The Aging Process Modifies the Distensibility of Elastic but not Muscular Arteries

Luiz A. Bortolotto, Olivier Hanon, Giovanna Franconi, Pierre Boutouyrie, Sylvie Legrain, Xavier Girerd

Abstract—Aging decreases the distensibility of large elastic arteries; however, the effects of age on the functional parameters of muscular, medium-sized arteries are not well determined. This study evaluated the consequences of aging on the functional parameters of the carotid and radial arteries in normotensive men. A total of 62 elderly subjects (aged 74±2 years) were compared with 87 young subjects (aged 35±3 years). Internal diameter and intima-media thickness (IMT) were measured by a high-resolution echo-tracking system to calculate distensibility and incremental elastic modulus (Einc). Although in the normal range, systolic and diastolic blood pressure levels were statistically different in the 2 groups at 128±19 and 74±13 mm Hg versus 121±27 and 71±18 mm Hg in the young and elderly subjects, respectively (P<0.05). At the carotid artery level, elderly subjects exhibited a greater IMT (742±144 versus 469±132 μm; P<0.01) and internal diameter (7067±828 versus 6062±1026 μm; P<0.01) than young subjects; elderly subjects also had lower distensibility (12±2 versus 21±2 kPa⁻¹·10⁻³; P<0.01) and higher Einc (0.9±0.2 versus 0.7±0.3 kPa · 10³; P<0.01). At the radial artery level, both IMT (240±42 versus 218±51 μm; P<0.01) and internal diameter (2685±432 versus 2491±444 μm; P<0.01) were greater in elderly subjects, but no differences in distensibility and Einc were observed between the 2 groups. All differences remained significant, even after adjusting for mean blood pressure. These results indicate that the increase of the internal diameter and IMT observed during the aging process can have opposite effects on the functional parameters of large elastic or medium-sized muscular arteries. (Hypertension. 1999;34[part 2]:889-892.)

Key Words: aging ■ carotid arteries ■ radial artery

The aging process modifies the functional and structural parameters of the arterial tree.1–3 These changes commonly include widening and elongation of large arteries and vessel-wall thickening. In addition to these geometrical changes, functional modifications are also observed, including a decrease in systemic arterial compliance and the cross-sectional distensibility of large elastic arteries.4–5 These modifications lead to an increase in systolic blood pressure and a decrease in diastolic blood pressure and result in a wider pulse pressure, which is associated with a higher cardiovascular risk in elderly subjects.6,7

Recent advances in ultrasound techniques have permitted the noninvasive determination of the internal diameter and wall thickness of medium-sized arteries, such as the radial artery, with high precision.8 Although several studies have demonstrated that geometrical changes with aging are not homogeneous along the arterial tree,9 the consequences of aging on functional parameters at the site of peripheral, predominantly muscular, middle-sized arteries are not yet established. Thus, the aim of our study was to compare the structural and functional modifications of the radial artery, a medium-sized muscular artery, and the carotid artery, a large elastic artery, in 2 groups of subjects that differed in age. Because arterial parameters are markedly altered during essential hypertension10 and because significant modifications have been observed under antihypertensive therapies,11 we studied only subjects with a history of normal blood pressure levels.

Methods

Population

The study population was part of an outpatient population referred to our department for the prevention of atherosclerosis because of the presence of ≥1 cardiovascular risk factors (ie, hypertension, dyslipidemia, diabetes, and/or smoking). A total of 149 men with an clinical history of normal blood pressure (systolic blood pressure <140 mm Hg and diastolic blood pressure <90 mm Hg) were selected for the study. A normal blood pressure was confirmed after an automated recording of blood pressure (systolic, diastolic, and mean) with an oscillometric method (Dynamap, Critikon). Blood pressure was recorded every 3 minutes for 30 minutes with subjects in the supine position. In each subject, the mean value of 5 consecutive measurements after the tenth minute was <140 mm Hg.
for systolic blood pressure and <90 mm Hg for diastolic blood pressure.

