ELECTROCARDIOGRAPHIC AND ECHOCARDIOGRAPHIC FINDINGS IN GHANAIAN SOCCER PLAYERS

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DECLARATION

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DR. PRINCE PAMBO

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ABBREVIATIONS

AV: Atrio Ventricular
BMI: Body mass index
BP: Blood pressure
BSA: Body surface area
cm: Centimeters
cMRI: Cardiac Magnetic Resonance Imaging
CV: Cardiovascular
cRBBB: Complete Right Bundle Branch Block
EA: East Africa

ECHO: Echocardiography
EF: Ejection Fraction
ESC: European Society of Cardiology
FIFA: Federation Internationale de Football Association
FS: Fractional shortening
GE: General Electric
GPL: Ghana Premier League
HCM: Hypertrophic Cardiomyopathy
HR: Heart Rate
IRBBB: Incomplete Right Bundle Branch Block
IVS: Interventricular Septum
Kg: Kilogram
LAD: Left Atrial Dilatation
LV: Left ventricle
LVH: Left Ventricular Hypertrophy
LVM: Left Ventricular Mass
LVMI: Left Ventricular Mass Index
LVWT: Left Ventricular Wall Thickness
LVEDd: Left Ventricular End Dimension in diastole
mLVWT: Maximum Left Ventricular Wall Thickness

M.A-A: Martin Adu-Adadey

mm: Millimeters

NA: North Africa

NFL: National Football League

NBA: National Basketball Association

P.P: Prince Pambo

PCMA: Pre- Competition Medical Assessment

PWT: Posterior Wall Thickness

RAD: Right Atrial Dilatation

RWT: Relative Wall Thickness

SCA: Sudden Cardiac Arrest

SCD: Sudden Cardiac Death

SPSS: Statistical Package of Social Sciences

TWI: T – Wave Inversion

U.K: United Kingdom

USA: United States of America

WA: West Africa

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LIST OF PUBLICATIONS RELEVANT TO THIS THESIS

1.! Pambo P, Scharhag J. Electrocardiographic and Echocardiographic Findings in Black athletes; A General Review; *Clin J Sports Med, 2019: 00 1-9. (published ahead of print)*

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2.! Pambo P, Adu-Adadey M, Agbodzakey H, Scharhag J. Electrocardiographic and Echocardiographic Findings in Elite Ghanaian Male Soccer Players. *Clin J Sports Med, 2019: 00; 1-7. (published ahead of print)*

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3.! Pambo P, Adu-Adadey M, Takyi-Ankrah P, Agbodzakey H, Scharhag J. Electrocardiographic and Echocardiographic Findings in Ghanaian Female Soccer Players. *Clin J Sports Med, 2020:00; 1-6. (published ahead of print)*

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ABSTRACT

Introduction: Participation in regular sports elicits various electrophysiological and structural cardiac changes which can be seen on athletes' electrocardiogram (ECG) and echocardiography (ECHO), and collectively known as 'athlete's heart'. While commonly falling within the defined limits of physiological normality, these cardiac adaptations can sometimes lead to a diagnostic dilemma for the practicing sports physician where they may overlap with the phenotypic expression of pathology. These physiological adaptations complicate the differentiation of sinister cardiac disorders implicated in sudden cardiac death (SCD) which is more prevalent among black athletes than Caucasians.

The aim of this study was to examine the electrocardiographic and echocardiographic tracings in Ghanaian (West Africans) male and female soccer players playing for the various National and premier soccer teams and to describe typical ECG and ECHO findings in this cohort. We believe data from this study will contribute to the development of a race sensitive ECG and ECHO interpretation criteria, hence minimizing the need for further investigations and unfair disqualification of this ethnic group.

Methods: In this cross-sectional study, subjects were current players of Ghanaian male and female national soccer teams, aged between 14 and 27 years and preparing for various international football tournaments. Players with any cardiovascular disease were excluded from the study.

The players have been involved in competitive soccer playing averagely six and ten years for the adolescents and adults respectively. They usually train six days every week, with each session lasting averagely 2 hours. As part of preparations for tournaments, all players had to go through a mandatory pre-competition medical assessment which included cardiac screening (12- lead ECG and 2-dimensional ECHO). A total of 289 male and female soccer players who are all Ghanaians (black west Africans) went through the screening. Our participants were made up of 139 adults and 150 adolescents. All ECGs and ECHOs were analysed independently by experienced investigators.

Results: Thirty male players representing 16% of the male participants had abnormal ECGs made up of inverted T- waves in lateral leads, deep T-wave inversion, long and short QT intervals and ST segment depression. About 11% of our female subjects had abnormal ECGs. About 8% and 9% of males and females respectively had T-wave inversions (TWI) in lateral leads (V_5-V_6). Voltage criteria for left ventricular hypertrophy (LVH) was respectively present in 67% and 28% of our male and female participants. Whilst 33% of our male players had LV wall thickness (LVWT) ranging from 12 mm to 15mm, only three players had LVWT of 16mm with no player exceeding 16 mm. About 10% of female players had LVWT greater than 11 mm with no female player exceeding 13 mm. LV cavity dimension greater than 60 mm and 54 mm was respectively present in 4% of males and 7% of female players.

Conclusion: Uncommon/training-unrelated ECG changes such as complete right bundle branch block, TWI in lateral leads and deep TWI, were more prevalent among both male and female Ghanaian soccer players compared to Caucasian and west Asian athletes, suggesting a combination of athletic training and black ethnicity or geographic origin may be responsible for such exaggerated cardiovascular responses.

From our findings the presence ST segment depression or deep T- wave inversions in lateral leads with associated LV wall thickness greater than 15 mm and 12 mm in males and female players respectively, is unlikely to be a normal physiological response and therefore warrants further investigation to rule out any cardiomyopathy. We can also conclude from our study and other studies that stark differences do exist in the way the hearts of black African athletes

originating from different geographic locations within Africa respond to the impact of chronic exercises or athletic training. The phrase “Black African athlete’s heart” should therefore not be simply taken as representative of the hearts of all black African athletes.

CHAPTER ONE

INTRODUCTION

1.1 Background of study

Athletes are increasingly subjected to pre-participation cardiovascular evaluations with the aim of reducing the prevalence of sudden cardiac death (SCD), which is less common in the general population than in athletes [1]. The term 'Athlete's Heart, describes cardiovascular adaptations with its clinical manifestations on Electrocardiogram (ECG) being decreased heart rate (sinus bradycardia), first degree AV block, incomplete right bundle branch block, early repolarization and isolated QRS voltage for left ventricular hypertrophy (LVH) [2]. These alterations in cardiac dimensions are also frequently reflected on imaging techniques like Echocardiography (ECHO) and cardiac MRI (cMRI). Various studies have confirmed differences in cardiac morphological adaptation between athletes of African ancestry and Caucasian athletes. The explication of the effects of African/Afro-Caribbean ethnicity on cardiac adaptation to exercise in athletes has not been comprehensive. Data from the USA indicate that adolescent BA are particularly susceptible to sudden cardiac death (SCD) [3, 4], and therefore, the distinction between athlete's heart and cardiac pathology is of particular significance in this group.

Although the electrical and structural remodeling observed in most athletes remain mild and within defined normal limits, there exist a relatively small group of athletes in whom differentiating cardiac disorders implicated in sudden cardiac death (SCD) in sports and physiologic adaptation poses a diagnostic challenge [5, 6]. Results from studies involving African/Afro-Caribbean athletes reveal cardiac remodeling extremely different from what is documented among Caucasians [7]. The extreme remodeling which include repolarization anomalies and voltage criteria for LVH do overlap with phenotypic expression of mild hypertrophic cardiomyopathy (HCM), hence posing a differential diagnostic dilemma among athletes of African descent [8].

This tends to raise questions regarding the relevance and applicability of criteria derived from Caucasian studies to this minority ethnic groups.

Pre-participation screening with 12-lead ECG is an increasingly global phenomenon [9, 10]. Although updated guidelines on the interpretation of an athlete's ECG make some allowance for African ethnicity [11], the criteria for further cardiac evaluation still rely on data from Caucasian athletes [12]. In a study by Sheikh et al. [8] , the issue is complicated further because 7% of adolescent BA in their study exhibited LVH, which in the context of coexistent repolarization anomalies poses significant challenges in differentiating physiological LVH from HCM. In a study that compared European Society of Cardiology (ESC) recommendations and Uberoi et al's definitions of abnormality, the authors found 19.7% abnormal ECGs applying strictly the ESC 2010 recommendations, and 3.9% applying Uberoi et al's criteria [13, 14]. As further indicated by Berge [13] the "Seattle" criteria reduced the number of athletes with abnormal ECGs considerably compared to the ESC recommendations. Based on echocardiographic evaluations this reduction increased the specificity of the Seattle criteria, without increasing the number of false negative ECGs. The need for different criteria related to black and white athletes has therefore been suggested [15].

Appreciable efforts have gone into studying the effects of age, gender, body size, sex and sporting discipline on cardiac remodeling. Researchers in the field of sports medicine and cardiology in recent years have focused on the influence of ethnicity on cardiovascular adaptation to sports coming from the backdrop of an increased number of athletes from a minority ethnic group (African and Afro-Caribbean) excelling at elite competitive levels [6, 16].

Although athletes are regarded as the epitome of good health owing to their physical achievements; yet a small proportion die suddenly from a pathological heart condition; sudden cardiac death. Most of the deaths are attributed to inherited or congenital heart disorders which predisposes them to malignant ventricular arrhythmias during physical activity [17]. In general, our study aims at establishing the influence of ethnicity, age, gender, type of sport and level of achievement on athletic ECGs and ECHO variants among our cohort and to determine if the current ECG interpretation criteria is applicable to both male and female football players of black west African ethnicity.

1.2 Problem statement

Participation in regular sports or physical activity elicits various electrophysiological and structural cardiac changes on electrocardiogram (ECG) and echocardiographs (ECHO) of athletes [18]. These responses to regular sports participation or prolonged training leads to an increase in cardiac output ultimately leading to an improved uptake of oxygen by various performing skeletal muscles, hence improved sports performance. FIFA technical analysis and statistics from the FIFA 2014 world cup in Brazil confirmed that, averagely the Ghanaian elite football player (Senior National team players) were running at a speed of 31km/h. This insatiable desire of our football players to excel at all levels put some strain on the heart. Long-term athletic training is associated with an increase in left ventricular (LV) diastolic cavity dimension, wall thickness, and mass [19, 20]. This chronic athletic training elicits an exaggerated cardiovascular response, posing a diagnostic challenge in distinguishing between normal physiological adaptation and signs of HCM in this ethnic minority group [2, 8, 18, 25, 49]. To help solve this dilemma, recent studies in sports medicine and cardiology have focused on the effect of ethnicity on the cardiovascular adaptation in athletes [6, 16]. Most of these studies have heterogenous groups of black African athletes forming the cohort. Data on ECG and ECHO patterns in a homogenous group of African players, including females and adolescents is scarce [21, 34], although soccer is the leading sports in Africa. ECG and ECHO data on sub-Saharan female athletes is actually non-existent. To prevent unnecessary over investigation and unfair disqualification of this under studied group during preparticipation cardiovascular screening, the development and definition of regional ECG and ECHO references is urgent.

Considering the increasing numbers of cases of SCA/SCD on the field of play, especially among athletes of Black/African ethnicity, the need for an appropriate/suitable cardiac screening tool/methodology for this ethnicity has become urgent. This study therefore seeks to assess the impact of chronic exercises on the ECG and ECHO appearances of Ghanaian football players in an attempt to establish the relevance of various criteria derived from studies involving Caucasian athletes to athletes of black African descent.

This study therefore seeks to examine the electrocardiographic and echocardiographic tracings in Ghanaian (West Africans) soccer players playing for the various National and premier soccer teams and to provide data on pre competition medical assessment for Ghanaian national team players since such data is currently not available. We believe data from this study will contribute to the development of a race sensitive ECG and ECHO interpretation criteria, in an attempt to establish the relevance of various criteria derived from studies involving Caucasian athletes to athletes of black African descent. It is our firm believe that this would lead to minimizing the need for further investigations and unfair disqualification of this ethnic group. This study will also form the basis for future longitudinal follow-up studies.

