The popliteal artery, an unusual muscular artery with wall properties similar to the aorta: Implications for susceptibility to aneurysm formation?

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Objective: **The popliteal artery is, after the aorta, the most common site for aneurysm formation. Why the popliteal artery is more susceptible than other peripheral muscular arteries is unknown. An important factor may be differences in arterial wall composition as compared with other peripheral muscular arteries, which in turn affect wall properties. These are however unknown. We studied the mechanical wall properties of the popliteal artery in healthy subjects.**

Material and Methods: **An ultrasound echo-tracking system was used to measure pulsatile changes in popliteal diameter in 108 healthy subjects (56 female, 52 male; age range, 9-82 years). In combination with blood pressure, stiffness (β), strain, cross-sectional artery wall compliance coefficient (CC), and distensibility coefficient (DC) were calculated. Intima-media thickness (IMT) was registered with a Philips P700 ultrasound scanner.**

Results: **The popliteal diameter increased with age, and was larger in male subjects than in female subjects ($P < .001$). Fractional diameter change (strain) decreased with age ($P < .001$), and strain values were lower in male subjects than in female subjects ($P < .01$). Accordingly, stiffness increased with age ($P < .001$), with higher stiffness values in male subjects ($P < .01$). DC decreased with age ($P < .001$), with lower DC values in male subjects ($P < .01$). CC decreased with age, with no difference between genders ($P < .001$). IMT increased with age ($P < .001$), with higher IMT values in male subjects ($P < .001$). The increase in IMT did not affect distensibility.**

Conclusion: **The wall properties of the popliteal artery are affected by age and gender, not only with an increase in diameter, but also with an age-related decrease in distensibility, with male subjects having lower distensibility than in female subjects. This seems not to be the behavior of a true muscular artery, but of a central elastic artery, such as the aorta, and might have implications for susceptibility to arterial dilatation, as well as the association of aneurysm formation between the aorta and the popliteal artery. (J Vasc Surg 2004;39:836-42.)**

Clinical Relevance: **The popliteal artery is, after the abdominal aorta, the most common location for aneurysm formation in the arterial system. Why it is more susceptible than other arteries is unknown. This study shows that the wall function of the popliteal artery differs from other peripheral arteries, and instead show striking similarities to the abdominal aorta, indicating that the functional arrangement of arterial wall components are similar in the two arteries. This may have implications for the susceptibility to aneurysm formation, as well as the association of dilating disease between the popliteal artery and the abdominal aorta.**

The possibility that abdominal aortic aneurysm (AAA) is not only a local vascular disease in the abdominal aorta but a generalized process in the vascular system has been emphasized.[1,2] In central elastic arteries such as the aorta and the common carotid artery there seems to be a tendency toward dilatation and defective wall function,[2-4] whereas in the peripheral muscular arteries of most patients with AAA functional defects rather than pathologic dilatation are found.[5,6] Despite this, the popliteal artery, after the aorta, is the most common site for aneurysm formation, and may have a part in multiple aneurysm disease, in which about 30% includes AAA.[7]

The mechanical properties in central elastic arteries such as the aorta show an age-related pronounced decrease in distensibility, whereas peripheral muscular arterial walls seem practically unaffected, indicating less age-related arterial wall degeneration.[8-13] Why the popliteal artery is more susceptible than other peripheral muscular arteries to aneu-

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rysmal disease is unknown. One underlying factor of importance may be differences in arterial wall composition as compared with other peripheral muscular arteries, which in turn affects the wall properties. The mechanical properties of the popliteal artery wall, however, are largely unknown.

The purpose of this study was to investigate, in vivo, the mechanical properties of the popliteal artery in relation to age and gender in healthy subjects.

MATERIAL AND METHODS

Material. The study included 108 healthy subjects; 56 were female, with ages ranging from 9 to 82 years, and 52 were male, with ages ranging from 9 to 78 years. The subjects were all nonsmokers, free from medications, and had no history of hypertension, cardiopulmonary or renal disease, cerebrovascular event, diabetes, or intermittent claudication. Ankle-brachial index was greater than 1 in all subjects. Pregnancy was an exclusion criterion. All subjects gave informed consent to participate in this study, according to the Helsinki Declaration, and the Ethics Committee at Lund University, Sweden, approved the study.

