Sudden Cardiac Death in Young Athletes

Christopher M. Rausch, MD
Medical Director, Cardiology Network of Care & Outreach
Director, Cardiopulmonary Exercise Laboratory
Director, Project ADAM Colorado
Children's Hospital Colorado and University of Colorado

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Disclosure

Christopher M. Rausch, MD

No relevant financial disclosures with ineligible companies to report.

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Overview

1. Case Presentation
2. Sudden cardiac death discussion
3. Screening and prevention

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Case Presentation

History of Present Illness

- 13-year-old male collapsed and became cyanotic while playing basketball
- Bystander unable to find pulse and began CPR
- EMS arrives and places defibrillator patches on the chest

Google image, June 2022

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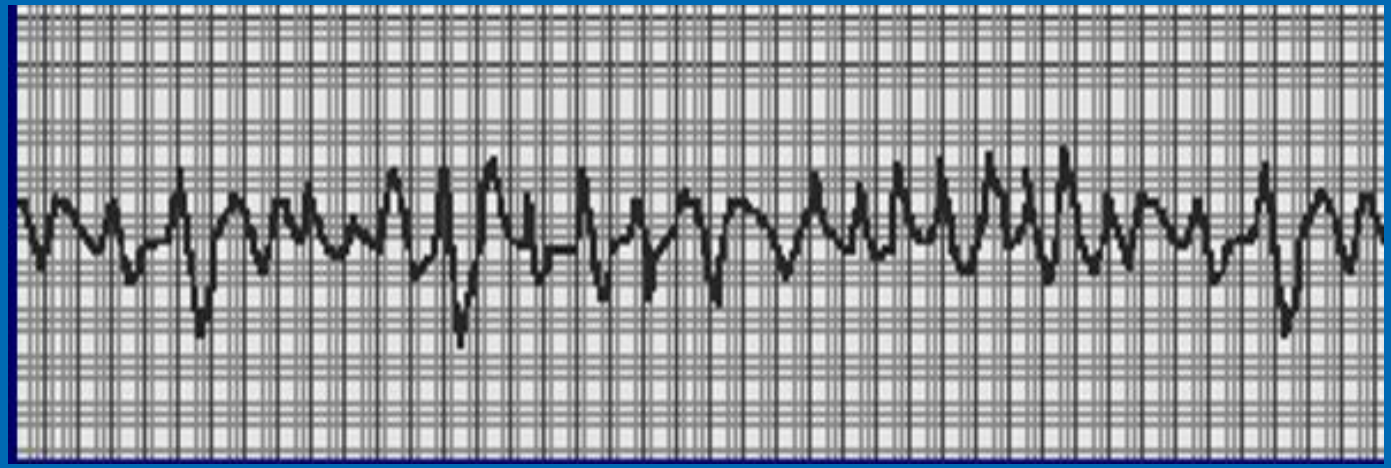
Ventricular Fibrillation (V Fib)



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Case Presentation

History of Present Illness

- Defibrillated with 100 joules causing successful conversion to sinus rhythm
- Bag and mask ventilation provided with improvement in mental status within 10-15 minutes
- Transferred to ICU

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See References slide for additional information.

Case Presentation

Past Medical History

- Episode of syncope 1 year prior
- No other major illnesses or hospitalizations

Family History

- Mother with episodes of lightheadedness and palpitations
- No history of sudden death
- No known inheritable diseases

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What is the most common cardiac cause of sudden death in athletes?

1. Tetralogy of Fallot
2. Commotio cordis
3. Hypertrophic cardiomyopathy
4. Long QT syndrome

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See References slide for additional information.

Sudden Cardiac Death

Incidence

- 1/40,000 - 1/300,000
  - AHA: 350,000 Americans each year (7,000 are children)
- Male>Female
- Occurs most commonly in the most common sports
- Two-thirds of the deaths occur during exercise, making SCA the leading cause of death in young athletes

Table 2 Incidence of sudden death stratified by athletic or general population

Country	Reference	Population	Years	Incidence per 100,000 person-years
Italy	Corrado [18]	Athletes	1980–1981	3.6
Italy	Corrado [18]	Athletes	2007–2008	0.4
Israel	Steinvil [39]	Athletes	1985–1997	2.54
Israel	Steinvil [39]	Athletes	1998–2009	2.66
USA	VanCamp [8]	Athletes	1983–1993	0.33
USA	Maron [40]	Athletes	1985–2006	0.44
Denmark	Holst [27]	Athletes	2000–2006	1.21
Denmark	Holst [27]	All children	2000–2006	3.76
Japan	Tanaka [38]	All children	1989–1997	1.32
USA	Eckart [50]	Military recruits	1997–2001	13
USA and Canada	Atkins [3]	All children ages 1–11	2005–2007	3.73
USA and Canada	Atkins [3]	All children ages 12–19	2005–2007	6.37

Modified from Link et al. [2]

J Interv Card Electrophysical (2013) 36: 167-175

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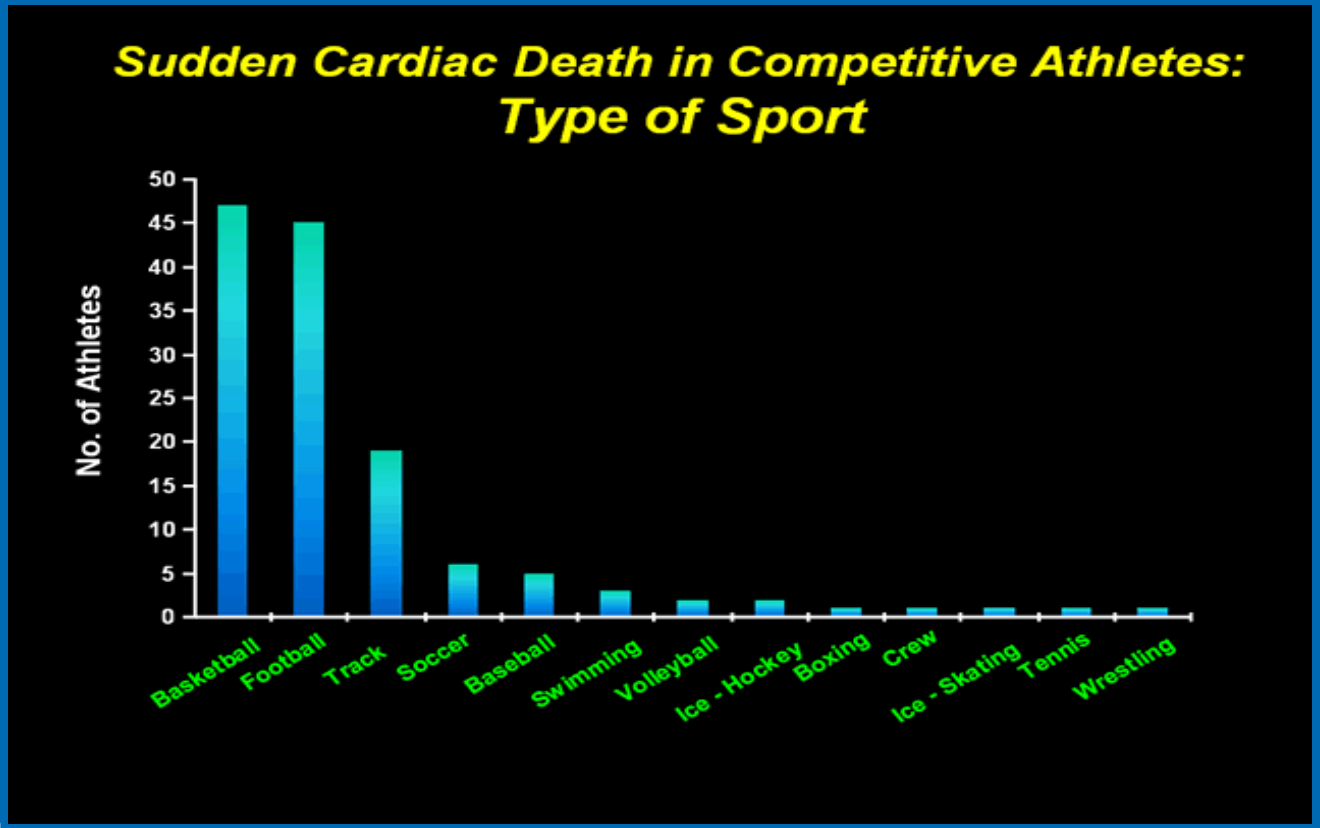
See References slide for additional information.

Sudden Cardiac Death



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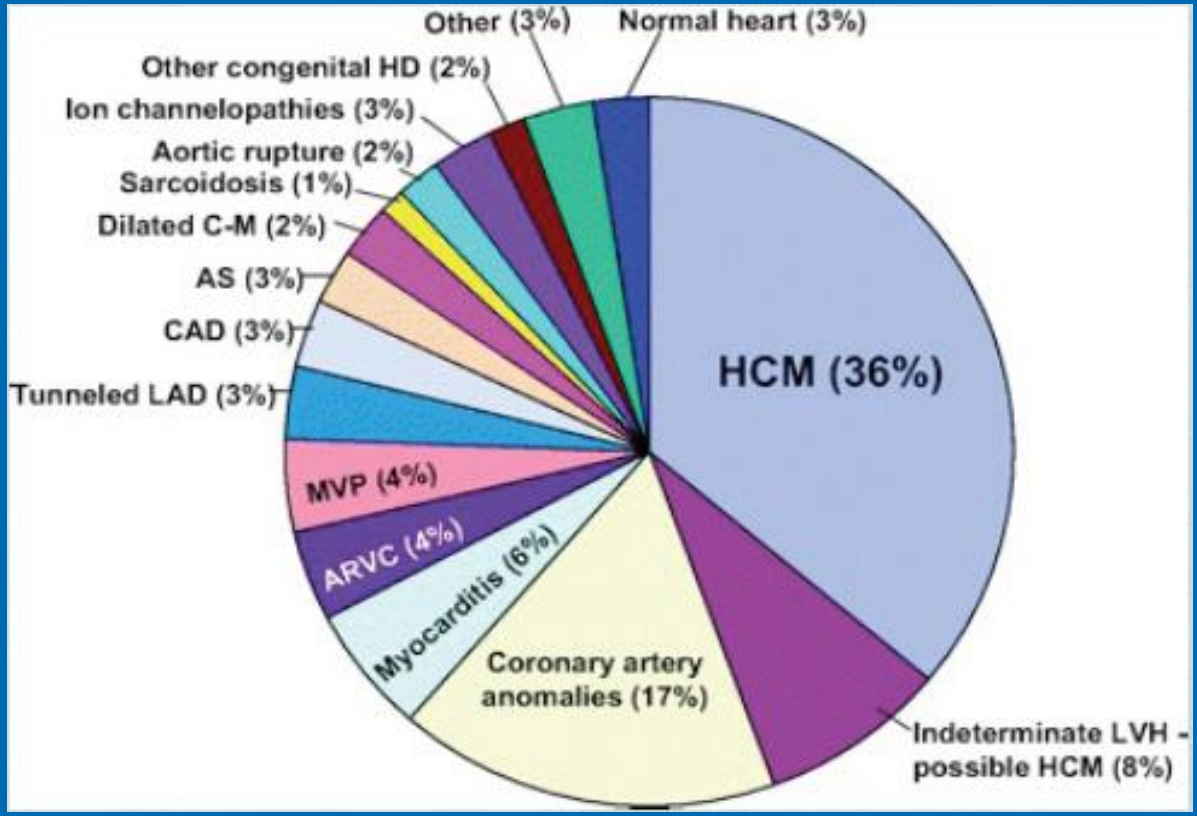
Maron, JAAC, 2003

See References slide for additional information.

