Effect of Age and Coronary Artery Disease on the Postural Adjustment of Peripheral Circulation

By ERNST SIMONSON, M.D.

Circulatory regulation tends to minimize gravitational effects of postural changes. The changes of the extracranial volume pulse, recorded by means of an impedance plethysmograph, in tilted head-up and head-down position, are significantly greater in older than in younger men, indicating impairment of circulatory postural regulation with age. Surprisingly enough, this impairment is partially compensated in coronary patients, possibly due to hyperactive carotid sinus reflexes.

CARDIOVASCULAR regulation in response to postural change which is, perhaps, the most common physiologic stress situation is one of the important mechanisms for environmental adjustment. The stress situation is dramatized in fainting in upright position, but significant changes of blood pressure, pulse rate, cardiac stroke volume and the electrocardiogram occur also in non-fainters as documented by a large literature, and functional orthostatic tests are widely used, particularly in Europe (Schellong,11 Hochrein,2 Knipping et al.,3 Holzmann4). It is surprising that only one study5 of age effects on postural circulatory regulation has been reported since demonstration of age trends in circulatory regulation would be important for the question of environment adjustment of older people, in normal conditions as well as in relation to cardiovascular disease.

In spite of the importance of peripheral circulation in postural changes, only a few such studies have been reported, the most notable being by Goetz,6 who also reviewed the literature. The development of impedance plethysmography provided a convenient method with the advantage that any part of the body surface is easily accessible for measurement.

We studied changes of peripheral circulation recorded from a pair of electrodes placed on forehead and occiput and from another pair placed on the foot in response to tilting upward and downward. While the head down position is a less common stress situation and rarely used in cardiovascular research, it is, from the point of circulatory adaptation, as interesting as the responses to upright position.

The circulatory changes of foot circulation during tilting were, as expected, opposite in direction to those of cranial circulation, but much smaller. We limit the presentation to the cranial circulation.

METHOD

In the impedance plethysmograph developed by Dr. O. H. Schmitt, the variation of the base line corresponding to the blood content is electronically eliminated, which is, in principle, similar to the base line stabilization in modern electrocardiographs. The tracing therefore represents an inertia-free recording of a peripheral volume pulse. The impedance plethysmograph is not sensitive to pressure changes. This is an indirect method. The calibration, in terms of units of resistance (deflection to an input of 1/100 Ohm), cannot be readily converted into units of peripheral blood flow; however, relative changes of blood flow recorded in the same individual from the same position of electrodes are accurately reflected. Changes of peripheral blood flow are associated with changes of the pulse contour and are accessible to measurement and statistical evaluation.7

Due to the high electric resistance of the bony skull, the pulse tracing represents essentially extracranial circulation, although some contamination with intracranial circulation cannot be excluded.

We evaluated the changes of amplitude and crest time in tilted-up and tilted-down position, with reference to the control pulse tracing in su-
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**TABLE 1.—Relative Changes of Pulse Amplitude and Absolute Changes of Peak Time in Response to Tilting-Up and Tilting-Down in 26 Young Men, 26 Older Men and 18 Patients with Coronary Artery Disease.**

<table>
<thead>
<tr>
<th>Amplitude group</th>
<th>Supine</th>
<th>Tilting 45 degrees up</th>
<th>Tilting 15 degrees down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young X = 26</td>
<td>X 100</td>
<td>96.05</td>
<td>90.42†</td>
</tr>
<tr>
<td></td>
<td>SD 0</td>
<td>20.04</td>
<td>19.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23.32</td>
<td>23.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27.66</td>
<td>33.46</td>
</tr>
<tr>
<td>Old X = 26</td>
<td>X 100</td>
<td>86.09†</td>
<td>77.07§</td>
</tr>
<tr>
<td></td>
<td>SD 0</td>
<td>20.09</td>
<td>27.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24.47</td>
<td>42.75</td>
</tr>
<tr>
<td>Cor. patients X = 18</td>
<td>X 100</td>
<td>97.11</td>
<td>101.93</td>
</tr>
<tr>
<td></td>
<td>SD 0</td>
<td>20.00</td>
<td>21.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>44.44</td>
<td>33.15</td>
</tr>
<tr>
<td>Young vs. old Xo - Xo</td>
<td>9.15</td>
<td>13.35†</td>
<td>12.38</td>
</tr>
<tr>
<td>Coronaries vs. old Xo - Xc</td>
<td>10.21</td>
<td>24.36§</td>
<td>22.40‡</td>
</tr>
</tbody>
</table>

