

Effect of Long Term and Intensive Endurance Training in Athletes on the Age Related Decline in Left and Right Ventricular Diastolic Function as Assessed by Doppler Echocardiography

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The aim of this study was to evaluate (1) the effect of endurance training on left ventricular and right ventricular diastolic function and (2) whether the normal aging effect on left ventricular and right ventricular diastolic function is slowed by endurance training. A total of 269 healthy subjects were prospectively enrolled for echocardiographic evaluation. Five groups were defined on the basis of age and athletic activities: (1) young (18 to 39 years) nonathletes (n = 62), (2) veteran (≥ 40 years) nonathletes (n = 33), (3) young regular athletes (9 to 18 hours of sports/week; n = 58), (4) young elite athletes (> 18 hours of sports/week; n = 63), and (5) veteran athletes (≥ 40 years and ≥ 9 hours of sports/week; n = 53). Pulsed-wave Doppler indexes for diastolic function in the left and right ventricles were obtained at rest. No significant differences were found among the young controls, regular athletes, and elite athletes in left ventricular and right ventricular pulsed-wave and tissue Doppler diastolic parameters. These were also comparable between the veteran athletes and controls. In athletes and controls, similar and significant correlations were found between age and diastolic parameters. Age was the most important determinant in almost all parameters in multivariate analysis, while the influence of the amount of training did not account for $> 2\%$ of the observed variance in any of these parameters. In conclusion, the amount of endurance training did not alter diastolic parameters in either ventricle in the young. Furthermore, the biventricular decreases in diastolic function observed in healthy, nonathletic subjects with age was also observed in aging athletes' hearts. © 2009 Elsevier Inc. All rights reserved. (Am J Cardiol 2009;104:1145–1151)

Although biventricular preservation of systolic function in young endurance athletes has been acknowledged in multiple studies,^{1–3} several small studies have reported conflicting results concerning the effects of long-term endurance training on diastolic function.^{1,4–9} Whether intense and/or long-term endurance training improves and/or slows the age-related decrease in diastolic function is also unclear.^{8–16} Therefore, the aims of this study were to evaluate (1) the effect of endurance training on left ventricular (LV) and right ventricular (RV) diastolic function and (2) whether the normal aging effect on LV and RV diastolic function is slowed by endurance training.

Methods

The local ethics committee approved the study protocol, and written informed consent was obtained before the ultrasound examination. All enrolled athletes were endurance athletes (rowing, triathlon, cycling, and long-distance run-

ning) participating in national and international competitions for > 5 years. A total of 269 healthy subjects were prospectively enrolled for echocardiographic evaluation after the exclusion of 2 athletes and 1 control because of cardiac pathology found during the study and hypertension in 2 athletes and 2 controls. Five groups were defined on the basis of age and athletic activities (see Figure 1): (1) young (18 to 39 years) nonathletes (n = 62), (2) veteran (≥ 40 years) nonathletes (n = 32), (3) young regular athletes (9 to 18 hours of sports/week; n = 59), (4) young elite athletes (> 18 hours of sports/week; n = 62), and (5) veteran athletes (≥ 40 years and ≥ 9 hours of sports/week; n = 54). The group of veteran athletes was also selected on the total duration in years (typically > 12 years) during which this amount of endurance training was practiced (≥ 9 hours of sports/week). All subjects were healthy, with no histories of cardiovascular disease, including diabetes and known or treated hypertension; no family histories of sudden cardiac death; and normal results on electrocardiography. Height, weight, heart rate at rest, and blood pressure were measured and electrocardiography was performed before the echocardiographic examination.

The echocardiographic examination was performed with the subject at rest, lying in the left lateral decubitus position. Ultrasound data were acquired using a Vivid 7 scanner (GE Vingmed Ultrasound AS, Horten, Norway) with a M3S broadband transducer. A complete echocardiographic study

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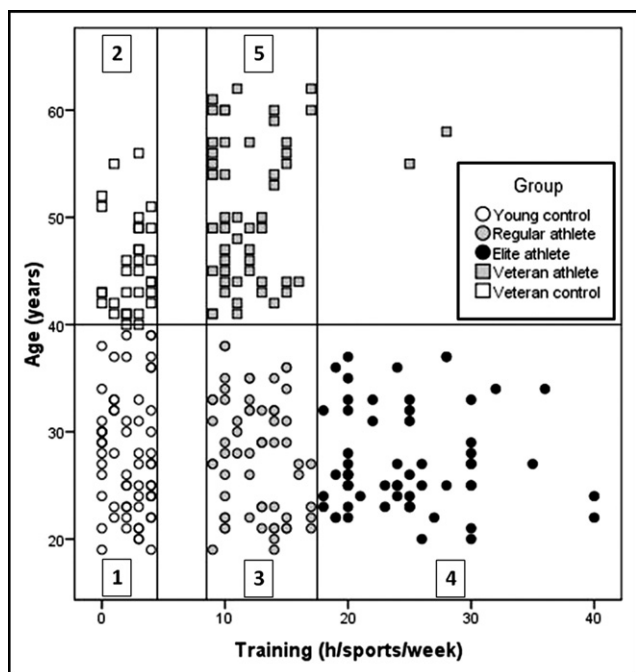