Examination. An experienced ultrasound technician performed all measurements in a darkened and quiet room. Auscultatory blood pressure was measured with a sphygmomanometer in both upper arms to exclude differences in blood pressure.

The subjects rested in the prone position for at least 15 minutes before ultrasound measurements were made. The right popliteal artery was examined with a 5-MHz transducer at the site of the popliteal fossa, with the patella as a landmark. The artery was visualized in the longitudinal section, and care was taken to minimize pressure from the transducer to the skin. After these measurements, brachial pressure was recorded.

Arterial diameter and distensibility measurements using echo-tracking system. An ultrasound echo-tracking system[14] (Diamove, Teltec AB, Lund, Sweden), interfaced with a 5-MHz B-mode real-time linear scanner (EUB 240, Hitatchi, Tokyo, Japan), was used to measure pulsatile changes in vessel diameter during the cardiac cycle. Details of the ultrasound echo-tracking system have been described.[9,15,16] In brief, two electronic markers are aligned with and locked on the echoes from the posterior interface of the anterior wall and the anterior interface of the posterior wall. The markers follow the pulsate movements of the vessel wall. The repetition frequency of the echo-tracking loops is 870 Hz, the time resolution is 1.2 ms and the smallest detectable movement is less than 10 μm.[14,17] A personal computer type 386 (Express, Tokyo, Japan) and a 12-bit analog to digital converter (Analogue Devices, Norwood, NJ) was used to sample the measurements.

The popliteal artery was examined three times, and the mean diameter, fractional diameter change (strain), and stiffness (β), from the corresponding diameters, pulsatile diameter changes, and blood pressure measurements, were calculated. The mean vessel diameter was defined as $(D_{max} + D_{min})/2$.

The fractional diameter change, strain, was defined as follows:

$$Strain = (D_{systolic} - D_{diastolic})/D_{diastolic} \qquad (1)$$

where $D_{systolic}$ and $D_{diastolic}$ are the maximal systolic and minimum diastolic diameters.

Distensibility characteristics of large arteries depend on the extent to which they are expanded, the vessel being very distensible at low pressures and small diameters, but gradually stiffer with increasing pressure and diameter. Thus there is a nonlinear pressure-diameter relationship of the arterial wall. It was observed that the relation between the logarithm of relative pressure and strain (fractional diameter change) was linear in vitro. Based on this logarithmic relation, and thus independent of pressure in the physiologic range, the index stiffness (β) was established as an estimate of vascular distensibility. It was later modified and used in vivo by Kawasaki et al.[18] This index has been used in this study, and is expressed as follows:

$$Stiffness\,(\beta) = ln(P_{systolic}/P_{diastolic})/(D_{systolic} - D_{diastolic})/D_{diastolic} \qquad (2)$$

where $P_{systolic}$ and $P_{diastolic}$ are systolic and diastolic blood pressures (mm Hg), and $D_{systolic}$ and $D_{diastolic}$ are systolic and diastolic vessel diameters (mm).

Body surface area (BSA) was estimated according to the formula of Du Bois[19]:

$$BSA\ (m^2) = weight^{0.425\ kg} \times height^{0.725\ cm} \times 71.84 \qquad (3)$$

Measurement of compliance coefficient and distensibility coefficient. Compliance coefficient (CC) was defined as follows[20]:

$$CC = \pi(2Dd * \Delta D + \Delta^2 D)/4\Delta P \qquad (4)$$

The unit for CC is mm^2/kPa.

Distensibility coefficient (DC) was defined as follows[20]:

$$DC = 2Dd * \Delta D + \Delta^2 D/\Delta P * Dd^2 \qquad (5)$$

where Dd is end-diastolic diameter, ΔD is diameter change $(D_{systolic} - D_{diastolic})$, and ΔP is pressure change $(P_{systolic} - P_{diastolic})$. The unit for DC is $10^{-3}/kPa$.

