Original Article

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Body Mass Index in Master Athletes: Review of the Literature

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Background: Masters athletes (MAs) have led a physically active lifestyle for an extended period of time or initiated exercise/sport in later life. Given the benefits of physical activity and exercise we investigated if body mass index (BMI), an indirect health indicator of obesity, was clinically superior in MAs as compared to controls or the general population.
Methods: Seven databases (Medline, PubMed, Scopus, Web of Science, CINAHL, PsycINFO, Cochrane) were electronically searched for studies on BMI (kg/m^2) or as a percentage of BMI categories (underweight, normal, overweight, obesity) in MAs.
Results: Of the initial yield of 7,431 papers, 60 studies met our inclusion criteria and were used in this literature review. Studies identified were classified as: endurance sports (n = 14), runners (n = 14), mixed sports (n = 8), cyclists (n = 4), soccer (n = 4) swimmers (n = 3), non-specific (n = 3), orienteering (n = 2), World Masters Games (n = 2) and individual sports (n = 5). Where BMI was presented for the group of MAs the mean was 23.8 kg/m^2 (± 1.1) with a range from 20.8 kg/m^2 (endurance runners) to 27.3 kg/m^2 (soccer players), this was significantly lower ($p < 0.001$) than controls (−9.5%, 26.13 ± 1.7 kg/m^2). Where gender specific BMI was reported the mean for male MAs was 23.6 kg/m^2 (± 1.5) (range 22.4 kg/m^2 endurance to 26.4 kg/m^2 swimmers) and 22.4 kg/m^2 (± 1.2) for female MAs (range 20.8 kg/m^2 mixed to 24.7 kg/m^2 WMG).
Conclusion: In most, but not all studies the BMI of MAs was significantly lower than controls. A clinically superior BMI affords MAs reduced risk with regard to a number of cardiometabolic diseases, osteoarthritis and certain types of cancers.

Key Words: BMI, Veteran athlete, World masters games, Physical activity, Obesity

INTRODUCTION

Globally, the prevalence of overweight and obesity has increased at an alarming rate throughout the world. In Australia, the percentage of adults classified as obese has increased two fold in the past two decades with approximately 11.2 million adults classified as overweight or obese, 42 percent of which are males and 29 percent females [1]. Extensive literature illustrates that there is an elevated risk of developing a number of chronic diseases and disorders with being overweight and obese and these include, dyslipi-

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demia, coronary heart disease, cardiovascular disease, cerebrovascular disease, gall bladder disease, sleep apnea, mental illness (depression/anxiety), insulin resistance, hypertension (HTN), atherosclerosis, osteoarthritis, and some cancers (kidney, postmenopausal breast, endometrial, colon) [2]. One common clinical measure of overweight and obesity easily attained with no specialized equipment is body mass index (BMI), this mathematical calculation only requires a participant's mass and height (BMI (kg/m^2) = mass (kg)/height squared (m^2)). The World Health Organization developed an international classification for BMI and includes normal ($18.5 \leq \text{BMI} < 25\ kg/m^2$), overweight ($25 \leq \text{BMI} < 30\ kg/m^2$) and obese ($\text{BMI} \geq 30\ kg/m^2$). This measure is commonly used in medical and sports medicine research [3].

Master athlete (MA) is a term applied to individuals, typically over the age of 35 who train (exercise) on a regular basis to compete in organized competitive sport. There is no definitive age for master athletes as different sporting organizations define MA at differing ages. For example, swimming MAs start at 25 years (although this in turn can vary between events), however USA Track and Field defines the age for MA as 30 years old yet long-distance runners must be at least 40 years old. There is considerable growth in the number of MAs [4], for example greater than 50% of the male finishers and 40% of female finishers of the New York marathon were MAs [4] and the recent World Masters Games (WMG), held quadrennially, attracted 28,676 MAs from 95 countries who competed in 28 different sports [5].

Master athletes have been proposed as a model for successful aging [6]. The benefits of long-term participation in exercise training, whether life-long or adopted in later life, are associated with a number of health benefits which includes decreased health risks associated with various chronic diseases and a reduction of premature death. In our study of WMG MAs [7,8] we have shown a lower BMI as compared to the US and Australian general populations, we believe these findings warranted investigation of BMI in MAs in general. The purpose of this paper was therefore to review the existing published studies on MAs that included BMI as either a primary, secondary or incidental outcome measure. We hypothesized that MAs would have clinically better (i.e. lower) BMIs as compared to a sedentary population or the general population.

MATERIALS AND METHODS

All studies considered for this review were required to have Institutional Review approval for the use of human subjects as per the Declaration of Helsinki [9].

1. Eligibility criteria

For studies to be included in this review, they were required to be full-length research articles, published in scientific journals (e-publication ahead of print, in hard copy print or online), in English with no limit set on the date of publication. Theses (masters or doctoral) were also considered if the degree had been awarded (conferred) to the higher degree candidate who completed the research. Studies included male and/or female participants so long as the participants were described as master athletes, veteran athletes, World Master Games athletes, Pan Pacific Masters Games athletes, or similar. Each of the studies must have included BMI (kg/m^2), gender specific BMI (kg/m^2) or a percentage of World Health Organization BMI categories (underweight, normal, overweight, obese) as an outcome variable. Body mass index was not required to be the primary outcome for consideration. Studies were included despite no comparison group or statistical analyses between groups. Studies were also included if the participants were free from disease or had documented disease (i.e., acute myocardial infarction, atrial fibrillation, HTN).

The following exclusion criteria were applied during study selection: abstracts, case studies, conference presentations, conference posters, letters to the editor, book chapters, unpublished papers or papers not in English. Publications that did not evaluate human subjects or have BMI as an outcome variable were excluded from this review.

2. Search methods

To identify all relevant published studies, a multistep literature search was conducted from December 2017 to March 2018 without any limits on the date of publication in the following electronic databases: CINAHL (via EBSCO, 1982-present), Medline (via OvidSP, 1946-present), PsycINFO (via OvidSP, 1806-present), PubMed (1809-present), Scopus, SPORTDiscus and Web of Science all of which were available from our institutions. Additionally, manual searches of the reference lists of each publication were completed to identify additional studies which possibly met our inclusion criteria. Search terms included the following: BMI, master athlete, older athlete, veteran athlete, World Masters Game(s), Pan Pacific Masters Game(s) and were tailored to the distinctions of the specific database.