1.3 Aim

The main aim of this study is to determine the ECG and ECHO findings among adolescent and adult Ghanaian football players.

1.3.1 Objectives

The objectives of the study are:

1.! To determine the ECG and ECHO findings among Ghanaian football players

2.! To determine the impact of geographic origin on ECG and ECHO changes seen among Ghanaian (black west African) football players

3.! To identify risk factors for ECG and ECHO changes by comparing:

ii. Elite/Adult (19 to 35years) players to adolescent (14 to 18years) players

iv.! Findings in male players to findings in age-matched female players

1.4 Significance of study

Abnormal ECG findings are important reasons for follow-up investigations after pre-participation cardiac screening in athletes. The results of our study will contribute significantly to the development of an appropriate criteria to be to be used in the interpretation of ECGs and ECHOs of athletes of black African descent. This will help minimize the numbers of young talented athletes who get disqualified from participating in sports because of false positives. Since our study is made up of a homogenous group of black west African males and female athletes, our findings, to a large extent is representative of the ECG and ECHO appearances of athletes originating from this region within Africa. Our findings will also be used as a basis to promote regular Pre-Competition Medical Assessment in Ghana; which will eventually lead to early detection of cardiac diseases like hypertrophic cardiomyopathy (HCM) which is implicated in most cases of sudden cardiac death in sports. By this, the incidence of sudden cardiac arrests and deaths will be reduced.

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CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The proportion of athletes of African descent participating in competitive sports in Caucasian-inhabited countries has seen a sharp increase in recent times [21]. In the United States of America (USA) and the United Kingdom (UK) where just about 13% and 2% of the population is of black ethnicity respectively, over 70% of National Football League (NFL) and National Basketball Association (NBA) players in the USA are blacks and a disproportionate 20% of the English Premier League (EPL) players are of African descent [6].

The diagnostic evaluation of cardiovascular-related symptoms, a family history of inheritable cardiac disease or premature SCD, or for screening of asymptomatic athletes; ECG interpretation is an important skill for physicians involved in the cardiovascular care of athletes. Various ECG and ECHO studies have revealed cardiac morphological adaptations in black athletes that occasionally overlap with phenotypic expression of Hypertrophic cardiomyopathy (HCM) [22]. Since it is also established that athletes of black African descent compared to their Caucasian counterparts are at a higher risk of sudden cardiac death [23], attempts to differentiate between a physiological athlete's heart and pathologies like HCM has become crucial.

2.1 ECG findings among athletes

Athletic training, age, gender, body size, type of sport and ethnicity are some of the documented factors that influence ECG patterns. About 80% of trained athletes demonstrate mild and acceptable ECG changes which are largely attributable to athletic conditioning [12].

Sheikh, et al. [8] in their study involving adolescents, reported marked depolarisation changes like those seen in HCM patients. 49.5% of the black athletes had ST segment elevation as compared to 20.2% of their Caucasian counterparts. ST depression was observed in 0.6% of black athletes compared 0% of white athletes. T-wave inversion was five times more common in black athletes than whites with only 0.2% of white athletes showing deep T-wave inversions compared to 6.7% of the black athletes. Whilst 2.1% of blacks demonstrated T-wave inversion in lateral leads only 0.3% of their white counterparts demonstrated this ECG change. In order to reduce the risk of taking too many black athletes through further investigations, it would be appropriate to make allowance for black ethnicity in the criteria for further investigation which was developed solely from data from Caucasian athletes [8]. Further investigations by Sheikh and his friends revealed none of the athletes with T-wave inversions including deep T- waves and LVH exhibited features of HCM.

In a study by Di Paolo, et al. [21] involving adolescent soccer players, R/S voltage criteria for left ventricular hypertrophy (LVH), ST elevation and T- wave inversions were respectively observed in 89%, 91% and 14% of black athletes compared to 42%, 56% and 3% of Caucasian athletes respectively. Results from this study revealed differences in ECG patterns among African athletes in relation to their country of origin (ethnic origin).

Whilst North Africans demonstrated larger left ventricular cavity dimensions, sub-Saharan African athletes demonstrated thicker ventricular walls and higher abnormal reporlarisation patterns. Race-related ECG differences should always be considered during pre-participation screening of athletes in a multi-ethnic population [21]. This goes to support the many proponents of the motion that a lot more ECG and ECHO studies involving a homogenous African cohort in order to come up with an appropriate criterion for interpreting ECGs and ECHOs of black athletes during screening exercises.

2.1.1 ECG abnormalities among athletes

The prevalence, distribution and clinical outcomes of ECG reporlarisation patterns in male athletes of African/Afro-Caribbean descent was studied by Papadakis and his group. Subjects were drawn from 25 different sporting disciplines covering both endurance and resistance type of training. ST segment elevation and T- wave inversions were respectively seen in 63.2% and 22.8% of black athletes compared to 26.5% and 3.7% recorded among their Caucasian colleagues. Whilst 4.1% of the black athletes had these T-wave inversions in the lateral leads none of the white athletes had T- wave inversions in the lateral leads. This study established the significant association between ST segment elevation and black ethnicity and between T-wave inversions and black ethnicity [7].

Based on the current recommendations, which were derived from studies among Caucasian athletes, the almost 25% of the black athletes who had T- wave inversions would have been subjected to further investigations and potentially face an unfair disqualification from competitive sports [9].

Kervio, et al. [24] compared ECG features in Japanese soccer players to players of African and Caucasian ethnicities. R/S voltage for LVH, ST segment elevation and deep T-wave inversions were observed in 16.6%, 16.5% and 6.2% respectively in players of African ethnicity compared to 4.2%, 1.5% and 0% of Caucasian players. Equally lower percentages 10.3%, 5.8% and 0% were respectively recorded among Japanese players [24].

Magalski, et al. [25], in their study involving 1,959 American football players, observed that 30% of the black players compared to 13% of the white players had abnormal ECGs. Black race was the only independent predictor of an abnormal ECG when they adjusted for all variables in a multivariable analysis [25].

Basavarajaiah and his colleagues sought to differentiate physiological LVH from HCM by comparing the ECG and ECHO findings of 300 elite black male athletes with 300 highly trained white male athletes. 68%, 85% and 12% of the black athletes respectively had LVH, ST segment elevation and deep T-wave inversion, versus 40%, 62% and 0% for the white athletes. The study also brought out regional differences in cardiac remodeling among the African athletes. 20% of the 246 West Africans had LVH compared to 7% of the 54 East Africans with LVH [26].

Pelà, et al. [27] investigated ethnicity-related variations of left ventricular remodeling in adolescent footballers. Black ethnicity was the strongest predictor of S1+R5 voltage criteria for LVH when multivariate regression analysis was done. 69% of black athletes had LVH compared to 39% of white athletes. ST segment elevation and T-wave inversion was present in 79% and 12% of black athletes respectively. 43% and 15% of white athletes elevated ST segments and inverted T-waves.

It is obvious from the above findings that black race or ethnicity is a strong predisposing factor for 'abnormal' ECGs per criteria derived from Caucasian studies. The differential diagnostic challenge of distinguishing between a pathology and physiologic adaptation still exist among this ethnicity [28, 29]. Allowance need to made in the recommendations for further investigations to accommodate the peculiarities present in this minority ethnic group. This will reduce the numbers of black African athletes who have to be taken through expensive further investigations exposing them to the risk of unfair disqualifications.

2.2 Echocardiographic findings among athletes

Echocardiography (ECHO) and Electrocardiogram (ECG) are the basic assessment tools used during pre-competition medical assessment of athletes. Various studies have confirmed differences in cardiac morphological adaptation between athletes of African ancestry and Caucasian athletes.

The study by Sheikh, et al. [8] revealed that black athletes as young as 14 years could have a Left Ventricular Wall Thickness (LVWT) of 15mm with associated reporlarisation changes mimicking HCM. In a separate study by Di Paolo and his group, four sub-Saharan African athletes compared to no Caucasian athlete had left ventricular wall thickness in excess of 13mm but without any evidence of cardiomyopathies [21]. In both studies, Left Ventricular Mass (LVM) and Left Ventricular End-Diastolic diameter (LVEDd) were similar in both black and white adolescent athletes.

Papadakis, et al. [7] discovered that 12.4% of black athletes and 1.6% of white athletes exhibited maximum-LVWT greater than 12mm. In an adult study by Kervio and his colleagues, Afro-Caribbean athletes and Caucasian athletes had similar LVEDd and LVM. Two African athletes had LVWT of 13mm and 15mm respectively and increased R/S voltage for LVH. Further investigation with cardiac MRI (CMR) and 24-hour Holter monitoring revealed no anomalies. Two other African athletes had LVWT of 14mm and 15mm together with inverted T-waves and high R/S voltages.

Further investigations revealed no anomalies but a follow up CMR a year later revealed apical HCM pattern in one black athlete. Results from the study by Basavarajaiah, et al. [26] revealed that 54 black athletes (18%) compared to 12 white athletes (4%) had LVWT greater than 12mm. 9 (3%) black athletes (of west African ancestry) compared to 0% of white athletes had wall thickness greater than 15mm. Further investigations with CMR failed to reveal any cardiac anomalies in this group.

It is evident from the above that extrapolations from data on Caucasian athletes has the grave consequences of generating false positives among black athletes hence leading to the disqualification of these 9 (3%) black athletes. Pelà, et al. [27], recorded greater wall thickness and smaller ventricular cavity (LVEDd) in black athletes compared to white athletes, consistent with the concentric type of left ventricular remodelling in black athletes [30].

Absolute values for LVM(g) for black athletes and white athletes are 194±8 and 164±24 respectively. These major findings are similar to those reported by other ethnicity-based studies in adults and adolescent amateur and professional athletes [19, 21, 28, 29]. Gjerdalen, et al. [31] in their Scandinavian athlete's heart study confirmed a concentric ventricular remodeling in black athletes. Their study reported similar increases in both right and left ventricles and atria.

In their Preparticipation Echocardiographic screening for cardiovascular diseases in a predominantly black population of collegiate athletes, Lewis, et al. [32] reported 11% (29 out of 265) of the athletes showing ventricular wall thickness ≥13mm. None of these athletes had any other signs suggestive of a cardiac anomaly. Three athletes had LVWT 16-18mm. Follow up investigations after one year revealed no anomaly. The wall thickness reduced from 18mm to 14mm and cavity dimensions from 51mm to 48mm in one athlete who had stopped active sports participation over a ten Month period. Average absolute values for ventricular mass was 202 ± 56 falling within a 96-337g range [32].

It can be inferred from this study results and others that standards for LV wall thickness assembled from almost entirely white populations might not be equally applicable to all segments of the general population [32, 33].

Rawlins, et al. [34] discovered that compared to their white counterparts, black female athletes exhibit a greater LVH and higher prevalence of reporlarisation changes. Deep T- wave inversions in inferior and lateral leads and LVWT greater than 13mm was however an uncommon finding and hence warrants further investigation.

2.3 Criteria for ECG interpretation in athletes

Proper distinguishing of physiologic changes in athletes that are training related require careful analysis of ECG interpretation considering findings that suggest underlying pathologic condition. Abnormal findings such as cardiomyopathies and primary electrical diseases observed on a 12-lead electrocardiogram (ECG) form majority of disorders associated with increased risk of sudden cardiac death (SCD).

