Arrhythmias and Adaptations of the Cardiac Conduction System in Former National Football League Players

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Background—Habitual high-intensity endurance exercise is associated with increased atrial fibrillation (AF) risk and impaired cardiac conduction. It is unknown whether these observations extend to prior strength-type sports exposure. The primary aim of this study was to compare AF prevalence in former National Football League (NFL) athletes to population-based controls. The secondary aim was to characterize other conduction system parameters.

Methods and Results—This cross-sectional study compared former NFL athletes (n=460, age 56±12 years, black 47%) with population-based controls of similar age and racial composition from the cardiovascular cohort Dallas Heart Study-2 (n=925, age 54±9 years, black 53%). AF was present in 28 individuals (n=23 [5%] in the NFL group; n=5 [0.5%] in the control group). After controlling for other cardiovascular risk factors in multivariable regression analysis, former NFL participation remained associated with a 5.7 (95% CI: 2.1–15.9, P=0.001) higher odds ratio of AF. Older age, higher body mass index, and nonblack race were also independently associated with higher odds ratio of AF, while hypertension and diabetes mellitus were not. AF was previously undiagnosed in 15/23 of the former NFL players. Previously undiagnosed NFL players were rate controlled and asymptomatic, but 80% had a CHA2DS2-VASc score ≥1. Former NFL players also had an 8-fold higher prevalence of paced cardiac rhythms (2.0% versus 0.25%, P<0.001), compared with controls. Furthermore, former athletes had lower resting heart rates (62±11 versus 66±11 beats per minute, P<0.001), and a higher prevalence of first-degree atrioventricular block (18% versus 9%, P<0.001).

Conclusions—Former NFL participation was associated with an increased AF prevalence and slowed cardiac conduction when compared with a population-based control group. Former NFL athletes who screened positive for AF were generally rate controlled and asymptomatic, but 80% should have been considered for anticoagulation based on their stroke risk. (J Am Heart Assoc. 2019;8:e010401. DOI: 10.1161/JAHA.118.010401.)

Key Words: athlete’s heart • atrial fibrillation • conduction disease • National Football League

The health benefits of regular moderate exercise are well established. Recently, concerns have been raised about the cardiovascular risk of long-term, strenuous endurance activity, in particular as it relates to atrial fibrillation (AF) and cardiac conduction disease. In a meta-analysis, the prevalence of AF was 5-fold higher in veteran endurance athletes compared with age-matched sedentary controls. Long-term alterations in autonomic tone with increased atrial refractory period, atrial dilation caused by increased preload, heightened inflammation, and atrial fibrosis are some of the mechanisms postulated to induce AF in athletes. Cardiac conduction system disease, including the need for permanent pacemaker implantation, is also more common in former endurance athletes compared with age-matched, more sedentary peers.

Prior studies have focused on the effects of long-term participation in endurance sports; however, the impact of prolonged exposure to strength-type sports on the cardiac conduction system is largely unknown. Therefore, the primary aim of this study was to evaluate the prevalence of AF in former National Football League (NFL) players compared with a population-based non-elite athlete control group. The secondary aim was to characterize other cardiac conduction system parameters in both groups.
Clinical Perspective

What Is New?

- While several studies have associated long-term participation in endurance-type sports with an increased risk of atrial fibrillation (AF), this is the first study associating participation in strength-type sports with AF.
- The majority of former NFL athletes with AF were previously undiagnosed, rate controlled, and asymptomatic, but 80% met indications for anticoagulation, highlighting the need for a high level of clinical suspicion for occult AF in this group.
- Sinus bradycardia and first-degree atrioventricular block are typically benign findings in former athletes, but more severe conduction abnormalities requiring cardiac pacing also appear more prevalent in this population.

What Are the Clinical Implications?

- These data should be placed in the context of recently published work indicating that former participation in the NFL is associated with overall reduced all-cause and cardiovascular mortality compared with the general population.

