

NONINVASIVE EVALUATION OF CENTRAL HAEMODYNAMIC PARAMETERS

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Abstract

Ageing is one of the relevant cardiovascular risk factors. Non-invasive assessment of cardiac function is an important approach in preventive medicine. The aim of our study was to evaluate the effect of age and gender on central haemodynamics. Seventy-six clinically healthy individuals were divided into four groups according to their age and gender. Applanation tonometry was applied using Sphygmocor device (AtCor, Australia). Pulse wave analysis was utilized for non-invasive assessment of central pressures (systolic, diastolic, mean, pulse, augmentation and end-systolic). Several important derivative indices such as augmentation index $\text{AIx75} \left(\frac{\text{Augmentation pressure}}{\text{Pulse pressure}} \times 100, \text{corrected for heart rate } 75 \text{ beats/minute} \right)$, arterial elastance $\left(\text{Ea}, \frac{\text{End} - \text{systolic pressure}}{\text{Stroke volume}} \right)$ and wasted effort (Ew) were computed. Ew is the ventricular force that is generated to overcome the late systolic peak and does not contribute to an increased stroke volume. Arterial stiffening was confirmed by the significantly higher central systolic and pulse pressures, AIx75 and arterial elastance in the middle-aged groups ($P < 0.01$). Those alterations were most pronounced in middle-aged females in support to the concept for a postmenopausal effect of female gender beyond ageing. We have shown a positive correlation between Ew and Ea valid only for the middle-aged individuals ($R = 0.70, P < 0.001$) that coincided with similar correlation between Ea and AIx75 for the same age groups ($R = 0.53, P < 0.001$). Our supposition is that arterial stiffening

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contributes to the elevation of the ‘pulsatile’ afterload thus impairing vascular/ventricular coupling and increasing myocardial load and oxygen demands. In conclusion, applanation tonometry and PWA provide reliable measures of central haemodynamics and myocardial afterload.

Key words: arterial stiffness, arterial elastance, augmentation index, wasted effort, pulse wave analysis

Introduction. Ageing contributes to cardiovascular pathology per se even in the absence of other cardiovascular risk factors [1]. Afterload is an important determinant of cardiac performance. Since aortic pressure and flow measurement for assessment of afterload is not applicable in everyday practice, surrogate parameters were introduced [2]. In the 1980’s arterial elastance, E_a , was proposed as the ratio of end-systolic pressure (ESP) to stroke volume (SV) [3] (Fig. 1A). Arterial elastance was assumed to integrate both the stable (determined by total peripheral vascular resistance) and the pulsatile component of afterload (determined by arterial compliance and the characteristics of the reflected wave) [4,5]. In the young individuals pulse wave velocity is lesser, arterial compliance is larger; therefore, reflected wave returns later in the cardiac cycle (Fig. 1B). In the older persons the pulse wave returns earlier, the second systolic peak P_2 gets higher than the incident one, P_1 (Fig. 1C). The increased force generated in response to the elevated afterload is not utilized for ejection of a bigger stroke volume. It is needed to overcome the elevated pulsatile component of arterial afterload. This is the reason it was named wasted effort, E_w , or wasted energy [6,7] (Fig. 1C). Since it also depends on the duration of systole, it might be an additional marker of myocardial load and oxygen demands [6,8]. Recently, renewed interest in pulse wave analysis (PWA) was attained thanks to the wider introduction of applanation tonometry into medical practice [8–10]. Based on a validated transfer function

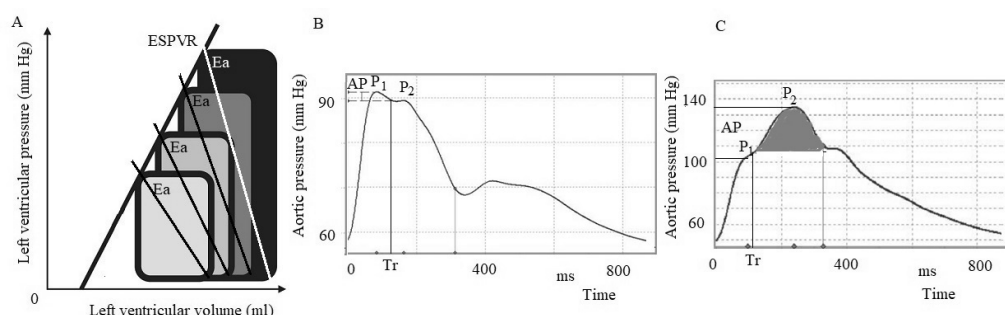


Fig. 1. A. Arterial elastance (ESP/SV). B and C are screenshots from our device. B. Aortic pulse waveform of a young individual; AP is negative. C. Aortic pressure waveform of an aged individual; AP is positive. The shaded area represents the wasted effort, E_w . ESPVR – End-systolic pressure/volume relationship; E_a – Arterial elastance; AP – Augmentation pressure; Tr – time to return of the reflected wave

the central aortic pressure waveform is computed and a series of parameters of central haemodynamics are derived from the aortic waveform.