Figure 1. Study population. Subdivisions in the study population by age (at 40 years) and by training intensity (at 4, 9, and 18 hours/week) are indicated by the horizontal and vertical bars, respectively. Numbers allocated to each group are listed in the tables.

was performed, including standard parasternal and apical views. LV and RV dimensions were measured according to the standards of the American Society of Echocardiography. The parasternal 2-dimensional measurements (M-mode) included left atrial and aortic root diameters, LV internal diameter at end-diastole and at end-systole, and septal and posterior wall thicknesses. From these measurements the LV mass was calculated. RV outflow tract end-diastolic diameter was determined in the long-axis (perpendicular to the septum) recording. In the apical 4-chamber view, left atrial and right atrial end-systolic areas and LV and RV inflow tract diameters (at the level of the mitral valve tips) were measured.

Conventional pulsed Doppler imaging was used to obtain LV and RV diastolic parameters using a sample area of 5 mm. All images were acquired at end expiration during breath hold. All Doppler measurements were averaged over 2 beats. Transmitral (MV) and transtricuspid flow were measured at the tips of the valve leaflets. From this, the peak early (E) and late (A) inflow velocity were measured; the E/A ratio calculated; and, only at the mitral valve, the E-wave deceleration time. From the 4-chamber view, the RV and LV peak early (E') and late (A') diastolic velocities (average of 3 measurements) were recorded at the tricuspid and mitral annuli, respectively. For the left ventricle, we used the septal and lateral annulus, and for the right ventricle, we used the lateral tricuspid annulus. All velocities were derived from color-coded tissue Doppler imaging small-angle recordings (frame rate >180 frames/s) and measured off-line (EchoPAC version 6.0.1; GE Vingmed Ultrasound AS), as described previously.¹⁷ From this, the RV and LV E/E' and E'/A' ratios were calculated. Tricuspid E-wave deceleration time was not included in the final

analysis, because almost 10% of all available trace measurements of this parameter were of unsatisfactory quality. In the Doppler recordings of the pulmonary vein and sub-diaphragmatic hepatic veins, the peak systolic (S) and diastolic (D) flow velocities were measured, and the S/D ratio was calculated.

All values are presented as mean \pm SD. Unpaired Student's *t* tests were used to compare groups, and 1-way analysis of variance with Bonferroni's post hoc correction for multiple comparisons was used for comparisons among >2 groups. The univariate association of age and the amount of endurance training on diastolic parameters was examined by linear regression analysis and partial correlation test using Pearson's methods. Using multiple regression analysis, we tested whether the relation between diastolic parameters and age differed between controls and athletes. Stepwise multiple regressions were performed to assess the independent correlations of diastolic parameters with baseline characteristics (age, heart rate, systolic and diastolic blood pressure, body surface area, LV mass, and hours of sports per week). We set the *p* values for variables to enter and stay in the regression models at 0.05 and 0.10, respectively. A *p* value <0.05 was considered to indicate significance. Statistical calculations were performed using commercially available software (SPSS version 15.0 for Windows, SPSS, Inc., Chicago, Illinois).

Results

The baseline characteristics of the study population are listed in Table 1. By study design, age and amount of training were different among groups. Relevant differences among groups were the younger age of the veteran controls compared to the veteran athletes, slightly increased blood pressure in the veteran athletes, and, as expected, lower heart rates in all athlete groups. The amount of endurance training per week in the veteran athlete group was comparable to that in the regular athlete group. Only 2 veteran athletes (4%) reported training >18 hours/week.

All ventricular and dimensions are listed in Table 2. Almost all dimensions were increased in the athlete groups compared to their age-matched control group; in particular, the elite athletes showed the most pronounced remodeling. With respect to age, left and right atrial dimensions increased in the control and athlete populations. Ventricular dimensions were comparable in the control population, while in the athlete groups, RV dimensions were significantly larger in the veterans compared to the young athletes, and consequently the LV/RV ratio was lower. When comparing the regular to the elite athletes, all parameters were larger in the elite athlete group but reached significance only for LV mass.

In line with the 2 aims of this study, we assessed LV and RV diastolic parameters in 2 separate groups. The young controls and the young regular and elite athletes were used to evaluate the first aim: the impact of the amount of endurance training on ventricular diastolic function. The young and veteran controls and athletes, excluding the elite athletes to match the hours of sports per week, were used to evaluate the second aim: the effect of endurance training on the age-related changes in diastolic parameters.

