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Age-related intramyocardial patterns in healthy subjects evaluated with Doppler tissue imaging☆

Esther Pérez-David[a,1], Miguel A. García-Fernández[a,*], Maria Jesús Ledesma[b,2], Norberto Malpica[b,2], Teresa López Fernández[a,1], Andrés Santos[b,2], Mar Moreno[a,1], José C. Antoranz[c], Javier Bermejo[a,1], Manuel Desco[b,d,2]

[a]*Laboratorio de Ecocardiografía, Department of Cardiology, Hospital Gregorio Marañón, C/Doctor Esquerdo, 46, 28007 Madrid, Spain*
[b]*ETSIT-Universidad Politécnica de Madrid, Spain*
[c]*Physics Department, Universidad Nacional de Educación a Distancia, Spain*
[d]*Experimental Medicine, Hospital Gregorio Marañón, Spain*

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Background The aim of this study is to analyse spatial distribution of myocardial velocities (MV) and myocardial velocity gradient (MVG) with color M-mode Doppler tissue imaging (DTI) and to analyse the influence of age in such parameters.
Methods and results A prospective study including 66 healthy volunteers was carried out with color M-mode DTI. Postprocessing of images was performed using proprietary software allowing the division of the myocardial wall into subendocardium, mesocardium and subepicardium. MV corresponding to the three layers and MVG time curves were obtained and systolic, early diastolic and late diastolic peak values were identified. MV were highest in subendocardium in systole, protodiastole and telediastole compared to external layers. Protodiastolic peak MV decreased in all layers with age, but with a higher impact in the subendocardium ($r = 0.72$, $b = 0.136$ (IC 95% 0.107–0.164), $p = 0.0005$). Older age resulted in larger telediastolic peak MV, without significant differences among layers. Linear

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* Corresponding author. Tel.: +34 91 586 82 83; fax: +34 91 586 67 27.
E-mail addresses: eperezdavid@arrakis.es (E. Pérez-David), magfeco@primus.es (M.A. García-Fernández), mledesma@die.upm.es (M.J. Ledesma), nmalpica@die.upm.es (N. Malpica), tlf@eresmas.com (T.L. Fernández), desco@mce.hggm.es (M. Desco).
[1] Tel.: +34 91 586 82 83; fax: +34 91 586 67 27.
[2] Tel.: +34 91 586 66 78.

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correlation between protodiastolic peak mitral flow and peak protodiastolic velocity was higher in endocardium than in other layers ($r = 0.79$, $p = 0.0005$).
Conclusions Color M-mode DTI multilayer analysis showed that endocardium is more susceptible to age-related changes involving diastolic function. This dependency on age should be considered when assessing MV in other clinical settings.

Introduction

Normal changes in the aging heart have been extensively studied with different diagnostic techniques.[1] Doppler tissue imaging allows for quantification of regional function, thus providing a useful tool to objectively analyse the impact of age in myocardial performance. Several papers have addressed this issue, initially by means of color M-mode pulsed Doppler tissue imaging (DTI) and more recently with Doppler-derived velocity, strain and strain rate.[2–5] Most of these works have been focused in the evaluation of changes in longitudinal function with age, though some data are also available concerning the effects of aging in radial function.

However, not only transmural regional function is known to be influenced by age. It has been suggested that separate evaluation of the different myocardial layers can be more accurate to detect age-related myocardial dysfunction.[6,7]

Color M-mode DTI is an accurate method to assess the non-uniformity of transmural myocardial velocities and could be used for the purpose of evaluating the impact of age in the different myocardial layers.[8] Transmural MV and myocardial velocity gradients (MVG) have been analysed in healthy hearts and in other clinical conditions.[9–11] However, functional analysis of velocities corresponding to different myocardial layers using color M-mode DTI has been neglected in spite of its excellent spatial and temporal resolution.

The purpose of this study is to evaluate age-related changes in MV with color M-mode DTI in three different layers (subendocardium, mesocardium and subepicardium). In order to describe physiologic age-related intramyocardial functional patterns a healthy population with a broad age spectrum was used.

Methods

Study population

Seventy-five healthy volunteers with no history of current or remote cardiac disease or any current medical illness were recruited for this study. Patients with hypertension and diabetes were excluded. Three patients were excluded for pathologic findings in the standard echocardiographic study and six patients because of poor image quality. Informed consent was obtained from all subjects prior to entry into the study. The study group consisted of 66 patients (38 females and 28 males). Mean age was 42 ± 20 years old (range: 18–94). There were 9 participants between 18 and 25 years old (13.6%), 11 between 26 and 35 years old (16.7%), 12 between 36 and 45 years old (18.2%), 10 between 46 and 55 years old (15.2%), 11 between 56 and 65 years old (15.2%), and 13 above 65 years (19.7%). Their resting heart rates varied between 47 bpm and 84 bpm (mean 67 ± 10 bpm). Their systolic blood pressure varied from 80 to 120 mmHg (mean: 110 ± 10 mmHg) and their diastolic blood pressure varied from 60 to 80 mmHg (mean: 70 ± 10 mmHg).

