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REVIEW

Coronary Atherosclerosis in Masters Athletes: Contemporary Evidence and Clinical Implications

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Abstract

Purpose of Review A growing body of evidence suggests that Masters athletes have a higher prevalence of coronary artery calcification and plaque compared to more sedentary, but low-risk individuals. This clinical paradox has sparked interest in understanding underlying mechanisms, prognostic importance, and clinical management of coronary atherosclerosis in highly-trained Masters athletes.

Recent Findings Data from multiple observational studies evaluating coronary atherosclerosis in Masters athletes have demonstrated a higher-than-expected prevalence of calcified plaque. More recent studies have also identified a greater burden of mixed plaques in Masters athletes, the prognostic significance of which remains uncertain. In parallel, contemporary exercise guidelines for Masters athletes with coronary atherosclerosis have evolved and emphasize shared decision-making, while also taking into account the Masters athlete's overall cardiovascular risk profile.

Summary In this review, we summarize the contemporary evidence on the epidemiology and plaque features of coronary atherosclerosis in Masters athletes, including sex differences and the impact of exercise intensity and traditional cardiovascular risk factors. We review potential mechanisms, including the effects of hemodynamic stress, oxidative stress, inflammation, calcium homeostasis, and genetic factors, as well as their interaction with classic risk factors. Finally, we review current clinical approaches to risk assessment and treatment options, highlighting recent shifts toward personalized assessments and shared decision-making.

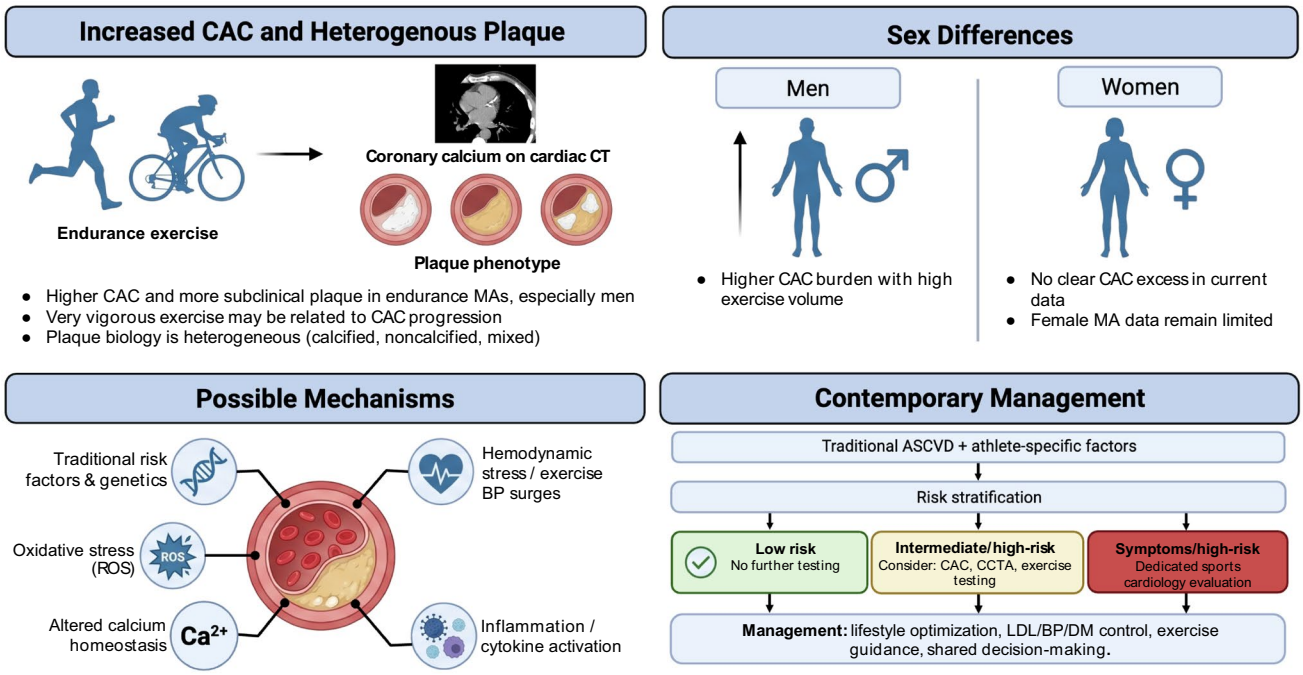
Graphical Abstract

Coronary Atherosclerosis in Masters Athletes. Abbreviations: CAC, Coronary artery calcium; MA, Masters athlete; ROS, Reactive oxygen species; ASCVD, Atherosclerotic cardiovascular disease; CCTA, Coronary computed tomography angiography; BP, Blood pressure; DM, Diabetes mellitus; LDL, Low-density lipoprotein

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Keywords Masters athletes · Coronary artery calcium · Coronary atherosclerosis · Shared decision-making · Cardiovascular risk factors

Abbreviations

MA	Masters Athlete
ASCVD	Atherosclerotic Cardiovascular Disease
CV	Cardiovascular
CVD	Cardiovascular Disease
CAC	Coronary Artery Calcium
MET	Metabolic Equivalent of Task
CCTA	Coronary Computed Tomography Angiography
ROS	Reactive Oxygen Species
IL-1ra	Interleukin-1 Receptor Antagonist
IL-6	Interleukin-6
PTH	Parathyroid Hormone
ACC	American College of Cardiology
AHA	American Heart Association
ESC	European Society of Cardiology
Astro-CHARM	Astronaut Cardiovascular Health and Risk Modification
SCORE2	Systematic Coronary Risk Evaluation 2
PREVENT	Predicting Risk of Cardiac Disease EVENTs
SDM	Shared Decision-Making
CAD	Coronary Artery Disease
LV	Left Ventricle
PCSK9	Proprotein Convertase Subtilisin/Kexin Type 9
LDL-C	Low Density Lipoprotein Cholesterol

Introduction

Masters athletes (MAs), defined as individuals aged 35 years or older who engage in habitual, high-volume recreational exercise and/or competitive sports, represent one of the fastest-growing athletic populations worldwide [1]. MAs are primarily motivated by performance or competitive goals beyond just health benefits, and exercise habits consistently exceed physical activity recommendations [2–4]. Regular physical activity remains one of the most effective interventions to prevent atherosclerotic cardiovascular disease (ASCVD) and lower cardiovascular (CV) mortality through favorable effects on traditional and numerous cardiovascular disease (CVD) risk factors [4–6]. The relationship between physical activity and CVD risk reduction is curvilinear with an initial dose-dependent decrease in CV events, but diminishing returns at higher levels of physical activity [7, 8].

