


Long-term function, body composition and cardiometabolic health in midlife former athletes: a scoping review

Jena Heck Street,¹ Zebadiah P Boos,¹ Alissa Fial,² Shannon L Lennon,³ Carolyn S Smith,¹ Seth A Creasy,⁴ Sandra K Hunter,¹ William B Farquhar,³ Jacob John Capin ^{1,5}

To cite: Street JH, Boos ZP, Fial A, *et al.* Long-term function, body composition and cardiometabolic health in midlife former athletes: a scoping review. *BMJ Open Sport & Exercise Medicine* 2023;**9**:e001605. doi:10.1136/bmjsem-2023-001605

► Additional supplemental material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/bmjsem-2023-001605>).

Accepted 23 September 2023



© Author(s) (or their employer(s)) 2023. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

¹Physical Therapy, Marquette University, Milwaukee, Wisconsin, USA

²Research, Teaching & Learning, Raynor Memorial Libraries, Marquette University, Milwaukee, Wisconsin, USA

³Kinesiology and Applied Physiology, University of Delaware, Newark, Delaware, USA

⁴Endocrinology, Metabolism, and Diabetes, University of Colorado Anschutz Medical Campus, Aurora, Colorado, USA

⁵Clinical and Translational Science Institute, Medical College of Wisconsin, Milwaukee, Wisconsin, USA

Correspondence to

Dr Jacob John Capin;
jacob.capin@marquette.edu

ABSTRACT

While sports medicine has traditionally focused on recovering from injury and returning athletes to sport safely after injury, there is a growing interest in the long-term health of athletes. The purpose of this scoping review was to (1) summarise the literature (methodologies and findings) on physical function, body composition and cardiometabolic health in midlife (age 40–65 years) former competitive athletes compared with non-athlete controls, (2) identify areas for future study in long-term health in athletes and (3) determine outcomes that could be evaluated in a future systematic review(s). We searched PubMed, CINAHL, Web of Science and SPORTDiscus for studies published between 2000 and 2022 evaluating former athletes and controls on physical function, body composition and/or cardiometabolic measures using MeSH terms. We identified 20 articles that met our criteria. Outcomes varied considerably across studies, most of which were cross-sectional and evaluated only males. Limited data suggest that former endurance athletes have leaner body compositions, higher aerobic capacity and better cardiometabolic indicators than controls; former athletes who maintain higher physical activity (ie, self-reported exercise) are healthier than those who do not; and former team sport athletes, who have higher injury prevalence, may have poorer functional performance than controls who were recreationally active in college. Studies rarely evaluated functional performance, did not control for prior injury or diet and seldom assessed current physical activity levels. Future research should include females and evaluate sex differences, control for prior sports-related injury(ies), quantify physical activity, use standardised outcome measures including performance-based functional assessments and incorporate longitudinal designs.

INTRODUCTION

Approximately 7.6 million high school¹ and 480 000 collegiate² athletes engage annually in competitive, organised sport in the USA alone. Participating frequently in competitive sports may have beneficial and harmful long-term health implications, as athletes often engage in vigorous intensity exercise and strength-training yet are also exposed to high

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Physical activity, exercise and sport confer many benefits across physical, cognitive and psychological domains.
- ⇒ Former elite athletes tend to live longer than non-athlete peers.
- ⇒ Former elite athletes, especially those with histories of lower extremity injury, have high rates of knee and hip osteoarthritis and joint replacement.
- ⇒ Former athletes report similar physical component quality of life scores and higher mental component quality of life scores compared with non-athlete controls.

WHAT ARE THE NEW FINDINGS

- ⇒ We identified 20 articles published since 2000 that evaluated at least one functional, body composition and/or cardiometabolic outcome in midlife former athletes compared with controls. Outcome measures varied considerably across studies, most of which were cross-sectional and evaluated only male participants. Studies did not control well for prior injury nor present behaviours such as physical activity patterns and dietary intake.
- ⇒ The available data suggest former national and international class endurance athletes may have leaner body compositions, higher aerobic capacity (ie, higher VO₂ max) and better cardiometabolic indicators than non-athlete controls.
- ⇒ Data from a few studies suggest former athletes who maintain higher activity patterns (ie, self-reported exercise frequency) in midlife are healthier than former athletes who lead more sedentary lives and controls.
- ⇒ Though limited by very few studies and relatively small samples, former team sport athletes—who also have a much higher prevalence of former time-loss injury—may have poorer physical function and poorer cardiometabolic health than individuals who were recreationally active during young adulthood.

training loads and musculoskeletal injury risk. Recently published studies suggest former athletes live longer than age-matched peers^{3–5} yet also have a higher risk for lower extremity osteoarthritis (OA) and joint replacement.^{6–8}

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ This scoping review surveyed the literature to summarise the implications of competitive athletics on long-term function, body composition, and cardiometabolic health and may inform how healthcare providers counsel or treat athletes for optimal long-term health.
- ⇒ Our findings suggest that prior engagement in high levels of exercise, even at an elite level, does not provide lifelong protection for cardiometabolic health, function, or body composition. Continued activity is important in aging athletes, as former athletes who maintain higher physical activity levels are healthier than those who do not.
- ⇒ Future research should include females and evaluate sex differences (when possible), control for prior sports-related injury, objectively quantify physical activity patterns, use more standardised outcome measures including performance-based functional assessments, and incorporate longitudinal study designs.

A systematic review and meta-analysis of cardiovascular disease risk factors in male former team-sport athletes found inconsistencies in the reporting of cardiovascular disease risk factors and inconclusive results.⁹ Traditional sports medicine focuses on athletes' health during or soon after their athletic careers and rarely evaluates health outcomes later in life. Describing the implications of competitive sports participation on long-term function, body composition and cardiometabolic health may guide how clinicians and coaches counsel athletes for life-time injury prevention and optimal health and elucidate areas for future research.

Several factors suggest sports are beneficial to function, body composition and cardiometabolic health that could have important implications for ageing former athletes in midlife and beyond. Athletes regularly participate in vigorous exercise, which is strongly linked to many health benefits across physical, cognitive and psychological domains.^{10–18} Factors such as greater strength and higher VO_2 max, common among athletes, may help preserve long-term cardiometabolic health and functional independence.¹⁹

Participating in competitive sports may also come with a cost, as athletes are at substantially higher risk for musculoskeletal injury than non-athletes and novice athlete counterparts.^{20–24} Injury rates, especially traumatic knee injuries among young athletes in collision, contact and jumping/cutting/pivoting sports (eg, football (American, Australian rules), lacrosse, hockey, soccer, basketball), appear to have risen in recent years.^{25–27} These traumatic knee injuries, in turn, place athletes at profoundly increased risk for subsequent injury²⁸ and early OA.^{29–30} Chronic injury can also impair function and limit daily activities, reducing overall health.^{31–33} Some sports prioritise high body weight (eg, American football), whereas other sports emphasise weight cycling (eg, wrestling, powerlifting) or restriction (eg, gymnastics, running)—all of which could hypothetically have harmful effects of on cardiometabolic and/or body composition metrics.

