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COMMON CAROTID WALL ELASTICITY AND INTIMA-MEDIA THICKNESS EXAMINATIONS BY MEANS OF ULTRASOUND

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The aim of this study was to examine the relation between the intima-media thickness and the wall elasticity measured simultaneously in the same cross-section of the common carotid artery. A group of 40 persons (19 healthy and 21 with hypertension and/or atherosclerosis) aged 22 to 81 were diagnosed by means of ultrasound. A high correlation occurred between the wall stiffness coefficient α and the intima-media thickness ($r = 0.950$, $p < 0.00001$).

Keywords: arterial wall elasticity, intina-media thickness, carotid artery, ultrasound.

1. Introduction

Non-invasive examinations of arteries walls are essential in modern medical diagnosis. Changes in the wall structure resulting from age and vascular diseases, including hypertension and atherosclerosis contribute to the increase of its stiffness and thickness [1, 2, 5, 9 – 11, 15, 17, 19, 22, 23, 25, 26]. Ultrasonic measurements of vascular wall dimensions and its elasticity are carried out independently, owing to the different measuring techniques and applied apparatus. The wall thickness is assessed through analysis of two-dimensional ultrasonic image (B-mode) of artery [1, 5, 9, 10, 26]. Wall elasticity is examined by means of ultrasonic wall tracking systems detecting changes in vascular diameter influenced by blood pressure changes [2, 11, 15, 19].

The paper presents the results of simultaneous ultrasonic measurements of wall elasticity and intima-media thickness in the common carotid artery which were carried out on a group of 40 persons (19 healthy and 21 with hypertension and/or atherosclerosis) aged 22 to 81.

2. Method and equipment

Wall elasticity in the common carotid artery was determined on the basis of ultrasonic measurement of the maximum and minimum diameters of the common carotid artery and the systolic and diastolic blood pressures taken by cuff on the brachial artery. The subjects were examined in a lying position. The vascular wall elastic properties were evaluated through the following parameters: compliance coefficient CC, distensibility coefficient DC and stiffness coefficient α [19]. They are formulated as follows:

$$\mathrm{CC} = \frac{\pi\left(D_{\max}^2 - D_{\min}^2\right)}{4(P_s - P_d)}, \tag{1}$$

$$\mathrm{DC} = \frac{D_{\max}^2 - D_{\min}^2}{D_{\min}^2(P_s - P_d)}, \tag{2}$$

$$\alpha = \frac{D_{\min}^2}{(D_{\max}^2 - D_{\min}^2)} \ln\left(\frac{P_s}{P_d}\right), \tag{3}$$

where $D_{\max}$, $D_{\min}$ being the maximum and minimum arterial diameter values for the systolic P_s and diastolic P_d blood pressure respectively.

The intima-media thickness (IMT) was measured simultaneously with the elasticity parameters in the same vessel cross-section. The examinations were performed using the VED system designed by the authors from the Institute of Fundamental Technological Research, Polish Academy of Sciences. The apparatus comprised of a pulse system tracking displacement of vascular wall with measurement precision of up to 7 μm. The inner diameter was determined through digital time measurement between chosen echoes (RF signal) received from the inner vascular wall layer. The frequency of transmitted ultrasound was 6.75 MHz. The wave was focused at 1 to 3 cm below the skin surface. The longitudinal resolution of the apparatus obtained by model examination was 0.33 mm

