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Sudden Cardiac Death in Famous Athletes, Lessons Learned, Heterogeneity in Expert Recommendations and Pitfalls of Contemporary Screening Strategies

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Abstract

Sudden cardiac death (SCD) in competitive athletes, though relatively uncommon, invariably leads to controversy. Specific limitations of an extensive screening process include lack of robust evidence to support prevention of SCD, poor cost-effectiveness and uncertain downstream implications of a positive screening test. An emerging body of evidence points to enhanced neurologically intact survival to hospital discharge when automated external defibrillators (AEDs) are used in a timely manner following sudden cardiac arrest (SCA). A viable alternative to an expansive screening process could be a robust secondary prevention system comprising of improvements in AED availability, stringent enforcement of CPR training in athletes and trainers to provide timely and effective resuscitation to reduce death following SCA. This strategy could widen the window to diagnose and treat the underlying etiology and prevent recurrence of SCA while also offering financial feasibility. Restricting athletes from competitive sports is a difficult decision for physicians owing to a lack of well-defined cutoffs for acceptable and prohibitive risk from pathology predisposing to SCD, especially in the absence of a protective medico-legal framework. In this review, we highlight a few cases that generated intense scrutiny by the public, media and medical professionals about the efficacy, feasibility and pitfalls of the existing screening process to diagnose cardiovascular pathology predisposing to SCD. Furthermore, contrasting approaches to screening, diagnosis and downstream workup protocols between the European Society of Cardiology and the American Heart Association are analyzed.

Introduction

Athletes have traditionally been known to exhibit an exorbitant level of physical fitness and excellent cardiac health. Contrary to the general belief that they are relatively well protected from cardiac pathology, a diverse array of cardiac conditions have come to the fore of media attention by virtue of sudden unexpected deaths of celebrated athletes. SCD is defined as unexpected death due to a cardiac etiology occurring within 1 hour of symptom onset, most commonly from a lethal ventricular arrhythmia in individuals without a known potentially fatal condition.[1] This paper focuses on highlighting the conditions which are uncommon but carry a significant risk of SCD in young athletes, the incidence of SCD, available screening techniques and the pitfalls of contemporary screening for athletes with conditions predisposing to SCD. Our report emphasizes on delays in the recognition of sudden cardiac arrest (SCA), timely and effective delivery of cardiopulmonary resuscitation (CPR), and concurrent use of automated external defibrillators (AEDs) and their efficacy as a safety net once SCA has occurred. Often, SCA is the sentinel manifestation of these underlying conditions when individuals are subject to rigorous physical activity.

The highest incidence of SCD in young athletes is among those participating in sports like basketball, football, track, and soccer.[2] Triggers such as extreme physical exertion coupled with a substrate like underlying structural heart disease constitutes the pathologic basis of SCD in athletes.[1, 3] An age cutoff of 35 years delineates younger from older athletes.[4] Hypertrophic cardiomyopathy (HCM) is reportedly the leading cause of sudden cardiac death in the younger age while atherosclerotic coronary artery disease predominate the older age group.[5, 6] Controversies have predominated aspects regarding modalities of screening, their cost-effectiveness, downstream efficacy and implications of testing for pathological entities predisposing to SCD.

We present cases highlighting SCD in famous athletes who gathered considerable public attention after their demise [Table 1]. These cases were influential in the study of SCD in athletes and were recommended by the American Sports Medicine Institute, American

Key Words
Atrial fibrillation, Sudden cardiac death, Sudden cardiac arrest.

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Sudden Cardiac Death in Professional Athletes

Reggie Lewis was a professional basketball player selected in the first round of the 1987 draft by the Boston Celtics and went on to become the league's leading scorer. He underwent a treadmill test which was reportedly unremarkable, days prior to a near-syncopal event during a playoff game in 1993 against the Charlotte Hornets. He continued through the game without subsequent events. Subsequent cardiac assessment revealed conflicting reports with a team of eminent cardiologists suggesting ventricular tachycardia (VT) from hypertrophic cardiomyopathy (HCM) and strongly advised against further participation in competitive sports. In contrast, a different cardiologist suggested neurocardiogenic syncope which and reinstate privileges to continue competitive sports. Amidst conflicting reports, Reggie Lewis resumed light workouts and Lewis succumbed to SCD at age 27 years during an off-season practice game. Autopsy revealed dilated cardiomyopathy with extensive myocardial scarring and normal coronary arteries. The complicated dynamics of this case generated immense media attention on the heterogeneity among experts and the need for aggressive risk assessment in trained athletes.

