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Exercise Induced Cardiac Remodeling



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Financial Disclosures

Affiliations:

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- Department of Defense
- National Football League Player’s Association
- American Medical Society for Sports Medicine

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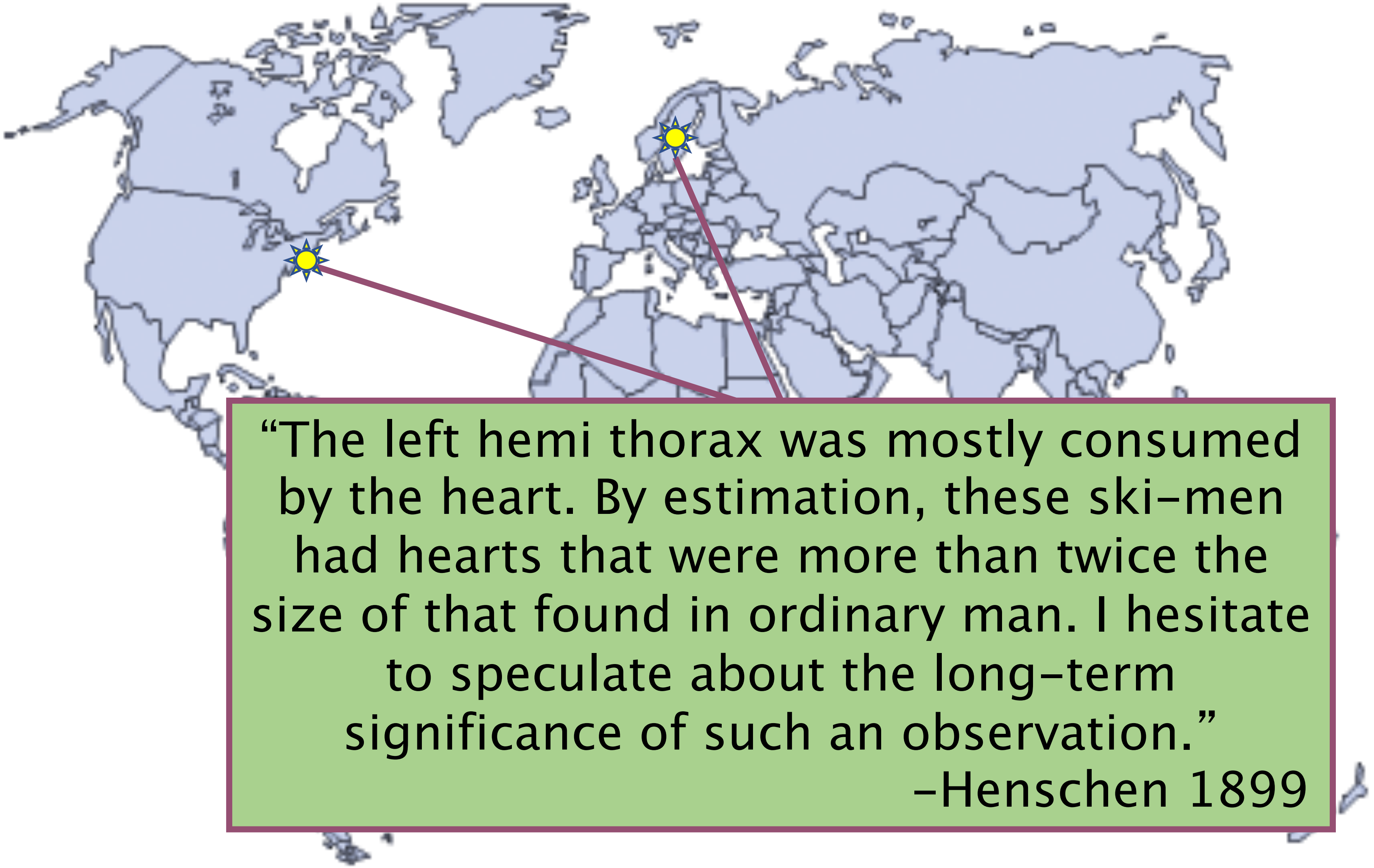
The Athlete's Heart

Cardiovascular Performance Program



"The left hemi thorax was mostly consumed by the heart. By estimation, these ski-men had hearts that were more than twice the size of that found in ordinary man. I hesitate to speculate about the long-term significance of such an observation."

–Henschen 1899

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The Athlete's Heart

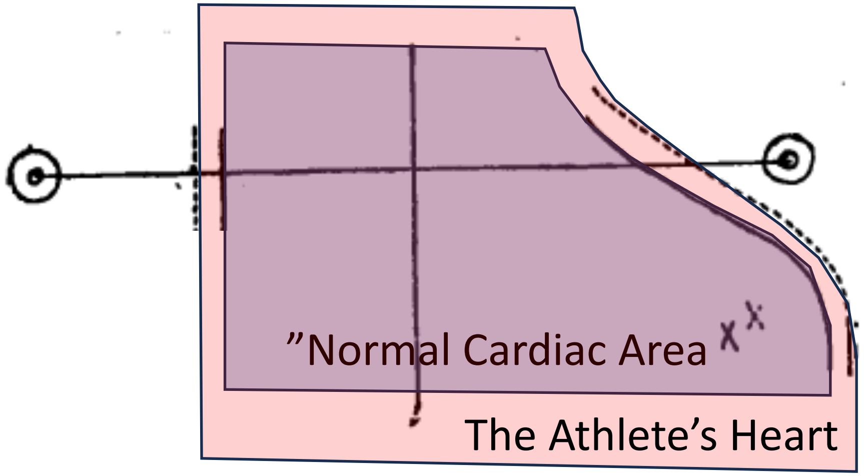
Cardiovascular Performance Program

MGH 1811

Original Articles.

THE EFFECTS OF TRAINING.
A STUDY OF THE HARVARD UNIVERSITY CREWS.

BY EUGENE A. DARLING, M.D., CAMBRIDGE.



BOSTON MEDICAL AND SURGICAL JOURNAL. [SEPTEMBER 7, 1899.

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The Athlete's Heart

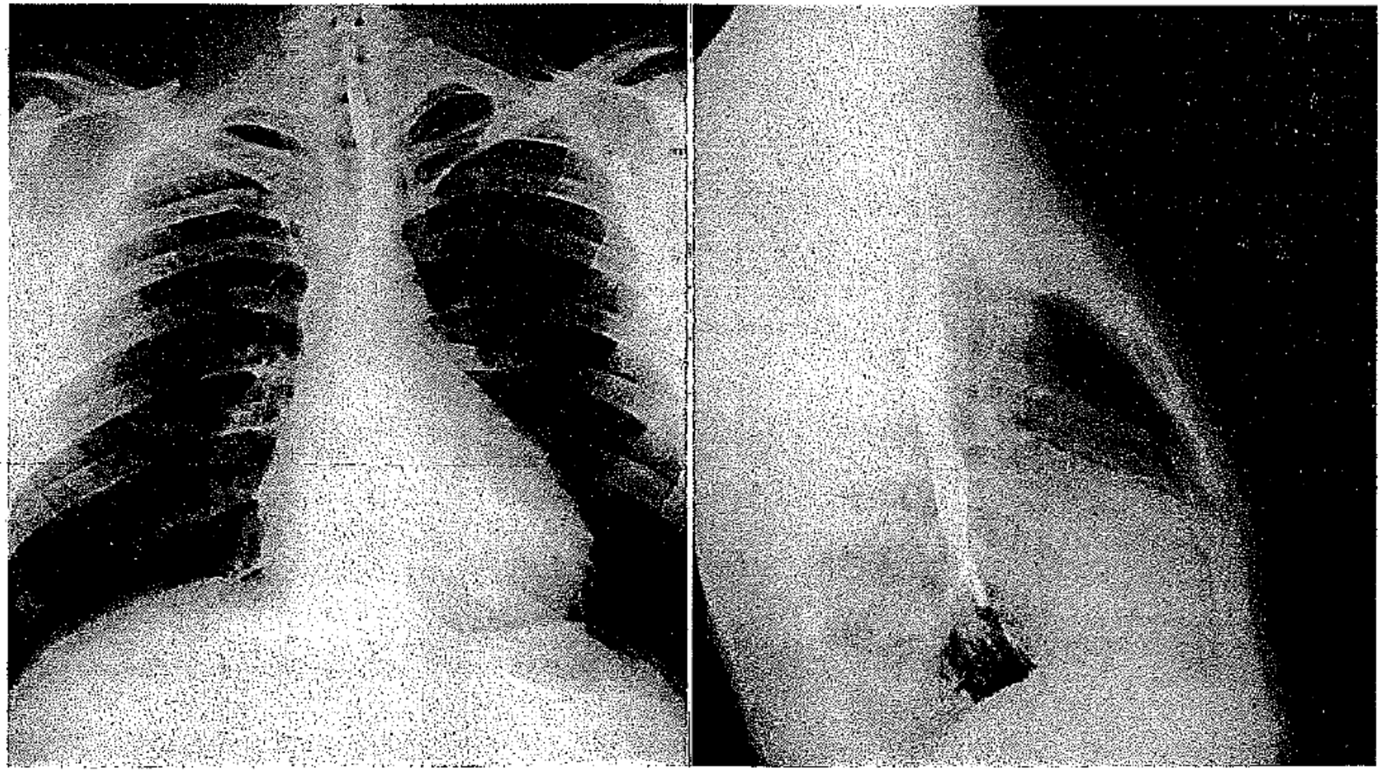
The Athletic Heart Syndrome

Five-Year Cardiac Evaluation of a Champion Athlete

Peter H. Gott, MD; Harry A. Roselle, MD; and Richard S. Crampton, MD, New York

He had occasionally noticed "weakness," "faintness," and vague "chest pressure" after particularly strenuous exercise.

Fig 1.—Cardiac esophogram showed large globular heart with prominence of both ventricles.



Arch Int Med 1958;122:340

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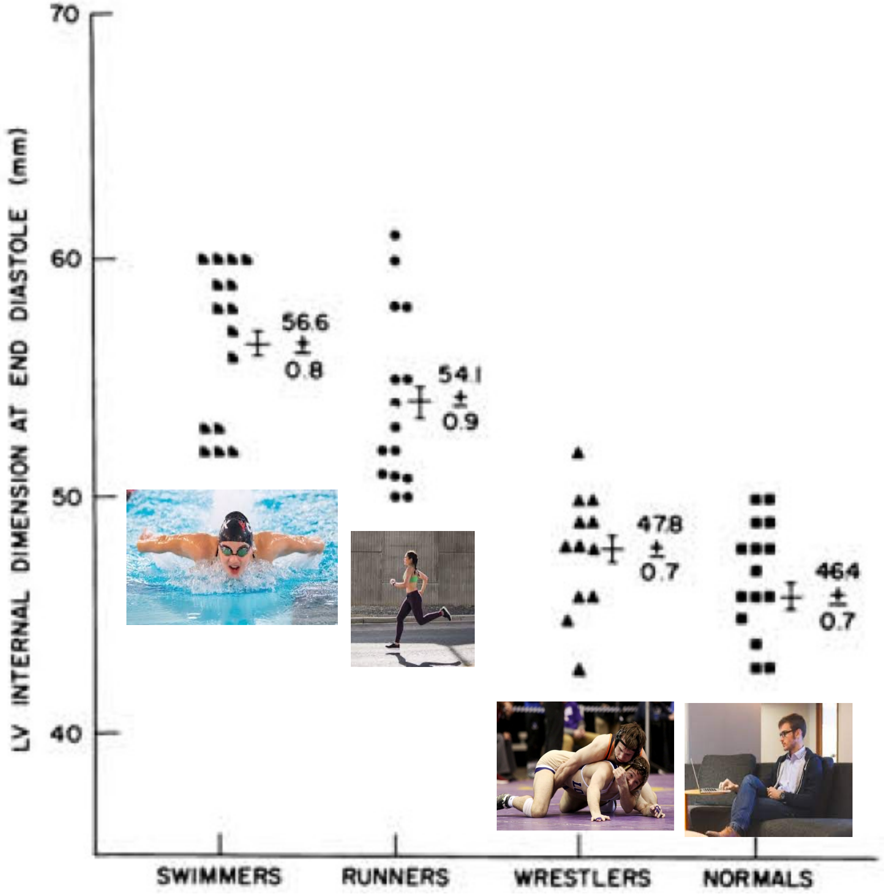
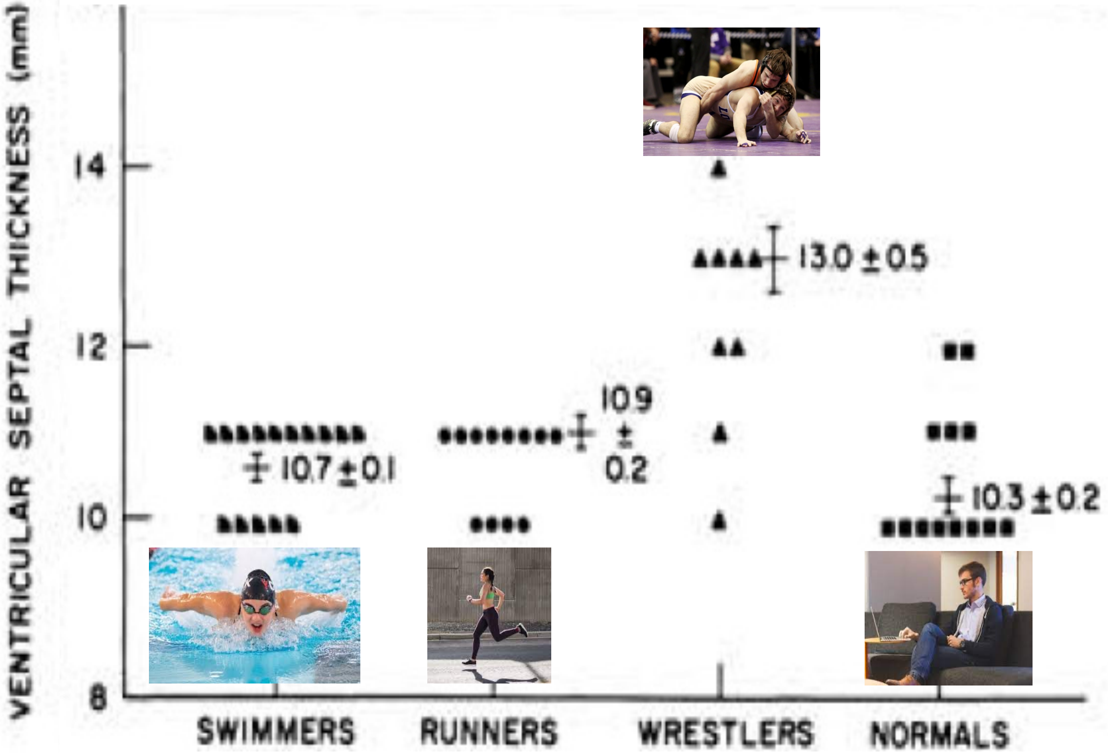
The Athlete’s Heart

