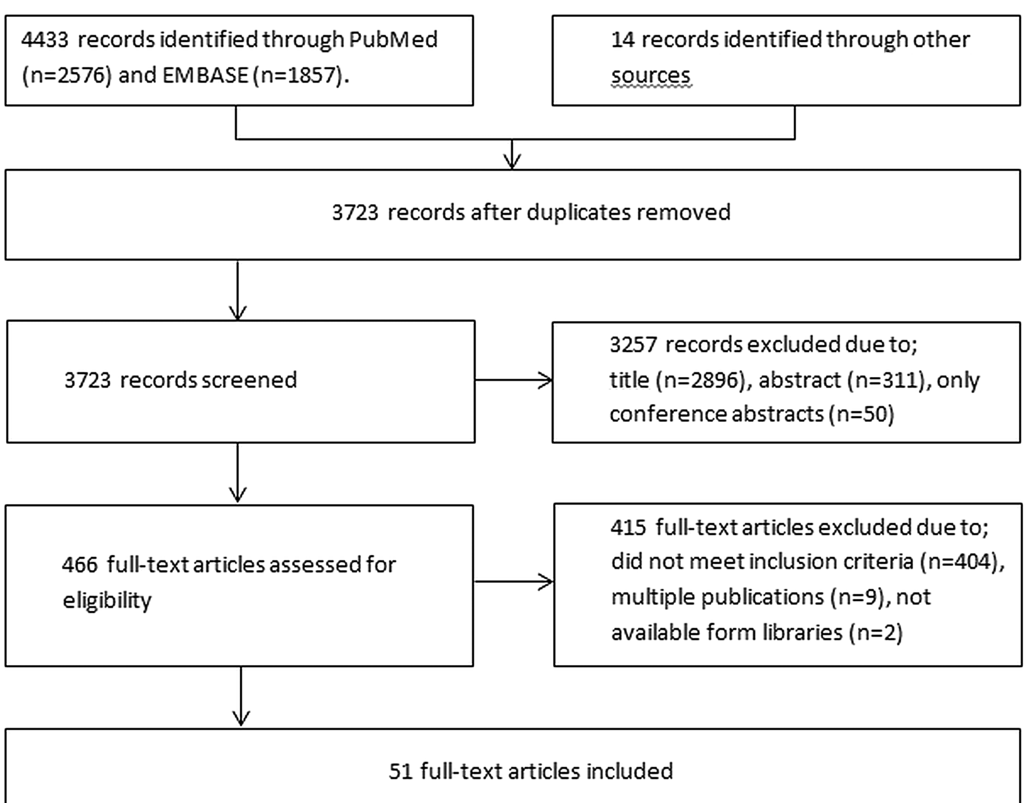

Figure 1 Flow chart illustrating search strategy.

Table 1 Study characteristics

First author, year of publication	Number of athletes (males %)	Age (mean±SD (range, in years))	Sports disciplines	Level	Hours of training per week	Previous years of training	Number of controls
Helzberg, 2010[37]	224	24 (18–36)	Football and baseball	Professional			
van Buuren, 2013[63]	291 (100)	25.3±4.4 (18–39)	Handball	Top level athletes			
Lively, 1999[5]	596 (68.0)	18.9 (17–25)	Mixed	Intercollegiate			
Sofi, 2008[64]	30 065 (78.4)	30.7±14 (5–92)	Mixed	?	4–6		
Pelliccia, 2010[40]	114 (78)	22±4	Endurance	Olympic	28	16	
Munoz, 2009[65]	135 (41)	20 (17–25)	Mixed	Intercollegiate, NCAA Division II			
De Matos, 2011[6]	623 (85)	NA (13–77)	Mixed	Professional and amateur			
Berge, 2013[13]	595 (100)	25.1±4.5 (18–40)	Soccer	Professional soccer			47
Weiner, 2013[14]	183 (100)	19±1 (≥18)	Football and rowing	College	8		
Tucker, 2009[29]	504 (100)	26.7	Football	NFL			1959
Guo, 2013[34]	261 (50.2)	21	Strength	Professional		5–7	
Karpinos, 2013[18]	636 (100)	18.7±0.8	Mixed	Mixed			
Lewis, 1989[66]	265 (83)	19 (18–28)	Mixed	Intercollegiate			
Corrado, 2006[23]	42 386	12–35	Mixed	Competitive			
Thunenkotter, 2010[28]	582 (100)	26.8±4	Football	FIFA World Cup 2006			
Wilson, 2012[59]	1220 (100)	22.6±6 (12–35)	Mixed	National	≥6		
Gati, 2013[43]	2533 (72.2)	21.8±5.7	Mixed	Regional to national	19		9997
Zaidi, 2013[39]	627 (69.9)	21.5±5.0 (14–35)	Mixed	Regional to international	20		
Riding, 2013[49]	1175	Arabic: 22.7±5.9, BA: 24.6±4.7, WA: 24.4±5.4. (13–40)	Mixed	High-level	≥6		201
Di Luigi, 2004[67]	32 652 (80)	22.3±12.5 (5–84)	Mixed	Competitive	<10		
Magalski, 2011[68]	964 (48)	18–21	Mixed	Mixed			
Papadakis, 2011[41]	2 745 (100)	NA (14–35)	Mixed	Regional to international	13–15		119
Schmied, 2013[25]	210 (100)	18.6 (18–22)	Soccer	High-level, competitive soccer			
Maron, 1987[69]	501 (71.3)	19.3 (17–30)	Mixed	Intercollegiate			
Rontoyannis, 1998[27]	188 (100)	36.4±4.5	Football referees	Greece football division A-D			
Urhausen, 1996[70]	135 (47.4)	♂ 20.6±4.1, ♀ 21.5±3.4	Rowing	National and regional level			
Pelliccia, 2000[71]	1 005 (74)	23 (9–55)	Mixed	National team		2–30	
Maskhulia, 2006[24]	221 (100)	22.8±0.3 (18–35)	Soccer	Highly trained		5–26	
Caselli, 2011[42]	434 (78)	26±5 (15–45)	Mixed	Olympic		≥3	98
Noseworthy, 2011[36]	879 (62)	18.4±0.8	Mixed	Intercollegiate level	7		
Varga-Pinter, 2011[45]	3 697 (61)	23.7±4.6 (19–40)	Mixed	Low to top level	10–13		
Pougnet, 2012[72]	200 (86)	38 (19–57)	Diving	Professional			
Schmied, 2012[73]	1 047 (49)	22±5.87 (13–64)	Mixed	Competitive			
Zaidi, 2013[38]	675 (80.6)	BA: 21.8±5.4, WA: 21.7±4.6	Mixed	Regional to international	17–20		
Berry, 1949[46]	201 (100)	NA (16–47)	Mixed	Olympic			
Andersen, 1956[48]	326 (100)	20–29 years: 208, 30–39 years: 118	Mixed	Mixed and national level			526
Siegel, 1992[44]	1 061 (100)	<20 years; 105, 20–29 years; 807, 30–39 years; 99, >40 years; 42	Baseball	Professional and minor league			