Table 1
Baseline characteristics

Variable	Controls		Athletes		
	Young (1) (n = 62)	Veteran (2) (n = 32)	Regular (3) (n = 58)	Elite (4) (n = 63)	Veteran (5) (n = 54)
Age (years)	27.9 ± 5.6	45.5 ± 4.3 [†]	27.9 ± 5.4	27.1 ± 4.7	50.8 ± 6.5 ^{†,§}
Men	58.1%	31.3%*	52.5%	69.9%	72.2%* [§]
Training (hours/week)	2.2 ± 1.6	2.5 ± 1.5	12.4 ± 2.3 ^{§,}	24.4 ± 5.4 [§]	11.9 ± 3.8 ^{§,}
Heart rate (beats/min)	59.3 ± 10.6	59.8 ± 8.6	50.7 ± 7.3 [§]	50.4 ± 9.0 [§]	50.1 ± 11.1 [§]
Body surface area (m ²)	1.89 ± 0.20	1.88 ± 0.25	1.90 ± 0.15	1.96 ± 0.17	1.87 ± 0.18
Length (m)	178.8 ± 9.0	174.4 ± 11.7	179.7 ± 7.4	183.3 ± 8.3 [‡]	176.4 ± 7.9
Weight (kg)	71.4 ± 12.3	73.7 ± 16.1	71.7 ± 9.3	73.9 ± 10.3	71.3 ± 11.2
Systolic blood pressure (mm Hg)	126.3 ± 14.2	126.8 ± 16.3	125.5 ± 14.2	122.8 ± 11.2	137.1 ± 17.3 ^{§,}
Diastolic blood pressure (mm Hg)	72.9 ± 9.6	78.8 ± 12.0	73.0 ± 9.7	70.4 ± 8.5	81.4 ± 10.5 ^{†,}

Data are expressed as mean ± SD or as percentages. Numbers after group classifications refer to subdivisions from Figure 1.

* p < 0.05 and [†] p < 0.01 versus training-matched young; [‡] p < 0.05 and [§] p < 0.01 versus age-matched controls; ^{||} p < 0.05 and ^{|||} p < 0.01 regular/veteran versus elite athletes (all using Bonferroni's post hoc correction).

Table 2
Echocardiographic dimensions

Variable	Controls		Athletes			ANOVA p Value
	Young (1)	Veteran (2)	Regular (3)	Elite (4)	Veteran (5)	
LVIDd (mm/m ²)	25.7 ± 1.9	25.7 ± 2.4	26.9 ± 1.8 [‡]	27.2 ± 2.0 [§]	26.6 ± 2.6	<0.001
LVIDs (mm/m ²)	17.3 ± 2.1	16.3 ± 2.1	17.7 ± 2.0	18.2 ± 2.0	17.2 ± 2.8	0.002
IVSd (mm/m ²)	5.23 ± 0.48	5.46 ± 0.66	5.62 ± 0.59 [§]	5.76 ± 0.72 [§]	5.98 ± 0.61* [§]	<0.001
LVPWd (mm/m ²)	4.84 ± 0.55	5.08 ± 0.75	5.30 ± 0.56 [§]	5.32 ± 0.64 [§]	5.08 ± 0.75* [§]	<0.001
LV mass (g/m ²)	87.6 ± 15.8	90.4 ± 13.9	107.2 ± 18.1 [§]	117.0 ± 24.0 [§]	110.1 ± 18.8 [§]	<0.001
LA diameter (mm/m ²)	19.3 ± 1.8	21.3 ± 1.7 [†]	20.8 ± 2.6 [§]	21.5 ± 2.5 [§]	23.0 ± 2.9* [‡]	<0.001
Aortic diameter (mm/m ²)	14.3 ± 1.4	15.6 ± 1.7 [†]	14.4 ± 1.5	15.1 ± 1.7 [‡]	15.7 ± 1.7 [†]	<0.001
RVOT (mm/m ²)	14.0 ± 2.1	14.8 ± 2.0	14.9 ± 2.2	15.2 ± 2.6 [‡]	16.7 ± 1.9 ^{†,§}	<0.001
LVIT (mm/m ²)	22.9 ± 1.9	22.6 ± 2.6	24.4 ± 1.8 [§]	24.6 ± 2.1 [§]	24.4 ± 2.6 [§]	<0.001
RVIT (mm/m ²)	18.5 ± 2.2	19.9 ± 2.0	20.4 ± 2.2 [§]	21.0 ± 2.1 [§]	22.4 ± 2.2 ^{†,§}	<0.001
LVIT/RVIT ratio	1.25 ± 0.15	1.15 ± 0.13 [†]	1.21 ± 0.14	1.18 ± 0.13 [‡]	1.10 ± 0.11 [†]	<0.001
LA area (cm ² /m ²)	8.63 ± 1.68	10.17 ± 1.48 [†]	10.20 ± 1.50 [§]	10.56 ± 1.77 [§]	11.21 ± 2.18 ^{†,‡}	<0.001
RA area (cm ² /m ²)	8.44 ± 1.48	9.76 ± 1.62*	10.21 ± 1.66 [§]	10.92 ± 2.25 [§]	12.29 ± 2.00* [§]	<0.001