Riding, et al. [2] considered ECG abnormalities using the three criteria including the Seattle Criteria, European Society of Cardiology recommendations (ESC), and Refined Criteria. In their study, abnormal ECG was observed in 555 (22.3%) of 2491 athletes according to the ESC recommendations. Common among the abnormalities were T-wave inversion, prolonged QT interval, short PR interval and RAE. In using the Seattle Criteria, number of abnormal ECGs reduced significantly from 22.3% to 11.6% [2]" " as" compared to the ESC recommendations. The majority of this improvement was accounted for by two main ECG parameters thus QTc cut-offs increase and the fact that in asymptomatic black athletes, isolated anterior T-wave inversion is benign. Compared with Arabic and Caucasian athletes, abnormal ECG are more likely to present significantly in Black athletes. However, the number of abnormal ECGs across all three ethnicities was significantly reduced compared with the ESC recommendations. The number of abnormal ECGs was further reduced in the athletes applying the Refined Criteria. A 76% and 54% reduction in abnormal ECGs numbers were observed compared with the ESC recommendations and the Seattle Criteria respectively as indicated by Riding, et al. [2]. However, compared with Arabic and Caucasian athletes, significantly higher prevalence of abnormal ECGs were found in black athletes.

Many physicians have relatively poor ability to interpret ECG of athletes accurately, as a result an secondary evaluations that are not necessary and unacceptable rate of false-positive interpretations have been observed [9, 10]. However, making available standardized criteria to physicians for evaluating ECG would improve accuracy considerably [10]. In a study where a simple two-page criteria tool to guide ECG interpretation was used among physicians across different specialties, accuracy in distinguishing normal from abnormal findings significantly improved, even in physicians with little or no experience[10]. Therefore, educating physician on ECG interpretation is achievable when reference standards are provided to assist in interpretation for improvements in accuracy. A larger infrastructure of skilled physicians needs to be produced with the capability of accurate interpretation of athletes ECGs.

2.4 Sudden Cardiac Death among adolescent athletes

The risk of sudden cardiac death (SCD) following atherosclerosis reduces with regular exercise. Owing to this, athletes are considered as the epitome of health, due to their extraordinary physic and unique lifestyle. Yet, a small, but significant proportion of them suddenly die. These sudden deaths are highly publicised, particularly when the athletes are of high-profile. Studies in the United States that examined sudden death reports a 1:200 000 per year prevalence in athletes, whereas significantly higher rate have been observed from the Italian preparticipation screening programs [5, 35]. Multiple factors may account for the variations in sudden death prevalence data. This may be attributed to study population's characteristics, geographic variability in the prevalence of causal diseases, and techniques for case ascertainment. In most competitive sports unlike physically intense sports such as soccer, more sudden death has been documented. In addition to the type of sports, the risks of sudden death have been attributed to sex and ethnicity, with increased likelihoods of sport-related sudden death in male participants and individuals of Afro-Caribbean descent. In young athletes, underlying cardiovascular pathology have accounted for most sport-related sudden death cases [20]. For individuals with such conditions, sport eligibility criteria have been established by the American Heart Association/American College of Cardiology and the European Society of Cardiology. The endorsed guidelines by these 2 groups are largely similar aside from the approach for athletes with genotype-positive/phenotype-negative myocardial or electric heart disease and the management of athletes with asymptomatic Wolff-Parkinson-White syndrome. Considerable efforts have been invested in sudden death prevention owing to the tragic nature of sudden death in previously asymptomatic young athletes. This has also brought about preparticipation screening for athletes in that sudden cardiac death incidence may reduce if the detection and management of cardiovascular disease is performed before sport participation. The AHA/ACC and the ESC have published consensus committee-based recommendations for preparticipation athlete screening. Medical history and physical examination have been recommended by both groups. The ESC recommends the addition of a 12-lead ECG to medical history and physical examination. In the United States, recent prospective trial data is suggestive of improved sensitivity for ECG in preparticipation cardiovascular screening. Observational data from the Italian national experience also suggests same[35]. However, implementing a mandatory 12-lead ECG as part of preparticipation screening in the United States has been faced with some considerable obstacles including mandated ECG financial and manpower costs, follow-up testing cost for athletes with abnormal finding, the high rate of false-positive ECG findings, the logistics of ECG acquisition and interpretation, and considerations about athletes future insurability. Although additional observational data from organizations or nations using ECG are welcomed, this issue will almost certainly remain controversial until a prospective, randomized, multinational trial is conducted to provide a definitive answer.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Design and Population

A total of two hundred and eighty-nine (289) Ghanaian soccer players (males and females) aged between 14 and 27 years, who played in the Ghana premier league (GPL) and/or for any of the Ghana National soccer teams participated in this cross-sectional study. The players have been playing competitive sports (soccer) averagely for 6 and 10 years respectively for the adolescent and adult players. These players trained averagely two hours per day on six days every week. A pre-competition medical assessment, which includes cardiac screening using a 12-lead ECG and a 2-dimensional ECHO, is a mandatory requirement for these players playing in the GPL and in the National teams. All players consented to using their data in this PhD study and ethics approval (approval number: GHS-ERC: 13.07.16) was granted by the Ghana Health Service Ethics Review Committee.

3.1.1 Sample size justification

The sample size formula based on differen~~ce in proportions~~ is given by

! = #2% × %'%(1% − %') ,2

Where;

N: sample size, **t**: confidence interval of 95% (standard value of 1.96), **P**: minimum prevalence rate of cardiac abnormality from ECG and ECHO readings among black athletes (22.3%), **m**: margin of error (standard value of 0.05). Hence N= 266 (minimum).

3.1.2 Preparticipation Cardiovascular Screening

The various National team Doctors, the Premier club Doctors and the Principal Investigator (PI) helped the participants to complete a questionnaire regarding family history, past medical history and present symptoms if they had any. Weight, height and blood pressure of participants were measured as well as assessment of physical characteristics for diseases such as Marfan's syndrome which are sometimes implicated in sudden cardiac arrests/deaths. Subjects with any patent cardiovascular disease based on history and blood pressure (BP) >140/90mmHg were excluded from the study.

None of the participants has ever been implicated in any antidoping offence.

3.1.3 Resting 12-Lead ECG

Standard 12-lead ECGs were performed using a commercially available ECG machine (Welch Allyn, United Kingdom). Subjects were made to rest in the supine position for five minutes after which the ECGs were recorded at a standard speed of 25 mm/s.

The heart rate, P wave duration, PR intervals, QRS axis were calculated. P-, Q-, R-, S-, and T-wave voltages; ST segments; QRS duration; PR interval; and QT interval were measured in each lead with callipers. QT interval were corrected for the heart rate by use of the Bazett formula[36].

ST segment shift was considered significant if ! 0.1mV in ! 2 contiguous leads. Early reporlarisation pattern was defined as ST segment elevation with J-point elevation ! 0.1mV in !

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2 contiguous non-anterior leads. T –wave inversion of ! -0.1mV in ! 2 leads was considered significant, (excluding aVR, V1 and III in isolation). T –wave inversions of ! 0.2mV in any lead were defined as deep T -wave inversions[37]. T- wave inversions were classified as anterior (V2-V4), inferior (II, III and aVF) and lateral (I, aVL, V5 and V6). ST segment depression was defined as !0.5mm in depth in two or more contiguous leads. Electrocardiographic LVH was defined with the Sokolow-Lyon voltage criterion[38].

ECGs were analysed independently by experienced investigators (M.A.-A and P.P) using the most recent criteria published[39].

3.1.4 Transthoracic 2D-ECHO

A 2-dimensional echocardiography was performed using cardiac ultrasound machines (GE Vivid E by General Electric, China and CX50 by Philips, The Netherlands). For optimal image acquisition, standard views were obtained with the subjects placed in the left lateral position as per the European Society of Echocardiography protocol[40].

Left ventricular wall thickness (LVWT) and left ventricular end diastolic dimensions (LVEDd) were measured using the 2-dimensional guided M-Mode method between the tip of the mitral valve leaflets and papillary muscles, and left ventricular mass (LVM) calculated with the Devereux formula[41] and was indexed for body surface area (BSA). Left ventricular wall thickness (either interventricular wall or posterior wall greater than 12 mm and 11 mm[34] is defined as maximal LVWT (mLVWT)[26, 42, 43] in males and females respectively. LV cavity dimension was described as enlarged when left ventricular end-diastolic diameter (LVEDd) was greater than 60 mm[26, 44, 45] and 54 mm[34] in males and females respectively.

LV ejection fraction was calculated from LV volumes by Simpson's rule[46]. Assessment of diastolic function included traditional pulsed-wave Doppler across the mitral valve [47] and tissue Doppler velocity imaging [37] of the septal and lateral mitral valve annulus.

Echocardiographic images were saved to compact discs. Measurements were repeated independently by an experienced cardiologist (M.A.-A) blinded to the identity of the athlete and unclear cases were discussed by the study group.

3.1.5 Statistical analysis

Statistical analyses were performed using SPSS software (Chicago, Illinois, USA; V.21). Continuous variables were tested for normality using the Kolmogorov-Smirnov test. Results are expressed as means and standard deviations (SD) and percentages as appropriate. ECG and ECHO findings of adolescent and adult male and female soccer players were compared to evaluate differences between means using the unpaired t-test for continues variables. The X^2-test was used to evaluate differences between proportions for categorical ECG and ECHO findings of adolescent and adult male and female soccer players. An alpha error <0.05 was considered statistically significant.

CHAPTER FOUR

RESULTS

4.1 Demographic Characteristics

Our study cohort of two hundred and eighty nine (289) soccer players were made up of 186 males and 103 females, ages ranging from 14 to 27 years. Out of the 186 male players, 107 were adults (19 to 27 years) and 79 adolescents (14 to 18 years). The total of 103 females were made up of 32 adults players (19 to 27 years) and 71 adolescents players aged 14 to 18 years. All players were Ghanaians (black west Africans) playing in the Ghana premier league and/or the National soccer teams. Weight (kg), height (cm) and body surface area (BSA) (m^2) in both male and female players were higher in adult players compared to adolescent players and also generally higher in males compared to female players (Table 1). Blood pressures were normal (below 140/90 mmHg) in all players.

Table 1 Anthropometrics of Ghanaian soccer players

Table 1a. Anthropometrics of Ghanaian Male and Female soccer players

Variable	**Male (n=186)**	**Female (n=103)**	**P-value**
Age (Years)	19.16 ± 2.71	18.27 ± 3.46	0.017*
Weight (Kg)	68.89 ± 7.90	57.37 ± 6.75	<0.0001*
Height (cm)	175.32 ± 7.63	162.89 ± 5.92	<0.0001*
BSA (m^2)	1.84 ± 0.14	1.61 ± 0.11	<0.0001*

BSA= Body Surface Area; * Significant difference at p<0.05

Table 1b. Anthropometrics of Ghanaian Adolescent and Adult Male soccer players

Variable	Total (n=186)	Adolescent (n=79)	Adult (n=107)	P-value
Age (Years)	19.16 ± 2.71	16.82 ± 1.17	20.89 ± 2.17	<0.0001*
Weight (Kg)	68.89 ± 7.90	66.47 ± 7.53	70.67 ± 7.71	<0.0001*
Height (cm)	175.32 ± 7.63	174.28 ± 6.80	176.08 ± 8.13	0.111
BSA (m2)	1.84 ± 0.14	1.80 ± 0.13	1.86 ± 0.14	0.002*

BSA= Body Surface Area; * Significant difference at p<0.05

Table 1c. Anthropometrics of Ghanaian Adolescent and Adult Female soccer players

Variable	Total (n=103)	Adolescent (n=71)	Adult (n=32)	P-value
Age (Years)	18.27 ± 3.46	16.32 ± 1.08	22.59 ± 2.99	<0.0001*
Weight (Kg)	57.37 ± 6.75	57.20 ± 6.65	57.75 ± 7.04	0.702
Height (cm)	162.89 ± 5.92	162.66 ± 6.12	163.41 ± 5.50	0.557
BSA (m2)	1.61 ± 0.11	1.61 ± 0.11	1.62 ± 0.11	0.658

BSA= Body Surface Area; * Significant difference at p<0.05

Table 1d. Anthropometrics of Ghanaian Male and Female adolescent soccer players

Variable	Total (n=150)	Male Adolescent (n=79)	Female Adolescent (n=71)	P-value
Age (Years)	16.59 ± 1.15	16.82 ± 1.17	16.32 ± 1.08	0.008*
Weight (Kg)	62.08 ± 8.49	66.47 ± 7.53	57.20 ± 6.65	<0.0001*
Height (cm)	168.78 ± 8.70	174.28 ± 6.80	162.66 ± 6.12	<0.0001*
BSA (m2)	1.71 ± 0.16	1.80 ± 0.13	1.61 ± 0.11	<0.0001*

BSA= Body Surface Area; * Significant difference at p<0.05

Table 1e. Anthropometrics of Ghanaian Male and Female Adult soccer players

Variable	Total (n=139)	Male Adult (n=107)	Female Adult (n=32)	P-value
Age (Years)	21.28 ± 2.48	20.88 ± 2.17	22.59 ± 2.99	0.001*

Weight (Kg)	67.70 ± 9.31	70.67 ± 7.71	57.75 ± 7.04	<0.0001*
Height (cm)	173.17 ± 9.28	176.08 ± 8.13	163.41 ± 5.50	<0.0001*
BSA (m2)	1.81 ± 0.17	1.86 ± 0.14	1.62 ± 0.11	<0.0001*

BSA= Body Surface Area; * Significant difference at p<0.05

4.2 Electrocardiography Patterns

4.2.1 Electrocardiographic Characteristics of Ghanaian Soccer Players

Table 2 presents the Electrocardiographic characteristics of Ghanaian Male and Female Soccer Players. The results shows significantly low heart rate (beats/min) and QTc interval (ms) for the male soccer players than the female soccer players (p=0.023; p=0.013). However, PR interval (ms) QRS duration (ms) and R/S Voltage (mm) were significantly higher among the male soccer players than the female soccer players (p<0.005).

