Habitual Physical Activity and Vascular Aging in a Young to Middle-Age Population at Low Cardiovascular Risk

Michaela Kozakova, MD, PhD; Carlo Palombo, MD; Leila Hhamdi, MSc; Thomas Konrad, MD; Peter Nilsson, MD; Peter Bisgaard Staehr, MD, PhD; Marco Paterni, Eng; Beverley Balkau, PhD; on behalf of the RISC Investigators

Background and Purpose—Regular endurance exercise has been shown to reduce the age-related increase in arterial stiffness that is thought to contribute to cardiovascular risk. The aim of this study was to evaluate the influence of age and habitual physical activity on carotid artery wall thickness and stiffness in a population of young to middle-age subjects at low cardiovascular risk.

Methods—The study population consisted of 432 healthy subjects (166 men; mean±SD age, 43±8 years; range, 30 to 60 years) free of carotid atherosclerosis and with low coronary heart disease risk, as determined by the Framingham prediction score sheet. All subjects underwent B-mode ultrasonography of the extracranial carotid arteries and physical activity assessment by actigraph, an accelerometer capable of monitoring the intensity and duration of body movements. The intima-media thickness of the common carotid artery was measured on ultrasound images, along with systodiastolic changes in luminal diameter, and indices of carotid stiffness were calculated.

Results—Intima-media thickness and carotid stiffness increased with age in both men and women (r=0.24 to 0.52, P<0.001). The magnitude of objectively assessed daily physical activity was negatively related to indices of carotid stiffness (r from −0.20 to −0.25, P<0.001) but not to intima-media thickness. In multivariate regression analyses that included several cardiovascular risk factors such as obesity, blood pressure, plasma lipids, and smoking habits, age and physical activity were independently related to carotid stiffness.

Conclusions—This study provides cross-sectional evidence that habitual physical activity is inversely related to the age-dependent increase in carotid wall stiffness in a young to middle-age population at low risk. (Stroke. 2007;38:2549-2555.)

Key Words: carotid arteries ■ intima-media thickness ■ aging ■ exercise

Aging is associated with structural changes within the arterial wall that result in age-related increases in arterial wall thickness and stiffness.1 Increased arterial wall thickness is an independent predictor of cardiovascular events,2 and growing evidence emphasizes a possible relation between cardiovascular risk and arterial stiffness.3 Therefore, if vascular aging contributes to cardiovascular risk, age-dependent vascular changes represent a potential target for preventive interventions, lifestyle interventions above all. Several studies have suggested that regular endurance training and vigorous physical activity may reduce the age-related increase in arterial stiffness.4,5 Data regarding the impact of leisure-time and habitual physical activity on arterial structure and function are less convincing,6–8 possibly owing to the fact that the assessment of physical activity has been performed by self-reported questionnaires. Subjective interpretation of questions and perception of physical activity may lead to misclassification of the magnitude of activity.9

Physical activity is defined as any body movement that results in energy expenditure. Body movements can be continuously monitored by small accelerometers that use piezoelectric transducers and microprocessors to quantify the magnitude and direction of the acceleration.9 An objective estimate of habitual physical activity that comprises activities during occupation, leisure time, sports, transportation, and household behavior might provide an insight on individual lifestyle and might help investigators to understand the possible impact of daily activity on vascular structure and function. Thus, the purpose of this cross-sectional study was to evaluate the relations between age, habitual physical activity, and large-artery wall thickness and stiffness in a population of young to middle-age subjects at low cardiovascular risk. An objective assessment of habitual physical activity is available at http://stroke.ahajournals.org DOI: 10.1161/STROKEAHA.107.484949

© 2007 American Heart Association, Inc.

Stroke is available at http://stroke.ahajournals.org

2549
activity used accelerometers to monitor body movements during daily behavior.