Sudden Cardiac Death



AHA, Circulation: 2007

See References slide for additional information.

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Cardiomyopathies

Hypertrophic Cardiomyopathy (HCM)

Arrhythmogenic Right Ventricular Dysplasia/Cardiomyopathy (ARVD)

Dilated Cardiomyopathy

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See References slide for additional information.

Cardiomyopathies: Hypertrophic Cardiomyopathy

- Prevalence 1:500
- Left ventricular hypertrophy
  - May be concentric or variable pattern
  - Disorganized myocardial architecture
  - Predisposition for ventricular arrhythmias
- Autosomal dominant
  - Any of 12 different cardiac sarcomere genes
  - Over 400+ mutations identified

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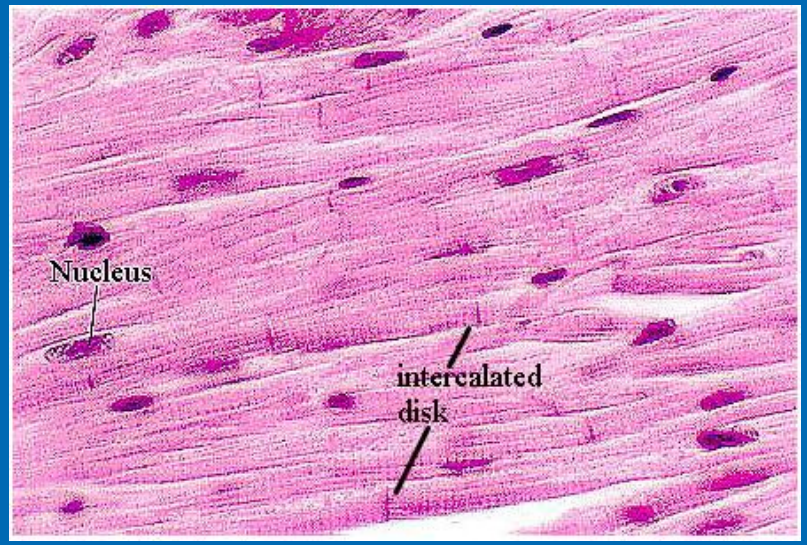
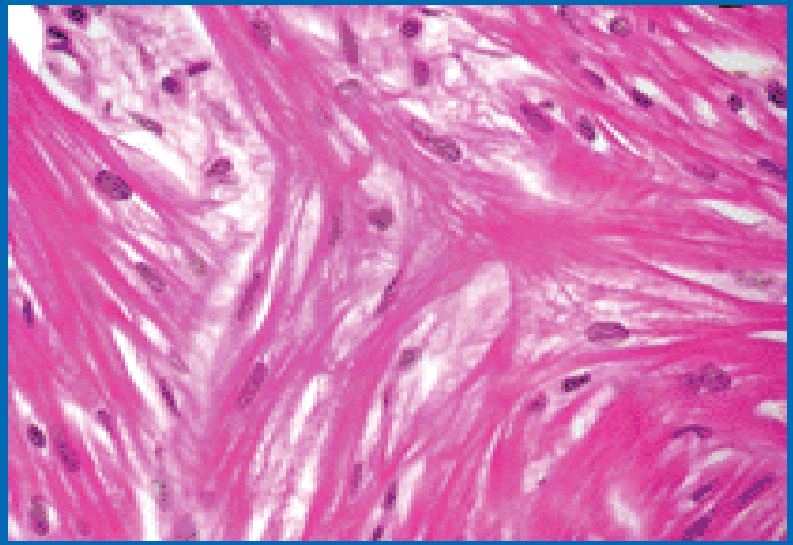
AHA, Circulation: 2007

See References slide for additional information.

Hypertrophic Cardiomyopathy





AHA, Circulation Research; 2017

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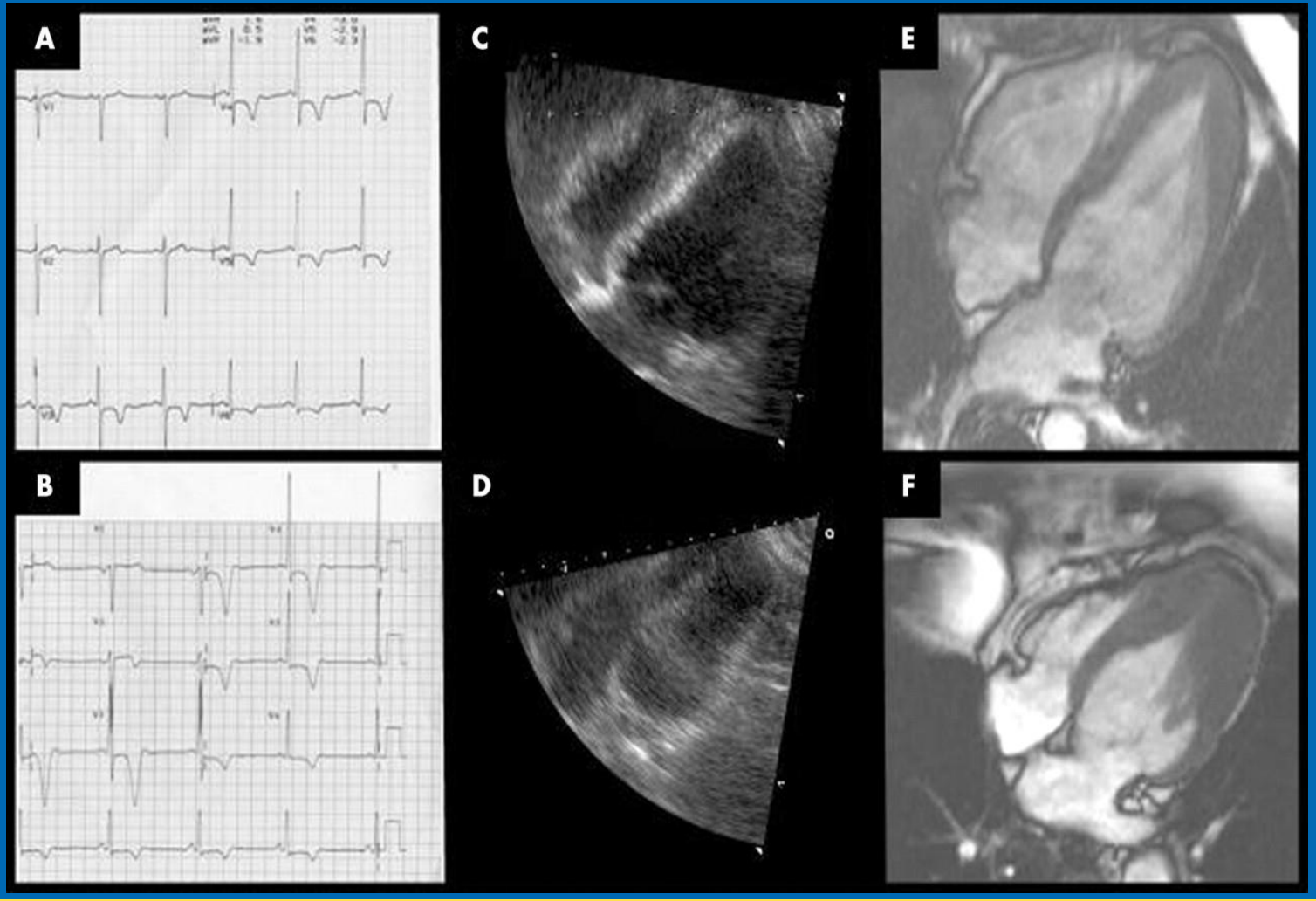
See References slide for additional information.

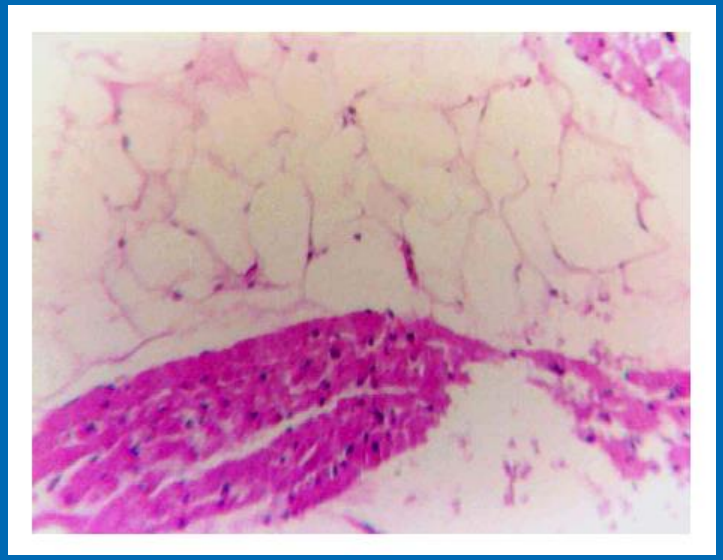


Moon, Heart; 2004

See References slide for additional information.