Continued

Table 1 Continued

First author, year of publication	Number of athletes (males %)	Age (mean±SD (range, in years))	Sports disciplines	Level	Hours of training per week	Previous years of training	Number of controls
Douglas, 1997[30]	140 (73)	30±1 (18–39)	Triathlon	Ironman, Hawaii	21		
D'Andrea, 2002[35]	263 (60.5)	E: 28.1±4.2, S: 27.2±5.4	Endurance and strength	Top competitive	15–20	4	
Abergel, 2004[74]	286 (100)	28.4±3.2	Cycling	Professional			52
Sharwood, 2004[31]	148		Triathlon	Ironman, South Africa			
Maldonado, 2006[26]	212 (100)	20±5.7	Soccer	Competitive	15	2–25	211
Babaee Bigi, 2007[22]	100 (100)	22.1±3.6	Strength	Professional			128
Basavarajaiah, 2008[75]	600 (100)	BA: 20.5±5.8, WA: 20.2±4.9. (14–35)	Mixed	National level	14		150
Molina, 2008[16]	183 (100)	39±9	Long distance running	Marathon runners			305
Miranda-Vilela, 2009[32]	125 (60.8)	(15–67)	Long distance running	Trained athletes			
D'Andrea, 2012[47]	410 (70.7)	E: 28.7±10.7, S: 29.2±11.2. (18–40)	Endurance and strength	Elite	15–20	4	240
Pagourelias, 2013[76]	108 (100)	E: 31.2±10.4, S: 27.4±5.7	Endurance and strength	Moderately and highly trained	15–17	10–11	26
Vitarelli, 2013[77]	105	E: 28.7±10.7, S: 30.3±9.4, Mix: 29.4±9.8	Endurance and strength	Competitive	15	6	35
Malhotra, 2011[53]	1 473 (49.7)	♂: 19±2, ♀: 19±2	Mixed	NCAA Division I			
Chandra, 2014[78]	4081 (80.5)	19.5±5.2 (14–35)	Mixed	Regional to international	15		7764

The studies are presented in chronological order dependent on increasing cut-off values for hypertension.
♀, women; ♂, men; BA, black athletes; E, endurance; NCAA, National Collegiate Athletic Association; S, strength; WA, white athletes.

