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The Influence of Aging on Pulmonary Arterial Dynamics and Pulmonary Flow Signal Assessed by Transesophageal Echocardiography

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Abstract To assess the effect of aging on pulmonary arterial distensibility, we analyzed right pulmonary arterial M-mode echogram and main pulmonary arterial flow signal in 45 patients with normal pulmonary arterial pressure and normal left ventricular function by transesophageal echocardiography. The right pulmonary arterial dimension became significantly greater as age became older, associated with significant reduction of pulmonary arterial distensibility and acceleration time of main pulmonary arterial flow. The earlier appearance of the reflection wave resulted from the reduced compliance of pulmonary artery might cause the earlier onset of the deceleration of the main pulmonary arterial flow.

Key Words : Transesophageal Echocardiography, Pulmonary Arterial Dynamics, Pulmonary Arterial Flow, Aging

Introduction

The physical properties of the pulmonary arterial wall, in particular to its elasticity and extensibility, have been studied previously[1-5]. It appears that the properties of the pulmonary arterial wall differ between healthy subjects and patients with pulmonary hypertension. They may be related also to age and to the period of suffering from pulmonary hypertension. The influence of aging on the right pulmonary arterial dimension has been examined using angiocardiography[6-9], chest radiography[10], and suprasternal echocardiography[11-13], however, little has been reported concerning the influence of aging on pulmonary arterial dynamics in subjects with normal pulmonary arterial pressure. Transesophageal Doppler echocardiography is now available, and it allows us to image the main and right pulmonary arteries easily and satisfactorily, and to obtain flow dynamics in the pulmonary artery[14,15].

The aim of this study is to evaluate the influence of advancing age on dynamic property of the right pulmonary artery and blood flow velocity profile in the main pulmonary artery in subjects with normal pulmonary arterial pressure and normal left ventricular systolic function using transesophageal echocardiography.

Methods

Study patients

Consecutive forty-five patients with normal pulmonary arterial pressure, normal cardiac output (cardiac index >2.21/min/m²) and normal left ventricular ejection fraction (>50%) were examined in the study. They were 32 men and 13 women, aged 40-74 years old (61±8, mean± SD). They consisted of 31 patients with coronary artery disease, 1 with atypical chest pain, 3 with mild mitral regurgitation, 9 with essential hypertension, and 2 with aortic aneurysm. The patients were divided into 4 groups according to age; 4 with 5th decades, 13 with 6th decades, 22 with 7th decades, and 6 patients with 8th decades. All patients underwent cardiac catheterization and coronary angiography within one week before the transesophageal echocardiographic study.

Transesophageal Echocardiography

Transesophageal two-dimensional echocardiography was performed using a transesophageal probe with a 9mm diameter and a hand-controlled flexible tip reported elsewhere(17). A 3.5MHz or 5.0MHz phased-array transducer with 48 elements was attached to the tip of the cable. The transducer could be angled sufficiently at a point approximately 4cm from the tip and could be rotated easily at the proper level. Echocardiograms were acquired with commercial echocardiograph (Aloka SSD-860, 870 or Toshiba SSH-65A). A procedure for transesophageal echocardiography in our laboratory has been reported in detail elsewhere(16.17). The pharyngeal region was locally anesthetized with a viscous xylocaine (2%) and prifinium bromide (7.5 mg) was injected intramuscularly to avoid salivation. Ten minutes after injection the transesophageal transducer was advanced into the esophagus approximately 30cm from the incisors. This position places the transducer posterior to the left atrium. Following imaging four chamber view of the heart by tilting left-lateraly or by slightly withdrawing the transducer, left atrium aortic valve, right atrium and right ventricular outflow tract, and then, longitudinal section of the main pulmonary artery and right pulmonary artery behind the transverse section of the ascending aorta(17).

Measurements of dimensional change of right pulmonary artery

M-mode echocardiogram of the right pulmonary artery was obtained with imaging the two-dimensional transverse view of the right pulmonary artery, and dimensional changes of the right pulmonary artery through a cardiac cycle was recorded on a strip chart recorder simultaneously with a lead II electrocardiogram and a phonocardiogram (Fig.1).. Systolic maximum and end-diastolic diameters of the right pulmonary artery in one cardiac cycle were measured. The right pulmonary artery dimensional change throughout a cardiac cycle (maximum diameter−end-diastolic diameter), the percent dimensional change which was defined as the ratio of dimensional change to end-diastolic diameter× 100, and the wall compliance index of the right pulmonary artery which was defined as the ratio of dimensional change to pulmonary arterial pulse pressure obtained by cardiac catheterization were calculated. Maximum and end-diastolic diameters were normalized by body surface area. The wall compliance index was normalized by end-diastolic diameter. Measurements were made in five consecutive cardiac cycle and averaged.