Table 2 Electrocardiographic Characteristics of Ghanaian Male and Female Soccer Players

ECG Parameter	Male (n=186)	Female (n=103)	P-value
Heart Rate (beats/min)	59.15 ± 9.82 (37.0-90.0)	62.01 ± 10.90 (40.0-95.0)	0.023*
PR interval (ms)	179.24 ± 28.55 (80.0-265.0)	171.00 ± 26.01 (130.276.0)	0.016*
QRS duration (ms)	92.87 ± 11.42 (70.0-137.0)	81.05 ± 7.83 (60.0-100.0)	<0.0001*
R/S Voltage (S1+ R5)(mm)	42.84 ± 11.75 (20.0-94.0)	32.14 ± 8.62 (17.0-59.0)	<0.0001*
QTc interval (ms)	408.31 ± 25.08 (338.0-493.0)	415.78 ± 22.44 (333.0-467.0)	0.013*

* Significant difference at P< 0.05.

4.2.2 Electrocardiographic Abnormalities among Ghanaian soccer players

The results in Table 3 shows that Electrocardiographic Abnormalities among Ghanaian Male and Female soccer players. The results depicts that greater proportion of the male soccer players (38, 20.4%) had First-degree AV block compared to female proportion of 8.7% (9). Similarly, Sokolow-Lyon criteria for LVH, Incomplete RBBB and Complete RBBB was significantly associated with the male soccer players than the females (p<0.005). The results further shows the proportion of ST elevation to be more in males than the females. Furthermore, majority of both genders had Convex ST elevation than Concave ST elevation. TWI were present in equal proportions among males and females.

Table 3 Electrocardiographic Abnormalities among Ghanaian Male and Female soccer players

ECG findings	Male (n = 186)	Female (n = 103)	P-value
First-degree AV block (PR interval>200ms)	38 (20.4)	9 (8.7)	0.009*
Second-degree AV block, Type I	2 (1.1)	0 (0.0)	0.291
Sinus bradycardia (HR <60 beats/min)	98 (52.7)	47 (45.6)	0.251
Sokolow-Lyon criteria for LVH	124 (66.7)	29 (28.2)	<0.0001*
Incomplete RBBB (100ms<QRS<120ms)	34 (18.3)	1 (1.0)	<0.0001*
Complete RBBB (QRS ≥120ms)	7 (3.8)	0 (0.0)	0.046*
Long QT (QTc ³ 470ms)	3 (1.6)	0 (0.0)	0.195
Short QT (QTc≤)	2 (1.1)	1 (1.0)	0.933
RAD	5 (2.7)	0 (0.0)	0.093
LAD	1 (0.5)	0 (0.0)	0.456
ST elevation	78 (41.9)	42 (40.8)	0.848
Convex ST elevation	52 (28.0)	42 (40.8)	0.026*
Concave ST elevation	26 (14.0)	0 (0.0)	<0.0001*
ST depression	1 (0.5)	0 (0.0)	0.456
T-wave inversion (Total)	63 (33.9)	31 (30.1)	0.512
Deep T-wave inversion	10 (5.4)	1 (1.0)	0.061
T- wave inversions Leads			
V_1-V_4	49 (26.3)	22 (21.4)	0.346
V_5-V_6	14 (7.5)	9 (8.7)	0.716

*Significant at p<0.05. AV: Atrio-ventricular; HR: Heart Rate; LAD: Left Axis Deviation; LVH: Left Ventricular Hypertrophy; RAD: Right Axis Deviation; RBBB: Right Bundle Branch Block

4.2.3 ECG findings Male soccer players

4.2.3.1 Electrocardiographic Characteristics of Ghanaian Male Soccer Players

The table 4 below presents ECG findings in our male cohort. Significantly, first degree atrioventricular (AV) block was more prevalent in the adult players compared to the adolescents (30% vs 7.6% $p < 0.0002$) whilst Mobitz type I (Wenckebach) AV block was present in only one adult and one adolescent player. More than half of the total male players had heart rates (HR) less than 60 beats per minute, confirming the high prevalence of sinus bradycardia among sports men and women. Two thirds (66.7%) of our male participants had LVH per the Sokolow-Lyon criteria with significantly more adolescents compared to adult players (74.7% vs 60.7% $p<0.046$) demonstrating high voltage criteria for LVH. Incomplete right bundle branch block (IRBBB) was demonstrated in a third of our male players with no significant difference between adult and adolescent players. Complete RBBB (QRS ! 120ms) was present in seven male players. Whilst QT interval was elongated (QTc ! 470ms) in three adult players , only 1 adult and 1 adolescent player had a shortened QT interval.

Table 4 Electrocardiographic Characteristics of Ghanaian Adolescent and Adult Male soccer players

ECG Parameter	Total (n=186)	Adolescent (n=79)	Adult (n=107)	P-value
Heart Rate (beats/min)	59.15 ± 9.82 (37.0-90.0)	59.58 ± 10.24(41.0-90.0)	58.83 ± 9.53 (37.0-90.0)	0.608
PR interval (ms)	179.24 ± 28.55 (80.0-265.0)	172.22 ± 27.17 (120.0-261.0)	184.43 ± 28.56 (80.0-265.0)	0.004*
QRS duration (ms)	92.87 ± 11.42 (70.0-137.0)	90.06 ± 10.47(70.0-122.0)	94.96 ± 11.70 (70.0-137.0)	0.004*
R/S Voltage (S1+ R5)(mm)	42.84 ± 11.75 (20.0-94.0)	44.26 ± 12.94(20.0-94.0)	41.79 ± 10.73 (27.0-69.0)	0.158
QTc interval (ms)	408.31 ± 25.08 (338.0-493.0)	405.11 ± 21.48 (338.0-464.0)	410.70 ± 27.31 (338.0-493.0)	0.134

* Significant difference at P< 0.05.

4.2.3.2 Electrocardiographic Abnormalities among Ghanaian Male soccer players

A total of 78 (42%) male players had ST segment elevation with the convex (domed) pattern more prevalent than the concave (28% vs 14%) (Table 5). Most of the ST segment elevations are followed by inverted T-waves, confirming the high prevalence of early repolarisation among athletes of black African origin. ST segment depression still remains a rare (0.5% of our male players) finding in healthy athletes regardless of their race or age. T- waves were inverted in about 34% of our male cohort, with 26% having T- wave inversions in the anterior leads (V_1 – V_4) , and 7.5% have T- wave inversions in the lateral leads (V_5 – V_6). Deep T- wave inversions were present in five adult and five adolescent male players. Thirty (16%) and thirteen (7%) male players had abnormal and borderline ECGs respectively, per the international consensus standards for ECG interpretation in athletes[39] (Table 6). Whilst T- wave inversions, ST segment depression and deep T- wave inversions accounted for the abnormal ECGs, CRBBB, LAD and RAD accounted for the borderline ECGs.

Table 5 Electrocardiographic Abnormalities among Ghanaian Adolescent and Adult Male soccer players

ECG findings	Total (n = 186)	Adolescent (n = 79)	Adult (n = 107)	P-value
First-degree AV block (PR interval>200ms)	38 (20.4)	6 (7.6)	32 (29.9)	0.0002*
Second-degree AV block, Type I	2 (1.1)	1 (1.3)	1 (0.9)	0.829
Sinus bradycardia (HR <60 beats/min)	98 (52.7)	40 (50.6)	58 (54.2)	0.630
Sokolow-Lyon criteria for LVH	124 (66.7)	59 (74.7)	65 (60.7)	0.046*
Incomplete RBBB (100ms<QRS<120ms)	34 (18.3)	13 (16.5)	21 (19.6)	0.580
Complete RBBB (QRS ≥120ms)	7 (3.8)	2 (2.5)	5 (4.7)	0.448
Long QT (QTc≥ 470ms)	3 (1.6)	0 (0.0)	3 (2.8)	0.134
Short QT (QTc=210-340)	2 (1.1)	1 (1.3)	1 (0.9)	0.829
RAD	5 (2.7)	2 (2.5)	3 (2.8)	0.910
LAD	1 (0.5)	1 (1.3)	0 (0.0)	0.243
ST elevation	78 (41.9)	29 (36.7)	49 (45.8)	0.215
Convex ST elevation	52 (28.0)	24 (30.4)	28 (26.2)	0.527
Concave ST elevation	26 (14.0)	5 (6.3)	21 (19.6)	0.010*
ST depression	1 (0.5)	0 (0.0)	1 (0.9)	0.389
T-wave inversion (Total)	63 (33.9)	26 (32.9)	37 (34.6)	0.812
Deep T-wave inversion	10 (5.4)	5 (6.3)	5 (4.7)	0.621
T- wave inversions Leads				
V_1-V_4	49 (26.3)	18 (22.8)	31 (29.0)	0.344
V_5-V_6	14 (7.5)	8 (10.1)	6 (5.6)	0.248

*Significant at p<0.05. AV: Atrio-ventricular; HR: Heart Rate; LAD: Left Axis Deviation; LVH: Left Ventricular Hypertrophy; RAD: Right Axis Deviation; RBBB: Right Bundle Branch Block

Table 6 ECG Classification; Ghanaian Male Soccer Players

Variable	**Total (n = 186)**	**Adolescent (n = 79)**	**Adult (n = 107)**	**P-value**
Normal ECGs	143 (76.9)	60 (75.9)	83 (77.6)	0.796
Borderline ECGs	13 (7.0)	5 (6.3)	8 (7.5)	0.762
Abnormal ECGs	30 (16.1)	14 (17.7)	16 (15.0)	0.612

4.2.4 ECG findings of Female soccer players

4.2.4.1 Electrocardiographic Characteristics of Ghanaian Female Soccer Players

First degree AV block was observed in nine female players. Sinus bradycardia and voltage criteria for LVH was respectively present in 46% and 28% of our female players (Table 7). The difference between adult female players and adolescent female players was not significant. QRS duration abnormalities and QT interval abnormalities were all rare findings among our female cohort.

