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Noninvasive Assessment of Artery Wall Properties in Children Aged 4–19 Years

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ABSTRACT. The vessel wall properties of the common carotid artery were noninvasively studied in 53 normotensive, presumed normal boys of various ages (4–19 yr) with the use of a multigate pulsed Doppler system. This device allows the on-line recording of velocity profiles and the relative changes in carotid artery diameter during the cardiac cycle. From the width of these profiles, the internal diameter of the carotid artery can be determined. With the use of internal carotid artery diameter, relative changes in carotid artery diameter during the cardiac cycle, and pulse pressure the pulse pressure, as measured in the brachial artery, the distensibility coefficient and the cross-sectional compliance were calculated. The children were allotted to three different age groups: group I (4–10 yr), group II (11–14 yr), and group III (15–19 yr). In the older children (group III) the systolic arterial pressure and the pulse pressure were significantly higher than in groups I and II. The carotid artery diameter was significantly larger and the distensibility coefficient was significantly smaller in group III than in groups I and II. The cross-sectional compliance was not significantly different in the age groups, which can be explained by the larger artery diameter in the older age group. The findings indicate that the carotid artery wall is less distensible in adolescents than in younger children. The subjects in group III showed similar carotid artery wall properties as the young adults (aged 20–34 yr) in a previous study. Therefore, it is likely that in adolescents the vascular system can be considered as mature as far as the arterial wall properties are concerned. (*Pediatr Res* 25:94–96, 1988)

Abbreviations

P_s, systolic arterial pressure
P_d, diastolic arterial pressure
Δp, pulse pressure
d, internal carotid artery diameter
$\Delta d/d$, peak arterial diameter increase during systole
CC, cross-sectional compliance
DC, distensibility coefficient
$\Delta d/d$ * 100%, relative changes in carotid artery diameter during the cardiac cycle

It has long been known that aging alters the histologic structure of artery walls and, hence, changes their dynamic properties (1). Most of the information available on artery wall properties has been obtained from excised vessels (2–5) or experiments on anesthetized animals (2, 3, 6, 7). The limited number of noninvasive investigations on human arteries nearly all concern adults (8, 9). One of these studies (9) showed that carotid artery distensibility and cross-sectional compliance decrease linearly with age, starting in the 3rd decade. The only study (10) that includes children (6–25 yr) does not provide information about the changes in artery wall properties with age in children and adolescents, because the children were not allotted to different age groups.

It was the aim of our study to investigate the distensibility (the relative increase in arterial diameter during systole normalized with respect to the arterial pulse pressure) and cross-sectional compliance (distensibility multiplied by the arterial diameter) of the common carotid artery in children aged 4–19 yr. The common carotid artery was chosen because it is known to be rather elastic and easily accessible to ultrasound. The relative diameter changes during the cardiac cycle and the vessel diameter were assessed with the use of a specially designed multigate pulsed Doppler system.

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MATERIALS AND METHODS

The study was performed on 53 healthy male volunteers, aged 4–19 yr. The study was limited to male subjects, because in previous studies women were found to have less distensible arteries than men (10, 11). The parents responded to a written request asking their children for a short noninvasive examination. The request was handed out at two nearby schools, after consultation with the teachers. In all cases, informed consent of the parent(s) was obtained. All respondents were included in the study. They took no medication, and all had normal arterial blood pressures. The volunteers were allotted to three age groups: group I, 4–9 yr ($n = 18$); group II, 10–14 yr ($n = 25$); and group III, 15–19 yr ($n = 10$).

The ultrasound investigations were performed with the subjects in the supine position with the head tilted slightly to the contralateral side. The $\Delta d/d \times 100\%$ was recorded on-line with a high resolution multigate pulsed Doppler system (12–14). These diameter changes were recorded in the plane of the carotid artery bifurcation. The assessment of vessel wall displacement is based upon the processing of low frequency Doppler signals, originating from the sample volumes coinciding with the anterior and posterior walls. The Doppler signals originating from the walls were 30–100× higher in amplitude than the signals originating from the slowly moving blood cells close to the vessel wall and, hence, mask the signals induced by these cells completely. The small size of the sample volume excludes contamination with other slowly moving structures (1.2 mm^3 at a depth of 15 mm; the width of the ultrasound beam is about 1 mm at this depth). To ensure that the initial relative change at the beginning of the cardiac cycle is constant, it is reset to 0 by a trigger derived from the R-wave of a standard lead of the ECG. The ECG was also used to calculate heart rate. The relative arterial diameter changes are independent of the angle of interrogation and can be determined with an absolute accuracy of 0.5% (15), comparing favorably to the peak excursions observed. This means that for a relative excursion of, for instance, 7% a relative change in diameter between 6.5–7.5% can be measured. The coefficient of variation in assessing relative arterial diameter changes was found to be 10.7% when volunteers were investigated 2× at intervals of 2 to 6 wk (unpublished results). The multigate pulsed Doppler system also allows the on-line recording of velocity profiles in arteries, that is, the velocity distribution over the cross-sectional area of the vessel, at discrete time intervals during the cardiac cycle (9, 13, 14). From the width of these velocity profiles, the internal diameter of an artery can be assessed rather accurately with an error about 0.7 mm. Inasmuch as the multigate pulsed Doppler system shows on-line the gates that display blood velocity, city, the largest diameter can be found by assessing the maximal number of adjacent gates showing velocity. Because the arterial diameter, as obtained in this way, is dependent on the angle of interrogation, the values measured were corrected for this angle, i.e., 60° in the present study. The relative arterial diameter changes during the cardiac cycle and the diameter of the common carotid artery were determined approximately 3 cm proximal to the carotid artery bifurcation. The site of measurement was localized through a velocity image of the bifurcation (16). In this technique, a transducer of a Doppler system is connected to a mechanical scanning arm. The position of the transducer and beam is electronically sensed by position sensing circuitry which causes the beam of an image storage oscilloscope to move in correspondence with the position of the transducer. The output of the Doppler system intensifies the Z-axis of the image storage oscilloscope only for a given direction of flow, and the threshold of the Z-axis beam control circuit is set so that only signals above, for instance, 10% of peak flow will be imaged. By repeatedly passing the transducer over the artery and following the artery along its course, a two-dimensional picture of arteries can be made. The image formed is similar to the anatomic display of x-ray arteriography, but represents a functional projection of local blood flow velocities.

