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Prevalence of electrocardiographic markers associated with myocardial fibrosis in masters athletes: a cohort study

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ABSTRACT

Objectives Myocardial fibrosis (MF) is associated with an increased predisposition to adverse cardiac events. The accumulation of high-volume and high-intensity exercise over an extended duration potentially increases the risk of MF. Specific electrocardiographic markers have been correlated with the presence of MF. This study assessed the prevalence of MF-related electrocardiographic markers in a Track and Field Master Athletics Cohort (TaFMAC).

Methods Twelve-lead resting electrocardiograms (ECGs) were conducted on 155 athletes (90 males and 65 females) participating in the World Masters Athletics 2022. The ECG markers associated with MF, including pathological Q waves, inverted T waves, fragmented QRS complex, and prolonged QRS complex, were compared among different athletic specialities (endurance athletes n=51, sprinters n=69 and strength and power n=35).

Results Overall, 71 instances of MF-related markers were identified from 155 ECG recordings (46%). Fragmented QRS emerged as the most common marker, with a prevalence of 29% in endurance and strength and power athletes, and 35% in sprinters. No significant group differences were observed in the prevalence of MF markers, whether analysed collectively (p=0.467) or individually (pathological Q waves p=0.367, inverted T waves p=0.309, fragmented QRS complex p=0.747 and prolonged QRS complex p=0.132).

Conclusions The prevalence of MF markers, as determined by resting ECG, was evident in nearly half of masters athletes, irrespective of sex and sporting specialisation. These findings suggest resting ECG as a promising non-invasive method for the early identification of MF in athlete's hearts.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Regular exercise is crucial for overall health, especially with ageing, with masters athletes exemplifying healthy ageing through active lifestyles. However, prolonged and intense physical activity over many years may elevate the risk of cardiac diseases, including myocardial fibrosis (MF), which increases the risk of sudden cardiac death. Despite this understanding, the prevalence of MF-related ECG markers in masters athletes across different track-and-field specialisations remains poorly documented.

WHAT THIS STUDY ADDS

⇒ This study identifies a high prevalence of MF-related ECG markers, particularly fragmented QRS, in masters athletes, consistently observed across different athletic disciplines and genders.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Using non-invasive resting ECG to detect MF in masters athletes could refine screening protocols and tailor clinical decisions regarding cardiovascular risk, enhancing personalised healthcare strategies and ultimately improving the management and prevention of cardiac events in this population.

INTRODUCTION

Regular exercise is crucial for overall health, particularly as individuals age.[1 2] Masters athletes exemplify healthy ageing through active lifestyles, demonstrating various health benefits attributed to their high physical activity levels.[3–5] Athletes, irrespective of age, experience distinctive cardiovascular adaptations known as 'athlete's heart' due to intense and extensive exercise training, including left ventricular hypertrophy and alterations in cardiac rhythm, such as sinus bradycardia.[6–8] The type of athletic training, whether power or endurance-focused, induces specific adaptations in heart function and mass.[8 9]

Despite the positive aspects of exercise, emerging evidence suggests that prolonged and intense physical activity over many years may elevate the risk of cardiac diseases and events.[6] Sudden cardiac death (SCD), often resulting from undiagnosed cardiovascular disease, is a leading cause of mortality in

athletes during sports activities.[6] Myocardial fibrosis (MF), resulting from prolonged ventricular pressure and volume overloads during intense training, is a significant risk factor for increased susceptibility to SCD,[6 9–11] leading to myocardial remodelling and progressive tissue damage.[8 12–14] The myocardium is predominantly composed of type I collagen, with up to 80% of damaged myocardial tissue being substituted by this collagen type.[13 14] MF develops by accumulating new type I collagen, forming scar tissue in the affected myocardial regions.[15] MF, resulting from various causes like cardiomyopathies,[16] myocardial infarction and myocarditis,[17] increases the risk of cardiac arrhythmias, conduction disorders and adverse cardiac events by affecting myocardial tissue impedance and electrical excitation propagation.[17]

Cardiac MRI is the gold standard for MF assessment,[18] but 12-lead ECG serves as a valuable screening tool. ECG markers such as T wave inversion (TWI), fragmented QRS complex (fQRS), prolonged QRS complex and pathological Q waves are strongly associated with MF detected by cardiac MRI.[19–22] This study focuses on assessing the prevalence of these ECG markers in a Track and Field Master Athletics Cohort (TaFMAC) at the World Masters Athletics (WMA) Championships. The hypothesis posits a higher prevalence of MF, particularly among endurance athletes. Additionally, the study hypothesises the existence of sex differences in ECG parameters among masters athletes, a neglected aspect in this population.

METHODS

Study design and ethical approval

This investigation constitutes a sub-analysis within the TaFMAC study. Ethical approval was obtained from the Ethical Committee of the Medical Chamber North-Rhine (Düsseldorf, Germany), under reference number 2020401. The study is registered in the German Register of Clinical Trials (www.drks.de) with the identifier DRKS00025846.

Data collection and recruitment:

Data collection took place during the WMA Championship 2022 in Tampere, Finland, hosted at the Ratina Stadium during the summer of 2022. Participants were recruited through diverse channels, including the WMA website, posters, flyers and face-to-face engagement. Some athletes had received prior invitations during the WMA games in Malaga in 2018 (DRKS00015172). Informed consent was obtained from all athletes before inclusion. Inclusion criteria specified participants to be aged 35 years or older and actively engaged in a track-and-field competition sanctioned by the WMA. The sole exclusion criterion was the presence of a medical condition deemed unsuitable for study participation by the executive medical director.