Measurements of flow signal in the main pulmonary artery

Flow velocity signals in the main pulmonary artery were examined with pulsed Doppler echocardiography at the sampling site about 2 or 3cm distal from the pulmonary valve. Doppler signals in the main pulmonary artery were simultaneously recorded with an electrocardiogram (lead II) and a phonocardiogram during a held expiration on a strip-chart recorder at a paper speed of 100mm/sec. Doppler signal toward the transducer was represented by the sound spectrogram above the baseline, which was from the right ventricular outflow tract into the main pulmonary artery. Systolic peak flow velocity, ejection time, acceleration time, and deceleration time were measured (Fig.2). We also calculated mean acceleration rate to the peak velocity which was defined as the ratio of the peak systolic velocity to the acceleration time, and we also calculated the ratio of acceleration time to the ejection time.

Statistical analysis

Data are presented as mean±SD. Statistical analysis was performed with Student's t-test for unpaired data. The level of statistical significance was $p<0.05$.

Results

Dimensional change of right pulmonary artery

Measurements of the right pulmonary arterial dimensional change in each decade are

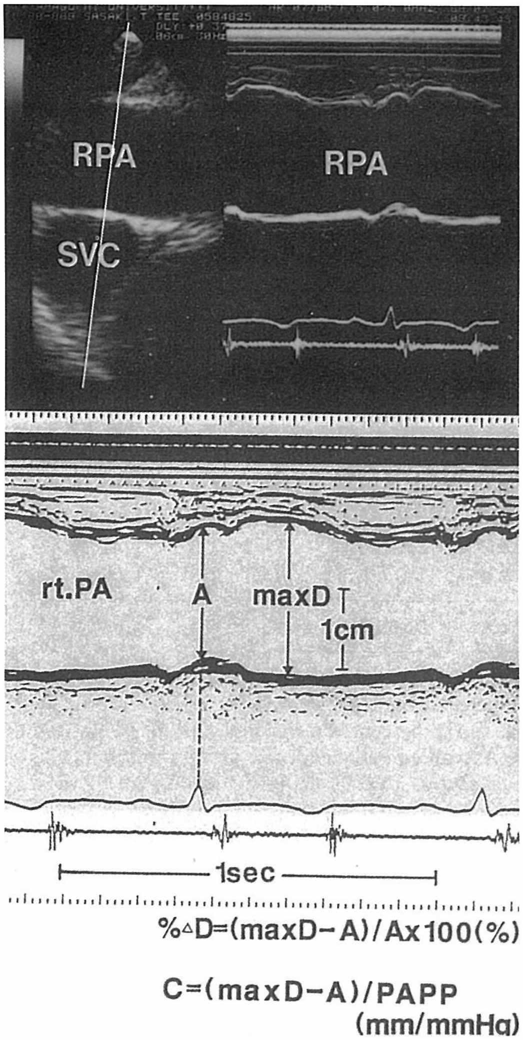

Fig. 1 Transesophageal 2-dimensional and M-mode echograms of right pulmonary artery (upper panel), and measurements of dimensional changes (lower panel).
RPA: right pulmonary artery, SVC: superior vena cava, maxD(mm): systolic maximum diameter of the right pulmonary artery, A(mm): end-diastolic diameter of the right pulmonary artrey, %ΔD=percent dimensional change of the right pulmonary artery, C=compliance index, PAPP=pulmonary arterial pulse pressure.