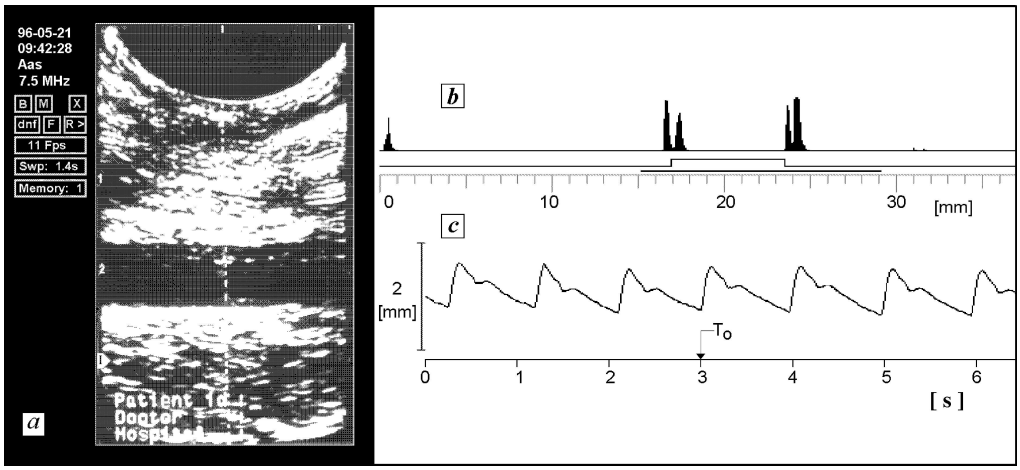

Fig. 1. The longitudinal ultrasound image of the common carotid artery (a) and the data presented in the course of the measurements in the common carotid artery by means VED ultrasonic system: b) echoes from the wall of the artery, c) artery diameter variations. T_o — the time of registering the echoes.

in water. The measured data were displayed on the screen of an IBM PC (Fig. 1) connected on-line with the ultrasonic equipment and stored in the computer memory. The intima-media thickness (IMT) was determined on the basis of the ultrasonic echo image (A-mode) of the arterial wall (Fig. 2).

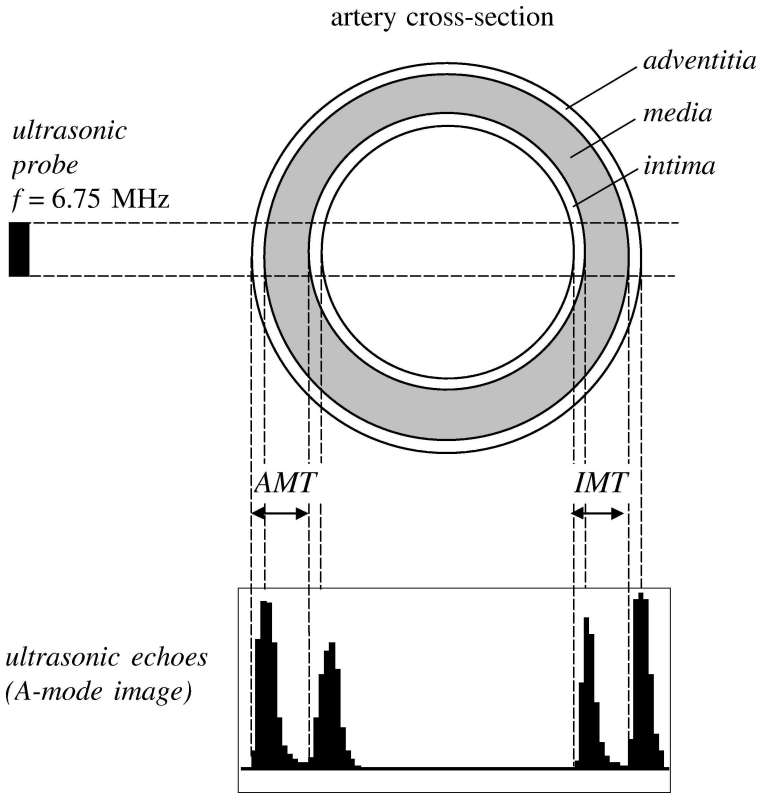

Fig. 2. The method of intima-media thickness (IMT) examination by means of ultrasound.

The common carotid artery wall is composed of three layers: the adventita, media and intima. The basic difficulty in examination of wall thickness is limited longitudinal resolution of ultrasonic systems used for this purpose. For the applied transmission frequency between 5 – 10 MHz the longitudinal resolution is from 0.4 to 0.2 mm. Generally it is not enough to measure the intima thickness which value is less than 0.2 mm [8, 27]. In this situation, the intima-media thickness (IMT) was calculated on the basis of the distance between two successive echoes which correspond to reflection from intima and adventitia layers respectively (Fig. 2). Moreover, the wall thickness changed under the blood pressure change during the cardiac cycle [6, 12, 14]. In VED system for each cardiac cycle 8 echo pictures were recorded synchronously with instantaneous value of artery diameter. The mean value of IMT over cardiac cycle was used for analysis.

The reproducibility of the measurements was tested on a control group of 10 healthy persons: 5 women and 5 men aged 23 to 30. Each person was tested independently by

two examiners experienced in such measurements. Coefficient of variation CV was taken as a criterion of reproducibility. It was calculated for every parameter investigated as a ratio of a standard deviation between two compared groups of results to mean value of one of the groups chosen as a reference for a comparative evaluation.