Echocardiographic study

A standard transthoracic echocardiographic examination was performed with an Acuson-Siemens Sequoia System ultrasound scanner equipped with a phased-array 3.5 MHz transducer and DTI capabilities. M-mode measurements of left ventricle diameters, septum and posterior wall thickness were taken at the level of the mitral valve leaflets tips in the parasternal long-axis (PLAX) view, in telediastole and telesystole. Pulsed Doppler E and A transmitral velocities were measured on the apical view with the sample volume placed at the mitral valve leaflets tips. Table 1 shows standard echocardiographic data from the study population according to age.

Color Doppler M-mode myocardial imaging

Simultaneous separate recordings of M-mode greyscale and color DTI were obtained from the basal posterior segment in a PLAX view, ensuring a perpendicular incidence of scanline.

The region of interest corresponding to myocardial posterior wall was magnified. The DTI color scale velocity map was adjusted to a velocity of $23\ cm\ s^{-1}$ to minimize aliasing. When a good

Table 1 Standard echocardiographic measurements of systolic and diastolic left ventricular function in the study group according to age (data are presented as mean ± SD)

Measurement	Age 18–25 years ($n = 9$)	Age 26–45 years ($n = 23$)	Age 46–65 years ($n = 22$)	Age 66–94 years ($n = 13$)	p
LV telediastolic diameter (mm)	48.5 ± 5.0	46.8 ± 3.0	45.6 ± 3.0	44.7 ± 2.0	NS
LV fractional shortening (%)	39.8 ± 4.5	40.4 ± 4.6	40.2 ± 8.8	45.2 ± 8.0	NS
PW telediastolic thickness (mm)	8.5 ± 1.2	9.3 ± 1.3	9.5 ± 1.0	10.7 ± 1.3	0.01
LVPW fractional thickening (%)	54.5 ± 5.5	52.4 ± 4.5	52.1 ± 3.5	52.1 ± 2.4	NS
LV mass ($g\,m^{-2}$ BSA)	78.0 ± 17.3	83.3 ± 18.6	84.6 ± 12.6	104.1 ± 18.7	0.02
Peak E wave velocity ($m\,s^{-1}$)	0.9 ± 0.1	0.9 ± 0.1	0.6 ± 0.1	0.5 ± 0.1	0.005
Peak A wave velocity ($m\,s^{-1}$)	0.4 ± 0.1	0.5 ± 0.1	0.6 ± 0.1	0.9 ± 0.1	0.005

LV, left ventricle; PW, posterior wall; SD, standard deviation; BSA, body surface area.

quality record was shown, a sequence of ≥ 2 consecutive beats was acquired at end-expiration, digitally stored and transferred to a workstation for image analysis. This was accomplished using proprietary software developed in our institution, which has been previously validated.[12,13]

Quantitative velocity information was obtained from the color calibration bar displayed at the side of the Doppler myocardial image. A selective median filtering algorithm was used to correct black spots, which are a source of error in the calculation of DTI velocities.[12,13] At least two cycles were averaged using the onset of the ECG R wave in order to improve the signal-to-noise ratio.

Spline curves were adjusted to endocardial and epicardial boundaries and the wall was automatically divided into three layers of equal thickness, corresponding to subendocardium, mesocardium and subepicardium. This segmentation was performed in greyscale imaging and automatically exported to color M-mode DTI.

The mean MV in these three different layers was calculated along the cardiac cycle. The mean layer velocities were defined as the average value of the MV measured along each M-mode scanline throughout the thickness of the layer. Peak mean velocity was defined as the maximum value of the mean velocity during a particular cardiac phase. MVG was calculated as the unitary spatial rate of change of velocity across the myocardium.[14] MV were considered positive when myocardium was moving toward the centre of the left ventricle.

The beginning of systole was set at the beginning of QRS in the electrocardiographic tracing; the end of systole was identified as the moment of cardiac cycle where MVG diminished to zero at the end of the red band in the color M-mode image, as previously defined by other authors.[15] Peak MV and MVG in systole, early diastole and late diastole were identified.

Two examples of MV and MVG patterns corresponding to young and elderly patients can be seen in Fig. 1.

Intraobserver and interobserver variability

A cardiologist, experienced in the performance of DTI studies, obtained standard echocardiographic examinations and color M-mode image acquisition. The same cardiologist carried out postprocessing of images and assessed intraobserver variability. Six months after this first examination the same cardiologist carried out a secondary analysis from a random sample of 15 cases belonging to the whole volunteer group.

A second cardiologist experienced in DTI and blind to the previous results, assessed interobserver variability by performing an analysis of another random sample of 15 cases from the whole series.

Statistical analysis

All statistical procedures were performed with a standard statistical package (SPSS 9.0). The data were expressed as mean value and standard deviation (mean ± SD). Paired Student's t-test was used to compare peak velocities.