Cardiomyopathies: Arrhythmogenic Ventricular Cardiomyopathy

- Incidence 1:5000
- Autosomal dominant primarily (some recessive)
  - Multiple different genetic variants identified (at least 17)
  - Right and Left ventricular involvement
- Linked to disorder of desmosomes and adherens in the majority of cases
- Fibrofatty replacement of myocardium



Frances, Int J of Cardiol; 2006

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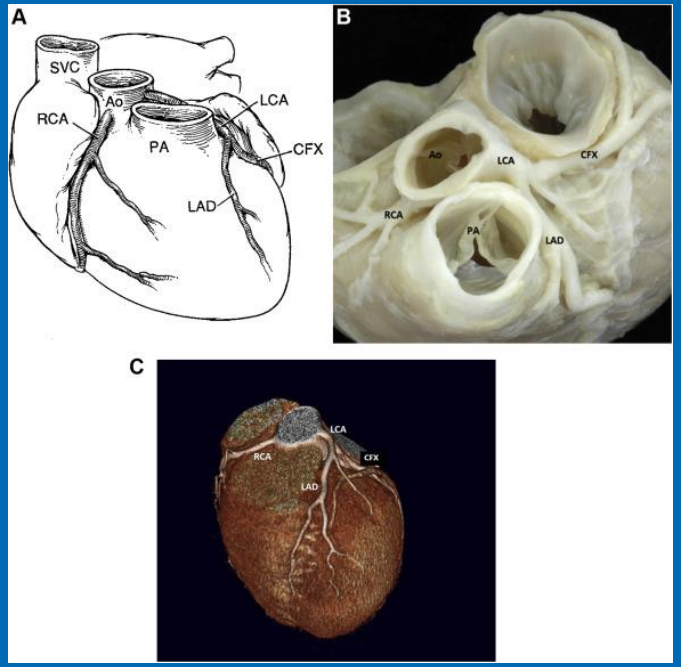
Congenital Coronary Artery Anomalies



Frommelt, JASE; 2020

- Coronary originating from the opposite sinus of Valsalva
  - Acute angle takeoff
  - Intramural coronary
- Myocardial bridge

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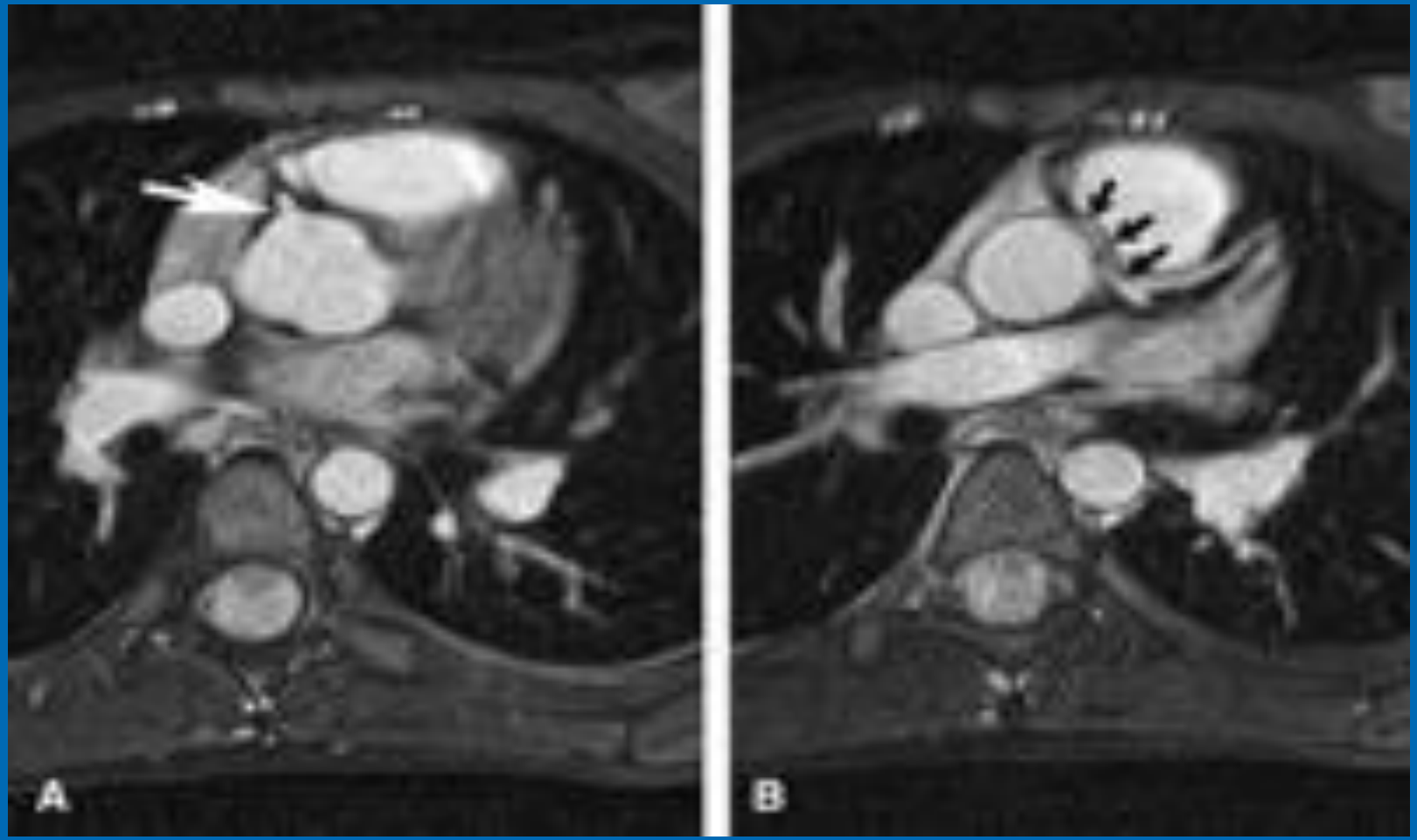
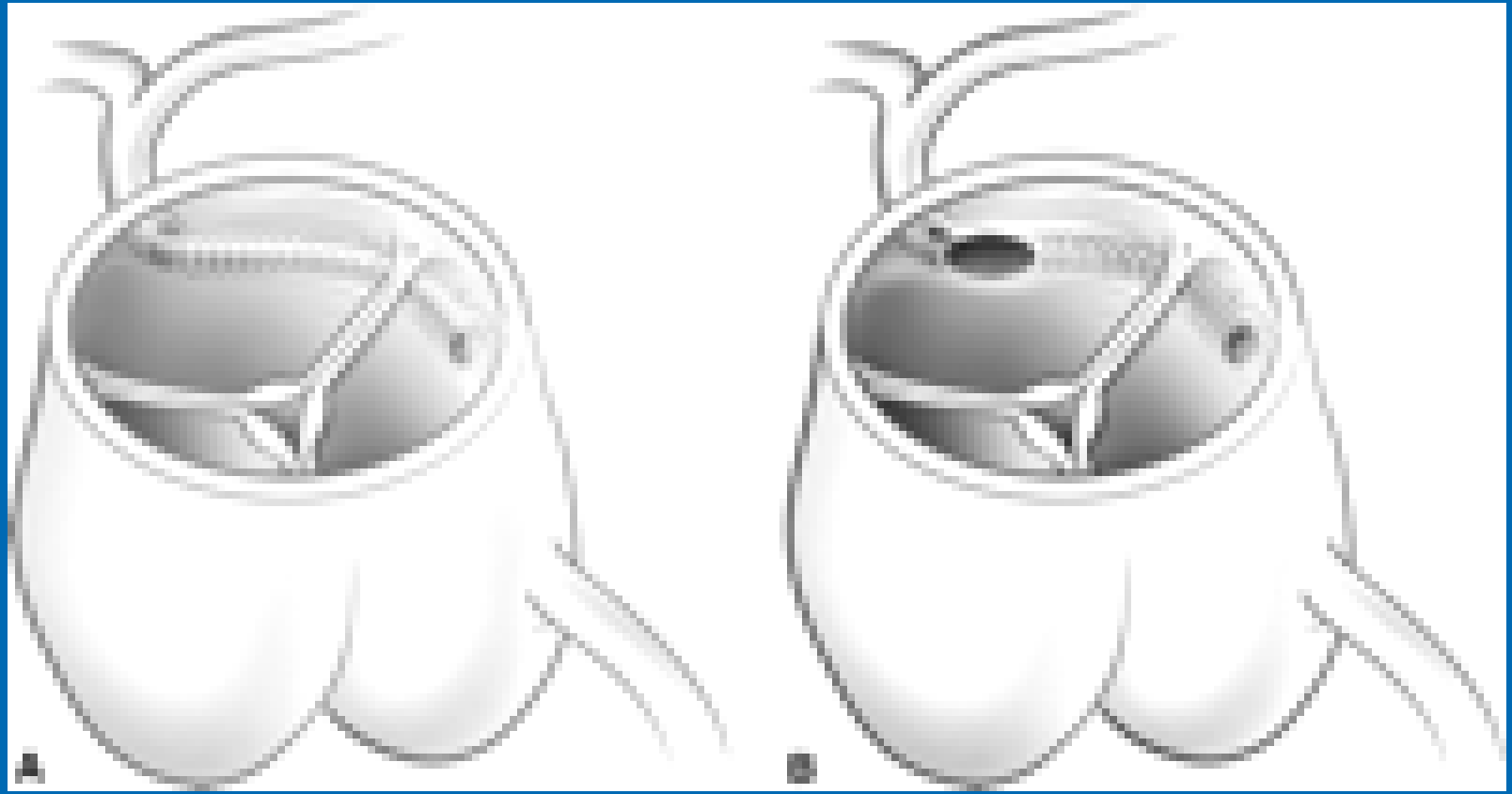
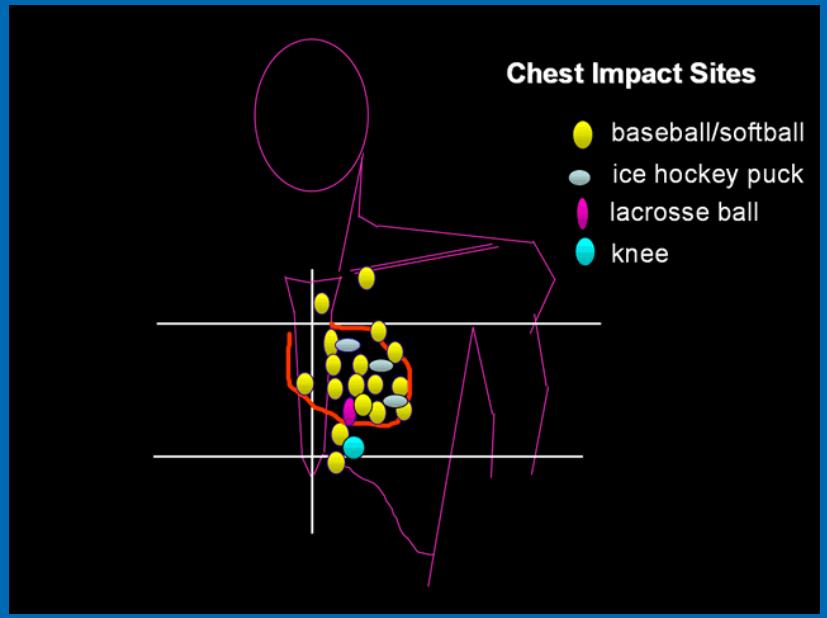
See References slide for additional information.