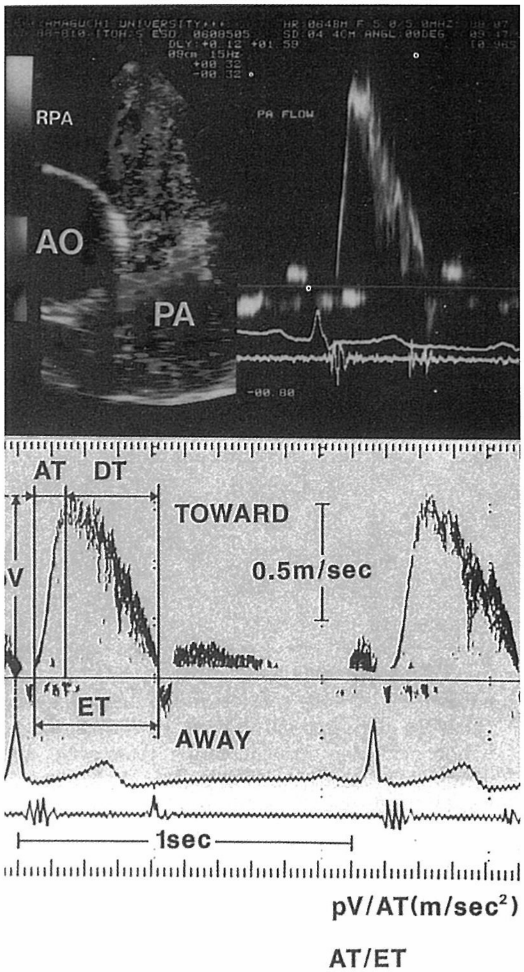

Fig. 2 Transesophageal Doppler color flow image and pulsed Doppler echocardiogram in the main pulmonary artery (upper panel), and measurements of flow signal (lower panel).
PA: main pulmonary artery, RPA: right pulmonary artery, AO: aorta, pV(m/sec): systolic peak flow velocity, ET(sec): ejection time, AT(sec): acceleration time, DT(sec): deceleration time, pV/AT(m/sec²): mean acceleration time, AT/ET: the ratio of acceleration time to ejection time.

summarized in Table I. The values of the maximum and end-diastolic dimensions of the right pulmonary artery normalized by body surface area showed a tendency to increase with advancing age (Fig.3). The maximum dimension in the 8th decade was significantly greater than that in the 5th ($p<0.01$) or the 6th decade ($p<0.05$), and that in the 7th decade was significantly greater than that in the 5th decade ($p<0.02$). The end-diastolic dimension of the right pulmonary artery in the 8th decade was significantly greater than that in the 5th ($p<0.01$), the 6th ($p<0.02$), or the 7th decade ($p<0.05$), and its value in the 7th decade was significantly greater than in the 5th decade ($p<0.05$). The value of the percent dimensional change of the right pulmonary artery through a cardiac cycle was significantly decreased in the 8th decade compared with the 5th decade ($p<0.05$, Fig.4). The compliance index of the right pulmonary artery normalized by the end-diastolic dimension showed a tendency to decrease with advancing age (Fig.5). The compliance index was significantly decreased in the 7th decade compared with the 5th decade ($p<0.01$).

Table I Transesophageal echocardiographic measurements of the right pulmonary arterial dimension in each decade (mean±SD).

Decade	n	maxD (mm)	maxD/BSA (mm/m²)	A (mm)	A/BSA (mm/m²)	%ΔD (%)	ΔD/ΔP/A (mmHg⁻¹)
5th	4	18.5±2.7	10.9±1.3	14.8±2.5	8.7±1.2	25.7±5.3	2.30±0.95
6th	11	20.2±3.3	12.4±1.8	16.7±3.1	10.3±1.7	21.6±7.9	1.66±1.09
7th	20	21.0±2.1	13.3 ± 1.6^{B}	17.4±2.3	11.0 ± 1.5^{C}	21.2±7.3	1.41 ± 0.42^{C}
8th	4	22.8±2.0	$14.9\pm0.7^{C,D}$	19.7±1.8	$12.9\pm0.5^{C,E,F}$	15.7 ± 2.3^{A}	1.00±0.20
Total	39	20.7±2.7	13.0±1.9	17.2±2.8	10.8±1.8	21.2±7.3	1.53±0.79

maxD: systolic maximum diameter of the right pulmonary artery, maxD/BSA: maximum diameter normalized by body surface area, A: end-diastolic diameter of the right pulmonary artery, A/BSA: end-diastolic diameter normalized by body surface area, %ΔD: percent dimensional change of the right pulmonary artery throughout a cardiac cycle, ΔD/ΔP/A: wall compliance index of the right pulmonary artery (ΔD=maxD-A, ΔP= pulmonary arterial pulse pressure). A:$p<0.05$, B:$p<0.02$, C:$p<0.01$ vs 5th; D:$p<0.05$, E:$p<0.02$ vs 6th; F:$p<0.05$ vs 7th.