Data are expressed as mean ± SD. Numbers after group classifications refer to subdivisions from Figure 1.

* p < 0.05 and [†] p < 0.01 versus training-matched young; [‡] p < 0.05 and [§] p < 0.01 versus age-matched controls (all using Bonferroni's post hoc correction).

ANOVA = analysis of variance; IVSd = septal wall thickness; LA = left atrial; LVIDd = LV end-diastolic diameter; LVIDs = LV end-systolic diameter; LVIT = LV inflow tract; LVPWd = LV posterior wall thickness; RA = right atrial; RVIT = RV inflow tract; RVOT = RV outflow tract.

Doppler-derived parameters for the first aim of the study are listed in Table 3. The only significant differences were encountered in the elite athlete group, in which peak MV E, MV A, and transtricuspid A velocities were moderately reduced. All other parameters, including the E/A and E/E' ratios, were comparable between groups. Univariate analysis, however, did show significant but weak correlations between the amount of endurance training and some diastolic parameters in the entire group (n = 183). For the left ventricle, MV E and MV A showed negative associations with the amount of training (R = -0.19, p < 0.05, and R = -0.24, p < 0.01, respectively), and MV E-wave deceleration time increased with an increase in training (R = 0.15, p < 0.05). All other parameters showed no correlations. In the right ventricle, only transtricuspid A showed a significant correlation with respect to training (R = -0.17, p < 0.05).

Mean values of Doppler parameters in the different age groups, the second aim of the study, are listed in Table 4. In the control groups, all diastolic parameters, with the exception of peak MV E velocity and MV E-wave deceleration

time, showed significant changes indicative of a decrease in diastolic function with aging. In the right ventricle, these changes were less apparent; nonetheless, the E/A and E'/A' ratios were significantly reduced in the veteran controls. In the athlete groups, the differences between young and old were comparable to those described in the control group for the left and right ventricles.

Univariate analysis of the correlations between age and diastolic parameters in the control and the athlete groups are listed in Table 5. In the control group, almost all parameters for the left ventricle and most for the right ventricle were affected by age. Notable differences between the left and right ventricles were the inflow velocities and consequently the E/A ratio and the change in E', which seemed less affected in the right ventricle with increasing age. In the athlete group, findings were comparable to those observed in the controls, also for the differences between the 2 ventricles (see Figure 2). Of all diastolic parameters, the only difference in the regression coefficients between athletes and nonathletes was observed in the MV E/E' ratio (p =

Table 3
The effect of the amount of training on diastolic function

Parameter	Controls (1)	Regular Athletes (3)	Elite Athletes (4)	ANOVA p Value
Left ventricle				
MV E (cm/s)	79.8 ± 12.5	78.1 ± 13.6	74.0 ± 13.7*	0.026
MV EDT (ms)	178.3 ± 21.3	180.8 ± 21.5	186.3 ± 19.4	NS
MV A (cm/s)	38.8 ± 6.3	38.0 ± 7.0	33.9 ± 8.1 ^{†‡}	0.001
MV E/A	2.10 ± 0.43	2.11 ± 0.45	2.31 ± 0.66	NS
MV E' (cm/s)	12.6 ± 1.9	12.3 ± 1.6	12.5 ± 2.0	NS
MV E/E' (cm/s)	6.39 ± 1.07	6.42 ± 1.08	5.99 ± 1.09	NS
MV E'/A'	3.00 ± 1.30	2.95 ± 1.31	3.26 ± 1.58	NS
PV S/D	0.84 ± 0.20	0.80 ± 0.23	0.79 ± 0.24	NS
Right ventricle				
TV E (cm/s)	60.9 ± 10.4	56.9 ± 10.2	59.5 ± 11.3	NS
TV A (cm/s)	27.2 ± 6.3	24.9 ± 6.3	24.1 ± 5.0*	0.010
TV E/A	2.35 ± 0.59	2.40 ± 0.57	2.56 ± 0.59	NS
TV E' (cm/s)	11.0 ± 1.8	11.2 ± 1.7	11.5 ± 2.0	NS
TV E/E' (cm/s)	5.43 ± 1.50	4.91 ± 1.35	5.21 ± 1.48	NS
TV E'/A'	1.53 ± 0.56	1.50 ± 0.53	1.71 ± 0.61	NS
HV S/D	1.79 ± 0.44	1.62 ± 0.54	1.75 ± 0.54	NS

Data are expressed as mean ± SD. Numbers after group classifications refer to subdivisions from Figure 1.