Initial assessment and follow-up

Comprehensive information on personal and training characteristics, competition history and health status was collected during registration and the initial interview. A cardiologist was present to assess any abnormalities in the ECG readings and communicate potential risks to the athletes. Athletes with ECG abnormalities were promptly contacted, and information about recommended further treatment options was received from the cardiologist. The TaFMAC study adhered to the STROBE Checklist for cohort studies, ensuring strict compliance with established research reporting guidelines.

Participants

A total of 178 athletes were enrolled in the TaFMAC study. A 12-lead resting ECG was performed on 160 athletes (94 men, 66 women). Eighteen athletes did not undergo ECG testing due to scheduling conflicts. Among the remaining 160 athletes, five participants (four males one female) were excluded due to incomplete datasets. Table 1 presents the characteristics of the remaining 155 athletes.

Athletes (n=155), with a mean age of 61±17 years, were categorised into three groups based on their athletic specialisation: sprint events (n=69, 22 females), endurance events (n=51, 25 females) and strength and power events (n=35, 18 females). These classifications align with previous TaFMAC studies.[23 24] Specifically, sprint events encompassed short-distance running (100 m, 200 m, 400 m) and short-distance hurdles. Endurance events comprised long-distance running and walking disciplines, including 5 km, 10 km, 20 km, marathon, steeplechase, 8 km cross-country running, walking events, 1500 m and 800 m. Strength and power events covered all throwing and jumping disciplines, such as shot put, hammer throw, weight throw, javelin, discus, throw pentathlon, long jump, high jump, triple jump and pole vault. Athletes participating in multiple specialisation groups were assigned to the group where they achieved their best age grade (data from https://mastersrankings.com).

Patient and public involvement statement

No direct involvement of patients or the public occurred in this research's design, conduct, reporting or dissemination plans. Due to the study's technical focus and resource constraints, extensive patient or public engagement was not feasible. However, the absence of direct involvement does not diminish the study's potential implications for public health.

Equity, diversity and inclusion (EDI) statement

The TaFMAC study prioritised diversity in both participant recruitment and author composition. Our gender-balanced team, representing diverse backgrounds, ensures a comprehensive perspective. In data collection, a key focus was inclusivity, considering accessibility needs and diverse backgrounds. Equity considerations

Table 1 Characteristics of masters athletes stratified by sex and sports specialities. Values represent means±SD

	Sprint			Endurance			Strength and power			Athletic group p value	Males p value	Females p-value
	Combined n=69	Males n=47	Females n=22	Combined n=51	Males n=26	Females n=25	Combined n=35	Males n=17	Females n=18			
Age (year)	60±13	62±13	55±12	61±13	59±13	62±12	62±12	65±13	60±12	0.795	0.392	0.162
Height (cm)	173±8	176±7	166±8	169±10	175±7	163±8	172±7	177±4	167±5	0.108	0.285	0.285
Weight (kg)	71±11	76±8	59±7	64±10	71±8	58±7	76±13	80±11	71±11	0.0001***	0.006**	<0.001***
BMI (kg/m^2)	23.6±2.4	24.6±1.9	21.1±1.8	22.3±1.9	23.1±1.9	21.1±1.6	25.6±3.9	25.7±3.5	25.5±4.4	0.0001***	0.001***	<0.001***
Training years	27±19	29±21	20±14	28±17	27±20	30±14	29±18	28±17	30±19	0.663	0.968	0.035*
Training hours/w	11±7	11±6	13±7	12±5	11±5	13±5	13±9	10±6	15±11	0.568	0.752	0.783
Training RPE	16.2±2.3	16.5±2.1	15.7±2.6	16.4±2.1	16.5±1.8	16.3±2.4	14.9±1.5	15.4±1.5	14.5±1.5	<0.001***	0.058	0.02*

BMI, Body mass index; Training hours/w, Average training hours of track-and-field training per week; RPE, Maximal rating of perceived exertion in training using a 4–20 scale; SD, SD deviation.

in the analysis involved scrutinising gender, racial and socioeconomic disparities, enhancing the study's relevance for diverse populations. Our commitment to EDI is evident in our efforts to address the needs of individuals from various backgrounds, fostering inclusivity in masters athletes, where people of different ages, races and nationalities unite in the spirit of sportsmanship and shared athletic pursuits.

Measurements

Participant characteristics were collected during registration interviews and through questionnaires translated into multiple languages. Height and body weight were measured with a Seca scale-stadiometer (Hamburg, Germany). An exercise training history was documented, including years of continuity, average weekly hours and intensity, and it was assessed by Borg's rating of perceived exertion (RPE).

Twelve-lead ECGs were acquired using the Medset Flashlight 4.4.0.0 PADSY 7.5.7.1 ECG system and Marquette Hellige Medical Systems CardioSmart ST ECG, set at 50 mm/s and 10 mm/mV in the supine position for 3 min. Results were stored in prints and digital files, collected by one researcher (VV) and interpreted blindly by a cardiologist (TK), following established recommendations.[21 22] Consistent ECG collection, blinded interpretation and statistical adjustments aimed to reduce potential bias. Age, genetics, medical conditions, lifestyle and challenges in measuring training intensity within a sports discipline are potential confounders that might impact the association between sports discipline and MF-related ECG markers.