Pearson's correlation coefficient was determined to assess the possible association between DTI measurements (peak velocity in the three myocardial layers and peak MVG) and age. Linear regression analysis was used to obtain regression equations describing the slope of such relationship. 95% confidence intervals of the regression equations' slopes were calculated and differences between slopes were considered significant following such confidence intervals. Correlation between DTI measurements and standard echocardiographic measurements of left ventricular function was also tested with Pearson's coefficient and the slope of the relationship obtained by linear

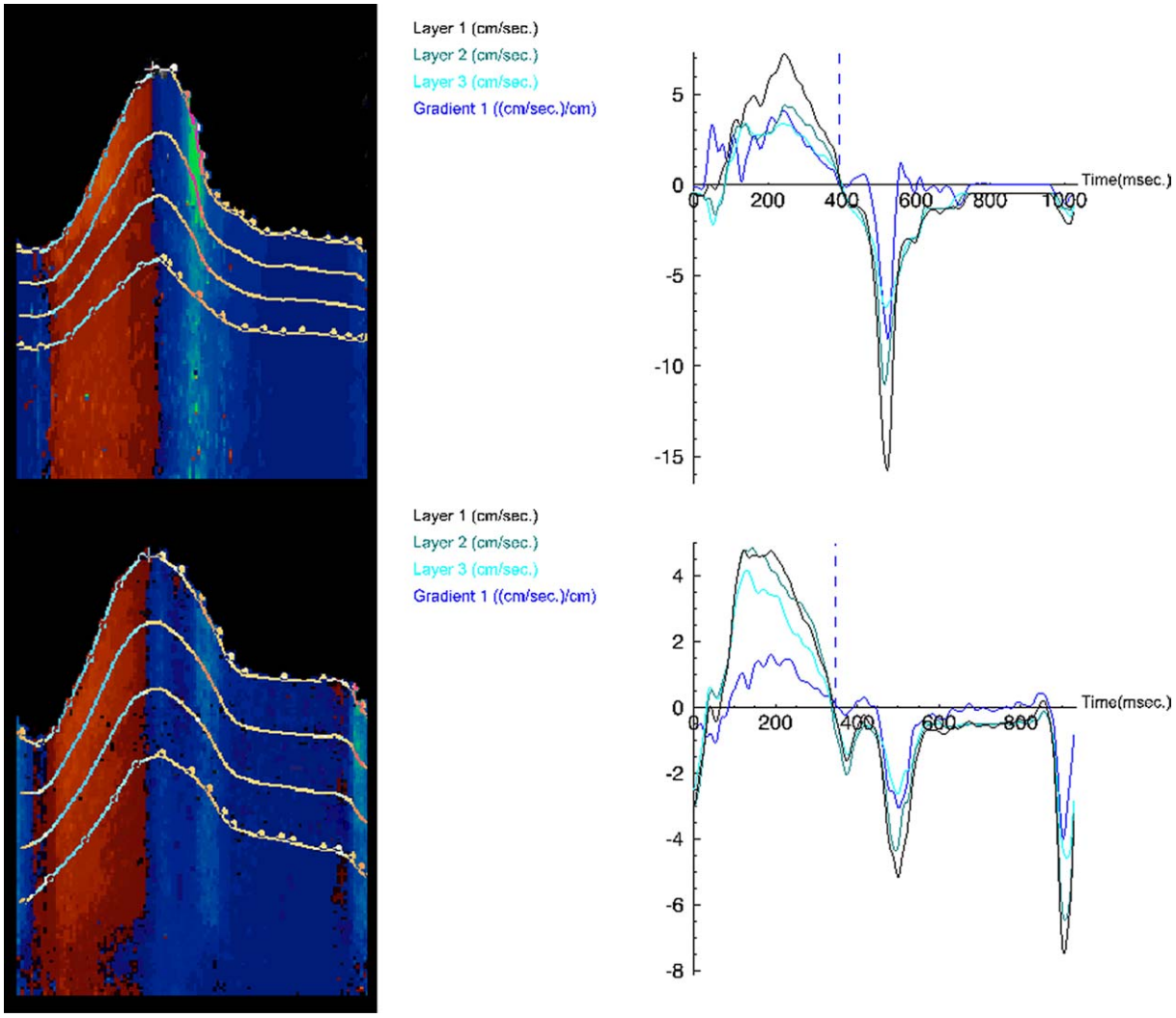

Figure 1 A—B. Color M-mode DTI image corresponding to a 29-year-old healthy subject after image postprocessing and time curves displaying myocardial velocities (MV) in three myocardial layers and myocardial velocity gradient (MVG) from the region of interest. Peak protodiastolic MV and MVG are dominant over peak telediastolic values. C—D. Color M-mode DTI image and time curves corresponding to a 85-year-old healthy volunteer. Note the change in balance between protodiastolic and telediastolic MV in the three layers compared to the young subject. Layer 1, endocardium; layer 2, mesocardium; layer 3, epicardium; gradient 1, Fleming's MVG.

regression analysis. $p < 0.05$ was considered significant.

Interobserver and intraobserver variabilities were assessed using the Bland—Altman technique.[16]

Results

Doppler tissue velocities across myocardial layers

MV were highest in subendocardium throughout the cardiac cycle compared to mesocardium and subepicardium, as shown in Fig. 2. Differences among layers were most prominent in early diastole, but significant differences among layers also existed in late diastole and systole.