* p < 0.05 and † p < 0.01 versus controls; ‡ p < 0.01 elite versus amateur (all using Bonferroni's post hoc correction).

A = late diastolic velocity; A' = late diastolic tissue Doppler imaging velocity; E' = early diastolic tissue Doppler imaging velocity; E = early diastolic velocity; EDT = early diastolic deceleration time; HV = hepatic vein; MV = mitral valve; PV = pulmonary vein; S/D = systolic velocity/diastolic velocity ratio; TV = tricuspid valve; other abbreviation as in Table 2.

0.003) and in the pulmonary vein S/D ratio (p = 0.045). Thus, the changes in all other parameters occurring with aging were not significantly different between athletes and nonathletes.

On multivariate analysis (see supplementary file), age remained a significant factor affecting all LV diastolic parameters, whether the elite athletes were included in the analysis or not. The amount of training contributed significantly, but to a lesser degree, in MV E, MV E/A, and MV E/E', but the resulting R² change was never >0.02. For the right ventricle, age was a significant factor affecting all diastolic parameters, except the E/E' ratio, for which the amount of training was the only (weak) significant factor.

Discussion

This cross-sectional study showed that in 269 athletic and nonathletic subjects aged 18 to 62 years, the amount of endurance training did not alter echocardiographic parameters of diastolic function in either ventricle. Furthermore, the decrease in diastolic function observed in healthy, nonathletic subjects with aging was also observed in aging athletes' hearts for all evaluated diastolic parameters. The influence of the level of training did not account for >2% of the observed variance of any of these parameters.

The progressive deterioration of diastolic function with aging occurs in healthy individuals, free of cardiovascular disease,^{18–22} and it is believed to be an important reason for the exponential increase of diastolic heart failure with aging.^{23,24} The possible mechanisms that occur during myo-

cardial senescence, which contributes to the reduction in diastolic function, include an increase in peripheral resistance, extracellular matrix proliferation and collagen cross linking, and an alteration in calcium handling.²³

It has been shown that the effects of aging on most diastolic parameters are independent of the age-related alterations in LV morphology and systolic function.^{19,22} The findings of the present study in the nonathletic subjects confirm and extend these previous observations. For the right ventricle, this is less well established, and even not observed in 1 study.²⁵ Our study showed a similar trend toward decreased RV diastolic function resembling that for the left ventricle. Aging alone may not totally explain all the changes that occur during myocardial senescence. Other factors that change with age, such as diminishing cardiovascular fitness, could also account for the gradual decrease of diastolic function. Indeed, small studies have suggested that long-term endurance training delays the age-associated diastolic decrease.^{8–11,16} These findings are further supported by animal studies in which endurance training, to some degree, stopped the progress or reversed the impairment of early diastolic filling with aging in rats.²⁶ To the contrary, our study in human subjects showed no evidence of this “beneficial” effect of long-term endurance training on the age-associated decrease in diastolic function.

Several small studies have suggested that early diastolic function is augmented in young endurance athletes.^{4,6,8} Other reports have challenged these findings by demonstrating no differences from controls.^{1,5,7} The findings in our study comply better with the latter. Compared to previous published work, we included a relatively large number of young athletes (n = 121) and ensured that amateur and high-level, professional athletes were investigated. The only changes we observed were for the LV diastolic inflow velocities, which were lower in the elite athletes, possibly because of ventricular (and thus annular) dilatation in this group. Nevertheless, newer indexes (tissue Doppler imaging), which are more independent of heart rate, loading, and ventricular dilatation, showed very comparable values in all groups. In the retrospective analysis of Pavlik et al,⁹ diastolic LV function using the E/A ratio was assessed in a comparable, larger study population. An increase in the E/A ratio was observed in endurance athletes, while in our study, this ratio and the E'/A' ratio were only moderately increased in the elite athletes. We could therefore not clearly establish that Doppler parameters in endurance athletes indicate an improved diastolic function compared to nonathletes. Research on RV diastolic function in athletes is scarce and conflicting.^{4,7} Because we have previously shown that RV structural adaptations in athletes' hearts are very common,² sometimes even mimicking specific forms of cardiomyopathy, knowledge on the normal physiology is very relevant in the clinical evaluation of endurance athletes. Our data indicate that RV diastolic function is unchanged in athletes, considering that all relevant parameters were similar between groups.