Hank Gathers from the Loyola Marymount University was college basketball's leading scorer and a candidate for the player of the year for the 1988-89 season. Moments after he dazzled the crows with a two-handed dunk, Gathers had a sudden cardiac arrest (SCA) in the first half of the game against the Portland Pilots. He was pronounced dead less than two hours later. Notably, the AED was not present courtside, leading to a fatal delay in recognition and definitive treatment of VT. Autopsy reports revealed idiopathic cardiomyopathy with residual interstitial myocarditis.

The deaths of Marc Vivien Foe, Miklos Feher, and Antonio Puerta within 3 years (2004-2007) prompted Fédération Internationale de Football Association (FIFA) to enforce screening of players at all levels before competitions. Presence of AEDs and sideline medical teams with specialized training in cardiopulmonary resuscitation (CPR) were made mandatory at every professional soccer stadium in the world. In 2013, FIFA mandated the availability of at least 1 AED at the sideline of all FIFA matches. FIFA also introduced consolidated medical emergency bags containing AEDs and airway equipment to sideline medical emergency teams at the 2014 world cup in Brazil. More recently, FIFA has launched the FIFA Sudden Death Registry in 2014 to identify potential delays in recognition and enforce timely definitive therapy for SCA during football events.

Marc Vivien Foe played in the 1994 and 2002 World cups, won 2 African championships with Cameroon and also won the French league title in 1998 and 2002. On June 26, 2003, Foe was playing for Cameroon in a semi-final match for the FIFA Confederations Cup against Colombia when he was noted to have SCA and subsequent CPR for 45 minutes before death was declared. Autopsy results revealed HCM with resultant VT as the likely cause of death.

Miklos Feher, a Hungarian soccer player who played for Benfica based out of Lisbon, earned top division totals of 80 games and 27 goals along with international credentials of 7 goals in 25 games. On January 25, 2004, after he helped create the game winning goal in the 25th minute following which he suffered a fatal SCA followed by prolonged CPR. His autopsy also revealed HCM and resultant VT as the likely cause of death which was not recognized on prior routine medical examinations.

Antonio Puerta played for Sevilla football club in Spain, helping them achieve an astounding 5 titles in 15 months. At age 22 years,

Table 1: Famous Athletes, Causes of Sudden Cardiac Death and Underlying Genetic Mechanisms

Athlete	Diagnosis	Incidence	Common Mutation
Reggie Lewis	HCM	1 in 500	Cardiac myosin binding protein C, β-myosin heavy chain, Troponin I, T, α-tropomyosin
Marc Vivien Foe	HCM	1 in 500	
Miklos Feher	HCM	1 in 500	
Zena Ray Upshaw	HCM	1 in 500	
Nick Knapp	HCM	1 in 500	
Hank Gathers	Idiopathic		N/A
Antonio Puerta	ARVD	1 in 2500 - 5000	Plakophilin-2, Desmoglein-2, Desmoplakin, Desmocollin-2
Wes Leonard	DCM	0.57 in 100,000 (≤18 years)	Titin, β-myosin heavy chain, α-myosin, myopalladin, troponin T
Flo Hyman	Marfans Syndrome	1 in 5000	Fibrillin-1, TGF-β receptor 1, 2
Sergei Grinkov	Myocardial infarction	12.9 per 1000 (30 - 34 years)	PLA-2 variant
Alexander Dale Oen	Myocardial infarction	12.9 per 1000 (30- 34 years)	
Darryl Kile	Myocardial infarction	12.9 per 1000 (30-34 years)	
Pete Maravich	Absent LMCA	Rare	N/A
Jim Fixx	Myocardial infarction	600 in 100,000	N/A

HCM = hypertrophic obstructive cardiomyopathy; ARVD = arrhythmogenic right ventricular dysplasia; DCM = dilated cardiomyopathy; CMN = cystic medial necrosis; MS = marfan syndrome; MI = myocardial infarction; PLA = platelet antigen gene; LMCA = left main coronary artery

Table 2: Limitations of Cardiovascular Screening Tests.