Commotio Cordis

- Blunt, low energy precordial blow
  - 15-30 ms before T-wave peak
  - VF
- No structural disease
- Mean age 13 yrs



Link, Circ; 1999

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See References slide for additional information.

Myocarditis

- Inflammatory disease of myocardium
- Most common etiology in North America is viral
  - Coxsackie A and B, ECHO viruses, and Influenza viruses
  - Drugs and toxins
- Inflammation, focal necrosis, and replacement fibrosis predisposes to ventricular arrhythmias

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See References slide for additional information.

COVID-19 Clinical Pathways

Cardiac Evaluation for Post COVID-19 (SARS-CoV-2) Infection Return to Play in Children and Adolescents

Return to Play Clinical Pathway

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Children's Hospital Colorado, 2022

See References slide for additional information.

Arrhythmias

- Wolff Parkinson White (WPW)
- Long QT syndrome
- Catecholaminergic Polymorphic Ventricular Tachycardia (CPVT)
- Brugada syndrome

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See References slide for additional information.

Wolff-Parkinson-White

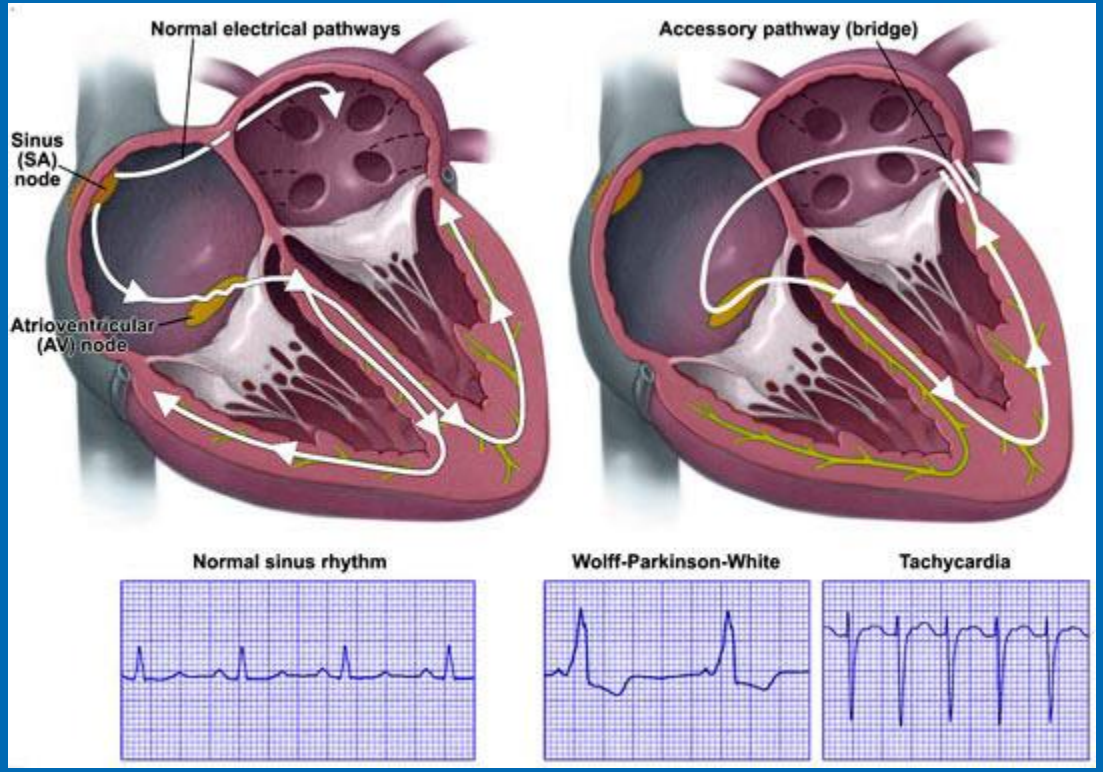

image from www.mayoclinic.org

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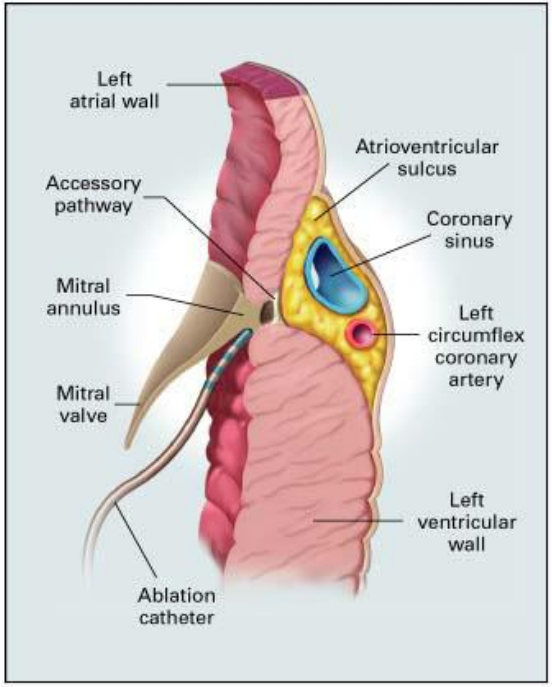
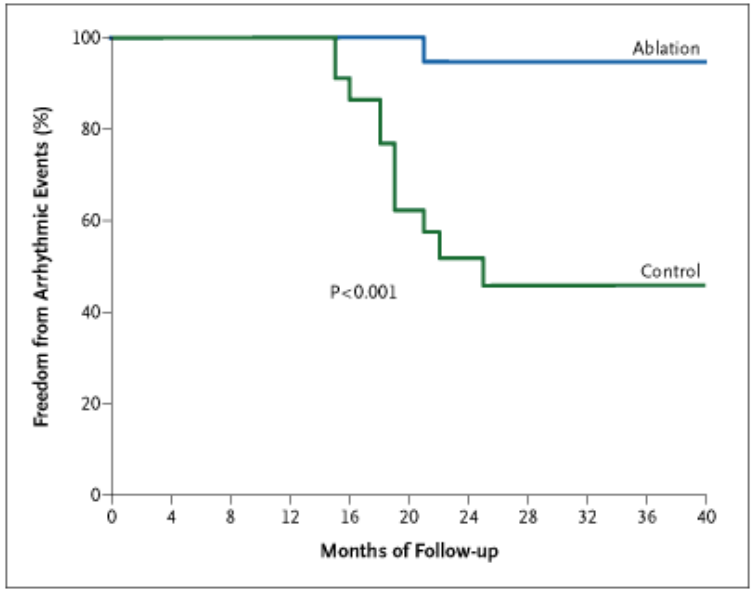
See References slide for additional information.

Wolff-Parkinson-White



Morady, NEJM; 1999



Papone, NEJM; 2004

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Long QT Syndrome

- Inherited mutations of cardiac ion channels
  - Autosomal dominant and recessive forms
  - 13 distinct genetic loci identified
  - Affects primarily K and Na channels
- Abnormal ion channel function results in delayed repolarization

Table 1. LQTS Genes

Gene	Syndrome	Frequency	Locus	Protein (Functional Effect)
KCNQ1 (LQT1)	RWS, JLNS	40–55	11p15.5	Kv7.1 (↓)
KCNH2 (LQT2)	RWS	30–45	7q35–36	Kv11.1 (↓)
SCN5A (LQT3)	RWS	5–10	3p21–p24	NaV1.5 (↑)
ANKB (LQT4)	RWS	<1%	4q25–q27	Ankyrin B (↓)
KCNE1 (LQT5)	RWS, JLNS	<1%	21q22.1	MinK (↓)
KCNE2 (LQT6)	RWS	<1%	21q22.1	MiRP1 (↓)
KCNJ2 (LQT7)	AS	<1%	17q23	Kir2.1 (↓)
CACNA1C (LQT8)	TS	<1%	12p13.3	L-type calcium channel (↑)
CAV3 (LQT9)	RWS	<1%	3p25	Caveolin 3 (↓)
SCN4B (LQT10)	RWS	<1%	11q23.3	Sodium channel-β4 (↓)
AKAP9 (LQT11)	RWS	<1%	7q21–q22	Yotiao (↓)
SNTA1 (LQT12)	RWS	<1%	20q11.2	Syntrophin α1 (↓)
KCNJ5 (LQT13)	RWS	<1%	11q24	Kir3.4 (↓)

Schwartz et al ,Circ Arr; 2012

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See References slide for additional information.