**Subjects and Methods**

The population studied is a part of the RISC (Relationship between Insulin Sensitivity and Cardiovascular risk) study cohort. The design of the RISC study, an ongoing prospective study aiming to evaluate the possible relation between insulin resistance and cardiovascular risk in a low-risk white population, has been reported elsewhere. In brief, between June 2002 and July 2004, 1400 apparently healthy subjects were recruited in 19 centers in 14 European countries. All recruited subjects were between 30 and 60 years, and their blood pressure (BP <140/<90 mm Hg), plasma cholesterol (<7.8 mmol/L), triglycerides (<4.6 mmol/L), and fasting and 2-hour plasma glucose (<7.0 and 11.1 mmol/L, respectively) values were within normal limits. Exclusion criteria were the presence of chronic diseases, overt cardiovascular disease, carotid stenosis >40%, and treatment for hypertension, diabetes, and dyslipidemia. Local ethics committee approval was obtained by each recruitment center, and written consent was obtained from all participants.

**Medical Data Collection and Standard Biologic Procedures**

Medical data were collected during face-to-face interviews according to a standardized questionnaire administered by trained interviewers. Information regarding medical history, drug use, and alcohol and cigarette consumption were collected. Clinical cardiovascular disease was excluded on the basis of medical history and resting ECG. Weight was measured in subjects in undergarments, height was measured by stadiometer, and body mass index was calculated. Waist circumference was measured as the narrowest circumference between the lower rib margin and the anterior superior iliac spine. Brachial BP and resting heart rate were measured 3 times with a digital electronic tensiometer (Omron model 705cp) and with the subject seated for at least 10 minutes. Plasma total, LDL, and HDL cholesterol; triglycerides; fasting and 2-hour plasma glucose; and insulin were measured in a central laboratory. A 10-year absolute risk for total coronary heart disease end points was estimated with the Framingham Heart Study prediction score sheet.

**Carotid Artery Ultrasound Imaging and Analysis**

High-resolution B-mode ultrasound was used to assess carotid wall thickness and stiffness. In the RISC study, the carotid images were obtained at each recruiting center by trained and certified technicians who followed a standardized protocol and used high-resolution ultrasound scanners (Acuson Aspen, Acuson Sequoia, ATL 5000 HDI, Agilent Sonos 4500, or Siemens Elegra, all with a 7.5- or 10.0-MHz linear-array transducer). The imaging protocol required acquisition of longitudinal B-mode images of the distal right and left common carotid artery (CCA), the carotid bifurcation, and the origin of the internal carotid artery from the anterior, lateral, and posterior angles, as recommended. At the end of the examination, longitudinal B-mode images of the left CCA were recorded on videotape during at least 15 cardiac cycles, and brachial BP was simultaneously measured (Omron model 705cp). Carotid images were analyzed in a centralized reading center (Pisa) by a single reader (M.K.) blinded to clinical data and using a high-resolution videorecorder (Panasonic AG-MD830) coupled to a computer-driven image-analysis system.

For the purpose of this study, longitudinal images of the left CCA recorded during several cardiac cycles were digitized, and the lumen-intima boundaries of the near and far walls were selected in an end-diastolic frame (Figure, A). Off-line measurement of carotid distensibility: A, End-diastolic longitudinal images of the left CCA with selected lumen-intima boundaries; B, Calibrated distension curves.
carotid bulb. Lumen-intima boundaries during the cardiac cycle were followed by a contour-tracking system developed at the Institute of Clinical Physiology, CNR, Pisa, Italy. The location procedure of the system is based on computation of the first-order absolute moment used as an edge detector. The changes in carotid diameter during the cardiac cycle were depicted in calibrated distension curves (Figure B), in which the minimal and the maximal diameters were measured in 5 cardiac cycles. In 30 subjects, left CCA distensions as measured by our off-line contour-tracking system were compared with measurements performed during the same session with the echo-tracking system based on radiofrequency data acquisition and postprocessing (Wall Track System 2, Pie Medical, Maastricht, The Netherlands). Furthermore, in 60 subjects, the minimal CCA luminal diameter as measured by our tracking system was compared with the diameter measured manually in frozen B-mode end-diastolic images as the distance between the lumen-intima interfaces of the near and far walls.