Table 2 Blood pressure and prevalence of hypertension

First author, year of publication	Definition of hypertension	Athletes N	Athletes Percentage with hypertension	Athletes SBP (mean±SD, mm Hg)	Athletes DBP (mean±SD, mm Hg)	Controls SBP (mean, mm Hg)	Controls DBP (mean, mm Hg)
Helzberg, 2010[37]	≥130/85	101	45.1				
van Buuren, 2013[63]	>135/80	3	1.0	125.7±17.8	77.3±10.6		
Lively, 1999[5]	≥140/90	22	3.7				
Sofi, 2008[64]	≥140/90	37	0.1				
Pelliccia, 2010[40]	≥140/90	0	0.0				
Munoz, 2009[65]	SBP ≥140 and/or DBP ≥90	3	2.2	♂ 117±12, ♀ 109±11	♂ 73±10, ♀ 72±8		
De Matos, 2011[6]	SBP ≥140 and/or DBP ≥90	49	7.9				
Berge, 2013[13]	SBP ≥140 and/or DBP ≥90	39	7.0	122±11	69±8	123.8	70.8
Weiner, 2013[14]	SBP ≥140 and/or DBP ≥90	1	0.5	Football: 116±8, Rowing: 114±9	Football: 64±8, Rowing: 60±9		
Tucker, 2009[29]	SBP ≥140 and/or DBP ≥90, or anti-HT medication	67	13.8	127	75	112.0	72.0
Guo, 2013[34]	SBP ≥140 and/or DBP ≥90, or anti-HT medication	56	41.9	LBW: ♂ 121.2±9.0, ♀ 110.8±10.1 UBW: ♂ 137.4±13.8, ♀ 124.6 ±15.2	LBW: ♂ 81.5±9.0, ♀ 73.6±8.2 UBW: ♂ 92.2 ±9.6, ♀ 83.8±12.0		
Karpinos, 2013[18]	SBP ≥140 and/or DBP ≥90, or anti-HT medication, or self-reported HT	84	13.2	Football: 126.4±11.0 Non-football: 122.5±9.8	Football: 75.3±9.9 Non-football: 72.3±9.0		
Lewis, 1989[66]	>140/90	4	1.5				
Corrado, 2006[23]	>140/90	205	0.5				
Thunenkotter, 2010[28]	>140/90	12	2.1	119±11 (≤190)	73±9 (≤105)		
Wilson, 2012[59]	>140/90	10	0.8				
Gati, 2013[43]	>140/90	12	0.5	120±12.6		115.0	
Zaidi, 2013[39]	>140/90	0	0.0				
Riding, 2013[49]	SBP >140	17	1.4	Arabic: 120±13, BA: 125.2±10.9, WA: 126.4 ±11.8	Arabic: 71±9, BA: 73.6 ±8.4, WA: 74.5±10.1	118.1	72.1
Di Luigi, 2004[67]	SBP >140 and/or DBP >90	587	1.8	♂ 119.8±12.5, ♀ 115.4 ±12.1	♂ 72.8±9.3, ♀ 70.2 ±9.0		
Magalski, 2011[68]	SBP >140 and/ or DBP >90	26	2.7				
Papadakis, 2011[41]	SBP >140 and/or DBP >90	22	0.8	BA: 116.5±13.1, WA: 111.8±11.0		121.7	
Schmied, 2013[25]	SBP >140 and/or DBP >90	12	5.7	125±4	72±2		
Maron, 1987[69]	>145/90	1	0.2				
Rontoyannis, 1998[27]	≥160/95	18	9.5				
Urhausen, 1996[70]		0	0.0				
Pelliccia, 2000[71]		3	0.3				
Maskhulia, 2006[24]		2	0.9				
Caselli, 2011[42]		1	0.2	117±10	76±6	119.0	75.0
Noseworthy, 2011[36]		3	0.3	116.6±8.6	56.9±11.5		
Varga-Pinter, 2011[45]		0	0.0	♂ 126±13, ♀ 116±13	♂ 80±10, ♀ 75±13		
Pougnet, 2012[72]		32	16.0	123.4	77.5		
Schmied, 2012[73]		2	0.2				
Zaidi, 2013[38]	>120/80	0	0.0				
Berry, 1949[46]				119.1±13.1	77.4±8.1		
Andersen, 1956[48]				20–29 years: 132.5 ±15.6, 30–39 years: 133.8±14.1	20–29 years: 80.6 ±10.9, 30–39 years: 83.0±3.4	135.6	85.4
Siegel, 1992[44]				117.1	71.8		
Douglas, 1997[30]				122±1	74±1		
D'Andrea, 2002[35]				E: 116.8±9.1, S: 137.9 ±7.1	E: 72.7±4.9, S: 78.9 ±4.0		
Abergel, 2004[74]				120±9	68±9	126.0	77.0

Continued

Table 2 Continued

First author, year of publication	Definition of hypertension	Athletes: N	Athletes: Percentage with hypertension	Athletes: SBP (mean±SD, mm Hg)	Athletes: DBP (mean±SD, mm Hg)	Controls: SBP (mean, mm Hg)	Controls: DBP (mean, mm Hg)
Sharwood, 2004[31]				133±12	78±9		
Maldonado, 2006[26]				127±7.2	70±9.0	130.0	73.0
Babaee Bigi, 2007[22]				137.5±5.7	86.2±6.5		
Basavarajaiah, 2008[75]				BA: 118±7, WA: 115±6		119.0	
Molina, 2008[16]				125±15	76±9	133.0	80.0
Miranda-Vilela, 2009[32]				♂ 117.1±0.9, ♀ 112.0 ±1.0	♂ 74.7±1.0, ♀ 69.3 ±1.1		
D'Andrea, 2012[47]				E: 115.8±6.1, S: 132.9 ±8.1	E: 72.7±4.9, S: 75.9 ±4.0	120.3	74.6
Pagourelias, 2013[76]				E: 120±7, S: 125.4±8	E: 70.3±8.5, S: 78±3	120.6	75.0
Vitarelli, 2013[77]				E: 121.9±6.8, S: 129.1 ±7.4, mix: 123.2±7.1	E: 71.3±5.4, S: 76.3 ±4.8, mix: 70.9±4.6	120.6	75.2
Malhotra, 2011[53]				♂ 126±12, ♀ 115±11	♂ 75±9, ♀ 73±22		
Chandra, 2014[78]				114.5±13.1	69.3±21.8	120.6	69.5

The studies are presented in chronological order dependent on increasing cut-off values for hypertension.
♀, women; ♂, men; BA, black athletes; DBP, diastolic blood pressure; E, endurance; HT, hypertension; LBW, limited body weight; S, strength; SBP, systolic blood pressure; UBW, unlimited maximum body weight; WA, white athletes.

137.9±7.1 mm Hg (Italian male strength sports athletes (mean age 27.2 years)).[35] Mean DBP ranged from 56.9±11.5 mm Hg (young college level athletes in the USA (mean age 18.4 years))[36] to 92.2±9.6 mm Hg (male Chinese strength sports athletes with mean body weight 130 kg (mean age 21.7 years)).[34] No studies reported ambulatory BP measurements.

Among the 16 studies that included non-athletes as controls, BP was lower in athletes than in controls in 9 studies and higher in athletes in 7 studies (figure 2). Only 3 of the 16 studies reported prevalence of hypertension in controls and 2 studies found more hypertension among athletes than controls. Overall, there was no significant difference in BP between athletes and controls.

Figure 3 shows the mean BP in different categories of athletes. Males had significantly higher BP than females (121.2 ±4.5/75.1±2.9 vs 113.5±2.9/71.9±2.6 mm Hg, $p<0.05$), but there was no significant difference in SBP between white and black athletes. We found that strength-trained athletes had higher BP than endurance-trained athletes (131.3±5.3/77.3 ±1.4 vs 118.6±2.8/71.8±1.2 mm Hg, $p<0.05$), while there was a trend towards higher BP in athletes training ≥10 h/week compared with those training <10 h/week (121.8±3.8/73.8 ±2.5 vs 117.6±3.3/66.8±6.9 mm Hg, p=0.058). There was no major difference between American football, soccer, triathlon and long distance running (figure 4).