Long QT Syndrome

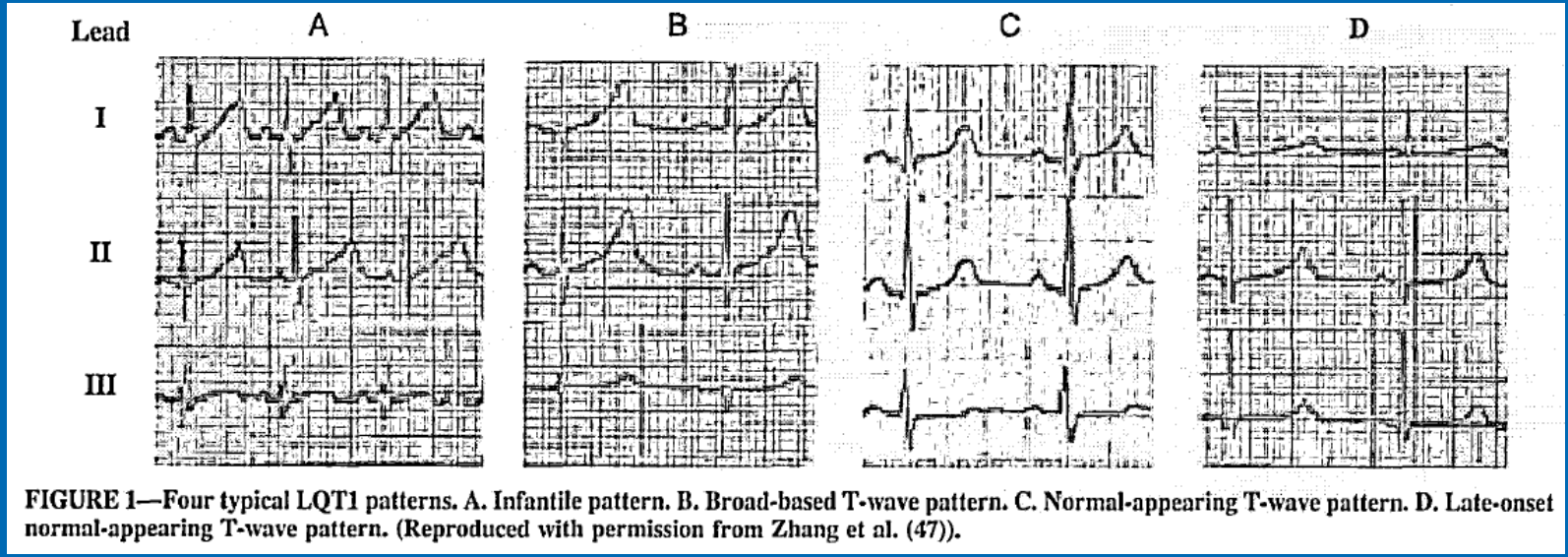

FIGURE 1—Four typical LQT1 patterns. A. Infantile pattern. B. Broad-based T-wave pattern. C. Normal-appearing T-wave pattern. D. Late-onset normal-appearing T-wave pattern. (Reproduced with permission from Zhang et al. (47)).

Zhang, 2014

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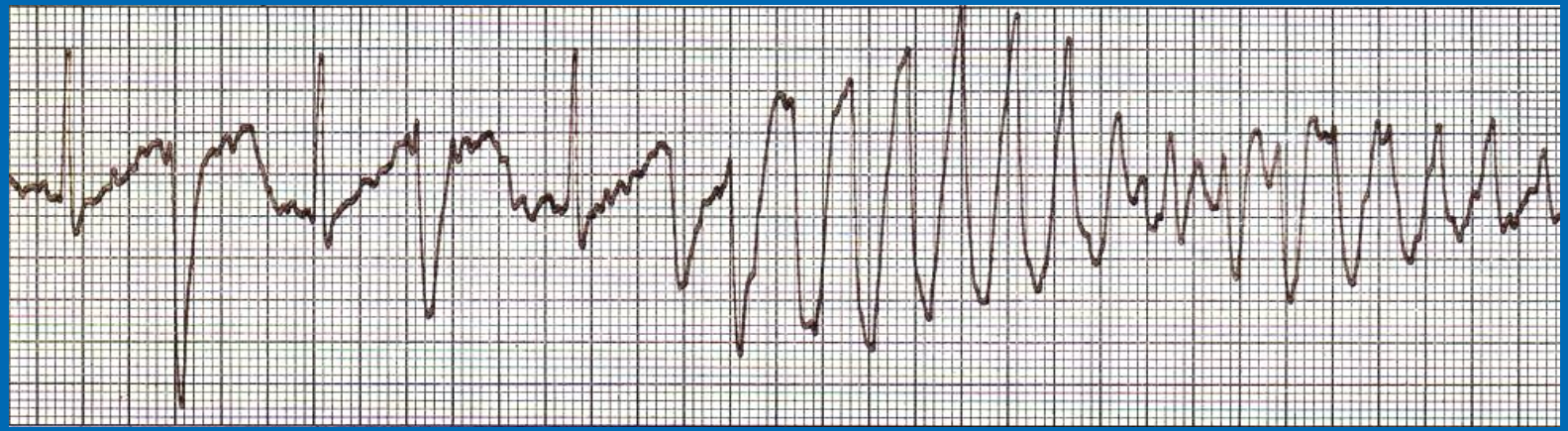
See References slide for additional information.

Long QT Syndrome

Torsades de pointes



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See References slide for additional information.

Long QT Syndrome

Probability of LQTS

≤ 1 pt = Low

2-3 pts = Intermediate

≥ 4 pts = High

	Points
ECG findings[a]	
A. QTc[b]	
> 480 ms	3
460–470 ms	2
450 ms (in males)	1
B. Torsade de pointes	2
C. T-wave alternans	1
D. Notched T wave in three leads	1
E. Low HR for age[c]	0.5
Clinical history	
A. Syncope[d]	
With stress	2
Without stress	1
B. Congenital deafness	0.5
Family history[e]	
A. Family members with definite LQTS[f]	1
B. Unexplained sudden cardiac death at younger than age 30 among immediate family members	0.5

Schwartz, Circ; 1993

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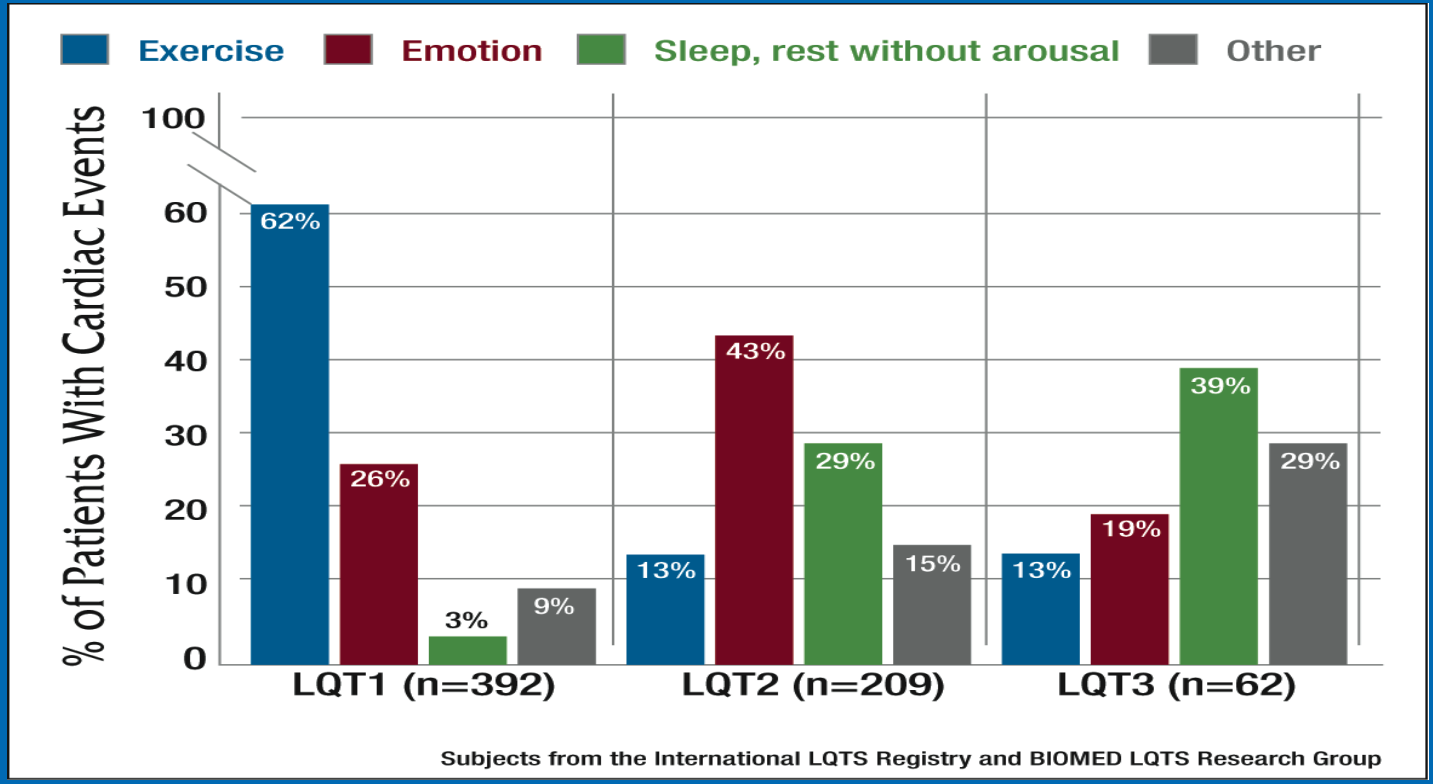
See References slide for additional information.