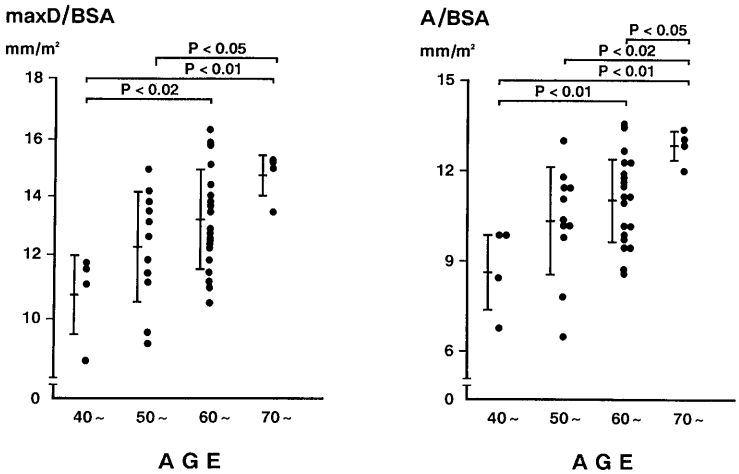

Fig. 3 Comparisons of maximum and minimum dimensions of the right pulmonary artery among each decade.
maxD/BSA(mm/m²): systolic maximum diameter of the right pulmonary artery normalized by body surface area, A/BSA(mm/m²): end-diastolic diameter of the right pulmonary artery normalized by body surface area.
Maximum and minimum dimensions of the right pulmonary artery were gradually and significantly increased with age.

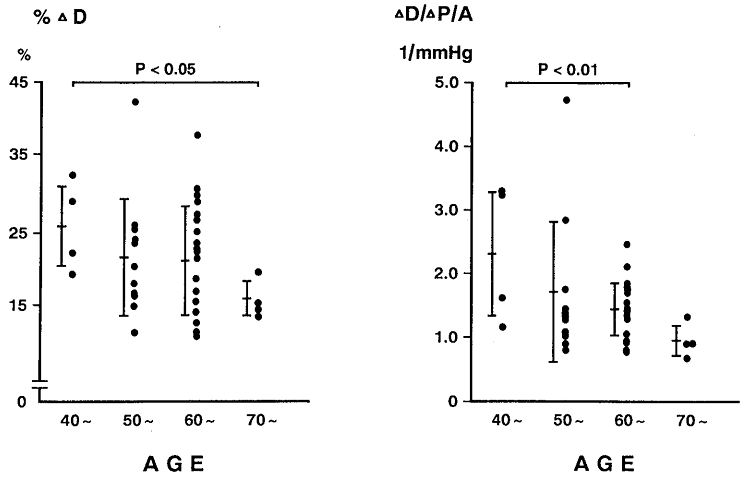

Fig. 4 Comparisons of the percent dimensional change during cardiac cycle (% ΔD) and the compliance index (ΔD/ΔP/A) of the right pulmonary artery among each decade. %ΔD was gradually decreased with age, and it was significantly reduced in 8th decade compared with 5th decade. ΔD = dimensional change of the right pulmonary artery during a cardiac cycle, ΔP = pulmonary arterial pulse pressure obtained by cardiac catheterization, A = end-diastolic dimension of the pulmonary artery.