The IMT of the near and far walls was measured in end-diastolic frames, in the same region where the lumen-intima boundaries were tracked. The measurements were performed manually by the operator at 5 measurement points for each wall, and the mean near- and far-wall IMTs were calculated by averaging the measurement points. CCA IMT was calculated as the mean of the near- and far-wall IMTs. CCA end-diastolic diameter (d), distension (Δd= maximal minus minimal diameter), and BP measured during ultrasound examination were used to calculate indices of carotid stiffness, β stiffness index and Young’s elastic modulus (Einc). β stiffness index indicates the changes in arterial diameter adjusted for distending pressure: β index=ln[systolic BP/diastolic BP]/(Δd/d). Einc provides an estimate of the intrinsic elastic properties of the arterial wall and is calculated as the ratio of stress and circumferential strain in the vessel wall: Einc=(systolic BP−diastolic BP)*d'/2Δd*IMT. Intraobserver and interobserver variabilities of all measurements were performed in 100 subjects.

Habitual Physical Activity Estimation

Habitual physical activity was estimated by actigraph, an accelerometer capable of monitoring body movements. The actigraph monitor used (Computer Science Applications model AM7164, Manufacturing Technology, Inc, Fort Walton Beach, Fla) was a single-axis accelerometer that used a piezoelectric transducer to sense accelerations ranging from 0.05 to 2.0 g. The limited frequency response (from 0.25 to 2.5 Hz) ensured that only normal human motions were detected. The acceleration signal was digitized by an 8-bit analog-to-digital converter at a sampling rate of 10 samples per second. Each digitized signal was summed for a 1-minute interval, and the total activity per minute was saved in memory. For each subject, the actigraph was secured by a belt at the small of the back from waking up until going to sleep. Subjects were asked to wear the monitor for 7 days if possible, a weekend included, and to behave in their usual manner. In the final analysis of recordings, only those days when the accelerometer was worn for at least 10 hours were included. The summary measure of habitual physical activity was expressed as the average number of counts per day worn.

Statistical Analysis

Quantitative data are expressed as mean±SD and categorical data as percentages. ANOVA was used to compare continuous variables, and a χ² test was used for categorical variables. Relations between the 4 outcome variables (CCA IMT, diameter, β stiffness index, and Einc) and continuous variables were evaluated by univariate Pearson correlation coefficients. Multiple-regression analysis was then used to study the independence of association of continuous variables that did not exhibit excessive colinearity with each other, after adjusting for center. Statistical significance was set at a value of P<0.05. Statistical analysis was performed with JMP software (SAS, Cary, NC).

Results

Measurement Validation

Absolute carotid distention (Δd) measured by our off-line contour-tracking system that follows inner-diameter changes (ie, that tracks lumen-intima boundaries) was higher than that measured by the radiofrequency wall-tracking system that follows outer-diameter changes (ie, that tracks media-adventitia boundaries): 0.53±0.13 versus 0.49±0.15 mm (P<0.01). The correlation coefficient and mean difference between the 2 measurements were, respectively, 0.91 and 0.04±0.06 mm. Pulse pressure was comparable during both acquisitions (50±8 versus 49±7 mm Hg, P=0.8). Minimal luminal diameter measured by off-line tracking was similar to that measured in frozen end-diastolic images (5.80±0.53 versus 5.77±0.51 mm, P=0.12). The correlation coefficient and mean difference between the 2 measurements were, respectively, 0.97 and 0.03±0.14 mm. The intraobserver and interobserver variabilities of measurements were, respectively, 4.1% and 6.8% for CCA IMT, 3.9% and 5.1% for minimal diameter, and 7.7% and 8.7% for absolute distension.

Characteristics of the Study Population

The population of the present study consisted of 432 subjects, 166 men and 266 women, who satisfied the following criteria: (1) low 10-year coronary heart disease risk as estimated from the Framingham prediction score sheet; (2) absence of carotid plaque (IMT measured in any carotid segment <1.5 mm); (3) left CCA near- and far-wall lumen-intima boundaries clearly visualized in digitized images in the whole cardiac cycle; and (4) actigraph recording available (average time of actigraph worn=5.5±1.5 days). Because the majority of atherosclerotic risk factors differed between men and women (Table 1), the 2 sexes were evaluated separately. Women had smaller CCA diameter, IMT, and carotid stiffness, as assessed by the β stiffness index and Einc but not to CCA IMT. Table 2. The average number of counts per day worn was comparable between men and women. The 2 sexes did not differ in smoking habits, but alcohol consumption was lower in women (Table 2). Fifty-five women (20%) were postmenopausal, and 11 of them took hormone replacement therapy.