The distensibility coefficient is the change in arterial diameter in relation to a given increase in pressure, and the compliance coefficient of an artery is the absolute increase in cross-sectional area for a given increase in arterial pressure, with the assumption that vessel length is constant during the pulse wave.[20]

The variability with the echo-tracking system used is 5% in measurement of arterial diameter and 10% to 15% for pulsatile diameter change.

Measurement of intima-media thickness and lumen diameter. A Philips P700 ultrasound device (Philips Ultrasound, Santa Ana, Calif) with a 5-MHz transducer was used for measuring arterial lumen diameter and intima-media thickness (IMT) at the level of the popliteal fossa. Longitudinal images of the vessel were recorded on a video

Table I. Demographic data for study population

Parameter	*Female subjects*	*Male subjects*	P
No. of subjects	56	52	
Age (y)	48 ± 22	46 ± 22	
Height (cm)	165 ± 8	177 ± 10	<.001
Weight (kg)	63 ± 9	76 ± 14	<.001
Blood pressure (mm Hg)			
Systolic	128 ± 24	129 ± 19	
Diastolic	77 ± 9	79 ± 10	
Diameter (mm)	6.4 ± 1.0	7.5 ± 1.3	<.001

Values represent mean ± SD.

monitor (Panasonic Ag-73501; Matsushita Electric Industrial Co, Osaka, Japan). The analyzing system was composed of a personal computer (Intel 486, Santa Clara, Calif), a video monitor (Panasonic H1450; Matsushita), and a video recorder (Panasonic NV-HS1000; Matsushita), linked to a text monitor and a digitizer (Summagraphics Summa Sketch III; GTCO CalComp, Scottsdale, Ariz). The longitudinal image was frozen in diastole, and the anterior and posterior vessel walls were marked.[21]

The mean IMT was then automatically calculated in a 10-mm long segment at the far wall of the vessel with a computerized system (VAP version 2.0). The software was written in Microsoft Pascal with MS-DOS operating system (Department of Applied Electronics, Chalmers University of Technology, Gothenburg, Sweden).

The mean value of IMT and lumen diameter was calculated on the basis of three images with good recording quality. The variability of the IMT measurements on the popliteal artery is 10%.[22]

Noninvasive blood pressure measurements. A sphygmomanometer was used when upper arm auscultatory blood pressure was measured. A cuff with appropriate size was chosen, and blood pressure was recorded immediately after recording of the diameter change in the popliteal artery.

Statistical analysis. Pearson's correlation coefficient was used to assess the relationship between age and diameter, strain, stiffness, distensibility coefficient, compliance coefficient, and IMT. Differences between genders were tested with analysis of covariance. A multiple exponential regression model was used. $P < .05$ was considered a significant difference. The statistical analyses were performed with SPSS software (SPSS, Chicago, Ill), and graph illustrations were performed with Statistica.

RESULTS

Demographic data for the study population are shown in the Table. Heart rate did not differ between genders: 59.9 ± 9.1 and 62.2 ± 9.3, respectively, in male and female subjects (NS). Furthermore, heart rate was not affected by age.

Popliteal artery diameter and strain. The diameter of the popliteal artery was 7.43 mm (95% confidence interval [CI], 7.16-7.71 mm) and 6.33 mm (CI, 6.11-6.56 mm), respectively, for male and female subjects ($P < .001$). The diameter increased with age, being 17% larger in male subjects compared with female subjects ($P < .001$). There was a relation between diameter and age in both male subjects ($r = 0.66$; $P < .001$) and female subjects ($r = 0.51$; $P < .001$). Furthermore, BSA also affected the diameter to some extent (7% in male subjects vs 6% in female subjects; $P < .001$), as well as systolic blood pressure (10% and 7%, respectively; $P < .01$).