Methods

Study Design

This is a cross-sectional study comparing a self-selected sample of former NFL players to a population-based non-elite athlete control group from the Dallas Heart Study-2 (DHS). An invitation to participate in voluntary cardiovascular screening, as part of the NFL Players Care Foundation Healthy Body and Mind Screening Program, was extended to former NFL players. All former players who had participated in at least 1 NFL game were eligible to participate in screening. Details of this screening have been described previously. Briefly, screening was conducted between January 2014 and January 2015 at multiple locations across the United States (Canton, OH; Chicago, IL; Cincinnati, OH; Dallas, TX; Indianapolis, IN; Las Vegas, NV; New York City, NY; Orlando, FL; Phoenix, AZ; and Pittsburgh, PA). The screening was performed by experienced personnel from the Cleveland Clinic Foundation. The data were de-identified and stored in a secure database with MedStar Sports Medicine. Screening comprised a cardiovascular history questionnaire that was reviewed with the player by a cardiologist to ensure accuracy of data, basic biometrics (height and weight), blood pressure readings, lipid profile, HbA1c, a 12-lead ECG, and an echocardiogram. The study was approved by the MedStar Institutional Review Board. All study participants provided written informed consent. The data that support the findings of this study are available from the corresponding author upon reasonable request.

The DHS was selected as the control group, given the racial diversity of the cohort with a significant black population. The design details of the DHS have been described previously. Briefly, it is a probability-based population cohort of 3072 adults from Dallas County approved by the University of Texas Southwestern Medical Center Institutional Review Board. All participants provided written informed consent. Participants were enrolled between 2000 and 2002 (DHS–1), and there was intentional oversampling of blacks. The second phase was performed between 2007 and 2009 (DHS–2) and included follow-up visits of 2485 DHS participants along with 916 spouses of the original cohort. For the present analysis, we prespecified selection of male, white and black DHS–2 participants at least 40 years of age and with a body mass index (BMI) of at least 20 kg/m². All individuals meeting those criteria were included in the analysis. The DHS–2 was chosen as the comparison cohort because it was better matched for age (as compared with the DHS–1) with the NFL group.

Definitions

In both the NFL and DHS groups, hypertension and hyperlipidemia were defined as self-reported history of disease or the use of antihypertensive or lipid-lowering drugs. Diabetes mellitus was defined as self-reported history of diabetes mellitus, hemoglobin A1c ≥6.5%, or use of oral hypoglycemic drugs or insulin. Coronary artery disease, stroke, and heart failure were defined as self-reported history of disease. Current smoking was defined as any cigarette smoking at time of evaluation. In the NFL group, current level of physical activity was defined by frequency of weekly exercise: low (<1 time per week), medium (1–2 times per week), or high (≥3 times per week).

Former NFL players who played in the tackle, guard, center, defensive tackle, defensive end, or linebacker were classified as linemen; those who played in the quarterback, running back, wide receiver, tight end, cornerback, safety, kicker, or punter position were classified as nonlinemen.

Twelve-lead ECGs were measured using a General Electric (GE) Marquette Medical System with a MAC 5000 hardware and software configuration. The 12-lead ECGs were interpreted according to the 2017 International Recommendations for ECG interpretation in athletes. AF was classified as history of physician-diagnosed AF (previously known AF), or AF detected for the first time on the 12-lead study ECG (previously unknown AF).

Transthoracic echocardiograms using Vivid q (GE Medical, Milwaukee, WI) and Philips iE33 (Philips Healthcare, Andover, MA) ultrasound systems were performed in all former NFL players.
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The following measurements were prospectively performed according to the American Society of Echocardiography guidelines: ejection fraction (EF) using disc summation algorithm calculated from left ventricular (LV) volumes from apical 2- and 4-chamber windows, left atrial volume index using a disc summation algorithm, end-diastolic interventricular septal and posterior wall thickness and LV internal dimension in diastole. LV mass index was calculated based on modeling the LV as a prolate ellipse. Mitral valve inflow waves (E and A waves) and the average of the medial and lateral mitral annular velocities (e’i) were measured using standard techniques.7

Statistical Methods
Summary statistics for continuous variables are reported as mean (1 SD) and categorical variables are reported as frequency (percentage). Participant characteristics were compared between the retired NFL and DHS groups using a Student unpaired t test for continuous variables and the χ² test for categorical variables. ANOVA was applied for the analysis of continuous variables across more than 2 groups. Univariable and multivariable (stepwise selection) logistic regression models were used to assess the association of baseline covariates with AF. Analysis limited to the NFL group, including echocardiographic parameters, was also performed.