**Peak time**

<table>
<thead>
<tr>
<th>Young</th>
<th>X .124</th>
<th>.116</th>
<th>.114</th>
<th>.118</th>
<th>Xo-Xo</th>
<th>.204§</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SD .042</td>
<td>.021</td>
<td>.018</td>
<td>.019</td>
<td></td>
<td>.068</td>
</tr>
<tr>
<td>Older</td>
<td>X .299</td>
<td>.249</td>
<td>.221§</td>
<td>.220§</td>
<td></td>
<td>.293</td>
</tr>
<tr>
<td></td>
<td>SD .079</td>
<td>.081</td>
<td>.077</td>
<td>.071</td>
<td></td>
<td>.051</td>
</tr>
<tr>
<td>Cor. patients</td>
<td>X .234</td>
<td>.173§</td>
<td>.192†</td>
<td>.201</td>
<td></td>
<td>.269</td>
</tr>
<tr>
<td></td>
<td>SD .071</td>
<td>.057</td>
<td>.054</td>
<td>.050</td>
<td></td>
<td>.059</td>
</tr>
<tr>
<td>Old vs. young Xo - Xo</td>
<td>1.33§</td>
<td>.107§</td>
<td>.108§</td>
<td></td>
<td>.089§</td>
<td></td>
</tr>
<tr>
<td>Old vs. coronaries Xo - Xc</td>
<td>.076§</td>
<td>.029</td>
<td>.025</td>
<td>.024</td>
<td>.014</td>
<td></td>
</tr>
</tbody>
</table>

*X, mean; SD, standard deviation.
†p = 0.05.
§p = 0.01.
‡p = 0.001.

Pine position. Amplitude changes are expressed in per cent of the amplitude in the control tracing; the crest time is given in absolute values (sec).

Subjects were placed on the tilting table after the electrodes were put on forehead and occiput. Flexible lead electrodes with a surface of about 1 square inch were moulded to the individual shape of the skull in order to secure firm contact and held in place by means of a rubber band. After the first record in the supine position, the subject was tilted up to 45° for 5 min. Records were taken immediately after tilting ("0"), and after 1, 2 and 5 min. Subsequently, the tilting table was tilted down to supine position and after several minutes of rest another control record was taken, followed by tilting head down to 15° for 2 min. (prolongation of downward tilting over 2 min. or tilting of more than 15° was abandoned because of discomfort in some subjects). Records were taken immediately after tilting and at the end of 1 and 2 min. The pulse tracings were measured and statistically analyzed at the intervals stated, but the changes at the end of the first minute of tilting (up or down) contributed little to the general trend and are, therefore, omitted.

Twenty-six healthy, older men (mean age 58.1 ± 4.5) were compared with 20 younger, healthy men (mean age 25.3 ± 6.4). The older men were part of an experimental group which has been under study at this laboratory for a period of 10 years. The annual investigations include, in addition to routine medical examination, a large number of laboratory tests and state of health (absence of disease) in this group, therefore, is better assured than in most other older control groups. In the younger group, only one medical routine examination was made, but latent cardiovascular disease is much less likely in the younger than in the older group.

In addition, 18 normotensive patients with coronary artery disease (with abnormal electrocardiograms) were investigated (mean age 60.1 ± 6.8 years, practically identical with that of the older normal group).

**RESULTS**

### Amplitude Changes

**Tilting Up.** In the younger men the pulse amplitude decreased during the first 2 min. by about 10 per cent (statistically significant), but increased later so that the initial amplitude was regained again at 5 min. (table 1). In the older group the depression immedi-
ately after tilting up ("0") was greater than the maximum depression of the younger group at 2 min. (statistically highly significant). The depression of the amplitude continued to 2 min. with only slight later recovery; the depression at 5 min. was still substantially below that of the control tracing in supine position (statistically highly significant). The greater drop of the pulse amplitude of the older men as compared to that of the younger men is statistically significant, indicating an impairment of orthostatic regulation in the older group.

In the group of patients with coronary disease, after an insignificant initial drop, the amplitude increased continuously, significantly exceeding the control amplitude in supine position after 5 min. The difference of the response between the older group and the group of patients is statistically highly significant ($p < .001$). The reaction of the patients is closer to the younger than to that of the older age group.

**Tilting Down (Table 1).** The increase of pulse amplitude as compared to that in supine position is highly significant in both groups ($p < 0.01$ in the younger, $p < 0.001$ in the older group), and so is the difference of reaction between both groups. In contrast to the changes of amplitude in tilted-up position, there is no significant time trend. The greater increase of amplitude in head down position in the older group showed again an impairment of circulatory adjustment, even
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more distinct than the response to tilted-up position.