Test	Diagnosis	Limitations
History and physical examination	Congenital aortic stenosis	Low specificity for SCD
	CAD risk factors in older athletes	
	Family history of SCD	
2D Echocardiography	HCM	$400 – 2000/study 1:500 HCM = $250,000 per case False (+) and (-)
	Valvular heart disease	
	Aortic root dilatation	
	Coronary artery anomalies	
Coronary arteriography	Congenital coronary artery anomalies	Invasive test
		Increased associated risks
MRI	Arrhythmogenic right ventricular dysplasia	Expense and availability
12 Lead EKG	Hypertrophic cardiomyopathy	Low specificity
	Coronary anomalies	
	Long QT syndrome	

Puerta suffered a SCA 35 minutes into a game against Getafe. Puerta regained consciousness, was substituted and had another SCA in the locker room. Despite timely CPR, he was subsequently placed on life support before being declared dead on August 28, 2007. The autopsy report identified the cause of death as arrhythmogenic right ventricular dysplasia but his prior medical examinations were unremarkable, even in the prior 3 weeks leading to his demise.

Wes Leonard was a 16 year-old basketball player for Fennville High School in Michigan. He was a standout athlete and a three year starter in basketball and football. On March 3, 2011, in overtime of the last game of the regular season, he made the game winning basket to achieve a 20-0 record. His teammates lifted him into the air and as soon as he was put down he collapsed to the court gasping for air. His presentation was misconstrued for heat exhaustion and his colleagues attempted to cool him down with ice and cool cloths. Ironically, the on-site medical personnel attached the AED from school to his chest and the device was non-functional owing to depletion of battery life, thereby resulting in ineffective CPR and subsequent death. Forensic pathology revealed dilated cardiomyopathy from either a genetic defect or due to prior undetected viral myocarditis which was again not detected on prior exams. Following his death, Leonard's mother Jocelyn became an advocate for CPR/AED training drills which resulted in the placement and routine maintenance of AEDs at all schools in Michigan.

Table 3: Comparison of U.S. And European Guidelines for Preparticipation Screening for Competitive Sports

Condition	[1]U.S. Recommendations	[2]European Recommendations
HCM	[a] Exclude from most sports	[a] Exclude from most sports
Genotype + Phenotype -	No data to exclude	Participation only in noncompetitive or leisure-time sporting activities
Marfan Syndrome	[b] Restricted to class IA & IIA sports	[c] Exclude from all sports
Long QT Syndrome	≥470ms (men); ≥480ms (women)	≥440ms for men; ≥460ms (women)
	Restriction to low intensity sports	Exclude from all sports
Genotype + Phenotype -	No exclusion	Discouraged participation in sports
	LQT1 genotype: refrain from competitive swimming	
Brugada Syndrome	Restriction to low intensity sports	Exclude from all sports
Genotype + Phenotype -	No exclusion	Exclude from all sports
Ventricular pre-excitation	[d] Asymptomatic: EPS not mandatory	Asymptomatic: EPS mandatory
(WPW Syndrome)	Symptomatic: EPS required	Symptomatic: EPS mandatory
	Return after RFA: 4 weeks	Return after RFA: 3 months
PVC	No restriction unless PVCs increase with exercise, then restriction to low intensity sports	
NSVT	No CV disease: No exclusion	No CV disease: No exclusion
	CV disease: restricted to low intensity sports	CV disease: restricted to recreational sports
ICD	Exclude from competitive sports	
	Exception: sports without associated risk of trauma to the device	
Screening	[3]Medical history + physical exam	[4]12 lead ECG + medical history + physical exam
Perform screening	Physician volunteers	Sports medicine physicians
	Healthcare workers	
Authority for disqualification	High school or college officials	Sports medicine physician