To further address the question of AF rates between the 2 groups, given baseline differences between NFL participants and DHS-2 participants, propensity score matching was used. For the purpose of propensity matching with the NFL cohort, DHS participants were restricted to males and black/white groups, given baseline differences between NFL participants and DHS participants in the DHS group. Propensity score matching was used. For the purpose of propensity matching with the NFL cohort, DHS participants were restricted to males and black/white race. NFL participants were matched in a 2:1 ratio, as the model allowed. Propensity matching was performed using a greedy matching algorithm for individual variables included in the CHADS2/VASC score, as they were available. Specifically, we matched for age (within 5 years), BMI (within 5 kg/m²), clinical heart failure, the presence of coronary artery disease or clinical heart failure (yes/no), hypertension status (yes/no), and diabetes mellitus status (yes/no). No information on peripheral vascular disease, stroke, or transient ischemic attack was available in the NFL group; thus, these variables of the CHADS2/VASC were not included in the matching algorithm. After matching, the odds ratio for the outcome of AF based on the exposure of a former NFL player was calculated.

Results
Study Population
A total of 484 former NFL players underwent screening. Of these, 460 former players (age 56±12 years, black 47%) had complete data and were included in the study. Of the 2485 participants in the DHS group, 925 participants (age 53.9±8.6 years, black 53%) met the inclusion criteria. Baseline characteristics of study participants are shown in Table 1. While the NFL group was older and had higher BMIs than the DHS group, the differences were small (55.9±12 versus 53.9±8.5 years, P=0.002 and 32.3±5 versus 30.5±6.3 kg/m², P=0.0001). Other risk factors associated with AF and cardiac conduction disease were higher in the DHS group, including the following: any history of smoking (56% versus 22%, P=0.001), hypertension (57% versus 50%, P=0.002), hyperlipidemia (45% versus 35%, P=0.001), diabetes mellitus (19% versus 13%, P=0.002), coronary artery disease (7.0% versus 3.7%, P=0.01), and heart failure (2.5% versus 1.2%, P=0.04).

Atrial Fibrillation
AF was present in 28 individuals (NFL group: n=23, 5%; DHS group: n=5, 0.5%). In the NFL group, AF was a previously known diagnosis in 8 (35%) and previously unknown in 15/23 (65%). All former NFL with previously unknown AF were asymptomatic from an AF perspective. All individuals in the DHS group had previously known AF.

In univariable regression analysis, former NFL player status was associated with 9.7 (95% CI: 3.7–25.6, P<0.001) times higher odds of AF. Stepwise multivariable regression analysis controlling for age, hypertension, diabetes mellitus, BMI, and race showed that former NFL players had 5.7 times higher odds of AF (adjusted odds ratio 5.7, 95% CI: 2.1–15.9, P<0.001) (Table 2).

Differences between former NFL players with and without AF are presented in Table 3. Compared with former NFL players without AF, former players with AF were older, larger, more inactive, and more likely to be white. They also had higher heart rate (HR), lower ejection fractions, larger left atria, and higher E/e’ on echocardiography (all P<0.05). However, the prevalence of hypertension, hyperlipidemia, diabetes mellitus, or history of coronary artery disease, player position (lineman versus non-lineman), or the number of years played in the NFL did not differ (Table 3).

In stepwise multivariable regression analysis including only former NFL players, a larger left atrial volume index (adjusted odds ratio 3.1, 95% CI: 2.1–4.6) and higher BMI (adjusted odds ratio 1.1, 95% CI: 1.0–1.3) were independently associated with higher odds of AF. Conversely, black race was independently associated with lower odds of AF (adjusted odds ratio 0.1, 95% CI: 0.02–0.4). Other parameters including age, hypertension, and diabetes mellitus were not significantly associated with AF (Table 4).