Table 7 Electrocardiographic Characteristics of Ghanaian Adolescent and Adult Female soccer players

ECG Parameter	Total (n=103)	Adolescent (n=71)	Adult (n=32)	P-value
Heart Rate (beats/min)	62.01 ± 10.90 (40.0-95.0)	62.86 ± 11.16 (44.0-95.0)	60.13 ± 10.21 (40.0-81.0)	0.241
PR interval (ms)	171.00 ± 26.01 (130.276.0)	171.55 ± 24.28 (130.0-276.0)	169.78 ± 29.87 (130.0-260.0)	0.751
QRS duration (ms)	81.05 ± 7.83 (60.0-100.0)	81.13 ± 7.89 (60.0-99.0)	80.88 ± 7.84 (66.0-100.0)	0.881
R/S Voltage (S1+ R5)(mm)	32.14 ± 8.62 (17.0-59.0)	32.96 ± 8.65 (17.0-59.0)	30.31 ± 8.42 (19.0-56.0)	0.151
QTc interval (ms)	415.78 ± 22.44 (333.0-467.0)	409.14 ± 20.40 (333.0-452.0)	430.50 ± 19.80 (391.0-467.0)	<0.0001*

* Significant difference at P< 0.05.

4.2.4.2 Electrocardiographic Abnormalities among Ghanaian Female soccer players

Forty-two female players had ST segment elevation with similar prevalence among adults and adolescents. ST segment depression was not recorded in this cohort. Out of a total of 31 players with T- wave inversions, 21% were inversions in the anterior leads (V_1 – V_4) and 9% in the lateral leads (V_5 – V_6). There were isolated TWI in other leads. Eleven female players had abnormal ECGs per the international criteria for ECG interpretation[39] (Table 9)

Table 8 Electrocardiographic Abnormalities among Ghanaian Adolescent and Adult Female soccer players

ECG findings	Total (n = 103)	Adolescent (n = 71)	Adult (n = 32)	P-value
First-degree AV block (PR interval>200ms)	9 (8.7)	6 (8.5)	3 (9.4)	0.878
Sinus bradycardia (HR <60 beats/min)	47 (45.6)	32 (45.1)	15 (46.9)	0.865
Sokolow-Lyon criteria for LVH	29 (28.2)	21 (29.6)	8 (25.0)	0.632
Incomplete RBBB (100ms<QRS<120ms)	1 (1.0)	1 (1.4)	0 (0.0)	0.500
Short QT (QTc=210-340))	1 (1.0)	1 (1.4)	0 (0.0)	0.500
ST elevation	42 (40.8)	29 (40.8)	13 (40.6)	0.983
T-wave inversion (Total)	31 (30.1)	21 (29.6)	10 (33.3)	0.864
Deep T-wave inversion	1 (1.0)	1 (1.4)	0 (0.0)	0.500
T- wave inversions Leads				
V_1-V_4	22 (21.4)	14 (19.7)	8 (25.0)	0.545
V_5-V_6	9 (8.7)	7 (9.9)	2 (6.3)	0.548

*Significant at p<0.05. AV: Atrio-ventricular; HR: Heart Rate; LAD: Left Axis Deviation; LVH: Left Ventricular Hypertrophy; RBBB: Right Bundle Branch Block

Table 9 ECG Classification; Ghanaian Female Soccer Players

Variable	Total (n = 103)	Adolescent (n = 71)	Adult (n = 32)	P-value
Normal ECGs	92 (89.3)	62 (87.3)	30 (93.8)	0.329
Borderline ECGs	0 (0.0)	0 (0.0)	0 (0.0)	-
Abnormal ECGs	11 (10.7)	9 (12.7)	2 (6.3)	0.329

4.2.4.3 Anthropometric characteristics associated with ECG abnormalities among Ghanaian soccer players

Results presented in Table 18 shows the Anthropometric characteristics associated with ECG abnormalities among Ghanaian soccer players. The results shows age association with ECG abnormality among male soccer player with odds of 1.24 (0.98-1.54, p=0.053). The adult male group showed higher odds of developing ECG abnormalities (OR=1.48 CI=0.42-5.23, P=0.541). Height and BSA of the male soccer player was also associated with ECG abnormalities (OR>1), however the odds for weight against ECG abnormalities in male soccer players was less (OR=0.96, CI=0.28-3.30, p=0.949).

Considering the female soccer players, age showed lower odds (OR<1) against ECG abnormalities. Similarly, the adolescent age group showed less odds for developing ECG abnormalities (OR=0.669 CI=0.04-12.79, P=0.789). Weight, Height and BSA for the female soccer players showed odds less than 1 (OR<1)

Table 10 Univariate analysis of Anthropometric characteristics associated with ECG abnormalities among Ghanaian soccer players

Male	Parameter	OR	95% CI	P-value
	Age (Years)	1.24	0.98-1.54	0.053
	Age group			
	Adolescent*	Ref		
	Adult	1.48	0.42-5.23	0.541
	Weight (Kg)	0.96	0.28-3.30	0.949
	Height (cm)	1.08	0.48-2.43	0.86
	BSA (m2)	1.086	0.00-4.85	0.964
Female	Parameter			
	Age (Years)	0.951	0.64-1.42	0.806
	Age group			
	Adolescent	0.669	0.04-12.79	0.789
	Adult*	Ref		
	Weight (Kg)	0.792	0.09-7.20	0.836
	Height (cm)	0.768	0.19-3.05	0.708
	BSA (m2)	0.831	0.00-3.07	0.796

OR=Odds ratio; CI=Confidence interval, *Reference

4.3 Echocardiography Patterns

4.3.1 Echocardiographic Characteristics of Ghanaian Soccer Players

Table 11 shows the Echocardiographic characteristics of Ghanaian Male and Female Soccer Players. Cardiac structural remodelling (LV wall thickness, LV mass and LV cavity dimensions) in response chronic exercises like playing soccer was significantly more exaggerated among our male soccer players compared to the female soccer players.

Table 11 Echocardiographic Characteristics of Ghanaian Male and Female Soccer Players

ECHO findings	Male (n = 186)	Female (n = 103)	P-value
IVS (mm)	10.83 ± 1.84 (7.0-16)	9.21 ± 1.19 (6.7-12.90)	<0.0001*
PWT (mm)	10.20 ± 1.19 (6.9-16.0)	8.26 ± 1.07 (5.8-10.30)	<0.0001*
mLVWT (mm)	11.12 ± 1.89 (7.5-16.0)	9.31 ± 1.12 (7.0-12.90)	<0.0001*
LV end-diastolic dimensions (mm)	50.81 ± 4.33 (42.0-69.0)	48.23 ± 3.55 (39.7-57.0)	<0.0001*
LV end-systolic dimensions (mm)	31.22 ± 4.14 (20.0-47.0)	29.77 ± 3.60 (22.0-48.0)	0.003*
Left ventricular mass (g)	186.53 ± 40.73 (101.9-351.30)	141.93 ± 23.28 (99.7-189.80)	<0.0001*
Relative Left ventricular mass	2.73 ± 0.58 (1.60-5.20)	2.50 ± 0.43 (1.8-3.30)	<0.0001*
Left ventricular mass index (g/m^2)	101.56 ± 20.65 (59.0-189.30)	88.19 ± 13.93 (66.1-116.60)	<0.0001*
RWT (%)	41.43 ± 6.51 (26.30-60.90)	36.14 ± 6.43 (26.6-49.0)	<0.0001*
FS (%)	38.44 ± 6.71	38.26 ± 5.93	0.827
EF (%)	63.32 ± 6.43	56.88 ± 12.51	<0.0001*
E-Wave (cm/s)	83.52 ± 14.75	93.78 ± 13.28	<0.0001*
A-wave (cm/s)	48.08 ± 11.89	50.79 ± 11.20	0.061
E/A ratio	1.83 ± 0.53	1.91 ± 0.53	0.236
E’ wave S (cm/s)	13.18 ± 2.72	13.24 ± 2.23	0.857
A’ wave S (cm/s)	8.68 ± 1.52	7.87 ± 1.31	<0.0001*
E’/A’ S	0.82 ± 0.65	1.68 ± 0.42	<0.0001*
E’ wave L (cm/s)	16.28 ± 4.11	17.21 ± 2.97	0.067
A’ wave L (cm/s)	9.49 ± 2.65	7.75 ± 1.79	<0.0001*
E’/A’ L	0.94 ± 0.46	2.32 ± 0.61	<0.0001*
E/E’	5.98 ± 1.82	6.44 ± 1.23	0.023*

*Significant at p<0.05. IVS: Interventricular septal wall thickness; PWT: Posterior wall thickness; mLVWT: Maximum left ventricular wall thickness; LV: Left ventricle; RWT: Relative wall thickness; FS: Fractional shortening; EF: Ejection Fraction;

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4.3.2 Echocardiographic abnormalities among Ghanaian Soccer Players

The results presented in Table 12 shows the Echocardiographic abnormalities among Ghanaian Male and Female Soccer Players. LV hypertrophy was present in almost as twice as many male players compared to female players. Whilst no female player had LV wall thickness greater than 13 mm, only three male players had LV wall thickness of 16 mm with no player exceeding 16 mm. Significantly RWT.

Table 12 Echocardiographic abnormalities among Ghanaian Male and Female Soccer Players

ECHO findings	Male (n = 186)	Female (n = 103)	P-value
LVH	80 (43.0)	29 (28.2)	0.013*
mLVWT	61 (32.8)	10 (9.7)	<0.0001*
mLVWT (≥16mm)	3 (1.6)	0 (0.0)	0.195
LV end-diastolic dimensions	7 (3.8)	7 (6.8)	0.250
RWT (> 42 %)	77 (41.4)	19 (18.4)	<0.0001*
Pulmonary Regurgitation	2 (1.1)	0 (0.0)	0.291
Mitrial Regurgitation	0 (0.0)	1 (1.0)	0.178
Left Atrial Dilatation	0 (0.0)	14 (13.6)	<0.0001*
Left Ventricular Dilatation	0 (0.0)	1 (1.0)	0.178

*Significant difference at p<0.05; mLVWT (Male=12mm-15mm; Female= 11mm-15mm); LV end-diastolic dimensions (Male> 60 mm; Female>54mm)

4.3.3 ECHO Findings among Male soccer players

4.3.3.1 Echocardiographic Characteristics among Ghanaian Male Soccer Players

Left ventricular wall thickness (LVWT), as well as LV mass (LVM) were both significantly greater in adult male players compared to adolescent players respectively (11.5 ± 1.78 mm vs 10.6 ± 1.94mm, p < 0.002) and (193.8 ± 40.2g vs 176.7 ± 39.5g p < 0.004). About 33% of the male players, comprising 17 adolescents and 44 adult players had LVWT ranging from 12mm to

15mm. Only two adolescents and one adult player had LVWT = 16mm, confirming the fact although LVWT of 16mm is possible among black African sportsmen, its occurrence is still rare and would always warrant a follow up or further investigation.

Left ventricular cavity size ranged from 42mm to 69mm with 7 (4%) players having LVEDd > 60mm. About 41% of male players had relative wall thickness (RWT) ranging from 0.42 to 0.60.