The population was divided in 2 groups: the first group included subjects classified as “young” (age range, 30 to 45 years; mean age, 35±2 years), and the other group included subjects classified as “elderly” (age range, 70 to 85 years; mean age, 74±3 years). The criteria for inclusion were as follows: no history or clinical evidence of cardiovascular disease, absence of treatment by any cardiovascular drugs, and satisfactory technical conditions of the carotid and radial arteries. All patients gave informed, written consent, and the local ethics committee approved the study.

**Hemodynamic Measurements of Radial and Carotid Arteries**

The measurements of the arterial parameters were performed sequentially with the patient in a recumbent position in a quiet room. For the common carotid artery, measurements were performed on the right, 2 cm below the bifurcation, at the site of the distal wall, and distant from an atherosclerotic plaque, if present.

**Radial Artery Parameters**

A high-resolution, pulsed, echo-tracking device (NIUS 02; SMH), which has previously been described and validated for the measurement of radial parameters in humans,10 was used. Briefly, the internal diameter and intima-media thickness (IMT) of the radial posterior wall were measured with electronic trackers that were positioned on specific peaks of the RF ultrasound signal that was acquired with a 10-MHz probe positioned at the wrist. The device presented an axial resolution of 160 μm for absolute internal diameter or wall-thickness measurements and of 2.5 μm for the same parameters during systolic-diastolic changes. All data were processed by specific software (NIUS 02), and the system was coupled to a commercially available digital photo-plethysmograph (Finapres system, Ohmeda, BOC Group Inc) for simultaneous blood pressure measurements. From the 2 simultaneous recordings of arterial diameter and blood pressure, the computerized data acquisition system derived the cross-sectional diameter pressure curve, fitted it by use of an arctangent model with 3 independent parameters,11 and then calculated the cross-sectional pressure curve, fitted by use of an arctangent model.

Operational distensibility and elastic modulus were defined as previously described.13

**Statistical and Data Analysis**

Data were expressed as mean±SD. Young subjects are aged 30 to 45 years, and elderly ones, 70 to 85 years. *P<0.05 compared with the young group. †P<0.001 compared with the young group.

**Radial Artery Parameters**

A high-resolution, pulsed, echo-tracking device (NIUS 02; SMH), which has previously been described and validated for the measurement of radial parameters in humans,10 was used. Briefly, the internal diameter and intima-media thickness (IMT) of the radial posterior wall were measured with electronic trackers that were positioned on specific peaks of the RF ultrasound signal that was acquired with a 10-MHz probe positioned at the wrist. The device presented an axial resolution of 160 μm for absolute internal diameter or wall-thickness measurements and of 2.5 μm for the same parameters during systolic-diastolic changes. All data were processed by specific software (NIUS 02), and the system was coupled to a commercially available digital photo-plethysmograph (Finapres system, Ohmeda, BOC Group Inc) for simultaneous blood pressure measurements. From the 2 simultaneous recordings of arterial diameter and blood pressure, the computerized data acquisition system derived the cross-sectional diameter pressure curve, fitted it by use of an arctangent model with 3 independent parameters,11 and then calculated the cross-sectional distensibility pressure curves, which reflect the functional properties of the artery. In contrast to distensibility, which provides information about the elasticity of the artery as a hollow structure, the incremental modulus of elasticity (Einc) provides direct information on the elastic properties of the arterial wall, independent of vessel geometry.12 We calculated Einc as:

\[
\frac{3}{\text{Dist}} \times \left(1 + \frac{\text{LCSA}}{\text{WSCA}}\right)
\]

where WSCA is the mean wall cross-sectional area, LCSA is the mean lumen cross-sectional area, and Dist is the distensibility calculated from the pressure-diameter curve. WSCA is calculated as \(\pi(\text{Re}^2 - \text{Ri}^2)\), where Re is the mean external radius plus mean IMT and Ri is the mean internal radius. LCSA is calculated as \(\pi(\text{Dia})^2/4\), where Dia is the internal diameter measured in diastole. Mean internal diameter, wall thickness, distensibility, and elastic modulus were calculated by integrating the time course of the systolic-diastolic variations over 20 consecutive cardiac cycles.