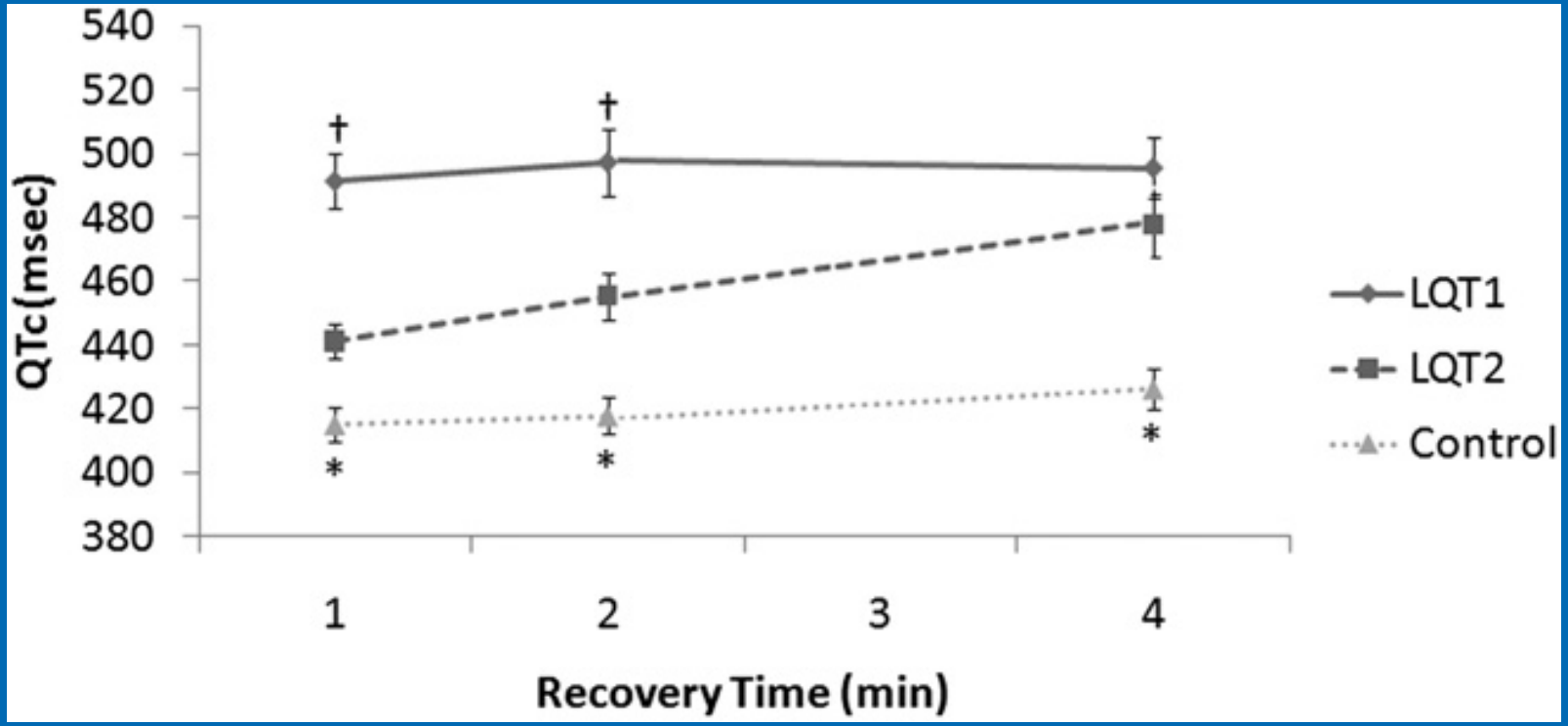
Arrhythmogenic Triggers Differ by LQTS Subtype



Schwartz PJ, Priori SG, Spazzolini C, et al, Circulation; 2001

See References slide for additional information.

Prolongation of QTc with exercise



Chattha, et al. Heart Rhythm 2010

See References slide for additional information.

Catecholaminergic Polymorphic Ventricular Tachycardia (CPVT)

Inherited arrhythmogenic disorder characterized by ventricular ectopy induced by exercise or emotional stress.

- Most commonly caused by mutations of the cardiac ryanodine receptor gene (*RYR2*).
- ~1%-2% of CPVT is caused by recessive mutations of the calsequestrin (*CASQ2*) gene.
- If left untreated, CPVT is lethal in 30%-50% of patients.
- The onset of CPVT symptoms typically occurs in childhood and adolescence.

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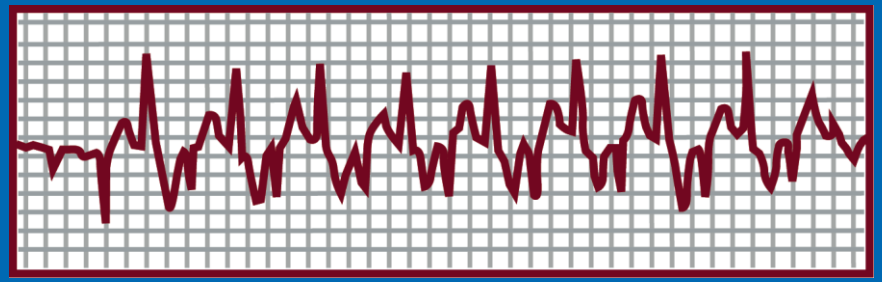
See References slide for additional information.

CPVT

- CPVT cannot be diagnosed on the basis of a resting ECG.
- Exercise stress testing is an important part of a CPVT workup.
  - However, in as many as 20% of CPVT patients, formal exercise
    stress testing will not produce ventricular ectopy.
- During exercise stress testing, bidirectional VT with a beat-to-beat 180-degree rotation of the QRS complex is often observed.



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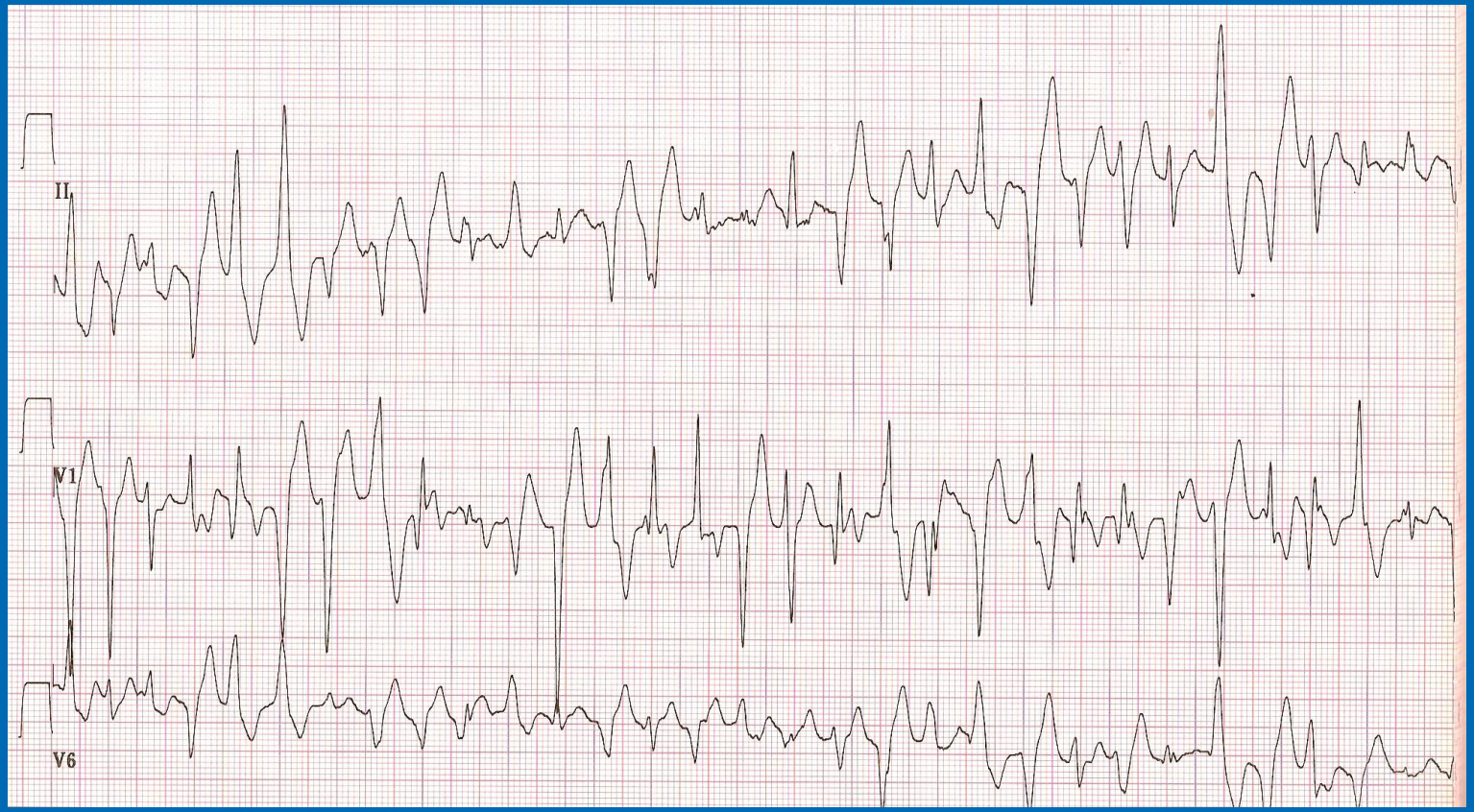
See References slide for additional information.

CPVT



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See References slide for additional information.

Brugada Syndrome

- Prevalence estimates vary from 5 – 66 / 10,000
- Increased prevalence in Asia, where identified as sudden unexplained nocturnal death syndrome (SUNDS)
- Male predominance in its phenotype (~8:1)
- Average age at presentation is 40 yr, but cases diagnosed from infancy into late 70s
- As in long QT syndrome Type 3, arrhythmia and death common during sleep and bradycardia

Probst, Circulation; 2007

See References slide for additional information.

Brugada Syndrome

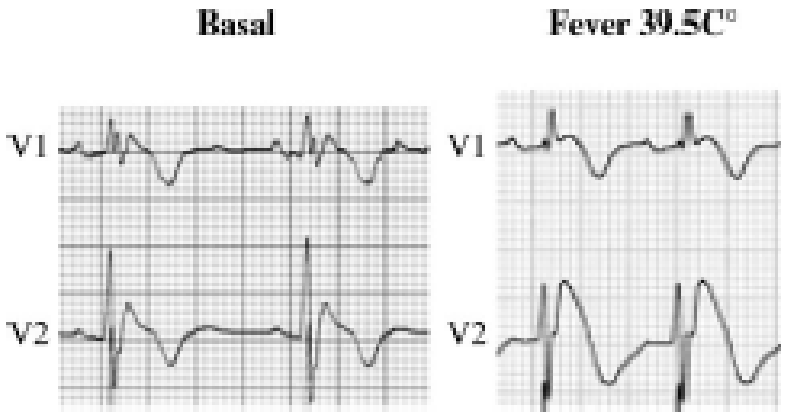

Figure 2. Representation of the right precordial leads V_1 and V_2 of a basal ECG (left) and an ECG taken during a febrile episode in a 5-year-old child. During fever, ST-segment elevation was accentuated, and coved-type morphology of the ST segment (>2 mm) occurred in lead V_2.

Probst, Circulation; 2007

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See References slide for additional information.

Case Conclusion

Work-up

- Echocardiogram demonstrated normal structure
- Cardiac catheterization confirmed normal structure
- EKG demonstrated sinus rhythm with corrected QT interval of 440-450 milliseconds
- Mother’s EKG showed a corrected QT interval of 480 milliseconds
- Started on Beta-blocker

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Case Conclusion

- Electrophysiology study
  - No inducible arrhythmias
  - QT prolongation with epinephrine challenge test

- Long QT syndrome diagnosis

- Dual chamber cardioverter/defibrillator placed

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See References slide for additional information.

What is the average survival for an out of hospital sudden cardiac arrest?

1. 79%
2. 52%
3. 37%
4. 7%
5. 0%

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See References slide for additional information.

Case Conclusion – What Worked?