With regard to propensity score matching, the matched cohort included a total of 1013 participants; 377 former NFL
### Table 1. Baseline Characteristics

| Characteristic                          | NFL Group (N=460) | DHS Group (N=925) | P Value |
|-----------------------------------------|-------------------|-------------------|---------|
| Age, y                                  | 55.9±12           | 53.9±8.5          | 0.002   |
| Race                                    |                   |                   |         |
| Black, %                                | 46.5              | 53.3              | 0.002   |
| White, %                                | 51.5              | 46.7              | 0.01    |
| Other, %                                | 2.0               | 0                 | <0.001  |
| BMI, kg/m²                              | 32.3±5.0          | 30.5±6.3          | <0.001  |
| Smoking                                 |                   |                   |         |
| Current, %                              | 9.8               | 26.4              | <0.001  |
| Former, %                               | 12.0              | 29.1              | <0.001  |
| Hypertension, %                         | 49.8              | 57.0              | 0.002   |
| Hyperlipidemia, %                       | 34.6              | 44.7              | <0.001  |
| Diabetes mellitus, %                    | 13.0              | 18.5              | 0.002   |
| Coronary artery disease, %              | 3.7               | 7.0               | 0.01    |
| Stroke/TIA, %                           | 2.6               | 3.3               | 0.34    |
| Heart failure, %                        | 1.2               | 2.5               | 0.04    |
| Heart rate, bpm                         | 62±11             | 66±11             | <0.001  |
| PR-interval, ms                         | 179±31            | 167±26            | <0.001  |
| First-degree atrioventricular block, %  | 18.0              | 9.0               | <0.001  |
| QRS-interval, ms                        | 96±17             | 93±13             | <0.001  |
| QTc interval, ms                        | 417±28            | 414±22            | 0.001   |
| Left anterior hemiblock, %              | 6.3               | 7.7               | 0.06    |
| Right posterior hemiblock, %            | 0                 | 0.1               | 0.63    |
| Left bundle branch block, %             | 0.7               | 0.8               | 0.26    |
| Right bundle branch block, %            | 2.2               | 1.6               | 0.13    |
| Incomplete right bundle branch block, % | 10.0              | 7.1               | 0.02    |
| Left ventricular hypertrophy, %         | 7.4               | 8.2               | 0.07    |
| Right ventricular hypertrophy, %        | 0.2               | 0.3               | 0.44    |
| Left atrial enlargement, %              | 7.8               | 8.7               | 0.07    |
| Right atrial enlargement, %             | 0                 | 1.8               | 0.002   |
| Pathologic Q-waves, %                   | 0.7               | 4.8               | <0.001  |
| T-wave inversions, %                    | 3.7               | 12.2              | <0.001  |
| ST-segment depression, %                | 0.4               | 3.9               | <0.001  |
| Premature atrial contractions, %        | 1.3               | 1.4               | 0.2     |
| Premature ventricular contractions, %   | 3.9               | 1.8               | 0.01    |
| Atrial fibrillation, %                  | 5.0               | 0.5               | <0.001  |
| Paced rhythm, %                         | 2.0               | 0.25              | 0.002   |
| Echocardiographic parameters            |                   |                   |         |
| Ejection fraction, %                    | 59±4.8            | …                 | …       |
| Left ventricular mass, g                | 213±54            | …                 | …       |
| Left ventricular mass index, g/m²       | 89±20             | …                 | …       |
| LVEDV, mL                               | 135±32            | …                 | …       |

Continued
Table 1. Continued

| Metric                     | NFL Group (N=460) | DHS Group (N=925) | P Value |
|----------------------------|-------------------|-------------------|---------|
| IVSeD, mm                  | 11.5±1.9          | ...               | ...     |
| PWTeD, mm                  | 10.8±1.6          | ...               | ...     |
| LVDeD, mm                  | 50±6              | ...               | ...     |
| Left atrial diameter, mm   | 39±6              | ...               | ...     |
| Left atrial volume index, mL/m² | 27±8              | ...               | ...     |
| E/A                        | 1.15±0.70         | ...               | ...     |
| E/e’                       | 8.7±3.0           | ...               | ...     |

BMI indicates body mass index; bpm, beats per minute; DHS, Dallas Heart study; E/A, ratio between peak early and late diastolic flow velocity; E/e’, ratio of early peak mitral flow velocity to the average of the medial and lateral mitral annular velocities; IVSeD, interventricular septum end-diastolic diameter; LVDeD, left ventricular dimension in end-diastole; LVEDV, left ventricular end-diastolic volume; NFL, National Football League; PWTeD, posterior wall thickness in end-diastole.

Cardiac Conduction and Ectopy

Compared with the DHS group, former NFL players had an 8-fold higher prevalence of paced rhythms (2.0% versus 0.25%, P<0.01). Former NFL players also had lower resting HR, longer PR intervals, a higher prevalence of first-degree atrioventricular block, and longer QRS intervals (Table 1). The prevalence of ventricular (3.9% versus 1.8%, P=0.01) but not atrial (1.3% versus 1.4%, P=0.2) premature contractions was also higher in the NFL group.