[1] 36th Bethesda Conference; [2] European Society of Cardiology Conference; [3] U.S. strategy for high school and collegiate athletes; [4]Italian screening model
[a] Exceptions: low static and low dynamic intensity sports such as golf; [b] Class IA & IIA: low and moderate static/low dynamic competitive sports. Cannot have one or more of following: aortic root dilatation ≥40mm in adults or more than 2 SDs from the mean for body surface in children, moderate to severe mitral regurgitation, family history of dissection or sudden death in Marfan relative; [c] Independent of aortic root dimension; [d] EPS advisable in moderate or high level competitive sports
CV - cardiovascular; ECG - electrocardiogram; EPS - electrophysiologic study; HCM - hypertrophic cardiomyopathy; ICD - implantable cardioverter-defibrillator; LQTS - long QT syndrome; NSVT – non-sustained ventricular tachycardia; PVC - premature ventricular complex; RFA - radiofrequency ablation; WPW - Wolff Parkinson white syndrome

Flo Hyman, a world class professional volleyball player was a silver-medalist for the United States in the 1984 Olympics, three time All-American champion and was also rated 69th greatest female athlete of the century by Sports illustrated in 1999. On January 24, 1986, she was substituted out of a game in Japan and suffered SCA while on the bench, resulting in SCD at age 31. Autopsy reports demonstrated an aortic dissection from undiagnosed Marfan syndrome. Her death prompted more research and attention to a disease that less extensively characterized in the 1980s. Multiple examinations by professional medical personnel were unremarkable for signs of Marfan's syndrome except for her height which one would expect with Olympians.

Sergei Grinkov was a pair skater with his wife Ekaterina Gordeeva. He won the Olympic championship in 1988 and 1994 and also four world championships. Amidst training with his wife in Lake Placid, New York in 1995 for the Stars on Ice tour, he suffered SCA. The etiology was a lethal myocardial infarction at a young age of 28. Autopsy showed a near-complete occlusion of the left anterior descending and diagonal arteries. He was discovered to have a genetic platelet antigen-2 (PLA-2) polymorphism which predisposes one to arterial thrombi. His father was noted to have prematurely died from a heart attack at age 40.

"Pistol" Pete Maravich, college basketball's all-time leading scorer with 3,667 points, was named the greatest college basketball player of all time by ESPN in 2005. Having excelled for Louisiana State University and 3 different NBA teams, he was named one of the 50 Greatest Players in NBA History in 1996. He was one of the youngest players inducted into the Naismith Memorial Basketball Hall of Fame. In January 1988, he suffered SCA at a promotional game at a church gymnasium in California, minutes following appearance on a national radio show. He was pronounced dead at the hospital at age 40 years. The coroner's reported the absence of a left coronary artery and chronic myocardial fibrosis due to ischemia from a single right coronary artery supplying his entire heart. None of his previous medical examinations raised suspicion of cardiovascular defects and his long successful stint in sports was remarkable considering the limited survival of patients with the underlying pathology.

Jim Fixx was the author of the New York Times best-selling book The Complete Book of Running which sold over a million copies. He advocated that regardless of diet or genetic susceptibility, an individual

Table 4: Survival Outcomes in Studies Evaluating the Efficacy of Automated Electrical Defibrillators in Out-of-the Hospital Cardiac Arrest