The one published review to-date on cardiovascular and body composition measures in former athletes, however, evaluated male team-sport athletes only, focusing almost exclusively of former professional American football players and yielded inconsistent findings.⁹

Despite mounting research on athletes, much remains unknown regarding the effects of previous high-level sport participation on long-term health. Recent review articles have evaluated pain,³⁴ quality of life,³⁵ OA,⁶ mortality^{3–5} and cardiovascular health⁹ among former athletes and the benefits of sport in adults 60 years of age and older.³⁶ Prior studies have yet to systematically review data on physical function or to examine body composition and cardiometabolic health in male and female midlife former athletes across a broad range of sports. Midlife, approximately age 40–65 years, is a significant yet understudied population, as health in middle age strongly predicts health in older age.^{37–39} The purpose of this scoping review was threefold: (1) summarise the literature (methodologies and findings) pertaining to physical function, body composition and cardiometabolic health in midlife former competitive athletes compared with non-athlete controls, (2) identify areas for future study in long-term health in athletes and (3) determine outcomes pertaining to physical function, body composition and/or cardiometabolic measures among midlife former athletes compared with controls that could be evaluated in a future systematic review(s).

METHODS

This scoping review followed the process established by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Review. A review protocol was not published or registered. A scoping review was more appropriate than a systematic review for several reasons,⁴⁰ such that our aim was to identify gaps in the literature and areas of future study while also determining the feasibility of conducting a future systematic review(s). We included a heterogeneous population of former athletes, including all sports, nations and high levels of competition. We also included studies that examined physical function, body composition or any cardiometabolic indicators.

Search strategy

Searches were conducted in four electronic databases: PubMed, CINAHL, Web of Science and SPORTDiscus. Searches focused on studies that included former athletes and controls and evaluated physical function, body composition and/or cardiometabolic measures. For a complete list of the literature search strategies, see online supplemental appendix 1. The initial search was conducted on 19 August 2022, with an additional search for any updated content run on 4 January 2023. The reference lists of articles that were reviewed during full-text screening were also reviewed for additional relevant articles for screening (see the Study selection and figure 1).

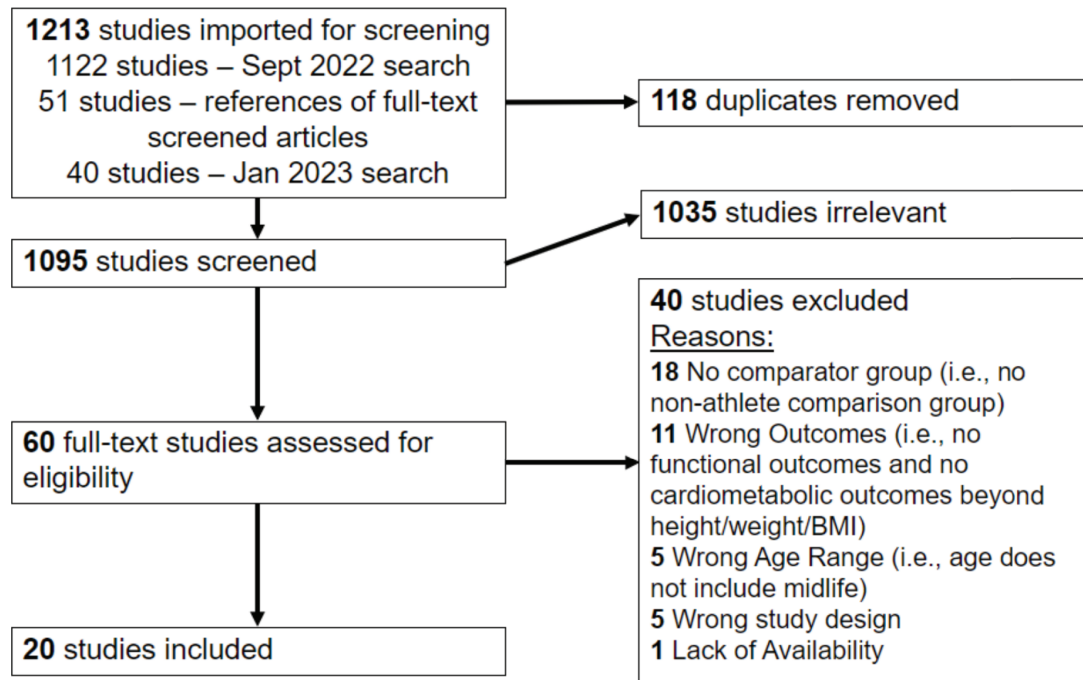


Figure 1 Flow chart of study selection. BMI, body mass index.

Inclusion/exclusion criteria

Studies published between 1 January 2000 and 31 December 2022 were eligible for inclusion to capture the most contemporary studies given that sports have changed dramatically in recent decades,²⁴ including higher injury rates and greater training and competition expectations.²⁴ Our search included former high-level athletes involved in competitive (ie, $\geq 3\times$ /week in organised sport training and matches), collegiate, professional and/or elite (ie, national/international) sports. Studies were included if the mean or median age of the former athletes was between 40 and 65 years. Studies were required to have a comparison group of non-athlete controls (also between the ages of 40 and 65 years). Outcomes needed to focus on functional measures (eg, aerobic capacity, strength and self-reported measures), body composition (eg, anthropometrics, body fat, lean mass, bone density) and/or cardiometabolic indicators (eg, blood pressure, blood lipids, inflammatory biomarkers). Articles where body mass index (BMI) was the sole outcome measure relevant to this review were not included due to the potential misclassification of overweight/obesity in athletes.^{9 41} We also did not include outcomes pertaining to cardiac arrhythmias (eg, atrial fibrillation) or abnormalities (eg, hypertrophic cardiomyopathy). Given that our focus was on former high-level athletes, articles were excluded if the participants were exclusively current master's athletes (ie, athletes over the age of 35 years who were presently active in sport competition). Articles were also excluded if the measurements focused exclusively on neurocognitive measures/traumatic brain injury or quality of life. While physical activity patterns were not an outcome of interest, we included studies that evaluated our outcomes

of interest and considered physical activity as another outcome or grouping variable.

Study selection

Our search yielded 1095 articles after removing duplicates. Titles and abstracts from the initial search were uploaded into Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia), a web-based collaboration software platform that streamlines study selection and data extraction. Two authors (JHS and ZPB) reviewed each title and abstract for inclusion and met to discuss and resolve disagreements; the senior author (JJC) served as the tiebreaker when consensus was not met. Sixty studies were reviewed in full text and 20 articles were included in the review (figure 1).

Data extraction and analysis

Data were pulled from the final articles using Covidence. Similar to study selection, two authors (JHS and ZPB) reviewed each article individually for extraction and met to discuss and resolve any disagreements; the senior author (JJC) served as the tiebreaker. Data extraction included study methodology (eg, design, testing methods); participant characteristics (eg, sex, sport, competition level, description of controls); functional performance (eg, aerobic capacity, walk tests, strength, self-reported functional measures); body composition (eg, anthropometrics, percent lean/fat mass, bone density) and cardiometabolic factors (eg, blood pressure, hypertension, blood lipids, inflammatory biomarkers). Data were reported as they were presented in the primary studies: outcomes are typically presented as mean \pm SD for continuous variables percentages for categorical (eg,

prevalence) outcomes; p values for statistical significance were extracted when possible. Subgroup analyses by sex, sport type and physical activity were also extracted and reported when available.