ECG marker definition

fQRS, characterised by RSR' patterns in the QRS interval (<120 ms) with or without the Q wave, was defined by additional R waves (R'), notching in the nadir of the S wave, or the presence of more than one R' within two contiguous leads corresponding to a major coronary artery territory. For example, fQRS in ≥2 contiguous anterior leads (V1 to V5) indicated MF in anterior segments or the left anterior descending territory, while fQRS in ≥2 contiguous lateral leads (I, aVL and V6) indicated MF in lateral segments or left circumflex territory. Similarly, fQRS in ≥2 contiguous inferior leads (II, III and aVF) was associated with MF in the inferior segments or the right coronary artery territory.[21 22] TWI was defined as a T wave amplitude of ≤−0.1 mV in at least two anterior (V1–V3), lateral (I, aVL, V4–V6) or inferior (II, aVF, III) leads. Pathological Q waves were defined as Q waves in at least two contiguous leads with the following criteria: >20 ms in V2 and V3, ≥40 ms and ≥0.1 mV deep in lead III and ≥30 ms and ≥0.1 mV deep in other leads. A prolonged QRS complex was defined as >110 ms without bundle branch blocks in at least two contiguous leads.[22] Left ventricular hypertrophy (LVH) and right ventricular hypertrophy (RVH) were determined by a positive Sokolow–Lyon index. Additionally, the presence of left bundle branch

block (LBBB), right bundle branch block (RBBB) and prolonged PR interval (>200 ms) were investigated for their association with MF-related ECG markers.

Statistical analyses

Qualitative variables were summarised using count and percentage, and quantitative variables were expressed as means±SD. Groupings based on sex and sports discipline were chosen to investigate differences in MF ECG marker prevalences, considering potential biological differences, training-specific effects, associations with risk factors, variations in training intensity and duration and possible interactions between gender and sports discipline. ECG data normality was assessed visually through histograms and validated using the Shapiro–Wilkins test. In cases of non-normal distribution, the non-parametric Kruskal–Wallis H analysis of variance test was used for statistical evaluations in comparisons of athletic specialities and sexes. Monte Carlo p values with 99% CIs were assigned to all group comparisons, and post-hoc tests determined adjusted significance p values for paired comparisons. For MF markers, X2 tests were conducted for between-group comparisons. All results are presented as means±SD unless otherwise specified. Statistical significance was indicated by *(p<0.05), **(p<0.01) or ***(p<0.001). All analyses were conducted using Statistical Package for the Social Sciences version 26 (SPSS for macOS, IBM, Chicago, IL, USA). Statistical analysis and presentation align with the CHAMP statement.[25]

RESULTS

Participant characteristics

Table 1 presents the characteristics of the masters athletes in this study. Endurance athletes exhibited the lowest body weight (64±10 kg, p=0.0001) and body mass index (BMI; 22.3±1.9 kg/m², p=0.0001) among both men (71±8 kg, p=0.006, 23.1±1.9 kg/m², p=0.001) and women (58±7 kg, p<0.001, 21.1±1.6 kg/m², p<0.001). Training intensity, expressed as RPE, was lower in strength and power athletes (14.9±1.5) compared with endurance athletes (16.4±2.1, p=0.001) and sprinters (16.2±2.3, p=0.004). In the comparison based on sex, female strength and power athletes exhibited lower RPEs in training (14.5±1.5) than female endurance athletes (16.3±2.4, p=0.020). When athletes were stratified by sex and athletic specialities, female sprinters had the least mean training experience in years (20±14, p=0.035), with a significant difference compared with female endurance athletes (30±14, p=0.049).

ECG parameters

Table 2 outlines ECG parameters stratified by athletic specialities and sex. Endurance athletes demonstrated the lowest resting heart rate (54±8 bpm, p<0.001) in both men (54±7 bpm, p=0.0001) and women (54±8 bpm, p=0.017). Additionally, endurance athletes exhibited the longest PR intervals (176±25 ms, p=0.046) and QT intervals (448±37 ms, p=0.0001). However, Bazett's

Table 2 Comparison of ECG parameters stratified by sex and sports specialities. Values represent means±SD

	Sprint			Endurance			Strength and power					
	Combined n=69	Males n=47	Females n=22	Combined n=51	Males n=26	Females n=25	Combined n=35	Males n=17	Females n=18	Athletic group p value	Males p value	Females p value
Heart rate at rest	63±12	64±12	63±13	54±8	54±7	54±8	62±12	63±15	61±7	<0.001 ***	0.0001***	0.017*
P interval (ms)	101±12	102±13	100±10	104±13	105±14	104±11	105±11	102±12	108±9	0.173	0.703	0.022*
PR interval (ms)	169±34	173±38	159±23	176±25	183±26	168±24	164±21	170±16	158±23	0.046*	0.045*	0.291
QRS interval (ms)	94±14	97±15	88±8	93±12	97±12	89±10	93±11	96±13	90±9	0.901	0.685	0.924
QT interval (ms)	413±33	408±32	427±38	448±37	442±34	455±39	417±39	416±49	417±28	0.0001***	<0.001***	0.002**
P axis	53±31	55±29	49±35	48±34	53±35	44±32	44±33	39±42	49±23	0.280	0.375	0.787
QRS axis	38±39	30±42	58±23	49±34	42±40	54±25	28±38	35±43	21±32	0.033*	0.500	<0.001***
T axis	39±37	35±43	48±15	39±26	41±31	36±20	35±18	37±20	33±16	0.769	0.318	0.029*
QTc(B) (ms)	421±19	418±19	428±18	423±22	416±17	431±24	421±20	419±21	423±20	0.815	0.910	0.622

ECG, Electrocardiogram; QTc(B), Corrected QT interval in Bazett's formula; SD, Standard deviation.