Table 13 Echocardiographic Characteristics of Ghanaian Adolescent and Adult Male soccer players

ECHO findings	Total (n = 189)	Adolescent (n = 79)	Adult (n = 107)	P-value
IVS (mm)	10.83 ± 1.84 (7.0-16)	10.42 ± 1.79 (7.0-16.0)	11.13 ± 1.83 (7.7-16.0)	0.008*
PWT (mm)	10.20 ± 1.19 (6.9-16.0)	9.75 ± 1.67 (6.90-16.0)	10.54 ± 1.72 (7.0-15.0)	0.002*
mLVWT (mm)	11.12 ± 1.89 (7.5-16.0)	10.63 ± 1.94 (7.5-16.0)	11.48 ± 1.78 (8.0-16.0)	0.002*
LV end-diastolic dimensions (mm)	50.81 ± 4.33 (42.0-69.0)	50.37 ± 3.99 (43.0-64.0)	51.14 ± 4.54 (42.0-69.0)	0.232
LV end-systolic dimensions (mm)	31.22 ± 4.14 (20.0-47.0)	30.65 ± 3.29 (22.6-37.5)	31.64 ± 4.63 (20-0-47.0)	0.106
Left ventricular mass (g)	186.53 ± 40.73 (101.9-351.3)	176.73 ± 39.45 (124.7-351.3)	193.78 ± 40.32 (101.9-299.6)	0.004*
Relative Left ventricular mass	2.73 ± 0.58 (1.60-5.20)	2.68 ± 0.57 (1.7-5.2)	2.76 ± 0.60 (1.60-4.80)	0.353
Left ventricular mass index (g/m^2)	101.56 ± 20.65 (59.0-189.30)	98.17 ± 20.29 (67.6-189.3)	104.06 ± 20.65 (59.0-159.10)	0.054
RWT (%)	41.43 ± 6.51 (26.30-60.90)	40.17 ± 6.21 (26.30-60.3)	42.36 ± 6.59 (27.10-60.90)	0.023*
FS (%)	38.44 ± 6.71	39.04 ± 5.44	37.99 ± 7.50	0.296
EF (%)	63.32 ± 6.43	64.05 ± 6.69	62.79 ± 6.21	0.186
E-Wave (cm/s)	83.52 ± 14.75	89.22 ± 12.62	79.32 ± 14.85	<0.0001*
A-wave (cm/s)	48.08 ± 11.89	45.87 ± 9.97	49.71 ± 12.95	0.209
E/A ratio	1.83 ± 0.53	2.02 ± 0.53	1.69 ± 0.48	<0.0001*
E' wave S (cm/s)	13.18 ± 2.72	13.47 ± 2.53	12.96 ± 2.85	0.204
A' wave S (cm/s)	8.68 ± 1.52	8.47 ± 1.62	8.97 ± 1.33	0.112
E'/A' S	0.82 ± 0.65	1.22 ± 0.85	0.52 ± 0.29	<0.0001*
E' wave L (cm/s)	16.28 ± 4.11	16.52 ± 3.66	16.11 ± 4.42	0.506
A' wave L (cm/s)	9.49 ± 2.65	8.84 ± 2.61	10.46 ± 2.44	0.003*
E'/A' L	0.94 ± 0.46	1.48 ± 1.06	0.56 ± 0.86	<0.0001*
E/E'	5.98 ± 1.82	6.22 ± 1.62	5.80 ± 1.93	0.127

*Significant at p<0.05. IVS: Interventricular septal wall thickness; PWT: Posterior wall thickness; mLVWT: Maximum left ventricular wall thickness; LV: Left ventricle; RWT: Relative wall thickness; FS: Fractional shortening; EF: Ejection Fraction

4.3.3.2 Echocardiographic abnormalities among Ghanaian Male Soccer Players

Regarding LV geometry, concentric hypertrophy (RWT > 0.42; LVMI > 115g/m^2, Table 17) was significantly more prevalent in adult players compared to adolescent players (34.6% vs 12.7% p < 0.0007) (Table 14). Significantly more adults than adolescents had LV wall thickness ranging from 12 mm to 15 mm (41% vs 22% p < 0.005). RWT greater than 0.42 was significantly more prevalent among adult male soccer players compared to adolescent players. Transmitral flow and diastolic mitral anulus velocities were normal in all athletes. Left ventricular ejection fraction (EF) was greater than 55% in all players. No segmental wall motion abnormalities on visual assessment.

Table 14 Echocardiographic abnormalities among Ghanaian Adolescent and Adult Male soccer players

ECHO findings	Total (n = 186)	Adolescent (n = 79)	Adult (n = 107)	P-value
LVH	80 (43.0)	27 (34.2)	53 (49.5)	0.037*
mLVWT (12mm-15mm)	61 (32.8)	17 (21.5)	44 (41.1)	0.005*
mLVWT ((≥16mm)	3 (1.6)	2 (2.5)	1 (0.9)	0.393
LV end-diastolic dimensions (> 60 mm)	7 (3.8)	2 (2.5)	5 (4.7)	0.448
RWT (> 42 %)	77 (41.4)	26 (32.9)	51 (47.7)	0.044*
Pulmonary Regurgitation	2 (1.1)	2 (2.5)	0 (0.0)	0.098

*Significant difference at p<0.05

4.3.4 ECHO Findings among Female soccer players

4.3.4.1 Echocardiographic Characteristics among Ghanaian Female Soccer Players

Echo findings in female soccer players are presented in Table 15. LVWT ranged from 7mm to 13mm with ten female players having wall thickness greater than 11mm but less than 13mm. LV end-diastolic dimensions (LVEDd) were similar in both adults and adolescent female players (48.9 ± 2.9 mm vs 47.9 ± 3.8 mm) with only seven players exceeding 54 mm. LVM ranged from 99 to 190g in both adults and adolescent female players. A total of 19 female players had RWT greater than 0.42 with the highest being an adolescent player with RWT of 0.49. LV ejection fraction and fractional shortening were normal in all players, with no segmental was motion abnormalities noted on visual assessment.

Left atrial diameter ranged from 25 mm to 41 mm in our female players with a total of 14 players having left atrial dilatation.

Table 15 Echocardiographic Characteristics of Ghanaian Adolescent and Adult Female soccer players

ECHO findings	Total (n = 103)	Adolescent (n = 71)	Adult (n = 32)	P-value
IVS (mm)	9.21 ± 1.19 (6.7-12.90)	9.35 ± 1.23 (6.7-12.9)	8.91 ± 1.03 (7.2-11.5)	0.085
PWT (mm)	8.26 ± 1.07 (5.8-10.30)	8.43 ± 1.11 (5.8-10.3)	7.91 ± 0.88 (6.2-9.8)	0.024*
mLVWT (mm)	9.31 ± 1.12 (7.0-12.90)	9.47 ± 1.13 (7.0-12.9)	8.95 ± 1.03 (7.2-11.5)	0.027*
LV end-diastolic dimensions (mm)	48.23 ± 3.55 (39.7-57.0)	47.93 ± 3.80 (39.7-57.0)	48.88 ± 2.88 (43.7-56.0)	0.209
LV end-systolic dimensions (mm)	29.77 ± 3.60 (22.0-48.0)	29.46 ± 3.40 (22.0-39.0)	30.45 ± 3.98 (25.2-48.0)	0.196
Left ventricular mass (g)	141.93 ± 23.28 (99.7-189.80)	143.35 ± 25.96 (99.7-189.8)	138.76 ± 15.72 (111.1-176.8)	0.359
Relative Left ventricular mass	2.50 ± 0.43 (1.8-3.30)	2.53 ± 0.47 (1.8-3.3)	2.43 ± 0.30 (1.9-3.3)	0.284
Left ventricular mass index (g/m^2)	88.19 ± 13.93 (66.1-116.60)	89.24 ± 15.63 (66.1-116.6)	85.87 ± 8.87 (69.0-106.1)	0.258
RWT (%)	36.14 ± 6.43 (26.6-49.0)	36.85 ± 7.07 (26.6-49.0)	34.58 ± 4.41 (27.5-46.2)	0.098
FS (%)	38.26 ± 5.93	37.99 ± 6.75	38.88 ± 3.37	0.49
EF (%)	56.88 ± 12.51	58.10 ± 13.76	54.16 ± 8.74	0.139
E-Wave (cm/s)	93.78 ± 13.28	93.59 ± 13.34	94.22 ± 13.36	0.825
A-wave (cm/s)	50.79 ± 11.20	49.87 ± 11.08	52.87 ± 11.38	0.216
E/A ratio	1.91 ± 0.53	1.94 ± 0.58	1.84 ± 0.37	0.374
E’ wave S (cm/s)	13.24 ± 2.23	13.41 ± 2.44	12.86 ± 1.68	0.249
A’ wave S (cm/s)	7.87 ± 1.31	7.57 ± 1.19	8.28 ± 1.28	0.020*
E’/A’ S	1.68 ± 0.42	1.71 ± 0.48	1.63 ± 0.31	0.415
E’ wave L (cm/s)	17.21 ± 2.97	16.88 ± 2.97	17.73 ± 2.96	0.214
A’ wave L (cm/s)	7.75 ± 1.79	7.81 ± 1.89	7.67 ± 1.67	0.743
E’/A’ L	2.32 ± 0.61	2.26 ± 0.62	2.39 ± 0.57	0.378
E/E’	6.44 ± 1.23	6.55 ± 1.30	6.19 ± 1.07	0.168

*Significant at $p<0.05$. IVS: Interventricular septal wall thickness; PWT: Posterior wall thickness; mLVWT: Maximum left ventricular wall thickness; LV: Left ventricle; RWT: Relative wall thickness; FS: Fractional shortening; EF: Ejection Fraction

4.3.3.2 Echocardiographic abnormalities among Ghanaian Female Soccer Players

Echo abnormalities observed among female soccer players are presented in Table 16 below. Out of the total of ten females with LV wall thickness between 11mm and 15mm, nine were adolescent soccer players. Left atrial dilatation was equally present in both adults and adolescents.

Table 16 Echocardiographic abnormalities among Ghanaian Adolescent and Adult Female soccer players

ECHO findings	Total (n = 103)	Adolescent (n = 71)	Adult (n = 32)	P-value
LVH	29 (28.2)	23 (32.4)	6 (18.8)	0.154
mLVWT (11mm-15mm)	10 (9.7)	9 (12.7)	1 (3.1)	0.130
mLVWT ((≥16mm)	0 (0.0)	0 (0.0)	0 (0.0)	-
LV end-diastolic dimensions (> 54 mm)	7 (6.8)	5 (7.0)	2 (6.3)	0.883
RWT (> 42 %)	19 (18.4)	17 (23.9)	2 (6.3)	0.032*
Mitrial Regurgitation	1 (1.0)	0 (0.0)	1 (3.1)	0.134
Left Atrial Dilatation	14 (13.6)	7 (9.9)	7 (21.9)	0.099
Left Ventricular Dilatation	1 (1.0)	0 (0.0)	1 (3.1)	0.134

*Significant difference at $p<0.05$

4.3.5 Left ventricular geometry of Ghanaian soccer players

Significantly more of the male players (25%) compared to the females (11%) had concentric hypertrophy. The results of eccentric hypertrophy when we compared males to female players showed 9.7% against 18.4% ($p < 0.033$) respectively.

Table 17 Left ventricular geometry of Ghanaian Male and Female soccer players

Geometry	Male (n = 186)	Female (n = 103)	P-value
Normal	91 (48.9)	63 (61.2)	0.046*
Concentric Remodeling	28 (15.1)	9 (8.7)	0.124
Concentric Hypertrophy	47 (25.3)	11 (10.7)	0.003*
Eccentric Hypertrophy	18 (9.7)	19 (18.4)	0.033*

4.3.5.1 Left ventricular geometry of Ghanaian Male soccer players

Table 18 below confirms concentric type of hypertrophy was more common among male soccer players, with a higher prevalence among adults compared to adolescent players.

Table 18 Left ventricular geometry of Ghanaian Adolescent and Adult Male soccer players

Geometry	Total (n = 186)	Adolescent (n = 79)	Adult (n = 107)	P-value
Normal (RWT≤0.42;LVMI≤115g/m^2)	91 (48.9)	46 (58.2)	45 (42.1)	0.029*
Concentric Remodeling (RWT>0.42;LVMI≤115g/m^2)	28 (15.1)	16 (20.3)	12 (11.2)	0.088
Concentric Hypertrophy (RWT>0.42;LVMI>115g/m^2)	47 (25.3)	10 (12.7)	37 (34.6)	0.0007*
Eccentric Hypertrophy (RWT<0.42;LVMI>115g/m^2)	18 (9.7)	7 (8.9)	11 (10.3)	0.746

4.3.5.2 Left ventricular geometry of Ghanaian Female soccer players

Eccentric type of LV hypertrophy was more prevalent among female players as presented in table 19.

