Scientific letter

Age-independent aortic dimensions in adolescent athletes: a practical approach using allometric scaling

Dimensiones de la aorta independientes de la edad en atletas adolescentes: una aproximación práctica con escalado alométrico

To the Editor,

In some cases of congenital aortic anomalies or potentially undiagnosed tubular dilations, structural weakness of the ascending aorta predisposes to pathological dilation during prolonged periods of increased wall stress. Indeed, aortic rupture is an uncommon but important finding in all series of sudden cardiac death in young, ostensibly healthy, athletes, even in those undergoing preparticipation screening.[1] Nevertheless, while aortic root values have been reported to be larger in pediatric athletes than in age-matched nonathletes,[2] no normative values are available for aortic dimensions in healthy pediatric/adolescent athletes in the 4 main planes––aortic annulus, sinuses of Valsalva, sinotubular junction and ascending aorta––which is distinct from the situation in adult athletes.[3] Clearly, having access to these data would aid clinicians in detecting pathologic abnormalities in young athletes.

Aortic root diameters are traditionally reported in absolute values; however, given the association between cardiac dimensions and anthropometric measures (ie, body surface area [BSA]), particularly in children, it has been proposed that allometric rather than linear scaling can provide cardiac measures that are body size-independent and would allow within- and between-subject comparisons along pubertal development.[4] Of note, allometric scaling has been recently proposed for athletes across a relatively wide age range (12-35 years),[5] but no specific subgroup analyses for pediatric/adolescent athletes were provided, and results were only available for the Valsalva sinus using M-mode ultrasonography. To address this issue, in the present study we report body size-independent aortic dimensions in pediatric/adolescent athletes.

We followed a cross-sectional, single-center study design. Participants were pediatric/adolescent athletes who underwent thorough preparticipation screening at the sports medicine center of the autonomous community of Madrid (Spain) during a recent 10-year period. Inclusion criteria were age 10 to 18 years and competing at national or international level. Exclusion criteria were having a bicuspid aortic valve, aortic dysplasia or prolapse, moderate or severe aortic regurgitation, high-gradient aortic stenosis, blood pressure > 95th percentile for the corresponding

Table 1
Main characteristics of participants by sex

	Boys (n = 299)	Girls (n = 230)	*P*
Demographics and anthropometric variables			
Age, y	14.9 ± 1.9	14.5 ± 1.9	.017
Height, cm	169 ± 12	161 ± 8	< .001
Weight, kg	58.7 ± 13.4	52.2 ± 10.6	< .001
BSA, m^2	1.67 ± 0.24	1.53 ± 0.18	< .001
Systolic blood pressure, mmHg	111 ± 10	107 ± 10	< .001
Diastolic blood pressure, mmHg	64 ± 9	62 ± 8	.003
Resting heart rate, bpm	64 ± 11	66 ± 11	.189
Competition experience, y	5.9 ± 2.6	5.5 ± 2.6	.119
Training regime, h/wk	15 ± 8	17 ± 9	< .001
Echocardiographic variables			
Ventricular septum, mm	8.7 ± 1.3	7.9 ± 1.0	< .001
Anteroposterior left ventricle dimensions, mm	47.8 ± 4.8	44.8 ± 3.9	< .001
Left ventricle posterior free wall, mm	8.5 ± 1.2	7.7 ± 0.9	< .001
Left ventricle end-diastolic volume/BSA, mL/m^2	64.4 ± 10.2	60.1 ± 9.1	< .001
Left ventricle ejection fraction, %	66 ± 7	66 ± 7	.998
Anteroposterior left atrium dimensions, mm	32.2 ± 4.7	30.4 ± 4.8	< .001
Superior-inferior left atrium dimensions, mm	44.2 ± 6.5	42.6 ± 5.6	.003
Superior-inferior right atrium dimensions, mm	46.8 ± 5.9	44.4 ± 5.3	< .001
Aortic annulus, mm	22.9 ± 2.4	21.1 ± 2.1	< .001
Sinuses of Valsalva, mm	27.2 ± 3.0	24.5 ± 2.4	< .001
Sinotubular junction, mm	22.6 ± 2.7	20.9 ± 2.3	< .001
Proximal ascending aorta, mm	23.8 ± 2.8	22.2 ± 2.4	< .001

BSA, body surface area.
Data are shown as mean ± standard deviation. Between-sex comparisons were performed with the unpaired Student *t* test.

https://doi.org/10.1016/j.rec.2021.12.003

Table 2

Pearson correlations results and age-independent aortic dimensions allometrically corrected by body surface area for adolescent athletes aged 10 to 18 years.