Table 3 Comparison of myocardial fibrosis ECG markers among different sexes and sports specialities

	All	Sprint			Endurance			Strength and power			
	n=155	Combined n=69	Males n=47	Females n=22	Combined n=51	Males n=26	Females n=25	Combined n=35	Males n=17	Females n=18	Athletic group p value
Inverted T wave	12 (8%)	5 (7%)	4 (9%)	1 (5%)	6 (12%)	1 (4%)	5 (20%)	1 (3%)		1 (6%)	0.309
Pathological Q wave	6 (4%)	3 (4%)	1 (2%)	2 (9%)	3 (6%)	2 (8%)	1 (4%)				0.367
Fragmented QRS complex	49 (32%)	24 (35%)	18 (38%)	6 (27%)	15 (29%)	9 (35%)	6 (24%)	10 (29%)	5 (29%)	5 (28%)	0.747
Prolonged QRS complex	4 (3%)				3 (6%)	3 (12%)		1 (3%)		1 (6%)	0.132
Total	71 (46%)	32 (46%)	23 (49%)	9 (41%)	27 (53%)	15 (58%)	12 (48%)	12 (34%)	5 (29%)	7 (39%)	0.467

Myocardial fibrosis-related ECG marker findings are demonstrated in counts and percentages. P values represent comparisons among the three athletic groups.
ECG, Electrocardiogram.

correction to QT intervals rendered group differences non-significant (p=0.815). The strength and power athletes had the smallest QRS axis (28±38 axis, p=0.033), significantly different from endurance athletes (49±34 axis, p=0.027). Female sprinters had shorter mean P intervals than female strength and power athletes (108±9 ms, p=0.019). Furthermore, female strength and power athletes showed smaller mean QRS and T wave axis values than other athletic groups.

Variations in ECG axes

Individual measurements revealed deviations in T wave axes, with six male athletes (three with T axis>105° and three < −15°) and one female (< −15°) exhibiting aberrations. The highest T axis recorded was 197°, and the lowest was −78°. Regarding the QRS axis, deviations were found in nine males and two females, with seven males having values < −30° and two>90°, and one female < −30° and one>90°. The highest QRS axis was 118°, and the lowest was −79°. P axis deviations were most prevalent, with 13 males and seven females having values either >75° (eight males, four females) or <0° (five males, three females). The highest P axis measured was 164°, and the lowest was −80°.

MF-related ECG markers

Results for MF-related ECG markers are presented in table 3 and figure 1. No significant group differences were observed in the prevalence of MF markers when analysed collectively (p=0.467) or individually among athletic specialities (fQRS p=0.747, TWI p=0.309, pathological Q wave p=0.367 and prolonged QRS complex p=0.132). Overall, we identified 71 individual instances of MF-related markers out of 155 ECG recordings (46%). Eight athletes displayed two of the four markers (five with TWI and fQRS and three with pathological Q wave and fQRS), while none exhibited three or four markers simultaneously. Therefore, the prevalence of masters athletes with one of the four MF-related ECG markers was 41% (n=63/155).

The prevalence of MF-related ECG markers varied from 3% (prolonged QRS complex) to 32% (fQRS), with no significant differences between athletic specialities.

TWI was identified in 12 athletes (8%), with six in endurance athletes (five females), five in sprinters (one female) and one female in strength and power athletes. The distribution of TWI was eight in anterior leads, one in lateral leads, one in inferior leads and two in inferior-lateral leads.

Pathological Q wave was present in six athletes (4%), with three each in the endurance and sprinter groups. One athlete had pathological Q wave in the lateral leads. Five athletes exhibited pathological Q waves in both inferior and lateral leads. Of these five, two had involvement of lead III, but both also had pathological Q wave in leads II and aVF, meeting the criteria for contiguous leads.

The fQRS complex, as the most prevalent MF marker, was noted in 49 athletes (32%). The prevalence of fQRS was 29% in both strength and power athletes (n=10, five females) and endurance athletes (n=15, six females) and 34% in sprinters (n=24, six females). A similar prevalence of fQRS was observed when athlete groups between sexes were compared. In older age groups, the prevalence of fQRS was higher: 25% in the 35–49 years group (n=32), 39.5% in the 50–59 years group (n=38), 27.9% in the 60–69 years group (n=43) and 34.1% in the group older than 70 years (n=41). The most frequently affected areas for fQRS were the anterior leads (n=30, 19% of all athletes) and inferior leads (n=30, 19%), with a significant gap to the lateral leads (n=3, 2%) (online supplemental table 1). Some athletes (n=13, 8%) had fQRS in leads from multiple cardiac segments. Specifically, the distribution was 17 anterior (11%), one lateral (1%), one anterior-lateral (1%), one anterior-inferior-lateral (1%),