Age was the most important determinant of variance in almost all Doppler parameters for diastolic function in both ventricles in the athletes. It has previously been suggested that older athletes have better filling properties than age-matched untrained subjects.^{8–11,16} Other small studies, how-

Table 4
The effect of age on diastolic function

Parameter	Controls		Athletes	
	Young (1)	Veteran (2)	Young (3)	Veteran (5)
Left ventricle				
MV E (cm/s)	79.8 ± 12.5	76.0 ± 14.3	78.1 ± 13.6	67.5 ± 13.6 ^{†,‡}
MV EDT (ms)	178.3 ± 21.3	182.1 ± 20.8	180.8 ± 21.5	190.2 ± 25.0*
MV A (cm/s)	38.8 ± 6.3	47.2 ± 12.4 [†]	38.0 ± 7.0	45.8 ± 8.9 [†]
MV E/A	2.10 ± 0.43	1.68 ± 0.48 [†]	2.11 ± 0.45	1.52 ± 0.39 [†]
MV E' (cm/s)	12.6 ± 1.9	10.5 ± 2.0 [†]	12.3 ± 1.6	10.2 ± 1.8 [†]
MV E/E' (cm/s)	6.39 ± 1.07	7.49 ± 2.04 [†]	6.42 ± 1.08	6.82 ± 1.58
MV E'/A'	3.00 ± 1.30	1.72 ± 0.63 [†]	2.95 ± 1.31	1.55 ± 0.48 [†]
PV S/D	0.84 ± 0.20	1.08 ± 0.27 [†]	0.80 ± 0.23	1.27 ± 0.48 ^{†,‡}
Right ventricle				
TV E (cm/s)	60.9 ± 10.4	54.4 ± 9.0*	56.9 ± 10.2	52.4 ± 9.0
TV A (cm/s)	27.2 ± 6.3	29.7 ± 5.7	24.9 ± 6.3	26.4 ± 5.7
TV E/A	2.35 ± 0.59	1.94 ± 0.43 [†]	2.40 ± 0.57	2.06 ± 0.46 [†]
TV E' (cm/s)	11.0 ± 1.8	10.7 ± 1.6	11.2 ± 1.7	11.1 ± 1.6
TV E/E' (cm/s)	5.43 ± 1.50	5.28 ± 1.38	4.91 ± 1.35	5.00 ± 1.33
TV E'/A'	1.53 ± 0.56	0.97 ± 0.30 [†]	1.50 ± 0.53	0.90 ± 0.24 [†]
HV S/D	1.79 ± 0.44	1.80 ± 0.51	1.62 ± 0.54	1.96 ± 0.58 [†]

Data are expressed as mean ± SD. Numbers after group classifications refer to subdivision from Figure 1.

* p < 0.05 and † p < 0.01 young versus training-matched old; ‡ p < 0.05 control versus age-matched athletes.

Abbreviations as in Table 3.

Table 5
Correlations between diastolic parameters and age in athletes and controls

Parameter	Controls (1,2)		Athletes (3,5) [‡]	
	Left Ventricle	Right Ventricle	Left Ventricle	Right Ventricle
E	-0.18	-0.41 [†]	-0.45 [†]	-0.30 [†]
EDT	0.049	—	0.21*	—
A	0.52 [†]	0.18	0.46 [†]	0.11
E/A	-0.54 [†]	-0.38 [†]	-0.64 [†]	-0.34 [†]
E'	-0.60 [†]	-0.22*	-0.60 [†]	-0.22*
E/E'	0.43 [†]	-0.10	0.13	-0.039
E'/A'	-0.59 [†]	-0.58 [†]	-0.64 [†]	-0.63 [†]
V S/D	0.59 [†]	0.11	0.64*	0.32 [†]

Values are Pearson's correlation coefficients (r). Numbers after group classifications refer to subdivision from Figure 1.

* p < 0.05; † p < 0.01.

[‡] Elite athletes training >18 hours/week were excluded.

V S/D = venous systolic velocity/diastolic velocity ratio.

ever, have not observed any differences between veteran athletes and controls.^{5,12-15} The results of our study, with extensive statistical evaluation, demonstrate that Doppler parameters of diastolic function in the 2 ventricles showed an identical decrease with age in athletes comparable to that in the control population (see Figure 2). The amount of training never accounted for >2% of total variance in any of the parameters.