The coefficient of variation CV in examining the intima-media thickness and vascular wall elastic properties was as follows: $11.84 \pm 0.18\%$ for IMT (mean IMT = 0.45 mm), $10.01 \pm 0.13\%$ for stiffness coefficient α, $12.85 \pm 0.73\%$ for distensibility coefficient DC and $14.73 \pm 0.14\%$ for compliance coefficient CC measurements.

3. Results

The measurements were carried out in the common carotid arteries of 40 persons (19 female, 21 male) aged 22 to 81 (mean age 49.9) of whom 19 were healthy, 3 were suffering from hypertension, 9 were suffering from atherosclerosis and a further 9 from both. The measurements were done while the subjects were lying down, following 15 minute rest periods. Ultrasonic B-mode examinations did not show any stenotic plaque in the common carotid artery where the measurements were taken.

The results, depicted in Fig. 3, show the increase of stiffness coefficient α to be coupled with the increase of intima-media thickness. The distensibility coefficient DC and the compliance coefficient CC decreased as a function of IMT increase. The correlation coefficient r between α and IMT was very high: 0.950 ($p < 0.00001$). It was slightly lower for IMT and DC ($r = -0.839$, $p < 0.00001$). The lowest correlation was for IMT and CC ($r = -0.554$, $p < 0.0002$). Table 1 shows the mean values of measurements in healthy and sick persons respectively.

Table 1. The values of parameters measured in the groups of healthy and sick persons.

Examined group	Age [years]	P_s [mmHg]	P_d [mmHg]	$D_{\min}$ [mm]	IMT [mm]	α	CC [10^{-7} m^2/kPa]	DC [10^{-3}/kPa]
healthy persons	44.0 ±17.9	119.7 ±14.3	74.2 ±8.0	6.78 ±0.80	0.57 ±0.08	3.31 ±1.19	9.75 ±3.52	27.64 ±11.20
sick persons	55.4 ±14.3	137.0 ±20.7	77.1 ±13.3	8.48 ±1.31	0.73 ±0.12	5.39 ±1.55	8.42 ±3.37	15.19 ±5.74

The results show a significant dependence between the increase of vascular wall stiffness in the common carotid artery and the intima-media thickness. This may be due to the vascular wall structural changes bringing about an increase in both its thickness and stiffness. The increase of vascular wall stiffness is mostly explained in terms of an increase of collagen fibres in the wall and an increase in the ratio of collagen fibres to elastin fibres [7].

The authors wanted to find out how the stiffness coefficient α and intima-media thickness are related to the age of examined persons. The analysis was carried out for the groups of healthy and sick persons described above. The results are shown in Fig. 3. In the healthy group the increase of α and IMT values as a function of age was very significant