3. Data collection and analysis

All search results were exported directly (or manually) into the EndNote (version X8.2) commercially available bibliographic management software program, duplicate records were then removed. Initially, the titles and abstracts were reviewed for possible inclusion or exclusion. Those studies with titles or abstracts warranting review, were subsequently downloaded as full manuscripts to determine if it met the inclusion criteria. The full-text manuscript was then attached to its EndNote citation if it met the inclusion criteria.

The electronic databases search initially retrieved 7,431 records, with four additional records identified through the manual search of reference lists. With duplicates removed a total of 2,824 records were screened for possible inclusion in the literature review. A total of 60 studies met the eligibility criteria and were used in the literature review (Fig. 1).

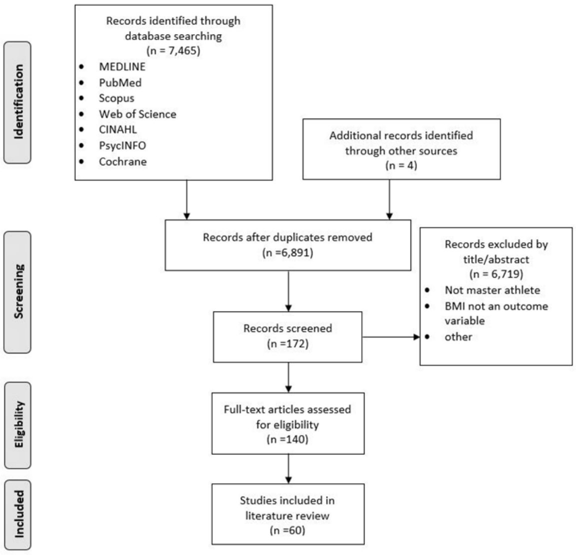

Fig. 1. CONSORT flow diagram of BMI literature search strategy in master athletes.

4. Study characteristics

The 60 studies included in the review were broken down into individual sports (i.e., runners, cycling, orienteering, soccer, x-country skiing, swimming), mixed/non-specified (where participants were from more than one sport or the sport is not specified), endurance (non-specific) and World Masters Games. The total number of master's athletes included in the 60 studies was 13,095. Study size of master athlete participants ranged from 5 to 1,435 (excluding control or comparison groups). Not all studies provided statistical analysis between groups for BMI, where no analysis was available, we have reported the difference between groups as a percentage (±%). Additionally, where there was a non-significant difference between the control group (when sedentary), we have reported the difference as a percentage (%).

RESULTS

The study characteristics of the 60 individual studies are summarized in Table 1 below. Table 1 includes a summary of the manuscript authors, participant characteristics (sports played and participant ages), pertinent study findings and other relevant information of note.

Of the 60 MA studies identified, runners (n = 14) [10-23] and endurance (n = 14) [24-37] categories had the highest number of investigations. This was following by the mixed category with eight studies and cyclists and soccer each with four studies. Swimming and the non-specified category each had three studies and the World Masters Games and orienteering comprised two studies. The remaining MA singular studies included basketball, ice skating, rowing, rugby (union) and cross-country skiing.

We identified a single study [38] that evaluated the BMI in master basketball athletes from the WMG. This was a large cohort study with over 400 participants, the authors compared the MAs BMI according to the World Health Organization [39] classification of obesity (BMI $\geq$ 30 kg/m^2) to the Australian general population (age and gender

Table 1. Study characteristics

			Individual Sports			
Walsh et al. [38] (2011) BASKETBALL	World Masters Games basketball players	408 Athletes • 228 males • 180 females 12,366 controls	Athletes 52.2 (8.0)	Athletes • 30-<40yrs 11.8% obese • 40-<50 yrs 13.4% obese • 50-<60 yrs 14.1% obese • 60-<70 yrs 11.7% obese Controls • 30-<40 yrs 20.4% obese • 40-<50 yrs 25.8% obese • 50-<60 yrs 26.9% obese • 60-<70 yrs 26.9% obese	$p < 0.01$ (all age groups)	• WMG basketball players • Controls from Australian general population who participated in the 2007-2008 national health survey
Bando et al. [47] (2015) ICE SKATERS	Master ice skaters	76 male athletes	54.2 (9.5)	23.4 (2.1)	NA	• no control or comparison group
Sliwicka et al. (2015) ROWERS	Master rowers	15 male rowers 15 controls	Athletes 45.1 (7.3) Controls 48.3 (6.1)	Athletes 25.4 (2.3) Controls 24.8 (2.7)	NS, $p = 0.482$ (+2.3%)	• Controls were age and BMI matched • Sports participation 18 (7.9) yrs • Rowed 4-7d/wk × 5 (1.5) hrs/wk • Controls were active professionals (1.2 (1.5) hrs/wk)
Climstein et al. (GORF 2011) RUGBY	Golden Oldies World Rugby participants	Athletes 120 males > 50yrs 96 males < 50yrs	Athletes >50 yrs 57.2 (4.9) Athletes <50yrs 43.8 (3.8)	Athletes > 50 yrs • 1.1% underweight • 8.5% normal • 53.1% overweight • 37.2% obese Athletes < 50 yrs • 0.0% underweight • 8.1% normal • 48.8% overweight • 43.0% obese	$p < 0.05$ on incidence of obesity between age groups	• All participants were from the Golden Oldies World Rugby competition • Control group were also rugby players however <50 yrs of age
Myrstad (2014) X-COUNTRY SKING	Master cross-country ski racers	509 male athletes 1,867 controls	Athletes 68.9 (65-90) Controls 71.6 (65-87)	Athletes 23.6 Controls 27.0	$p < 0.001$	• Comparison group was 1,768 men, aged matched from general population of Norway • 33.2 yrs endurance training • No SD provided for BMI