Discussion

The main finding in this study was a higher prevalence of AF in former NFL athletes compared with population-based controls, despite a similar age and racial composition and a lower prevalence of cardiovascular risk factors in the NFL group. The majority of former NFL athletes with AF were previously undiagnosed, rate controlled, and asymptomatic, but met indications for anticoagulation, highlighting the need for a high level of clinical suspicion for occult AF in this group. Furthermore, former NFL athletes had a higher prevalence of paced cardiac rhythms, as well as lower resting HRs, a higher prevalence of first-degree atrioventricular blocks, and longer QRS intervals compared with controls, all in line with slower cardiac impulse formation and propagation.

AF in Athletes

Multiple population-based studies have demonstrated that individuals who engage in regular light-to-moderate physical activity have a lower incidence of AF compared with sedentary controls. However, there is an increasingly recognized association between long-term, habitual participation in endurance sports and an increased risk of AF, The mechanisms linking endurance exercise and AF are incompletely understood and are likely multifactorial. In addition to

Table 2. Uni- and Multivariable Regression of AF Predictors

| Independent Variable | Odds Ratio | 95% CI       | P Value |
|----------------------|------------|--------------|---------|
| Univariable analysis |            |              |         |
| Former NFL player    | 9.7        | 3.7–25.6     | <0.001  |
| Age                  | 2.8        | 1.9–4.1      | <0.001  |
| BMI, kg/m²           | 1.6        | 1.2–2.1      | 0.002   |
| Black race           | 0.3        | 0.1–0.6      | 0.003   |
| Hypertension         | 1.0        | 0.5–2.2      | 0.92    |
| Diabetes mellitus    | 0.9        | 0.3–2.5      | 0.79    |
| Multivariable analysis |          |              |         |
| Former NFL player    | 5.7        | 2.1–15.9     | <0.001  |
| Age                  | 2.1        | 1.4–3.1      | <0.001  |
| BMI, kg/m²           | 1.9        | 1.2–2.8      | 0.002   |
| Black race           | 0.3        | 0.1–0.8      | 0.02    |

Hypertension and diabetes mellitus did not reach statistical significance in the stepwise selection model. AF indicates atrial fibrillation; BMI, body mass index; NFL, National Football League.
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ventricular end-systolic volume; NFL, National Football League.

septum end-diastolic diameter; LVEDV, left ventricular end-diastolic volume; LVESV, left ventricular end-systolic volume; NFL, National Football League.

This hypothesis is supported by animal data showing an increased expression of fibrosis markers and a higher susceptibility to arrhythmias in rats after 16 weeks of intense exercise. Further, in humans, higher levels of cardiac fibrosis markers as well as magnetic resonance imaging evidence of increased late gadolinium enhancement suggesting left atrial fibrosis have been reported in athletes. Changes in autonomic tone and increased atrial ectopy in athletes have also been proposed as potential AF triggers. Despite this, former NFL players had 5.7 times higher odds of AF compared to controls. Whether AF in former NFL players is being driven by similar mechanisms as those postulated to drive AF in endurance athletes is unclear. The present study, except for slightly higher age and BMI, risk factors known to be associated with an increased risk of AF, including smoking, hypertension, hyperlipidemia, and diabetes mellitus, were lower in the NFL players compared with controls. Despite this, former NFL players had 5.7 times higher odds of AF after multivariable adjustment and, similarly, a 4.9 times higher odds ratio after propensity score matching. Of note, the prevalence of AF in the control group was similar to the reported national prevalence of 0.2% in males <55 years of age. Interestingly, black race appeared protective against