Patient and public involvement

Given that this study is a scoping review of prior literature, patients were not directly involved. All data are from previously published works.

RESULTS

General study characteristics

Our search yielded 20 articles. Most studies were cross-sectional, evaluated males only, and were conducted in Europe (table 1, online supplemental appendix 2). Nine studies included former athletes from multiple sports with a mix of endurance and team sports,^{33 42–49} while three studies included only American football^{50–52} and three studies included only soccer (ie, football).^{53–55} Most (12 of 20) studies involved athletes who had competed at national and international competitions, including seven studies on Olympic athletes. Five studies included former professional athletes,^{50–53 56} while only two studies involved former college (ie, National Collegiate Athletic Association (NCAA)) athletes.^{33 44}

Physical function

Six studies evaluated functional performance using tests of aerobic capacity, strength and other outcomes (table 2), while five studies included self-reported functional measures (online supplemental appendix 3).

Functional performance tests

Aerobic capacity was evaluated using VO_2 max tests and walking tests. Three studies found that physically active former male athletes had a significantly higher VO_2 max than age-matched peers.^{54 55 57} One study found that former male endurance athletes who then led sedentary lives had a lower VO_2 max than physically active former athletes and controls,⁴⁵ whereas another found that sedentary former male soccer athletes had a lower VO_2 max than physically active former athletes but higher than controls.⁵⁴ Simon and Docherty³³ found that former NCAA Division I College athletes took longer than recreationally active controls to complete a one-mile walk test,³³ whereas Ravi *et al*⁴⁵ found that female former competitive adolescent athletes walked faster and further on a 6 min walk test compared with age-matched and sex-matched controls.⁵⁷ One study reported that former college athletes performed fewer repetitions on a chair stand test than recreationally active controls.³³

Two studies performed strength tests. Simon and Docherty³³ found that former athletes completed fewer push-up repetitions but similar half sit-up repetitions than controls that were recreationally active during college.³³ Ravi *et al*⁴⁵ reported that female former athletes produced higher forces for handgrip and knee extension

Table 1 Meta-data of the 20 included studies

Total sample size	Former athletes n=6535 Controls n=12 524
Study design	Cross-sectional study n=16 (80%) Retrospective study n=2 (10%) Cohort study n=1 (5%) Other n=1 (5%)
Method of testing	In-person testing n=17 (85%) Internet/email n=2 (10%) Mail n=1 (5%)
Country of origin	Europe n=11 (55%) Finland n=4 (20%) Estonia n=2 (10%) Portugal n=2 (10%) Germany n=1 (5%) Poland n=1 (5%) Sweden n=1 (5%) USA n=5 (25%) Brazil n=1 (5%) India n=1 (5%) Iran n=1 (5%) International (multiple countries) n=1 (5%)
Sex	Male only n=12 (60%) Female only n=4 (20%) Both male and female n=4 (20%)
Former athlete sport	Multisport n=9 (45%) Endurance sports n=4 (20%) American football n=3 (15%) Soccer (football) n=3 (15%) Javelin/high jump n=1 (5%)
Former athlete level of competition	International/national (60%) Olympics n=7 (35%) Professional n=5 (25%) National Football League n=3 (15%) Collegiate n=2 (10%) NCAA division 1 n=1 (5%) NCAA division 3 n=1 (5%) Youth n=1 (5%)
Values are presented as number (n) and percent (%). NCAA, National Collegiate Athletic Association.	

strength compared with physically active and sedentary controls.⁴⁵

Two studies^{45 46} analysed jump height. Ravi *et al*⁴⁵ found that former female athletes from several different sports jumped higher than controls who were either physically active or did not exercise,⁴⁵ whereas Rätty *et al*⁴⁶ compared former soccer, weightlifting, running and marksmen athletes, with former weightlifters performing the best.⁴⁶

Unt *et al*⁵⁷ concluded that physically active former athletes produced higher power during a Modified Balke test compared with sedentary former athletes and controls.⁵⁷ Simon and Docherty³³ found no differences between former athletes and controls on two flexibility tests (ie, back scratch and sit and reach).³³ Rätty *et al*⁴⁶ found that the former soccer, weightlifting, running and

Table 2 Functional performance tests

Study	Aerobic capacity (mean±SD)	Strength (mean±SD)	Other (mean±SD)
Babaei 2014 ⁵⁵	VO _{2max} test: FA aerobic group=45±5.8 mL/kg/min, FA anaerobic group=43±4.4 mL/kg/min, controls aerobic group=32±4.5 mL/kg/min, controls anaerobic group=33±4.8 mL/kg/min, aerobic groups p<0.01, anaerobic groups p<0.02	–	–
Dey 2002 ⁵⁴	VO _{2max} test: PAFA=44.9±1.48 mL/kg/min, SFA=40.0±2.19 mL/kg/min, controls=36.8±1.65 mL/kg/min, p<0.01	–	–
Räty 2002 ⁴⁶	–	–	Jumping height: soccer FA=26±3 cm, Weightlifting FA=27±4 cm, running FA=23±2 cm, marksmen FA=24±2 cm, p=0.012 Balance Test Completion Time: soccer FA=38±2.4 s, weightlifting FA=38±2.5 s, running FA=42±2.4 s, marksmen FA=37±2.4 s, 47-year-old controls=48±1.0 s, 57-year-old controls=54±1.2 s, p=0.38 between FA, p<0.01 between FA and controls Balance test times loss of balance: soccer FA=4.8±0.8, weightlifting FA=4.9±0.8, running FA=5.0±0.8, marksmen FA=3.5±0.8, 47-year-old controls=5.0±0.3, 57-year-old controls=7.1±0.4, p=0.49 between FA
Ravi 2020 ⁴⁵	6 min Walk Test: competitive FA=696.7 m (684.8–708.5), regular physical activity controls=667.5 m (662.3–672.7), no exercise controls=660.7 m (651.1–670.2), p<0.001 walking speed: competitive FA=2.9 m/s, regular physical activity controls=2.6 m/s, no exercise controls=2.6 m/s, p<0.001	Handgrip force: competitive FA=333.5 n (322.6–344.4), regular physical activity controls=313.5 N (308.7–318.4), no exercise controls=305.5 N (296.4–314.5), p=0.001 Knee extension force: competitive FA=509.1 N (488.4–529.8), regular physical activity controls=460.4 N (452.7–468.4), no exercise controls=442.3 N (425.6–458.9), p<0.001	Jumping height: competitive FA=21.3 cm, regular physical activity controls=19.0 cm, no exercise controls=18.7 cm, p<0.001
Simon 2017 ³³	1 Mile Walk Test: FA=16.03± 1.54 min, controls=13.61± 1.24 min, p=0.03	Sit to Stand Test: FA=17.97±5.79 reps, controls=22.29±6.14 reps, p=0.01 Push Up Test: FA=21.87±9.39 reps, controls=30.78±9.82 reps, p=0.01 Half Sit-Up Test: FA=49.59±6.26 reps, controls=49.96±7.18 reps, p value not stated	Back Scratch Test: FA=-3.68±-1.33 cm, controls=-3.97±-1.25 cm, p value not stated Sit and Reach Test: FA=25.79±8.51 cm, Controls=26.13±9.85 cm, p value not stated