Table 1. Continued

			Individual Sports			
Nicholas and Raugh [46] (2011) CYCLISTS	Master cyclists	19 male athletes 18 male controls	Athletes 50.7 (4.0) Controls 57.4 (4.2)	Athletes 22.3 (1.5) Controls 23.8 (2.2)	p = 0.74 (−6.7%)	• Competitive cyclists in US Cycling Federation races >10 yrs • 4.7 (0.7) d/wk • 178.3 (59.3) miles/wk • Control group was active males (non-athletes)
Deruelle et al. [43] (2005) CYCLISTS	Master cyclists athletes	19 male athletes 8 male controls	Athletes 63.1 (3.2) Controls 65.5 (2.3)	Athletes 24.8 (2.5) Controls 26.1 (3.3)	$p < 0.01$	• 9100 (700) km/yr • Control group was untrained older adults
Mukherjee et al. [44] (2014) CYCLISTS	Competitive Masters cyclists	9 male athletes 8 male controls	Athletes 53.4 (3.2) Controls 54.3 (5.0)	Athletes 24.1 (2.5) Controls 25.4 (3.2)	NS (p = 0.36) (−5.4%)	• VO2max 59.1 (+5.2) • Trained > 5 hrs/wk • >8 yrs competitive racing experience • Control group was minimally active (0.5-3.0 hrs/wk) matched for age, height, mass, BMI and waist circumference
Chilelli et al. [45] (2016) CYCLISTS	Master cyclists	47 male athletes	Athletes 46.0 (8.0)	Athletes 23.7 (2.4)	NA	• No comparison group
Kujala et al. [48] (1999) ORIENTEERING	Master orienteering runners	269 male athletes 188 controls	• Athletes 58.5 • Controls 60.3	Athletes 23.2 Controls 25.5	p = 0.0008	• Top-ranked Finnish orienteering runners • 77.6 MET h/wk
Hernelahti et al. [49] (1998) ORIENTEERING	Master orienteering runners	264 male athletes 388 male controls	• Athletes 58.5 (7.0) • Controls 60.6 (5.3)	Athletes 23.2 Controls 26.8	$p < 0.001$	• Top-ranked Finnish orienteering runners • Sedentary males free from disease
			Runners			
Hood and Northcote [10] (1999) RUNNERS	Veteran endurance runners	19 male athletes	Athletes 56-83	Athletes 20.8	NA	• Exclusively runners • BMI ranged from 17-8-23.5 kg/m^2 • No comparison group • Avg 36.2 km/wk • Includes record breakers and national champions in their age group • 50% had arrhythmia (ventricular couplets) • 47.3% hypertensive • 64.8% bradycardia

Table 1. Continued

Runners						
Wiswell et al. [11] (2001) RUNNERS	Master athletes (runners)	228 athletes • 146 males • 82 females	Males 53.8 (9.9) 39-87 Females 49.4 (7.7) 40-77	Males 23.4 (2.3) Females 22.31 (1.8)	NS	• National and international runners • Non-significant between groups and not related to age • No comparison group • Males 33.5 miles/wk • Females 33.3 miles/wk
Buyukyazi [12] (2005) RUNNERS	Master runner athletes	12 male athletes 12 male controls	Athletes 50.4 (4.2) Controls 49.0 (4.3)	Athletes 24.6 (1.8) Controls 28.0 (4.4)	$p < 0.020$	• 3,000-10,000m runners) • Athletes trained 5.5 (1.1)d/wk • 8.4 (1.6) hrs/wk
Northcote et al. [13] (1989) RUNNERS	Veteran endurance runners	20 male athletes 20 male controls	Athletes 56 (7) Controls 56 (7)	Athletes 22.4 (0.1) Controls 24.5 (2.5)	$p < 0.01$	• 47 miles/wk training • No SD for BMI • Controls were age-matched males who were sedentary
Piasecki et al. [14] (2016) RUNNERS	Master runners	13 male athletes 14 male controls	Athletes 69 (3) Controls 71 (4)	Athletes 22.9 (2.9) Controls 25.3 (3.9)	NS (−10.5%)	• National Masters Athletics competitors who achieved the merit standards of the British Masters Athletics Federation • Trained > 6 hrs/wk
Alfini et al. [15] (2016) RUNNERS	Master endurance athletes	12 athletes • 7 males • 5 females	Athletes 61.0 (7.8)	Athletes 23.4 (3.5)	NA	• Running club athletes who competed in regional and national endurance competitions • >15 yrs running • No gender specific BMI data
Couppe et al. [16] (2014) RUNNERS	Master endurance runners	15 males 12 controls	Athletes 64.0 (4.0) Controls 66.0 (4.0)	Athletes 23.0 (2.0) Controls 25.0 (2.0)	NS (−8.7%)	• Life-long endurance runners • Running 49 (+3) km/wk • Controls were untrained (>past 5yrs), weight-matched healthy males
Mikkelsen et al. [17] (2014) RUNNERS	Master endurance runners	15 male athletes 12 male controls	Athletes 64 (4) Controls 66 (4)	Athletes 23 (2) Controls 25 (2)	$p < 0.05$	• Lifelong runners • Running 49 (+3) km/wk over past 28 (+2) yrs • 8881 (1791) MET-min/wk
Knechtle et al. [18] (2012) RUNNERS	Master half marathoners, master marathoners and master ultra-marathoners	349 male athletes • 103 half-marathoners • 91 marathoners • 155 ultra-marathoners	Athletes • Half-marathoners 45.2 (7.6) • Marathoners 47.8 (7.9) • Ultra-marathoners 47.4 (7.8)	Athletes • Half-marathoners 23.8 (2.2) • Marathoners 23.5 (2.3) • Ultra-marathoners 23.5 (2.1)	NA	• Half-marathoners 33.5 (17.7) km/wk • Marathoners 45.3 (22.7) km/wk • Ultra-marathoners 71.3 (6.5) km/wk • No statistical analyses between groups for BMI