Comparative Left Ventricular Dimensions in Trained Athletes

JOEL MORGANROTH, M.D., BARRY J. MARON, M.D., WALTER L. HENRY, M.D., and STEPHEN E. EPSTEIN, M.D., Bethesda, Maryland





Annals of Int Med 1975;82:521

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The Athlete’s Heart

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100+ Years of Cross-Sectional Studies Showing Cardiac Enlargement in Athletes
BUT…..

Cross-Sectional Studies Cannot Establish Causality

Average Height 6’7”

Tall height is genetic, affords an a competitive advantage and thus tall people self-select for basketball ✓

Basketball MAKES people grow tall ✗

But why, can we make any causal conclusions from this photo??

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Does exercise cause heart enlargement or do people born with "big hearts" simply self select for sport?

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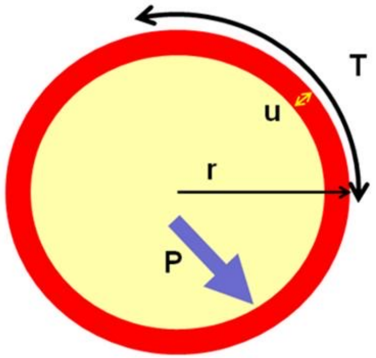
LaPlace’s Law



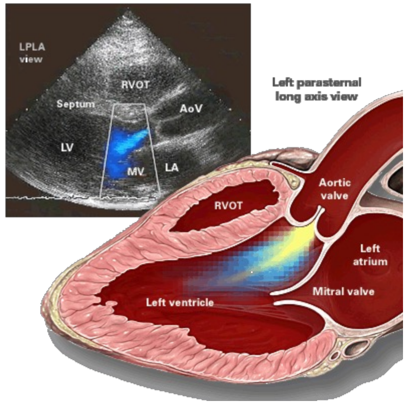
Stroke work ~ Wall tension ~ $\frac{\text{transmural pressure x radius}}{\text{wall thickness}}$

The heart remodels to normalize stroke work & meet metabolic demands

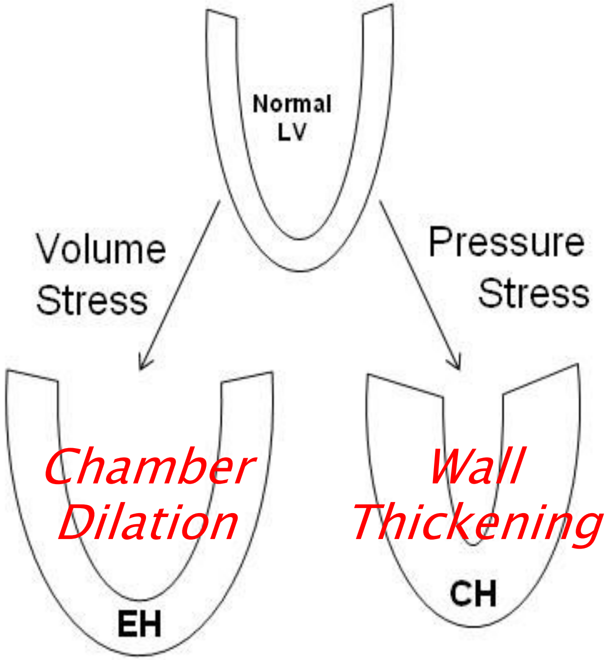
The Athlete's Heart

LV hypertrophy showing EH and CH variants

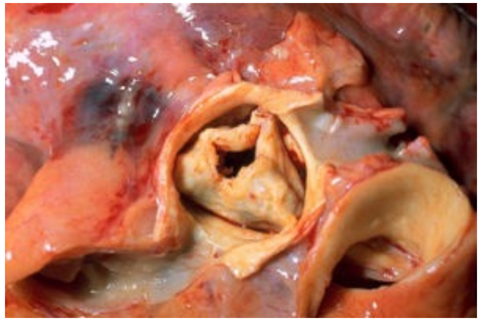
aortic regurgitation



Volume Challenge



aortic stenosis



pressure challenge

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Endurance Activities

Sustained ↑ CO

4 to 5 times rest

↑ ↑ ↑ HR & ↑ SV

Vasodilation

Volume Challenge

Strength Activities

Repetitive↑ BP

Systolic BP > 300 mmHg

Skeletal Mus. Contraction

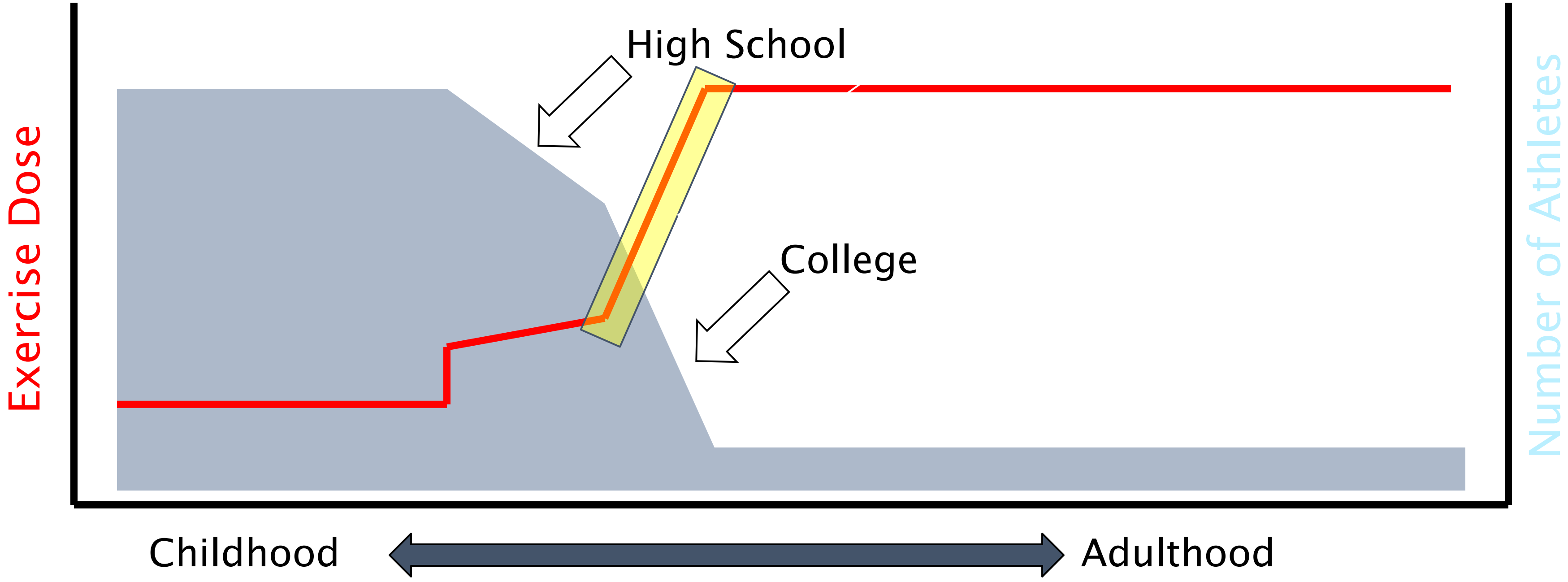
Vasoconstriction

Pressure challenge

The Athlete’s Heart

Athletic Trajectory in the US:

Precious Period of Plasticity (P 3)



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A platform for longitudinal, repeated measures studies of CV adaptation to exercise.

Jeremy Lin – NBA

Ryan Fitzpatrick – NFL

THE HARVARD ATHLETE INITIATIVE 2005-2022

Esther Lofgren – USA

Andrew Campbell – USA

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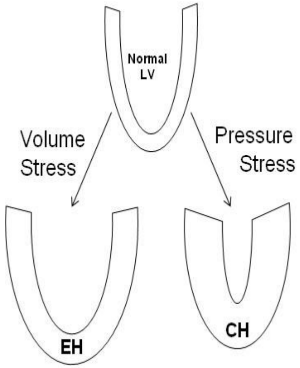
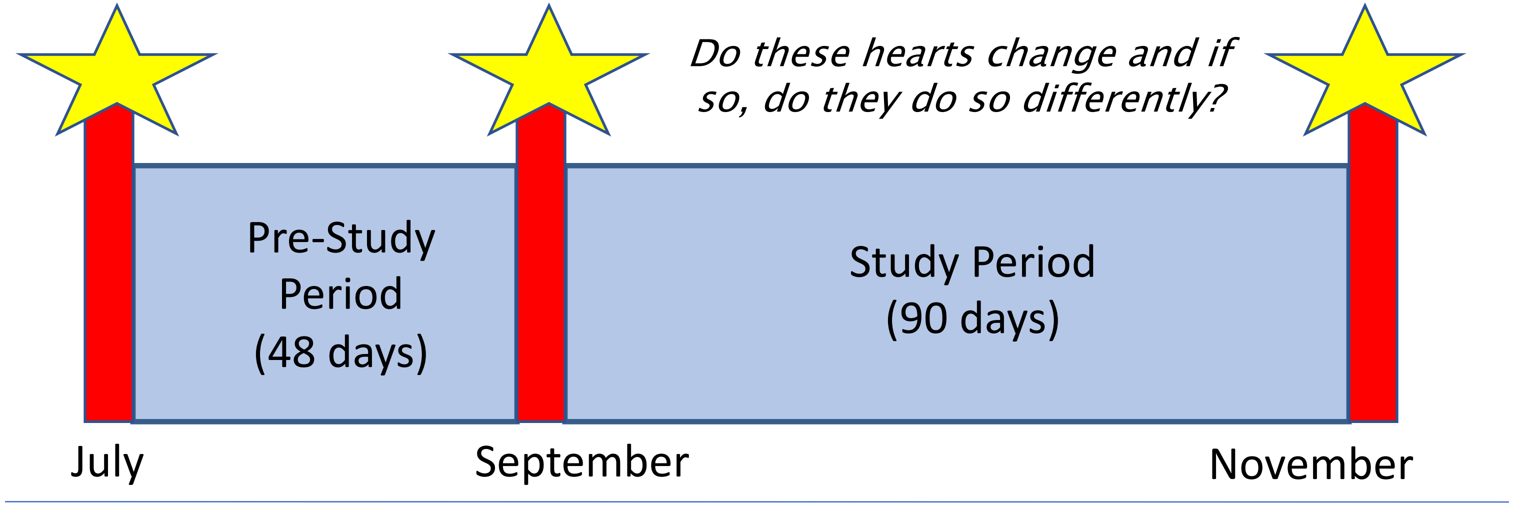
hypothesis





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J Appl Physiol 104: 1121–1128, 2008.
First published December 20, 2007; doi:10.1152/japplphysiol.01170.2007.