Despite the well-established CV benefits of exercise, prior observations have revealed an intriguing paradox related to intensive training habits and coronary artery disease (CAD). While physical activity is unequivocally beneficial for individuals who meet recommended levels, long-term and high-levels of endurance exercise training have been associated with a higher-than-expected prevalence of coronary artery calcium (CAC). Multiple studies

have shown that male Masters endurance athletes have a higher prevalence of CAC and subclinical coronary atherosclerosis compared to less active individuals with favorable CV risk profiles [9–12]. Plaque composition is also controversial in MAs, where earlier studies demonstrated a high prevalence of densely calcified and stable plaques in MAs, but recent research has challenged this paradigm [9–11, 13]. Moreover, mechanisms underlying increased CAC in MAs remain incompletely understood [14].

In this comprehensive review, we summarize contemporary evidence regarding the epidemiology and characteristics of coronary atherosclerosis in MAs, examine proposed mechanisms underlying CAC in this population, and review contemporary approaches to cardiovascular risk stratification and management in MAs. This review adds to the literature by integrating current evidence on coronary atherosclerosis in MAs, with particular emphasis on exercise dose, sex differences, plaque morphology, and the lack of prospective clinical outcome data. Finally, we highlight key knowledge gaps that will shape future research in this evolving arena.

Methods

We conducted a targeted literature review using PubMed/MEDLINE to identify literature examining the relationship between long-term endurance exercise and coronary atherosclerosis in masters athletes. Search terms included a combination of 'masters athlete,' 'endurance athlete,' 'high-volume exercise,' 'coronary atherosclerosis,' 'coronary artery disease,' 'coronary calcification,' 'coronary plaque,' and 'cardiovascular risk.' We included relevant observational, cohort, and imaging studies, as well as systematic reviews, meta-analyses, clinical guidelines, and society consensus statements. Reference lists of key studies and contemporary reviews were also examined to identify relevant publications not captured in the initial database search. The literature incorporated in this review spans from 2002 through 2026, with select earlier studies when necessary to provide historical or clinical context.

Coronary Atherosclerosis in Masters Athletes: What Do We Know?

Epidemiology of Coronary Atherosclerosis in Masters Athletes

CAD remains the leading cause of sudden cardiac death (SCD) among MAs [15–18]. In the general population, traditional ASCVD risk factors such as smoking, alcohol use, high cholesterol, and age contribute to the development of CVD, while regular physical activity mitigates CVD morbidity and mortality. Among MAs and individuals in the general population, men tend to develop CVD and associated complications at a younger age than women, likely because of sex-specific biological factors and hormonal differences [19–21]. Traditional CV risk factors persist among MAs, but increasing evidence suggests that lifelong high-volume exercise is associated with a higher prevalence of CAC and subclinical coronary atherosclerosis, particularly in men.

Exercise guidelines emphasize at least 150–300 min/week of moderate-intensity or 75 min/week of vigorous-intensity aerobic exercise accompanied by resistance exercise twice weekly for the general population [4, 22–25]. MAs consistently engage in multifold higher levels of physical activity at vigorous intensity. The exercise response curve typically demonstrates a curvilinear or reverse 'J-shape' relationship between exercise volume and CVD risk reduction, with extremes of exercise not conferring additional benefit [7, 8]. A 'U-shape' dose–response relationship has also been proposed, where extremes of exercise have been postulated to slightly reverse the benefits derived from routine physical activity. However, data suggesting a 'U-shape' relationship in athletes without known CVD have been subject to scrutiny due to methodological limitations [26–28]. Nevertheless, these prior observations associated with higher tiers of physical activity have challenged the conventional view that greater exercise volume uniformly translates into lower CVD burden (Fig. 1).

Multiple observational studies have shown a higher prevalence of CAC among male MAs compared to less active peers. Möhlenkamp et al. evaluated 108 male marathon runners who displayed a similar distribution of median CAC (36 vs. 38; $p=0.36$) to age-matched controls but a higher degree of CAC when factoring in Framingham Risk Score-matched controls (12 vs. 3; $p=0.02$). These findings suggested that conventional risk factors may underestimate ASCVD in male endurance MAs [12]. However, family history of early CAD was not controlled for in this study, and a high percentage of marathon runners were former or active smokers. Aengevaeren et al. studied 284 middle-aged men who participated in competitive or leisure sports, with activity levels stratified by metabolic equivalent of task (MET)-min/week. Among all participants, 53% had evidence of CAC, and athletes in the most active group (>2,000 MET-min/week) had significantly higher CAC prevalence than those in the least active group (<1,000 MET-min/week) (OR:3.2, 95%CI 1.6–6.6) [9]. The follow-up MARC-2 study showed that very vigorous-intensity exercise was also associated with increased CAC progression for every 10% increase in CAC score [29]. More recently, the Master@Heart Study