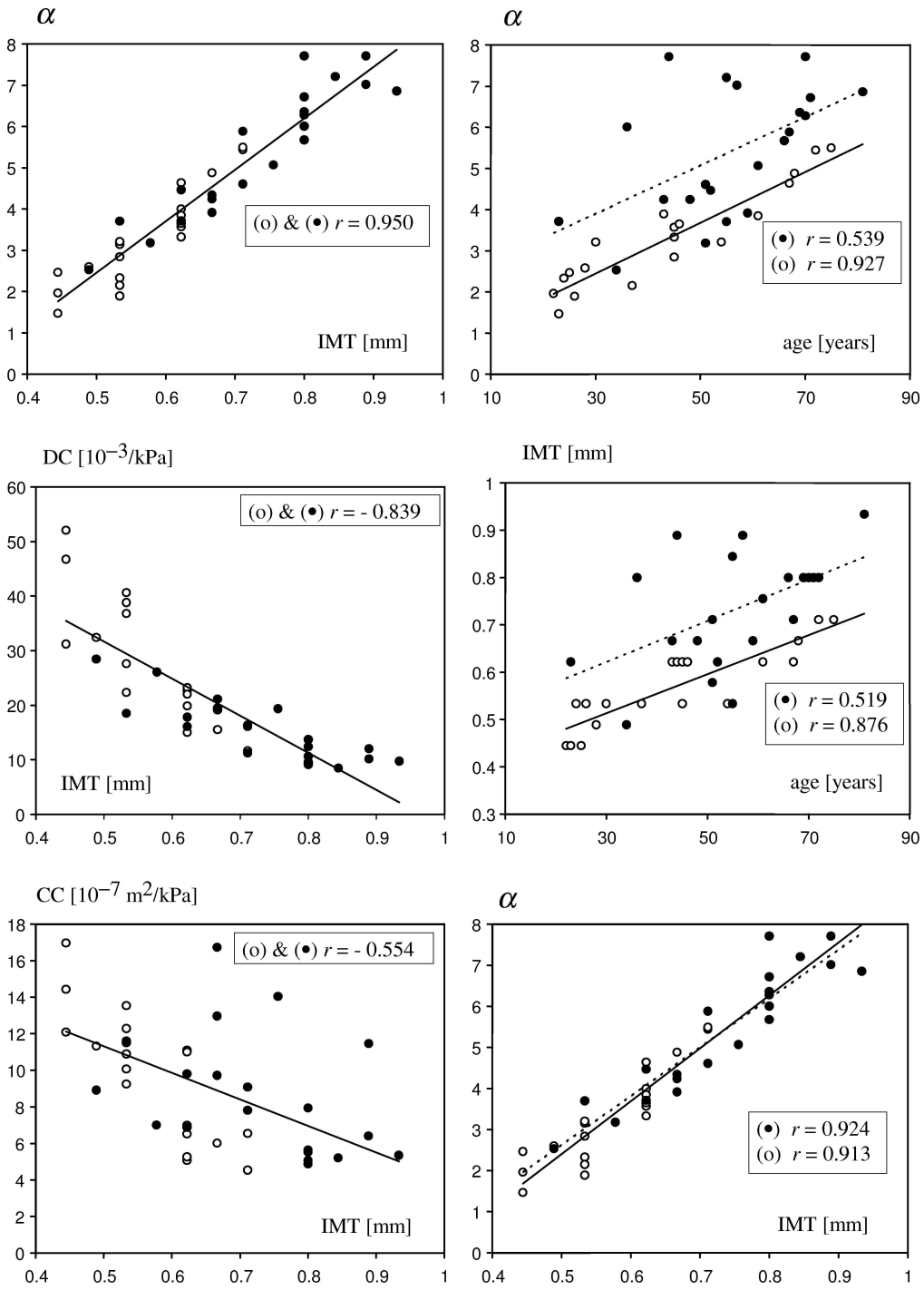

Fig. 3. The intima-media thickness IMT, compliance coefficient CC, distensibility coefficient DC and stiffness coefficient α determined in common carotid artery for healthy (○) and sick (•) persons.

(the correlation coefficients were $r = 0.972$ and 0.876 respectively, $p < 0.00001$). In the sick persons the dependence was very weak with the respective values of the correlation coefficient being $r = 0.539$ and $r = 0.519$ ($p < 0.02$). This means that the structural changes that occur in the vascular wall as a result of disease overshadow the symptoms of ageing. Nevertheless, the very high correlation between the value of α and the IMT for both groups is worth emphasising (the correlation coefficients were $r = 0.913$ and $r = 0.924$ for the healthy and sick group respectively, $p < 0.00001$).

Finally, it should be pointed out that the IMT correlates with the stiffness coefficient α to a much greater degree than with the distensibility and compliance coefficients DC and CC. This may be due to DC and CC being linked to the blood pressure value. Experimental studies performed on large arterial vessels (the aorta, the common carotid artery and the femoral artery) by BERGEL [3, 4], LOON *et al.* [18], SIMON *et al.* [24], LANGEWOUTERS ET AL. [16] and HAYASHI *et al.* [13] indicate that the reaction of the artery wall to a change in blood pressure is nonlinear. This means that the coefficients CC and DC described by formulae (1) and (2) depend on the blood pressure, making it difficult to comparatively evaluate the arterial wall elasticity studies performed on their basis. It is necessary to note that the values of coefficients CC and DC are most commonly used in the literature for evaluation of elasticity of arterial wall. The stiffness coefficient α was developed by POWAŁOWSKI and PEŃSKO [19] on the basis of the nonlinear function between cross-sectional area of the artery and the blood pressure. POWAŁOWSKI *et al.* show that the coefficient α is independent of the systolic blood pressure changes [20, 21].

4. Conclusions

The measurements carried out in the common carotid arteries of healthy and sick persons point to a statistically evident correlation between the increase of the wall stiffness and the increase of the intima-media thickness. The highest correlation with the wall thickness increase was observed for the stiffness coefficient α ($r = 0.950$, $p < 0.00001$) and the lowest for the compliance coefficient CC ($r = -0.554$, $p < 0.0002$). In persons suffering from hypertension and/or atherosclerosis an observed increase of stiffness coefficient α and intima-media thickness (IMT) was significant in comparison to healthy persons ($p < 0.001$).

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