- Average survival for out of hospital SCA = 5-10%
  - Improved survival if presenting rhythm is VF
- Immediate CPR
  - Survival decreases 10% per minute if no CPR
  - CRP prolongs VF and delays asystole
- Prompt defibrillation
  - CPR alone is unlikely to restore a perfusing rhythm

Link, et al; Circ; 2010

See References slide for additional information.

Screening

Preparticipation Evaluation

Electrocardiogram

Echocardiogram

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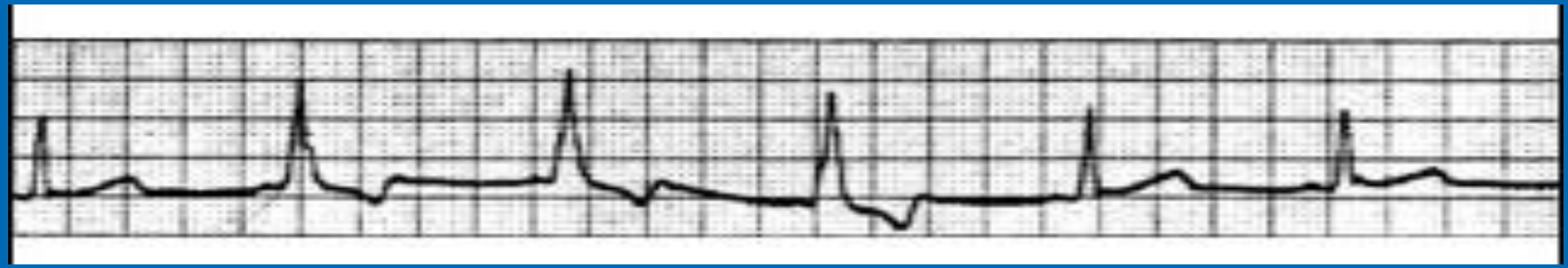
Electrocardiograms

Many causes of SCD produce EKG changes

- Abnormal in up to 95% of HCM
- Abnormal in >90% of ARVC



Electrocardiograms

ECG may pick up:

- HCM
- ARVC
- Dilated cardiomyopathy
- Pre-excitation syndromes
- Conduction diseases
- Long/short QT syndrome

ECG will not pick-up:

- CPVT
- Commotio cordis
- Marfan syndrome

- Valvular Heart Disease
- Congenital anomalies of coronary arteries
- Myocarditis
- Congenital heart disease

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See References slide for additional information.

Electrocardiograms - pro

- Italian study showed 10 fold decrease in SCD over a 20-year period (Corrado, JAMA, 2006)
  - >40,000 athletes aged 12-35 in Veneto, Italy from 1979-2004
  - Rate of SCD dropped 89% (P<0.001) from all causes
  - HCM diagnosed on ECG (82%) vs H/P (23%)

See References slide for additional information.

The Italian Experience

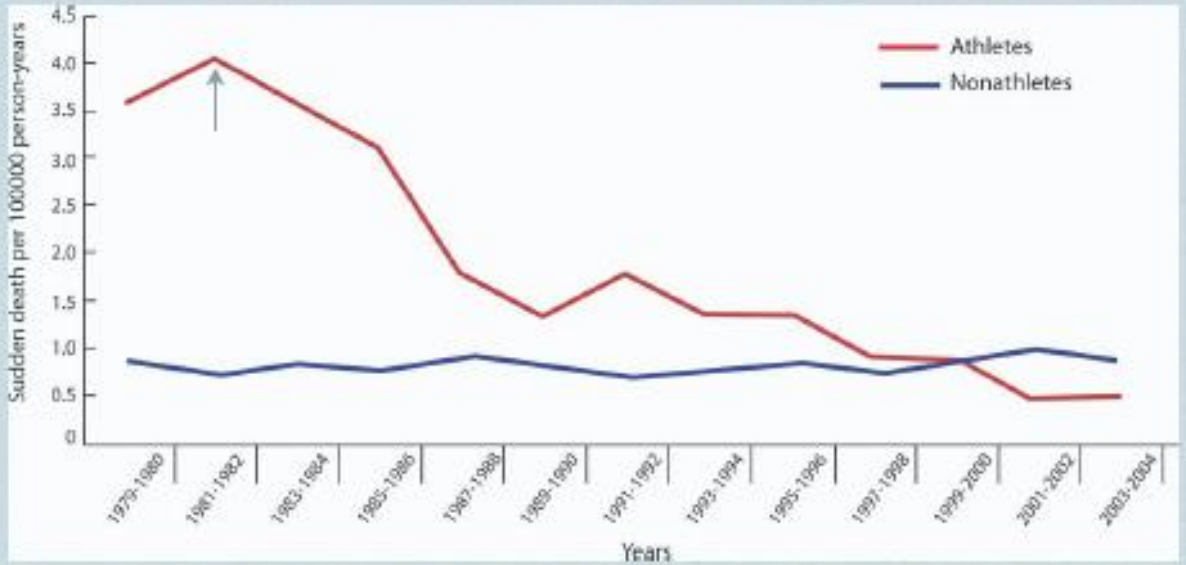

Figure 3 **Annual Incidence Rates of Sudden Cardiac Death Among Screened Competitive Athletes and Unscreened Nonathletes in the Veneto Region of Italy From 1979 to 2004**

Modified from Corrado et al. (23).

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Corrado, 2004

See References slide for additional information.

Is ECG Screening Cost Effective?

- 12 lead ECG is most cost effective: $44,000 per year of life saved
  - H&P would have to be 2x more sensitive for similar cost-effectiveness
  - Echocardiogram would have to decrease in cost 4.5x for similar cost-effectiveness

(Fuller, Med Sci Sports & Ex; 2000)

- Model based on Corrado estimates of sudden death
  - Adding ECG to H&P
    - Saves 2.06 life-years per 1000 athletes
    - increased cost $89 per athlete
    - Extra $42,900 ($21,200-$71,300) per life-year saved
  - H&P and ECG Versus NO SCREENING
    - Saves 2.66 life-years per 1000 athletes
    - $199 per athlete
    - $76,100 ($62,400-$130,000) per life-year saved

(Wheeler, Ann Intern Med; 2010)

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See References slide for additional information.

Electrocardiograms - con

- Italian study not applicable to US population
  - Large population of ARVC
- US screening unreasonable
  - 10-12 million young athletes
  - Athletes' EKGs frequently abnormal
  - 1.5 million abnormal EKG but only 35 true positives
  - $250,000 to detect one case of HCM (Maron, Circulation, 1996)
  - Medical legal (liability of PCP to read ECG)
  - Ethical (player disqualification)
  - Feasibility (Infrastructure)

Maron, Circulation, 1996

See References slide for additional information.

Electrocardiograms - con

Pediatric cardiologists in the U.S.	= 1,521
# of athletes to be screened	= 12 million
# of exams/ECGs to be performed by each pediatric cardiologist	= 7,890 / year = 658 / month = 150 / week

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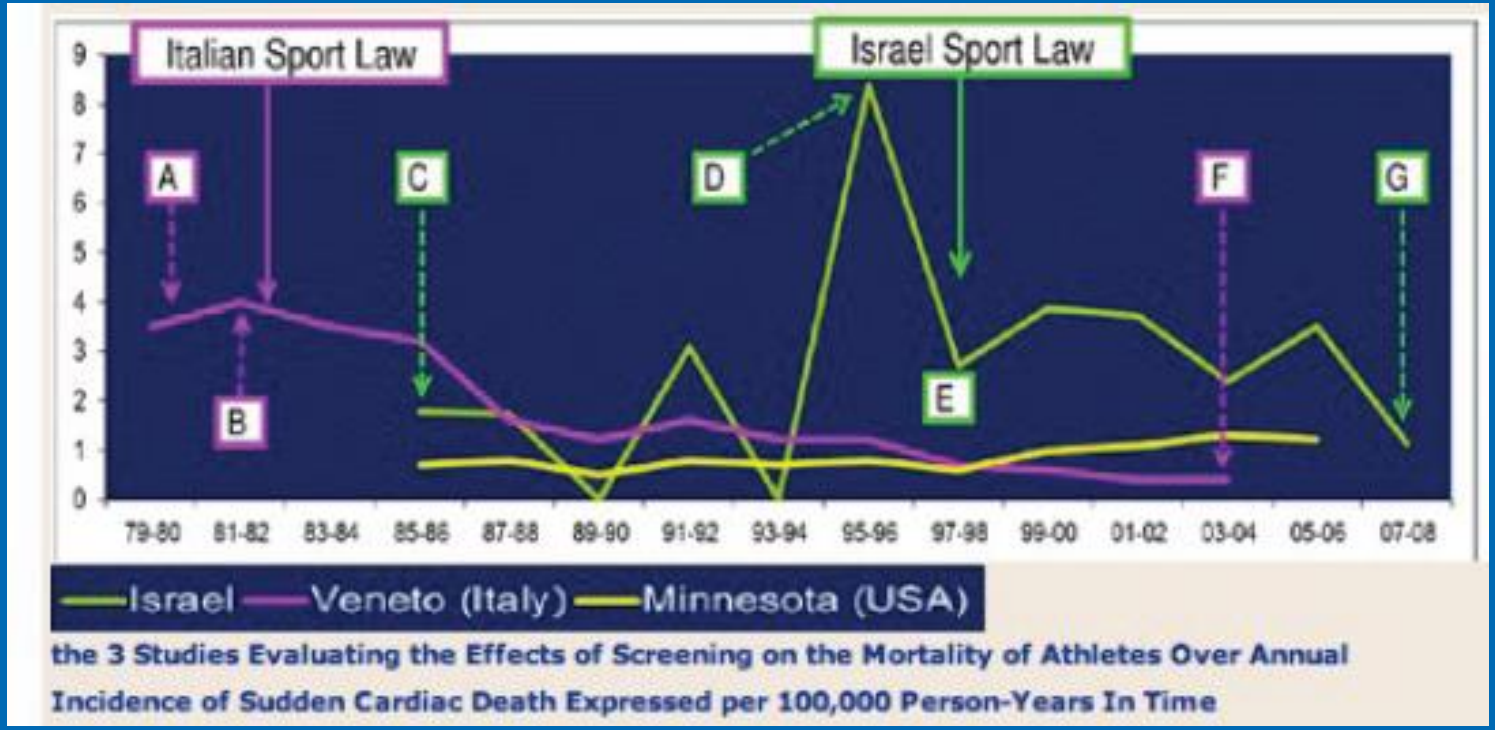
Maron, Circulation, 1996

See References slide for additional information.