Continued

Table 2 Continued

Study	Aerobic capacity (mean±SD)	Strength (mean±SD)	Other (mean±SD)
Unt 2008 ⁵⁷	VO _{2max} test: PAFA=4.0±0.5 L/min, SFA=3.42±0.56 L/min, controls=3.44±0.53 L/min, p<0.001 PAFA compared with SFA and controls VO _{2max} per body weight: PAFA=48.0±6.5 mL/kg/ min, SFA=37.0±6.5 mL/kg/ min, controls=37.9±7.1 mL/ kg/min, p<0.001 PAFA compared with SFA and controls	–	Modified Balke Test: PAFA=4.4±0.7 W/kg, SFA=3.5±0.7 W/kg, Controls=3.6±0.9 W/kg, p<0.001 PAFA compared with SFA and controls

FA, former athletes; PAFA, physically active former athletes; SFA, sedentary former athletes.

marksmen athletes performed better on a balance test than similarly aged controls.⁴⁶

Self-reported functional measures

Arlani *et al*⁵³ found that male former soccer athletes scored worse than controls on the Knee Injury and Osteoarthritis Outcome Score pain, symptom and knee-related quality of life subscales.⁵³ Former athletes, most notably those previously in endurance sports, had a lower prevalence of self-reported hip disability and pain than age-matched military controls.⁴⁷ In contrast, knee disability and pain were higher in former team sport athletes than in controls.⁴⁷

Body composition and cardiometabolic measures

All 20 studies included at least one body composition or cardiometabolic measurement (online supplemental appendixs 4; 5).

Body weight and anthropometrics

Several studies found that former athletes had a lower BMI than controls.^{42 49 53–55 57 58} Physically active former athletes had significantly lower BMI than their sedentary counterparts.^{54 57 58} Additionally, former female athletes had lower BMI values than their former male athlete peers.⁴³ Chang *et al*'s study⁵¹ was the only study that found higher BMI values in former athletes, all of whom were American football players.⁵¹

Three studies found a significantly lower body weight in former athletes compared with age-matched and sex-matched controls,^{49 54 58} while two studies found that former American football players had a higher body weight than controls.^{51 52} Physically active former athletes had a lower body weight compared with sedentary former athletes in three studies.^{54 57 58}

One study found that former female athletes had smaller waist circumferences compared with female controls.⁴² Former male athletes who were currently more physical active had lower waist-to-hip ratios compared

with sedentary athletes and controls.^{54 58} Dey *et al*⁵⁴ also found that active former athletes had lower waist-to-hip ratios than sedentary athletes or sedentary controls.⁵⁴

Body composition

Several studies evaluated body composition (figure 2). Simon and Docherty³³ found higher percent body fat in former collegiate athletes compared with recreationally active controls. In contrast, three studies found that former athletes had a lower percent body fat.^{45 49 59} Physically active former athletes had a lower body fat percentage compared with sedentary former athletes.^{54 57 58} Former athletes had greater total lean mass,^{45 49 59} lean mass index,⁴⁵ appendicular lean mass⁴⁵ and body surface area.⁵²

Bone density

Ravi *et al*⁴⁵ and Kettunen *et al*⁴⁸ found that former female and male athletes of various sports had higher femoral neck bone mineral density, while Kettunen *et al*⁴⁸ also found the same result in trochanter bone mineral density for male athletes.⁴⁸ Andreoli *et al*⁵⁹ determined that former female runners and swimmers also had higher total spine and leg bone mineral density than age-matched and sex-matched sedentary controls. Swimmers only had greater upper extremity bone mineral density than controls.⁵⁹

Blood pressure/hypertension

Two studies found that former athletes had a lower prevalence of hypertension,^{43 44} while another found that former National Football League (NFL) athletes had a higher prevalence of hypertension than controls.⁵⁰ Several studies found lower systolic blood pressure in former athletes,^{42 51 58} with physically active^{54 58} and female⁴³ former athletes having lower values compared with sedentary and male former athletes, respectively. In contrast, Hurst *et al*⁵² found higher systolic blood pressure in former NFL athletes.⁵² Regarding diastolic

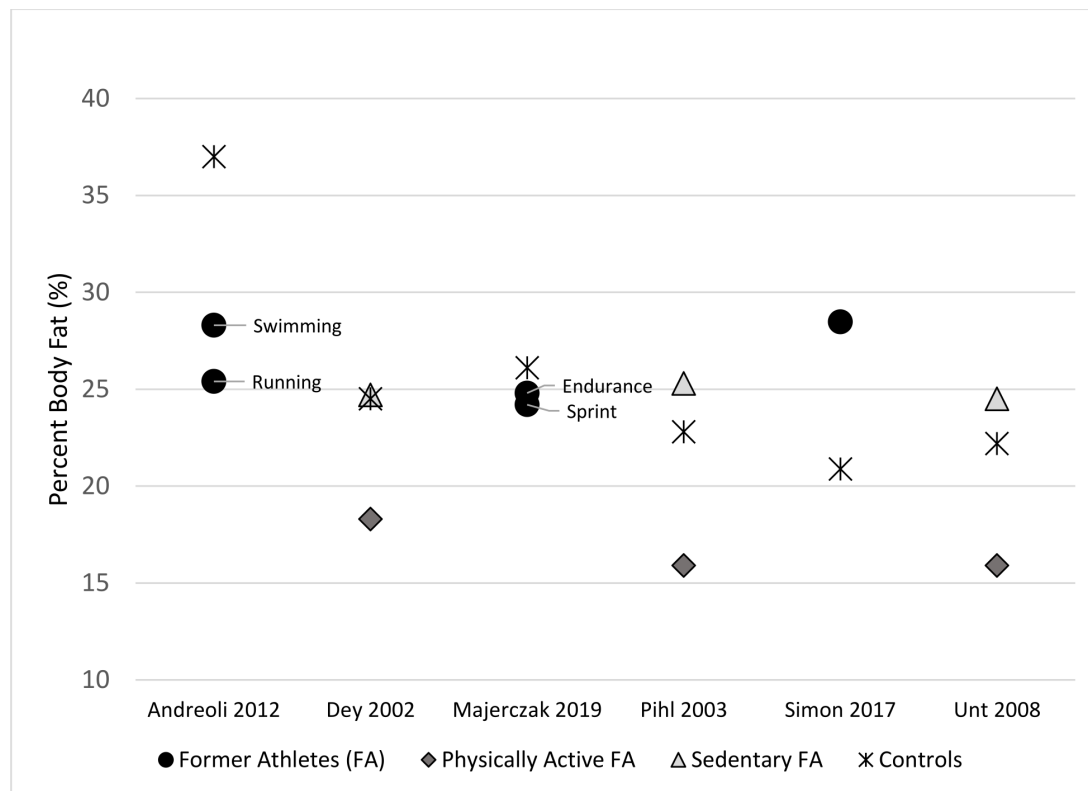


Figure 2 Percent body fat in former athletes and controls.

blood pressure, former NFL athletes had lower values,⁵¹ and physically active former male soccer and endurance athletes had lower values compared with their non-athletic peers.^{54 58} Hagmar *et al*⁴⁹ found that former female athletes had lower resting heart rates compared with age-matched controls.⁴⁹