All enrolled subjects in our study were free of cardiovascular complaints and showed no abnormalities on electrocardiography or echocardiography. The cardiovascular changes that occur with aging in healthy individuals, in particular the impairment of diastolic function, do not necessarily result in clinical heart disease. Nevertheless, the physiologic myocardial senescence does compromise the cardiac reserve capacity, which decreases the individual

threshold for the development of signs and symptoms, as well as the severity and prognosis of cardiac disease, when a disease-related challenge occurs.²³ This concept is supported by the increasing incidence of atrial fibrillation²⁷ and heart failure with increasing age.^{28,29} Accordingly, the most important determinant for the occurrence of diastolic heart failure is age.²⁴

Previous reports have suggested that lifelong endurance training somehow impedes myocardial senescence. This would imply that long-term endurance training throughout life determines changes in myocardial diastolic properties in a prognostic favorable direction. Our data on biventricular diastolic function do not support this hypothesis. From a different point of view, our data do show that diastolic function is normal irrespective of morphologic changes that are a consequence of regular endurance exercise, such as LV hypertrophy and RV dilatation, which differentiates these alterations from pathologic changes.

Limitations: A small study has shown that although Doppler parameters were comparable to controls in the supine position, significant changes appeared between athletes and nonathletes when evaluating pulmonary vein flow in the upright position.³⁰ Second, diastolic function seems to be augmented in athletes during exercise.⁸ We aimed to assess diastolic LV and RV function conforming to the typical clinical setting, in the supine position and at rest. It would nevertheless be interesting to evaluate aging athletes' hearts in these specific conditions, to assess whether diastolic reserve is better preserved by long-term training.

Subjects aged >65 years were not included in this study, mainly because high-level endurance training (≥9 hours/week) is very uncommon above this age. This lack of subjects aged >65 years could explain some of the unexpected findings, such as MV E-wave deceleration time,

Figure 2. LV and RV diastolic parameters versus age. The MV E/A ratio (A) and E'/A' ratio (B) in all controls and athletes (excluding elite athletes). Note the similar regression occurring with aging in the 2 groups. A similar pattern was observed for the transtricuspid E/A ratio (C) and E'/A' ratio (D). Open circles indicate controls and solid circles athletes. The solid and dashed lines correspond to the athlete and control linear regression curves.

which did not increase with aging, as would be expected. Nevertheless, the deterioration in diastolic parameters could be demonstrated in the control group in most parameters, matching the age-related decreases described by others. Finally, our study design was cross sectional, so on the basis of our results, it may not be completely justified to conclude that no improvement of diastolic function could be achieved by long-term endurance training. It would be of interest to evaluate the changes with aging and training in a longitudinal study design, in which variations in Doppler parameters that could be attributed to individual variations would become irrelevant.

Supplementary Data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.amjcard.2009.05.066.

1. Pluim BM, Zwinderman AH, van der Laarse A, van der Wall EE. The athlete's heart: a meta-analysis of cardiac structure and function. *Circulation* 2000;101:336–344.
2. Teske AJ, Prakken NH, De Boeck BW, Velthuis BK, Martens EP, Doevendans PA, Cramer MJ. Echocardiographic tissue deformation imaging of right ventricular systolic function in endurance athletes. *Eur Heart J* 2009;30:969–977.
3. Teske AJ, Prakken NH, De Boeck BW, Velthuis BK, Doevendans PA, Cramer MJ. Echocardiographic deformation imaging reveals preserved regional systolic function in endurance athletes with left ventricular hypertrophy. *Br J Sports Med*. In press.
4. 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* 2008;104:1121–1128.
5. Baldi JC, McFarlane K, Oxenham HC, Whalley GA, Walsh HJ, Doughty RN. Left ventricular diastolic filling and systolic function of young and older trained and untrained men. *J Appl Physiol* 2003;95:2570–2575.
6. Caso P, D'Andrea A, Galderisi M, Liccardo B, Severino S, De Simone L, Izzo A, D'Andrea L, Mininni N. Pulsed Doppler tissue imaging