Age-dependency in Doppler tissue myocardial velocities

The relationship between results from DTI measurements obtained in diastole and age is displayed in Figs. 3 and 4 and Tables 2 and 3. A strong dependency on age was observed in diastolic velocities. Peak protodiastolic velocity and peak MVG decreased in the three layers with increasing age. Linear correlation with age was strongest in subendocardium ($r = 0.72$, $p = 0.0005$) compared

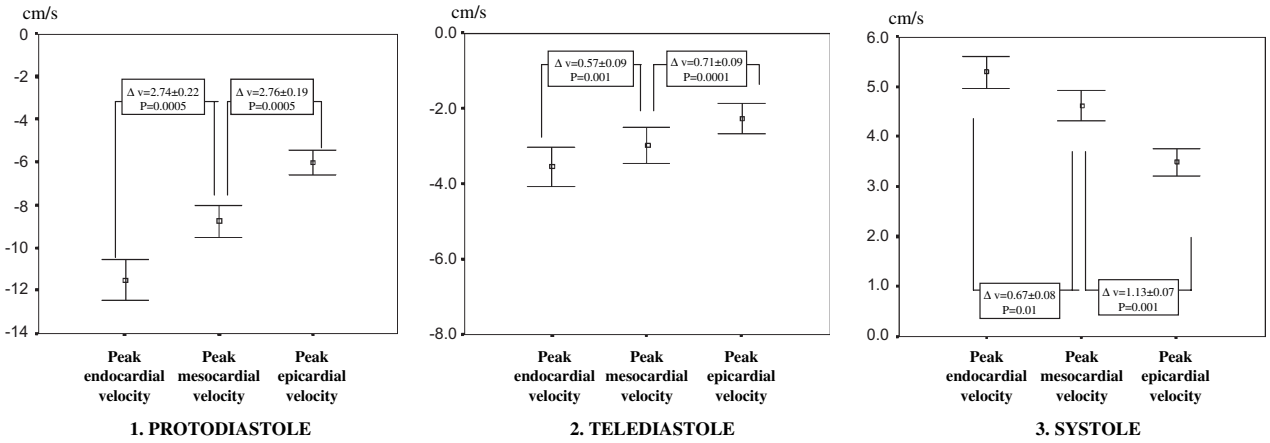

Figure 2 Comparison between three-layer peak velocities in the different cardiac periods. ΔV, difference of velocity.

to external layers. The regression slope was significantly higher in subendocardium ($b = 0.136\ \mathrm{cm\,s^{-1}\,year^{-1}}$) than in mesocardium and subepicardium ($b = 0.080\ \mathrm{cm\,s^{-1}\,year^{-1}}$ and $b = 0.053\ \mathrm{cm\,s^{-1}\,year^{-1}}$), suggesting a higher impact of age in endocardial protodiastolic velocities.

Conversely, peak telediastolic velocity and MVG significantly increased in the three layers with age. In this case, influence of age had a similar impact in the three layers. Subendocardial late diastolic velocity showed a regression slope of $0.067\ \mathrm{cm\,s^{-1}\,year^{-1}}$ that was not significantly different from slopes corresponding to external layers.

No correlation with age was demonstrated between peak systolic velocities nor peak systolic MVG corresponding to the different myocardial layers.

Age-related changes in standard echocardiographic parameters

Transmitral E-wave velocities decreased with age (regression slope of $-0.0071\ \mathrm{m\,s^{-1}\,year^{-1}}$, $r = 0.69$, $p = 0.0005$), whereas A-wave velocities rose with age (regression slope of $0.0067\ \mathrm{m\,s^{-1}\,year^{-1}}$, $r = 0.73$, $p = 0.0005$). Conversely, no age-dependency was observed regarding echocardiographic