Table 19 Left ventricular geometry of Ghanaian Adolescent and Adult Female soccer players

Geometry	Total (n = 103)	Adolescent (n = 71)	Adult (n = 32)	P-value
Normal (RWT≤0.42;LVMI≤95g/m^2)	63 (61.2)	39 (54.9)	24 (75.0)	0.053
Concentric Remodeling (RWT>0.42;LVMI≤95g/m^2)	9 (8.7)	8 (11.3)	1 (3.1)	0.176
Concentric Hypertrophy (RWT>0.42;LVMI>95g/m^2)	11 (10.7)	10 (14.1)	1 (3.1)	0.096
Eccentric Hypertrophy (RWT<0.42;LVMI>95g/m^2)	19 (18.4)	12 (16.9)	7 (21.9)	0.547

4.3.5.3 Left Ventricular Wall Thickness (LVWT) in Adult male and female soccer players

Whilst no adult female adult player had LV wall thickness greater than 12mm, no male soccer player had LV wall thickness exceeding 16 mm as demonstrated in the figure 1 below.

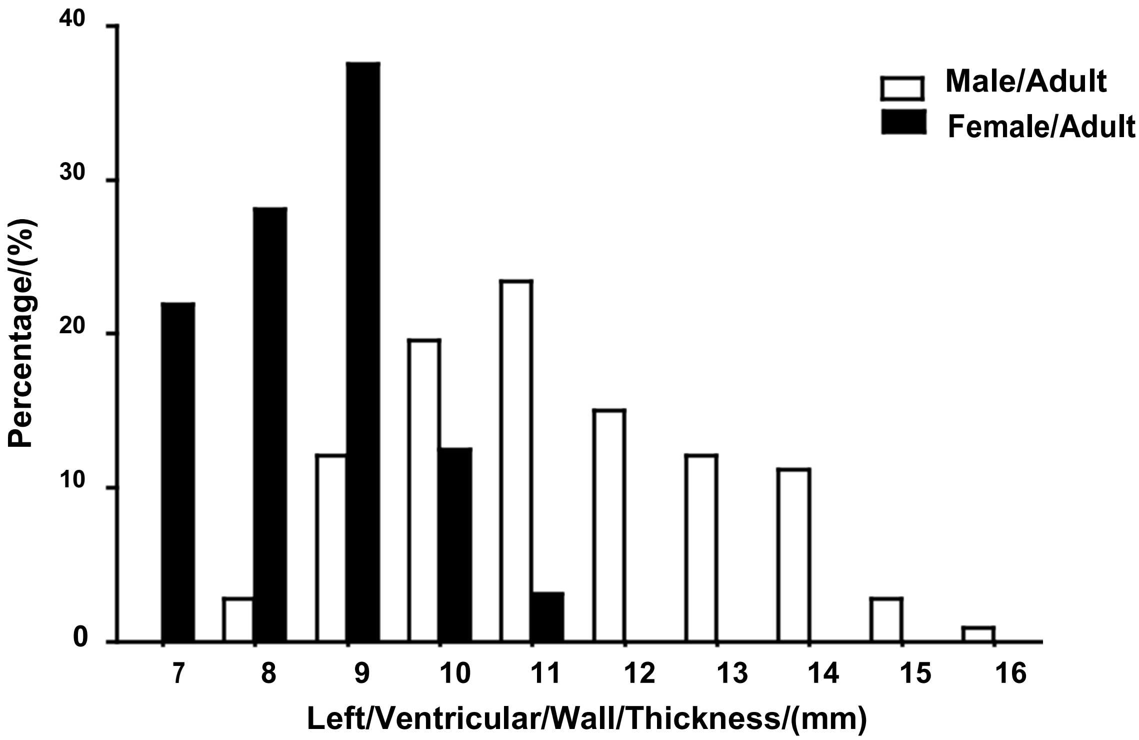

Figure 1 Distribution of Left Ventricular Wall Thickness (LVWT) in male and female Adult soccer players

4.3.5.3 Left Ventricular Wall Thickness (LVWT) in Adolescent soccer players

Figure 2 below reveals about 3% of adolescent males had wall thickness up t0 16 mm whilst no adolescent female player exceeded 13 mm.

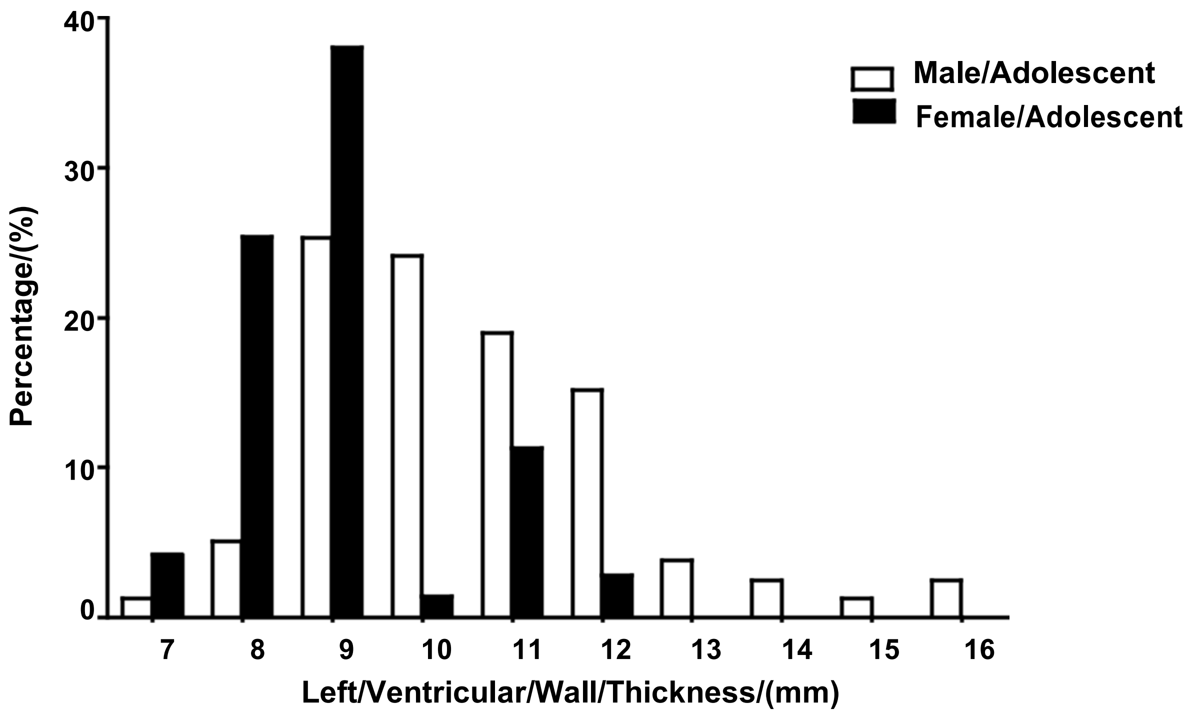

Figure 2 Distribution of Left Ventricular Wall Thickness (LVWT) in male and female Adolescent soccer players

CHAPTER FIVE

DISCUSION

5.0 Introduction

Black ethnicity as one of the influencers of exaggerated cardiovascular adaptation to sports has been confirmed in several studies [2, 7, 8, 18, 34, 48, 49]. These exaggerated responses are normally manifested on the athletes' ECG and ECHO, and collectively described as the athlete's heart.

Most of the studies which compared athletes of black African descent to their Caucasian counterparts revealed that both male and female athletes of black African descent exhibited a higher prevalence of both electrical and structural cardiac morphological changes on ECG and ECHO[6, 7, 16, 34, 48].

The heterogenous nature of the black Africans/Afro-Caribbeans forming the cohorts of these studies poses a limitation, considering the possibility of a genetic drift in black Americans, black Europeans or Afro Caribbeans as a result of ancestral migration[49].

It is believed that a combination of genetic, endocrine and hemodynamic factors[40] might be responsible for the exaggerated cardiovascular responses observed in black African sports men and women. These exaggerated responses sometimes make it difficult for sports physicians and cardiologists to appropriately distinguish between normal physiological adaptation and cardiac disorders like cardiomyopathies which are mostly implicated in most sudden cardiac deaths (SCDs) and more commonly seen in black African athletes than Caucasians[5, 18, 28, 50].

A recent study by Riding et al. [51] concluded that "the term 'black' should not imply that the hearts of all black athletes are universally comparable". Findings from same study further suggested that there is considerable variability in the cardiac electrical and structural remodelling response to exercise that appears to be dependent on geographic origin.

This cross-sectional study presents findings in a homogenous group of two hundred and eighty-nine (289) male and female Ghanaian adult and adolescent (black west African) soccer players competing at the elite levels in national and international competitions. Conclusions drawn from this study can therefore provide clinically significant data which could serve as a guide for the interpretation of ECGs and ECHOs of athletes from this region and to an extent, black African athletes in general.

5.1 Electrocardiography patterns

The prevalence of common/training-related ECG changes, such as sinus bradycardia, first degree AV block, voltage criteria for LVH, incomplete right bundle branch block, ST segment elevations and T – wave inversions (TWI) in anterior leads, as presented in table 3, was high among our study subjects and similar to other athletes (both blacks and white athletes) as reported in other studies[7, 48], confirming the fact that athletic training may be responsible for common/training-related cardiovascular adaptations manifested on ECG. On the other hand, uncommon/training-unrelated ECG changes such as complete right bundle branch block, TWI in lateral leads and deep TWI, were more prevalent among both male and female Ghanaian soccer players compared to Caucasian and west Asian athletes, suggesting a combination of athletic training and black ethnicity or geographic origin may be responsible for such exaggerated cardiovascular responses[51, 52]. Compared to the west African males in the study by Riding et al.[51], the prevalence of abnormal ECGs (Table 4a)[39] per the recent international criteria, among our homogenous group of west African male soccer players was higher (9% vrs 16%). About 11% of our female cohort Abnormal ECGs per same criteria, had abnormal ECGs.

It is also worth mentioning that the prevalence of these ECG changes, be it training-related or training-unrelated was higher among our male cohort compared to female cohort and also higher in adults when compared to adolescents. Significantly, first degree AV block and voltage criteria for LVH were more prevalent among Ghanaian male soccer players compared to female soccer players (20% vs 8.7% $p < 0.009$ and 66.7% vs 28% $p < 0.0001$) respectively. Out of the 289 participants, only one adult male player had ST segment depression, further confirming how rare this finding is, and its presence should always be further investigated.

The prevalence of TWI were high among our study cohort compared to other black African (self-assigned black ethnicity) athletes in other studies[7, 8, 24, 34, 48], further confirming the influence of geographic and ancestral origin suggested by Riding, et al. [51]. Whilst 26% and 21% of our male and female cohorts respectively exhibited TWI in anterior leads (V_1 – V_4), 7.5% and 9% respectively had inverted T -waves in the lateral leads (V_5 – V_6); in agreement with similar comparatively high prevalence (5% in west Africans and 5.1% in middle Africans), compared to other Africans (East 1.5%, North Africans 0.5%, and African Americans 1.2%) and white (south Europeans 0%) athletes[51]. High prevalence of inverted T- waves in lateral leads in 90% of hypertrophic cardiomyopathy (HCM) patients was confirmed by Calore, et al. [53], hence suggesting the need to exclude the presence of HCM in any athlete with inverted T-waves in the lateral leads. None of the players with inverted T-waves in lateral leads in our study had any corresponding features suggestive of HCM on ECHO. From our findings the presence ST segment depression or deep T- wave inversions in lateral leads with associated LV wall thickness greater than 15 mm and 12 mm in males and female players respectively is unlikely to be a normal physiological response and therefore warrants further investigation to rule out any cardiomyopathy. Our findings also seems to suggest that our study cohort (black west African male and female soccer players) had exaggerated electrical and cardiac structural responses to athletic training compared to other black Africans from different regions like southern, eastern and northern Africa and black African cohorts living in the Americas or Europe[7, 8, 48, 51].

Although an autopsy-based athlete population study suggested an association between LVH induced fatal arrhythmias and SCD[54] , it is highly unlikely that about 32% of our study population with repolarisation changes are potential candidates of SCD. We are however quick to caution that considering the very high prevalence of abnormal T-waves in black African patients with HCM[54], all black African athletes with abnormal TWI should be further investigated and followed up on.