Aortic dimensions	Pearson correlations				Allometric scaling				Boys (n = 299)			Girls (n = 230)		
	Age	Height	Weight	BSA	β exponent	Pearson correlation with age of allometry-scaled aortic dimensions (ie, divided by BSA$^{\beta}$)	Independence of allometry-scaled dimension with age	Allometrically corrected aortic dimensions	Mean ± SD	5th percentile	95th percentile	Mean ± SD	5th percentile	95th percentile
Annulus, mm	0.480 $P < .001$	0.649 $P < .001$	0.621 $P < .001$	0.659 $P < .001$	0.513	0.025 $P = .562$	Yes	Annulus/BSA$^{0.5}$, mm/m^2	17.8 ± 1.3	15.7	20.3	17.1 ± 1.5	14.7	19.6
Sinuses of Valsalva, mm	0.433 $P < .001$	0.601 $P < .001$	0.573 $P < .001$	0.608 $P < .001$	0.508	0.006 $P = .890$	Yes	Sinuses of Valsalva/BSA$^{0.5}$, mm/m^2	21.2 ± 1.9	18.1	24.6	19.9 ± 1.7	17.2	23.0
Sinotubular junction, mm	0.436 $P < .001$	0.548 $P < .001$	0.534 $P < .001$	0.563 $P < .001$	0.486	0.040 $P = .353$	Yes	Sinotubular junction/BSA$^{0.5}$, mm/m^2	17.5 ± 1.7	15.0	20.4	16.9 ± 1.7	14.4	19.6
Proximal ascending, mm	0.423 $P < .001$	0.569 $P < .001$	0.553 $P < .001$	0.582 $P < .001$	0.558	0.050 $P = .253$	Yes	Proximal ascending/BSA$^{0.5}$, mm/m^2	18.5 ± 1.8	15.9	21.6	17.9 ± 1.8	15.2	21.2

BSA, body surface area; SD, standard deviation.
Data are shown as mean ± standard deviation.

Scientific letter / Rev Esp Cardiol. 2022;75(7):607–616

age and height, exercise-induced bronchoconstriction or hypertension, cardiomyopathy, left-right shunt, acute pericarditis, supra-aortic trunk disease, or second-degree atrioventricular block. Both athletes and their parents or legal representatives provided written consent and the study was approved by the local ethics committee.

We measured participants' height and weight to the nearest 0.1 cm and 0.1 kg, respectively, and BSA. Echocardiographic evaluations were performed by the same sports cardiologist (AB, 30+ year experience) using a Siemens Sonoline G50 (Siemens Medical Solutions, Ann Arbor, United States) or a Mindray DC-70 (Shenzhen Mindray Bio-Medical Electronics, China) instrument with a 2 to 4 MHz phase array transducer. Aortic diameters were measured in the aforementioned 4 planes in 2D parasternal long-axis view at end-diastole (using the average of 3 consecutive cycles) with the inner-inner convention, as previously performed in young adult elite athletes.[3]

We used Pearson's correlation analysis to explore the association between aortic dimensions and age and anthropometric measurements. Thereafter, we studied the allometric relationship between aortic dimensions and BSA by nonlinear regression using the Levenberg-Marquardt algorithm,[6] also known as the 'damped least squares method', which is used to solve nonlinear least squares minimization. Minimization problems arise especially in least squares curve fitting, which is the process of constructing a curve or mathematical function that has the best fit to a series of data points. Thus, allometric-indexed aortic dimension = nonadjusted aortic dimension (mm)/(BSA, in $m^2)^{\beta}$, where β was determined with a confidence interval of 95%. Statistical analyses were performed with Stata 14.0 (StataCorp, College Stattion, United STates) with $\alpha = 0.05$.

Of the 637 athletes aged 10 to 18 years evaluated, 529 met the inclusion criteria (table 1). The athletes were engaged mostly in water polo (16%), swimming (16%), tennis (10%), synchronized swimming (6%), field hockey (13%), soccer (5%), and badminton (5%) competitions. Results showed that all 4 nonadjusted aortic dimensions positively and significantly correlated with age, height, weight, and BSA (all $P < .001$; table 2). However, significance for the correlation between each of the 4 dimensions and age was lost if the former were allometrically corrected for BSA ($P > .3$). All β-values for BSA were ~0.5 [0.486-0.513], and for practicality we consistently used an age-independent β-value of 0.5 (which is actually equivalent to square root) for all sex-specific normative values of aortic root dimensions allometrically normalized by BSA (table 2).