Prevalence of hypertension in athletes

Hypertension was defined in 11 different ways in the 25 studies presenting a definition (table 2). The most often used criteria for hypertension ranged from SBP ≥140 or DBP ≥90 mm Hg to BP>140/90 mm Hg. The lowest cut-off value for hypertension was BP ≥130/85 mm Hg[37] and the highest cut-off value was ≥160/95 mm Hg.[27] Three studies also used antihypertensive medication to define hypertension,[18 29 34] one accepted self-reported hypertension[18] and one only included participants with BP≤120/80 mm Hg.[38]

The prevalence of hypertension varied from 83%[34] to 0% (table 2).[39 40] The prevalence of hypertension was lower in studies that were restricted to athletes within the age range 18–40 years and six studies excluded patients with high BP, mostly >140/90 mm Hg.[38–43]

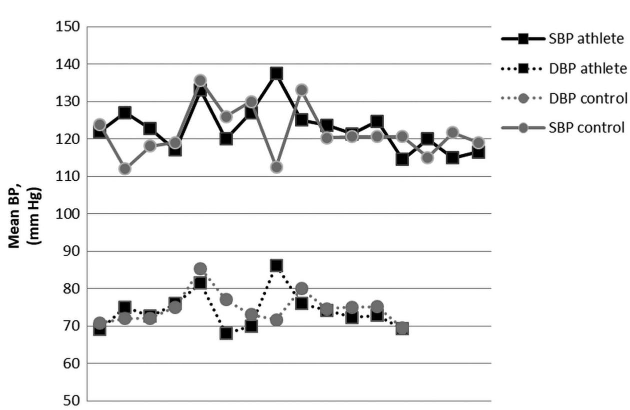

Figure 2 Mean systolic blood pressure (SBP; continuous line) and diastolic blood pressure (DBP; dotted line) in athletes (black squares) and controls (grey circles).

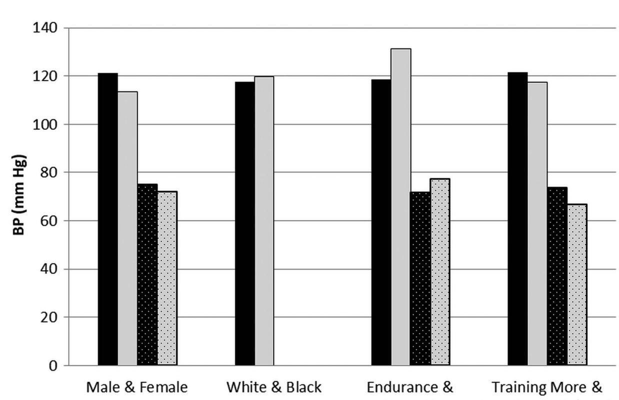

Figure 3 Blood pressure (BP) in relation to gender, ethnicity, type of training and hours of training per week.

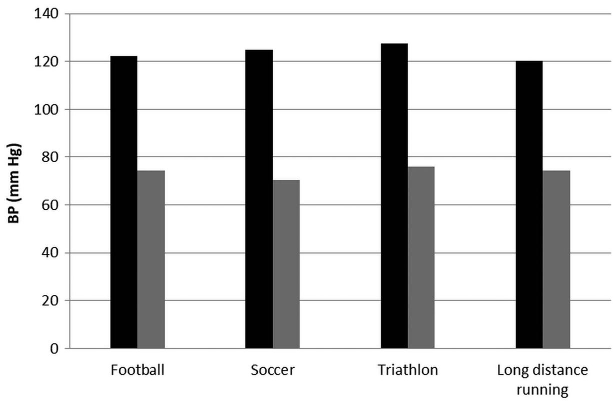

Figure 4 Blood pressure (BP) in different sports disciplines.

Method of measurement of BP in athletes

Some descriptions of measurement methods were present in 21 studies (figure 5; see online supplementary figure S3). BP was measured in the sitting position in 10 studies and in a supine position in 6 studies. At least 5 min of rest prior to BP recordings was required in 11 studies, while only 4 informed about time from physical activity to BP measurement.[6 13 44 45] Athletes abstained from caffeine and/or smoking prior to BP recordings in two studies[6 44] and no studies informed about the physical environment where the BP measurements took place. Only eight studies reported whether an appropriate cuff size was used. In the eight studies using a 'standard' mercury sphygmomanometer, the method of measurement performance was reported in three studies.[45–47] Only the three studies that used an automated BP device reported the device type and manufacturer.[13 26 29] A single measurement was used in five studies, but repeated in three of these if BP was high. The lowest of these values was registered in two studies[18 48] and the highest in one.[27] BP was recorded two and three times in six and four studies, respectively, and there was a significant difference in SBP between one and two BP recordings (127±4.7 vs 118±4.0 mm Hg, $p<0.05$). Choice of arm for measurement was presented in five studies and no study measured BP in both arms. Three studies recommended repeated BP recordings on a separate occasion if the BP was elevated. Only one study referred athletes with elevated office BP to ambulatory BP measurement.[49]

Association between BP and left ventricular hypertrophy

Three of the four studies relating high BP to left ventricular hypertrophy showed a significant positive linear association, either between BP and indexed left ventricular mass,[13] between resting SBP and left ventricle mass and left ventricle wall thickness,[49] or between SBP and the RaVL lead in ECG.[29] One study found no association between SBP and relative wall thickness.[30]

DISCUSSION

The most striking finding in this review was that the methods of BP measurement in athletes were poorly standardised and varied widely. The Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure states that at least two measurements shall be made and the averaged recorded,[33] and the European guidelines state that BP shall be measured three times after 5–10 min rest in the sitting position and the mean of the last two measurements shall be registered.[21] The IOC has recommended BP recordings from both arms during preparticipation cardiac screening.[50] All guidelines also recommend use of ambulatory BP measurements, but nearly all studies in our review were negligent to all these recommendations, as was a study among general practitioners in the UK.[51]