Training-specific changes in cardiac structure and function: a prospective and longitudinal assessment of competitive athletes

Aaron L. Baggish,[1] Francis Wang,[3] Rory B. Weiner,[1] Jason M. Elinoff,[2] Francois Tournoux,[1] Arthur Boland,[3] Michael H. Picard,[1] Adolph M. Hutter, Jr.,[1] and Malissa J. Wood[1]

[1]*Division of Cardiology, Massachusetts General Hospital, Boston;* [2]*Department of Medicine, Massachusetts General Hospital, Boston; and* [3]*University Health Services, Harvard University, Cambridge, Massachusetts*

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Baggish AL, Wang F, Weiner RB, Elinoff JM, Tournoux F, Boland A, Picard MH, Hutter AM Jr, Wood MJ. Training-specific changes in cardiac structure and function: a prospective and longitudinal assessment of competitive athletes. *J Appl Physiol* 104: 1121–1128, 2008. First published December 20, 2007; doi:10.1152/japplphysiol.01170.2007.—This prospective, longitudinal study examined the effects of participation in team-based exercise training on cardiac structure and function. Competitive endurance athletes (EA, $n = 40$) and strength athletes (SA, $n = 24$) were studied with echocardiography at baseline and after 90 days of team training. Left ventricular (LV) mass increased by 11% in EA (116 ± 18 vs. 130 ± 19 g/m^2; $P < 0.001$) and by 12% in SA (115 ± 14 vs. 132 ± 11 g/m^2; $P < 0.001$; P value for the compared Δ = NS). EA experienced LV dilation (end-diastolic volume: 66.6 ± 10.0 vs. 74.7 ± 9.8 ml/m^2, Δ = 8.0 ± 4.2 ml/m^2; $P < 0.001$), enhanced diastolic function (lateral E′: 10.9 ± 0.8 vs. 12.4 ± 0.9 cm/s, $P < 0.001$), and biatrial enlargement, while SA experience LV hypertrophy (posterior wall: 4.5 ± 0.5 vs. 5.2 ± 0.5 mm/m^2, $P < 0.001$) and diminished diastolic function (E′ basal lateral LV: 11.6 ± 1.3 vs. 10.2 ± 1.4 cm/s, $P < 0.001$). Further, EA experienced right ventricular (RV) dilation (end-diastolic area: 1,460 ± 220 vs. 1,650 ± 200 mm/m^2, $P < 0.001$) coupled with enhanced systolic and diastolic function (E′ basal RV: 10.3 ± 1.5 vs. 11.4 ± 1.7 cm/s, $P < 0.001$), while SA had no change in RV parameters. We conclude that participation in 90 days of competitive athletics produces significant training-specific changes in cardiac structure and function. EA develop biventricular dilation with enhanced diastolic function, while SA develop isolated, concentric left ventricular hypertrophy with diminished diastolic relaxation.

exercise physiology; cardiac remodeling; athlete's heart

AN ASSOCIATION between athletic participation and specific cardiac morphology has been well established. Increased left atrial size and left ventricular (LV) mass, wall thickness, and chamber size have been documented among trained athletes, and several recent reports have described right ventricular (RV) characteristics among such individuals (5, 26, 27, 30, 32, 37). Although copious data demonstrate a high prevalence of "abnormal" cardiac measurements among competitive athletes, such cross-sectional data are not sufficient to establish whether athletic training is causal in their development.

Several small prospective studies have reported LV changes in the context of exercise training (8, 9, 11, 21, 35, 36). At present, definitive longitudinal studies defining the LV structural and functional responses to sustained exercise training are lacking, and no such data exist regarding the RV. Further, the relationship between training discipline and cardiac remodeling has not been adequately characterized.

We sought to determine the impact of exercise training during a single season (90 days) of competitive athletics on cardiac structure and function. We hypothesized that significant structural and functional changes would occur and that the nature and magnitude of change would vary with training discipline. To address these hypotheses, we performed pre- and posttraining assessment of competitive university athletes.

METHODS

Study subjects. University students participating in official competitive athletics affiliated with the Harvard University Department of Athletics participated in this study. University athletes, not elite competitors, were studied as we anticipated that they would enter the study period relatively detrained and would then exercise with a high enough intensity and consistency to maximize our ability to define and quantify training-induced changes. Written informed consent was obtained from all participants before involvement. The Harvard University institutional review board and the Partner's Human Research Committee approved the protocol before study initiation.

Individuals were considered eligible if they were ≥18 yr old and had been previously selected as members of an organized competitive team program. Seventy-five athletes were enrolled before the beginning of the 2006 fall semester training season. To assess for and to compare changes attributable to endurance vs. strength training, athletes from two distinct sporting disciplines were enrolled. The endurance athlete group (EA) consisted of long-distance male rowers (MR) and female rowers (FR), while the strength athlete group (SA) was comprised of American-style male football players (MF).

Height, weight, resting vital signs, medication use, and personal/family medical historical data were recorded at the time of enrollment. Baseline transthoracic echocardiography was performed as detailed below. Training volume during a prestudy period, defined as the 8 wk before baseline assessment, was collected. Prestudy period endurance activity was defined as running, cycling, swimming, rowing, or aerobic machine use at an effort sustainable for ≥20 min, while strength activity was defined as weight lifting, plyometric exercise, and sprint running drills.

The study period began at the time of enrollment and lasted for 90 days. No effort was made to control training regimens during the study period, as the goal of this study was to examine the effects of participation in actual organized athletics. However, daily data were recorded on the duration and the type (endurance vs. strength) of training activities performed during the study period. EA performed rowing training aimed to optimize performance at a 5-km distance that consisted of long-duration open water and indoor ergometer sessions (1–3 h) at low stroke rates (20–24 stokes/min). Intermittent heart rate

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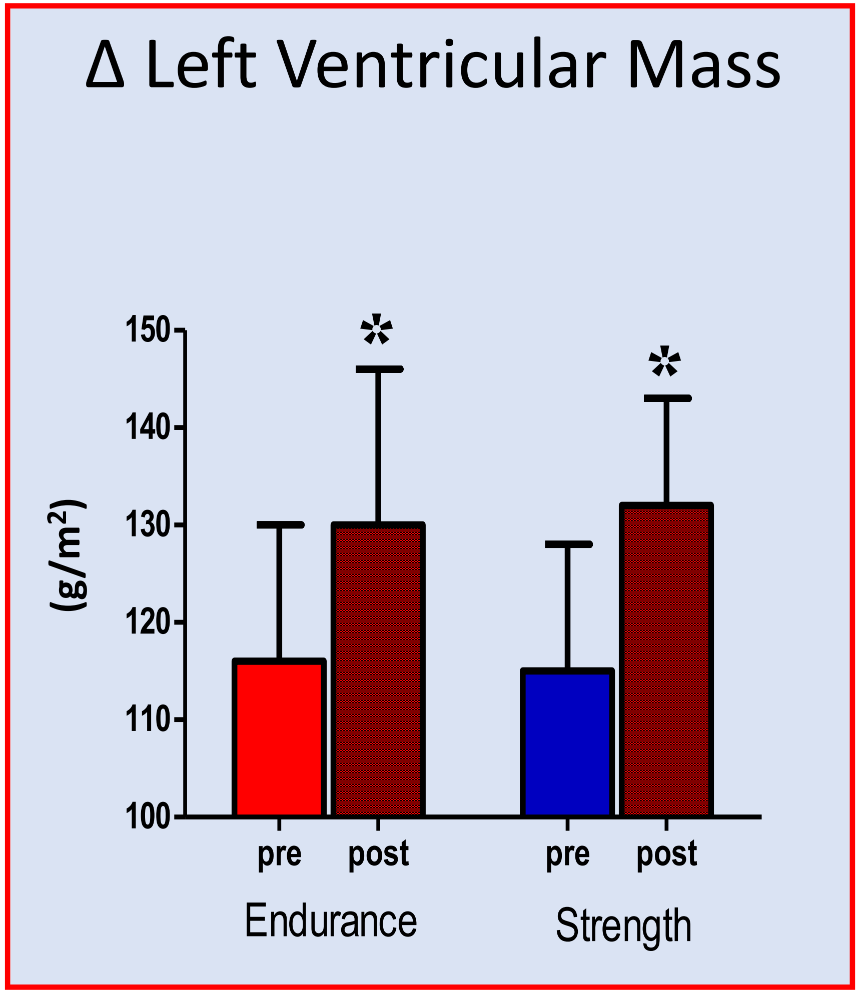

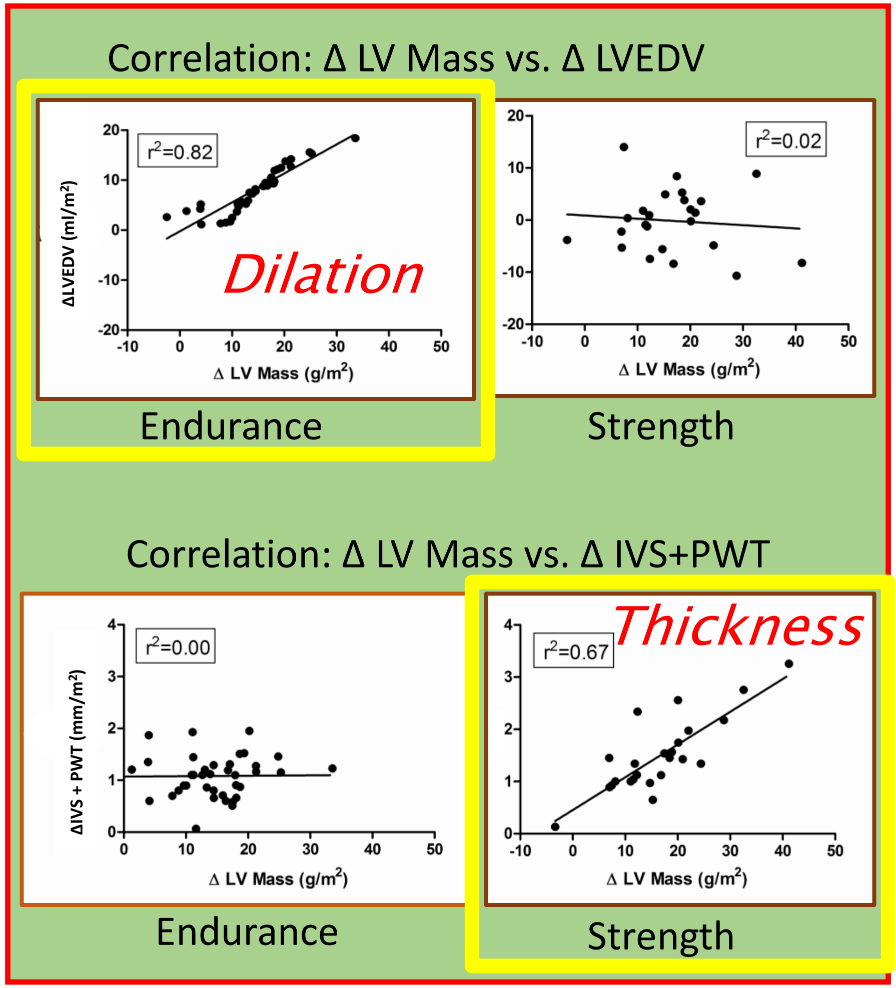

J Appl Physiol 2008;104:1121

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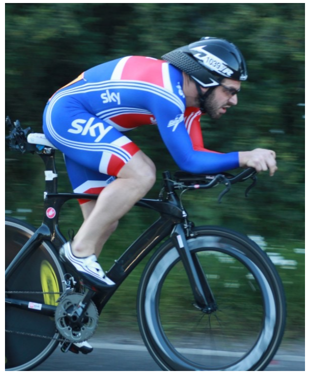

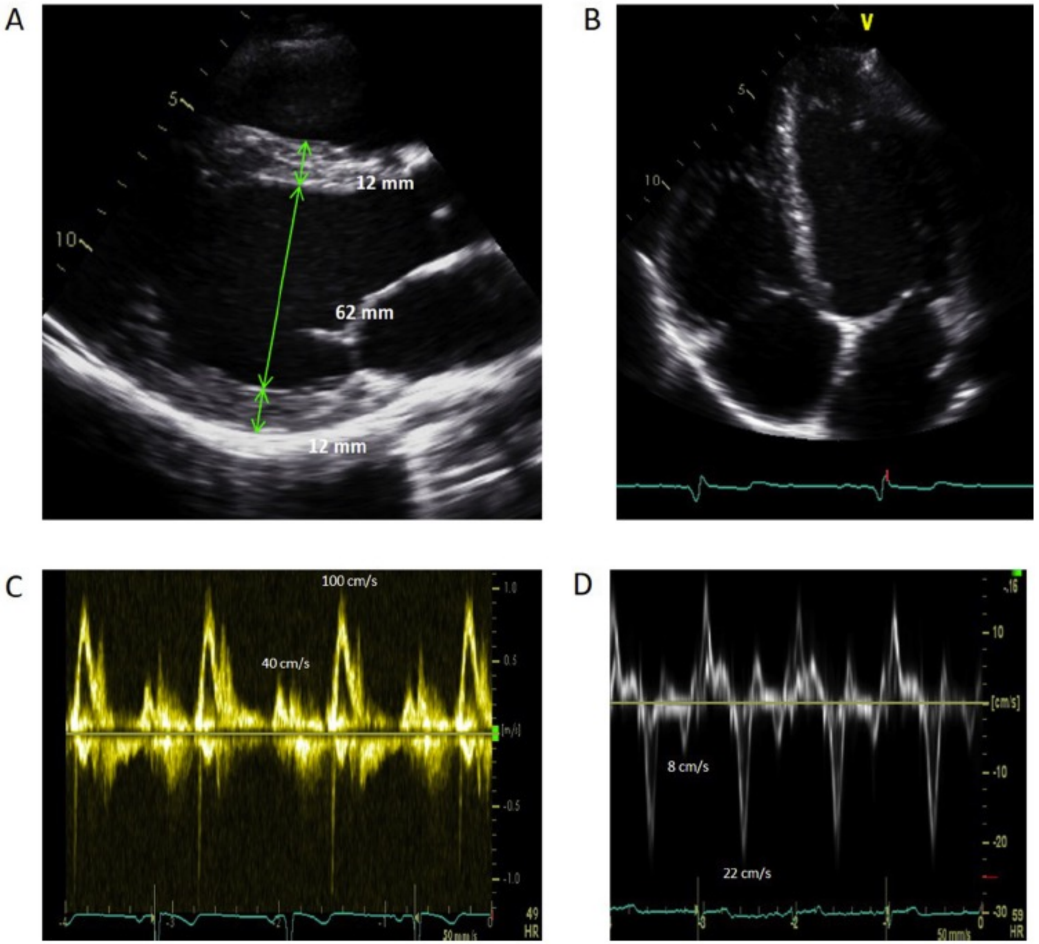

Figure 4 Representative transthoracic echocardiographic imaging from a healthy competitive endurance-sport athlete. **(A)** Parasternal long-axis view demonstrating eccentric left ventricular hypertrophy as manifested by simultaneous left ventricular wall thickening and chamber dilation. **(B)** Apical 4-chamber view demonstrating comparable left and right ventricular end-diastolic areas. **(C)** Transmitral pulsed-wave Doppler showing E/A ratio >2.0. **(D)** Tissue Doppler of the lateral mitral annulus showing e’ prominence with early diastolic relaxation velocities in excess of 20 cm/s.