Table 3. Baseline Characteristics in Former NFL Players With and Without AF

|                      | AF (N=23) | No AF (N=437) | P Value |
|----------------------|-----------|---------------|---------|
| **Race**             |           |               |         |
| Black, %             | 13        | 48            | <0.001  |
| White, %             | 87        | 50            | <0.001  |
| Other                | 0         | 2             | 0.54    |
| Heart rate, bpm      | 77±19     | 61±10         | <0.001  |
| **Position**         |           |               |         |
| Lineman              | 48        | 30            | 0.15    |
| Nonlineman           | 52        | 70            | 0.18    |
| Years played in the NFL | 7.3±3.4 | 7.4±3.7       | 0.88    |
| BMI, kg/m²           | 34.3±6.8  | 32.2±4.9      | 0.05    |
| **Current level of activity** |               |               |         |
| Low, %               | 26        | 12            | 0.04    |
| Medium, %            | 13        | 27            | 0.13    |
| High, %              | 57        | 53            | 0.75    |
| Unknown, %           | 4         | 8             | 0.45    |
| Hypertension, %      | 52        | 47            | 0.90    |
| Hypertension, %      | 52        | 35            | 0.09    |
| Diabetes mellitus, % | 9         | 13            | 0.56    |
| Coronary artery disease, % | 30 | 23  | 0.40 |
| Ejection fraction, % | 57±7      | 60±5          | 0.004   |
| Left ventricular mass index, g/m² | 96±21  | 88±20         | 0.06    |
| LVEDV, mL            | 130±39    | 136±32        | 0.43    |
| LVESV, mL            | 59±24     | 54±17         | 0.23    |
| IVSeD, mm            | 12.3±1.5  | 11.5±1.9      | 0.06    |
| Left atrial diameter, mm | 46±6   | 38±6          | <0.001  |
| Left atrial volume index, mL² | 40±12 | 27±7          | <0.001  |
| E/e                   | 11.6±5.3  | 8.6±2.8       | <0.001  |

Current physical activity was categorized into 3 groups: low <1 time per week, medium 1 to 2 times per week, and high ≥3 times per week. AF indicates atrial fibrillation; BMI, Body Mass Index; E/e, ratio of early peak mitral flow velocity to the average of the medial and lateral mitral annular velocities; IVSeD, interventricular septum end-diastolic diameter; LVEDV, left ventricular end-diastolic volume; LVESV, left ventricular end-systolic volume; NFL, National Football League.

Table 4. Uni- and Multivariable Regression of AF Predictors in the NFL Group

|                      | Univariable analysis | Multivariable analysis |
|----------------------|----------------------|------------------------|
|                      | Odds Ratio | 95% CI | P Value | Odds Ratio | 95% CI | P Value |
| **Univariable analysis** |           |       |        |           |       |        |
| Age, y               | 2.8        | 1.7–4.6 | <0.001 | 1.8        | 1.3–2.5 | <0.001 |
| BMI, kg/m²           | 1.4        | 1.0–2.0 | 0.05   | 1.1        | 0.8–1.5 | 0.29   |
| Black race           | 0.2        | 0.1–0.5 | 0.004  | 0.2        | 0.1–0.6 | 0.28   |
| Lineman              | 1.5        | 0.6–4.0 | 0.39   | 1.1        | 0.7–1.9 | 0.43   |
| Years played in NFL  | 1.0        | 0.6–1.5 | 0.88   | 1.1        | 0.7–1.8 | 0.65   |
| Coronary artery disease | 1.1    | 0.7–1.7 | 0.43   | 1.1        | 0.7–1.9 | 0.43   |
| Hypertension         | 1.2        | 0.5–2.9 | 0.65   | 1.1        | 0.7–1.6 | 0.65   |
| Diabetes mellitus    | 0.7        | 0.2–2.9 | 0.58   | 1.1        | 0.7–1.5 | 0.43   |
| LVMI, g/m²           | 1.4        | 1.0–2.0 | 0.07   | 1.1        | 0.7–1.4 | 0.43   |
| LAVI, mL/m²          | 2.8        | 2.0–4.0 | <0.001 | 1.1        | 0.7–1.5 | 0.43   |
| LVEF, %              | 0.7        | 0.5–0.9 | 0.01   | 1.1        | 0.7–1.5 | 0.43   |
| E/e                  | 3.1        | 2.1–4.6 | <0.001 | 1.1        | 0.8–1.5 | 0.29   |
| **BMI, kg/m²**       | 1.1        | 1.0–1.3 | 0.01   | 1.1        | 0.8–1.5 | 0.29   |
| **Multivariable analysis** |       |       |        |           |       |        |
| LAVI, mL/m²          | 3.1        | 2.1–4.6 | <0.001 | 1.1        | 0.8–1.5 | 0.29   |
| BMI, kg/m²           | 1.1        | 1.0–1.3 | 0.01   | 1.1        | 0.8–1.5 | 0.29   |
| Black race           | 0.1        | 0.02–0.4 | 0.01  | 1.1        | 0.8–1.5 | 0.29   |