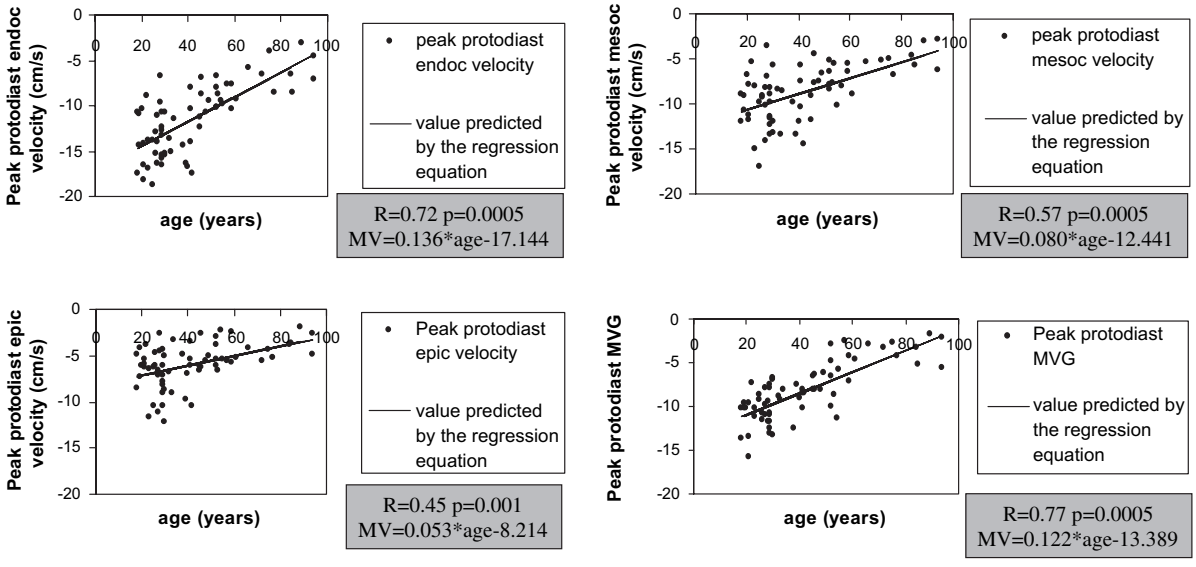

Figure 3 Relationship of three-layer peak protodiastolic MV and MVG with age. *R*, Pearson's coefficient; MV, myocardial velocity; MVG, myocardial velocity gradient.

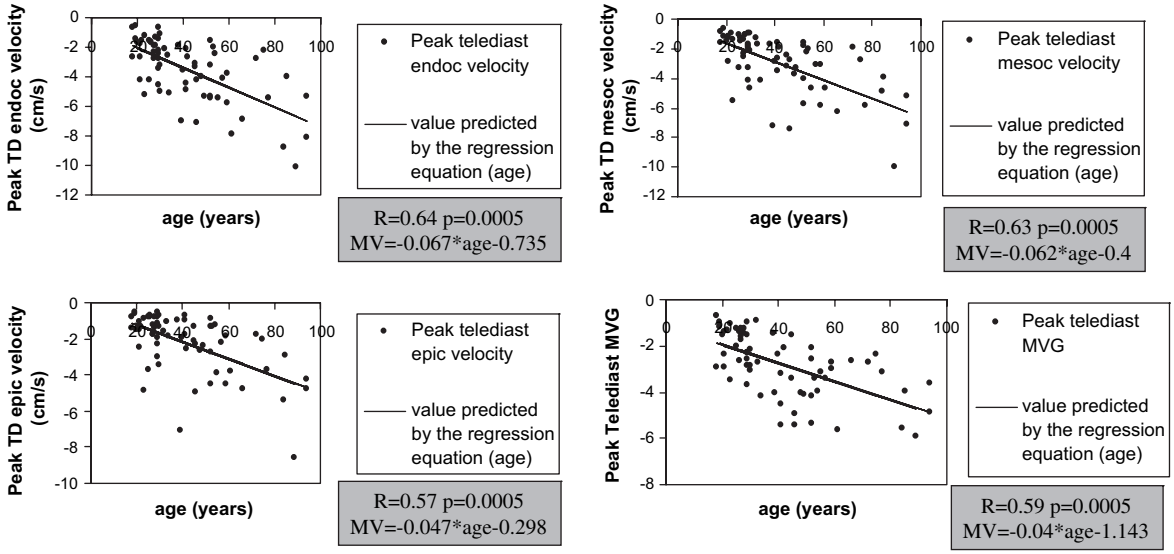

Figure 4 Relationship of three-layer peak telediastolic MV and MVG with age. *R*, Pearson's coefficient; MV, myocardial velocity; MVG, myocardial velocity gradient.

parameters of systolic left ventricular function (see Fig. 5).

Relationship between transmitral Doppler velocities and myocardial velocities

Peak early diastolic MV in all three myocardial layers were associated with protodiastolic mitral inflow, but linear correlation was highest between peak subendocardial protodiastolic velocity and E wave ($r = 0.79$, $p = 0.0005$). Excellent linear correlation was also observed between peak protodiastolic MVG and protodiastolic mitral inflow ($r = 0.81$, $p = 0.0005$). In the same way, telediastolic mitral inflow correlated significantly with late diastolic peak MV in the three layers and peak MVG.

Intraobserver and interobserver variability

There was a low variability between measurements obtained by the same observer, both in MV

Table 2 Results of the different myocardial layers' velocities according to age

	Age 18–25 years ($n = 9$)	Age 26–45 years ($n = 23$)	Age 46–65 years ($n = 22$)	Age 66–94 years ($n = 13$)	p
Protodiastole					
Peak endocardial PD velocity	−13.85 ± 3.19	−13.58 ± 2.89	−9.25 ± 1.57	−6.06 ± 1.91	0.0005
Peak mesocardial PD velocity	−9.71 ± 2.73	−10.29 ± 3.00	−7.47 ± 1.88	−4.98 ± 1.33	0.0005
Peak epicardial PD velocity	−6.41 ± 2.16	−7.05 ± 2.55	−4.93 ± 1.50	−4.02 ± 1.16	0.001
Peak PD MVG	−11.01 ± 2.34	−9.72 ± 1.90	−6.58 ± 2.35	−3.46 ± 1.33	0.0005
Telediastole					
Peak endocardial TD velocity	−2.16 ± 1.46	−2.85 ± 1.46	−4.37 ± 1.71	−5.95 ± 2.74	0.0005
Peak mesocardial TD velocity	−1.71 ± 1.40	−2.34 ± 1.40	−3.62 ± 1.61	−5.32 ± 2.41	0.0005
Peak epicardial TD velocity	−1.53 ± 1.23	−1.73 ± 1.32	−2.60 ± 1.28	−4.23 ± 2.06	0.0005
Peak TD MVG	−1.79 ± 0.95	−2.41 ± 1.13	−3.70 ± 1.18	−3.86 ± 1.31	0.0005
Systole					
Peak endocardial S velocity	5.71 ± 1.19	5.49 ± 1.26	4.87 ± 1.42	5.03 ± 1.42	0.3
Peak mesocardial S velocity	4.73 ± 1.06	4.83 ± 1.29	4.45 ± 1.34	4.30 ± 1.13	0.5
Peak epicardial S velocity	3.32 ± 0.89	3.61 ± 1.05	3.35 ± 1.11	3.50 ± 1.23	0.8
Peak S MVG	4.61 ± 1.05	4.30 ± 1.49	3.50 ± 1.23	3.8 ± 1.82	0.2