Given this background, it was difficult to give an estimate of BP or prevalence of hypertension in athletes. Naturally, the prevalence will be dependent on the definition of hypertension and varied from 0% to 83% in a subgroup of heavy weightlifters. The study with the lowest cut-off value (≥130/85 mm Hg) also had the highest overall prevalence of hypertension (45.1%,

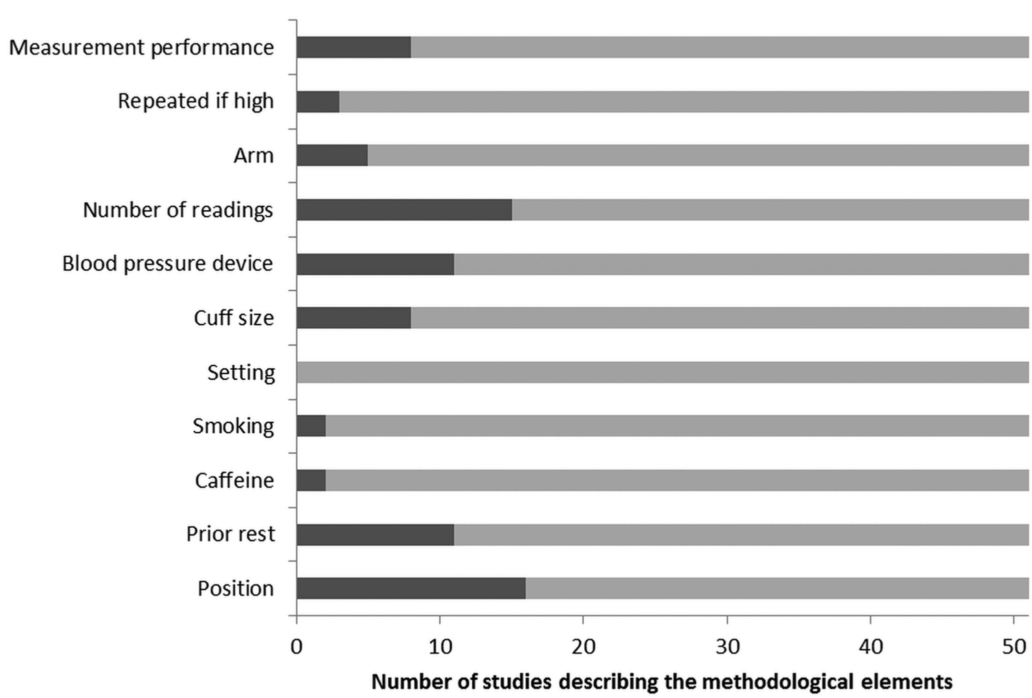

Figure 5 Number of studies describing each of the recommended elements in blood pressure measurements.

compared with 17% in an age-matched and gender-matched control group).[37] The study with the highest cut-off value for hypertension (≥160/90 mm Hg) still reported a prevalence of 9.5%,[27] but this study included athletes with the highest age (36.4±4.5 years), and selectively reported the highest of the measured BPs.

Two-thirds of the studies reported mean BP in the prehypertensive range. There are several possible explanations for this. First, in many of these studies, BP was measured only once and one recording is often higher than the mean of two recordings. Second, the cuff size might have been too small for the muscular upper arms of athletes, which means that BP is measured falsely too high since only a minority of studies reported if they had used an appropriate cuff size. Third, the environment was probably not quiet in most studies and the athletes had no rest prior to the BP recordings. Fourth, the BP was recorded postseason. In a recent study of 132 professional American-style football participants, both SBP and DBP increased significantly from before to after the season.[14] There is also the possibility that many athletes do have BP in the prehypertensive range, as suggested by several studies in this review and as supported by the trend towards a higher BP in athletes training ≥10 h/week than in those training <10 h/week. Physical activity has a well-known BP-lowering effect in the general population[33] and studies of 'exercise as medicine' report a decrease in BP of 4–9 mm Hg[33]; but the amount of physical activity in these studies is often limited to 30 min most days a week. In our review, most athletes were 'elite' or 'professional', training on average 14.4 h per week or had been training vigorously for an average of 8.8 years, and it may well be that BP reacts differently to such amounts of training than to more moderate amounts of physical activity. There can be many biological reasons for high BP in athletes. First, the mental stress associated with competition at a high level might increase the athletes' BP, as indicated by the finding of a larger difference in SBP between professional athletes and controls (4.4 mm Hg, p=0.350), than that between non-professional athletes and controls (0.2 mm Hg, p=0.916, data not shown). Second, BP might be increased due to 'spurious systolic hypertension' when BP is measured in the upper arm in athletes.[52] Third, some athletes might use BP-increasing drugs, as shown in several studies,[18 53] which is an argument for collecting information about use of medication during preparticipation screening of athletes.[33]

We also found interesting differences between subgroups of athletes. For example, male athletes had significantly higher BP than female athletes; this was also found in a small study of 15 pairs in sports dancing, which showed that male dancers had significantly higher BP than their female counterparts, despite similar levels of training.[54] We also found higher BP and a higher prevalence of hypertension in strength-trained athletes than in endurance-trained athletes, in accordance with the 'Morganroth hypothesis'.[55] The highest prevalence of hypertension, of 83.0%, was found in professional male Chinese strength athletes, predominantly weightlifters, in the unlimited maximum body weight class.[33]

There is increasing concern about the effects of vigorous, long-term athletic training on cardiovascular health[56–58] and it is possible that some of the harmful effects may be mediated through high BP. High BP in adulthood increases risk of cardiovascular disease in the general population[2 3]; we and others have found an association between high BP and left ventricular hypertrophy in athletes.[13 54 59] Whether this is a benign physiological adaptation to high BP or a beginning of pathological remodelling is not known. It may also be that left ventricular hypertrophy provokes hypertension or that other factors confound the association between high BP and left ventricular hypertrophy. High BP may also be a part of the explanation for the fivefold increased risk of atrial fibrillation in endurance athletes[15 60–62] and exercise-induced arrhythmogenic right ventricular cardiomyopathy[56] through repeated bouts of high BP on myocyte junctions in the atria and the ventricles.