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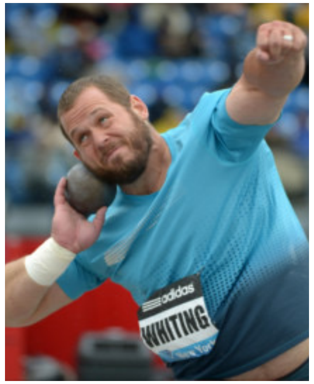

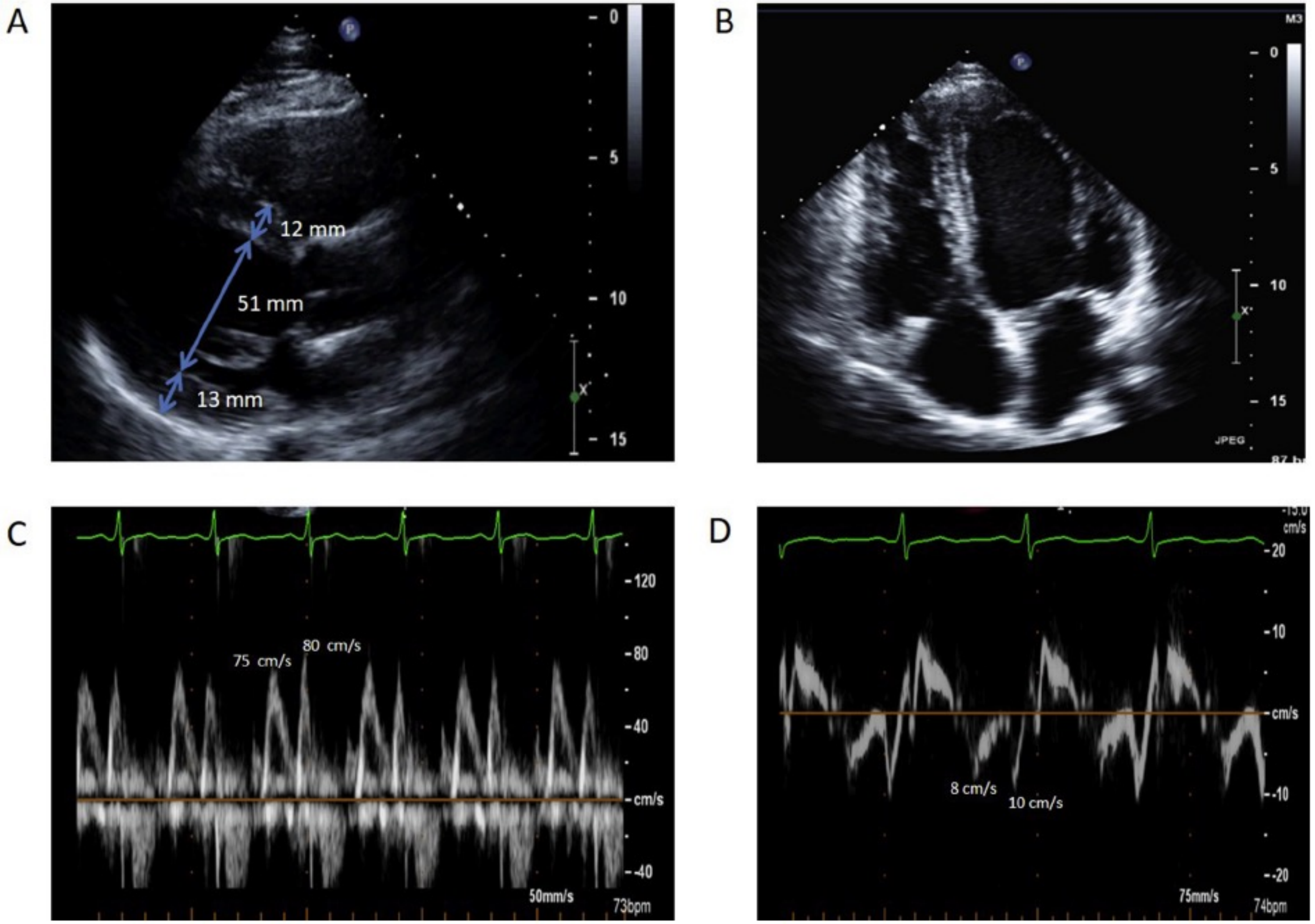

Figure 5 Representative transthoracic echocardiographic imaging from a healthy asymptomatic competitive strength-sport athlete. **(A)** Parasternal long-axis view demonstrating concentric left ventricular hypertrophy as manifested by left ventricular wall thickening in the absence of chamber dilation. **(B)** Apical 4-chamber view demonstrating left greater than right ventricular end-diastolic areas. **(C)** Trans-mitral pulsed-wave Doppler imaging showing E/A ratio ∼1.0. **(D)** Tissue Doppler imaging of the lateral mitral annulus showing mild reductions in early diastolic relaxation velocities (e' ∼ 8 cm/s) and a' prominence.

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THE PRESENT AND FUTURE

STATE-OF-THE-ART REVIEW

Sports Cardiology

Core Curriculum for Providing Cardiovascular Care to Competitive Athletes and Highly Active People

Aaron L. Baggish, MD,[a] Robert W. Battle, MD,[b] James G. Beckerman, MD,[c] Alfred A. Bove, MD, PhD,[d] Rachel J. Lampert, MD,[e] Benjamin D. Levine, MD,[f] Mark S. Link, MD,[f] Matthew W. Martinez, MD,[g] Silvana M. Molossi, MD, PhD,[h] Jack Salerno, MD,[i] Meagan M. Wasfy, MD,[a] Rory B. Weiner, MD,[a] Michael S. Emery, MD,[j] for the ACC's Sports and Exercise Council Leadership Group

ABSTRACT

The last few decades have seen substantial growth in the populations of competitive athletes and highly active people (CAHAP). Although vigorous physical exercise is an effective way to reduce the risk of cardiovascular (CV) disease, CAHAP remain susceptible to inherited and acquired CV disease, and may be most at risk for adverse CV outcomes during intense physical activity. Traditionally, multidisciplinary teams comprising athletic trainers, physical therapists, primary care sports medicine physicians, and orthopedic surgeons have provided clinical care for CAHAP. However, there is increasing recognition that a care team including qualified CV specialists optimizes care delivery for CAHAP. In recognition of the increasing demand for CV specialists competent in the care of CAHAP, the American College of Cardiology has recently established a Sports and Exercise Council. An important primary objective of this council is to define the essential skills necessary to practice effective sports cardiology. (J Am Coll Cardiol 2017;70:1902–18)
© 2017 Published by Elsevier on behalf of the American College of Cardiology Foundation.

Competitive athletes and highly active people (CAHAP) are a growing population. Although routine physical exercise is an effective way to reduce the risk of cardiovascular (CV) disease, it does not confer complete immunity (1,2), and actually increases the risk of CV events acutely, even in trained individuals (3). The complex interplay between CV disease and vigorous physical activity remains incompletely understood, but is increasingly relevant in clinical practice. People with occult CV disease are susceptible to sudden cardiac death during exercise. However, sudden death prevention represents only 1 element of caring for CAHAP. Accurate interpretation of diagnostic testing with an emphasis on differentiating pathology from physiological exercise-induced adaptation, efficient and targeted assessment of symptoms, and provision of longitudinal care including the development of exercise

The views expressed in this paper by the American College of Cardiology's (ACC's) Sports and Exercise Council Leadership Group do not necessarily reflect the views of the *Journal of the American College of Cardiology* or the ACC.

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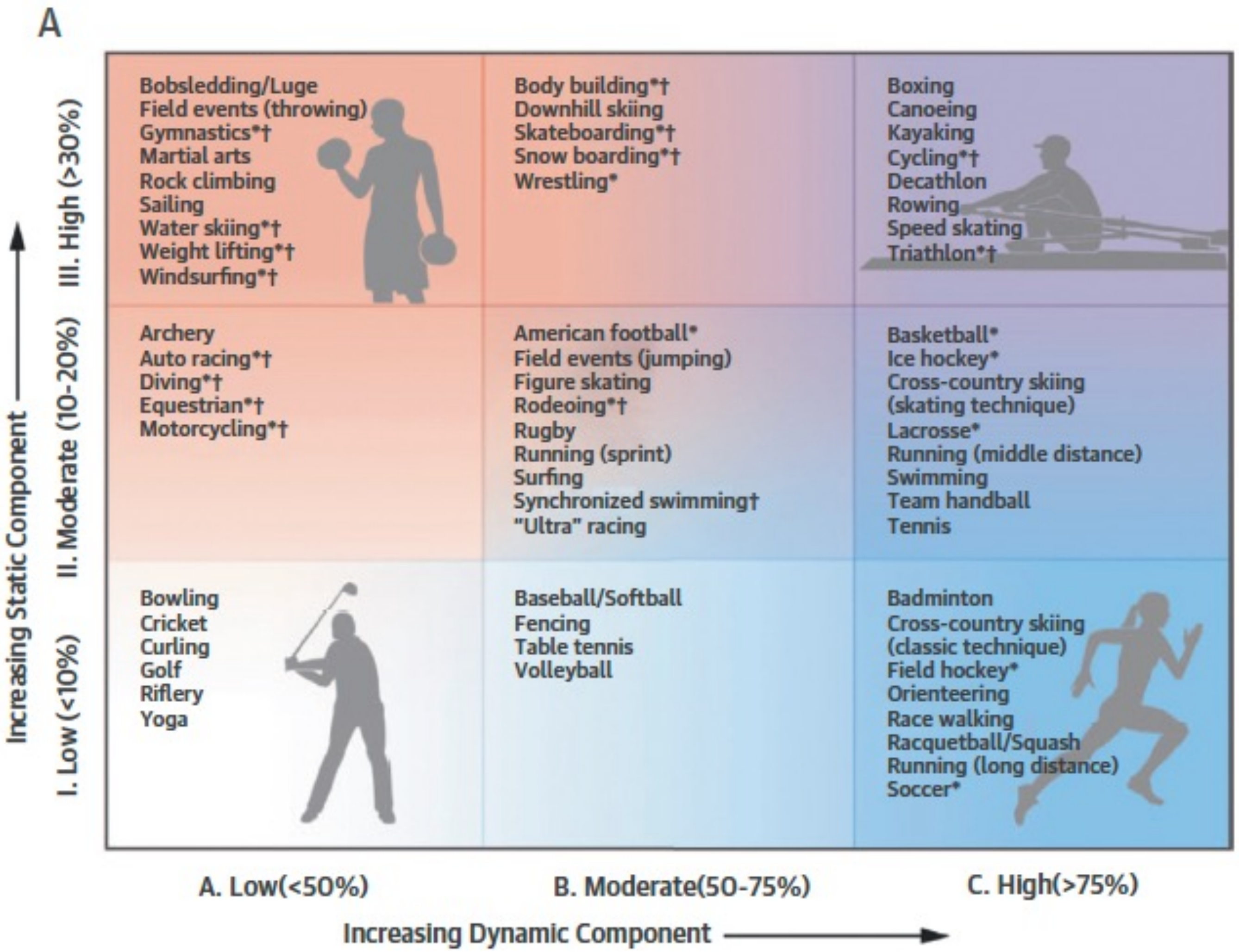

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The Athlete’s Heart

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GUIDELINES AND STANDARDS

Recommendations on the Use of Multimodality Cardiovascular Imaging in Young Adult Competitive Athletes: A Report from the American Society of Echocardiography in Collaboration with the Society of Cardiovascular Computed Tomography and the Society for Cardiovascular Magnetic Resonance

Check for updates

Aaron L. Baggish, MD, (Chair), Robert W. Battle, MD, Timothy A. Beaver, MD, FASE, William L. Border, MBChB, MH, FASE, Pamela S. Douglas, MD, FASE, Christopher M. Kramer, MD, Matthew W. Martinez, MD, Jennifer H. Mercandetti, BS, RDCS (AE/PE), ACS, FASE, Dermot Phelan, MD, PhD, FASE, Tamanna K. Singh, MD, Rory B. Weiner, MD, FASE, and Eric Williamson, MD, *Boston, Massachusetts; Charlottesville, Virginia; Kansas City, Kansas; Atlanta, Georgia; Durham and Charlotte, North Carolina; Morristown, New Jersey; Denver, Colorado; Cleveland, Ohio; Rochester, Minnesota*

Keywords: Athlete, Athlete’s heart, Pre-participation screening, Echocardiography, Cardiac computed tomography, Cardiac magnetic resonance

In addition to the collaborating societies listed in the title, this document is endorsed by the following American Society of Echocardiography International Alliance Partners: Argentine Federation of Cardiology, Argentine Society of Cardiology, Asian-Pacific Association of Echocardiography, Australasian Sonographers Association, Brazilian Department of Cardiovascular Imaging, Canadian Society of Echocardiography, Cardiovascular and Thoracic Society of Southern Africa, Cardiovascular Imaging Society of the Interamerican Society of Cardiology, Chinese Society of Cardiothoracic and Vascular Anesthesiology, Chinese Society of Echocardiography, Cuban Society of Cardiology Echocardiography Section, Indian Academy of Echocardiography, Indian Association of Cardiovascular Thoracic Anaesthesiologists, Iranian Society of Echocardiography, Israel Working Group on Echocardiography, Japanese Society of Echocardiography, Korean Society of Echocardiography, Mexican Society of Echocardiography and Cardiovascular Imaging, National Association of Cardiologists of Mexico, Philippine Society of Echocardiography, Saudi Arabian Society of Echocardiography, Thai Society of Echocardiography, and Vietnamese Society of Echocardiography.