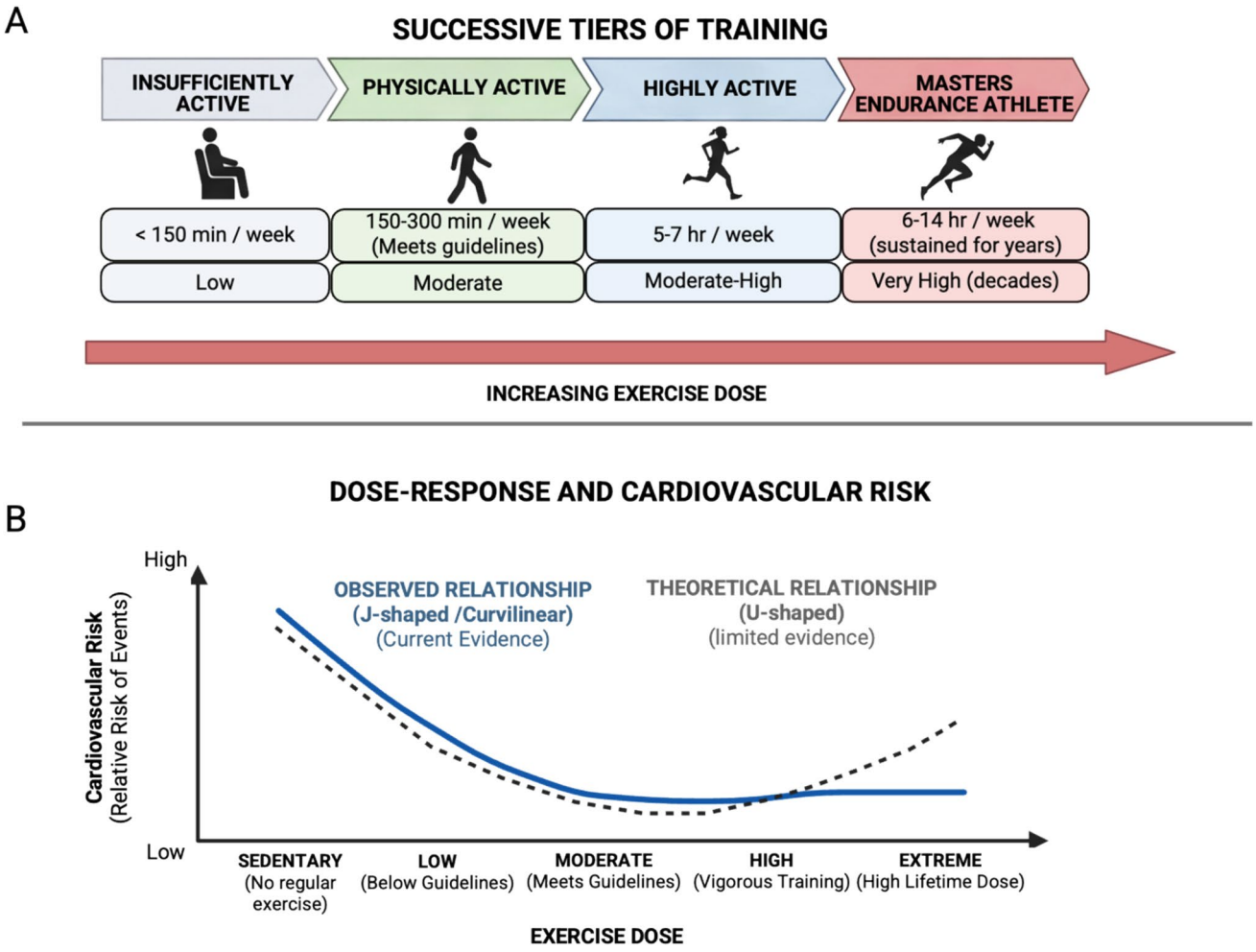


Fig. 1 **A**) Successive tiers of exercise training. The exercise tiers range from inactive or sedentary to high-level exercise performed by Masters endurance athletes. Masters athletes typically sustain, on average, 6–14 h of activity per week, with even higher levels during competitive seasons, resulting in a high lifetime volume of exercise exposure. **B**) Dose–response and cardiovascular risk. The observed exercise dose–response relationship is classically curvilinear (J-shape), with reduced benefits at high levels of activity, although some reports suggest higher cardiovascular risk at higher levels of activity (U-shape)

observed that lifelong endurance athletes had a greater risk of at least one coronary plaque than those with a healthy, non-athletic lifestyle (OR:1.86, 95%CI 1.17–2.94) [10]. Merghani et al. demonstrated that low-risk male endurance MAs had a higher prevalence of atherosclerotic plaques than controls (44.3% vs 22.2%; p = 0.009), and only male MAs had CAC > 300 [11]. Finally, Laddu et al. evaluated physical activity tiers over 25 years, with participants who met ≥ 3 times guideline levels having increased odds of CAC, particularly in men [30]. Taken together, these studies support the paradoxical observation that male MAs who engage in lifelong high-volume endurance exercise exhibit a higher-than-expected burden of CAC and subclinical atherosclerosis.

Sex differences in CAC prevalence among MAs are noteworthy. Abdelaziz et al. assessed rates of subclinical atherosclerosis in male and female endurance MAs compared to nonathlete controls. Males with exercise volume > 3,000 MET-min/week had higher overall CAC scores than nonathlete males, but no such difference was observed in female athletes compared to nonathletes [31]. In another study, female endurance MAs > 40 years-old who had competed for > 10 years were compared with age-matched controls. Female MAs had a lower prevalence of CAC scores > 50th percentile (19% versus 32%; p = 0.03) and > 75th percentile (14% versus 25%; p = 0.045) than controls. Both athletes and controls, predominantly postmenopausal women, had a low overall prevalence of atherosclerotic plaques [32]. Defina et al. studied a cohort of 5,341 women who underwent maximal-effort treadmill stress testing and CAC scanning. In univariate analysis, inverse relationships between CAC > 0 and fitness and between CAC > 100 and fitness were observed, but these associations were attenuated after adjustment for age and traditional CVD risk factors,

suggesting no independent effect of exercise on CAC [33]. While prior studies have reported little to no difference in coronary plaque prevalence in female MAs compared with sedentary controls, data are limited by variation in atherosclerotic risk profiles across groups, small sample sizes, and a predominance of premenopausal women [11, 32, 34]. A summary of studies evaluating CAC and coronary plaque related to exercise and sex is shown in Table 1.

Unfortunately, no studies have specifically explored racial disparities in health outcomes among MAs [1]. Data can only be extrapolated from large general population studies. The Multi-Ethnic Study of Atherosclerosis (MESA) found that White men had the highest prevalence of CAC compared to non-White men, with similar patterns in women [35]. Despite a higher burden of traditional CVD risk factors in Black adults, there was lower CAC prevalence compared to White adults. However, Black individuals experience higher rates of CVD and all-cause mortality across all CAC categories compared to other racial/ethnic groups [36]. In the CARDIA study, researchers evaluated CAC severity among young individuals based on self-reported exercise levels. Compared to Black individuals who performed exercise at three times physical activity guidelines, White young-to-middle-aged individuals had higher odds of developing CAC > 0 at 25-year follow-up (OR:1.86, 95%CI 1.16–2.98) [30]. Due to the paucity of studies of MAs with racial and ethnic diversity, future research is needed that includes balanced representation and increased focus on social determinants of health to understand whether disparities are present among MAs.

Plaque Composition

Plaque composition in male MAs can be heterogeneous, with earlier studies suggesting a predominance of calcified plaque. Results from prior studies suggest long-term exercise induces plaque remodeling through mechanisms analogous to those observed with statin therapy [37–39]. In prior computed coronary angiography (CCTA) studies, male endurance MAs consistently demonstrated a higher prevalence of calcified plaque compared to sedentary controls or less active individuals [9, 11]. Similarly, a prior systematic review reported that more than half of the characterized coronary plaques in MAs were calcified [40]. However, in the Masters@Heart study, lifelong endurance exercise was associated with the presence of a heterogeneous distribution of ≥1 calcified plaque (OR:1.58, 95%CI 1.01–2.49), non-calcified plaque (OR:2.80, 95%CI 1.39–5.65), or mixed plaque (OR:1.78, 95%CI 1.06–2.99) compared to a healthy cohort of non-athletes. There was no significant difference in the prevalence of calcified plaques between athletes and controls [10]. A follow-up analysis incorporated wearable technology for 12 consecutive months as a more reliable assessment of training load over self-reported physical activity levels. Compared with athletes in the 1st quartile of training intensity, those in the 4th quartile had higher odds of having ≥1 plaque (OR:5.85, 95%CI 2.33–14.71), ≥1 calcified plaque (OR:3.69, 95%CI 1.54–8.85), and ≥1 mixed plaque (OR:5.18, 95%CI 1.79–14.93) [41]. The definitive effects of long-term and intensive exercise training on plaque morphology in MAs remain uncertain, necessitating emphasis on larger prospective data capture.