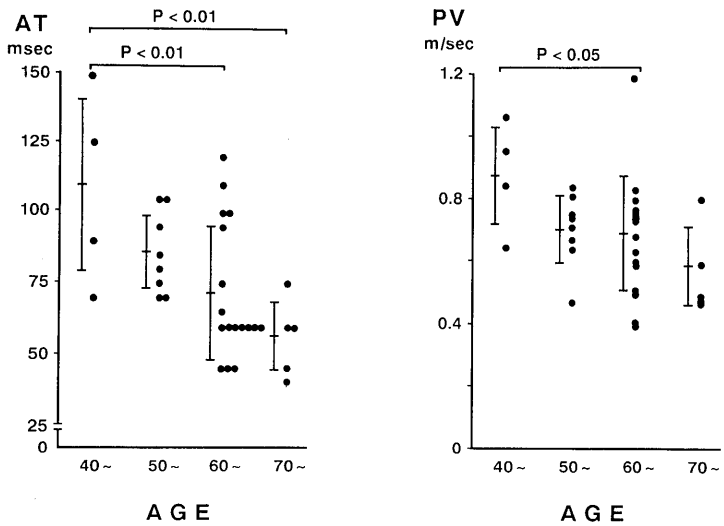

Fig. 5 Comparisons of acceleration time (AT) and systolic peak flow velocity of the main pulmonary arterial flow (pV) among each decade.
Acceleration time of the main pulmonary arterial flow was gradually reduced with age, accompanied by decrease in peak flow velocity, and it was significantly shortened in 7th and 8th decades compared with that in 5th decade.

Flow signal in the main pulmonary artery

The flow signal data are listed in Table II. The acceleration time and the systolic peak flow velocity of the pulmonary arterial flow showed the gradual but significant decrease with age, and the acceleration time in 7th and 8th decades was significantly less than that in 5th decade (both $p<0.01$), and the systolic peak flow velocity in 7th decade was significantly less than that in 5th decade ($p<0.05$, Fig.6). There were no significant differences in ejection time, deceleration time, the ratio of acceleration time to ejection time, or the mean acceleration rate (peak velocity divided by acceleration time) among each decade.

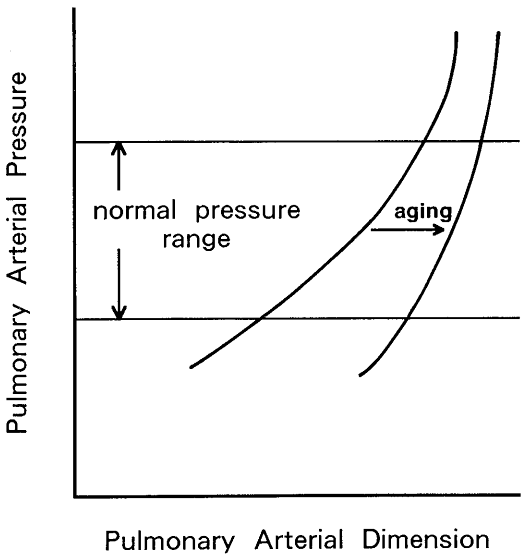

Fig. 6 Ideal pressure-dimension relationships of the right pulmonary artery in normotensive younger and elderly patients. The relationship may become steeper on its slope and shift to the right in parallel with age.

Discussion

The structure and physical properties of pulmonary arterial wall have been previously investigated[1-5], and the influence of aging on the pulmonary arterial dimension has been examined using angiography[6-9], chest radiography[10], and echocardiography[11-13].

Previous studies[1-5]showed that the changes of collagen and elastin contents in the pulmonary arterial wall with advancing age were not coincident among each report, however, many investigators showed the progressive decrease in the physical extensibility of the pulmonary arterial wall with age.

Dotter and coworkers first measured the right pulmonary arterial dimension using the angiocardiography in normal subjects[7]. The diameter of the right pulmonary artery varied between 17 and 30mm, and averaged 23.4mm. The age-caliber relationship present in aortic measurements was not so evident in the right pulmonary artery, and they suggested that it might be related to the relative infrequency of the right pulmonary artery atherosclerosis as compared with that of the aorta. Castellanos and coworkers[8] measured the end-systolic dimension of the

Table II Transesophageal echocardiographic measurements of the main pulmoanary flow signal in each decade (mean±SD).

Decade	n	ET (msec)	AT (msec)	DT (msec)	AT/ET	pV (m/sec)	pV/AT (m/sec^2)
5th	4	263±56	109±31	154±32	0.41±0.06	0.87±0.16	8.32±1.19
6th	8	264±55	86±14	178±61	0.34±0.11	0.70±0.11	8.43±1.95
7th	17	237±71	72±23[B]	165±54	0.31±0.06	0.69±0.18[A]	10.55±4.47
8th	5	194±70	56±12[B]	138±65	0.31±0.09	0.57±0.12	10.80±3.95
Total	34	240±69	77±26	163±57	0.33±0.08	0.69±0.17	9.83±3.80