Blood lipids

Half (n=10, 50%) of the studies included blood lipid measurements (figure 3A–D). Former athletes consistently had lower total cholesterol^{43 44 49 58} and lower triglyceride levels^{54 57 58} than controls. Compared with sedentary former athletes, physically active former athletes had lower total cholesterol in three studies,^{54 57 58} lower triglycerides in three studies,^{54 57 58} higher high-density lipoprotein (HDL) cholesterol in two studies^{54 58} and lower low-density lipoprotein (LDL) cholesterol in one study.⁵⁴ Dey *et al*⁵⁴ found that sedentary former male soccer athletes had higher total cholesterol, higher triglycerides and lower HDL cholesterol than sedentary controls.⁵⁴

Other blood biomarkers and cardiometabolic indicators

Several other blood biomarkers and cardiometabolic measures were evaluated. Former athletes had lower glucose levels than controls.^{42 43 51 52} Former athletes also had a lower prevalence of diabetes,⁵⁰ hyperglycemia⁴³ and metabolic syndrome⁴² than controls. One study found that former NFL football players had lower high-sensitivity C reactive protein compared with controls.⁵¹

Measures of oxidative stress differed between physically active and sedentary former athletes but not to controls.^{57 58}

DISCUSSION

The purpose of our scoping review was to summarise the literature published since 2000 on long-term function, body composition and cardiometabolic health in former athletes and to make recommendations for future research areas. We identified 20 published articles that met our criteria. In summary, our findings suggest that prior engagement in elite sport does not necessarily position individuals for optimal long-term health and function. The available data suggest that former national and international class endurance athletes may have higher aerobic capacity (ie, higher VO_2 max), better cardiometabolic indicators and leaner body compositions than non-athlete controls. Data from a few studies^{54 57 58} suggest former athletes who maintain higher activity patterns (ie, self-reported exercise frequency of at least 3×/week) in midlife are healthier than former athletes who lead more sedentary lives and controls. Though limited by quantity of studies and samples, our findings suggest that former team sport athletes—who also have a much higher prevalence of former time-loss injury⁶⁰—have poorer physical function and cardiometabolic health than individuals who were recreationally active during young adulthood.

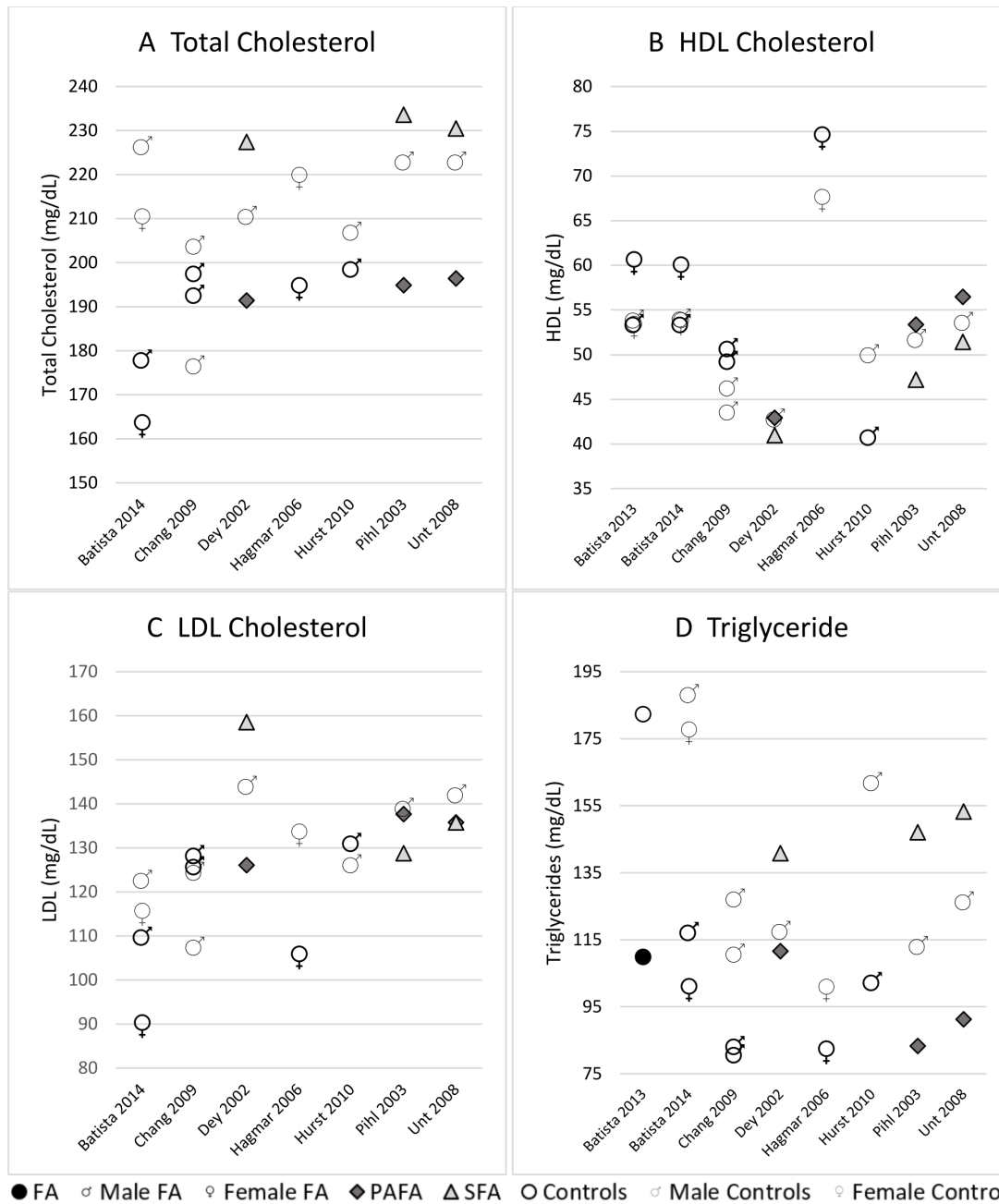


Figure 3 Mean blood lipid values in former athletes (dark) and controls (light): (A) total cholesterol, (B) HDL cholesterol, (C) LDL cholesterol and (D) triglyceride Levels. Batista and Soares⁴² only reported HDL cholesterol and triglyceride values and only separated sex comparisons for HDL levels, as the triglyceride values include both males and females. Chang *et al*⁵¹ have two values for FA and controls due to two different cohorts. FA, former athletes; HDL, high-density lipoprotein; LDL, low-density lipoprotein; PAFA, physically active former athletes; SFA, sedentary former athletes.

Our findings that few studies included females or evaluated sex differences are well supported by prior literature demonstrating inequalities in research conducted on female versus male athletes.⁶¹ While some sports (eg, American football) are not widely practiced among both sexes, including both males and females in studies and evaluating sex differences when possible is essential and may have substantial clinical implications. Female sports participation has seen drastic increases since the passage of Title IX, furthering the need for sports medicine research to actively include female athletes

in research studies to enable appropriate investigation of sex-based differences. Most of the former athletes in the included studies evaluated European males at a previous professional/elite level of competition, thus the findings may not generalise to females or athletes at lower competition levels. Four studies included only female participants,^{44 45 49 59} though two had sample sizes totalling less than 50 participants, including controls.^{49 59} Future studies should include female and male athletes to evaluate long-term health in both sexes and evaluate

sex differences in long-term health among athletes in similar sports.