All listed univariable parameters were entered in the step-wise multivariate selection model. Only LAVI, BMI, and black race remained independently associated with higher odds of AF. AF indicates atrial fibrillation; BMI, Body Mass Index; E/e, ratio of early peak mitral flow velocity to the average of the medial and lateral mitral annular velocities; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index; NFL, National Football League.
### Table 5. Former NFL Players With AF

| Case | Age (y) | Race | Position | Years in NFL | Smoking | Other Conditions | Activity Level | BMI | HR | CHA2DS2-VASc | LVEF | LAVI | LVMI |
|------|--------|------|----------|-------------|---------|-----------------|---------------|-----|----|--------------|------|------|------|
| 1    | 42     | White| NL       | 5           | Current | None            | High          | 34.2| 72 | 0            | 55   | 34   | 83   |
| 2    | 43     | White| L        | 8           | Never   | HLD             | Medium        | 39.0| 101| 1            | 35   | 41   | 100  |
| 3    | 60     | White| L        | 13          | Never   | HTN, HLD        | Low           | 44.9| 84 | 1            | 55   | 30   | 104  |
| 4    | 60     | White| L        | 4           | Never   | None            | Low           | 32.6| 105| 0            | 60   | 36   | 70   |
| 5    | 60     | White| L        | 7           | Never   | HTN             | Low           | 47.8| 62 | 1            | 60   | 30   | 89   |
| 6    | 61     | Black| NL       | 11          | Never   | HLD             | High          | 28.0| 126| 0            | 60   | 22   | 90   |
| 7    | 66     | White| NL       | 6           | Never   | DM, HLD         | High          | 40.7| 60 | 2            | 65   | 26   | 97   |
| 8    | 68     | White| L        | 11          | Never   | None            | Medium        | 33.5| 87 | 1            | 60   | 28   | 107  |
| 9    | 68     | Black| L        | 14          | Never   | HTN             | High          | 43.4| 96 | 2            | 60   | 36   | 157  |
| 10   | 71     | White| NL       | 6           | Former  | CAD, HTN        | High          | 31.1| 84 | 3            | 50   | 62   | 98   |
| 11   | 71     | White| L        | 12          | Never   | CAD, HLD        | High          | 28.8| 60 | 2            | 65   | 63   | 101  |
| 12   | 72     | White| NL       | 3           | Never   | Stroke, CAD, HTN, HLD | High | 28.1| 82 | 5            | 55   | 52   | 106  |
| 13   | 74     | White| NL       | 7           | Former  | Stroke, CAD, HTN, HLD | Medium | 25.9| 82 | 4            | 65   | 56   | 84   |
| 14   | 77     | White| L        | 5           | Never   | Stroke, CAD, HTN | Low           | 33.7| 87 | 6            | 65   | 35   | 84   |
| 15   | 84     | White| L        | 5           | Former  | DM, HLD         | High          | 39.8| 66 | 3            | 60   | 43   | 66   |

| Case | Age (y) | Race | Position | Years in NFL | Smoking | Other Conditions | Activity Level | BMI | HR | CHA2DS2-VASc | LVEF | LAVI | LVMI |
|------|--------|------|----------|-------------|---------|-----------------|---------------|-----|----|--------------|------|------|------|
| 16   | 61     | White| L        | 3           | Never   | HTN             | Low           | 46.3| 80 | 1            | 60   | 38   | 75   |
| 17   | 65     | White| L        | 2           | Never   | CAD, HTN        | High          | 32.3| 85 | 2            | 55   | 41   | 139  |
| 18   | 67     | White| NL       | 11          | Never   | None            | High          | 26.1| 81 | 1            | 50   | 33   | 108  |
| 19   | 69     | Black| NL       | 7           | Current | HLD             | High          | 27.4| 64 | 1            | 45   | 42   | 91   |
| 20   | 74     | White| NL       | 5           | Former  | Stroke          | High          | 31.1| 66 | 3            | 55   | 21   | 100  |
| 21   | 75     | White| NL       | 4           | Former  | CAD, HTN, HLD   | High          | 32.7| 46 | 4            | 60   | 46   | 103  |
| 22   | 76     | White| L        | 9           | Former  | HTN, HLD        | Low           | 26.6| 47 | 3            | 55   | 51   | 95   |
| 23   | 78     | White| NL       | 9           | Former  | HTN             | Unknown       | 35.8| 57 | 4            | 60   | 58   | 81   |