Potential Mechanisms Underlying Coronary Atherosclerosis

Traditional Risk Factors

Traditional ASCVD risk factors underlie the development of coronary atherosclerosis in MAs. Despite maintaining an active lifestyle, MAs are still susceptible to classic CV risks. Traditional risk factors, such as past or current tobacco use, hypertension, or family history of early ASCVD, are common among middle-aged and older MAs [42, 43]. Dietary habits of MAs may also contribute to CV risk. Genetic inheritance also significantly influences the development of CAC. While ~40% of interindividual variation in CAC in the general population can be explained by traditional risk factors, another ~40% may be explained by genetic factors according to an analysis from the Epidemiology of Coronary Artery Calcification Study [44]. Prior research has also identified credible gene loci that contribute to CAD progression, and polygenic risk has been associated with long-term plaque progression and the formation of high-risk plaque [45, 46].

Hemodynamic Stress

Intensive exercise induces systemic hemodynamic changes in the vasculature that may serve as a primer for atherosclerosis. Under normal physiological exercise conditions, there is a significant increase in myocardial oxygen demand that requires an appropriate matched increase in coronary artery blood flow. These changes are facilitated by an array of cellular signaling pathways that lead to arterial vasodilation, with moderate shear stress promoting endothelial health. Abnormal or excessive shear and tensile forces sustained during prolonged, frequent strenuous exercise have been postulated to promote endothelial dysfunction, activate pro-inflammatory signaling cascades, and facilitate the development of atherosclerosis [14, 47].

Hypertensive increases in systolic blood pressure at peak exercise may represent another potential mechanism

Table 1 Select studies evaluating the association between exercise volume, exercise intensity, and sex with coronary atherosclerosis in Masters athletes

Study	Population	Design/Exposure	Assessment	Key Findings	Implications	Limitations
Möhlenkamp et al., 2008[12]	108 male marathon runners aged ≥50 years-old with ≥5 marathons over previous 3 years Age-matched and Framingham-risk-matched controls	Cross-sectional; Long-term marathon participation	CAC	CAC ≥100 was more common in runners than in risk-factor-matched controls, 36.1% vs. 21.8% (p=0.01) Higher CAC predicted worse event-free survival (p= 0.018)	Early evidence suggesting an association between endurance training and CAC	Male-only study with controls drawn from external cohorts Did not control for family history of early CAD and included runners with CV risk factors
DeFina et al., 2014[33]	5,341 women, 40–90 years-old	Cross-sectional; treadmill fitness	CAC	CAC >0 was inversely associated with level of fitness (19% high-fit vs. 24% low-fit; p=0.006); relationship attenuated after adjustment	Suggests sex-specific differences in the exercise-CAC relationship	Non-athletic female cohort No assessment of lifetime exercise exposure
Merghani et al., 2017[11]	152 Masters endurance athletes 92 sedentary controls with low conventional ASCVD risk	Cross-sectional; endurance exercise	CAC and CCTA	Male athletes had more plaque (44.3% vs. 22.2%; p=0.009) and CAC ≥300 (11.3% vs. 0%) compared to controls; 60% of athletes and 63% of controls had CAC=0 Plaques in athletes were predominantly calcified compared to controls (72.7% vs. 61.5%)	Suggests male-specific association between long-term endurance exercise and calcified coronary plaque	Modest sample size with predominantly White male runners Limited female representation
Aengevaeren et al., 2017 — MARC-1[9]	284 middle-aged and older male recreational athletes	Cross-sectional; lifetime exercise volume	CAC and CCTA	>2,000 MET-min/week associated with higher prevalence of CAC >0 compared to <1,000 MET-min/week (68%, CAC 9.4, IQR 0–60.9 vs. 43%, CAC 0, IQR 0–43.5; p=0.02) and higher plaque prevalence (77% vs. 56%, OR:3.35, 95%CI 1.57–7.14) with predominantly calcified plaque	Suggests exercise dose response related to CAC burden	Male-only cohort Did not completely control for baseline ASCVD risk factors
Laddu et al., 2017 —CARDIA[30]	3,175 men and women; 25-year follow-up	Prospective cohort; long-term physical activity trajectories	Midlife CAC	Very high activity associated with increased odds of CAC compared to the lowest tier (OR:1.27, 95%CI 0.95–1.70), strongest in White men	Suggests increased CAC with higher activity Effect modification by sex and race (White males)	Not an athlete-specific cohort Fewer participants and women at the highest activity category

Table 1 (continued)

Study	Population	Design/Exposure	Assessment	Key Findings	Implications	Limitations
DeFina et al., 2019 — Cooper Center Longitudinal Study[64]	21,758 healthy men without CVD	Prospective cohort; self-reported physical activity	CAC and subsequent mortality	>3000 MET-min/week associated with CAC ≥100 (RR:1.11, 95%CI 1.03–1.20) with mean CAC 807, but not higher CV or all-cause mortality	Suggests CAC not associated with higher all-cause mortality in men at high activity levels	Male-only observational study Self-reported activity levels
De Bosscher et al., 2023 — Master@Heart[10]	558 male lifelong and late-onset endurance athletes and healthy non-athletes	Prospective cohort; endurance training history (lifelong vs. later-onset)	CCTA	Lifelong endurance athletes had higher odds of calcified (OR:1.58, 95%CI 1.01–2.49), non-calcified (OR:1.95, 95%CI 1.12–3.40), non-calcified proximal (OR:2.80, 95%CI 1.39–5.65), and mixed (OR:1.78, 95%CI 1.06–2.99) plaque	Suggests lifelong endurance exercise associated with potentially higher risk plaque morphology, not just CAC	Predominantly White men Control group consisted of fit nonathletes
Aengevaeren et al., 2023 — MARC-2[29]	289 male athletes; ~6-year follow-up (from MARC-1 cohort)	Prospective cohort; exercise volume and intensity assessed longitudinally	Serial CAC and CCTA	Very vigorous exercise intensity was associated with greater CAC (β:0.05, 95%CI 0.01–0.09) per 10% increase; p=0.01) and calcified-plaque progression (OR:2.09, 95%CI 1.09–4.0) for highest vs. lowest tertile while exercise volume was not	Suggests that the intensity of exercise may drive CAC progression vs. exercise volume	Exercise intensity assessed by self-reported questionnaires and partly assigned by sport participation type
Papatheodorou et al., 2024[32]	196 predominantly postmenopausal female Masters athletes 59 similarly aged controls with ≤3 hours of moderate intensity exercise per week	Cross-sectional; long-term endurance training	CAC and CCTA	Athletes had less CAC >50th percentile (19% vs. 32%; p=0.03) and less mixed plaque (18% vs. 37%; p=0.03) vs. controls	Suggests female Masters athletes are at decreased risk of CAC and plaque development	Study limited to predominantly postmenopausal female athletes
Abdelaziz et al., 2025[31]	61,150 male and female athletes and nonathletic comparators from nine observational studies	Meta-analysis; high exercise volume (>3,000 MET-min/week)	CAC	>3,000 MET-min/week associated with higher CAC (mean difference 31.62, 95%CI 10.66–52.58; p <0.001) among men but no difference in women or at lower exercise volumes	Suggests sex modification between high exercise volume and CAC	Predominantly White participants Heterogenous exercise exposure definitions