ET: ejection time, AT: acceleration time, DT: deceleration time, AT/ET: the ratio of acceleration time to the ejection time, pV: systolic peak flow velocity, pV/AT: mean acceleration rate to the peak velocity. A:$p<0.05$, B:$p<0.01$ vs 5th.

right pulmonary artery in normal individuals, which was related with the body surface area. Nakajima et al[9] also measured the right pulmonary arterial dimension with angiography, and they reported the gradual increase in the right pulmonary artery dimension with aging, accompanied by increased pulmonary arterial resistance. The diameter of the right descending branch of the pulmonary artery in chest radiographs had a highly significant relation with the age, reported by Teichmann and coworkers[10]. The factors influencing the diameter of pulmonary arteries were the body constitution, the physical properties of the lung, the intrathoracic pressure, the elasticity and distensibility of pulmonary arterial wall, the blood volume in the pulmonary arterial bed, the pulmonary blood flow, and pressure[10].

With suprasternal M-mode echocardiography proposed by Goldberg[11], Kasper et al examined the wall motion characteristics of the right pulmonary artery throughout a cardiac cycle in normal subjects and patients with pulmonary hypertension[12], and they also investigated the relation between the diameter of the right pulmonary artery and the pulmonary arterial pressure[13]. In 103 patients with normal pulmonary arterial pressure (end-diastolic <12mmHg; mean pressure <20mmHg), the end-diastolic size of the right pulmonary artery was 17.9 ± 0.2 mm (mean±SEM) and correlated best to the body surface area. The index size of the right pulmonary artery ($9.9 \pm 0.1 mm/m^2$) correlated best to the pulmonary end-diastolic pressure, and it was independent of the patients age. The systolic percent expansion was a negative log linear relationship to the pulmonary end-diastolic pressure. However, the measurement of the right pulmonary arterial diameter with suprasternal echocardiography could sometimes be unsatisfactory because of patient obesity, chronic obstructive pulmonary disease, and chest wall changes with age, such as 91.2% satisfactory image of the patients studied by suprasternal approaches[13]. Furthermore, M-mode echogram recorded by suprasternal approaches without visualizing the B-mode image was unreliable method of the measurement of the right pulmonary arterial dimension. Transesophageal echocardiography can provide the good pulmonary arterial image, because chest wall interference and intrathoracic attenuation are eliminated, and it allows us to record the right pulmonary arterial M-mode scan with sequential B-mode scan.

In 1977, we attached a 3-MHz, 6-mm transducer to the tip of the gastro-camera and obtained left ventricular images[18,19], which we used to evaluate the left ventricular anterolateral wall motion in awake patients with coronary artery disease[16,19]. In 1981, Tamaki and coworkers attached a 3.5-MHz, 13mm linear real-time ultrasound probe to the end of the endoscope and studied the right pulmonary artery in the patients with respiratory disease[14]. In 1988, Kobayashi and coworkers studied the estimation of the pulmonary arterial pressure by measuring the right pulmonary arterial dimension in the patients of respiratory diseases using transesophageal echocardiography[15]. The diameter of the right pulmonary artery normalized to the body surface area correlated well with the pulmonary arterial pressure in both systolic and diastolic phases.

In the present study, we studied the influence of aging on the right pulmonary arterial wall distensibility and blood flow signal in the main pulmonary artery in 45 patients with normal pulmonary arterial pressure, normal left ventricular ejection fraction and normal cardiac output with transesophageal echocardiography. The pulmonary arterial dimension was significantly increased and the pulmonary arterial compliance was significantly decreased with advancing age. From the results in the present study, as shown in Fig 6, we can expect the ideal diagrams of the pulmonary arterial pressure-diameter relationship that becomes steeper on its slope and shifts to the right in parallel with aging in normotensive younger and elderly patients.

Peak flow velocity and acceleration time in the main pulmonary arterial flow showed gradual but significant decrease with age, and the pulmonary arterial dimension became significantly greater as age became older, associated with significant reduction of its distensibility. The earlier appearance of the reflection wave probably resulted from the reduced distensibility of the pulmonary artery might cause the earlier onset of deceleration of the pulmonary arterial flow(20).

The evaluation of pulmonary hypertension by a pulsed Doppler technique to asses the flow velocity pattern in the right ventricular outflow tract might need to add the aging factor.

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