Current physical activity patterns in former athletes may be a key consideration for later health outcomes. Three studies^{54 57 58} compared male former athletes who led a more active lifestyle in midlife with former athletes who were sedentary in midlife, consistently finding that greater exercise in midlife was correlated with better functional performance,⁵⁷ higher VO_2 max^{54 57} and better body composition.^{54 57 58} While these athletes were male endurance athletes^{57 58} and male soccer players,⁵⁴ limiting generalisability, substantial literature supports the benefit of physical activity and exercise on health outcomes.^{10 62 63} The included studies^{54 57 58} also relied exclusively on self-reported exercise frequency, rather than quantifying physical activity patterns. Important physical activity patterns include varying levels of physical activity (ie, light, moderate and vigorous) and sedentary behaviour, which is high in current male professional soccer players.⁶⁴ Future studies should quantify activity patterns via continuous wear accelerometer protocols in current and former athletes and healthy non-athlete controls to determine more precisely the impact of activity patterns on long-term health in athletes.

Despite noted limitations, the importance of current health practices (ie, physical activity) on current health is clear, highlighting a reality for former athletes: prior engagement in high levels of exercise through elite sport does not provide athletes with lifelong protection for function, body composition and cardiometabolic health. Prior research on long-term cardiovascular health in former athletes has focused heavily on American football players.^{9 50–52 65} McHugh *et al*⁹ performed a systematic review and meta-analysis on cardiovascular health in male team-sport athletes (ie, American football (12 studies) and soccer (1 study)), finding that some factors (eg, fasting glucose, triglycerides) were better in former athletes whereas others (eg, systolic blood pressure, LDL cholesterol) were better in controls. While former NFL players who have higher BMI at time of professional sport participation have significantly greater cardiovascular disease risk,⁶⁵ current behaviours including physical activity, exercise, diet and sleep, likely influence not only cardiovascular disease risk but also function, body composition, and other health outcomes. Future research should explore biopsychosocial factors for why some former athletes engage in healthy behaviours and others do not.

While it is well known that athletes sustain musculoskeletal injuries at much higher rates than non-athletes, one notable finding of our scoping review was that the included studies did not rigorously control for prior injury. Given the well-established link between traumatic joint injury, particularly intra-articular knee injury and subsequent risk for early OA,^{29 30} future research must compare former athletes with and without prior injury/surgery. To illustrate this point, Simon and Docherty found poorer functional performance and higher body

fat percentage in former NCAA college athletes compared with controls, but 78/100 of the former athletes sustained a time-loss injury compared with just 20/100 controls.³³ In short, prior injury likely influences long-term health in athletes and should be evaluated thoroughly in future research.

One of the best datasets on long-term athlete health evaluated Finnish former athletes who competed in national/international competitions from 1920 to 1965.^{46–48 66–72} While several of these studies were published prior to 2000 or did not meet other inclusion criteria, three were included in our scoping review.^{46–48} Collectively, these studies suggest former athletes may be fitter, healthier and stronger well into midlife and older age,⁷³ despite high rates of radiographic OA.⁷² It is possible that former athletes benefit from persistently greater quadriceps muscle strength, which could help preserve better function,⁷⁴ and/or high cardiorespiratory fitness, which could (partially) counteract deleterious consequences of higher OA prevalence.^{67 72 75} Future studies could investigate the effect of prior sports participation on cardiorespiratory fitness and function in midlife and older adults who have OA. In recent decades, however, sports have changed dramatically,²⁴ including higher injury rates, differences in training and competition times and expectations, and artificial playing field surfaces.²⁴ These factors limit the applicability of studies on athletes from many years ago to today's athletes.

Limitations

A scoping review was pursued instead of a systematic review for several reasons, so our conclusions are limited primarily to summarising general findings, discussing gaps in the literature and identifying areas of future research. While we synthesised outcomes when possible, we did not perform meta-analyses or quality assessments of included studies in line with scoping review guidelines.⁴⁰ Most studies evaluated male participants only and athletes who competed at the professional/elite competition levels, thus the findings may not generalise to females or athletes at lower competition levels. Most studies also used a cross-sectional study design, limiting the ability to determine cause and effect. Prior injury, the type and level of sport, subsequent and current physical activity patterns, and outcome measures likely influence the findings and generalisability. Finally, we did not consider atrial fibrillation or other cardiac arrhythmias or abnormalities, though there has already been considerable research including a systematic review and meta-analysis on atrial fibrillation in athletes.⁷⁶ Further research is needed in many areas (eg, standardised functional performance tests, inclusion of females, study of sex differences) before a systematic review(s) would be feasible, although systematically evaluating BMI, body composition and blood lipids—at least in male former athletes—may be possible.

CONCLUSION

Our scoping review findings suggest that prior engagement in high levels of exercise, even at an elite level,

does not provide lifelong protection for cardiometabolic health, function or body composition. While many former endurance athletes have leaner body compositions, higher aerobic capacity and better cardiometabolic indicators than controls, other former athletes do not and may have similar or worse outcomes. Former team sport athletes, who have higher injury prevalence, may have poorer physical function than recreationally active controls. Continued activity is important in ageing athletes, as former athletes who maintain higher physical activity patterns are healthier than those who do not. Future research should include females and evaluate sex differences, control for prior sports-related injury(ies), objectively measure current physical activity patterns, use standardised outcome measures including performance-based functional assessments,⁷⁷ incorporate longitudinal designs and determine why some former athletes engage in positive health behaviours whereas others do not. Findings from these proposed studies may facilitate our understanding of high-level sports competition on long-term health and ultimately inform how sports medicine providers counsel and intervene for optimal long-term health.

Twitter Jacob John Capin @JacobCapin

Acknowledgements The authors are grateful for funding from the National Institutes of Health Office of the Director (DP5-OD031833) and for the support of Marquette University and the Athletic and Human Performance Research Center.

Contributors JHS contributed to study design, data acquisition, analysis and interpretation, drafting the manuscript and incorporating revisions. ZPB contributed to study design, data acquisition and analysis, and critical review. AF contributed to study design, data acquisition and analysis, drafting portions of the manuscript, and critical review. SLL, CSS, SAC, SKH and WBF contributed to conception and design, data interpretation and critical review. JJC contributed to conception and design, data acquisition, analysis and interpretation, drafting the manuscript and incorporating revisions. All authors approved the final version of the manuscript and take responsibility for the work.

Funding Funding for this work was provided by an NIH Director's Early Independence Award to JJC (DP5-OD031833).

Disclaimer The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Competing interests Funding for this work was provided by an NIH Director's Early Independence Award to JJC (DP5-OD031833).