CAC: Coronary artery calcium; **CAD**: Coronary artery disease; **CCTA**: Coronary computed tomography angiography; **CV:** Cardiovascular; **MET**: Metabolic equivalent of task; **ASCVD**: Atherosclerotic cardiovascular disease

contributing to atherosclerosis in MAs. In the general population, resting hypertension is associated with higher CAC scores, and similar findings are seen in male MAs [42, 48]. The CARDIA study showed that greater blood pressure responses to exercise are associated with an increased risk of CAC development over 25 years [30]. A recent study by Driscoll et al. demonstrated that among 198 Masters endurance athletes with low Framingham risk profiles, a hypertensive response to exercise was associated with coronary stenosis > 50% (OR:4.72, 95%CI 1.65–13.5) and CAC score ≥ 100 (OR:2.56, 95%CI 1.08–6.04) [48]. However, direct causal evidence is lacking, largely because of limitations in accurately modeling vessel hemodynamics during strenuous exercise.

Oxidative Stress and Inflammatory Mediators

Regular, moderate-intensity exercise is associated with the release of reactive oxygen species (ROS), which mediate an adaptive CV phenotype characterized by enhanced vascularization and mitochondrial biogenesis. However, during high-intensity exercise, ROS production significantly increases due to increased metabolic demand, thus reducing nitrous oxide bioavailability and increasing endothelial cell susceptibility to inflammation and lipoprotein deposition [14]. Although ROS inflammation is another plausible mechanism for the development of early CAD in MAs, direct evidence is lacking.

Endurance exercise has also been shown to trigger signaling through inflammatory pathways, with the magnitude of the effect varying by exercise intensity [49]. Marathon runners may develop significant elevations in inflammatory cytokines after completing a race. Suzuki et al. analyzed cytokine levels and neutrophilic responses pre- and post-exercise in 10 male marathon runners who completed a 43-km race. Compared with resting levels, myeloperoxidase and lactoferrin concentrations (markers of neutrophilic activation) and plasma inflammatory interleukin concentrations were higher [50]. Similarly, data from participants in the Western States Endurance Run showed that among ultramarathon runners who completed the 160-km race, interleukin-1 receptor antagonist (IL-1ra) and interleukin-6 (IL-6) increased above pre-race levels. Inflammatory pathways involving circulating cytokines are seen in chronic inflammatory diseases and are associated with a higher risk of atherosclerosis [51].

Altered Calcium Homeostasis

Calcium homeostasis represents another potential mechanism underlying CAC in MAs. Exercise induces transient increases in circulating parathyroid hormone (PTH) dependent on exercise intensity and duration [52–55]. PTH regulates circulating calcium concentrations through effects on bone, kidney, and vitamin D metabolism. Sustained PTH elevations are well recognized in numerous pathologic conditions, with similar elevations during continuous endurance exercise as compared to lower-intensity exercise or rest, suggesting a threshold effect [56–58]. Although these transient thresholds are physiologically distinct from chronic pathologic states, repeated episodes are thought to potentially contribute to the development of atherosclerosis in MAs. However, this concept remains theoretical.

Clinical Implications and Risk Stratification

Clinical Implications of Elevated CAC in MAs

While the negative prognostic CV implications of elevated CAC are well understood in the general population [59–61], how this generalizes to CV outcomes in MAs remains uncertain. At present, there are no prognostic ASCVD risk scores specific for MAs. As demonstrated in the longitudinal Cooper Center Heart Study, high cardiorespiratory fitness appears to attenuate the risk of adverse CV outcomes associated with CAC. Across all CAC score ranges (0, 1–99, 100–399, and ≥ 400), higher levels of cardiorespiratory fitness reduced CV risk compared to more sedentary individuals, with each additional MET associated with 11% lower risk of MACE (HR:0.89, 95%CI 0.84–0.94) [62]. In a follow-up analysis from the same group, high-volume physical activity was associated with lower all-cause mortality, but similar CAD risk [63]. In another study by these investigators, among men with CAC < 100 who engaged in high-intensity exercise (> 3000 MET-min/week) had lower all-cause mortality than less-active peers (HR:0.52, 95%CI 0.29–0.91). Although this benefit was lost with CAC ≥ 100, there was no increase in all-cause mortality [64].

Clinical Risk Stratification Considerations

Risk assessment for ASCVD in asymptomatic MAs has recently been addressed in several major clinical reference documents from the American College of Cardiology (ACC), the American Heart Association (AHA), and the European Society of Cardiology (ESC) (Fig. 2) [1, 65, 66]. Traditional ASCVD risk factors still predominate in the pathophysiology of CAD in MAs. As such, the initial CV risk assessment should still focus on traditional ASCVD risk factors (age, sex, blood pressure, cholesterol profile, glucose metabolism, substance use, and family history). In addition, a family history of early ASCVD