- in endurance athletes: relation between left ventricular preload and myocardial regional diastolic function. *Am J Cardiol* 2000;85:1131–1136.
7. Erol MK, Karakelleoglu S. Assessment of right heart function in the athlete's heart. *Heart Vessels* 2002;16:175–180.
 8. Levy WC, Cerqueira MD, Abrass IB, Schwartz RS, Stratton JR. Endurance exercise training augments diastolic filling at rest and during exercise in healthy young and older men. *Circulation* 1993;88:116–126.
 9. Pavlik G, Olexo Z, Osvath P, Sido Z, Frenkl R. Echocardiographic characteristics of male athletes of different age. *Br J Sports Med* 2001;35:95–99.
 10. Arbab-Zadeh A, Dijk E, Prasad A, Fu Q, Torres P, Zhang R, Thomas JD, Palmer D, Levine BD. Effect of aging and physical activity on left ventricular compliance. *Circulation* 2004;110:1799–1805.
 11. Douglas PS, O'Toole M. Aging and physical activity determine cardiac structure and function in the older athlete. *J Appl Physiol* 1992;72:1969–1973.
 12. Fleg JL, Shapiro EP, O'Connor F, Taube J, Goldberg AP, Lakatta EG. Left ventricular diastolic filling performance in older male athletes. *JAMA* 1995;273:1371–1375.
 13. Gates PE, Tanaka H, Graves J, Seals DR. Left ventricular structure and diastolic function with human ageing: relation to habitual exercise and arterial stiffness. *Eur Heart J* 2003;24:2213–2220.
 14. Nottin S, Nguyen LD, Terbah M, Obert P. Long-term endurance training does not prevent the age-related decrease in left ventricular relaxation properties. *Acta Physiol Scand* 2004;181:209–215.
 15. Popovic ZB, Prasad A, Garcia MJ, Arbab-Zadeh A, Borowski A, Dijk E, Greenberg NL, Levine BD, Thomas JD. Relationship among diastolic intraventricular pressure gradients, relaxation, and preload: impact of age and fitness. *Am J Physiol Heart Circ Physiol* 2006;290:H1454–H1459.
 16. Prasad A, Popovic ZB, Arbab-Zadeh A, Fu Q, Palmer D, Dijk E, Greenberg NL, Garcia MJ, Thomas JD, Levine BD. The effects of aging and physical activity on Doppler measures of diastolic function. *Am J Cardiol* 2007;99:1629–1636.
 17. Teske AJ, De Boeck BW, Olimulder M, Prakken NH, Doevendans PA, Cramer MJ. Echocardiographic assessment of regional right ventricular function: a head-to-head comparison between 2-dimensional and tissue Doppler-derived strain analysis. *J Am Soc Echocardiogr* 2008;21:275–283.
 18. Benjamin EJ, Levy D, Anderson KM, Wolf PA, Plehn JF, Evans JC, Comai K, Fuller DL, Sutton MS. Determinants of Doppler indexes of left ventricular diastolic function in normal subjects (the Framingham heart study). *Am J Cardiol* 1992;70:508–515.
 19. Innelli P, Sanchez R, Marra F, Esposito R, Galderisi M. The impact of aging on left ventricular longitudinal function in healthy subjects: a pulsed tissue Doppler study. *Eur J Echocardiogr* 2008;9:241–249.
 20. Munagala VK, Jacobsen SJ, Mahoney DW, Rodeheffer RJ, Bailey KR, Redfield MM. Association of newer diastolic function parameters with age in healthy subjects: a population-based study. *J Am Soc Echocardiogr* 2003;16:1049–1056.
 21. Yu CM, Sanderson JE. Right and left ventricular diastolic function in patients with and without heart failure: effect of age, sex, heart rate, and respiration on Doppler-derived measurements. *Am Heart J* 1997;134:426–434.
 22. Kuznetsova T, Herbots L, Lopez B, Jin Y, Richart T, Thijs L, Gonzalez A, Herregods MC, Fagard RH, Diez J, Staessen JA. Prevalence of left ventricular diastolic dysfunction in a general population. *Circ Heart Fail* 2009;2:105–112.
 23. Lakatta EG, Levy D. Arterial and cardiac aging: major shareholders in cardiovascular disease enterprises: part II: the aging heart in health: links to heart disease. *Circulation* 2003;107:346–354.
 24. Zile MR, Brutsaert DL. New concepts in diastolic dysfunction and diastolic heart failure: part I: diagnosis, prognosis, and measurements of diastolic function. *Circulation* 2002;105:1387–1393.
 25. Pye MP, Pringle SD, Cobbe SM. Reference values and reproducibility of Doppler echocardiography in the assessment of the tricuspid valve and right ventricular diastolic function in normal subjects. *Am J Cardiol* 1991;67:269–273.
 26. Brenner DA, Apstein CS, Saupe KW. Exercise training attenuates age-associated diastolic dysfunction in rats. *Circulation* 2001;104:221–226.
 27. Wolf PA, Abbott RD, Kannel WB. Atrial fibrillation as an independent risk factor for stroke: the Framingham study. *Stroke* 1991;22:983–988.
 28. Ho KK, Pinsky JL, Kannel WB, Levy D. The epidemiology of heart failure: the Framingham study. *J Am Coll Cardiol* 1993;22(suppl):6A–13A.
 29. Mosterd A, Hoes AW, de Bruyne MC, Deckers JW, Linker DT, Hofman A, Grobbee DE. Prevalence of heart failure and left ventricular dysfunction in the general population; the Rotterdam study. *Eur Heart J* 1999;20:447–455.
 30. Guazzi M, Musante FC, Glassberg HL, Libonati JR. Detection of changes in diastolic function by pulmonary venous flow analysis in women athletes. *Am Heart J* 2001;141:139–147.