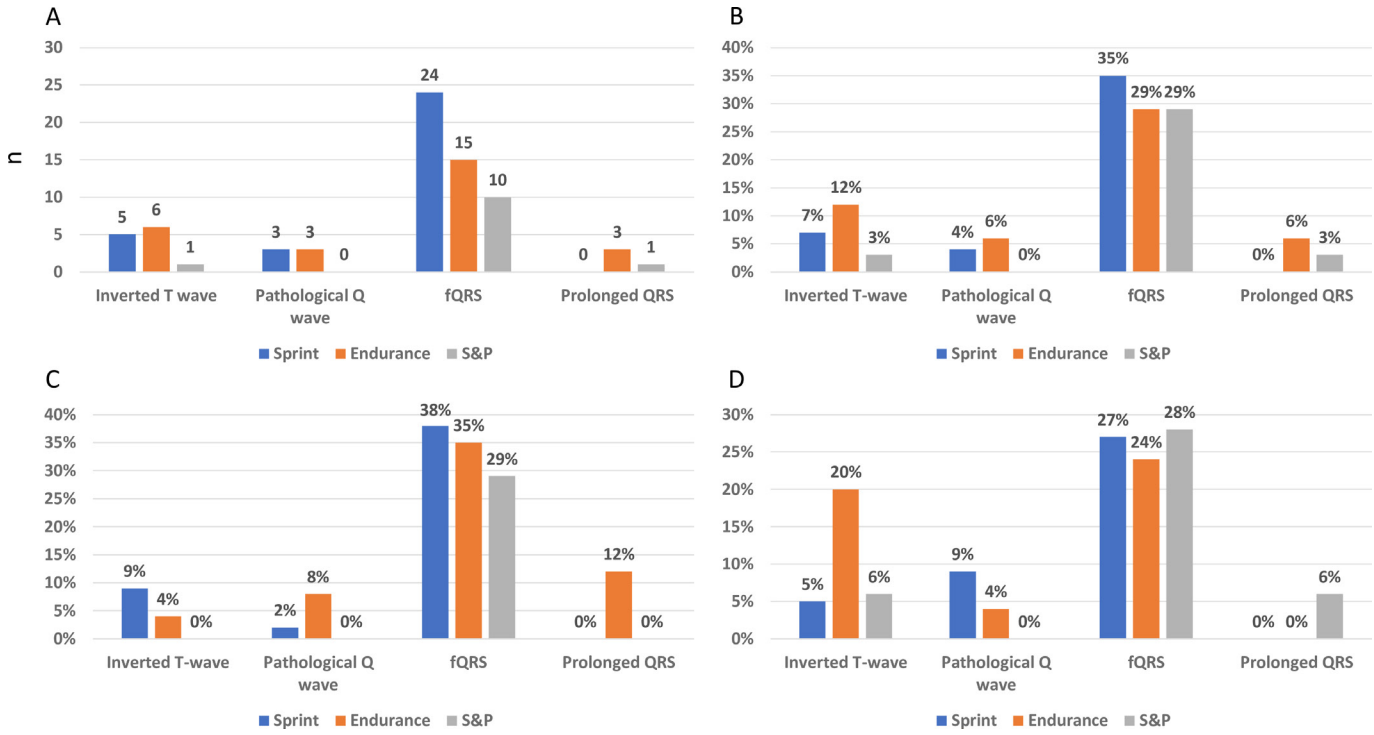

Figure 1 Distribution and prevalence of MF-associated ECG marker findings among masters athletes Panel A: The distribution (n) of MF-associated ECG marker findings (n=71) among all athletes (n=155) categorised by athletic groups: Sprint (n=69), endurance (n=51) and strength and power (n=35). Panel B: The prevalence (%) of MF-associated ECG marker findings (n=71; Sprint, n=32; endurance, n=27; and strength and power, n=12) among all athletes (n=155) in different athletic groups: Sprint (n=69), endurance (n=51) and strength and power (n=35). There were no significant differences in the prevalence of MF-associated ECG markers between the groups (p=0.467). Panel C: The prevalence (%) of MF-associated ECG marker findings (n=43; sprint, n=23; endurance, n=15; and strength and power, n=5) among male athletes (n=90) in different athletic groups: sprint (n=47), endurance (n=26) and strength and power (n=17). There were no significant differences in the prevalence of MF-associated ECG markers between the groups (p=0.283). Panel D: The prevalence (%) of MF-associated ECG marker findings (n=28; sprint, n=9; endurance, n=12; and strength and power, n=7) among female athletes (n=65) in different athletic groups: sprint (n=22), endurance (n=25) and strength and power (n=18). There were no significant differences in the prevalence of MF-associated ECG markers between the groups (p=0.485).

18 inferior (12%) and 11 anterior-inferior (7%) (online supplemental table 2).

Prolonged QRS complex was noted in three endurance athletes and one athlete in the strength and power group.

Sprinters showed the highest number of all MF-related ECG markers (32/69, 46%), while the highest prevalence of these markers was observed in endurance athletes (27/51, 53%). Overall, male athletes had a slightly higher prevalence of all MF-related ECG markers than female athletes (43/90, 48% vs 28/65, 43%) (table 3).

ECG abnormalities and their association with fQRS

We observed the following ECG abnormalities: 16 prolonged PR intervals, one LBBB, two RBBB, five incomplete RBBB, 22 LVH and seven RVH. Among the 49 patients with fQRS, it was associated with seven prolonged PQ intervals, two incomplete RBBB, 11 LVH and two RVH. When fQRS was associated with LVH, six instances involved leads from two cardiac territories, and one involved leads from all three territories. Additionally, in one patient with incomplete RBBB, the ECG leads from two cardiac segments were affected.

DISCUSSION

Our study aimed to uncover MF-related ECG marker prevalence in diverse track-and-field disciplines among masters athletes.[19–22] A significant finding is detecting these markers in apparently healthy masters athletes, with no significant differences observed among male and female athletes in various sports disciplines. The identification of fQRS as the predominant MF marker associated with an increased risk of SCD during physical activity accentuates concerns about potential cardiovascular risks within this demographic.[26] Other MF-related ECG markers, such as TWI and pathological Q waves, were also identified.