A number of aortic abnormalities predisposing to pathological dilation during exercise can increase the risk of sudden cardiac death in young, apparently healthy, athletes.[1] Accordingly, the assessment of aortic dimensions in the 4 planes is relevant in this population. However, in the absence of structural cardiopathies, the main determinants of aortic root and overall cardiac dimensions are sex, body size and age, which makes comparisons across children challenging.[4] In this context, allometric scaling (but not linear correction) of BSA-adjusted cardiac measures is a valid procedure for obtaining body size- and age-independent values, at least in athletes aged 10 to 18 years.

There are some limitations in our study. We did not assess a control group of children not engaged in sports, and we studied athletes participating in sport events that might differ in cardiovascular demands (static or dynamic components) and thus, potentially, in aortic remodeling. Our use of the inner-inner method limits the comparability of our findings with respect to prior research using the standard leading edge-to-leading edge convention. By contrast, measurement of aortic diameters in the aforementioned 4 different planes should be considered a methodological strength of the study. Indeed, as we previously noted,[3] performing only 1 to 2 measurements of the aortic root can result in over- or underestimation since aortic dilation distal to the supra-aortic ridge could be missed, with dilation potentially representing a risk factor for cardiovascular complications because of aortic dissection, especially in sports with higher hemodynamic loads.

We therefore propose normative values that might help clinicians to rapidly compare aortic root dimensions between children of different ages irrespective of their body size. This information should be useful in the early identification of aortic alterations that could limit sports participation, or at least justify close surveillance in pediatric/adolescent athletes.

FUNDING

M-E. Heras was funded by the Community of Madrid (Beca de investigación y formación postgrado de médicos especialistas en Medicina de la Educación Física y el Deporte, Orden 481/2016). Research by A. Lucia is funded by the Spanish Ministry of Economy and Competitiveness and Fondos Feder (grant PI18/00139).

AUTHORS' CONTRIBUTIONS

A. Boraita and M-E. Heras share first authorship. A. Santos-Lozano and A. Lucia share senior authorship. A. Boraita and M-E. Heras conceived the original idea, acquired and analyzed the data, and drafted the initial version of the manuscript. P.L. Valenzuela, F. Morales-Acuña, A. Santos-Lozano and A. Lucia helped in the interpretation of the data and drafted the final version of the manuscript. All authors revised the manuscript critically for important intellectual content and approved the final version.

CONFLICTS OF INTEREST

The authors have no conflicts of interest.

Acknowledgements

We thank Dr Kenneth McCreath for his editorial assistance.

Araceli Boraita,[a,*] María-Eugenia Heras,[a] Pedro L. Valenzuela,[b,c] Francisco Morales-Acuña,[d] Alejandro Santos-Lozano,[c,e] and Alejandro Lucia[b,c]

[a]*Centro de Medicina del Deporte, Agencia Española de Protección de la Salud en el Deporte, Madrid, Spain*
[b]*Facultad de Ciencias del Deporte, Universidad Europea de Madrid, Madrid, Madrid, Spain*
[c]*Instituto de Investigación del Hospital 12 de Octubre (grupos imas12 y PaHerg), Madrid, Spain*
[d]*Especialidad en Medicina del Deporte y la Actividad Física, Facultad de Ciencias, Universidad Mayor, Santiago, Chile*
[e]*i+HeALTH, Departamento de Ciencias de la Salud, Universidad Europea Miguel de Cervantes, Valladolid, Spain*

* Corresponding author:
E-mail addresses: araceli.boraita@aepsad.gob.es, araceliboraita@gmail.com (A. Boraita).