5.2 Echocardiography patterns

Our study cohort (Ghanaian male and female soccer players) who had increased left ventricular wall thickness also had accompanying increased LV mass and RWT, but LV cavity dimension remained normal, confirming the high prevalence of concentric LV hypertrophy among black African athletes[7, 8, 24, 31]. Significantly more of our male players compared to the females had concentric hypertrophy, we observed the right opposite in terms of eccentric hypertrophy when we compared males to female players.

RWT greater than 0.42 was present in 41% of male players and 18% of our female cohorts. Surprisingly adolescent females with RWT > 0.42 were significantly more that adult males (24% vrs 6% $p < 0.032$); a trend we could only explain by the fact that most of the adolescent female players were playing for two national soccer teams (under 20 and under 17) at the same time, hence a higher training load. Whilst sixty-one male players had LVWT ranging from 12 mm to 15 mm, ten of our female cohort had LVWT between 11mm and 15mm.

No male or female player had LVWT exceeding 16 mm and 13 mm respectively. We are tempted by this trend to agree with Basavarajaiah, et al. [26] who suggested that the upper limits of LV hypertrophy in black male athletes should be raised from 12 mm to 15 mmm; but data from the study by Basavarajaiah, et al. [26], Riding, et al. [51] and our current data reveals that prevalence of LVWT ! 12 mm is about five times higher in west African male athletes (much more higher in our male soccer players) compared to their East and North African counterparts. These findings go to confirm the difference in cardiac electrical and structural response to athletic training, and subsequent manifestations on ECG and ECHO of the black athlete's heart when geographic origin is considered; hence universally classifying "black athlete's heart" as a single unit representative of hearts of all black athletes has dire consequences. We therefore recommend that any athlete falling within the grey zone of 13mm to 15mm and up to 16mm in black west African athletes, should be further investigated thoroughly to exclude HCM.

Whilst only 4% our male players had LV cavity dimensions greater than 60 mm, 7 out of our 103 female players exceeded LV cavity dimension of 54 mm.

5.3 Male players versus Female players

The data from our study clearly confirmed that males have a much more exaggerated cardiovascular response to athletic training compared to female athletes. Abnormal and borderline ECGs per the international criteria[39] were more prevalent among male players compared to their female counterparts. LV wall thickness, LVM and LV cavity sizes were all higher in males and adults compared to females and adolescents. This goes to confirm the impact of gender and age upon the electrical and structural manifestations of the black athlete's heart. Whilst no female player exceeded a LVWT of 13 mm, the maximum LVWT in our male cohort was 16 mm. Among our male players, a significant number of adults compared to adolescents had LVWT > 12mm. We believe this trend may be due to the transition from adolescence to adulthood which is associated with body maturation and a longer exposure to continued athletic training. This trend was however not observed among our female players, where LVWT between 11 mm and 15mm was observed in 13% of adolescents compared to just 3% of adults. We observed that some of the female adolescent players played for two different national teams and therefore played more competitive games compared to the adult females. Whilst concentric hypertrophy was common among our male players, 18% of the female players rather exhibited the eccentric type of hypertrophy.

5.4 Clinical implications

Data from our study and other studies have confirmed regional differences when it comes to cardiovascular response to chronic exercise and how these responses/adaptations manifest on the black African athletes' ECG and ECHO[21, 26, 51]. The west African soccer player is more likely to have thicker heart walls (exaggerated LV remodeling) compared to the east African marathon runner, who is likely to have a wider LV cavity[26, 51].

It is therefore imperative for clinicians involved in athletes' pre-competition cardiovascular screening in a multi-ethnic setting, to consider ancestral origin of black African athletes when interpreting ECG tracings and ECHO reports. Our findings highlight the need for race and gender- sensitive ECG and ECHO interpretation criteria to reduce the risk of unfairly disqualifying otherwise healthy athlete, whilst not compromising the lives of athletes who might also be harbouring some sinister cardiac anomalies. Although an appreciable number of both male and female players from our study had abnormal ECGs, none of them had an abnormal

ECHO warranting a disqualification from competitive sports; hence establishing the need to go further than the use of ECG only during cardiovascular screening of athletes to determine eligibility and to reduce the risk of false positives from ECGs.

We believe our findings as reported here will help to improve the general understanding of the impact of geographic origin on the adaptation of the west African male and female, including adolescent players' heart to athletic training leading to a reduction in the number of black African athletes wrongly disqualified while continuing to identify athletes who truly have significant cardiac disease.

5.5 Study limitation

The fact that this is a cross-sectional study without a control group is a major limitation. Our inability to carry out long term follow ups and lack of other further screening tools such as cardiac magnetic resonance imaging (cMRI) and genetic testing, although not part of the original study design, also limited the scope of the study. The absence of these tools in Ghana as at the time of this study, make it difficult to completely rule out the presence of cardiomyopathies among our subjects. Participants were all Ghanaians (west Africans) who participated in only one sport, soccer, as such, we cannot consider our results as representative of the entire African continent. In addition, the effect of other sporting disciplines on the type of adaptation cannot be fully explained using our findings.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Common/training-related and uncommon/training-unrelated ECG and ECHO findings were observed in appreciable numbers in Ghanaian (black west African) soccer players. Although our study cohort demonstrated early repolarisation trends and LVWT up to 15 mm and even 16mm, these findings (LVWT < 15mm) and especially ST segment depression, deep TWI and TWI in lateral leads should always warrant further investigation.

We can also conclude from our study and other studies that, stark differences do exist in the way the hearts of black African athletes originating from different geographic locations within Africa respond to the impact of chronic exercises or athletic training. The phrase "Black African athlete's heart" should therefore not be simply taken as representative of the hearts of all black African athletes, considering the existence of significant regional differences within the African continent.

6.2 Recommendation

Future studies (including the use of cMRI and genetic testing) involving other sporting disciplines and participants from other regions in Africa are required to help develop a race and gender sensitive ECG and ECHO interpretation tool to be used during pre-competition cardiovascular screening of athletes in a multi-ethnic setting. More collaborative studies to compare homogenous groups of athletes of black African origin to a homogenous group of white athletes are required in the future.

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PROFILE/PROFESSIONAL SUMMARY

Dr. Prince Pambo is a multifaceted Sports and Exercise Medicine Physician. His vast experience in the field makes him highly sought after in his native country of Ghana and across the African continent.

For over a decade, in addition to being an attending Physician (Medical Director) at the Stadium/Civil Service Polyclinic, in Accra and conducting pre-competition medical assessment (PCMA) for soccer teams in Ghana, he also attends to both elite and recreational athletes presenting with sports related injuries. In his General Practice at the Parliament House clinic, Dr. Pambo sees clients with chronic non-communicable diseases (hypertension, diabetes, obesity and cancers), where exercise prescription forms the core of his practice. He is also an Honorary Visiting Clinician at the Thumbay Physical Therapy and Rehabilitation Centre, Gulf Medical University, United Arab Emirates.

He is a member of the Medical Committee of the Ghana Football Association. In this role, he plans and conducts pre-competition medical assessment and provides pitch side emergency medical services. He has also played the role of team doctor for a number of National soccer teams and performs his duty excellently; endearing him to elite players.

At the National level, Dr. Pambo is a member of the National Anti-Doping Organisation (NADO). He is also part of a Technical Working Group tasked by the Ministry of Health and the World Bank to develop a National Policy for non-communicable diseases (NCDs) and strategies to mitigate the incidence of NCDs.

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Dr. Pambo is a member of the Medical Committee of Confederation of African Football (CAF) and as a Doping Control Officer (DCO), he is extremely passionate about fair play in sports.

Dr. Pambo maintains a keen interest in Sports Cardiology; he is involved in collaborative research with colleagues in Germany (Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken) and Austria (Department of Sports Medicine, Exercise Physiology and Prevention, University of Vienna) on ethnic specific and sensitive ECG and ECHO interpretation criteria which could be ground breaking in reducing false positives and unfair disqualifications during pre-competition medical assessment in a multi-ethnic setting.

The issue of age verification in competitive sports is an area of study he finds great interest in. His research is aimed at creating a fair playing field for participants to remain in their age brackets through scientific verification method and workable means of enforcing same on the African Continent.

He is an alumnus of the Kwame Nkrumah University of Science and Technology where he obtained his BSc and MB.chB, the University of Nottingham, where he specialised in Sports and Exercise Medicine and the Saarland University, Saarbrücken, Germany where he did his PhD study (*"ECG AND ECHO FINDINGS AMONG ELITE AND ADOLESCENT FOOTBALL PLAYERS IN GHANA")* in the area of Sports Cardiology at the Institute of Sports and Preventive Medicine.

Dr Pambo a member of the British Association of Sports and Exercise Medicine (BASEM).

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RECENT PUBLICATION

1.! Fuller CW, Junge A, Amaning J, Kaijage RR, Kaputa J, Magwende G, Pambo P, Dvorak J (2014). FIFA 11 for Health programme: Implementation in five countries in sub-Saharan Africa; HEJ; DOI: 10 1177/0017896914523152.

2.! Ocansey R, Aryeetey R, Sofo S, Badasu DM, Pambo P, Nyawornota VK (2014). Results from Ghana's 2014 Report Card on Physical Activity for Children and Youth; JPAH; 11(Supp 1), S58-S62.

3.! Sarkodie BD, Ofori EK, Pambo P (2013). MRI to determine chronological age of Ghanaian footballers; SAJSM; 25(3):74-76.

4.! Long Standing groin pain and Femoroacetabular impingement, Focus on Active lifestyle living and sport (2) 15-20.

5.! Sarkodie BD, Botwe BO, Pambo P, (2018). MRI age verification of U 17 players: The Ghana study. Journal of Forensic Radiology and Imaging; 12: 21-24

6.! P. Pambo J. Scharhag (2019). Electrocardiographic and Echocardiographic Findings in Black athletes; A General Review; Clinical Journal of sports medicine. **(published ahead of print)**

7.! P. Pambo et al. (2019); Electrocardiographic and Echocardiographic Findings in Elite Ghanaian male soccer players. Clinical journal of sports medicine. **(Accepted for publication)**

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APPENDIX: PUBLICATIONS RELEVANT TO THIS THESIS

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1.! Pambo, P., Scharhag, J. (2019). **Electrocardiographic and Echocardiographic Findings in Black Athletes; A General Review;** *Clinical Journal of sports medicine.* (published ahead of print)

2.! Pambo, P., Adu-Adadey, M., Agbodzakey, H., Scharhag, J**.** (2019); **Electrocardiographic and Echocardiographic Findings in Elite Ghanaian Male Soccer Players.** *Clinical journal of sports medicine.* (published ahead of print)

3.! Pambo, P., Adu-Adadey, M., Takyi-Ankrah, P., Agbodzakey, H., Scharhag, J. (2020); **Electrocardiographic and Echocardiographic Findings in Ghanaian Female Soccer Players.** *Clinical journal of sports medicine.* (published ahead of print)

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PUBLICATIONS RELEVANT TO MY PhD THESIS

1. Pambo, P., Scharhag, J. (2019). Electrocardiographic and Echocardiographic Findings in Black Athletes; A General Review; Clin J sports Med. 2019. doi:10.1097/JSM.00000000000754. Online ahead of print.

2. Pambo, P. , Adu-Adadey, M., Agbodzakey, H., Scharhag, J. (2019); Electrocardiographic and Echocardiographic Findings in Elite Ghanaian Male Soccer Players. Clin J Sports Med. 2019. doi: 10.1097/JSM.00000000000801 Online ahead of print.

3. Pambo, P., Adu-Adadey, M., Tekyi-Ankrah, P., Agbodzakey, H., Scharhag, J. (2020); Electrocardiographic and Echocardiographic Findings in Ghanaian Female Soccer Players. Clin J Sports Med. 2020. doi: 10.1097/JSM.000000000000851 Online ahead of print.

INFORMATION ON PhD THESIS DEFENSE

Date: **25.06.2021**

Dean: **Prof. Dr. M.D MENGER**

EXAMINERS/RAPPORTEURS

1. **PROF. J. SCHARHAG**
2. **PROF. B. SCHELLER-CLEVER**