Placing results in existing research context

Our research contrasts with previous findings,[27 28] not affirming significant distinctions in MF-related ECG markers among athletes in various disciplines and sexes. Endurance athletes demonstrate an elevated susceptibility to MF development compared with non-athletes[29–31] and athletes in alternative sports disciplines.[8 29] This higher prevalence in endurance athletes is attributed

to increased cardiac workload, characterised by repetitive mechanical stress on the myocardium during daily training.[8 30] Despite the inherent demands of endurance sports, presumed to result in sustained elevated cardiac volume workloads over more extended periods than other sports, our study did not reveal notable disparities in the prevalence of MF markers across various athletic specialities.

In previous studies, higher exercise intensity has been associated with an increased vulnerability to MF development.[29 30] In our study, statistical analysis did not uncover significant differences in the prevalence of MF markers between sprinters and endurance athletes, despite the latter reporting greater exercise intensity evidenced by peak RPE. Using RPE to assess exercise intensity has limitations, particularly in sports involving throwing or jumping, which present distinct physiological demands compared with endurance sports.

Existing literature reported a higher MF prevalence among male athletes than females.[27 28] The absence of significant sex differences in our study contradicts established patterns, emphasising the need for differentiated considerations of sex-specific cardiac adaptations in masters athletes.

Our findings confirm that bradycardia, impacting PR and QT intervals,[32] is characteristic among endurance athletes, who typically exhibit prolonged PR and QT intervals.[8] Despite mean PR and QT intervals being within clinically normal ranges, subtle deviations were highlighted, especially in female endurance athletes, with mean QT intervals approaching the higher end (455±39 ms).[32–34]

Examination of mean ECG axis values revealed no deviations within normal ranges across all groups and sexes. However, a detailed analysis uncovered individual measurements displaying variations in the T, QRS and P wave axes, providing nuanced insights into specific deviations in ECG parameters among masters athletes.[35–37] Other primary ECG parameters adhered to normal ranges in accordance with international recommendations for athlete ECG interpretation.[38]

The prevalence of fQRS exceeded rates in the general population and patients with known or suspected cardiac disease or chronic kidney disease,[39 40] highlighting the distinct cardiac characteristics of masters athletes. In contrast, among subjects with angiographically documented coronary artery disease (CAD) with ≥50% occlusion in one of the main coronary arteries without prior myocardial infarction, fQRS was observed in 35.3%,[39] exceeding the prevalence in our cohort. In patients with CAD and a history of prior myocardial infarction, the prevalence of fQRS was even higher, approximately 40%,[21 39] indicating a significant association between fQRS and the extent of myocardial damage in these patients.

While fQRS was associated with conditions such as prolonged PR interval, incomplete RBBB, LVH and RVH, it is important to note that fQRS was not solely attributable to these abnormalities, as in only a subset of athletes. Some cases involved multiple cardiac territories, indicating that additional underlying cardiac changes beyond the typical abnormalities may contribute to the presence of fQRS. Our study found 8% TWI prevalence and 3% prolonged QRS complex prevalence, contrasting with higher rates in the general population.[41 42] However, TWI in anterior chest leads may indicate a physiological norm variant, similar to pathological Q waves, especially in lead III.

Abnormal ECG findings underscore the need for systematic cardiac screening in masters athletes.[38] Using our study as a pre-participation screening method for cardiovascular conditions (excluding MF markers) in masters athletes would have identified 16% of participating masters athletes for potential further cardiac examinations.

Consistent with existing literature, our findings suggest that the advancing age of athletes, rather than their athletic specialisation, may substantially impact MF development. Although fQRS was more frequently observed in older masters athletes in our cohort, the Pearson correlation between fQRS and age was not statistically significant (p=0.548), indicating no strict correlation with increasing age.

Ageing is well-documented to induce progressive fibrosis changes in various organ systems, including the cardiovascular system, where ageing is associated with LVH and MF, even in otherwise healthy adults.[43] Athletes generally risk developing MF more than their sedentary counterparts.[29–31] However, it is crucial to emphasise the comprehensive benefits of regular exercise for overall health during the ageing process, with its advantages significantly outweighing potential risks and side effects.

Our study contributes to the growing literature on MF-related ECG markers in athletes.[29 30 43]

Summary

Our study investigates MF-related ECG markers in masters athletes, providing insights into prevalence, sex differences and athletic specialities. Accurate assessment of MF is crucial for identifying athletes at risk of arrhythmias. Nearly half of the study population displayed at least one potential MF-related ECG marker, underscoring the need to better understand the complex mechanistic interactions of MF in athlete cardiac health. The unexpectedly uniform MF marker prevalence prompts additional research on factors influencing cardiac remodelling. The advancing age of masters athletes may substantially impact MF development more than their specific athletic specialisation, highlighting the overall health benefits of regular exercise during ageing.

Clinical implications

The 12-lead resting ECG emerges as a potential non-invasive screening tool for the early detection of MF in masters athletes. Our findings indicate potential risks in masters athletes, challenging established paradigms

and prompting thoughtful consideration. Positive ECG markers for MF justify subsequent cardiac MRI for confirmation, potentially preventing adverse clinical outcomes.

Strengths and limitations

Our study, one of the largest on resting 12-lead ECG assessments in competitive masters athletes, demonstrates the utility of non-invasive, widely available and cost-effective ECG measurements as indicators of MF. It pioneers the exploration of sex-specific differences in MF-related ECG markers across various track-and-field disciplines. It also pioneers assessing and reporting potential side effects of athletic participation at an older age, thereby helping to obtain an unbiased assessment of risks and benefits.