Current physical activity was categorized into 3 groups: low: <1 time per week, medium: 1 to 2 times per week, and high: ≥3 times per week. AF indicates atrial fibrillation; BMI, body mass index; CAD, coronary artery disease; DM, diabetes mellitus; HLD, hyperlipidemia; HR, heart rate; HTN, hypertension; L, lineman; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index; NFL, National Football League; NL, nonlinear.
AF, which is in keeping with population studies showing a lower prevalence of AF in blacks, despite a higher AF risk factor burden. Higher BMI is associated with obstructive sleep apnea, a condition that is more prevalent in NFL players than the general population and a strong risk factor for the development of AF. Unfortunately, we did not have data regarding obstructive sleep apnea in the studied populations.

In a separate analysis of the NFL group, we found a strong association between enlarged left atrial size and AF. This is in line with prior studies linking exercise, left atrial enlargement, and AF risk. It is also consistent with a recent meta-analysis of left atrial dimensions in athletes, which indicated that the left atria were significantly larger in both strength athletes and combined trained athletes compared with sedentary controls. However, the average left atrial volume index in the former NFL group was within established limits for the general population. Therefore, the observed left atrial enlargement may be because of AF itself, rather than prior sporting participation.

It has been suggested that the number of lifetime hours of strenuous physical activity may play a role in the risk of future AF. Indeed, there appears to be a threshold of 1500 lifetime hours of exercise, beyond which AF risk increases. The lack of an association between years of NFL participation and AF may be explained by this “threshold effect,” because all NFL players likely had accumulated at least 1500 lifetime hours of sports through their high school, collegiate, and professional careers. In this study, the current level of activity was overall similarly distributed between former NFL athletes with and without AF.

The use of anabolic steroids is another risk factor that has been described in isolated case reports as a cause of AF in athletes. However, these reports involved young active athletes developing AF at the peak of exercise, while the majority of sports-related AF occurs in middle-aged individuals, decades after cessation of professional competition.

Clinical Implications

Of the former NFL players diagnosed with AF at the time of screening, 80% had a CHA2DS2-VASc score ≥1, indicating a potential benefit from anticoagulation to reduce stroke risk. Moreover, 8/15 (53%) of former athletes with AF had a score ≥2 and therefore a solid indication for Oral anticoagulation. Physicians caring for former athletes should also be aware that while sinus bradycardia and first-degree AV block are typically benign findings in former athletes, more severe conduction abnormalities requiring cardiac pacing also appear more prevalent in this population. However, these data should be placed in the context of recently published work indicating that former participation in the NFL is associated with overall reduced all-cause and cardiovascular mortality compared with the general population.

Limitations

We acknowledge several limitations to our study. First, subjects were invited to participate, and recruitment bias cannot be excluded. By way of context, a recent mortality study of all NFL players with 1 credited season between 1986 and 2012 included 9778 players. However, given the overall lower prevalence of cardiovascular risk factors and cardiac disease in the NFL group, we do not believe that the higher prevalence of AF can be explained by differential recruitment bias alone. Second, the number of AF events in both cohorts is small, limiting our ability to perform multivariable analyses. Third, our data are based on reported history of disease, as well as arrhythmias discovered on a single 12-lead ECG screening. We did not use long-term cardiac monitoring to detect clinically silent arrhythmias, and the true prevalence of electrophysiological abnormalities, including AF, is likely higher than reported. However, this limitation applies equally to both groups. Finally, sleep apnea is prevalent in former NFL players and a known AF risk factor in the general population. We lacked data on sleep apnea, along with other risk factors for AF including thyroid disease and alcohol consumption, and therefore could not assess these potential relationships.
Conclusions

Former participation in the NFL was associated with an increased prevalence of AF and slowed cardiac conduction compared with a population-based control group. Former athletes who screened positive were generally in rate-controlled AF and asymptomatic, but 80% should have been considered for anticoagulation based on their stroke risk.

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