PD, protodiastole; TD, telediastole; S, systole; MVG, myocardial velocity gradient.

Table 3 Relationship between age, multilayer velocities and MVG

	Age			
	r	*b* (Std error)	CI 95%	*p* Value
Protodiastole				
Peak endocardial PD velocity	0.72	0.136 (0.015)	0.107—0.164	0.0005
Peak mesocardial PD velocity	0.57	0.080 (0.014)	0.053—0.106	0.0005
Peak epicardial PD velocity	0.45	0.053 (0.013)	0.027—0.074	0.001
Peak PD MVG	0.77	0.122 (0.013)	0.096—0.147	0.0001
Telediastole				
Peak endocardial TD velocity	0.64	−0.067 (0.01)	−0.047 to −0.087	0.0005
Peak mesocardial TD velocity	0.63	−0.062 (0.009)	−0.044 to −0.080	0.0005
Peak epicardial TD velocity	0.57	−0.047 (0.008)	−0.031 to −0.063	0.0005
Peak TD MVG	0.59	−0.04 (0.007)	−0.026 to −0.054	0.0005
Systole				
Peak endocardial S velocity	0.16	−0.010 (0.008)	−0.026 to 0.006	0.2
Peak mesocardial S velocity	0.15	−0.009 (0.008)	−0.025 to 0.007	0.2
Peak epicardial S velocity	0.04	−0.002 (0.007)	−0.016 to 0.012	0.7
Peak S MVG	0.18	−0.013 (0.009)	−0.028 to 0.008	0.2

r, Pearson's correlation coefficient and *b*, regression slope, units = cm s^{-1} $year^{-1}$). PD, protodiastole; TD, telediastole; S, systole; MVG, myocardial velocity gradient.

and MVG. The following values correspond to the mean difference and standard deviation between measurements in MV: in systolic MV, 0.08 ± 0.02 cm s^{-1} with *r*: 0.94 ($p < 0.0005$), in early diastolic MV, 0.37 ± 0.16 cm s^{-1} with *r*: 0.96 ($p < 0.0005$) and in late diastolic MV, 0.31 ± 0.20 cm s^{-1} *r*: 0.96 ($p < 0.0005$). The following values correspond to the mean difference and standard deviation between measurements in MVG: in systolic MVG, 0.19 ± 0.05 cm s^{-1} with *r*: 0.87 ($p < 0.0005$), in early diastolic MVG, 0.45 ± 0.24 cm s^{-1} with *r*: 0.74 ($p = 0.005$) and in late diastolic MVG, 0.30 ± 0.22 cm s^{-1} with *r*: 0.79 ($p < 0.0005$).

The two measurements obtained by the two different blind observers also showed low variability. The following values correspond to the mean difference and standard deviation between measurements from different observers: systolic MV, 0.13 ± 0.15 cm s^{-1} with $r = 0.86$ ($p = 0.0005$),