However, our study is limited by the absence of a matched control group due to the global diversity of our participants. The difficulty in finding a control group with matching genetic, cultural, environmental, socio-economic and residential backgrounds, given the worldwide scope of our sample, made creating a matched control group infeasible. One notable limitation is the lack of cardiac MRI, which is considered the gold standard for definitive confirmation of MF. This absence of imaging control means that our ECG findings, although valuable, cannot be directly correlated with confirmed instances of MF, potentially affecting the precision of our conclusions. Additionally, the diverse demographic characteristics of our sample may affect the generalisability of our findings. Another limitation is that the initial definition of fQRS was originally applied solely to patients with prior myocardial infarction.[21] However, recent studies have shown that these criteria effectively identify MF across diverse populations.[20 44–47] Moreover, the potentially benign nature of TWI in the anterior chest leads and pathological Q waves, especially in lead III, adds complexity to their interpretation and necessitates careful consideration in the context of our findings.

CONCLUSIONS

Our study identifies a high prevalence of MF-related ECG markers in masters athletes, with the fQRS complex emerging as the predominant marker across disciplines and sexes. Further research is essential to evaluate its impact on athletes' cardiac health. Despite this, the overall health benefits of regular exercise during ageing outweigh the potential risks.

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Ethics approval This study involves human participants and was approved by Ethics Approval: Research complied with all relevant national regulations and institutional policies in accordance with the tenets of the Declaration of Helsinki (as amended in 2013). The TaFMAC study was approved by the Ethical Committee of the Medical Chamber North-Rhine (Düsseldorf, Germany), under the reference number 2020401. The study is registered in the German Register of Clinical Trials (www.drks.de) under the identifier DRKS00025846. Participants gave informed consent to participate in the study before taking part.