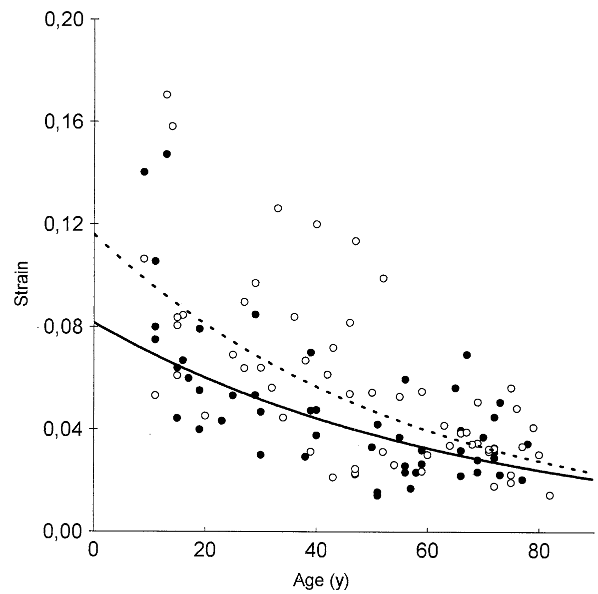

Fig 1. Fractional diameter change (strain) of the popliteal artery in healthy male subjects *(black circles, solid line)* and female subjects *(open circles, dashed line)* in relation to age. There was a significant negative correlation between strain and age in both male and female subjects. Further, there was a significant gender difference, with male subjects having lower strain values than in female subjects.

The relation between fractional diameter change and age in male and female subjects is shown in Fig 1. The strain values in both male and female subjects decreased exponentially with age (male subjects, $r = -0.64$, $P < .001$; female subjects, $r = -0.67$, $P < .001$), with higher strain values in female subjects compared with male subjects ($P < .01$).

Strain was mainly influenced by age (41% in male subjects vs 45% in female subjects; $P < .01$), although the diameter also had some effect (4% and 5%, respectively; $P < .05$). IMT had no influence on strain. The coefficient of variation regarding measured arterial diameter was 4%, and fractional diameter change was 24%.

Popliteal artery stiffness, distensibility coefficient, and compliance coefficient. Stiffness (β) and distensibility coefficient of the popliteal artery in relation to age in male and female subjects are shown in Fig 2. The stiffness values increased with age ($r = 0.69$ and $r = 0.75$, $P < .001$, in male and female subjects, respectively), and were 25% higher in male subjects compared with female subjects ($P <$