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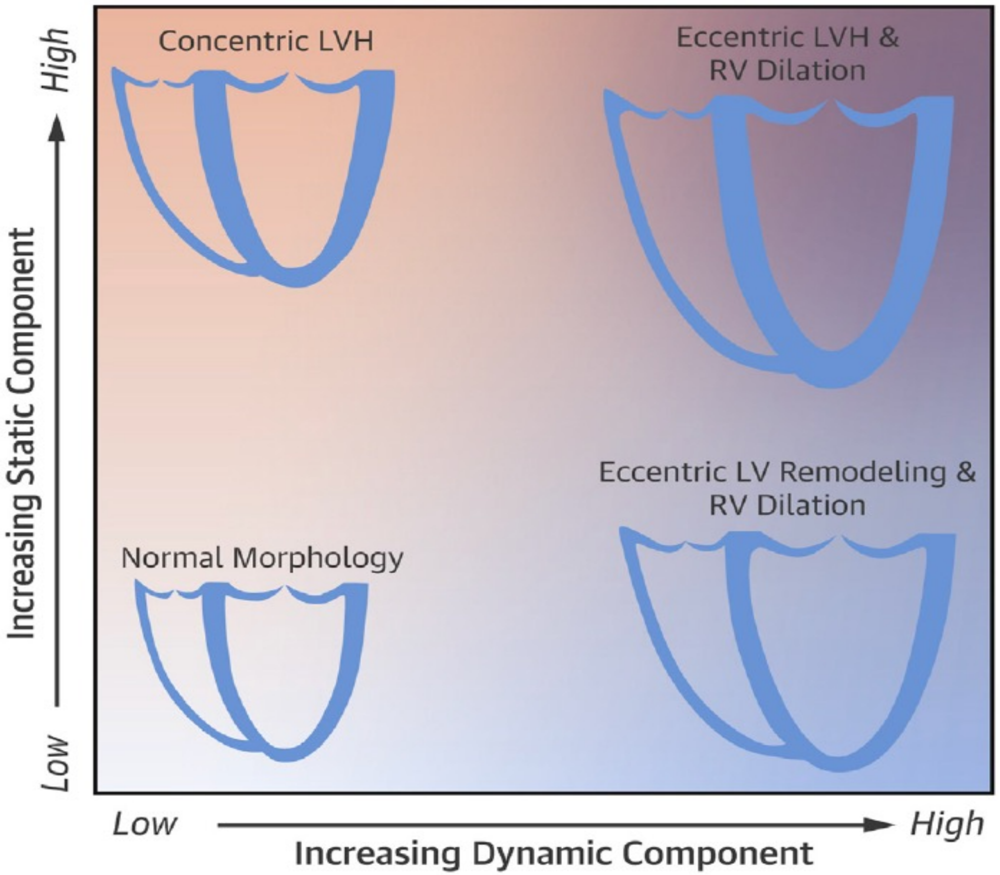
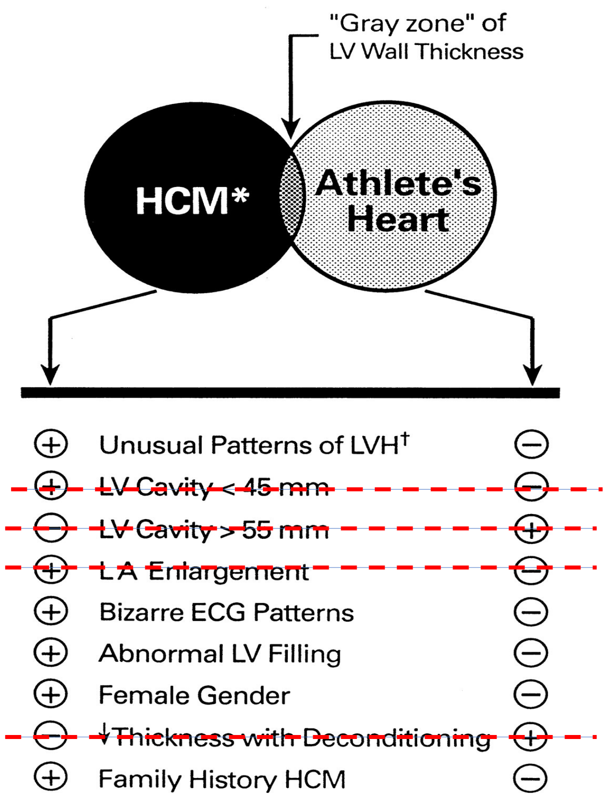


Figure 3 Anticipated exercise-induced cardiac remodeling based on relative component contributions of isotonic and isometric stress.

Baggish et al. JACC 2017

The Athlete's Heart

LV walls of 13-15 mm



Maron, et al. Circulation 1995;91:1596-1601

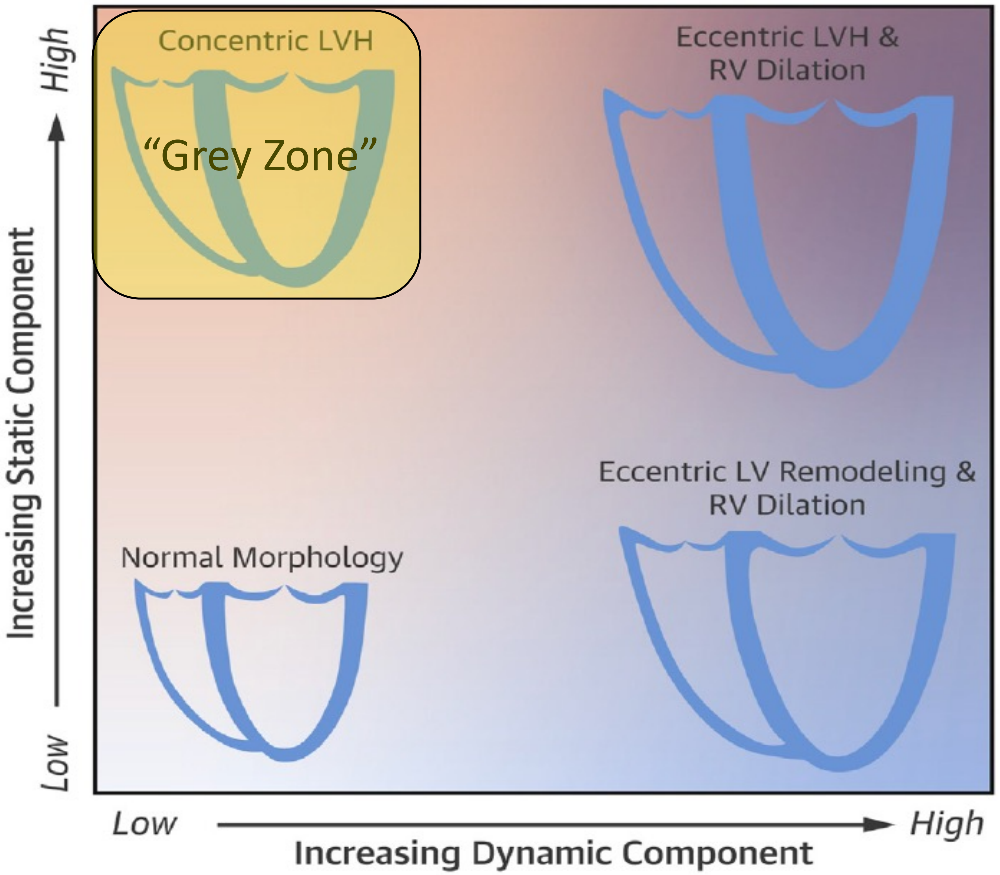


Figure 3 Anticipated exercise-induced cardiac remodeling based on relative component contributions of isotonic and isometric stress.

Baggish et al. JACC 2017

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In addition to the collaborating societies listed in the title, this document is endorsed by the following American Society of Echocardiography International Alliance Partners: Argentine Federation of Cardiology, Argentine Society of Cardiology, Asian-Pacific Association of Echocardiography, Australasian Sonographers Association, Brazilian Department of Cardiovascular Imaging, Canadian Society of Echocardiography, Cardiovascular and Thoracic Society of Southern Africa, Cardiovascular Imaging Society of the Interamerican Society of Cardiology, Chinese Society of Cardiothoracic and Vascular Anesthesiology, Chinese Society of Echocardiography, Cuban Society of Cardiology Echocardiography Section, Indian Academy of Echocardiography, Indian Association of Cardiovascular Thoracic Anaesthesiologists, Iranian Society of Echocardiography, Israel Working Group on Echocardiography, Japanese Society of Echocardiography, Korean Society of Echocardiography, Mexican Society of Echocardiography and Cardiovascular Imaging, National Association of Cardiologists of Mexico, Philippine Society of Echocardiography, Saudi Arabian Society of Echocardiography, Thai Society of Echocardiography, and Vietnamese Society of Echocardiography.

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0894-7317/$36.00

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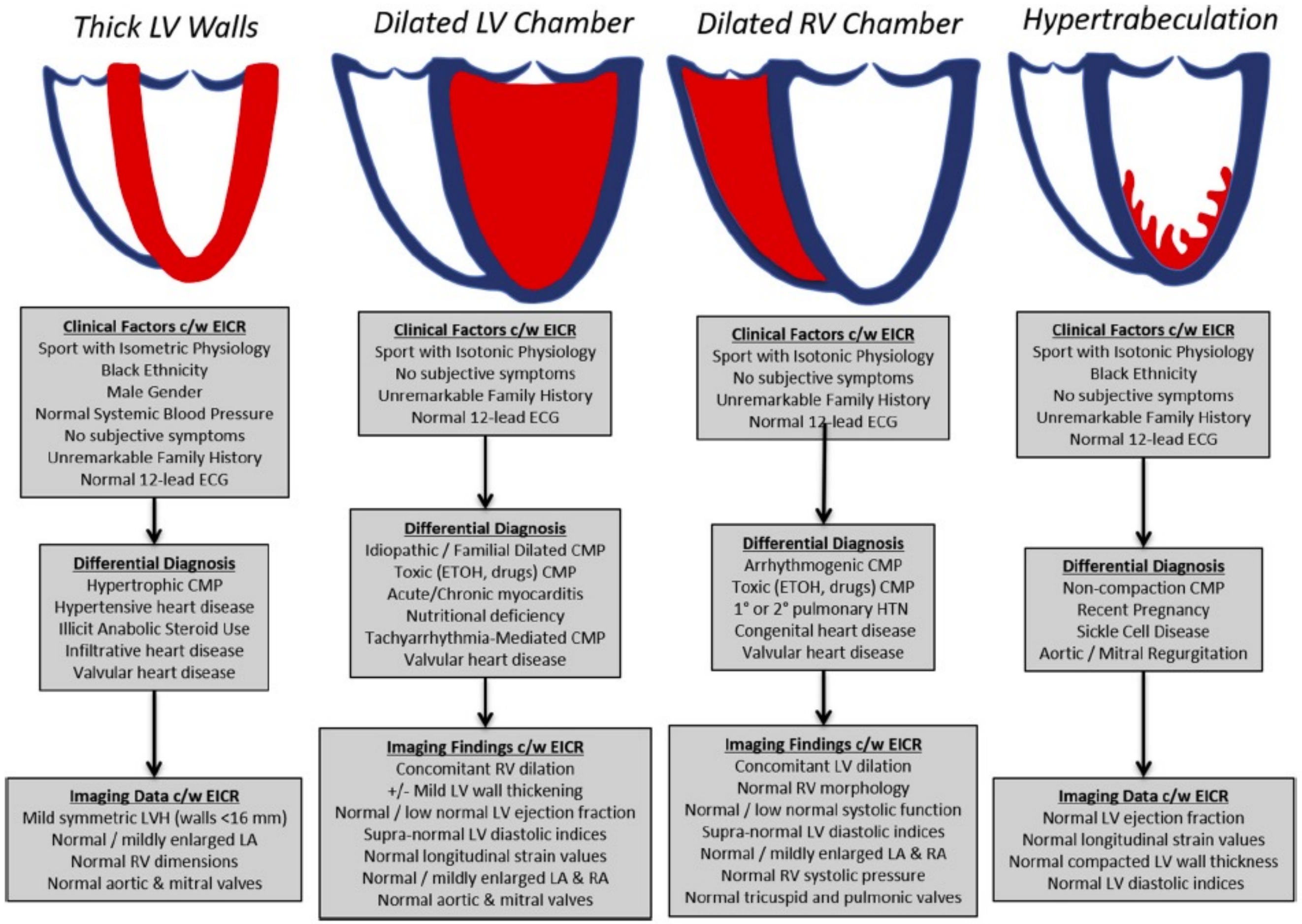

Figure 8 Overview of the clinical assessment of the 4 cardinal "gray zone" imaging findings in competitive athletes for use in differentiating exercise-induced cardiac remodeling (EICR) from pathologic cardiomyopathy (CMP).