Investigator	Study Design	Sample Size	Study Comparison	Outcomes
Hansen et al.[29]	Retrospective (CARES Registry)	N = 4,961	Impact of providing focused training for BS and FRs on survival in OHCA	BS resuscitation had higher survival rates: EMS (CPR + Defibrillation)= 15.2% BS (CPR + Defibrillation)= 33.6% BS CPR + FR Defibrillation= 24.2% FR CPR + Defibrillation= 25.2%
Berdowski et al.[26]	Retrospective	N = 2,833	Onsite vs. dispatched AED on time to defibrillation and NIS to discharge	Onsite AED: 4.1 min, NIS 49.6% Dispatched AED: 8.5 min, NIS 17.2%
Blom et al.[28]	Retrospective	N = 6,133	Is NIS after OHCA due to AED use in those with initial shockable rhtyhms?	NIS: 29.1% (no AED) vs. 41.4% (with AED)
Capucci et al.[32]	Prospective	N = 3,366	AED use by FR vs. EMS on survival to discharge	Survival : FR (41.4%) vs. EMS: 5.9%
Ringh et al.[33]	Retrospective	N = 474	Defibrillation by FR vs. EMS on 1-month survival	1-month survival: FR with public AEDs (70%) vs. EMS 31%
Lijovic et al.[34]	Retrospective (Victorian Ambulance Cardiac Arrest Registry)	N = 2,270	AED use by BS vs. EMS on survival to discharge	Survival to discharge: 45% (BS) vs. 31% (EMS)
Nakahara et al.[19]	Retrospective (Japanese Nationwide OHCA Registry)	N = 167,912	Defibrillation by FR vs. EMS on NIS to discharge	NIS: 40.7% (BS) vs. 15% (EMS)
Hallstrom et al.[31]	Prospective, randomized public access defibrillation trial	N = 3,413	CPR only vs. CPR+AED by trained laypersons on survival to discharge following OHCA	23.4% (CPR+AED) vs. 14% (CPR only)
Agerskov et al.[25]	Retrospective (Mobile Emergency Care Unit and the Danish Cardiac Arrest Registry)	N = 521	30-day survival for AED application before and after EMS arrival	AED before EMS (64%) vs. after EMS arrival (37%); 15% OHCAs occurred within 100m of AED but only 3.8% had AED use
Weisfeldt et al.[35]	Prospective population based cohort study	N = 13,769	AED vs. no AED use before EMS arrival on survival to discharge	Survival: no AED (9%) vs. AED only (24%) vs. AED+shock (38%)
Eckstein et al.[27]	Prospective, longitudinal and observational study	N = 59	Impact of public access AED on survival to diacharge	Public access AED use = 69% NIS to discharge.

AED = automated external defibrillator; BS = bystander; CARES =Cardiac Arrest Registry to Enhance Survival; CPR = cardiopulmonary resuscitation; EMS = emergency medical services; FR = first responder; NIS = neurologically intact survival; OHCA = outside of hospital cardiac arrest

would not suffer a fatal heart attack if they were a non-smoker and exercised sufficiently. Fixx popularized running and was considered the face of America's fitness revolution. Prior to embarking on a fitness journey, he was a heavy smoker and weighed over 220 pounds and had a familial history of premature myocardial infarctions. By the time his first book was published he had lost 60-70 pounds and quit smoking. On July 20, 1984, Fixx was on a daily run when he suffered SCA from a fatal heart attack at age 52 years. Ironically, his demise triggered a debate on the benefits of physical exercise and life expectancy. Autopsy reports showed critical occlusions in all 3 coronary arteries, diffuse atherosclerosis of the aorta and peripheral arteries and at least 3 myocardial infarctions in the weeks prior to death. He exhibited no angina symptoms and was noted to run 10 miles a day.

Zena Ray "Zeke" Upshaw was American professional basketball player who played in the D league after going undrafted in the NBA. In the final game of the regular reason, he collapsed and was taken to the hospital. He passed away 2 days later and autopsy showed hypertrophic cardiomyopathy as the cause of SCD. His death raised questions regarding failure of the NBA to have proper policies and procedures in place to detect players who could potentially suffer SCD.

Alexander Dale Oen was a Norwegian swimmer who was the first male from his country to win a Gold medal at a major international long course championship. He collapsed while taking a shower at training camp. His teammates found him and started CPR, however he was pronounced dead upon arriving to the hospital. Cause of death was myocardial infarction from underlying severe atherosclerotic disease, and resultant triple vessel disease with up to 90% occlusion.

Darryl Kile was an American Major League baseball starting pitcher for the St. Louis Cardinals and in June 2002, he was missing from pre-game warmups and personnel found him dead on his hotel bed. Cause of death was myocardial infarction at the age of 33 and an autopsy performed showed 90% occlusion in two coronary arteries.