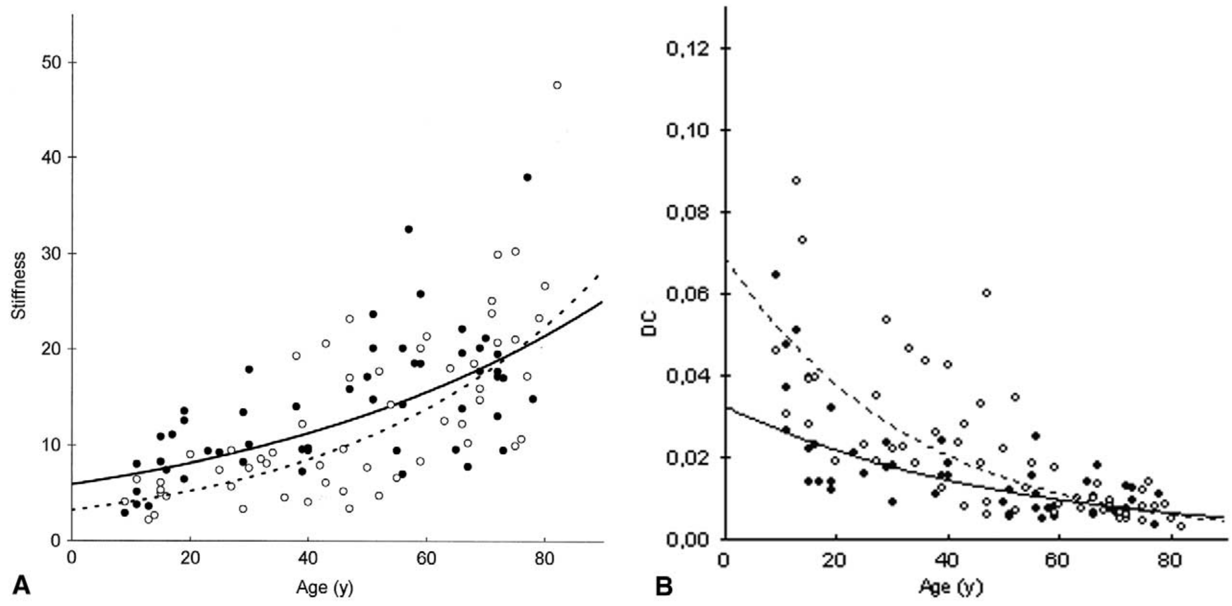

Fig 2. A, Stiffness of the popliteal artery in healthy male subjects *(black circles, solid line)* and female subjects *(open circles, dashed line)* in relation to age. There was a significant correlation between the increase in stiffness and age in both male and female subjects, with higher stiffness values in male subjects. **B,** Distensibility coefficient *(DC)* of the popliteal artery in healthy male subjects *(black circles, solid line)* and females (open circles, dashed line) in relation to age. There was a significant correlation between the decrease in DC and age in both male and female subjects, with lover DC values in male subjects.

.01). Stiffness was mainly influenced by age (45% for male subjects vs 56% for female subjects; $P < .01$). Systolic arterial pressure (SAP) and mean arterial pressure (MAP) were of minor importance (SAP, 3% for male subjects vs 4% for female subjects [$P < .001$]; MAP, 3% for male subjects vs 1% for female subjects [$P < .05$]). The distensibility coefficient values decreased with age ($r = -0.71$ and $r = -0.80$ in male and female subjects, respectively; $P < .001$), and were 24% lower in male subjects compared with female subjects ($P < .01$). Distensibility coefficient was mainly influenced by age, being 51% and 64% in male and female subjects, respectively ($P < .01$). SAP (7%; $P < .01$) and diameter 4% ($P < .05$) were of minor importance. MAP and IMT did not influence distensibility coefficient.

Cross-sectional artery wall compliance (compliance coefficient) decreased with age ($r = -0.40$, $P < .01$ in male subjects; $r = -0.69$, $P < .001$ in female subjects), without gender differences. Compliance coefficient was mostly influenced by SAP (33% and 62%, respectively, in male and female subjects; $P < .001$. Age (6% and 3%; $P < .01$) and diameter (4% and 1%; $P < .01$) were of minor importance.

Fig 3 shows a comparison of the increase in stiffness (β) between ages 20 and 70 years (times the measured value at age 20 years) in the popliteal artery (muscular artery, present study), and earlier published data regarding the common femoral artery, with all subjects from the present investigation included (muscular artery)[13] and the abdominal aorta (elastic artery).[9] Note the similar stiffness increase in the popliteal artery and the abdominal aorta, and the lack of increase in the common femoral artery.

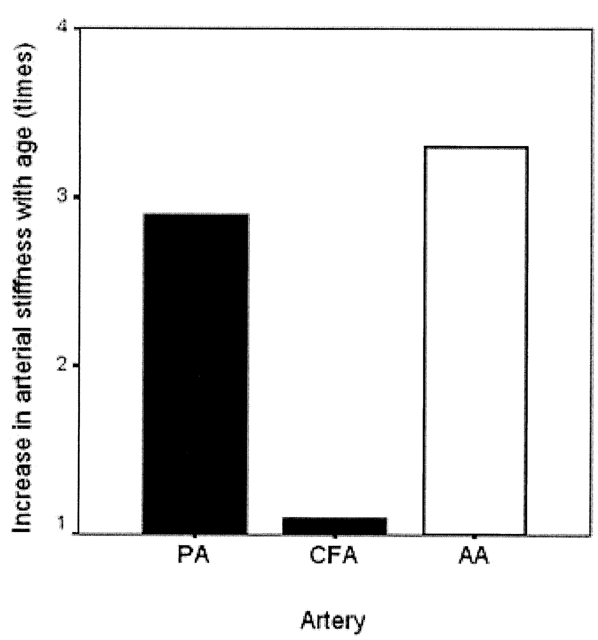

Fig 3. Increase in stiffness (β) between ages 20 and 70 years (times the measured value at age 20 years) in the popliteal artery (*PA;* muscular artery, present study), and earlier published data regarding the common femoral artery (*CFA;* muscular artery[13]) and the abdominal aorta (*AA;* elastic artery[9]). Note similar increase in the popliteal artery and the abdominal aorta, and the lack of increased stiffness in the common femoral artery.