The aim of our study was to evaluate the effect of age and gender on central haemodynamics non-invasively with the help of PWA data.

Materials and methods. Seventy-six clinically healthy individuals were divided into four groups according to their age and gender as shown in Table 1 (F – females, M – males, 20 y/o and 50 y/o – average age in years). All subjects signed an informed consent to take part in the study that was completely in compliance with the principles of Helsinki declaration [11]. Applanation tonometry was performed using the Sphygmocor device (AtCor Medical, Australia) after supine rest for 10 min. The right radial pulse waveform was adjusted to the brachial arterial. Pulse wave analysis provided important parameters of central haemodynamics: aortic systolic, mean, pulse, augmentation (AP, the pressure difference between the two systolic peaks), and end-systolic pressures. Augmentation index AIx75 was calculated as $\frac{AP}{PP} \times 100$ %, standardized for heart rate 75/min. Stroke volume was computed using the formula $SV = -6.6 + (0.25 \text{ ET}) - (0.62 \text{ HR}) + (40.4 \text{ BSA}) - (0.51 \text{ Age})$ ml (ET is ejection time in ms, HR is heart rate in beats per minute, BSA is body surface area in m²) [12]. Total vascular resistance (TVR) was calculated using the formula $TVR = \frac{MAP \times 1333.3 \times 60}{\text{Cardiac output}}$ dyn.s.cm⁻⁵. Arterial elastance (Ea) was determined as $Ea = \frac{ESP}{SV}$ mm Hg/ml. Wasted effort was computed as

Table 1

General characteristics and haemodynamic parameters of the studied individuals. * $P < 0.01$ vs. F20; # $P < 0.05$, ## $P < 0.01$ vs. M20; + $P < 0.05$ vs. M50; HR Heart rate; ASP Aortic systolic pressure; APP Aortic pulse pressure; AI75% Augmentation index, standardized for heart rate 75 beats per minute; SV Stroke volume; TVR Total vascular resistance; Ea Arterial elastance; Ew Wasted ventricular effort

	F20 y/o <i>n</i> = 21	M20 y/o <i>n</i> = 22	F50 y/o <i>n</i> = 21	M50 y/o <i>n</i> = 12
Age (years)	21.5 ± 0.7	22 ± 1	57 ± 2	47 ± 3
HR (min ⁻¹)	70 ± 3	66 ± 2	68 ± 2	73 ± 4
ASP (mm Hg)	95 ± 2	100 ± 2	120 ± 5*##	120 ± 3*##
APP (mm Hg)	25 ± 1	33 ± 1**	43 ± 4**#	42 ± 3**#
AIx75	-2 ± 3	-8 ± 2	28 ± 3*###+	14 ± 4*##
SV (ml)	78 ± 3	92 ± 2**	68 ± 2*###+	80 ± 3##
TVR (dyn.s.cm ⁻⁵)	1257 ± 89	1101 ± 37	1601 ± 105*##	1421 ± 82##
Ea (mm Hg.ml ⁻¹)	1.1 ± 0.1	0.9 ± 0.05	1.6 ± 0.07*###+	1.3 ± 0.08##
Ew (dyn.s.cm ⁻² .10 ²)	2 ± 4	-8 ± 3	83.5 ± 12.2*###+	32.7 ± 9.7*##

$2.09 \times AP \times (ET - Tr) \times 1.33 \times 10^2 \text{ dyn.s.cm}^{-2}$ [6]. The Wilcoxon Mann–Whitney test and regression statistical analysis were applied. The level of significance for P was assumed to be at least 0.05.

Results. The general characteristics of our subjects are presented in Table 1. Aortic ASP and APP were significantly higher in the older subjects ($P < 0.01$). The AIx75 was biggest in F50y/o. It was markedly higher not only as compared to the younger groups ($P < 0.01$), but also compared to M50 y/o ($P < 0.05$). Stroke volume was largest in M20 y/o ($P < 0.01$ vs. all groups). Effective arterial elastance and wasted effort were highest in F50y/o ($P < 0.01$ vs. F20 y/o and M20 y/o; $P < 0.05$ vs. M50 y/o) (Table 1). Those parameters were significantly higher in M50 y/o as compared to the young groups as well ($P < 0.01$). Regression analysis showed significant dependence between Ea and the ratio R-to-T (total vascular resistance referred to the duration of cardiac cycle) (Fig. 2A). This correlation was stronger and of higher significance in the

