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Abstract—Physical training is associated with an increase in arterial distensibility. Whether the effect of training on this variable is evident also for ordinary levels of exercise or no exercise is unknown, however. We have addressed this issue by investigating the effect on radial artery distensibility of prolonged monolateral immobilization of the ipsilateral limb versus the following resumption of normal mobility. We studied 7 normotensive subjects (age, 25.4±3.0 years; systolic/diastolic blood pressure, 119±9/68±6 mm Hg, mean±SE) in whom 1 limb had been immobilized for 30 days in plaster because of a fracture of the elbow. At both the day after plaster removal and after 45 days of rehabilitation, radial artery distensibility was evaluated by an echo-tracking device (NIUS-02), which allows arterial diameter to be measured noninvasively and continuously over all pressures from diastole to systole (finger monitoring), with the distensibility values being continuously derived from the Langewouters formula. In both instances, the contralateral arm was used as control. Immediately after removal of the plaster, radial artery distensibility was markedly less in the previously immobilized and fractured limb compared with the contralateral limb (0.4±0.1 versus 0.8±0.1, 1/mm Hg 10^{-3}, $P<0.05$). After rehabilitation, the distensibility of the radial artery was markedly increased in the previously fractured limb (0.65±0.1 1/mm Hg 10^{-3}, $P<0.05$), whereas no change was seen in the contralateral limb. Thus, complete interruption of physical activity is associated with a marked reduction of arterial distensibility, indicating that even an ordinary level of activity plays a major role in modulation of arterial mechanical properties. **(*Hypertension*. 1998;32:584-587.)**

Key Words: arterial distensibility ■ training ■ exercise ■ vessels ■ circulation

Exercise training is associated with several changes in cardiac and arteriolar structure and function.[1–9] There is evidence, however, that large and conduit artery mechanical properties are also modified by training and that the modification consists of an increase in distensibility[10–13] that is particularly evident in the arteries of the limbs most involved in the physical activity.[14]

Whether arterial mechanical properties are modified also by ordinary levels of physical activity (rather than becoming manifest only during exercise training) has never been investigated. In the present study, we addressed this issue by measuring radial artery diameter and distensibility in subjects in whom 1 arm was immobilized in plaster for 30 days because of an elbow fracture. The examination was performed on the day after removal of the plaster and after 45 days of rehabilitation, in both instances using the contralateral radial artery as control.

Methods

Subjects

We studied 7 healthy, right-handed young subjects (5 males, 2 females) aged from 17 to 30 years (25.4±3.0 years, mean±SE). The subjects suffered from elbow fracture that had been treated by complete immobilization of the limb in plaster for 30 days. All subjects had sphygmomanometric blood pressure values <140/90 mm Hg (mean of 3 measurements). They volunteered to participate in the study after being informed of its nature and purpose. The study protocol was approved by the ethics committee of our hospital.

Radial Artery Evaluation

In the present study, the time-dependent changes in arterial diameter were obtained with an A-mode ultrasonic echo-tracking device that recorded the displacement of the radial artery over the whole cardiac cycle (NIUS-02 system, Asulab, and Capital Medical Service)[15] and thus over the whole diastolo-systolic pressure range. Briefly, the device uses a highly focalized transducer operating at a frequency of 10 MHz that was stereotaxically positioned over the radial artery 2 to 4 cm above the wrist, with gel used as a medium to prevent direct contact with the skin. With the subject supine and the arm immobile at the heart level, the transducer was oriented perpendicularly to the longitudinal axis and the largest cross-sectional dimension of the artery, based on the Doppler acoustic quality signal. After the switch to A-mode, the echo beams corresponding to the inner posterior and anterior walls of the artery were visualized on a computer screen (via an analog/digital fast transducer), thus allowing internal diameter variations to be derived. The spatial resolution was 150 μm.[15] The internal diameter of the pulsating radial artery was measured at 50 Hz, and the device resolution allowed the identification of diameter changes of 0.0025 mm during the blood pressure cycle[15,16] (see below).