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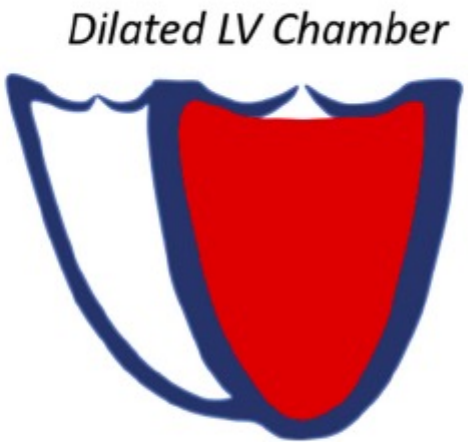
The Athlete’s Heart

Cardiovascular Performance Program
MGH 1811

>15 mm ♂
>12 mm ♀
Marked Asymmetry



Size not helpful
Uni-ventricular Dilation
Abnormal Diastology

Size not helpful
Uni-ventricular Dilation
Abnormal Morphology

Absence of Dynamic Phys.
Adjacent wall thinning
Systolic Dysfunction

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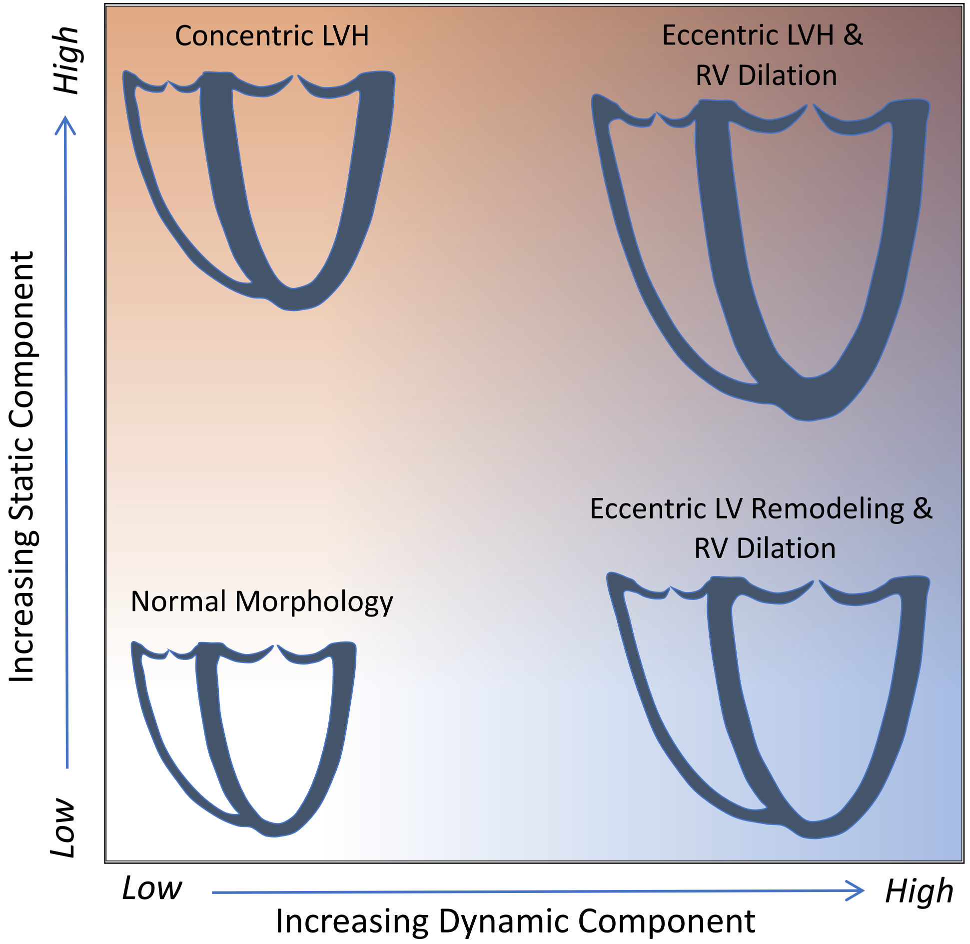
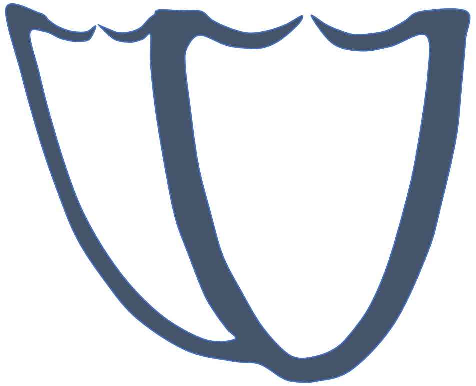
The Athlete's Heart

Cardiovascular Performance Program (MGH 1811)

Imaging / Patient Discordance

B.





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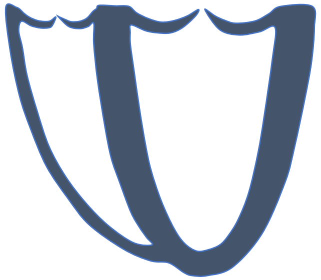

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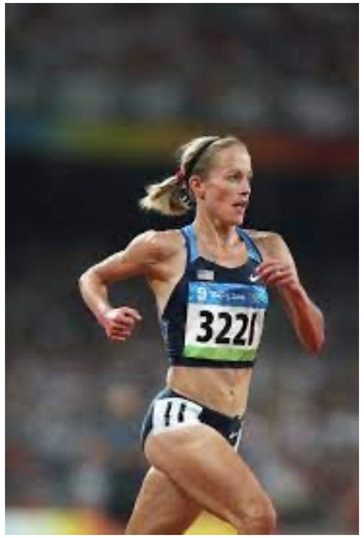

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The Athlete's Heart

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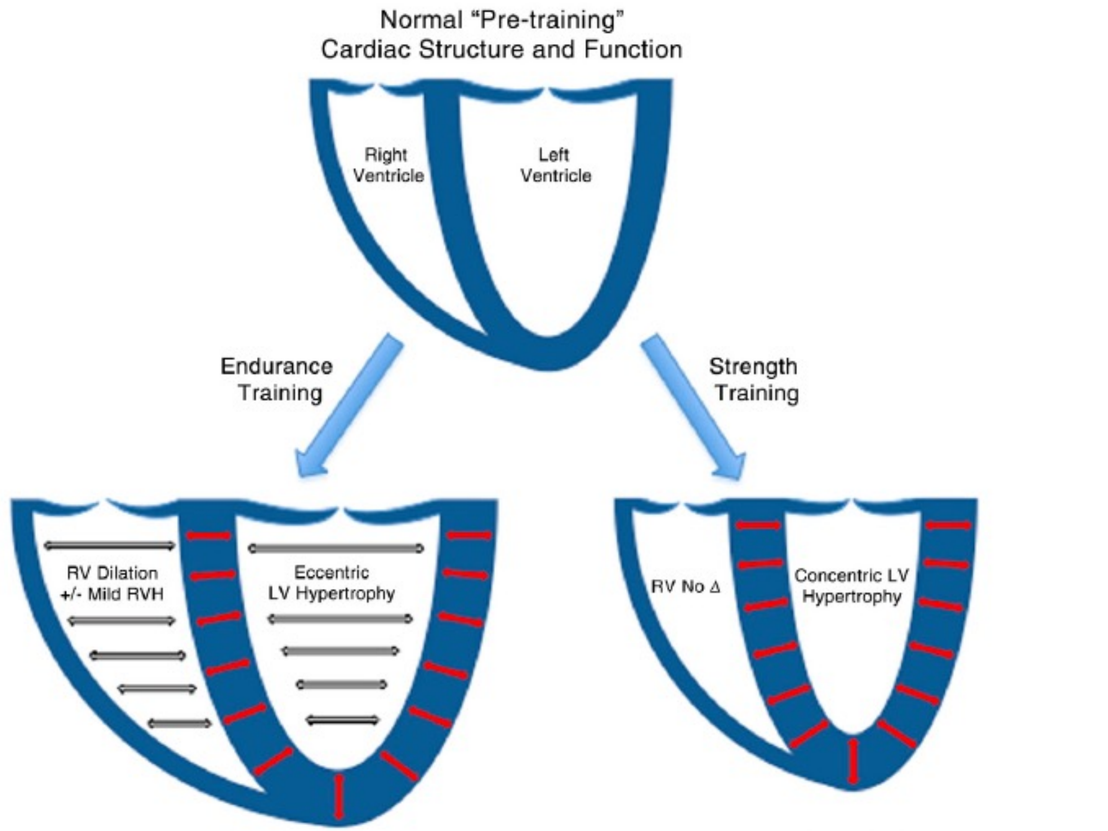

R.B. Weiner, A.L. Baggish / Progress in Cardiovascular Diseases 54 (2012) 380–386

	Skill	Power	Mixed	Endurance
LOW	Golf (buggy) Golf (18 holes walking) Table tennis (double) Table tennis (single) Shooting	Shot putting (recreational) Discus (recreational) Alpine skiing (recreational)	Soccer (adapted) Basketball (adapted) Handball (adapted)	Jogging Long distance walking Swimming (recreational) Speed walking Mid/long distance running Style dancing
MEDIUM	Curling Bowling Sailing Yachting Equestrian	Short distance running Shot putting Discus Alpine skiing Judo/karate	Volleyball Tennis (double)	
HIGH		Weight lifting Wrestling Boxing	Ice-Hockey Hockey Rugby Fencing Tennis (single) Waterpolo Soccer (competitive) Basketball (competitive) Handball (competitive)	Cycling (road) Mid/long distance swimming Long distance skating Pentathlon Rowing Canoeing X-country skiing Biathlon Triathlon

RV Dil.

European Heart Journal (2020) **00**, 1–80

Low intensity — Medium intensity — High intensity

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The Athlete's Heart

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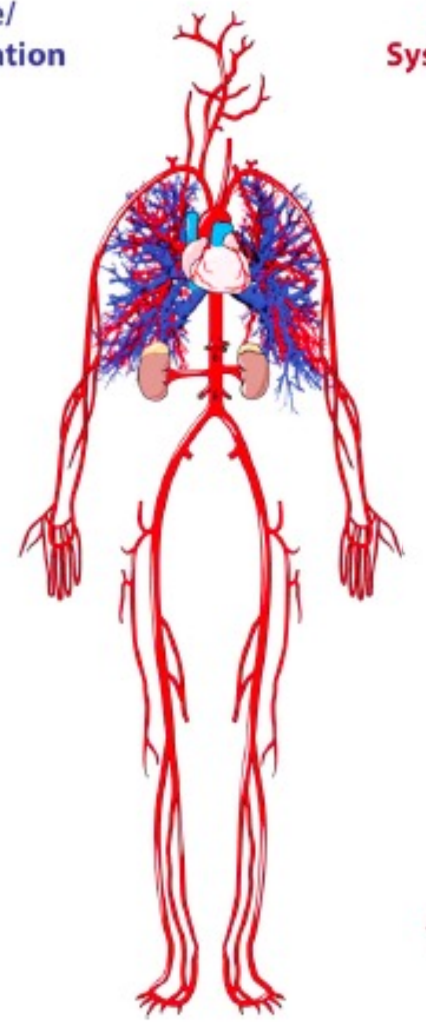
	Right Ventricle/ Pulmonary circulation	Left Ventricle/ Systemic circulation
Rest		
Cardiac Output (L/min)	5	5
Vascular resistance (dyne-sec.cm^5)	Low (90)	High (1300)
Vascular Compliance (ml/mmHg)	High (10)	Low (2)
Afterload Pressure (mmHg)	25/ 10 (15)	125/ 75 (90)
Exercise		
Cardiac Output (L/min)	30	30
Vascular resistance (dyne-sec.cm^5)	↓ 60	↓↓↓ 240
Vascular Compliance (ml/mmHg)	↓↓ 4	↓ 1.2
Afterload Pressure (mmHg)	↑↑↑ 65/ 25 (40)	↑ 190/ 70 (110)



Jerome A. Dempsey,[1] Andre La Gerche,[2,3] and James H. Hull[4,5] *J Appl Physiol* 129: 1235–1256, 2020.