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iD

Jacob John Capin <http://orcid.org/0000-0001-9361-3700>

REFERENCES

- NFHS. *NFHS Releases First High School Sports Participation Survey in Three Years*. NFHS News, 2022.
- NCAA. *Estimated Probability of Competing in College Athletics*. NCAA Resources, 2020.
- Lemez S, Baker J. Do elite athletes live longer? A systematic review of mortality and longevity in elite athletes. *Sports Med Open* 2015;1:16.
- Clarke PM, Walter SJ, Hayen A, *et al*. Survival of the fittest: retrospective cohort study of the longevity of Olympic Medallists in the modern era. *Br J Sports Med* 2015;49:898–902.
- Runacres A, Mackintosh KA, McNarry MA. Health consequences of an elite sporting career: long-term detriment or long-term gain? A meta-analysis of 165,000 former athletes. *Sports Med* 2021;51:2233–4.
- Migliorini F, Marsilio E, Torsiello E, *et al*. Osteoarthritis in athletes versus Nonathletes: A systematic review. *Sports Med Arthrosc Rev* 2022;30:78–86.
- Palmer D, Cooper D, Whittaker JL, *et al*. Prevalence of and factors associated with osteoarthritis and pain in retired Olympians compared with the general population: part 2 - the spine and upper limb. *Br J Sports Med* 2022;bjsports-2021-104978.
- Nilsen DH, Furnes O, Kroken G, *et al*. Risk of total hip Arthroplasty after elite sport: linking 3304 former world-class athletes with the Norwegian Arthroplasty register. *Br J Sports Med* 2022;57:bjsports-2022-105575:33–9..
- McHugh C, Hind K, Davey D, *et al*. Cardiovascular health of retired field-based athletes: A systematic review and meta-analysis. *Orthop J Sports Med* 2019;7:2325967119862750.
- Garber CE, Blissmer B, Deschenes MR, *et al*. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and Neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine & Science in Sports & Exercise* 2011;43:1334–59.
- Eddolls WTB, McNarry MA, Lester L, *et al*. The association between physical activity, fitness and body mass index on mental well-being and quality of life in adolescents. *Qual Life Res* 2018;27:2313–20.
- Cox EP, O'Dwyer N, Cook R, *et al*. Relationship between physical activity and cognitive function in apparently healthy young to middle-aged adults: A systematic review. *J Sci Med Sport* 2016;19:616–28.
- Li JW, O'Connor H, O'Dwyer N, *et al*. The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *J Sci Med Sport* 2017;20:841–8.
- Colcombe S, Kramer AF. Fitness effects on the cognitive function of older adults: A meta-analytic study. *Psychol Sci* 2003;14:125–30.
- Oja P, Titzel S, Kokko S, *et al*. Health benefits of different sport disciplines for adults: systematic review of observational and intervention studies with meta-analysis. *Br J Sports Med* 2015;49:434–40.
- Janssen I, Leblanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act* 2010;7:40.
- Booth FW, Roberts CK, Laye MJ. Lack of exercise is a major cause of chronic diseases. *Compr Physiol* 2012;2:1143–211.
- Smith JJ, Eather N, Morgan PJ, *et al*. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. *Sports Med* 2014;44:1209–23.
- Shephard RJ. Maximal oxygen intake and independence in old age. *Br J Sports Med* 2009;43:342–6.
- Kay MC, Register-Mihalik JK, Gray AD, *et al*. The epidemiology of severe injuries sustained by National collegiate athletic Association student-athletes, 2009–2010 through 2014–2015. *J Athl Train* 2017;52:117–28.
- Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train* 2007;42:311–9.
- Kerr ZY, Marshall SW, Dompier TP, *et al*. College sports-related injuries - United States, 2009–10 through 2013–14 academic years. *MMWR Morb Mortal Wkly Rep* 2015;64:1330–6.
- Matheson GO, Anderson S, Robell K. Injuries and illnesses in the Preparation evaluation data of 1693 college student-athletes. *Am J Sports Med* 2015;43:1518–25.
- Kemler E, Valkenberg H, Verhagen E. More people more active, but there is a counter site. novice athletes are at highest risk of injury in a large population-based retrospective cross-sectional study. *BMJ Open Sport Exerc Med* 2022;8:e001255.
- Agel J, Rockwood T, Klossner D. Collegiate ACL injury rates across 15 sports: national collegiate athletic Association injury surveillance system data update (2004–2005 through 2012–2013). *Clin J Sport Med* 2016;26:518–23.