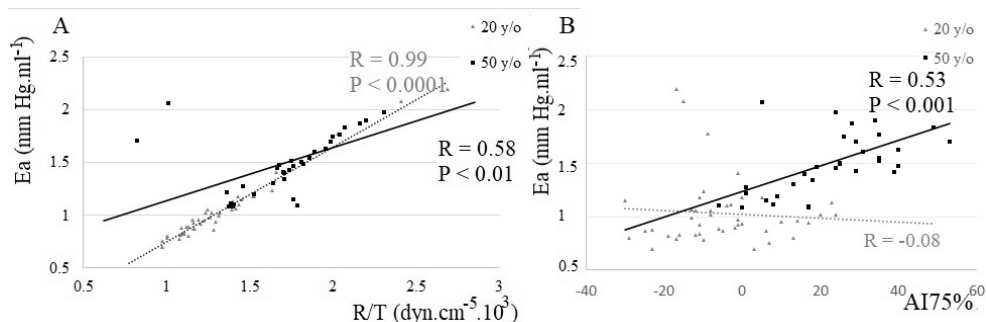


Fig. 2. A. Dependence between Ea and vascular resistance (R-to-T ratio) B. Contribution of the AIx75 to the value of Ea

young individuals ($R = 0.99$, $P < 0.0001$) than in the middle aged ($R = 0.58$, $P < 0.01$). On the contrary, no correlation was observed between Ea and AIx75 in the young persons ($R = -0.08$), while significant correlation existed between those parameters in the older subjects ($R = 0.53$, $P < 0.001$) (Fig. 2B). Regression analysis showed a highly significant correlation between Ew and Ea in the middle-aged individuals ($R = 0.70$, $P < 0.001$), while no correlation existed between those indices in the young groups (Fig. 3).

Discussion. This study was focused on the effect of the ‘physiologic arterial structural alterations’ on central haemodynamics related to ageing. Significant differences between the aortic pressures of the young and older groups were demonstrated in agreement with our previous findings [13]. We considered the elevated aortic pulse pressure in the aged individuals to be of special significance since it was recognized as a sensitive indicator of arterial stiffening and reduced arterial compliance [9,14]. Female gender was an additional contributing factor for the arterial alterations. As absolute value aortic pulse pressure was virtually

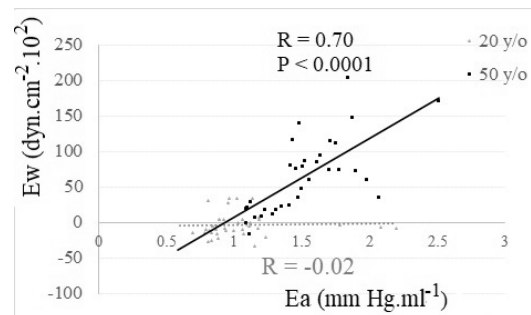


Fig. 3. Correlation between wasted effort (Ew) and arterial elastance (Ea)

equal in F50y/o and M50y/o; however, SV was significantly larger in 50 y/o males. This finding might be explained only by a more pronounced reduction of aortic compliance in F50 y/o. It was in accordance with the assumption for age-sex interaction in arterial stiffening that concurred with the elevated cardiovascular risk in postmenopausal women [15]. The distribution pattern of AIx75 data was similar. The AIx75 was highest in F50y/o as compared to the other groups. The augmentation index is one of the indirect measures of arterial stiffness [9,10]. Our data were in accordance with the conclusions of the large Anglo-Cardiff Trial for a higher AIx in females beyond the effect of the minor height [16]. This phenomenon might be explained by the accelerated postmenopausal morphological alterations in the large arterial tree [17].

The above data correlated with the elevation of Ea in the older subjects, which we interpreted as an evidence for an increased pulsatile afterload. It was shown that in young and healthy individuals the pulsatile component was of small contribution to the Ea value [18]. Our data from regression analysis were in agreement with this concept. Highly significant positive correlation existed between total vascular resistance referred to the heart period (R-to-T ratio) and Ea. This correlation was remarkably high ($R = 0.99$) for the young individuals confirming that at this age vascular resistance was the only relevant determinant of afterload [19,20]. Quite the opposite, we believe Ea elevation in the aged persons was a consequence of the earlier return of the reflected wave and the increased pulsatile load imposed on the left ventricle. The high correlation between AIx75 and Ea in the aged individuals was a strong indication in this direction. Increased pulsatile load caused a futile increase of the generated ventricular force and of myocardial oxygen demands. The trendline of the correlation between Ew and Ea had a similar course to the correlation between AIx75 and Ea. This was an additional evidence for the underlying effect of arterial stiffening on the impairment of vascular/ventricular interactions and the ensuing disbalance between oxygen needs and supply in middle-aged individuals.

In conclusion, applanation tonometry and PWA provided additional and reli-

able measures of central haemodynamics, arterial/ventricular coupling and after-load that might be implemented in the early diagnosis and prevention of cardiovascular disorders.

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