**Carotid Artery Parameters**

The vessel-wall properties of the right carotid artery were assessed by a pulsed ultrasound echo-tracking system (Wall-Track System, Neurodata), which is based on the RF-signal analysis that has been described, validated, and used in previous clinical studies.13 The accuracy of the system is 30 μm for the diastolic diameter measurement and <1 μm for the pulsatile change in diameter (systolic diameter minus diastolic diameter). Carotid pulse pressure was estimated as the difference between systolic and diastolic blood pressure, as measured with an oscillometric recorder (Dynmap Model 845, Critikon) at the site of the brachial artery, and obtained automatically. Operational distensibility and elastic modulus were defined as previously described.13

**Results**

Table 1 shows the clinical parameters observed in the 2 groups of subjects. Although in the normal range, blood pressure levels were statistically different in the 2 groups, with a higher pressure in the young group. Table 2 shows the functional and structural parameters obtained in the common carotid and radial arteries. For the carotid artery, elderly subjects exhibited a greater IMT and internal diameter than young subjects. Furthermore, the distensibility was lower and the Einc was higher in elderly subjects. For the radial artery, both IMT and internal diameter were greater in elderly subjects, but no difference in distensibility and Einc was observed between the 2 groups. Because blood pressure was different in the 2 groups, arterial parameters were compared after adjustments for mean blood pressure. All differences remained significant after the adjustment.

**Discussion**

This study indicates that the aging process is associated with geometrical modifications of both large elastic and medium-sized muscular arteries, independent of blood pressure changes. Furthermore, enlargement of arterial diameter and thickening of the arterial wall have opposite effects on the functional parameters of these arteries. An alteration in elastic properties is observed for the carotid artery, but functional properties are preserved in the radial artery. Our results suggest that geometrical modifications associated with aging could be a means by which arteries try to maintain normal distensibility.

Several studies have described arterial changes associated with the aging process.15,16 Kawasaki et al17 studied the common carotid artery, abdominal aorta, femoral artery, and
brachial artery in 39 subjects aged 6 to 81 years with an ultrasonic phase-locked echo-tracking system, and they observed a significant increase in the diameter of all arteries, with a reduction in the percentage change in diameter, with advancing age. They also demonstrated that the stiffness index increased with age in all arteries, but the age-associated increase in stiffness was statistically significant only in the common carotid artery and the abdominal aorta.17 Our study reinforces the results obtained by this group and demonstrates more precisely that the functional parameters of different sites of the arterial tree respond differently with aging, independent of arterial pressure.

Another salient modification observed with aging is the lumen enlargement of arteries. This modification has been well described for large elastic arteries. To elucidate the causal factors for carotid arterial enlargement in elderly subjects, Bonithon-Kopp et al18 assessed the association between arterial wall lesions and cardiovascular risk factors in 1272 men and women aged 59 to 71 years. A stepwise multiple regression analysis showed that male gender, body height and weight, common carotid artery IMT, plaque score, systolic blood pressure, and alcohol consumption were positively and independently related to lumen diameter.18 However, an independent negative association was observed between LDL cholesterol and lumen diameter. In our study, the elderly subjects showed an increase in the internal diameter of the radial artery, although it was less prominent than that in the carotid artery. This result was not observed in a previous study by our group,4 and we hypothesize that this was because of a too narrow range of age in the former study. The present study also demonstrated a significant increase in IMT with aging in both the carotid and radial arteries. As for the internal diameter, the increase in IMT was more pronounced in the carotid artery. Indeed, one of the main factors that influences IMT in the carotid artery is aging; other independent factors include blood pressure and body mass index.19 Furthermore, in the radial arteries of never-treated hypertensive patients and normotensive subjects, IMT was independently predicted by age, gender, and mean blood pressure.20