Table 1. Continued

Runners						
Knobloch et al. [19] (2008) RUNNERS	Elite masters runners	291 male athletes • 250 males • 41 females	Athletes 42 (9)	Athletes 23 (2.2) • Male 23.2 (2) • female 21.3 (2)	NA	• 65.2 (28.3) km/d • Training 47.5 (4.9) wks/yr • No statistical analyses between genders for BMI
Michaelis et al. [20] (2008) RUNNERS	Master runners	495 athletes • 126 male short-distance • 98 female short distance • 53 male middle-distance • 26 female middle-distance • 116 male long-distance • 76 female long-distance	Athletes • Male short-distance 56 (13) • Female short distance 55 (13) • Male middle-distance 59 (13) • Female middle-distance 59 (11) • Male long-distance 60 (12) • Female long-distance 55 (10)	Athletes • Male short-distance 24 (2) • Female short distance 22 (2) • Male middle-distance 23 (3) • Female middle-distance 21 (2) • Male long-distance 22 (2) • Female long-distance 21 (2)	NS	• European Veteran Championships and World Master Athletic Championships • Short <400 m • Middle 800-1500 m • Long >1500 m • No statistical analyses between groups for BMI
Galetta et al. [21] (2005) RUNNERS	Master long-distance runners	20 male athletes 20 male controls	Athletes 68.5 (4.5) Controls 68.2 (3.7)	Athletes 23.4 (0.4) Controls 24.1 (0.5)	NS (−3.0%)	• Competitive endurance runners >40 yrs • 5-10 hrs/wk
Ulman et al. [22] (2004) RUNNERS	Master runners	12 male athletes 12 male controls	Athletes 50.4 (4.2) Controls 49.0 (4.3)	Athletes 24.6 (1.8) Controls 28.0 (4.3)	$p = 0.020$	• 3000-10,000 m runners who trained regularly for past >10 yrs • Training for 27 (10.4) yrs • 8.4 (1.6) hrs/wk • Control group was recreational athletes who were in an aerobic training program > 10 yrs
Marcell et al. [23] (2003) RUNNERS	Master runners	74 athletes Males • 23 athletes 40's • 19 athletes 50's • 9 athletes 60's Females • 13 athletes 40's • 4 athletes 50's • 6 athletes 60's	Males • 40s' 44.9 (0.7) • 50's 54.2 (0.8) • 60's 61.1 (0.3) Females • 40s' 45.1 (0.6) • 50's 54.0 (1.6) • 60's 66.5 (1.9)	Males • 40s' 23.2 (0.5) • 50's 23.3 (0.5) • 60's 22.9 (0.4) Females • 40s' 22.4 (0.4) • 50's 22.4 (0.5) • 60's 22.0 (1.0)	NS	• 29.9-40.3 miles/wk • No control group • No statistical analyses between genders for BMI

Table 1. Continued

			Soccer			
Sotiriou et al. [50] (2013) SOCCER	Master soccer players	14 soccer players 16 controls	Athletes 48.9 (5.8) Controls 46.1 (3.8)	Athletes 27.3 (2.8) Controls 28.2 (4.7)	NA (−3.3%)	• No statistics completed between groups
Paxinos et al. [51] (2016) SOCCER	Veteran soccer players	Athletes 100 Controls 100	Athletes 46.9 (5.9) Controls 45.2 (5.7)	Athletes 26.7 (4.1) Controls 27.3 (3.0)	NA (−2.2%)	• Greek soccer players who participated in > 5yrs national soccer championships • Control group was age matched, active military personnel • No statistics for BMI between groups
Schmidt et al. [52] (2015) SOCCER	Veteran Soccer players	17 athletes 26 controls	Athletes 68.1 (2.1) Controls 68.2 (3.2)	Athletes 24.6 (2.3) Controls 27.2 (3.8)	$p = 0.016$	• Participated in European Masters Games • Lifelong participation in soccer training
Walsh et al. [53] (2012) SOCCER	World Masters Games soccer players	592 athletes • 262 males • 330 females 15,565 controls	Athletes 47.6 (6.9)	Athletes 25.1 (SD ± 3.6) • 30-<40 yrs 7.7% obese • 40-<50 yrs 10.5% obese • 50-<60 yrs 8.5% obese • 60-<70 yrs 3.0% obese Controls • 30-<40 yrs 20.5% obese • 40-<50 yrs 25.8% obese • 50-<60 yrs 26.9% obese • 60-<70 yrs 26.9% obese	$p < 0.05$	• WMG soccer players • Controls from Australian general population who participated in the 2007-2008 national health survey
			Swimming			
Mrakic-Sposta et al. [54] (2015) SWIMMING	Master swimmers	16 males	Athletes 30.0 (5.0)	Athletes 23.7 (2.0)	NA	• No comparison group • 11 (4) yrs training experience • Front crawl 50-400 m Master swimmer category as defined by Federation Internationale de Natation Amateur and Italian Swimming Federation
Walsh et al. [55] (2013) SWIMMERS	World Masters Games swimmers	527 athletes • 262 males • 265 females	29 to 77 (mean 52.2, SD ± 8.0)	25.3 (SD ± 4.0)	$p < 0.001$ (male vs female) $p < 0.01$ (Australian general population)	• BMI lower compared to a representative sample of population controls