The device also uses a photoplethysmographic system (Finapres, Ohmeda) that allows blood pressure to be recorded noninvasively from a finger ipsilateral to the radial artery examined with an accuracy similar to intra-arterial radial artery pressure[17] and with a resolution of 2 mm Hg.[17]

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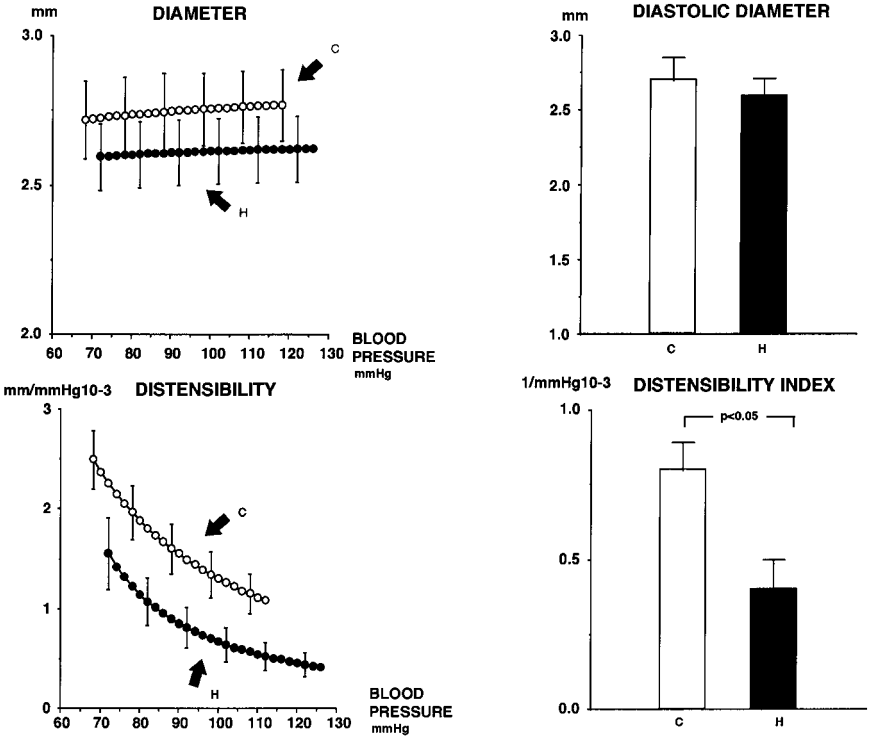

Figure 1. Radial artery diameter/blood pressure curves, distensibility/blood pressure curves, diastolic diameter, and distensibility index in the healed (H) and contralateral (C) arms. Data are mean±SE.

Blood pressure and arterial diameter signals were directed to a computer that was programmed to calculate the cross-sectional/pressure curve of the vessel. The curve was analyzed according to its fit with the arctangent model of Langewouters et al,[18] which is based on the formula

$$S=\alpha\left[\frac{\pi}{2}+\tan^{-1}\left(\frac{P-\beta}{\gamma}\right)\right]$$

where S is the cross-sectional area of the vessel, P is the intravascular pressure, and α, β, and γ are 3 optimal parameters describing the spatial position of the diameter-pressure curve.[18] From this formula, cross-sectional compliance ($C=\Delta S/\Delta P$[19]) was calculated as follows:

$$C=\frac{\alpha}{\gamma}\,\frac{1}{1+\left(\frac{P-\beta}{\gamma}\right)^2}$$

and expressed as consecutive values for blood pressure ranging from diastole to systole (cross-sectional compliance/pressure curve). The above formula was then used to calculate cross-sectional distensibility (cross-sectional compliance divided by vessel section) over the blood pressure range from diastole to systole (cross-sectional distensibility/pressure curve).

All measurements were performed by a single operator. The variation coefficient of radial artery diameter measurements obtained by the same operator in 2 different sessions (the within-operator variability) was 3.0%. The corresponding variation coefficient of radial artery cross-sectional distensibility was 7.0%.

Protocol and Data Analysis

The study was conducted on the morning of the day after removal of the plaster, following a 12-hour abstinence from alcohol consumption, caffeine consumption, and smoking. The protocol of the study was as follows: (1) Each subject was placed in the supine position and fitted with the finger pressure and the echo-tracking devices after exclusion of the presence of edema at the measurement sides. (2) After a 10-minute interval, radial artery diameter and cross-sectional distensibility were continuously measured over a 15-minute baseline period together with blood pressure and heart rate. The measurements were performed first in 1 limb and then in the contralateral limb, the first measuring side being selected randomly. (3) The whole procedure was repeated following the same sequence after 45 days of rehabilitation of the healed limb. Rehabilitation included intermittent handgrip exercise of the forearm muscles (squeezing a ball) and repeated flexion and extension of the forearm for 30 minutes per day.