Nick Knapp, a college basketball player for Northwestern in 1994, was one of the lucky ones who survived a sudden cardiac arrest. While playing a preseason pickup game in Peoria, Nick collapsed. Luckily, Nick's dad, certified CPR instructor, along with an off-duty firefighter, happened to be at the scene and started CPR until paramedics arrived shortly afterwards. After 3 rounds of shock via defibrillator, he gained return of spontaneous circulation. He was diagnosed with hypertrophic cardiomyopathy afterwards. His case underscores the importance of CPR training and awareness among the general public.

Lastly, Omar Carter, a 25-year old during a semi-professional basketball game, on July 2013 suddenly collapsed and suffered a 13-minute SCA. He laid there for 13 minutes waiting for someone to start CPR until paramedics arrived. Fortunately, he survived. To show his gratitude and increase awareness regarding sudden cardiac

arrest, CPR and AEDs, he has started a foundation called 'Omar Carter Foundation' which so far has helped teach CPR to more than 15,000 people. His goal is to teach 1 million people bystander CPR so people aren't afraid to step in and start resuscitation if they witness a sudden cardiac arrest until paramedics arrive. His foundation also works to identify locations for AED devices along with community outreach.

The superlative physical fitness of athletes and the success in their careers often leads people to believe they are protected from heart disease. Contrary to this belief, there is often considerable discussion regarding the adequacy and efficacy of contemporary screening modalities in a special population such as athletes. The initial manifestation of underlying undetected heart disease pathology as SCD and the paucity of symptoms often associated with these conditions often pose a diagnostic challenge to cardiologists. There remain several clinically pertinent questions: Whom to screen? How to screen? Do we screen for all possible genetic and developmental pathological entities? How effective are our contemporary detection techniques? Does early detection lead to change in practice? Is it ethical to recommend refrainment from sports if such a condition is detected? How cost effective are our strategies? The relatively low incidence of these conditions has imposed heavy reliance on expert consensus rather than randomized research evidence.

Difference in Screening and Workup Protocols between the European Society of Cardiology and the American Heart Association

Continuous Professional societies like European Society of Cardiology (ESC) and the American Heart Association (AHA) have presented clinicians with recommendations and a body of evidence to guide screening of athletes.[7, 8] The European recommendations are based upon a well validated screening model derived from the Italian guidelines called COCIS providing data spanning 25 years.[9] The efficacy of the nationwide systematic preparticipation athletic screening introduced in Italy in 1982 is underscored by a staggering 89% reduction in SCD among athletes (driven by reduction in SCD from cardiomyopathies) as compared to the unscreened non-athletic general population.[10, 11] The American Heart Association does not have a screening program on a national level as in Italy or Israel and is heavily reliant on a 14-point history and physical examination model alone.[12] Both these guidelines are similar in multiple regards; However, a strikingly aggressive nature of screening, further workup of individuals identified on screening and also restriction from competitive sports are noted with the European guidelines.[8, 13] Contrasting recommendations from both professional societies are noted in [Table 3].[13]

The Italian Approach

Contemporary literature suggests a more stringent and aggressive screening and diagnostic approach in Europe with a body of evidence emanating from an Italian screening model introduced in 1982, which mandates annual history and physical examinations coupled with a 12-lead EKG at the Center of Sports Medicine in Padua.[13] Over a span of 26 years, this model has elicited a staggering 89% reduction in SCD among screened athletes while the incidence has remained static in unscreened individuals, thereby leading to endorsement of this model by the International Olympic Committee medical commission and the ESC.[13] Similar efficacious results were noted in identification of subclinical HCM in young athletes despite the absence of echocardiography as a diagnostic tool, clearly reinstating the robust and well-validated nature of this screening model.[11] Of note, the Italian government mandates procurement of an eligibility certificate in all individuals willing to participate in competitive sports after a rigorous screening process and an annual medical assessment.[14] None of the other European countries and the U.S. advocate for this requirement. In the U.S., there is no law which requires medical clearance prior to participation in school and college level competitive sports. Moreover, the screening process is exclusively conducted by sports medicine specialists as opposed to the U.S where the process is conducted by physician volunteers and other allied medical professionals which could potentially offer room for errors.