Clinical impact and conclusions

BP and prevalence of hypertension in athletes varies considerably partly because of variations in measurement methods, but type and intensity of training seem to play a role. Strength-trained athletes have significantly higher BP than endurance-trained athletes and vigorous physical activity does not seem to reduce BP in athletes compared with controls. Some studies found an association between high BP and left ventricular hypertrophy, but the clinical impact of high BP in athletes is not known. Future studies should adhere more rigorously to the recommendations for measurement of BP and should be designed to determine more precisely the prevalence, determinants and prognostic significance of hypertension in athletes.

Contributors All authors contributed to study design, discussion of the data and the final manuscript. CBI performed the systematic searches and extracted the data. HMB controlled the extracted data, performed the analyses and wrote the first draft of the manuscript.

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REFERENCES

1 Kearney PM, Whelton M, Reynolds K, *et al*. Global burden of hypertension: analysis of worldwide data. *Lancet* 2005;365:217–23.
2 Sundstrom J, Neovius M, Tynelius P, *et al*. Association of blood pressure in late adolescence with subsequent mortality: cohort study of Swedish male conscripts. *BMJ* 2011;342:d643.
3 Gray L, Lee IM, Sesso HD, *et al*. Blood pressure in early adulthood, hypertension in middle age, and future cardiovascular disease mortality: HAHS (Harvard Alumni Health Study). *J Am Coll Cardiol* 2011;58:2396–403.
4 Sealy DP, Pekarek L, Russ D, *et al*. Vital signs and demographics in the preparticipation sports exam: do they help us find the elusive athlete at risk for sudden cardiac death? *Curr Sports Med Rep* 2010;9:338–41.
5 Lively MW. Preparticipation physical examinations: a collegiate experience. *Clin J Sport Med* 1999;9:3–8.
6 De Matos LD, Caldeira NA, Perlingeiro PS, *et al*. Cardiovascular risk and clinical factors in athletes: 10 years of evaluation. *Med Sci Sports Exerc* 2011;43:943–50.
7 Corrado D, Basso C, Schiavon M, *et al*. Pre-participation screening of young competitive athletes for prevention of sudden cardiac death. *J Am Coll Cardiol* 2008;52:1981–9.
8 Leddy JJ, Izzo J. Hypertension in athletes. *J Clin Hypertens (Greenwich)* 2009;11:226–33.
9 Pelliccia A, Fagard R, Bjornstad HH, *et al*. Recommendations for competitive sports participation in athletes with cardiovascular disease: a consensus document from the Study Group of Sports Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. *Eur Heart J* 2005;26:1422–45.
10 Levy D, Garrison RJ, Savage DD, *et al*. Prognostic implications of echocardiographically determined left ventricular mass in the Framingham Heart Study. *N Engl J Med* 1990;322:1561–6.
11 Manolis AJ, Rosei EA, Coca A, *et al*. Hypertension and atrial fibrillation: diagnostic approach, prevention and treatment. Position paper of the Working Group 'Hypertension Arrhythmias and Thrombosis' of the European Society of Hypertension. *J Hypertens* 2012;30:239–52.
12 Maron BJ, Pelliccia A. The heart of trained athletes: cardiac remodeling and the risks of sports, including sudden death. *Circulation* 2006;114:1633–44.
13 Berge HM, Gjerdalen GF, Andersen TE, *et al*. Blood pressure in professional male football players in Norway. *J Hypertens* 2013;31:672–9.
14 Weiner RB, Wang F, Isaacs SK, *et al*. Blood pressure and left ventricular hypertrophy during American-style football participation. *Circulation* 2013;128:524–31.
15 Grimsmo J, Grundvold I, Maehlum S, *et al*. High prevalence of atrial fibrillation in long-term endurance cross-country skiers: echocardiographic findings and possible