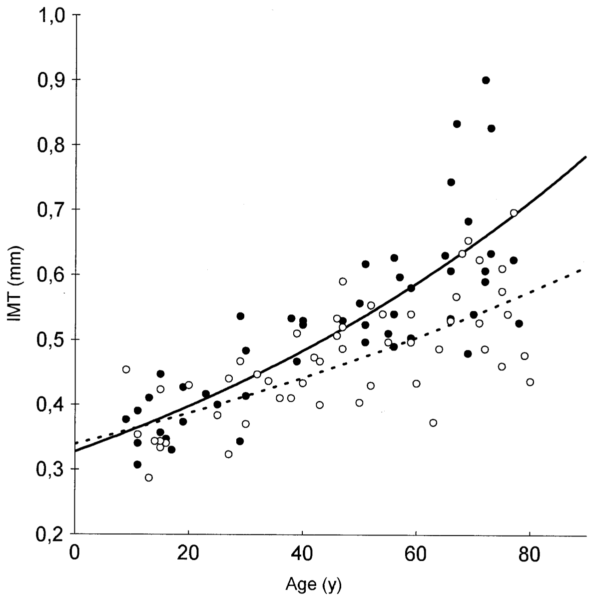

Fig 4. Intima-media thickness *(IMT)* of the popliteal artery in healthy male subjects *(black circles, solid line)* and female subjects *(open circles, dashed line)* in relation to age. There was a significant correlation between the increase in IMT and age in both male and female subjects, with no difference between genders.

Popliteal IMT. The relation between IMT of the popliteal arterial wall and age in male and female subjects is shown in Fig 4. IMT values increased with age ($r = 0.84$ and $r = 0.72$, $P < .001$, in male and female subjects, respectively, with male subjects having IMT values 12% higher than in female subjects ($P < .001$). IMT was mostly influenced by age, 70% and 52% in male and female subjects, respectively ($P < .001$). Diameter was of minor importance, 1% in both male and female subjects ($P < .001$). SAP and MAP did not have any significant influence on IMT.

DISCUSSION

It has been emphasized that AAA is not only a local vascular disease in the abdominal aorta, but a generalized process in the vascular system.[1,2] In central elastic arteries there is both a tendency toward dilatation and defect wall function, as shown by decreased arterial wall compliance,[2-4] whereas in most patients with AAA the walls of peripheral muscular arteries seem only to be functionally defective rather than changed in diameter.[5,6,23]

In healthy subjects the mechanical properties in central elastic arteries such as the aorta show an age-related, pronounced decrease in distensibility, whereas peripheral muscular arterial walls seems practically unaffected, indicating less age-related arterial wall degeneration.[8-13] Although the popliteal artery is characterized as a muscular artery, after the aorta it is the most common location in the arterial system for aneurysm formation. Thus about 5% of patients with AAA may be affected with popliteal aneurysms,[6] and about 30% of patients with popliteal aneurysm also have an AAA.[7] Why the popliteal artery is more susceptible than other peripheral muscular arteries to aneurysmal disease is unknown.

The absence of an age-related change in distensibility of muscular arteries may seem surprising, because it is well known that the arterial wall structure changes with an increase in collagen and thickening of the vessel wall. There is no reason to believe that age-related histologic changes and subsequent remodeling are absent in muscular arteries,[24] inasmuch as age-related dilatation of muscular arteries of similar magnitude to that in elastic arteries has been found.[9,13,18,25-28] As in other muscular arteries, the diameter of the popliteal artery increases with age, being affected by age and body size, and is larger in male subjects than in female subjects.[29] Apart from the study of Sandgren et al,[29] earlier studies on the size of the popliteal artery are sparse and without conclusive data, owing to the small number of subjects investigated, in combination with mixed male and female populations.[30,31] One factor that might influence dilatation is the distending force acting on the arterial wall, that is, the blood pressure. A positive correlation between abdominal aortic expansion rate and blood pressure has been shown,[32] and it is well known that blood pressure increases with age. Accordingly, we also found a correlation between arterial dilatation and blood pressure.