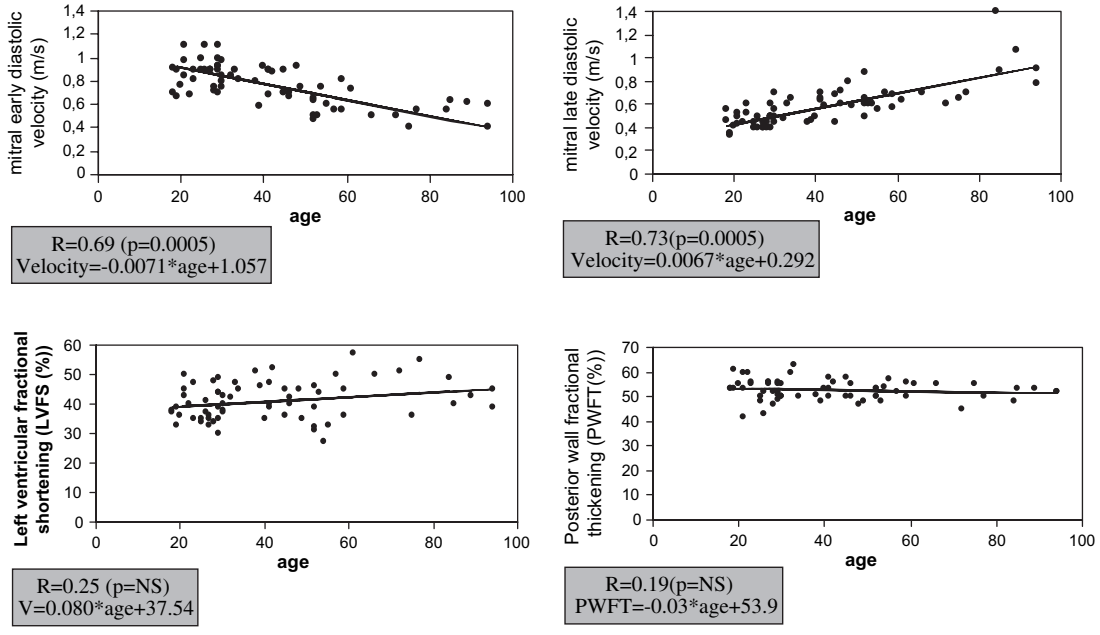

Figure 5 Relationship between standard echocardiographic parameters and age. *R*, Pearson's coefficient.

early diastolic MV, $0.45 \pm 0.17\,cm\,s^{-1}$ with $r = 0.85$ ($p < 0.0005$) and late diastolic MV $0.32 \pm 0.19\,cm\,s^{-1}$ with $r = 0.84$ ($p < 0.0005$). The corresponding data from MVG are the following: in systolic MVG, $0.21 \pm 0.05\,cm\,s^{-1}$ with r: 0.84 ($p < 0.0005$), in early diastolic MVG, $0.48 \pm 0.27\,cm\,s^{-1}$ with r: 0.72 ($p = 0.004$) and in late diastolic MVG, $0.34 \pm 0.24\,cm\,s^{-1}$ with r: 0.75 ($p = 0.005$).

Discussion

Our method of analysis of myocardial velocities in color-M mode DTI images enabled us to assess radial function in the different myocardial layers. Consistent differences in MV were observed across the myocardial wall in all groups of age, with higher velocities in the subendocardium both in systole and in diastole. Besides, our results suggest that impact of age in radial function is particularly relevant in diastole. In protodiastole, impairment of MV was more prominent in the subendocardial layer, whereas in telediastole MV increased progressively with age in all myocardial layers.

Possible mechanisms for the different velocities in the myocardial layers

The distribution of MV across the myocardium was asymmetrical, showing higher velocities in the subendocardium than in the subepicardium. This behaviour was observed in peak systolic MV, peak protodiastolic MV and peak telediastolic MV. These data were confirmed by MVG curves across a broad age range.

Irregularity of myocardial wall thickening of left ventricle during systole has been widely described.[8,17] Sabbah et al.[18] reported that the maximal rate of systolic thickening of the total ventricular wall was higher than the maximal rate of systolic thickening of the epicardial portion. Several explanations for this phenomenon have been suggested. Models of left ventricular wall mechanics have demonstrated that the orientation of cardiac fibers, which is heterogeneous in the normal heart, determines the distribution of fiber strain during ejection.[19] Greater dimensional changes in subendocardium during systole are also consistent with predictions based on geometric constraints in a model of concentric cylinders, due to incompressibility of the myocardium.[20]

In early diastole, the maximal rate of thinning of the total wall during diastole was significantly greater than the maximal rate of thinning of the epicardial portion in experimental models.[18] A previous report from Palka et al.[11] evaluating DTI in healthy subjects also concluded that subendocardium moved faster than subepicardium during rapid ventricular filling. It has been suggested that protodiastolic MV reflect the process of active myocardial relaxation.[21] Early diastolic left ventricular filling has long been known as an active, energy-consuming phenomenon.[22] The non-uniform distribution of velocities in this period could be explained by a more active role played by subendocardial and mesocardial layers in myocardial relaxation.

Possible mechanisms of age-dependency on diastolic myocardial velocities

In all three myocardial layers protodiastolic MV decreased significantly with age. However, the impact of age was higher in the peak velocity of the subendocardium than in external myocardial layers. When assessed with protodiastolic MVG a relative change in balance across the three layers was observed; in addition, an absolute change in velocities also existed.

The relationship between age and relaxation of the normal myocardium is well known. Studies in isolated muscle preparations demonstrated prolonged relaxation in aged rats.[23] A progressive prolongation of myocardial relaxation also occurs in the human heart with normal aging.[24] The decrease in protodiastolic MV with age probably reflects this phenomenon. This finding has also been reported in other studies: Yamada et al. found a good inverse correlation between pulsed E wave and age both in the long axis and the short axis of the left ventricle.[2] The impact of age on LV diastolic long-axis performance has also been studied by Henein et al., using pulsed DTI, and, more recently, by Sun et al. with 2D-DTI. In both papers a highly significant effect of age on LV diastolic long-axis performance is reported, and an opposite behaviour of protodiastolic and telediastolic MV occurs reflecting age-related diastolic dysfunction.[4,25]

In our series, the impact of age was higher in protodiastolic subendocardial velocities than in external layers. Experimental studies by Anversa et al. have demonstrated that progressive myocardial cell loss in senescent animals and replacement fibrosis take place mainly in the subendocardium of the left ventricle.[26] A wider extent of damage in subendocardium compared to external layers could explain the greater loss of its relaxation capability.