Table 1. Continued

			Swimming			
Crow et al. [56] (2017) SWIMMING	Master pool swimmers	Athletes 103 • Males 76 • Females 27 Controls 49,935	Athletes 54.3 (10.8)	Athletes 25.9 (3.6) • Males 26.4 (3.3) • Females 24.6 (4.2) • Males 11.8% obese • Females 7.4% obese Controls 27.2 • Males 27.6 • Females 26.8	p = .024 between athlete genders p = 0.003 between genders in prevalence of obesity p < 0.001 between groups p < 0.003 between males p < 0.011 between females	• San Francisco Dolphin club cold-water swimmers • No age data provided for each gender • No SD provided for California state general population
			Endurance sports			
Hubert et al. [24] (2017) ENDURANCE	Endurance athletes with atrial fibrillation	27 males • 10 runners • 17 cycling/triathlete	Athletes 59.9 (+7.4)	Athletes 24.1 (+2.9) Controls 24.2 (+2.4)	NS (−0.04%)	• Controls were endurance athletes without documented atrial fibrillation • Athletes 6.4 hrs/wk • Controls 6.4 hrs/wk
Beshgetoor et al. [25] (2000) ENDURANCE	Master cyclists	21 female athletes • 12 cyclists • 9 runners 9 female controls	Athletes • Cyclists 48.2 (8.4) • 7 Runners 50.9 (7.5) Controls 50.1 (8.5)	Athletes • Cyclists 21.5 (2.2) • 7 Runners 20.4 (1.8) Controls 21.3 (2.8)	NS	• Training 7.7-9.4 hrs/wk • training 4.9-5.1 d/wk
Shapero et al. [26] (2016) ENDURANCE	Veteran endurance athletes, mixed	591 • 390 males • 201 females	Group 50 (9) • Males 51.0 (+9.0) • Females 48.0 (+9.0)	Group 23.4 (3.6) • Males 22.4 (2.8) • Females 24.0 (+3.8)	P < 0.001	• Boston (MA, USA) masters athletes • 21.3 (5.5) yrs competitive endurance experience
Fitzpatrick [27] (2014) ENDURANCE	Master athletes (runners and triathlon)	24 males 11 females	Group 53.8 (7.4) Male 53.3 (7.4) 40-67 Female 55.0 (7.6) 45-73 Controls 20,015	Group 24.0 (3.1) Male 24.8 (3.1) Female 22.2 (2.3) Controls 29.1 (0.1)	p < 0.03	• Significantly lower compared to general population • Males trained 5.5 d/wk • Females trained 5.4 d/wk
Cataldo et al. [37] (2018)	Master endurance athletes	10 males	Athletes 52.1 (6.4)	Athletes 23.6 (1.9)	NA	• No comparison group
Velez et al. [28] (2008) ENDURANCE	Endurance Master athletes	87 athletes • 43 runners • 43 swimmers 87 controls	Runners 73.3 (7.1) Swimmers 72.6 (6.8) Controls 75.3 (5.4)	Runners 23.5 (2.6) Swimmers 27.2 (3.8) Controls 28.3 (3.9)	p < 0.01 between athletes (combined) and controls	• Competitors from National Senior Olympic games • Age matched controls

Table 1. Continued

Endurance sports						
Eijsvogels et al. [29] (2017) ENDURANCE	Veteran endurance athletes	5 without fibrosis 4 with fibrosis	Fibrosis 59 (2) No fibrosis 57 (8)	No fibrosis 24.6 (3.1) fibrosis 23.5 (1.7)	NA (4.6%)	• Without fibrosis 44 years training • With fibrosis 42 years training
Kujala et al. [30] (1996) ENDURANCE	Veteran endurance athletes	15 male athletes • runners 9 • cycling 4 • triathlon 2 16 controls	Athletes 49.3 42-56 Controls 47.0 42 to 54	Athletes 22.8 Controls 25.1	$p < 0.010$	• 95.9 MET hr/wk • No SD for age of BMI
Bourvier et al. [31] (2001) ENDURANCE	Veteran endurance athletes	10 males • 8 orienteers • 2 runners 12 controls	Athletes 72.8 (2.9) Controls 74.9 (+2.4)	Athletes 22.6 (2.1) Controls 25.8 (3.5)	$p < 0.02$	• 3-7hrs strenuous exercise per week • Lifelong regular/intense endurance exercise training
Drey et al. [32] (2016) ENDURANCE	Master endurance athletes	23 athletes • 10 males • 13 females 149 controls • 65 males • 84 females	Athletes 58 (1.2) Controls 77 (6.0)	Athletes 22.0 (2.2) Controls 26 (4.2)	NA (−18.2%)	• European Veteran Athletics Championships • Trained 7.2 hr/wk • No statistics for BMI between groups
Matelot et al. [33] (2016) ENDURANCE	Endurance Master athletes	13 male athletes • 4 runners • 7 cyclists • 2 running + cycling 10 controls	Athletes 62.3 (3.0) Controls 59.3 (3.0)	Athletes 24.1 (1.9) Controls 26.1 (3.2)	NS (−8.3%)	• Trained 7.3 hr/w • Endurance training for 39 (4) yrs
Shapero et al. [26] (2016) ENDURANCE	Master athletes	591 athletes 246 cycling 147 running 72 swimmers 54 Triathlon 56 rowers 11 other • 391 males • 200 females	Group 50 (9) Males 51.0 (9.0) Females 48.0 (9.0)	Group 23.4 (3.6) Males 22.4 (2.8) Females 24.0 (3.8)	$p < 0.001$	• 21.3 (5.5) yrs competitive endurance sport exposure • 10.3 (5.5) hrs/wk
Kwon et al. [34] (2016) ENDURANCE	Master endurance athletes, unspecified	50 male athletes • 34 marathon runners • 7 cyclists • 9 triathletes 50 male controls	Athletes 48.3 (5.9) Controls 49.1 (5.6)	Athletes 23.3 (1.9) Controls 23.9 (2.0)	NS ($p = 0.17$)	• Athletes trained 6.6 (3.4) hrs/wk