- 26 Zbrojkiewicz D, Vertullo C, Grayson JE. Increasing rates of anterior Cruciate ligament reconstruction in young Australians, 2000-2015. *Med J Aust* 2018;208:354-8.
- 27 Maniar N, Verhagen E, Bryant AL, et al. Opar DA: trends in Australian knee injury rates: an Epidemiological analysis of 228,344 knee injuries over 20 years. *Lancet Reg Health West Pac* 2022;21:100409.
- 28 Paterno MV, Rauh MJ, Schmitt LC, et al. Incidence of contralateral and ipsilateral anterior Cruciate ligament (ACL) injury after primary ACL reconstruction and return to sport. *Clin J Sport Med* 2012;22:116-21.
- 29 Lohmander LS, Ostenberg A, Englund M, et al. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior Cruciate ligament injury. *Arthritis Rheum* 2004;50:3145-52.
- 30 Snoeker B, Turkiewicz A, Magnusson K, et al. Risk of knee osteoarthritis after different types of knee injuries in young adults: a population-based cohort study. *Br J Sports Med* 2020;54:725-30.
- 31 Davies MAM, D Judge A, Delmestri A, et al. Health amongst former Rugby Union players: A cross-sectional study of morbidity and health-related quality of life. *Sci Rep* 2017;7:11786.
- 32 Golightly YM, Marshall SW, Callahan LF, et al. Early-onset arthritis in retired National Football League players. *Journal of Physical Activity and Health* 2009;6:638-43.
- 33 Simon JE, Docherty CL. The impact of previous athletic experience on current physical fitness in former collegiate athletes and Noncollegiate athletes. *Sports Health* 2017;9:462-8.
- 34 Purcell C, Duignan C, Fullen BM, et al. Comprehensive assessment and classification of upper and lower limb pain in athletes: a Scoping review. *Br J Sports Med* 2023;57:535-42.
- 35 Filbay S, Pandya T, Thomas B, et al. Quality of life and life satisfaction in former athletes: A systematic review and meta-analysis. *Sports Med* 2019;49:1723-38.
- 36 S Oliveira J, Gilbert S, Pinheiro MB, et al. Effect of sport on health in people aged 60 years and older: a systematic review with meta-analysis. *Br J Sports Med* 2023;57:230-6.
- 37 Lachman ME. Mind the gap in the middle: A call to study Midlife. *Res Hum Dev* 2015;12:327-34.
- 38 Kishimoto H, Hata J, Ninomiya T, et al. Midlife and late-life Handgrip strength and risk of cause-specific death in a general Japanese population: the Hisayama study. *J Epidemiol Community Health* 2014;68:663-8.
- 39 Lachman ME, Teshale S, Agrigoroaei S. Midlife as a pivotal period in the life course: balancing growth and decline at the crossroads of youth and old age. *Int J Behav Dev* 2015;39:20-31.
- 40 Munn Z, Peters MDJ, Stern C, et al. Systematic review or Scoping review? guidance for authors when choosing between a systematic or Scoping review approach. *BMC Med Res Methodol* 2018;18:143.
- 41 Jonnalagadda SS, Skinner R, Moore L. Overweight athlete: fact or fiction. *Curr Sports Med Rep* 2004;3:198-205.
- 42 Batista C, Soares JM. Are former elite athletes more protected against metabolic syndrome? *J Cardiol* 2013;61:440-5.
- 43 Batista CHX, Soares JM. Is athletic background associated with a future lower prevalence of risk factors for chronic disease. *Journal of Exercise Science & Fitness* 2014;12:47-54.
- 44 Stracciolini A, Amar-Dolan L, Howell DR, et al. 3rd: female sport participation effect on long-term health-related quality of life. *Clin J Sport Med* 2020;30:526-32.
- 45 Ravi S, Kujala UM, Tammelin TH, et al. Adolescent sport participation and age at menarche in relation to Midlife body composition, bone mineral density, fitness, and physical activity. *J Clin Med* 2020;9:3797.
- 46 Rätty HP, Impivaara O, Karppi S-L. Dynamic balance in former elite male athletes and in community control subjects. *Scand J Med Sci Sports* 2002;12:111-6.
- 47 Kettunen JA, Kujala UM, Kaprio J, et al. Lower-limb function among former elite male athletes. *Am J Sports Med* 2001;29:2-8.
- 48 Kettunen JA, Impivaara O, Kujala UM, et al. Hip fractures and femoral bone mineral density in male former elite athletes. *Bone* 2010;46:330-5.
- 49 Hagmar M, Eriksson MJ, Lindholm C, et al. Endothelial function in post-menopausal former elite athletes. *Clin J Sport Med* 2006;16:247-52.
- 50 Grashow R, Shaffer-Pancyzk TV, Dairi I, et al. Healthspan and chronic disease burden among young adult and middle-aged male former American-style professional football players. *Br J Sports Med* 2022;57:166-71.
- 51 Chang AY, FitzGerald SJ, Cannaday J, et al. Cardiovascular risk factors and coronary Atherosclerosis in retired National Football League players. *Am J Cardiol* 2009;104:805-11.
- 52 Hurst RT, Burke RF, Wissner E, et al. Incidence of Subclinical Atherosclerosis as a marker of cardiovascular risk in retired professional football players. *Am J Cardiol* 2010;105:1107-11.
- 53 Arliani GG, Astur DC, Yamada RKF, et al. Early osteoarthritis and reduced quality of life after retirement in former professional soccer players. *Clinics (Sao Paulo)* 2014;69:589-94.
- 54 Dey SK, Ghosh C, Debray P, et al. Coronary artery disease risk factors & their association with physical activity in older athletes. *J Cardiovasc Risk* 2002;9:383-92.
- 55 Babaei P, Damirchi A, Mehdipoor M, et al. Long term habitual exercise is associated with lower resting level of serum BDNF. *Neurosci Lett* 2014;566:304-8.
- 56 Majerczak J, Grandys M, Frolow M, et al. Age-dependent impairment in endothelial function and arterial stiffness in former high class male athletes is no different to that in men with no history of physical training. *J Am Heart Assoc* 2019;8:e012670.
- 57 Unt E, Zilmer K, Mägi A, et al. Homocysteine status in former top-level male athletes: possible effect of physical activity and physical fitness. *Scand J Med Sci Sports* 2008;18:360-6.
- 58 Pihl E, Zilmer K, Kullisaar T, et al. High-sensitive C-reactive protein level and oxidative stress-related status in former athletes in relation to traditional cardiovascular risk factors. *Atherosclerosis* 2003;171:321-6.
- 59 Andreoli A, Celi M, Volpe SL, et al. Long-term effect of exercise on bone mineral density and body composition in post-menopausal elite athletes: a retrospective study. *Eur J Clin Nutr* 2012;66:69-74.
- 60 Simon JE, Docherty CL. Current health-related quality of life in former national collegiate athletic Association division I collision athletes compared with contact and limited-contact athletes. *J Athl Train* 2016;51:205-12.
- 61 Paul RW, Sonnier JH, Johnson EE, et al. Inequalities in the evaluation of male versus female athletes in sports medicine research: A systematic review. *Am J Sports Med* 2022;2022:3635465221131281.
- 62 Chen L-J, Hamer M, Lai Y-J, et al. Can physical activity eliminate the mortality risk associated with poor sleep? A 15-year follow-up of 341,248 MJ cohort participants. *J Sport Health Sci* 2022;11:596-604.
- 63 Jakicic JM, Kraus WE, Powell KE, et al. Physical activity guidelines advisory C: association between bout duration of physical activity and health systematic review. *Med Sci Sports Exerc* 2019;51:1213-9.
- 64 Weiler R, Aggio D, Hamer M, et al. Sedentary behaviour among elite professional Footballers: health and performance implications. *BMJ Open Sport Exerc Med* 2015;1:e000023.
- 65 Baron SL, Hein MJ, Lehman E, et al. Body mass index, playing position, race, and the cardiovascular mortality of retired professional football players. *Am J Cardiol* 2012;109:889-96.
- 66 Kujala UM, Sarna S, Kaprio J, et al. Natural selection to sports, later physical activity habits, and coronary heart disease. *Br J Sports Med* 2000;34:445-9.
- 67 Kujala UM, Marti P, Kaprio J, et al. Occurrence of chronic disease in former top-level athletes. *Sports Medicine* 2003;33:553-61.
- 68 Laine MK, Eriksson JG, Kujala UM, et al. A former career as a male elite athlete--does it protect against type 2 diabetes in later life. *Diabetologia* 2014;57:270-4.
- 69 Kujala UM, Sarna S, Kaprio J, et al. Hospital care in later life among former world-class Finnish athletes. *JAMA* 1996;276:216-20.
- 70 Kettunen JA, Kujala UM, Kaprio J, et al. All-cause and disease-specific mortality among male, former elite athletes: an average 50-year follow-up. *Br J Sports Med* 2015;49:893-7.
- 71 Sarna S, Kaprio J, Kujala UM, et al. Health status of former elite athletes. The Finnish experience. *Aging (Milano)* 1997;9:35-41.
- 72 Kujala UM, Kaprio J, Sarna S. Osteoarthritis of weight bearing joints of lower limbs in former elite male athletes. *BMJ* 1994;308:231-4.
- 73 Kujala UM. Fitter, healthier and stronger? many factors influence elite athletes' long-term health. *Br J Sports Med* 2021;55:77-8.
- 74 Luc-Harkey BA, Safran-Norton CE, Mandl LA, et al. Associations among knee muscle strength, structural damage, and pain and mobility in individuals with osteoarthritis and symptomatic Meniscal tear. *BMC Musculoskelet Disord* 2018;19:258.
- 75 Palmer D, Cooper D, Whittaker JL, et al. Prevalence of and factors associated with osteoarthritis and pain in retired Olympians, with comparison to the general population: part 1-the lower limb. *Br J Sports Med* 2022;56:1123-32.
- 76 Newman W, Parry-Williams G, Wiles J, et al. Risk of atrial fibrillation in athletes: a systematic review and meta-analysis. *Br J Sports Med* 2021;55:1233-8.
- 77 Capin JJ, Bade MJ, Jennings JM, et al. Total knee Arthroplasty assessments should include strength and performance-based functional tests to complement range-of-motion and patient-reported outcome measures. *Phys Ther* 2022;102.