The RV & Pulmonary Circulation Are Optimally Designed for Rest and <u>Low Intensity</u> Physical Activity:

Low Resistance (PVR)
High Compliance
Low RV Afterload (Work)

The RV & Pulmonary Circulation Are Sub-Optimally Designed for <u>High Intensity</u> Physical Activity:

Minimal PVR Decline
Marked Decline in Vascular Compliance
High RV Afterload (Work)

Disproportion Susceptibility to the "Good" & "Bad"

The Athlete's Heart

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Clinical significance of electrocardiographic right ventricular hypertrophy in athletes: comparison with arrhythmogenic right ventricular cardiomyopathy and pulmonary hypertension

Abbas Zaidi[†], Saqib Ghani[†], Nabeel Sheikh[†], Sabiha Gati[†], Rachel Bastiaenen, Brendan Madden, Michael Papadakis[†], Hariharan Raju[†], Matthew Reed, Rajan Sharma, Elijah R. Behr, and Sanjay Sharma[†*]

N=627 Athletes

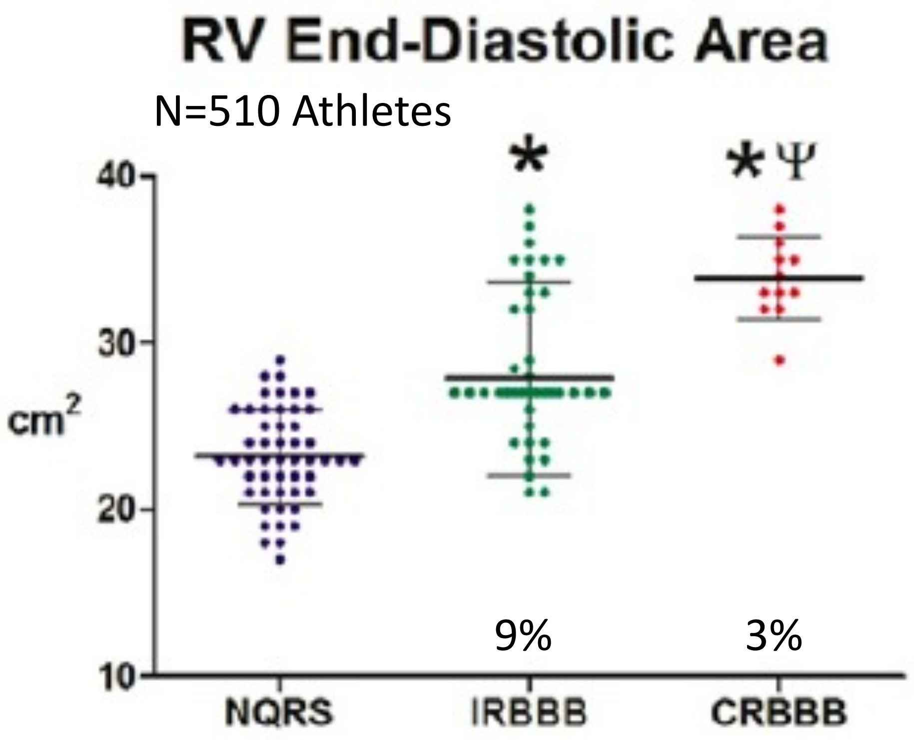
Table 3 Electrocardiographic findings in athletes exhibiting echocardiographic right ventricular hypertrophy

	Athletes with RVWT >5 mm	Athletes with RVWT ≤5 mm	*P*-value
Normal ECG, %	39.3	49.9	0.24
Isolated Sokolow RVH, %	10.7	4.2	0.13
Isolated Sokolow LVH, %	10.7	23.2	0.16
Isolated inferior TWI, %	10.7	0.2	<0.001
Isolated anterior TWI, %	10.7	2.3	0.039
Isolated pRBBB, %	3.6	0.9	0.27

European Heart Journal (2013) **34**, 3649–3656

Significance of Electrocardiographic Right Bundle Branch Block in Trained Athletes

Jonathan H. Kim, MD[a], Peter A. Noseworthy, MD[a], David McCarty, MD[a], Kibar Yared, MD[a], Rory Weiner, MD[a], Francis Wang, MD[b], Malissa J. Wood, MD[a], Adolph M. Hutter, MD[a], Michael H. Picard, MD[a], and Aaron L. Baggish, MD[a,*]



(Am J Cardiol 2011;107:1083–1089)

The Athlete's Heart

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Dilated RV Chamber

Clinical Factors c/w EICR
Sport with Isotonic Physiology
No subjective symptoms
Unremarkable Family History
Normal 12-lead ECG

↓

Differential Diagnosis
Arrhythmogenic CMP
Toxic (ETOH, drugs) CMP
1° or 2° pulmonary HTN
Congenital heart disease
Valvular heart disease

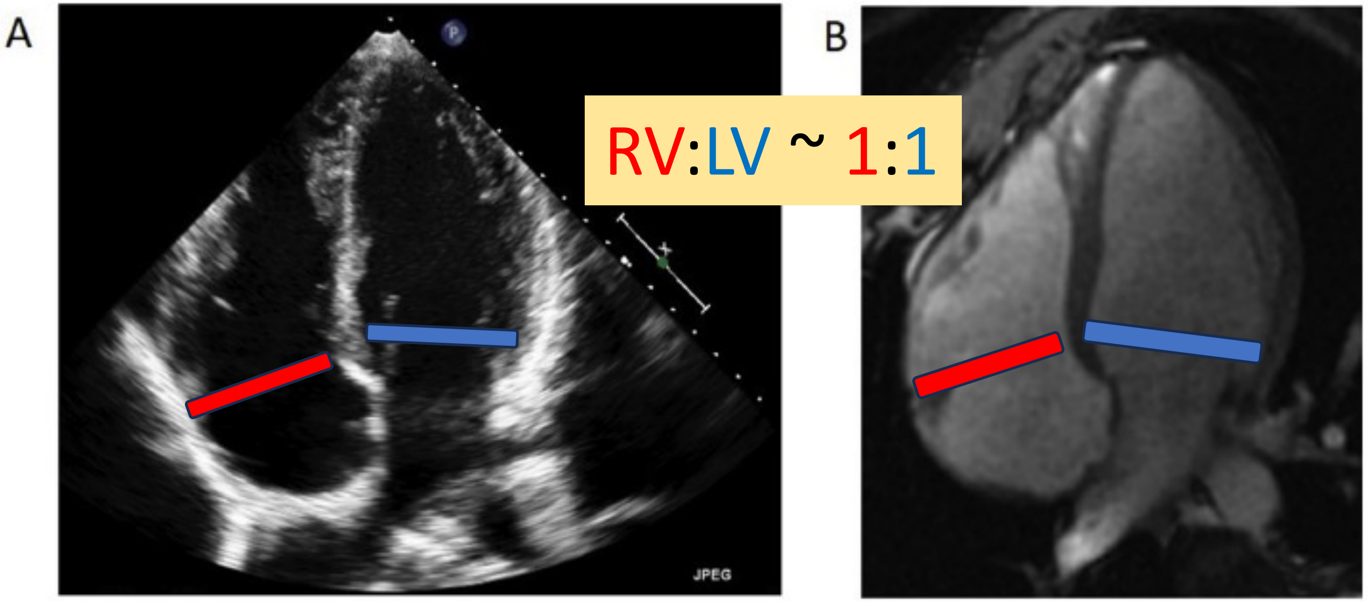
↓

Imaging Findings c/w EICR
Concomitant LV dilation
Normal RV morphology
Normal / low normal systolic function
Supra-normal LV diastolic indices
Normal / mildly enlarged LA & RA
Normal RV systolic pressure
Normal tricuspid and pulmonic valves

Recommendations on the Use of Multimodality Cardiovascular Imaging in Young Adult Competitive Athletes: A Report from the American Society of Echocardiography in Collaboration with the Society of Cardiovascular Computed Tomography and the Society for Cardiovascular Magnetic Resonance

Check for updates

Aaron L. Baggish, MD, (Chair), Robert W. Battle, MD, Timothy A. Beaver, MD, FASE, William L. Border, MBChB, MH, FASE, Pamela S. Douglas, MD, FASE, Christopher M. Kramer, MD, Matthew W. Martinez, MD, Jennifer H. Mercandetti, BS, RDCS (AE/PE), ACS, FASE, Dermot Phelan, MD, PhD, FASE, Tamanna K. Singh, MD, Rory B. Weiner, MD, FASE, and Eric Williamson, MD, *Boston, Massachusetts; Charlottesville, Virginia; Kansas City, Kansas; Atlanta, Georgia; Durham and Charlotte, North Carolina; Morristown, New Jersey; Denver, Colorado; Cleveland, Ohio; Rochester, Minnesota*



The Vast Majority of Endurance Athletes Have Benign Physiologic Remodeling

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RV Exercise Physiology

RV Exercise-Induced Remodeling

RV Fatigue & Injury (?)

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The Athlete's Heart

Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes

André La Gerche[1,2*], Andrew T. Burns[3], Don J. Mooney[3], Warrick J. Inder[1], Andrew J. Taylor[4], Jan Bogaert[5], Andrew I. MacIsaac[3], Hein Heidbüchel[2], and David L. Prior[1,3]

Table 1 Baseline demographic and functional measures according to the endurance event completed

	Overall	Marathon run	Endurance triathlon[a]	Alpine cycling	Ultra triathlon[a]	P-value
Number of athletes	40	7	11	9	13	
Race distance (km)		42.2	1.9/90/21.1	207	3.8/180/42.2	
Race completion time		2 h 59 min ± 30 min	5 h 24 min ± 25 min	8 h 5 min ± 42 min	10 h 52 min ± 1 h 16 min	
Ambient temperature (°C)		16–20	18–31	24–34	17–28	
Age (years)	37 ± 8	38 ± 3	33 ± 7	44 ± 9	34 ± 8	0.014
Male (%)	90	86	91	78	100	0.378
BMI (kg/m²)	23.6 ± 1.9	22.3 ± 1.6	24.0 ± 2.1	23.9 ± 2.1	23.5 ± 1.3	0.306
% of predicted VO_2max	146 ± 18	142 ± 8	141 ± 20	154 ± 20	148 ± 18	0.36
Training (years)	10 ± 9	13 ± 8	6 ± 5	12 ± 14	11 ± 9	0.277
Training (h/week)	16.3 ± 5.1	14 ± 6	14 ± 3	13 ± 4	21 ± 5	<0.0001

Table 2 Haemodynamic and echocardiographic measures at baseline, post-race, and delayed

	Baseline	Post-race	Delayed	ANOVA P-value
Heart rate (b.p.m.)	52 ± 7	72 ± 9	54 ± 6	<0.0001
Systolic BP (mmHg)	147 ± 14	117 ± 13	134 ± 20	<0.0001
Diastolic BP (mmHg)	77 ± 7	70 ± 11	74 ± 10	0.001
PASP (mmHg)	21.5 ± 3.8	18.0 ± 3.3	20.0 ± 3.3	<0.0001
Right ventricular measures				
RVEF (%)	51.0 ± 3.6	46.4 ± 6.5	50.0 ± 3.8	<0.0001
RVFAC (%)	51.5 ± 6.0	44.3 ± 11.2	49.8 ± 6.6	<0.0001
TAPSE (mm)	24.9 ± 3.9	24.0 ± 4.5	26.5 ± 4.1	0.035
RV strain (%)	−27.2 ± 3.4	−23.7 ± 3.7	−25.6 ± 3.0	0.001
RVSRs (s^{-1})	−1.42 ± 0.24	−1.26 ± 0.23	−1.29 ± 0.19	0.008

The Athlete's Heart

Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes

André La Gerche[1,2]*, Andrew T. Burns[3], Don J. Mooney[3], Warrick J. Inder[1], Andrew J. Taylor[4], Jan Bogaert[5], Andrew I. MacIsaac[3], Hein Heidbüchel[2], and David L. Prior[1,3]