Limitations of an Expansive Screening Process and Heterogeneity in Outcomes Following Adoption of Electrocardiograms as a Routine Screening Tool

Presently, the screening process recommended by the ACC/AHA for prescreening of young healthy individuals aged 12-25 years does not include a 12-lead EKG.[15] Evidence suggesting beneficial results remains isolated to the Italian screening model. Data from U.S. investigating this effect has shown lack of beneficial results with routine utilization of EKG as a screening tool.[16, 17] Similar strategies adopted in Israel have demonstrated no reduction in the incidence of SCD among athletes.[16] Differences in the pre-participation screening timeframes between studies from Italy and Israel could explain the discrepant findings (2 years [Italy] vs. 12 years [Israel]). Coincidentally, both studies had a high incidence of SCD in the 2-years prior to adoption of EKG as a routine mandatory screening tool (Italy: 3.6 per 100,000 person-years; Israel: 8.4 per 100,000 person-years). However, the Italian approach reported a significant reduction from 3.6 per 100,000 person-years with a 2-year pre-enforcement period to 0.4 per 100,000 person-years at the end of follow-up. In contrast, results from Israel noted a non-significant reduction in SCD from 2.6 per 100,000 person-years in a much longer 12-year pre-enforcement period to 1.1 per 100,000 person-years 12–years after adopting mandatory screening with EKGs. Interestingly, if the same 2-year pre-participation period similar to the Italian approach was analyzed in Israel, the same study demonstrated a significant reduction in SCD from 8.4 to 1.1 per 100,000 person-years. This raises doubts whether the perceived lack of benefit noted by the Israeli experience is merely from a large yearly non-linear variation in SCD incidence with a lower pre-enforcement incidence rate due to averaging SCD incidence over a longer 12-year period as opposed to a 2-year period than a true lack of benefit from EKG screening enforcement. The persistently low incidence of SCD over 3 decades of follow-up after the adoption of mandatory screening in Italy further lends credence to EKG as an effective screening tool. However, similar results were not replicated in studies involving the U.S.[15]

The incidence of SCD among athletes remains considerably low at 1 in 200 000 in young athletes under 35 years of age.[4] With the lack of incremental value of EKG and echocardiography in detection and subsequent prevention of SCD in athletes, even with the best

of screening tests which provides a specificity approaching 100%, approximately 2000 athletes would need to be screened to successfully identify one true positive result which limits financial feasibility.[18] Recent literature elicits a cost-effectiveness ratio of $42,900/life-year saved with mandatory EKG screening in contrast to history and physical alone which provides higher a cost-effectiveness ratio of $76,100/life-year saved when compared to no screening.[19] These statistics demonstrate potential for an enormous financial burden on the healthcare system of the U.S. with inclusion of EKGs to the screening process. The lack of cost-effectiveness of adding EKG to history and physical versus the latter alone has been well demonstrated [20-22] and these findings were mainly driven by the high rate of false-positive results.

HCM is the most common cause of SCD in athletes with an estimated prevalence of 1:500 with a strong genetic component comprising of >1500 specific mutations and >11 involved genes.[23] Comprehensive screening of genetic abnormalities lacks feasibility and poses financial constraints when performed on a routine basis. In addition, the natural course of genotype-positive phenotype-negative individuals is variable in terms of phenotypic expression to overt HCM. [24] Data from screening of asymptomatic athletes in Italy has shown that routine mandatory echocardiography showed no incremental value over history, physical examination and 12-lead EKG in the detection of HCM. [11]

Automated External Defibrillators: A Potential Solution to Improve Survival Outcomes from Sudden Cardiac Arrest?