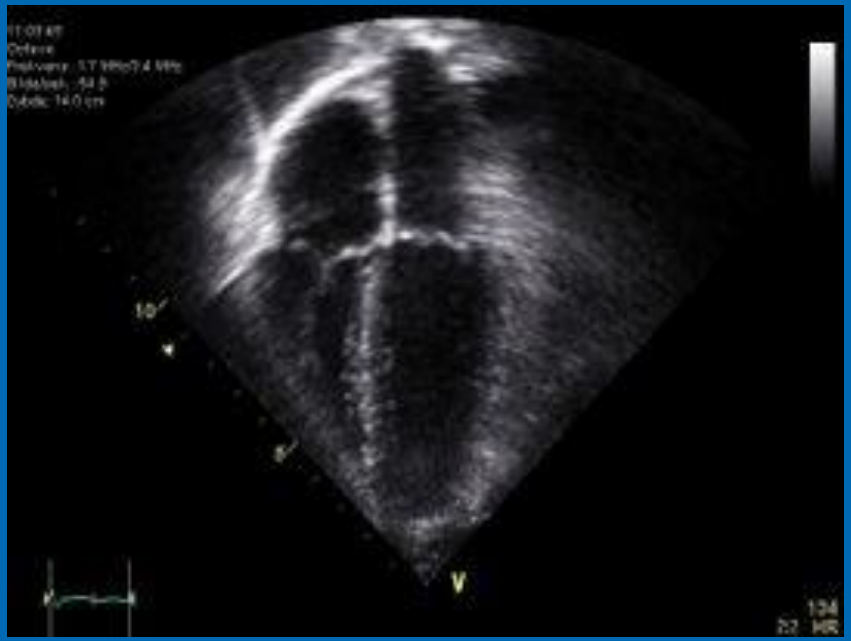
Does it make a difference?



Viskin, JACC; 2011

See References slide for additional information.

Echocardiograms



- Identify structural abnormalities
  - valvular disease, cardiomyopathy, coronary abnormalities, aortic root dilation, etc.
- Identify functional abnormalities
  - cardiomyopathy, myocarditis
- May not identify
  - arrhythmia syndromes, coronary abnormalities, early cardiomyopathy

See References slide for additional information.

Screening

$1.8 billion per year to screen US athletes

$30 million to detect one athlete at risk for sudden cardiac death

Moss and Adams'; 7th ed

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See References slide for additional information.

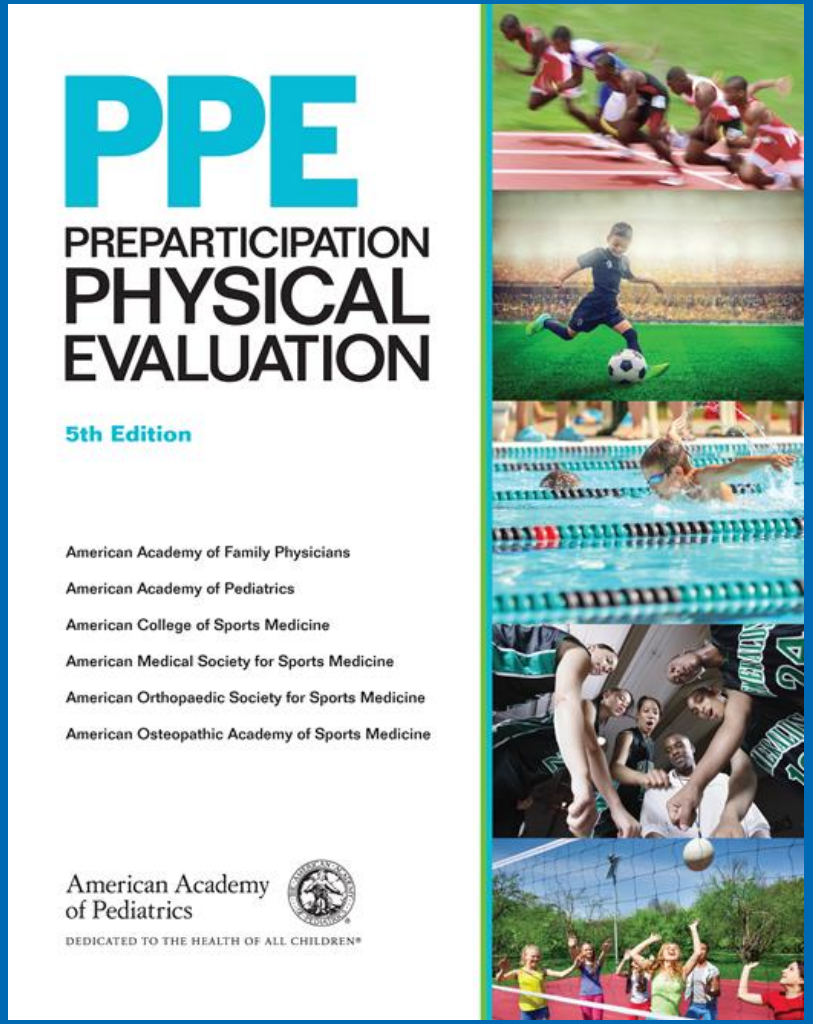
Screening

The Preparticipation evaluation

- Goal: identify clinically relevant cardiovascular abnormalities
  - Many causes of SCD are inheritable
  - Many patients with early symptoms
  - Identify noncardiac concerns

AHAJOKES.com, 2022

See References slide for additional information.



American Academy of Pediatrics, 2021

See References slide for additional information.

Screening - History

- Passed out during exercise?
- Passed out after exercise?
- Chest pain/discomfort during exercise?
- Heart race or skip beats with exercise?
- Test for heart?
- HTN, high cholesterol, heart murmur or infection?
- Sudden death in family?
- FHx heart condition?
- FHx death before 50?
- FHx Marfan Syndrome?

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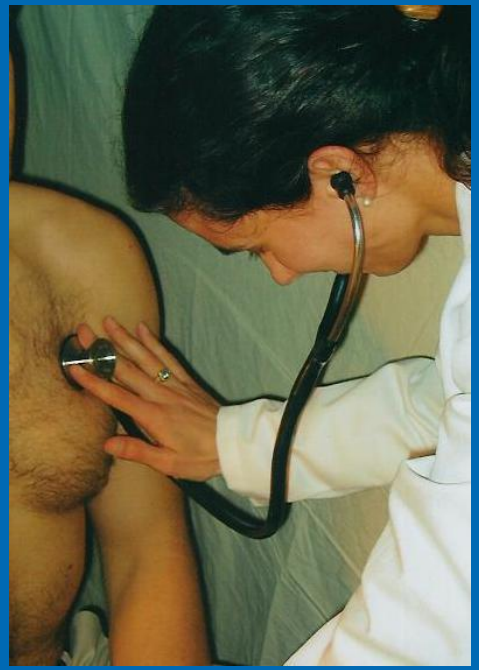
See References slide for additional information.

Screening - Exam

- Normal PE
- Blood pressure
  - F/U if abnormal
- Palpate pulses
- Cardiac auscultation
  - Supine and standing
- Marfan's stigmata



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See References slide for additional information.

The Pre-Participation Evaluation

Current practice makes an unclear picture

- Multiple venues
- Multiple practitioners with variable knowledge base (Glover, AJC; 2007)

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Glover, AJC; 2007

See References slide for additional information.

The Pre-Participation Evaluation

- Retrospectively, only 3% athletes who died of SCD were suspected to have predisposing cardiac disease by routine history and physical (Maron, JAMA; 1996)

- 40% of SCD events have unrecognized or underappreciated warning symptoms (Campbell, Pediatrics; 2006)

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See References slide for additional information.

Other interventions (AED, Mandatory CPR)?

Effectiveness of Emergency Response Planning for Sudden Cardiac Arrest in United States High Schools With Automated External Defibrillators

Jonathan A. Drezner, MD; Ashwin L. Rao, MD; Justin Heistand, MD; Megan K. Bloomingdale; Kimberly G. Harmon, MD

Table 1. Proportion of US High Schools With AED Programs That Train School Staff in CPR or AED Use and Include Staff in Annual Practice of the EAP for SCA

	CPR Trained, %	AED Trained, %	Practice EAP, %
Coaches	80	72	34
School nurses	75	71	22
Administrators	64	63	30
Teachers	49	45	22

Table 3. Comparison of Case Details of SCA in High School Student Athletes and Older Nonstudents

SCA Victims	Age (Range), y	Witnessed Collapse, n/N (%)	Seizure-Like Activity After Collapse, n/N (%)	Bystander CPR, n/N (%)	Time From Arrest to CPR, Mean; Median; Range, min	Shock Delivered, n/N (%)	Time From Arrest to First Shock, Mean; Median; Range, min	Survival to Hospital Discharge, n/N (%)
High school student athletes (n=14)	16 (14–17)	14/14 (100)	7/12 Reported (58)	13/14 (93)	1.5; 0.5; 0–5.75	13/14 (93)	3.6; 2.4; 0.75–11.5	9/14 (64)
Older nonstudents (n=22)	57 (42–71)	21/22 (95)	5/17 Reported (29)	21/22 (95)	0.8; 0.75; 0–1.75	19/22 (86)	1.8; 1.75; 0.5–3.25	14/22 (64)

Conclusions—School-based AED programs provide a high survival rate for both student athletes and older nonstudents who suffer SCA on school grounds. High schools are strongly encouraged to implement onsite AED programs as part of a comprehensive emergency response plan to SCA. (***Circulation*. 2009;120:518-525.**)

Is your school prepared for a cardiac emergency?

Development and Implementation of Heart Safe Schools in Your District

https://www.childrenscolorado.org/doctors-and-departments/departments/heart/programs-and-clinics/project-adam/

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Children's Hospital Colorado, Heart Programs, 2022

Conclusions

- SCD a tragedy that affects society's "models of health"
- Many causes of SCD include personal or family history
- Currently, PPE is the most accessible and affordable screening tool
- Use of adequate PPE forms needed
- Prompt CPR and defibrillation is critical to survival of SCA events

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See References slide for additional information.

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Google Image (June, 2022)https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.union-bulletin.com%2Fsports%2Fsports_columns%2Fcolumn-inside-the-amazing-convoluted-journey-marjon-beauchamp-took-from-yakima-to-the-nba-draft

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Thank You

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