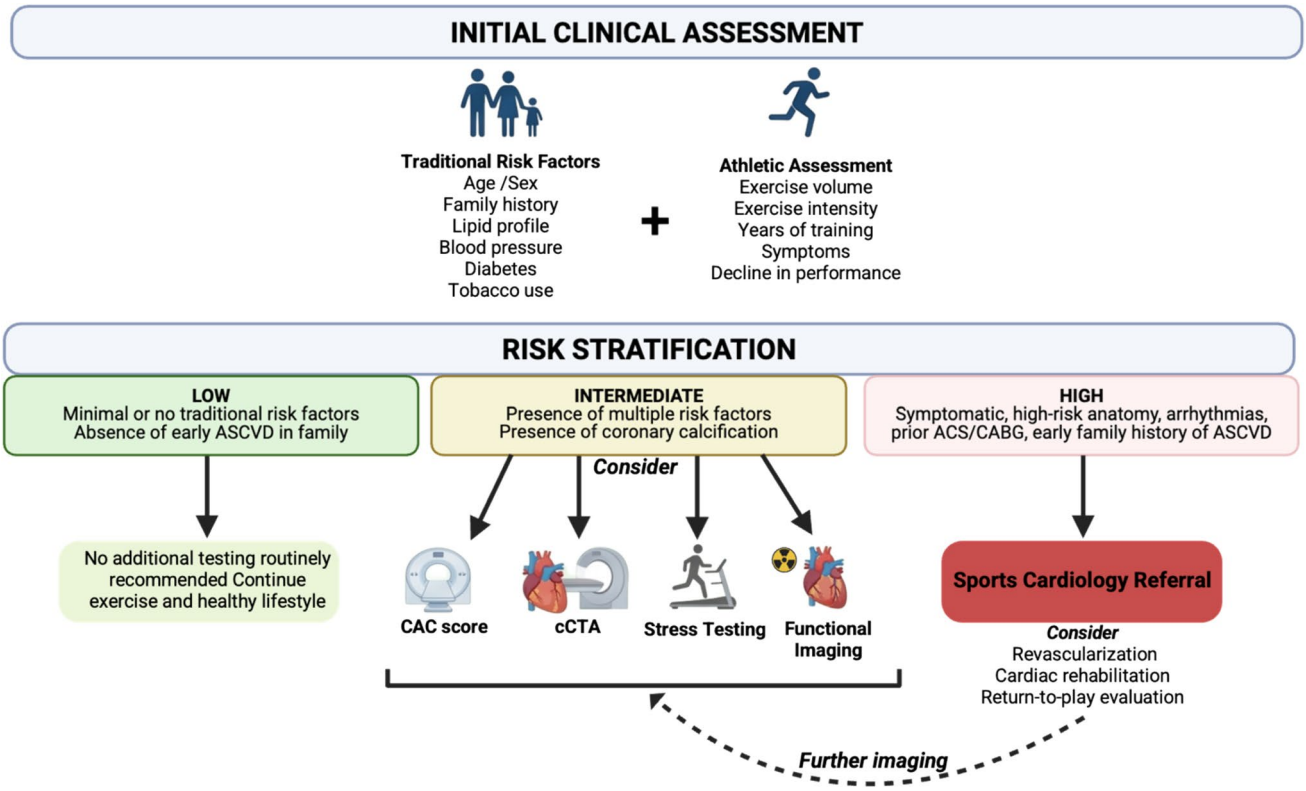


Fig. 2 Adapted from recent guidelines [1, 65, 66], summary of the proposed clinical approach to the evaluation and management of coronary atherosclerosis in Masters athletes. The initial assessment combines assessment of traditional cardiovascular risk factors with athlete-specific characteristics to guide risk stratification. Low-risk athletes require no further testing, whereas intermediate-risk athletes may undergo selective additional risk stratification. High-risk athletes should be referred for a complete sports cardiology evaluation, with subsequent management guided by shared decision-making considering risk stratification findings, clinical risk, and individualized return-to-play considerations

represents a high-risk feature [65]. Low-risk MAs are characterized as having minimal or no traditional risk factors. Although not validated for MAs, it is reasonable to use established CV risk scores, such as Astro-CHARM (Astronaut Cardiovascular Health and Risk Modification), SCORE2 (Systematic Coronary Risk Evaluation 2), the pooled cohort equation, and the PREVENT (Predicting Risks of Cardiovascular EVENTs) score [67–70]. Caution is advised in applying these scores, as they may overestimate risk in this population [65]. For clearly low-risk MAs, no further cardiac risk stratification, including CAC, is recommended [65, 71].

Further risk stratification can be considered for asymptomatic MAs deemed intermediate- to high-risk based on traditional risk factors and CV risk scores within a shared decision-making (SDM) framework. Options for further risk stratification testing include maximal effort exercise stress testing, CCTA, and CAC assessment. Among MAs with chronic stable CAD, patients should be counseled on lifestyle modifications and medical therapy. If higher-risk features, including reduced left ventricular (LV) function, significant inducible ischemia, wall motion abnormalities, or exercise-induced ventricular arrhythmias [65, 72, 73], are identified during risk stratification, these patients should undergo coronary angiography [65, 72, 73].

The choice of clinical tools used for risk stratification should be individualized for the MA and guided by the sports cardiologist. Functional exercise testing or cardiopulmonary exercise stress tests are routinely considered and performed in MAs. Importantly, it is critical to ensure maximum effort during exercise stress testing [74]. Targeting heart rate thresholds as the termination point of an exercise test is inappropriate, as this may fail to cross potential ischemic thresholds. In addition, sport-specific testing is essential when possible, as peak exertion varies by sport intensity and symptoms may be provoked more reliably, thus improving the diagnostic yield of the exercise stress assessment [75]. Based on the SCOT-HEART and PROMISE trials, which evaluated the effects of non-invasive imaging on CV outcomes, both CCTA and functional imaging are reasonable options for assessing stable angina [76]. While both tests are useful, MAs may benefit from assessing both coronary anatomy and functional hemodynamics at maximum exercise intensity.

These diagnostic strategies provide information on plaque phenotype and functional significance, both of which are important for guiding clinical management decisions for MAs.

MAs with exertional cardiopulmonary symptoms require careful attention during clinical evaluation. Reductions in exercise capacity should be compared to their "normal" or baseline level of activity. Moreover, symptoms of obstructive CAD may not present as typical angina in MAs, but rather manifest as a decline in peak exercise performance [71]. MAs with exercise-associated angina should undergo diagnostic testing according to contemporary chest pain guidelines [73, 77], with the stipulation that exercise stress testing is preferred over pharmacological testing. Due to physiological adaptations, pharmacologic vasodilation often does not equate to the flow dynamics achieved during maximum-effort exercise [65, 77].

Following acute coronary syndromes, return to intensive exercise can be assessed at 3–6 months following the event as recommended in recent consensus documents [1, 65, 74], with risk stratification included to ensure LV function has normalized and there is no evidence of exercise-induced ischemia or arrhythmias. With an additional emphasis on intensive pharmacotherapy, including lipid-lowering therapy, a 3–6-month timeframe is recommended to ensure both completion of a cardiac rehabilitation program and time for plaque stabilization, which may take 6–24 months on medical therapy [74].

Clinical Management and Sports Participation Considerations

Clinical Management Strategies

For MAs, the management of CV risk factors and CAD begins with established guideline recommendations [2, 72, 73, 78]. The initial management should emphasize comprehensive risk factor modification and incorporate guideline-directed medical therapy when appropriate. This multifaceted approach includes supporting ongoing exercise habits and maintaining high cardiorespiratory fitness, optimizing diet, initiating lipid-lowering therapy (when indicated), and achieving effective blood pressure control to reduce overall CV risk (Fig. 3).