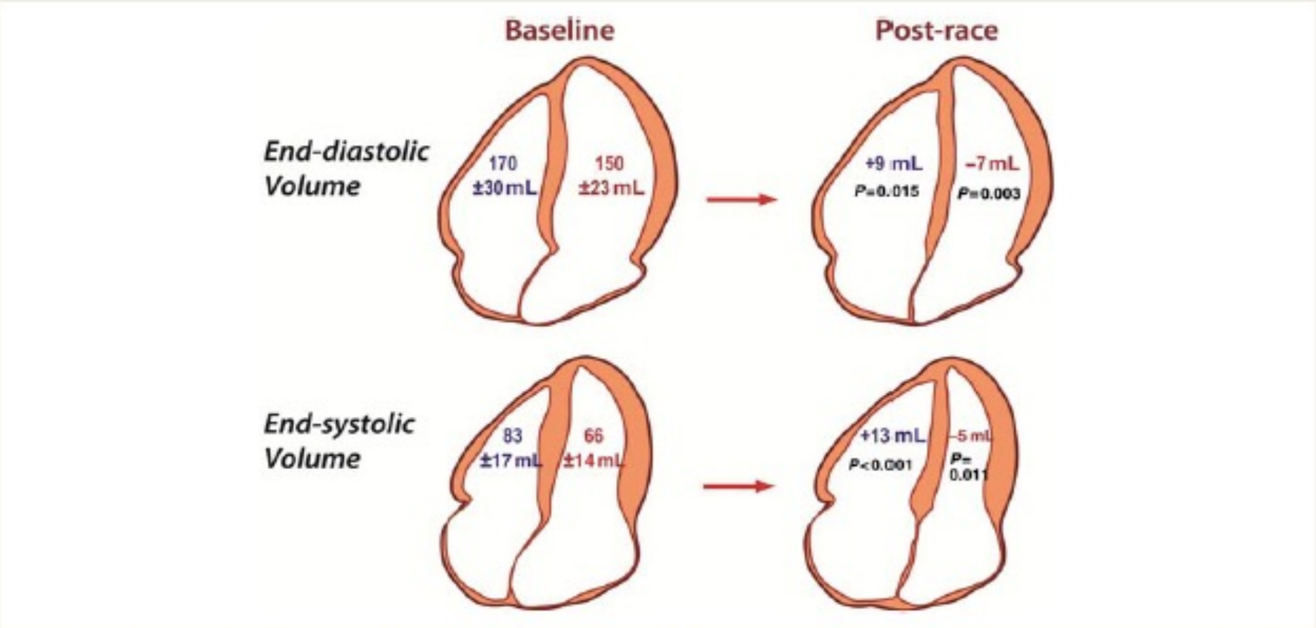
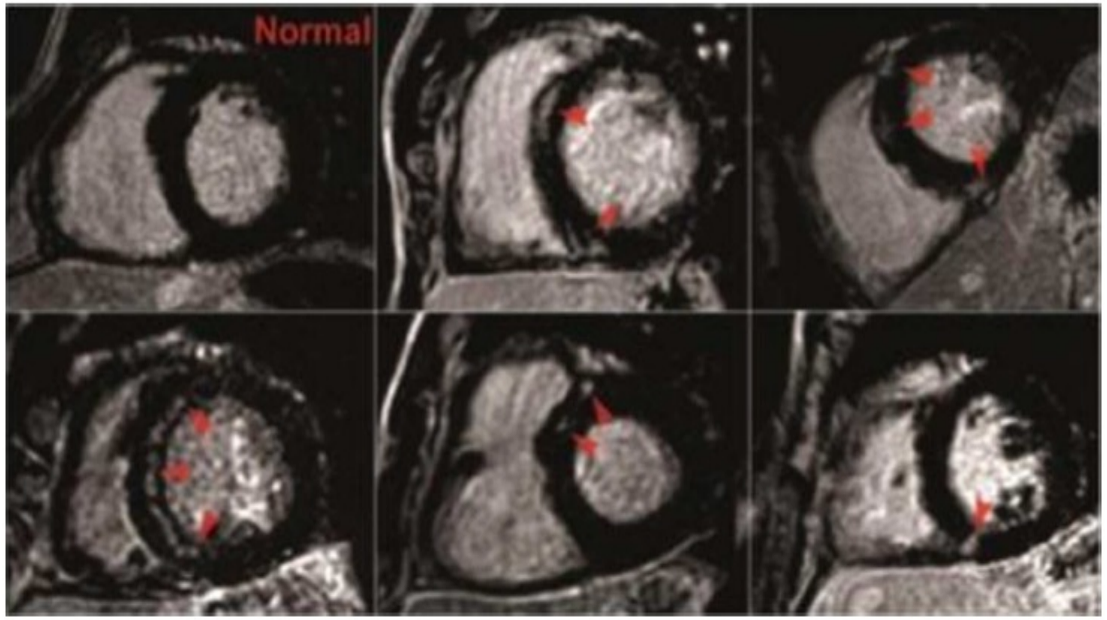


Figure 1 Differential effect of prolonged intense exercise on right and left ventricular volumes. Baseline volumes are shown on the left and the changes in volume post-race are shown on the right. Right ventricular volumes increased in the post-race setting while left ventricular volumes decreased resulting in a decrease in right ventricular ejection fraction but not left ventricular ejection fraction.



This is the minority, not the majority

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The Athlete's Heart

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Chronic Extreme Volume & Intensity

+

Training / Recovery Mismatch

+

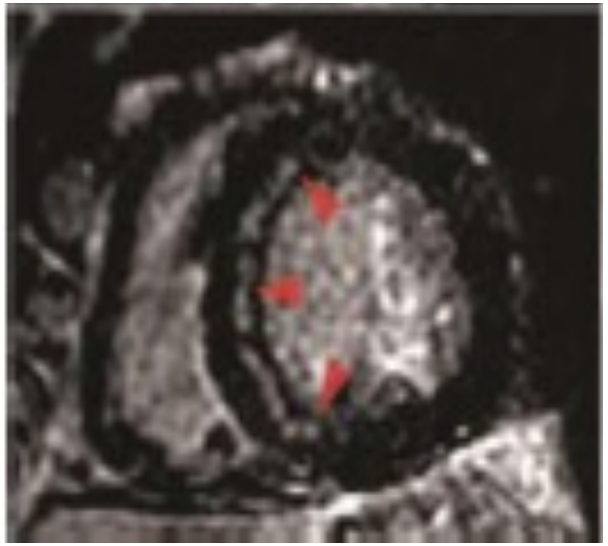
Host Susceptibility (Genetics)

+

Secondary Process (Drugs, Infection, Disease)

A Theoretical Pathogenic Cascade

"The Rare Perfect Storm"



Don't go looking for scar, but be ready to evaluate complex arrhythmias…

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Isolated Subepicardial Right Ventricular Outflow Tract Scar in Athletes With Ventricular Tachycardia

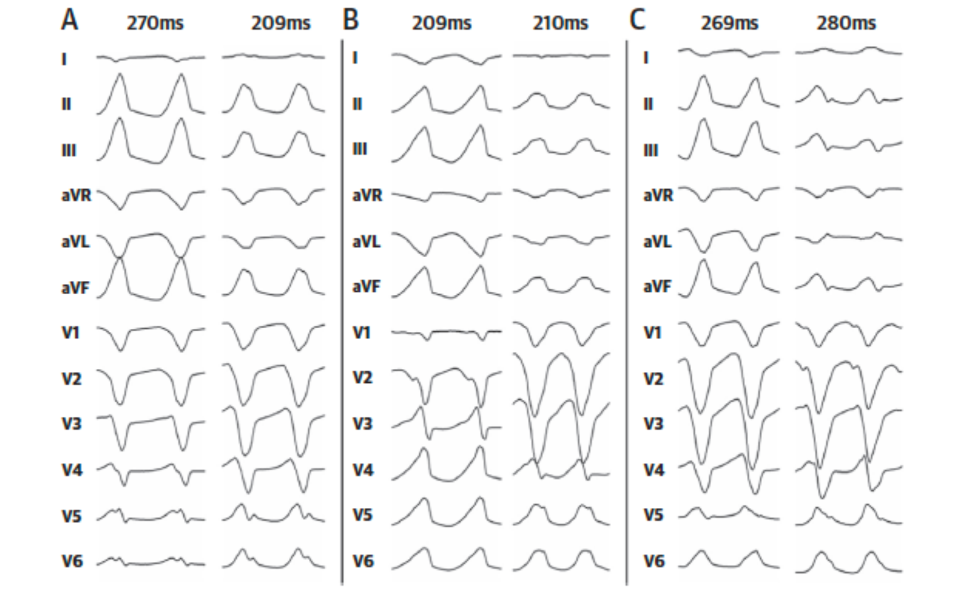
Venlet et al. JACC VOL. 69, NO. 5, 2017

TABLE 1 Baseline Characteristics

	All Patients (N = 57)	Group A (Subtricuspid) (n = 46)	Group B (Isolated RVOT) (n = 11)	p Value*
Age, yrs	48 ± 16	49 ± 16	42 ± 15	0.152
Male	47 (83)	38 (83)	9 (82)	0.951
ICD (before ablation)	31 (54)	27 (59)	4 (36)	0.182
White/black/Asian	54/2/1	43/2/1	11/0/0	0.685
NT-proBNP, pg/ml	146 (75-286)	180 (84-366)	46 (25-116)	0.001
First presentation				
OHCA	6 (11)	6 (13)	0	0.205
Pre-syncope	18 (32)	12 (26)	6 (55)	0.068
Palpitations	26 (46)	23 (50)	3 (27)	0.174
Other	7 (12)	5 (11)	2 (18)	0.507
Exercise-related	28 (49)	17 (37)	11 (100)	0.001
First documented VA				
VT	52 (92)	41 (89)	11 (100)	0.252
VF	5 (9)	5 (11)	0	
VT cycle length, ms	278 ± 37	283 ± 39	257 ± 22	0.043
Ventricular tachycardia				
Superior axis	12 (21)	12 (26)	0	
Inferior axis	19 (33)	8 (17)	11 (100)	<0.001
Both axes	26 (46)	26 (57)	0	
Endurance athlete	27 (47)	16 (35)	11 (100)	<0.001
Training, h/week	5 (2-10)	4 (2-8)	15 (10-20)	<0.001
Training, yrs	15 (8-25)	18 (6-26)	13 (10-18)	0.029
MET-h/yrs	2,613 (888-5,121)	2,142 (607-3,867)	9,405 (6,270-12,540)	<0.001
Family history of ARVC	14 (25)	14 (30)	0	0.025
Genetic testing	n = 56†	n = 45†	n = 11	

METHODS In 57 consecutive patients (mean age 48 ± 16 years; 83% male) undergoing catheter ablation for scar-related right ventricular VT, 2 distinct scar distributions were identified: 1) scars involving the subtricuspid right ventricle in 46 patients (group A); and 2) scars restricted to the anterior subepicardial right ventricular outflow tract in 11 patients (group B).

FIGURE 3 Group B VT Morphologies



Typical examples of 12-lead ventricular tachycardia (VT) electrocardiograms of 3 endurance athletes of group B, in whom 2 distinct fast VT morphologies could be recorded in the same athlete: both left bundle branch block type and inferior axis with either a dominant negative or isoelectric/positive deflection in limb lead I.

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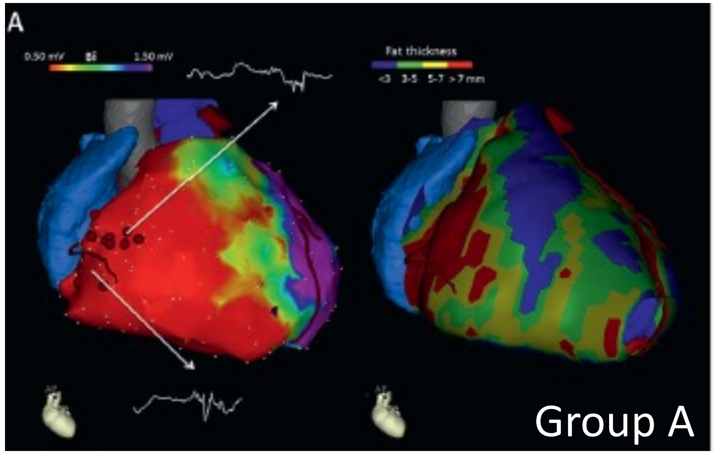
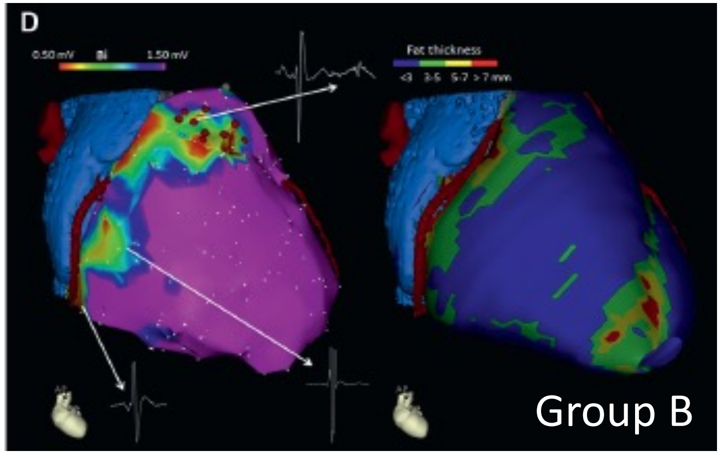
MGH 1811 Cardiovascular Performance Program

Isolated Subepicardial Right Ventricular Outflow Tract Scar in Athletes With Ventricular Tachycardia

Venlet et al. JACC VOL. 69, NO. 5, 2017





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Summary Thoughts

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1.) Exercise-induced cardiac remodeling (EICR) refers to the causal relationship between cardiac enlargement and habitual high volume / high intensity exercise training.

2.) Left ventricular remodeling involves a sport physiology specific combination of dilation and wall thickening in response to pressure and volume stress

3.) Marked remodeling can overlap with forms of mild cardiomyopathy and strategies integrating patient & family history and cardiac imaging can be used to resolve “gray zone” cases

4.) The right ventricle is uniquely responsive to EICR in endurance athletes and largely benign RV insertion point and septal scars may be found in the minority…clinical relevance?

5.) A very unique form of VT, occasionally be seen in endurance athletes, occurs due to RV epicardial scarring and requires a specific catheter-based treatment approach

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Thank You

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