Carotid Wall Thickness and Stiffness, Age, and Atherosclerotic Risk Factors

Table 3 demonstrates the relations of carotid structure and function with age, anthropometric parameters, systolic BP, metabolic measures, and physical activity in both men (upper part of Table, in italics) and women (lower part of Table, in bold). CCA IMT, minimal diameter, and indices of stiffness were directly related to age, several atherosclerotic risk factors, and 10-year risk of total coronary events. In both sexes, the magnitude of habitual physical activity, assessed as the average number of counts per day worn, was inversely related to the β index and Einc but not to CCA IMT. Table 3 also shows the relations between habitual physical activity, atherosclerotic risk factors, and metabolic measures. To assess whether any of the variables that showed a significant association with carotid structure and function in univariate analysis contributed independently to the variabil-
TABLE 1. Characteristics of the Study Population

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>166</td>
<td>266</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>42±8</td>
<td>44±8</td>
<td>0.08</td>
</tr>
<tr>
<td>Height, cm</td>
<td>178±6</td>
<td>165±7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>80±11</td>
<td>66±11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>25.1±2.8</td>
<td>24.0±3.9</td>
<td>0.002</td>
</tr>
<tr>
<td>Waist girth, cm</td>
<td>90±9</td>
<td>79±11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Office BP, mm Hg</td>
<td>120±10/75</td>
<td>112±10/71/78</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total cholesterol, mmol/L</td>
<td>4.7±0.8</td>
<td>4.7±0.9</td>
<td>0.54</td>
</tr>
<tr>
<td>HDL cholesterol, mmol/L</td>
<td>1.3±0.3</td>
<td>1.7±0.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LDL cholesterol, mmol/L</td>
<td>2.8±0.7</td>
<td>2.6±0.8</td>
<td>0.004</td>
</tr>
<tr>
<td>Triglycerides, mmol/L</td>
<td>1.1±0.6</td>
<td>0.9±0.4</td>
<td>0.001</td>
</tr>
<tr>
<td>Fasting glucose, mmol/L</td>
<td>5.2±0.5</td>
<td>5.0±0.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2-hour glucose, mmol/L</td>
<td>5.3±1.8</td>
<td>5.7±3.0</td>
<td>0.001</td>
</tr>
<tr>
<td>Fasting insulin, pmol/L</td>
<td>31±16</td>
<td>30±18</td>
<td>0.70</td>
</tr>
<tr>
<td>10-year CHD risk, %*</td>
<td>3.5±1.9</td>
<td>2.2±1.4</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*The 10-year coronary heart disease (CHD) risk was the 10-year absolute risk of total coronary events as determined from the Framingham prediction score sheet.

TABLE 2. Left CCA Structure and Stiffness, Habitual Physical Activity, and Lifestyle Habits

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT, mm</td>
<td>0.60±0.08</td>
<td>0.58±0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>Minimal diameter, mm</td>
<td>6.23±0.65</td>
<td>5.55±0.55</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Distension, mm</td>
<td>0.59±0.17</td>
<td>0.51±0.14</td>
<td>0.0002</td>
</tr>
<tr>
<td>BP during ultrasound, mm Hg</td>
<td>122±11/74/78</td>
<td>115±14/72/78</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>( \beta ) stiffness index, U</td>
<td>5.95±2.15</td>
<td>5.58±2.40</td>
<td>0.01</td>
</tr>
<tr>
<td>( E_{inc} ), kPa</td>
<td>400±147</td>
<td>329±141</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Actigraph

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average No. of counts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per day worn</td>
<td>368 787±179 377</td>
<td>342 004±152 407</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Lifestyle habits