Lipid-lowering therapy remains a gold-standard treatment intervention for MAs with high-risk profiles. Despite the known limitations of traditional CV risk prediction models in this population, low density lipoprotein cholesterol (LDL-C) treatment targets should be individualized based on CAC burden, with progressively lower LDL-C goals for higher CAC scores and those with established ASCVD. However, it must be acknowledged that treatment decisions should be guided within a SDM model. MAs with substantial coronary calcification may still experience major adverse cardiac events despite high cardiorespiratory fitness [62]. Furthermore, individuals in the general population with CAC≥300 have a risk of MACE comparable to that

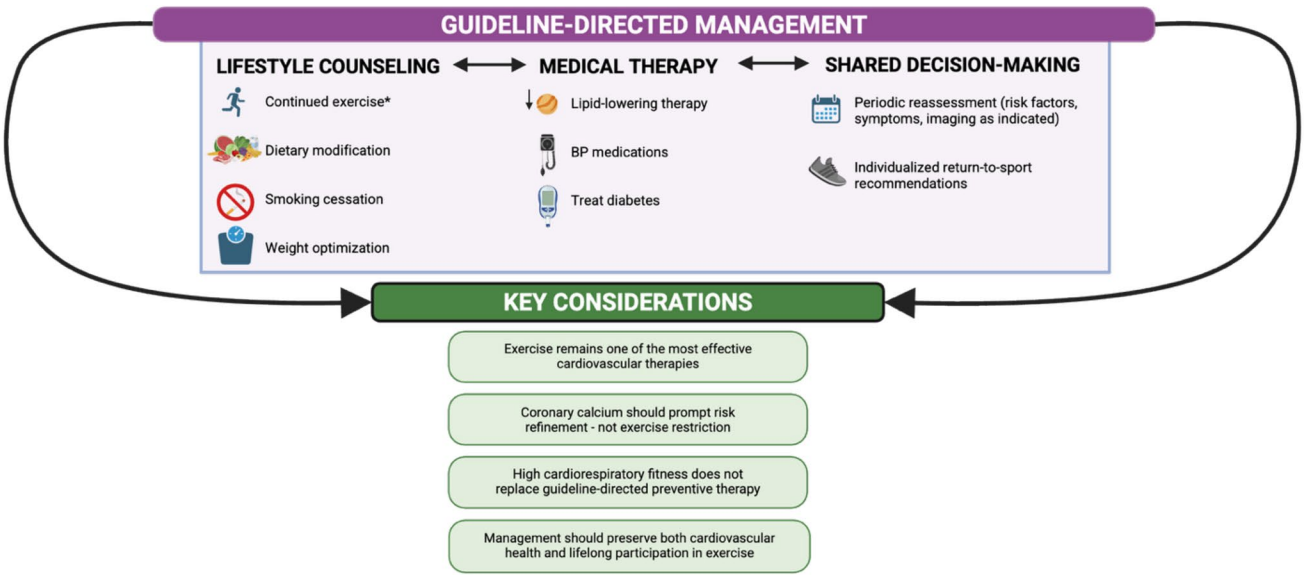


Fig. 3 Proposed management framework for Masters athletes with coronary atherosclerosis. Management should integrate guideline-directed preventive therapies with athlete-centered shared decision-making. Lifestyle interventions, including continued exercise habits, dietary optimization, smoking cessation, and weight management, remain the foundation of treatment. Medical therapy should emphasize aggressive risk factor modification, including lipid-lowering therapy, blood pressure control, and diabetes management if present. Ongoing follow-up should include periodic reassessment of cardiovascular risk, symptoms, and risk stratification, as indicated, to guide individualized recommendations. *Continued exercise counseling should assess for symptoms and recent cardiovascular events, incorporating shared decision-making

of patients with established ASCVD, including prior myocardial infarction, stroke, or peripheral arterial disease [61].

An additional cornerstone of CV risk reduction is the accurate identification and treatment of hypertension [79]. In the EXERTION study, among 12,743 adults who underwent exercise stress testing, exercise blood pressure relative to fitness (MET-peak) was associated with an increased risk of cardiac events across all systolic blood pressure/MET-peak quartiles [80]. An additional finding from Driscoll et al. was that ~ 39% of studied MAs had hypertension detected by ambulatory blood pressure monitoring [48]. Accordingly, MAs with borderline or intermittently elevated office blood pressures should undergo ambulatory monitoring. After lifestyle and dietary counseling, guideline-directed antihypertensive therapy should be initiated if indicated. In MAs, preference should be given to agents that lower blood pressure through vasodilatory mechanisms, whereas medications with negative chronotropic effects or diuretic properties may impair exercise performance and thermoregulation [79]. Although the 2025 AHA/ACC hypertension guidelines do not provide athlete-specific blood pressure targets [81], targets consistent with recommendations for the general adult population are advised.

Among MAs with obstructive CAD, revascularization in the absence of symptoms is controversial. In the ISCHEMIA trial, patients with stable obstructive CAD did not derive a mortality benefit from revascularization compared to optimal medical therapy [82]. However, MAs engage in high-intensity exercise, where the risk of crossing ischemic thresholds leading to significant demand ischemia is increased. This has been shown in large registries of MAs who participate in ultra-endurance events, where the most common cause of sudden cardiac arrest is CAD, with many cases precipitated by demand ischemia [15, 16, 83]. Decisions to pursue revascularization in MAs should be guided by SDM that include symptoms, findings on sport-specific stress testing, and potentially the presence of high-risk lesions [65, 66, 73].

An important consideration for all MAs, regardless of diagnosis, is reluctance to initiate guideline-directed medical therapy due to concerns about potential negative effects on exercise capacity and side effects. Importantly, regular exercise should not be viewed as a substitute for evidence-based medical therapy when clinically indicated. Despite widespread concerns about statin-associated muscle symptoms among competitive athletes, available evidence does not demonstrate that statins are associated with reductions in exercise performance or strength [84–86]. In statin-intolerant patients, the 2026 ACC/AHA dyslipidemia guideline recommends a stepwise lipid-lowering strategy that begins with the maximally tolerated statin dose, followed by the sequential addition of non-statin therapies, including ezetimibe, bempedoic acid, and proprotein convertase subtilisin/kexin type 9 (PCSK9) inhibitors, to achieve guideline-recommended LDL-C targets [78]. Beta-blockers may also negatively affect athletic performance due to negative chronotropic effects during exercise. Consequently, they may not be tolerated as antihypertensive therapy in MAs [79].