Subendocardium is a critical area in the left ventricular myocardium. Its larger oxygen consumption makes it more sensitive to ischemia or increased afterload.[27] Indeed, normal aging is related to an increase in afterload. A progressive increase in aortic diameter with age has been reported, which in turn tends to compensate for the increased aortic stiffness associated with age, at the expense of increasing impedance.[28] Age-associated changes in stiffness of the peripheral vascular bed may also produce an increase in total vascular resistance and therefore in impedance.[1]

Telediastolic peak velocities increased progressively with age in all myocardial layers. This phenomenon reflects the increasing importance of atrial emptying observed in normal aging to reach the end-diastolic volume necessary to maintain the cardiac output. Many studies have underlined this age-related change in balance between protodiastolic and telediastolic velocity profiles both in transmitral flow and in MV.[2,4,25,29]

Impact of age in intramyocardial function was similar among the different myocardial layers in telediastole. The different behaviour of age-related changes in late diastole compared to early diastole is related to the physiologic differences existing between these two periods. Telediastolic MV seem to be more related to atrial contraction than to active phenomena located in the left ventricle.[25] For this reason, specific changes in the subendocardium, which could be critical in protodiastole, are probably not relevant in late diastole.

Relationship of DTI parameters with standard echocardiographic parameters

Good correlation was shown between DTI measurements and transmitral blood flow parameters. Among the different layers, the strongest correlation was found between peak endocardial protodiastolic velocity and E transmitral wave. These results underline the active role played by subendocardium in the early diastolic filling. During late diastole, good correlation was observed between DTI parameters and A transmitral wave. Correlation between A wave and peak subendocardial velocities was higher than with other layers though the differences were not as important as in the early diastole. This suggests a more homogeneous distribution of velocities throughout the myocardial wall.

These results are in agreement with other reports in healthy patients in which the relationship between DTI parameters and transmitral flow velocities was evaluated.[11,25] When preload is normal, a high correlation between MV and transmitral flow indices is expected.[11] This is not the case when an elevation of filling pressure is present; as happens in many cardiomyopathies as DTI parameters such as peak negative MVG are less affected by preload alterations than transmitral flow velocity indices.[22]

Additional information provided by multilayer myocardial velocities compared to standard DTI studies

Early diastolic MV declined significantly with age in the three layers, but to a greater extent in subendocardium. This phenomenon produces a progressive age-related variation of intramyocardial function so that different intramyocardial functional patterns can be found in healthy patients. Our results based on DTI multilayer analysis show that not only is there a change in MVG but that absolute values of MV are also decreased in the three layers. In protodiastole, peak endocardial velocity was approximately 49% lower in an 80-year-old volunteer than in a 30-year-old.

Palka et al.[11] did not find a good correlation between transmural peak protodiastolic velocities and age in a group of healthy volunteers, whereas excellent correlation was found with protodiastolic MVG. The authors explained these results by the fact that peak velocities were less accurate than MVG in studying regional diastolic function because they are more affected by overall heart motion. In addition to this we hypothesize that the heterogeneity of roles played by the different layers in the early diastole may be heavily related to this finding.

Limitations

Color M-mode images can only be correctly acquired when the ultrasound beam is perpendicular to the myocardium. This condition is best fulfilled in the basal segment of the posterior wall but most cardiac segments cannot be analysed correctly with this technique. A recent report from Henein et al.[25] concluded that age-related changes in velocities were most marked at the basal level. It can therefore be assumed that the basal segment of the posterior wall is a suitable area to study age-related changes in MV.

This kind of analysis allows us to investigate radial, but not longitudinal function. However,

significant differences between long- and short-axis motion features have been described.[2,30] Further studies focused on the comparison of the role of the different layers in longitudinal and radial function are warranted.

Coronary lesions are frequently found in elderly people[31] and asymptomatic ischemic heart disease could modify some DTI parameters. In our study, patients with pathologic findings in standard echocardiographic studies and hypertensive or diabetic patients were excluded. As a result, a low-risk population for ischemic heart disease has been selected. Moreover, changes in MV and MVG were not only observed in elderly patients but were progressive across the entire age span. This supports a physiologic age-related origin of DTI changes as reported in our study.

Conclusions

Color M-mode DTI multilayer analysis may provide data on intramyocardial functional patterns and help to define the phenomena involved in normal aging. In our series of healthy volunteers, impact of age in protodiastolic myocardial function was irregular across left ventricular myocardial wall, defining a specific intramyocardial functional pattern related to normal aging. Besides, protodiastolic subendocardial peak velocities also showed the best correlation with protodiastolic peak mitral flow confirming that protodiastolic phenomena related to myocardial relaxation depends on the correct performance of subendocardium.

These data may call into question DTI studies ignoring the effect of age in diastolic intramyocardial function. An accurate definition of the normality pattern is required to establish a distinction between physiologic and pathologic processes. For this reason, age-related changes in intramyocardial function must be taken into account when evaluating DTI patterns in other settings in order to improve the clinical value of Doppler myocardial imaging parameters.

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