Previously published literature suggests 67% survival from SCA if immediate by-stander CPR, defibrillation and advanced cardiac life support (ACLS) were concurrently initiated within a minute of SCA.[25] These results were reinforced by Berdowski et al who demonstrated a 3.9-fold higher neurologically intact survival rate with onsite AED use for initial shockable rhythms.[26] The AHA has reported that up to 40% of out-of-the hospital SCAs are treated by lay public and only 60% are familiar with CPR.[27] Randomized trial evidence from the public access defibrillation trial has shown that volunteers trained in CPR administration coupled with AED use leads to substantial improvement in survival following SCA in public places without compromise in neurological function.[28] [Table 4] elucidates a summary of evidence suggesting enhanced outcomes following early use of AED to treat shockable rhythms. These results reinforce that timely AED use and effective CPR by well-trained individuals could translate into better survival outcomes. However, among out-of-the hospital SCAs, only 20% occur in public places while approximately 80% occur at home.[28] Extensive implantation of AED units and improving availability of trained personnel could improve outcomes in only approximately 20% of this subset, thereby limiting extrapolation to SCA occurring at home which unfortunately happens to be the major fraction among this subset.

However, in the relatively narrow spectrum of training fields and stadiums where athletes reach near-maximal limits of physical exertion, the substantial body of evidence depicting enhanced survival outcomes following SCA with early use of AEDs could be applicable. Prevalence of SCA in older spectators, coaches and officials is up to 80% of SCA cases in NCAA division I college sporting venues, the rest being accounted for by students and athletes.[29, 30] Importantly, survival to discharge was reported in 67% of these cases.[30] The prevalence of at least one AED in NCAA colleges, most commonly in the training room, is estimated at 90% in division I but only in 77% and 81% in divisions II-III, respectively, which is clearly suboptimal.[31] Division I colleges were also noted to have twice the median number of AEDs in comparison to lower divisions, thereby eliciting a disparity in the AED penetrance.[31] Increasing availability of AEDs across training locations, diversification of personnel to be trained in CPR (including athletes themselves, athletic faculty, emergency responders, security guards, and the common person), formulation and coordination of response plans, periodic monitoring of AED function and quality control of these interventions could potentially reduce death from SCA, specifically pertaining to athletes. Successful resuscitation after SCA could provide an opportunity to retrospectively identify, treat and prevent recurrence of SCA resulting from disease entities which were missed by the screening process.

Contrasting Approaches between Europe and America for Restrictions and Disqualification from Competitive Sports

In Italy, the decision to restrict or disqualify athletes from competitive sports once diagnosed with a condition with high risk for SCD is exclusively vested with the sports medicine physician. In addition, there is presence of a legal framework which gives the physician the authority to disqualify athletes from participation in sports which could be lethal. However, in the U.S., the Physician can only recommend but not restrict or disqualify athletes from participation. The ultimate authority remains a shared responsibility between the athlete and the educational institution, thereby shifting the autonomy to the individual and institution under question. Moreover, restriction from competitive sports, even if diagnosed with structural heart disease with high risk for SCD, is considered violation of personal freedom. In the absence of federal laws to uphold decisions made by specialized physicians on restriction and disqualification, the legal liabilities remain high and decision-making becomes more conservative in the U.S.

Conclusion

SCD in athletes, despite its low incidence, remains highly publicized. Contemporary evidence highlights multiple similarities in the screening process between Europe and the United States. Striking differences which are to be noted are the inclusion of 12-lead EKGs in the routine screening process and the shift in autonomy towards the sports medicine physician with regards to restriction from competitive sports in confirmed cases of increased risk for SCD in Europe. A more expansive screening process would entail a less-evidence based approach and a higher financial burden on the health system. An alternative to an expansive screening process could be a robust secondary prevention system comprising of widespread availability of AEDs and improving the penetration of CPR training in athletes themselves and athletic trainers to provide timely and effective resuscitation to reduce death following SCA. This strategy could provide a feasible and financially viable diagnostic and therapeutic window to address the underlying etiology of SCA and to prevent further occurrence of SCD. The decision to restrict athletes from competitive sports in the setting of high risk

for SCD remains a challenge since there exists a exists an unclear distinction between acceptable and prohibitive risk for SCD in this elite subgroup. The lack of a protective medico-legal framework and pertinent social repercussions associated with disqualification further impose a challenging situation on the sports physicians in the U.S, thereby contributing to a conservative approach. Further evidence could possibly help streamline the existing process.

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