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Smokers (never:ex:current), %</td>
<td>59:29:12</td>
<td>51:29:20</td>
<td>0.09</td>
</tr>
<tr>
<td>Alcohol consumption, g/wk</td>
<td>101±99</td>
<td>60±96</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Values are mean±SD.

of these indices, a multiple-regression analysis was performed in which standardized IMT, minimal diameter, \( \beta \) index, and \( E_{inc} \) were entered as independent variables and all their significant correlates were entered as independent variables. Office BP was included among independent variables because office BP was correlated only modestly with BP measured during the ultrasound examination (correlation coefficients in men \( r=0.56 \), 0.45, and 0.44, and in women, \( r=0.61 \), 0.56, and 0.47 for systolic, diastolic, and pulse pressure, respectively). All analyses were adjusted for center, smoking habit, and in women, for menopausal status. Independent factors affecting IMT were age, arterial diameter, and LDL cholesterol in men, and age, arterial diameter, and office systolic BP in women. These factors accounted for 35% and 42% of the variance in IMT (Table 4). Independent correlates of luminal diameter were body mass index in men and waist girth and systolic BP in women. In men, independent correlates of carotid stiffness indices were age and the average number of counts per day worn, which accounted for 23% and 22%, respectively, of their variability. In women, independent correlates of the \( \beta \) stiffness index were age, menopausal status, fasting insulin, and average number of counts per day worn, and of \( E_{inc} \), menopausal status, office systolic BP, fasting insulin, and average number of counts per day worn. These variables explained 21% and 23%, respectively, of the variability in carotid stiffness (Table 4).

Discussion

In the present study, the associations between age and objectively assessed habitual physical activity with carotid wall thickness and stiffness were studied in a young to middle-age European population without carotid atherosclerosis and free of known risk factors that might interact with vascular aging. In such a population, age was the strongest predictor of carotid artery wall thickness, and the age-associated increase in IMT was not influenced by the magnitude of habitual physical activity. In contrast, daily physical activity was inversely related to the age-dependent increase in carotid wall stiffness.

Carotid Artery Wall Thickness and Stiffness Versus Age

In our healthy, young to middle-age men and women at low cardiovascular risk and an IMT within normal limits (range, 403 to 920 \( \mu \)m), independent predictors of CCA wall thickness were age, luminal diameter, and in women, systolic BP. These findings are in keeping with clinical and experimental evidence suggesting that a minor degree of carotid wall thickening may reflect structural changes within the intima and media related to physiologic aging\(^ {17–20} \) or even an adaptive response to changes in diameter, distending pressure, and shear stress.\(^ {14,17,21,22} \) The independent relation
between IMT and plasma LDL cholesterol observed in men might indicate an interaction between physiologic vessel remodeling and early atherosclerosis.

The age-associated increase in carotid wall thickness is accompanied by an increase in wall stiffness that is attributed to accelerated fragmentation of elastin and excess...
sive synthesis of collagen within the arterial media. In our population, age was the strongest independent predictor of carotid stiffness in men only. Sex differences in the mechanical properties of the large arteries might be linked to endogenous estrogen levels, as estrogens have been shown to modulate the elastin-collagen ratio and smooth muscle cell numbers within the vascular wall. Indeed, in our population, a high percentage of women (80%) were premenopausal, and menopausal status was an independent predictor of carotid stiffness.

Carotid Artery Wall Thickness and Stiffness Versus Habitual Physical Activity

Regular physical activity is believed to slow the atherosclerotic process both by reducing atherosclerotic risk factors and by retarding aging of the arterial wall. However, it is not established whether physical activity may attenuate only the age-related increase in arterial stiffness or also the age-associated increase in wall thickness and whether a favorable effect on the arterial wall can be obtained only by endurance exercise training or also by less vigorous activities.

Previous studies assessing the effect of endurance training and cardiorespiratory fitness on carotid structure and function in healthy subjects have demonstrated that endurance exercise and higher aerobic capacity attenuate the age-related increase in arterial stiffness but not in wall thickness. Studies with self-reported questionnaires to evaluate the effect of habitual physical activity on carotid properties in the general population have produced opposing results. In the Atherosclerosis Risk in Communities study, habitual physical activity had no effect on carotid stiffness, whereas physical activity at work was a protective factor for increased IMT. The protective effect of leisure-time physical activity on IMT has also been observed in the Tromso study, and in the Los Angeles Atherosclerotic study, activity during leisure was inversely related to the progression of carotid atherosclerosis.