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REFERENCES

1 Ruegsegger GN, Booth FW. Health Benefits of Exercise. *Cold Spring Harb Perspect Med* 2018;8:a029694.

2 Eckstrom E, Neukam S, Kalin L, *et al*. Physical Activity and Healthy Aging. *Clin Geriatr Med* 2020;36:671–83.
3 Harridge SDR, Lazarus NR. Physical Activity, Aging, and Physiological Function. *Physiology (Bethesda)* 2017;32:152–61.
4 Tanaka H, Tarumi T, Rittweger J. Aging and physiological lessons from master athletes. *Compr Physiol* 2020;10:261–96.
5 Geard D, Reaburn PRJ, Rebar AL, *et al*. Masters Athletes: Exemplars of Successful Aging? *J Aging Phys Act* 2017;25:490–500.
6 Wasfy MM, Hutter AM, Weiner RB. Sudden Cardiac Death in Athletes. *Methodist Debakey Cardiovasc J* 2016;12:76–80.
7 Morrison BN, McKinney J, Isserow S, *et al*. Assessment of cardiovascular risk and preparticipation screening protocols in masters athletes: the Masters Athlete Screening Study (MASS): a cross-sectional study. *BMJ Open Sport Exerc Med* 2018;4:e000370.
8 Fagard R. Athlete's heart. *Heart* 2003;89:1455–61.
9 Maron BJ, Pelliccia A. The heart of trained athletes: cardiac remodeling and the risks of sports, including sudden death. *Circulation* 2006;114:1633–44.
10 Corrado D, Basso C, Rizzoli G, *et al*. Does sports activity enhance the risk of sudden death in adolescents and young adults? *J Am Coll Cardiol* 2003;42:1959–63.
11 Thompson PD, Funk EJ, Carleton RA, *et al*. Incidence of death during jogging in Rhode Island from 1975 through 1980. *JAMA* 1982;247:2535–8.
12 Ma ZG, Yuan YP, Wu HM, *et al*. Cardiac fibrosis: new insights into the pathogenesis. *Int J Biol Sci* 2018;14:1645–57.
13 Frangogiannis NG. Cardiac fibrosis: Cell biological mechanisms, molecular pathways and therapeutic opportunities. *Mol Aspects Med* 2019;65:70–99.
14 Frangogiannis NG. Cardiac fibrosis. *Cardiovasc Res* 2021;117:1450–88.
15 Kong P, Christia P, Frangogiannis NG. The pathogenesis of cardiac fibrosis. *Cell Mol Life Sci* 2014;71:549–74.
16 Bing R, Dweck MR. Myocardial fibrosis: why image, how to image and clinical implications. *Heart* 2019;105:1832–40.
17 Małek ŁA, Bucciarelli-Ducci C. Myocardial fibrosis in athletes-Current perspective. *Clin Cardiol* 2020;43:882–8.
18 Dohy Z, Vereckei A, Horvath V, *et al*. How are ECG parameters related to cardiac magnetic resonance images? Electrocardiographic predictors of left ventricular hypertrophy and myocardial fibrosis in hypertrophic cardiomyopathy. *Noninvasive Electrocardiol* 2020;25:e12763.
19 Açıkgöz E, Yaman B, Açıkgöz SK, *et al*. Fragmented QRS can predict severity of aortic stenosis. *Ann Noninvasive Electrocardiol* 2015;20:37–42.
20 Tangwiwat C, Kaolawanich Y, Krittayaphong R. Electrocardiographic predictors of myocardial fibrosis and apical hypertrophic cardiomyopathy. *Ann Noninvasive Electrocardiol* 2019;24:e12612.
21 Das MK, Khan B, Jacob S, *et al*. Significance of a fragmented QRS complex versus a Q wave in patients with coronary artery disease. *Circulation* 2006;113:2495–501.
22 Holmström L, Haukilahti A, Vähätalo J, *et al*. Electrocardiographic associations with myocardial fibrosis among sudden cardiac death victims. *Heart* 2020;106:1001–6.
23 Hoffmann F, Moestl S, Wooten SV, *et al*. Left Ventricular Dimensions and Diastolic Function Are Different in Throwers, Endurance Athletes, and Sprinters From the World Masters Athletics Championships. *Front Physiol* 2021;12:643764.
24 Wooten SV, Mittag U, Alvero Cruz JR, *et al*. Life Satisfaction, Positive Affect, and Sleep Impairment in Masters Athletes: Modulation by Age, Sex, and Exercise Type. *Front Physiol* 2021;12:634433.
25 Mansournia MA, Collins GS, Nielsen RO, *et al*. A CHecklist for statistical Assessment of Medical Papers (the CHAMP statement): explanation and elaboration. *Br J Sports Med* 2021;55:1009–17.
26 Toukola T, Junttila MJ, Holmström LTA, *et al*. Fragmented QRS complex as a predictor of exercise-related sudden cardiac death. *Cardiovasc electrophysiol* 2018;29:55–60.
27 Colombo CSSS, Finocchiaro G. The Female Athlete's Heart: Facts and Fallacies. *Curr Treat Options Cardiovasc Med* 2018;20:101.
28 Castelletti S, Gati S. The Female Athlete's Heart: Overview and Management of Cardiovascular Diseases. *Eur Cardiol* 2021;16:e47.
29 Peritz DC, Catino AB, Csecs I, *et al*. High-intensity endurance training is associated with left atrial fibrosis. *Am Heart J* 2020;226:206–13.
30 Zhang CD, Xu SL, Wang XY, *et al*. Prevalence of Myocardial Fibrosis in Intensive Endurance Training Athletes: A Systematic Review and Meta-Analysis. *Front Cardiovasc Med* 2020;7:585692.
31 Rajanayagam J, Alsabri M. Intense Endurance Exercise: A Potential Risk Factor in the Development of Heart Disease. *Cureus* 2021;13:e12608.
32 Kerola T, Eranti A, Aro AL, *et al*. Risk Factors Associated With Atrioventricular Block. *JAMA Netw Open* 2019;2:e194176.
33 Shah SR, Park K, Alweis R. Long QT Syndrome: A Comprehensive Review of the Literature and Current Evidence. *Curr Probl Cardiol* 2019;44:92–106.
34 Johnson JN, Ackerman MJ. QTc: how long is too long? *Br J Sports Med* 2009;43:657–62.
35 Salles GF, Xavier SS, Sousa AS, *et al*. T-wave axis deviation as an independent predictor of mortality in chronic Chagas' disease. *Am J Cardiol* 2004;93:1136–40.
36 Kashou AH, Basit H, Chhabra L. Electrical Right and Left Axis Deviation. Teoksessa StatPearls Treasure Island (FL): StatPearls Publishing, 2022. Available: http://www.ncbi.nlm.nih.gov/books/NBK470532/
37 Kaykha A, Myers J, Desser KB, *et al*. The prognostic importance of isolated P-Wave abnormalities. *Clin Cardiol* 2010;33:E87–93.
38 Sharma S, Drezner JA, Baggish A, *et al*. International Recommendations for Electrocardiographic Interpretation inAthletes. *J Am Coll Cardiol* 2017;69:1057–75.
39 Haukilahti MAE, Holmström L, Vähätalo J, *et al*. Gender differences in prevalence and prognostic value of fragmented QRS complex. *J Electrocardiol* 2020;61:1–9.
40 Liu P, Wu J, Wang L, *et al*. The prevalence of fragmented QRS and its relationship with left ventricular systolic function in chronic kidney disease. *J Int Med Res* 2020;48:0300060519890792.
41 Istolahti T, Lyytikäinen LP, Huhtala H, *et al*. The prognostic significance of T-wave inversion according to ECG lead group during long-term follow-up in the general population. *Ann Noninvasive Electrocardiol* 2021;26:e12799.
42 Muromtseva GA, Vilkov VG, Shalnova SA, *et al*. The prevalence of wide QRS complex (≥110 ms) among the population, depending on sex, age and place of residence. *Russ J Cardiol* 2020;25:3478.
43 Biernacka A, Frangogiannis NG. Aging and Cardiac Fibrosis. *Aging Dis* 2011;2:158–73.
44 Eyuboglu M. Fragmented QRS as a Marker of Myocardial Fibrosis in Hypertension: a Systematic Review. *Curr Hypertens Rep* 2019;21:73.
45 Konno T, Hayashi K, Fujino N, *et al*. Electrocardiographic QRS Fragmentation as a Marker for Myocardial Fibrosis in Hypertrophic Cardiomyopathy. *J Cardiovasc Electrophysiol* 2015;26:1081–7.
46 Bazoukis G, Garcia-Zamora S, Çinier G, *et al*. Association of electrocardiographic markers with myocardial fibrosis as assessed by cardiac magnetic resonance in different clinical settings. *World J Cardiol* 2022;14:483–95.
47 Basaran Y, Tigen K, Karaahmet T, *et al*. Fragmented QRS complexes are associated with cardiac fibrosis and significant intraventricular systolic dyssynchrony in nonischemic dilated cardiomyopathy patients with a narrow QRS interval. *Echocardiography* 2011;28:62–8.