At the time of the examination, brachial artery cuff blood pressure measurements were performed with the subjects in the supine position according to the technique described by Savage *et al.* (17). When assessed in this way, the diastolic pressure values (disappearance of the sounds) correlate well with those determined invasively (17). The width of the cuff was adapted to the upperarm circumference of the children in the various age groups (group I, 11 cm; groups II and III, 14 cm). The measurements were repeated 2–3 times, and the lowest value was taken as the subject's reading. The arterial Δp, that is the difference between systolic and diastolic blood pressure, was estimated from this pressure reading. The peak systolic value of Δd/d and the absolute d and Δp values were used to calculate the DC and CC, as previously described in detail (9, 18), with the use of the following equations:

$$DC = \frac{2\Delta d/d}{\Delta p}$$

$$CC = \frac{\Delta d/d}{2\Delta p} \cdot \pi d^2$$

Differences between the groups were evaluated for statistical significance with the use of the nonparametric Kruskal-Wallis test. A p value < 0.05 was considered to be a significant difference.

RESULTS

The values for age, P_s, and P_d, Δp, Δd/d * 100%, d, DC, and CC in the various age groups are presented in Table 1. There were no significant differences for any of the variables studied between groups I and II. In group III, the carotid artery diameter (d) was significantly larger, and the systolic arterial pressure and the pulse pressure were significantly higher than in groups I and II. The DC was significantly lower in group III than in groups I and II. CC was not significantly different in the three groups.

Table 1. *P_s and P_d arterial pressure, Δp, Δd/d, d, DC, and CC in the three age groups (mean ± SD)*

	Group I (4–9 yr) *n* = 18	Group II (10–14 yr) *n* = 25	Group III (15–19 yr) *n* = 10
Age (yr)	7.67 ± 1.5	11.6 ± 1.6	17.1 ± 1.7
P_s (mm Hg)	110.0 ± 3.2	114.5 ± 8.6	125.7 ± 9.8*
P_d (mm Hg)	66.0 ± 8.0	65.5 ± 8.6	67.1 ± 3.9
Δp (mm Hg)	43.4 ± 8.1	49.2 ± 12.3	59.3 ± 11.0*
Δd/d (%)	9.1 ± 1.3	9.8 ± 2.0	8.9 ± 1.7
d (mm)	5.5 ± 0.6	5.8 ± 0.8	6.5 ± 0.7*
DC (10^{-3}/KPa)	31.4 ± 4.5	29.8 ± 6.1	22.5 ± 4.3*
CC (10^{-7} m^2/KPa)	7.6 ± 1.1	7.9 ± 1.6	7.5 ± 1.4

* Significantly different from the values in groups I and II ($p < 0.05$).

DISCUSSION

The common carotid artery is less distensible in adolescents than in younger children, as indicated by the diminished DC in children aged 15–19 yr, as compared with children 4–14 yr of age. The diminished distensibility is not associated with a decrease in CC because the d is larger in the older children. In this way, the capacity to store energy temporarily in the common carotid artery, as during a heartbeat, is preserved with increasing age, despite the loss of distensibility.

To evaluate whether the vascular system in group III can be considered to be mature, the arterial wall properties in this age category were compared with those assessed in our laboratory in a previous study on healthy normotensive males aged 20–34 yr (19). In this study, the distensibility coefficient of the common carotid artery was found to be 20.0 ± 5.1 10^{-3}/kPa (mean ± SD) and the cross-sectional compliance 6.5 ± 1.7 $10^{-7}m^2$/Kpa (mean ± SD). These values are not significantly different from those found in group III (Mann-Whitney test). The adult blood pressure values (P_s = 128 ± 8 mm Hg, P_d = 71.2 ± 6.5 mm Hg, Δp = 55.8 ± 9.3 mm Hg) were not significantly different from the adolescent values either (Mann-Whitney test).

These findings indicate that the vascular system can be considered to be mature at the adolescent age as far as arterial wall properties are concerned. The less distensible arterial wall in older than in younger children is likely to be responsible for the higher systolic arterial pressure in the adolescents. Because diastolic arterial pressure is not significantly different in the three age groups, indicating that peripheral vascular resistance is similar in these groups, arterial pulse pressure is higher in older than in younger children. The comparable degree of distensibility of the arterial wall in young adults and adolescents likely explains the similar systolic arterial pressure and arterial pulse pressure values in the two age categories.

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