Blood pressure, heart rate, and radial artery diameter and distensibility were obtained by averaging the values of five 30-second periods taken at 3-minute intervals. Radial artery diameter/pressure curves, cross-sectional distensibility/pressure curves, and diameter at diastolic blood pressure obtained in individual subjects were summed and expressed as mean values for the group as a whole, separately for either arm and either experimental condition. This was done also for the area under the curve relating cross-sectional distensibility to blood pressure normalized for pulse pressure, ie, the "distensibility index."[20–24]

The statistical significance of the differences in mean values between arms and situations was assessed by 2-way ANOVA. The 2-tailed unpaired Student t test was used to locate differences between arms, whereas the paired Student t test was used to locate differences before and after rehabilitation. Throughout the text, values are mean±SEM.

Results

Figure 1, left panels, shows that in the study performed immediately after the removal of the plaster, the increase in blood pressure from diastole to systole was accompanied by a slight progressive increase in radial artery diameter and by a steep progressive and nonlinear reduction in radial artery distensibility; this was the case in both the previously immobilized limb and the contralateral limb. In the previously immobilized limb, radial artery diameter was only slightly less than in the contralateral limb (Figure 1, right top). Radial artery distensibility, however, was much smaller, the difference in the distensibility index being statistically significant (Figure 1, right bottom). This was the case also when the distensibility index was calculated for the portion of the 2 curves that shared the same blood pressure range, ie, the "isobaric" distensibility index.[20–24]