Table 1. Continued

			Endurance sports			
Degens et al. [35] (2013) ENDURANCE	Master endurance athletes	16 male athletes • 1500 m + runners • triathlon • Orienteering • Cross-country skiing Controls 17	Athletes 73 (5) Controls 71 (4)	Athletes 23.3 (1.9) Controls 27.3 (3.2)	NS (−17.2%)	• World Masters Athletics Indoor championships • Training 7.3 (3.4) hrs/wk
Pratley et al. [36] (1995) ENDURANCE	Master athletes	11 athletes • 9 runners • 2 triathletes 10 controls	• Athletes 63.5 (1.9) • Controls 62.4 (1.8)	Athletes 23.5 (0.5) Controls 24.8 (0.7)	NS (−5.5%)	• Competed at local and state levels • 52 (5) km/wk • Trained 6 (1) d/wk
			Mixed sports/athletes			
Fien et al. [66] (2017) MIXED	Pan Pacific Masters Games, mixed sports	156 • 78 males • 78 females	Athletes • Males 40-86 • Female 40-77	• 40-49 yo: 25.5 (+3.5) • 50-59 yo: 25.6 (+4.3) • 60-69 yo: 25.9 (+4.7) • 70-79 yo: 26.3 (+5.7)	p < 0.001	• Comparison group is the Australian general population
Sallinen et al. [60] (2008) MIXED	Finnish Master athletes	17 Athletes • Middle-aged athlete 9 • Older master 8 Controls • Middle aged control 11 • Older control 10	Athletes • Middle-aged 52.1 (4.7) • Older master 71.8 (3.8) Controls • Middle aged control 51.9 (3.1) • Older control 70.6 (3.3)	Athletes • Middle-aged 29.0 (2.6) • Older master athlete 28.4 (4.3) Controls • Middle aged control 22.7 (1.7) • Older control 24.7 (1.3)	p < 0.001 (middle age athlete vs middle-aged control) p < 0.001 (old age athlete vs old age control)	• National level in shot put, discus or hammer throw • Strength/power training for 22.8 (14.9) yrs • Training 2.1d/wk • Middle aged athlete vs middle-aged controls p<0.001 • Old aged athlete vs old-aged controls p<0.001
Kettunen et al. [67] (2006) MIXED	Finnish Master track and field athletes	102 male athletes 777 controls	Athletes 58.3 (10.3) Controls 55.0 (10.3)	Athletes 24.1 (3.4) Controls 26.4 (3.6)	p < 0.001	• Participated in the World Veterans Games • Athletes MET dose 82.7 MET-hr/wk • Controls healthy males
Di Girolamo et al. [68] (2017) MIXED	Elite senior athletes, mixed sports	50 athletes • 38 males • 12 females	Athletes 71.5	Athletes 24.0	NA	• Participants at the European Master Games aged 65-80 yo • No SD for age or BMI • No comparison group
Gervasi et al. [61] (2017) MIXED	European Master Indoor Championships athletes	390 athletes • male 243 • female 147	Male 53.5 (13.1) Female 51.0 (11.6)	Males 23.3 (2.5) Females 20.8 (2.2)	NA (+12.0%)	• Participants from the European Master Athletics Indoor Championships • No comparison group

Table 1. Continued

Mixed sports/athletes						
Gori et al. [69] (2015) MIXED	Master athletes	109 athletes • 82 males • 18 females 27 controls • 27 males • 24 females	Athletes 50.0 (6.7) Controls 51.1 (5.7)	Athletes 23.8 (2.5) Controls 24.0 (2.8)	NS (+.08%)	• Age matched sedentary controls • 7.0 (2.6) hrs sports activity/wk
Yataco et al. [70] (1997) MIXED	Master athletes	61 athletes • 50 runners • 2 cyclists • 9 cross-trained 39 controls lean 51 controls obese	• Athletes 63.3 (6.1) • Controls lean 60.6 (5.6) • Controls obese 59.9 (6.9)	Athletes 22.9 (1.9) Controls lean 25.6 (2.1) Controls obese 29.2 (3.2)	$p < 0.05$ (athletes vs lean controls) $p < 0.0001$ (athletes vs obese controls)	• Maryland Senior Olympics • Vigorous exercise > 4 d/wk
Walsh et al. [71] (2011) MIXED	World Masters athletes	535 athletes • 344 males • 191 females • 362 soccer • 61 rugby union • 114 touch football 20,800 controls	• Athletes 47.4 (7.1) • Controls aged 35 to 75	Athletes (male) 14.5% BMI > 30 kg/m^2 Athletes (female) 7.3% BMI$\geq$30 kg/m^2 Controls 25% BMI$\geq$30 kg/m^2	$p < 0.001$	• Athletes from rugby union, soccer, touch football • Controls from Australian general population who participated in the 2007-2008 national health survey
Mixed: World master games						
DeBeliso et al. [72] (2014) WMG	World Masters Games athletes from N American, mixed sports	928 athletes • 495 males • 433 females	Athletes 52.6 (9.8) • Males 50.2 (9.7) • Females 52.6 (9.1)	Group • 1.7% underweight • 50.3% normal • 34.1% overweight • 13.9% obese	$p < 0.05$ for • Canadian obesity prevalence 25.6% general population • USA obesity prevalence 33%	• North American athletes (mixed) participating in World Masters Games
Climstein et al. [7] (2018) WMG	World Masters Games, mixed	1,435 athletes • 868 males • 567 females 32,000 controls	Athletes 54.9 (9.4) Males 56.7 (9.5) Females 52.2 (8.8)	Athletes 25.5 (4.0) • Males 26.1 (3.6) • Females 24.7 (4.3) Controls 27.5	$p < 0.05$ (male vs female) $p < 0.001$ (Australian general population)	• No SD available for control group • Control group data attained Australian general population who participated in the 20011-2012 National Health Survey

Table 1. Continued

			Non-specified sports/athletes			
Maessen et al. [63] (2017) NON-SPECIFIED	Master athletes	18 male athletes 13 male controls	Athletes 61 (7) Controls 58 (7)	Athletes 23.3 Controls 26.9	$p < 0.01$	• Athletes trained 7.1 hrs/wk • Athletes MET dose 60 MET-hr/wk • No SD for BMI
Condello et al. [64] (2016) NON-SPECIFIED	Senior athletes	61 athletes aged 65-74 • 37 males • 24 females 51 athletes aged 75-84 • 30 males • 21 females	NA	Athletes 65-74 • Male 20.4 (0.4) • Female 26.5 (2.0) Athletes 75-84 • Male 23.3 (2.9) • Female 24.4 (1.4) Controls 65-74 • Male 29.8 (2.7) • Female 27.9 (3.6) Controls 75-84 • Male 26.8 (2.1) • Female 25.3 (3.2)	NA	• Senior athletes • No statistics for BMI between groups
D'Elia et al. [65] (2017) NON-SPECIFIED	Master athletes	753 males	Athletes 53 (10)	Athletes 26 (3) Athletes w/HTN 27 (1.5)	NS ($p = 0.6$)	• Comparison group was athletes with HTN matched for age, BMI and resting HR • Participant numbers in each group not specified

matched) given the majority of participants from that WMG were from the host country Australia. Walsh et al. reported the MA basketball players had a significantly ($p < 0.01$) lower percentage of obesity (based upon BMI) across all age groups (30-40 yrs, 40-50 yrs, 50-60 yrs and 60-70 yrs) as compared to the Australian general population. The difference between groups in percentage obesity ranged from 11.7-14.1% for the MA basketball players and 20.4%-26.9% in the Australian general population. Given the BMI findings in the Walsh et al. study was according to WHO classifications of BMI via additional WHO cut-off points it was difficult to compare to other studies. However a recent study by Gryko et al. [40] reported the BMI of professional adult male basketball players, where mean BMI was in the overweight classification (24.0 kg/m^2±1.81). The Gryko et al. finding is similar to the average BMI reported for 2016 US male basketball players (24.7 kg/m^2) [41] and national basketball league players (1953-2009) (24.08 kg/m^2) [42].