predictors—a 28–30 years follow-up study. *Eur J Cardiovasc Prev Rehabil* 2010;17:100–5.
16 Molina L, Mont L, Marrugat J, *et al*. Long-term endurance sport practice increases the incidence of lone atrial fibrillation in men: a follow-up study. *Europace* 2008;10:618–23.
17 Milne C, Waddell R, Trease L, *et al*. Mythbusters in rowing medicine and physiotherapy: nine experts tackle five clinical conundrums. *Br J Sports Med* 2014;48:1525–8.
18 Karpinos AR, Roumie CL, Nian H, *et al*. High prevalence of hypertension among collegiate football athletes. *Circ Cardiovasc Qual Outcomes* 2013;6:716–23.
19 Berge HM, Andersen TE, Solberg EE, *et al*. High ambulatory blood pressure in male professional football players. *Br J Sports Med* 2013;47:521–5.
20 Ljungqvist A, Jenoure P, Engebretsen L, *et al*. The International Olympic Committee (IOC) Consensus Statement on periodic health evaluation of elite athletes March 2009. *Br J Sports Med* 2009;43:631–43.
21 Mancia G, De BG, Dominiczak A, *et al*. 2007 Guidelines for the Management of Arterial Hypertension: the task force for the management of arterial hypertension of the European Society of Hypertension (ESH) and of the European Society of Cardiology (ESC). *J Hypertens* 2007;25:1105–87.
22 Babaee Bigi MA, Aslani A. Aortic root size and prevalence of aortic regurgitation in elite strength trained athletes. *Am J Cardiol* 2007;100:528–30.
23 Corrado D, Basso C, Pavei A, *et al*. Trends in sudden cardiovascular death in young competitive athletes after implementation of a preparticipation screening program. *JAMA* 2006;296:1593–601.
24 Maskhulia L, Chabashvili N, Kakhabrishvili Z, *et al*. Electrocardiographic patterns and systolic and diastolic functions of the heart in the highly trained football players with increased left ventricular mass. *Georgian Med News* 2006;3:76–80.
25 Schmied C, Di Paolo FM, Zerguini AY, *et al*. Screening athletes for cardiovascular disease in Africa: a challenging experience. *Br J Sports Med* 2013;47:579–84.
26 Maldonado J, Pereira T, Polonia J, *et al*. Modulation of arterial stiffness with intensive competitive training. *Rev Port Cardiol* 2006;25:709–14.
27 Rontoyannis GP, Stalikas A, Sarros G, *et al*. Medical, morphological and functional aspects of Greek football referees. *J Sports Med Phys Fitness* 1998;38:208–14.
28 Thunenkotter T, Schmied C, Dvorak J, *et al*. Benefits and limitations of cardiovascular pre-competition screening in international football. *Clin Res Cardiol* 2010;99:29–35.
29 Tucker AM, Vogel RA, Lincoln AE, *et al*. Prevalence of cardiovascular disease risk factors among National Football League players. *JAMA* 2009;301:2111–19.
30 Douglas PS, O'Toole ML, Katz SE, *et al*. Left ventricular hypertrophy in athletes. *Am J Cardiol* 1997;80:1384–8.
31 Sharwood KA, Collins M, Goedecke JH, *et al*. Weight changes, medical complications, and performance during an Ironman triathlon. *Br J Sports Med* 2004;38:718–24.
32 Miranda-Vilela AL, Pereira LC, Goncalves CA, *et al*. Pequi fruit (Caryocar brasiliense Camb.) pulp oil reduces exercise-induced inflammatory markers and blood pressure of male and female runners. *Nutr Res* 2009;29:850–8.
33 Chobanian AV, Bakris GL, Black HR, *et al*. Seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. *Hypertension* 2003;42:1206–52.
34 Guo J, Zhang X, Wang L, *et al*. Prevalence of metabolic syndrome and its components among Chinese professional athletes of strength sports with different body weight categories. *PLoS ONE* 2013;8:e79758.
35 D'Andrea A, Limongelli G, Caso P, *et al*. Association between left ventricular structure and cardiac performance during effort in two morphological forms of athlete's heart. *Int J Cardiol* 2002;86:177–84.
36 Noseworthy PA, Weiner R, Kim J, *et al*. Early repolarization pattern in competitive athletes: clinical correlates and the effects of exercise training. *Circ Arrhythm Electrophysiol* 2011;4:432–40.
37 Helzberg JH, Waeckerle JF, Camilo J, *et al*. Comparison of cardiovascular and metabolic risk factors in professional baseball players versus professional football players. *Am J Cardiol* 2010;106:664–7.
38 Zaidi A, Ghani S, Sharma R, *et al*. Physiologic right ventricular adaptation in elite athletes of African and Afro-Caribbean origin. *Circulation* 2013;127:1783–92.
39 Zaidi A, Ghani S, Sheikh N, *et al*. Clinical significance of electrocardiographic right ventricular hypertrophy in athletes: comparison with arrhythmogenic right ventricular cardiomyopathy and pulmonary hypertension. *Eur Heart J* 2013;34:3649–56.
40 Pelliccia A, Kinoshita N, Pisicchio C, *et al*. Long-term clinical consequences of intense, uninterrupted endurance training in Olympic athletes. *J Am Coll Cardiol* 2010;55:1619–25.
41 Papadakis M, Carre F, Kervio G, *et al*. The prevalence, distribution, and clinical outcomes of electrocardiographic repolarization patterns in male athletes of African/Afro-Caribbean origin. *Eur Heart J* 2011;32:2304–13.
42 Caselli S, Di PR, Di Paolo FM, *et al*. Left ventricular systolic performance is improved in elite athletes. *Eur J Echocardiogr* 2011;12:514–19.
43 Gati S, Sheikh N, Ghani S, *et al*. Should axis deviation or atrial enlargement be categorised as abnormal in young athletes? The athlete's electrocardiogram: time for re-appraisal of markers of pathology. *Eur Heart J* 2013;34:3641–8.
44 Siegel D, Benowitz N, Ernster VL, *et al*. Smokeless tobacco, cardiovascular risk factors, and nicotine and cotinine levels in professional baseball players. *Am J Public Health* 1992;82:417–21.
45 Varga-Pinter B, Horvath P, Kneffel Z, *et al*. Resting blood pressure values of adult athletes. *Kidney Blood Press Res* 2011;34:387–95.
46 Berry WT, Beveridge JB, . The diet, haemoglobin values, and blood pressure of Olympic athletes. *Br Med J* 1949;1:300–4.
47 D'Andrea A, Cocchia R, Riegler L, *et al*. Aortic stiffness and distensibility in top-level athletes. *J Am Soc Echocardiogr* 2012;25:561–7.
48 Andersen KL, Elvik A. The resting arterial blood pressure in athletes. *Acta Med Scand* 1956;153:367–71.
49 Riding NR, Salah O, Sharma S, *et al*. ECG and morphologic adaptations in Arabic athletes: are the European Society of Cardiology's recommendations for the interpretation of the 12-lead ECG appropriate for this ethnicity? *Br J Sports Med* 2014;48:1138–43.
50 Ljungqvist A, Jenoure PJ, Engebretsen L, *et al*. The International Olympic Committee (IOC) consensus statement on periodic health evaluation of elite athletes. *Clin J Sport Med* 2009;19:347–65.
51 Heneghan C, Perera R, Mant D, *et al*. Hypertension guideline recommendations in general practice: awareness, agreement, adoption, and adherence. *Br J Gen Pract* 2007;57:948–52.
52 Palatini P. Cardiovascular effects of exercise in young hypertensives. *Int J Sports Med* 2012;33:683–90.
53 Malhotra R, West JJ, Dent J, *et al*. Cost and yield of adding electrocardiography to history and physical in screening Division I intercollegiate athletes: A 5-year experience. *Heart Rhythm* 2011;8:721–7.
54 Zemva A, Rogel P. Gender differences in athlete's heart: association with 24-h blood pressure. A study of pairs in sport dancing. *Int J Cardiol* 2001;77:49–54.
55 Naylor LH, George K, O'Driscoll G, *et al*. The athlete's heart: a contemporary appraisal of the 'Morganroth hypothesis'. *Sports Med* 2008;38:69–90.
56 Heidbuchel H, Prior DL, La GA. Ventricular arrhythmias associated with long-term endurance sports: what is the evidence? *Br J Sports Med* 2012;46(Suppl 1):i44–50.
57 O'Keefe JH, Patil HR, Lavie CJ, *et al*. Potential adverse cardiovascular effects from excessive endurance exercise. *Mayo Clin Proc* 2012;87:587–95.
58 Elliott AD, La GA. The right ventricle following prolonged endurance exercise: are we overlooking the more important side of the heart? A meta-analysis. *Br J Sports Med* 2014 Oct 3. doi:10.1136/bjsports-2014-093895. [Epub ahead of print].
59 Wilson MG, Chatard JC, Carre F, *et al*. Prevalence of electrocardiographic abnormalities in West-Asian and African male athletes. *Br J Sports Med* 2012;46:341–7.
60 Abdulla J, Nielsen JR. Is the risk of atrial fibrillation higher in athletes than in the general population? A systematic review and meta-analysis. *Europace* 2009;11:1156–9.
61 Pelliccia A, Maron BJ, Di Paolo FM, *et al*. Prevalence and clinical significance of left atrial remodeling in competitive athletes. *J Am Coll Cardiol* 2005;46:690–6.
62 Eshoo S, Ross DL, Thomas L. Impact of mild hypertension on left atrial size and function. *Circ Cardiovasc Imaging* 2009;2:93–9.
63 van Buuren F, Mellwig KP, Butz T, *et al*. Left ventricular mass and oxygen uptake in top handball athletes. *Int J Sports Med* 2013;34:200–6 .
64 Sofi F, Capalbo A, Pucci N, *et al*. Cardiovascular evaluation, including resting and exercise electrocardiography, before participation in competitive sports: cross sectional study. *BMJ* 2008;337:a346.
65 Munoz L, Norgan G, Rauschhuber M, *et al*. An exploratory study of cardiac health in college athletes. *Appl Nurs Res* 2009;22:228–35.
66 Lewis JF, Maron BJ, Diggs JA, *et al*. Preparticipation echocardiographic screening for cardiovascular disease in a large, predominantly black population of collegiate athletes. *Am J Cardiol* 1989;64:1029–33.
67 Di Luigi L, Pelliccia A, Bonetti A, *et al*. Clinical efficacy and preventive role of the pre-participation physical examination in Italy. *Med Sport* 2004;57:243–70.
68 Magalski A, McCoy M, Zabel M, *et al*. Cardiovascular screening with electrocardiography and echocardiography in collegiate athletes. *Am J Med* 2011;124:511–18.
69 Maron BJ, Bodison SA, Wesley YE, *et al*. Results of screening a large group of intercollegiate competitive athletes for cardiovascular disease. *J Am Coll Cardiol* 1987;10:1214–21.
70 Urhausen A, Monz T, Kindermann W. Sports-specific adaptation of left ventricular muscle mass in athlete's heart. I. An echocardiographic study with combined isometric and dynamic exercise trained athletes (male and female rowers). *Int J Sports Med* 1996;17(Suppl 3):S145–51.
71 Pelliccia A, Maron BJ, Culasso F, *et al*. Clinical significance of abnormal electrocardiographic patterns in trained athletes. *Circulation* 2000;102:278–84.
72 Pougnet R, Costanzo LD, Lodde B, *et al*. Cardiovascular risk factors and cardiovascular risk assessment in professional divers. *Int Marit Health* 2012;63:164–9.