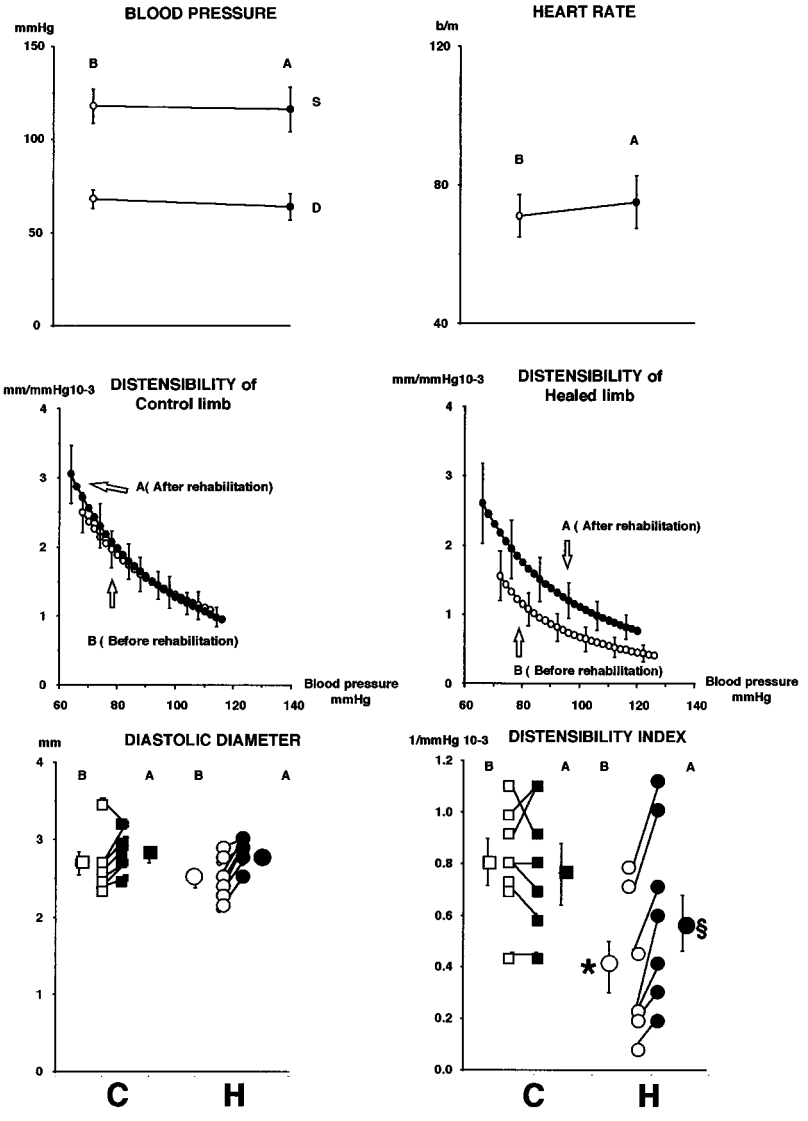

Figure 2. Blood pressure, heart rate, distensibility/blood pressure curves, individual and mean distensibility indexes, and individual and mean diastolic diameters in the healed (H) and contralateral (C) limbs before (B) and after (A) mobilization. Data are mean±SE. S indicates systolic; D, diastolic. *$P<0.01$ vs control; §$P<0.05$ vs before rehabilitation.

As shown in Figure 2, systolic blood pressure, diastolic blood pressure, and heart rate were not modified after 45 days of rehabilitation of the healed limb, which showed a slight and not significant increase in radial artery diameter. Radial artery distensibility, however, increased significantly, and the difference in the distensibility index from the value seen immediately after removal of the plaster was statistically significant, which was also the case for the isobaric distensibility index. The rehabilitation period did not modify radial artery diameter and distensibility in the contralateral limb, for which the distensibility index value remained slightly greater than that of the healed limb even after rehabilitation.

The forearm circumference in the healed limb was 24.0±2.1 cm before and 26.1±2.0 cm after rehabilitation ($P<0.05$). The corresponding values in the contralateral limb were 26.5±1.8 and 26.3±1.9 cm.

Discussion

Several studies have shown that exercise training is accompanied by an increase in arterial distensibility.[10–14] The present study, however, offers the first demonstration that the effect of exercise on arterial mechanical properties is not limited to that obtained by an increase in the exercise level but is already evident and marked for an ordinary level of physical activity. That is, that when arterial distensibility is quantified in a limb first after prolonged immobilization and then after physical rehabilitation, its value is much greater in the latter compared with the former condition. Physical activity should thus be regarded as a mechanism involved in the determination of arterial mechanical function in all subjects, its role coexisting with other mechanisms involved in the tonic modulation of these functions, eg, sympathetic nerve activity.[4,21,23,25–27] Our study does not clarify the mechanisms responsible for the effect of an ordinary level of physical activity on arterial distensibility. We can speculate, however, that both structural and functional factors are involved. Structural factors may reflect the fact that immobilization may lead to a reduction of the more distensible components of the wall tissues (eg, smooth muscle and elastin) to a greater extent than a reduction in the stiffer components (eg, collagen).[28,29] Functional factors may reflect the fact that immobilization leads to a local increase in sympathetic tone, given the evidence that sympathetic tone reduces radial artery distensibility, probably via contraction of smooth muscle in the arterial wall.[3,4,20,21,25] They may also reflect the

fact that immobilization may be accompanied by a reduction in limb blood flow (as indirectly suggested by the reduced forearm circumference after immobilization) and thus in the shear stress–determined endothelial secretion of substances (eg, nitric oxide) that relax vascular smooth muscle and make it more distensible than in the contracted state.[30–33] Unfortunately, the structural hypothesis cannot be tested because of the need for a bioptic and thus invasive approach. The functional hypothesis, on the other hand, can be tested by examining whether a difference in arterial distensibility disappears in the period immediately after prolonged ischemia (ie, when smooth muscle tone in the arterial wall is completely abolished).[20,22,34] This was not possible in our subjects, however, because of the difficulty of performing these maneuvers immediately after removal of the plaster when effective skeletal muscle contraction and limb extension were impaired.

Our findings that an ordinary level of physical activity already exerts a positive influence on arterial distensibility has pathophysiological implications. We can speculate that sedentariness should be regarded as an unfavorable condition as far as large artery function is concerned, given the adverse consequences (increased cardiac work, greater reflection of pulse waves, greater central blood pressure, greater trauma to the vessel wall) that increased artery stiffness has on the cardiovascular system.[35] We can also speculate that these consequences may develop in cardiovascular diseases, which are accompanied and characterized by a reduced level of physical activity, although the neurohumoral situation is different and complex; one of these could be congestive heart failure, in which radial artery distensibility has indeed been shown to be reduced.[21,23,26,36]

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