There were three papers [43-45] which investigated MA cyclists (n = 75 athletes). The mean BMI for the cyclists (across all three studies) was 23.7 kg/m^2 (± 1.1) (range 22.3-24.8 kg/m^2) compared to 25.1 kg/m^2 (± 1.0) for controls. In the two studies which utilized a control group, only one study [43] reported a significant ($p < 0.01$) difference between groups, however the other study by Nicholas and Raugh [46] reported no difference ($p = 0.74$). The Nicholas and Raugh [46] study did however incorporate active males as controls. The third study by Chilelli and colleagues [45] had no comparison group.

A single [47] study of MA ice skaters (n = 76 athletes) was identified, their mean BMI was categorized as normal at 23.7 kg/m^2 (± 2.4), unfortunately there was no comparison group. There were two studies [48,49] which investigated master orienteering athletes. Both studies incorporated top-ranked Finnish MA orienteering runners (n = 533) and both studies reported a significantly ($p = 0.0008$ and $p < 0.001$) lower BMI in the MAs as compared to controls. The mean BMI classification for the both studies was normal (23.2 and 23.2 kg/m^2) while the control groups were classified as overweight (25.5 and 26.8 kg/m^2).

There were 14 studies which investigated MA runners [10-23], ranging from 12 to 495 participants, there were a total of 1,575 MAs with a group mean BMI ranging from 20.8 to 24.6 kg/m^2 , all MA runners group means were classified as normal for BMI. Comparatively, the mean controls BMI was 25.7 kg/m^2 (± 1.5) which is classified as overweight. Only four studies reported BMI specified by gender, males had a mean of 23.1 kg/m^2 (± 0.5) with females having a significantly lower ($p < 0.001$) mean of 21.8 kg/m^2 (± 0.6). Only three of the studies reported significant differences between groups, the studies reporting non-significant differences had the runners mean BMI 3.0 to 10.5% lower than controls.

We identified four studies [50-53] which reported BMI in MA soccer players, only 2 of the studies found a significant difference between groups (MA vs controls), Schmidt et al. [52] utilized healthy, age-matched controls ($p = 0.016$) while Walsh et al. [53] found a significant ($p < 0.05$) difference between MA soccer players and the Australian general population. The BMI for MA soccer players ranged from a group mean of 24.6 (normal) to 27.3 kg/m^2 (overweight).

Despite the popularity of masters swimming, we only identified three studies [54-56] which included MA swimmers. The mean BMI across all three studies for the MA swimmers was 25.0 kg/m^2 (overweight), range 23.7 kg/m^2-25.9 kg/m^2. Crow et al. [56] compared master pool swimmers to the state of California (USA) general population and found a significant difference between MA swimmer genders ($p = 0.024$) and between genders in the prevalence of obesity between groups ($p < 0.001$, MAs vs general population) and between genders and the general population (males $p < 0.003$; females $p < 0.01$). Walsh et al. [55] compared MAs competing at the World Masters Games to the Australian general population. A significant difference between MA swimmers genders ($p < 0.001$) and the Australian general population ($p < 0.01$) was demonstrated (55).

A single study was identified for each of BMI in MA rowers [57], MA rugby union [58] and MA x-country skiers [59]. Sliwicka and colleagues [57] found a non-significant ($p = 0.482$) difference between master rowers and active-professional controls; the rowers had a +2.3% higher mean BMI as compared to the control group (25.4 vs 24.8 kg/m^2). Climstein and colleagues [58] investigated master rugby union athletes who participated in the International Golden Oldies World Rugby festival. There was a total of 120 MA rugby players, and they found a significant difference ($p < 0.05$) in the percentage of obese in the older (≥ 50 yrs) versus younger (< 50 yrs) rugby MAs (37.2 vs 43.0%). There was also a single investigation of male MA x-country skiers. Myrstad et al. [59] found a significant difference ($p < 0.001$) between MA skiers and aged-matched controls from the general population of Norway (23.6 vs 27.0 kg/m^2).

Fourteen studies were identified, which were classified as investigating endurance MAs ranging from 10 to 591 endurance participants. These studies had a cumulative total of 907 endurance MAs with a group mean BMI of 23.6 kg/m^2 (range 20.4-27.2 kg/m^2) whereas controls had a significantly lower ($p < 0.001$) group mean of 25.6 kg/m^2 (± 2.1). Only two studies [26,27] reported BMI by gender, where males had a mean BMI of 22.4 kg/m^2 and females higher (+18.8%) at 26.6 kg/m^2. Of all MA endurance studies, only five (35.7%) found a significant difference between groups (athletes vs controls), where there was no statistical difference the endurance runners' BMI was 0.4% to 18.2% lower than controls.

There were eight studies we classified as mixed, these studies included 1,318 MA athletes from mixed sports, study size ranged from 17 to 535. Five of the eight studies resulted in a significant difference between groups however in a study by Sallinen et al. [60], the MAs actually had a significantly higher ($p < 0.001$) BMI as compared to the controls (middle-aged athletes 29.0 vs 22.7 kg/m^2 and older athletes 28.4 vs 24.7 kg/m^2). These MAs were strength and power athletes (shot put, hammer, discus) and their increased lean mass may account for the inconsistency found in BMI. Only a single study of 390 mixed athletes [61] reported gender specific BMIs, no statistical analysis was completed however males had a 12.0% higher BMI as compared to females (23.3 vs 20.8 kg/m^2).