Our results do not indicate that daily physical activity has a protective effect on carotid IMT. The discrepancy with previous studies can be explained by (1) the fact that habitual physical activity was objectively estimated by monitoring body movements during daily behavior and (2) a study population that was at low cardiovascular risk. However, even in this selected population, the magnitude of daily physical activity was inversely related to indices of carotid stiffness. Habitual physical activity was also inversely related to some proatherosclerotic factors, such as central adiposity, BP, plasma lipids, and insulin, a finding that could support the hypothesis that the favorable effect of activity on the vascular wall is mediated by a BP decrease and metabolic profile improvement. However, in a multiple-regression model that included all of these factors, physical activity was independently related to carotid stiffness. Mechanisms by which regular physical activity might directly influence vascular stiffness are still speculative and include the effect of activity on the bioavailability of nitric oxide, connective tissue cross-linking, vascular smooth muscle tone, and gene expression.

Study Limitations

The design of the RISC study, a multicenter European study, allows investigation of a large and well-characterized white population at low risk. However, owing to a high number of recruiting centers, heterogeneous and only conventional ultrasound scanners were used for the carotid studies. To restrict the first limitation, all ultrasound technicians were trained and certified in the ultrasound reading center, the entire carotid imaging procedure was performed according to a standardized protocol, and a single reader processed and analyzed all carotid images. All analyses were center-adjusted. The use of conventional B-mode ultrasound scanners and an off-line contour-tracking system, instead of a radiofrequency-based wall-tracking system, which may estimate arterial diameter changes with higher resolution, represents an additional caveat related to the multicenter character of the study. The validation of our contour-tracking system that follows inner-diameter changes against radiofrequency wall tracking that follows outer-diameter changes showed a good correlation between the 2 methods, although the absolute distensions measured by our approach were higher. This observation is in agreement with data showing that with inner-diameter measurements, absolute and relative distensions are significantly larger compared with outer-diameter measurements.

Brachial BP was used for calculation of carotid stiffness indices after assuming that pulse pressure measured in the brachial artery is representative of pulse pressure in the CCA. Owing to a pressure-amplification phenomenon throughout the arterial tree, pulse pressure is higher in the brachial artery than in more central vessels, and this difference decreases with age. Consequently, with the use of brachial pulse pressure, carotid stiffness can be overestimated, especially in younger subjects.

Conclusions and Perspectives

The present cross-sectional study has confirmed a strong association between age and carotid IMT, even in a young to middle-age population at low cardiovascular risk. In such a selected population, habitual physical activity does not influence carotid IMT. By contrast, the magnitude of daily activity is inversely related to indices of carotid artery stiffness. The benefit of physical activity appears to increase throughout the activity continuum and is not merely mediated by its influence on atherosclerotic risk factors. Because of the prospective design of the RISC study, 3-year follow-up data will help to verify the effect of daily activity on IMT progression and large-artery stiffness in a middle-age, low-risk population.

Acknowledgments

Habitual Physical Activity and Vascular Aging


Coordinating Office: Pisa, Italy: S.A. Hills, L. Landucci, L. Mota.

Sources of Funding

The RISC Study is supported by European Union grant QLG1-CT-2001-01252, AstraZeneca, and Merck Sante.

Disclosures

None.

References


Kozakova et al
Habitual Physical Activity and Vascular Aging in a Young to Middle-Age Population at Low Cardiovascular Risk
Michaela Kozakova, Carlo Palombo, Leila Mhamdi, Thomas Konrad, Peter Nilsson, Peter Bisgaard Staehr, Marco Paterni and Beverley Balkau
on behalf of the RISC Investigators

Stroke. 2007;38:2549-2555; originally published online July 26, 2007;
doi: 10.1161/STROKEAHA.107.484949

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/38/9/2549