In contrast to the majority of other studies, we evaluated only normotensive subjects, which made it possible to study only the effects of aging on the vascular system, without the confounding factor of hypertension. In fact, essential hypertension and the aging process cause similar functional and/or structural modifications.20 As a result, hypertension is often considered an accelerated form of vascular aging, and it has been shown that arterial distensibility decreases more rapidly with aging in hypertensive subjects than in normotensive subjects.21

One limitation of our study is related to the significant difference in blood pressure levels between the groups, because arterial parameters are markedly influenced by the blood pressure level per se. For this reason, we performed ANCOVA with blood pressure as the cofactor. With this adjustment, the data were analyzed as if they were at the same level of arterial pressure. Because the results remained significant after adjustment, we can confirm that the differences observed in the arterial parameters were related to aging and not to differences in blood pressure.

In conclusion, our results suggest that at the site of distal, muscular, medium-sized arteries, aging-associated structural changes show a possible advantage by maintaining normal distensibility. However, in large arteries, the structural modifications associated with the aging process do not compensate for the changes in the arterial elastic properties. The higher cardiovascular risk observed in elderly subjects could also be the result of the geometrical and functional modifications detected in the vascular system.

**Acknowledgments**

This study was partly supported by Assistance Publique, Hôpitaux de Paris (contrat de recherche clinique vieillissement 1994), and by the Fondation Nationale de Gérontologie. Dr Bortolotto was supported by the Fundação de Amparo ‘a Pesquisa do Estado de São Paulo (FAPESP).

---

**TABLE 2. Functional and Geometrical Parameters of the Radial and Carotid Arteries in 2 Populations of Normotensive Men at Different Ages**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Young</th>
<th>Elderly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial artery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT, μm</td>
<td>218±51</td>
<td>227±53</td>
</tr>
<tr>
<td>Diameter, μm</td>
<td>2491±444</td>
<td>2440±457</td>
</tr>
<tr>
<td>Operational distensibility, (kPa(^{-1})·10(^{-3}))</td>
<td>5.4±1.5</td>
<td>5.6±1.5</td>
</tr>
<tr>
<td>Operational Einc, kPa·10(^{3})</td>
<td>3.5±3.4</td>
<td>3.0±3.5</td>
</tr>
<tr>
<td>Common carotid artery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT, μm</td>
<td>469±132</td>
<td>478±136</td>
</tr>
<tr>
<td>Diameter, μm</td>
<td>6062±1026</td>
<td>6244±1038</td>
</tr>
<tr>
<td>Operational distensibility (kPa(^{-1})·10(^{-3}))</td>
<td>21±2</td>
<td>20±2</td>
</tr>
<tr>
<td>Operational Einc, kPa·10(^{3})</td>
<td>0.7±0.3</td>
<td>0.7±0.3</td>
</tr>
</tbody>
</table>

Data are shown for crude values and for values adjusted for mean arterial pressure and are expressed as mean±SD. Young subjects are aged 35 to 45 years, and elderly ones, 70 to 85 years.

*\(P<0.01\) vs the young group for crude values.
†\(P<0.01\) vs the young group for adjusted values.
References
The Aging Process Modifies the Distensibility of Elastic but not Muscular Arteries
Luiz A. Bortolotto, Olivier Hanon, Giovanna Franconi, Pierre Boutouyrie, Sylvie Legrain and Xavier Girerd

Hypertension. 1999;34:889-892
doi: 10.1161/01.HYP.34.4.889

Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1999 American Heart Association, Inc. All rights reserved.
Print ISSN: 0194-911X. Online ISSN: 1524-4563

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://hyper.ahajournals.org/content/34/4/889

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in *Hypertension* can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the *Permissions and Rights Question and Answer* document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to *Hypertension* is online at:
http://hyper.ahajournals.org//subscriptions/