The World Masters Games (WMG) cohort MAs had two investigations, Climstein and colleagues [62] reported cardiovascular risk which included BMI while DeBeliso and colleagues [8] reported on a sub-sample of the WMG athletes, specifically the BMI of North American participants (USA and Canada). Climstein et al. [62] found a significant difference between genders ($p < 0.05$) with males' BMI higher (+5.7%) as compared to female WMG MAs. Climstein et al. also compared the WMG MAs as a group to the Australian general population and found a significantly lower BMI in the MAs (−7.8%, $p < 0.001$). In the DeBeliso et al. [8] study the incidence of obesity was reported on and the WMG North American participants injury incidence was significantly lower than the Canadian population (13.9 vs 25.6%, $p < 0.05$) and also the USA general population (13.9 vs 33.0%, $p < 0.05$).

There were three studies [63-65] which did not specify the type of MAs. Massen et al. [63] investigated MAs who trained lifelong and an average of seven hrs/wk, a significant difference was identified as compared to controls (−15.5%, $p < 0.01$). Condello and colleagues [64] investigated senior athletes from 65 to 84 years of age (65-74, 75-84), they did not analyses between groups however the MAs BMI values were lower than controls for both genders across both age groups. D'Elia et al. [65] investigated normotensive and hypertensive MAs. No was no difference in BMI noted between groups (26.0 vs 27.0 kg/m^2).

DISCUSSION

The purpose of this review was to examine the BMI in MAs and determine if there was a reduced risk identified in MAs as compared to controls or the general population. It was hypothesized that differences in BMI would exist when MAs were compared to sedentary controls and when compared to the general population. To the authors' knowledge, this is the first study to thoroughly review BMI in MAs.

Our review identified 60 studies which met our inclusion criteria, this involved a total of 10,061 MAs (73.8% male) and 70,353 controls. The mean BMI of all MA was found to be significantly ($p < 0.001$) lower than controls (−9.5%, 23.78+1.4 vs 26.13+1.7 kg/m^2). Where gender specific MAs BMI was available, females tended ($p = 0.126$) to have a lower (−4.7%, 22.62+1.2 kg/m^2) BMI as compared to males (23.68+1.5 kg/m^2).

According to the US National Health and Nutrition survey (N = 17,375) [73] findings, our MAs as a group was lower (−11.4%) than that of the average US adult (23.78

vs 26.5 kg/m^2). This finding is similar to that found when comparing MAs BMI to that of the Australian general population. As a group, MAs were found to have a lower (−17.3%) BMI as compared to the Australian general population (23.78 vs 27.9 kg/m^2). This finding was similar with regard to gender specific BMI with male (−23.9%) and female (−22.0%) MAs were lower than the general population.

Seidell and Halberstadt [74] had investigated if a high BMI was actually associated with a lower risk of mortality and increased life expectancy, they found that the relative mortality risk was increased with a BMI of 25 kg/m^2 however higher BMI was associated with a reduced risk. They further explained that their observation was explained by methodological bias.

Dr Afzal [75] and his colleagues investigated BMI with regard to mortality, they identified the lowest all-cause mortality was associated with a BMI of 26.4 kg/m^2 (2003-2013, 95% CI, 23.4-24.3 kg/m^2) this value is higher than the mean BMI found in our review of MAs. This value was shown to increase by 3.3 kg/m^2 from 1976 to 2013. Wang and colleagues [76] also investigated BMI with regard to mortality and reported a higher BMI (28.6 kg/m^2).

There is substantial literature indicating that a high BMI (overweight and obese) is associated with an increased risk of developing a number of number of chronic diseases and conditions. Kearns et al. [77] evaluated the risk and determined that the highest risk (risk ratio (RR) in parentheses) was associated with HTN (RR 2.1) followed by osteoarthritis (RR 2.0), T2dm (RR 1.6), hypercholesterolemia (RR 1.3) and low back pain (RR 1.2). With regard to gender specific risk, HTN and osteoarthritis was the highest risk in overweight and obese males while T2dm and HTN were the highest risk in overweight and obese females.

In Australia, the highest burden associated with overweight and obesity was all linked cardiovascular diseases (37.9%) followed by cancers (19.3%), T2dm (17.2%) and musculoskeletal conditions (16.7%) [78]. Despite the lowered risk, clinicians continue to consider ageing athletes at risk for a cardiac event and musculoskeletal injury [79]. Walsh and colleagues have however, shown a significantly less incidence of injury in MAs than other sporting cohorts [80].

The health benefit seen in MAs is illustrated by the work of Climstein and colleagues [81] who compared the incidence of chronic diseases and conditions in MAs to the Australian general population and reported a significantly lower incidence of anxiety ($p < 0.01$), depression ($p < 0.01$) and a trend of a lower incidence of arthritis (−30.4%, $p = 0.06$). DeBeliso et al. [8] investigated the incidence of chronic diseases and disorders of north American WMG MAs, they found a significantly lower ($p < 0.01$) incidence of arthritis (rheumatoid and osteoarthritis), HTN, hyperlipidemia, asthma and depression as compared to the US general population.

Body mass index, although widely used and a simple risk factor to attain however, it is not withstanding its limitations which are well recognized [82-84]. Principally, the equation does not take the various tissues (i.e., lean mass, fat mass, bone) into account and this subsequently results in an overestimation and underestimation of BMI. It has been proposed that the standard BMI equation exaggerates thinness in short individuals and fatness in tall and muscular individuals, the latter being athletes. The higher muscle (i.e., lean mass) content in athletes skews BMI as lean mass is approximately 22% denser than fat tissue. Alternative equations for BMI have been proposed, for example Nuttall [85] recommended that the trunk should be considered as a three-dimensional volume and proposed an alternative equation, namely $weight/height^{1.6}$.

In summary, this review of BMI in MAs provides an initial insight into one indirect multifaceted health benefit seen in MAs (namely lower BMI). Further research is warranted into the health benefits associated with MAs.

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