REFERENCES

1. Papagiannis J. Sudden death due to aortic pathology. *Cardiol Young.* 2017;27(S1):S36–S42.
2. McClean G, Riding NR, Ardern CL, et al. Electrical and structural adaptations of the paediatric athlete's heart: A systematic review with meta-analysis. *Br J Sports Med.* 2018;52:230.
3. Boraita A, Heras ME, Morales F, et al. Reference Values of Aortic Root in Male and Female White Elite Athletes According to Sport. *Circ Cardiovasc Imaging.* 2016;9:1–10.
4. Kaski JP, Daubeney PEF. Normalization of echocardiographically derived paediatric cardiac dimensions to body surface area: Time for a standardized approach. *Eur J Echocardiogr.* 2009;10:44–45.
5. Abulí M, Grazioli G, Sanz de la Garza M, et al. Aortic root remodelling in competitive athletes. *Eur J Prev Cardiol.* 2020;27:1518–1526.
6. Marquardt D. An Algorithm for Least- Squares Estimation of Nonlinear Parameters. *J Soc Ind Appl Math.* 1963;11:431–441.

https://doi.org/10.1016/j.rec.2021.12.003

Clinical and economic impact of cardiac magnetic resonance-guided decision-making

Impacto clínico y económico de la toma de decisiones guiada por resonancia magnética cardiaca

To the Editor,

Cardiac magnetic resonance (CMR) is the gold standard for the study of myocardial function and viability. However, its costs and clinical usefulness as part of the patient's progress in a health care system with high care demands and limited economic resources remain to be established, particularly with the emergence of new management models for the technique.[1]

We carried out a retrospective, single-center, observational, intervention simulation study in patients who had undergone a CMR for clinical purposes between July 2014 and December 2017. After approval by the hospital ethics committee and following a previous methodology, we analyzed a random sample of 10% of the total activity performed during the inclusion period and obtained a representative sample.[2] We recorded the suspected diagnosis and investigations or interventions requested. The full CMR report was then sent to 2 consultants, and a new request was issued for the investigations or interventions that they considered necessary despite CMR. The cost analysis was based on the calculation of the total cost or saving generated as a result of the decisions made in the intervention simulation study. The reference prices used were those available in the Regional Health care System[3], or, if unavailable, the mean of the available prices in other regions was taken. All the prices were updated to euros with the 2020 value according to the Consumer Price Index. Lastly, we analyzed the mean radiation dose saved per patient after taking out the studies involving ionizing radiation.[4] The statistical analysis was performed with Stata Version 14.2 (StataCorp, USA). Continuous variables are expressed as mean ± standard deviation, and categorical variables as number and percentage.

In the period analyzed, 4046 CMRs were performed. A sample of 10% of these was taken, excluding those that were performed for research purposes, giving a final sample of 343 patients, with no differences in the baseline characteristics from the original population. CMR represented a significant change in diagnosis in 35.3% (121 patients) as a result of exclusion of the initial diagnosis in 88 patients (25.7%) and finding an unexpected diagnosis in 33 (9.6%).

Based on the clinical simulation analysis, the CMR result would have meant the end of the diagnostic process in 47.8% (164 patients), which represents a combined saving of 62.2% of the studies planned before CMR (table 1). Transthoracic echocardiography was the investigation with the greatest potential for reduction, up to 94.6% of studies (–229 studies). Furthermore, the use of CMR allowed a mean reduction of 1.54 mSv/patient attributable to the nonperformance of investigations or procedures involving ionizing radiation in the simulation. In the analysis of the

Table 1
Investigations performed before and after cardiac magnetic resonance report

Test/treatment	Before CMR	After CMR	Overall balance, No. (%)
Transthoracic echocardiogram	244	15	–229 (–94.6)
Transesophageal echocardiogram	30	12	–18 (–60)
SPECT	37	2	–35 (–95)
Cardiac catheterization	49	59	+10 (–20)
24-h Holter ECG	37	40	+3 (+8)
Coronary CT	42	10	–32 (–76)
Ergospirometry	57	52	–5 (–9)
Scintigraphy	6	0	–6 (–100)
ICD/ICD-CRT	21	19	–2 (–10)
Pacemaker-implantable Holter	1	2	+1 (+50)
Percutaneous coronary intervention	20	15	–5 (–25)
Surgical revascularization	7	5	–2 (–29)
Other cardiac surgery	9	13	+4 (+44)
Structural intervention	2	3	+1 (+50)
Ablation	15	13	–2 (–13)

CMR, cardiac magnetic resonance; CT, computed tomography; ICD, implantable cardioverter-defibrillator; ICD-CRT, implantable cardioverter-defibrillator and cardiac resynchronization therapy; Holter ECG, Holter electrocardiogram; SPECT, single photon emission computed tomography.