73 Schmied C, Notz S, Cribari M, *et al*. Cardiac pre-competition screening in Swiss athletes. Current situation in competitive athletes and short-time assessment of an exemplary local screening program. *Swiss Med Wkly* 2012;142:w13575.
74 Abergel E, Chatellier G, Hagege AA, *et al*. Serial left ventricular adaptations in world-class professional cyclists: implications for disease screening and follow-up. *J Am Coll Cardiol* 2004;44:144–9.
75 Basavarajaiah S, Boraita A, Whyte G, *et al*. Ethnic differences in left ventricular remodeling in highly-trained athletes relevance to differentiating physiologic left ventricular hypertrophy from hypertrophic cardiomyopathy. *J Am Coll Cardiol* 2008;51:2256–62.
76 Pagourelias ED, Kouidi E, Efthimiadis GK, *et al*. Right atrial and ventricular adaptations to training in male Caucasian athletes: an echocardiographic study. *J Am Soc Echocardiogr* 2013;26:1344–52.
77 Vitarelli A, Capotosto L, Placanica G, *et al*. Comprehensive assessment of biventricular function and aortic stiffness in athletes with different forms of training by three-dimensional echocardiography and strain imaging. *Eur Heart J Cardiovasc Imaging* 2013;14:1010–20.
78 Chandra N, Bastiaenen R, Papadakis M, *et al*. The prevalence of ECG anomalies in young individuals; relevance to a nationwide cardiac screening program. *J Am Coll Cardiol* 2014;63:2028–34.