The mechanical properties of arteries are of importance for the regulation of heart work and blood pressure, and decreased arterial wall distensibility is an independent predictor of cardiovascular morbidity and mortality.[33-35] In central elastic arteries the structure of the arterial wall is the main determinant of wall mechanics, whereas in muscular arteries intrinsic myogenic mechanisms, endothelial-dependent detection of change in wall shear force with resultant release in nitric oxide, and sympathetic modulation of vascular smooth muscle tone may be more important in the regulation of arterial wall compliance.[36,37]

When measuring wall motion in relation to intraarterial pulse pressure variation to calculate the mechanical properties, it would be favorable to measure blood pressure at the site of wall motion detection, because the blood pressure undergoes transformation in the arterial tree.[38] Direct measurement of blood pressure in the popliteal artery may be performed, but seems unethical and difficult in studies with a large population. Instead, we used the brachial artery for blood pressure measurements. To our knowledge, thus far no direct comparison has been performed between popliteal and brachial arterial pressure. Rydén Ahlgren et al[13] compared blood pressure in the femoral artery with auscultatory blood pressure in the upper arm, and found slightly higher systolic blood pressure and somewhat lower diastolic blood pressure in the femoral artery. The differences in blood pressure within the arterial tree are reduced at older ages, but in younger ages this might introduce an error in calculations of compliance.

The fractional diameter change (strain) of the popliteal artery was initially calculated without use of the pressure measurements from the arm (equation 1). This showed an age-related decrease, with female subjects having strain values higher than in male subjects, indicating an age-related decrease in distensibility and lower distensibility in male subjects (Fig 1). With the aid of the brachial pressure measurements, the distensibility indices were calculated. This showed decreased distensibility with age in both male and female subjects, with reduced distensibility in male vs female subjects, in line with the calculated strain data (Figs 1, 2). Earlier studies on the distensibility of the popliteal artery in healthy subjects are sparse. Tai et al[39] investigated 11 young subjects and 12 older subjects and found indications of decreased distensibility with age. No differentiation between genders was performed, however. Brodskij et al[40] studied only young female subjects, without any attempt to define the relation between popliteal distensibility and age or gender. Our findings differ from the near superficial and common femoral artery region, as well as other regions of muscular arteries where no decrease in distensibility with age has been found.[10-13,39] On the other hand, the distensibility values for the popliteal artery show similarities to the aorta, with an age-related decrease and with men having higher stiffness values than in female subjects[8,9] (Fig 3). The reduced distensibility of the popliteal wall, as in the aorta, probably reflects a decreased elastin-collagen ratio. Furthermore, incipient atherosclerosis might also add to increased stiffness, although the ankle-brachial index was greater than 1 in all investigated subjects. Current opinion in the literature concludes, however, that the effect of atherosclerosis on arterial distensibility is minor.[38] Another factor that might be of importance is wall thickness, according to the equation of Young's modulus.[38] Thus increased arterial wall thickness may decrease distensibility. The IMT of the popliteal artery increased with age in both genders, but was higher in male subjects compared with female subjects, in accordance with findings in the femoral artery[41] (Fig 4). In the investigated healthy subjects the IMT was correlated with age, but did not affect the distensibility of the popliteal artery wall. Thus it seems reasonable to assume that the components of the popliteal artery wall may be more similar to central elastic arteries such as the aorta than to other peripheral muscular arteries. This may be of relevance to the fact that the popliteal artery and the aorta share similar pathologic findings, with a tendency to aneurysm formation.

In conclusion, this study has shown that the wall properties of the popliteal artery are affected by age and gender, not only with an increase in diameter, but also with an age-related decrease in distensibility, which is lower in male subjects than in female subjects. This seems not to be the behavior of a true muscular artery, but of a central elastic artery such as the aorta, and might have implications for the susceptibility to aneurysm formation, as well as the association of dilating disease, between the popliteal artery and the aorta.

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