Clinical management strategies for MAs should follow contemporary guideline-directed CV care while also considering the physiologic demands of training, effects of treatment on exercise performance, and priorities of the MA. While data on MA-specific CV outcomes are limited, high cardiorespiratory fitness confers protective benefits. Therefore, exercise should not be discouraged for MAs with CV risk factors or disease. Instead, clinical management should integrate individualized risk stratification, SDM, and optimization of modifiable CV risk factors to preserve both long-term CV health and the ability to safely participate in exercise.

Competitive Sports for MAs with CVD

In the past, the landscape of considerations for competitive sports for athletes with CVD followed a paternalistic approach in which risk tolerance was limited, and athletes were not included in any clinical decision-making [87–90]. However, there has been a shift in clinical approach to a model grounded in SDM [65]. This shift has coincided with outcomes data on competitive athletes with CVD that suggest cardiac risks associated with competitive sports participation are lower than previously believed [65]. The approach to sports eligibility considerations has clearly shifted with emphasis on preserving the ethical principle of autonomy.

Updated clinical considerations for competitive sports participation also apply to competitive MAs with underlying CAC/CAD [65]. Importantly, the presence of subclinical coronary atherosclerosis should not be viewed as a contraindication to competitive sports. After an acute coronary event, the benefits of returning to competitive sports often outweigh the risks. With risk stratification confirming low-risk features and in the absence of symptoms, return to competitive sports participation may be reasonable. All processes should be individualized with SDM.

Limitations

The present literature has several important limitations. First, the data are predominantly observational, largely cross-sectional and cohort-based, and subject to residual confounding. Second, much of the foundational literature

has focused on White men, with female-specific data and other ethnicities comparatively limited. Third, observational comparisons range from sedentary individuals to recreationally active adults, which may substantially alter observed differences in CAC and plaque burden. Finally, substantial heterogeneity exists in the definition and quantification of lifetime exercise exposure and participant characteristics, contributing to confounding as well as selection and misclassification bias.

Knowledge Gaps

Important questions remain regarding the clinical significance of CAC in MAs. Although studies have shown greater CAC in some MAs, it remains uncertain whether these findings translate into a higher risk of adverse CV events. Further research is needed to clarify plaque composition and whether noncalcified-mixed plaque also increases with greater exercise exposure. Current CV risk prediction models were not developed specifically for highly-trained athletes, and therefore risk assessment remains largely based on traditional CV risk factors. Finally, female MA and racially and ethnically diverse MA populations remain underrepresented in the existing literature.

Future Directions

There are several critical future research directives to improve our understanding of coronary atherosclerosis in MAs. First, there is an immediate need to develop prospective and large registries of MAs, diverse in composition and sport-type, to better understand long-term CV outcomes in MAs. Beyond capturing traditional CV risk factors, there should be an emphasis on unique athlete-specific factors, such as training habits and dietary intake. Second, future research in this arena should aim to define underlying mechanisms that lead to the development of coronary atherosclerosis in MAs. Prospective, longitudinal research is needed to better understand the natural history of plaque progression and the specific mechanistic factors that lead to plaque development. Finally, while disparities in CV risk and outcomes are well documented in the general population, disparities among MAs are poorly understood. Research inclusive of social determinants of health and whether disparities in CV outcomes occur among MAs is urgently needed to develop equitable, evidence-based screening and clinical management strategies.

Conclusion

Understanding the natural history and clinical implications of coronary atherosclerosis in MAs has become a key focus in sports cardiology. Current data suggest a higher-than-expected prevalence of CAC among male MAs. However, understanding the underlying causal mechanisms and the prognostic significance of subclinical coronary atherosclerosis in MAs remains limited. Clinical management strategies for MAs with coronary atherosclerosis should prioritize risk stratification, lifestyle counseling, guideline-directed medical strategies, and potential coronary interventions guided within a SDM framework. High cardiorespiratory fitness is protective, thus exercise for MAs with coronary atherosclerosis should be supported by SDM and emphasis on evidence-based strategies to optimize CV risk reduction.

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  - A prospective cohort study evaluating plaque morphology in lifelong endurance athletes demonstrated higher odds of calcified (OR:1.58), non-calcified (OR:1.95), and mixed plaques (OR:1.78) compared with a nonathletic population. These findings suggest that lifelong endurance exercise may be associated with a greater burden of potentially higher-risk plaque phenotypes.
- Kim JH, Baggish AL, Levine BD, Ackerman MJ, Day SM, Dineen EH, et al. Clinical Considerations for Competitive Sports Participation for Athletes With Cardiovascular Abnormalities: A Scientific Statement From the American Heart Association and American College of Cardiology. J Am Coll Cardiol. 2025;85(10):1059-108. https://doi.org/10.1016/j.jacc.2024.12.025.
  - Scientific statement addressing clinical considerations and risk assessment for athletes with cardiovascular abnormalities. The report included the evaluation of coronary atherosclerosis in Masters athletes, focusing on risk stratification using traditional risk factors, contemporary diagnostic approaches, medical therapy, and shared decision-making.

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  - A cross-sectional study comparing coronary artery calcium burden and plaque phenotype in female Masters athletes with less active women demonstrated a lower prevalence of coronary calcium above the 50th percentile (19% versus 32%; p=0.03) and mixed plaque (18% versus 37%; p=0.03) among athletes. These findings suggest that female Masters athletes may have a lower burden of coronary calcium and higher-risk plaque.
- Aengevaeren VL, Mosterd A, Bakker EA, Braber TL, Nathoe HM, Sharma S, et al. Exercise Volume Versus Intensity and the Progression of Coronary Atherosclerosis in Middle-Aged and Older Athletes: Findings From the MARC-2 Study. Circulation. 2023;147(13):993–1003. https://doi.org/10.1161/CIRCULATIONAHA.122.061173.
  - A prospective cohort study evaluating exercise volume and intensity and their associations with coronary calcium and plaque progression. Very vigorous exercise was associated with a greater CAC score (β:0.05; p=0.01) per 10% increase in exercise intensity and calcified plaque progression compared with lower exercise intensities. Exercise volume was not associated with either outcome, suggesting that exercise intensity may drive coronary calcium progression more than volume.
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  - A meta-analysis evaluating the association between high exercise volumes (>3,000 MET-min/week) and coronary artery calcium included 61,150 male and female athletes and nonathletes. Higher exercise volume was associated with greater coronary calcium among men (mean difference 31.62; $p < 0.001$) but not among women, whereas lower exercise volume was not associated with significant differences in coronary artery calcium. In addition, lower exercise volumes had no significant difference in coronary calcium. These findings suggest that sex may modify the relationship between high-volume exercise and coronary calcification.

Author Contribution BD and JK wrote and prepared all aspects of this review paper.

Data Availability No datasets were generated or analysed during the current study.

Declarations

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