The response of the patients was between that of the two normal age groups; the difference between the older normal group and the group of coronary patients is highly significant ($p < 0.001$).

Peak Time

**Tilting Up.** In supine position, the peak time of the older normal group was significantly larger than that of the younger group, in confirmation of our earlier investigation on the toe pulse. In tilted-up position, the peak time of the younger group shortened slightly, without attaining statistical significance. In contrast, there was a pronounced, highly-significant shortening of the peak time in the older normal group, continuing to the second minute. Immediately after tilting the peak time was shortened to a greater extent in the group of patients, but lengthened later, so that at 5 min. the difference to the peak time in supine position is no longer statistically significant. The trend of the reaction is quite different between the normal older group and the group of patients.

**Tilting Down** significantly lengthened the peak time in the younger normal group, ($p < .001$), while that of the older normal group remained unchanged. The response of the group of patients is between that of the two normal age groups. Figure 1 shows typical individual records in tilted-up position, figure 2 in tilted down position, of one young man, two older men, and one patient with coronary disease. The deformation of the contour is more pronounced in the tilted down position (fig. 2), the dicrotic notch moves to the peak and becomes less pronounced. The figures illustrate the greater amplitude changes in the older men.

**DISCUSSION**

The volume pulse as recorded by the impedance plethysmographic method reflects essentially the pulsations of small arteries and arterioles, while changes of the blood content are electronically compensated. In this respect the method differs from previous plethysmographic investigations of postural effects. Goetz noticed significant changes in the mechanically transmitted plethysmogram of the toe on comparatively small postural changes, with the axis of rotation in the hip joint.

The changes of the peripheral arterial pulse suggest that the increase of volume in the foot in the erect position is due to increased arterial inflow as well as venous congestion. The circulatory adjustment will tend to reduce the changes produced by gravitational effects. In an ideal regulation the volume pulse would be kept constant and this was approached in the response of the younger men to tilted-up position. Overcompensation will produce a change in a direction opposite to that of gravitational effects, i.e. an increase of amplitude of cranial circulation in tilted-up position. Such exaggerated counter-regulation was shown in the response of the group of coronary patients to tilted-up position. The greater efficiency of circulatory regulation in the tilted-up as compared with in the tilted-down position (shown by the smaller amplitude changes), is in the expected direction. The upright position is a common stress situation and some adaptation or training effects may be assumed. In contrast, the tilted-down position represents a stress situation which is quite unusual for most individuals.

The greater postural changes of the peripheral pulse in the older group show an impairment of circulatory regulation. The results agree well with the greater drop of the systolic blood pressure of older people in 45° tilted-up position, as reported by Norris et al. Therefore, the changes of the peripheral volume pulse as recorded with our method reflect a general circulatory response to gravitational stress and not localized peripheral circulatory changes only. The postural changes of the peripheral volume pulse as well as the age differences are much more impressive than the changes of the blood pressure and probably reflect the primary circulatory disturbance.
Whether the impairment of circulatory postural regulation in older people is due to a loss of sensitivity of the carotid mechanism or a loss of peripheral vascular tone is impossible to decide at present. The difference in the response between older healthy people and coronary patients of the same age suggests that the impairment is functional rather than due to vascular degeneration. As a consequence, postural changes impose a more severe stress situation in older than in younger people, which means some impairment in the environmental adjustment. While in ordinary conditions of life the effect might, however, not be noticeable, it probably decreases the working efficiency of older people in more pronounced or prolonged postural stress situations. The impedance-plethysmographic tracings, recorded from electrodes on the scalp, essentially extracranial circulation, but there is reason to expect that the postural changes of intracranial circulation are in the same direction, though probably different in extent. Greater postural fluctuation of intracranial circulation in older people may be a contributing factor to the occurrence of cerebral accidents in case of septic changes in cerebral arteries.

In the circulatory functions studied in previous investigations (electrocardiogram, peripheral circulation, pulse wave velocity, the change in patients with coronary disease or with peripheral arteriosclerosis were in the direction of normal age trends. It was concluded that there is a continuity of age trends to the development of arteriosclerotic degeneration. The response of coronary patients to postural changes is an important exception: it is opposite in direction of the age trend, so that the reaction of the patients is more similar to that of the younger group than to that of the older group.

Perhaps in coronary patients the sensitivity of the carotid sinus may be increased. Sigler, in his study of hyper-reactive carotid sinus reflexes, suggests that "... local circulatory disturbances in the medulla or in the efferent endings of the vasomotor system in the vascular tree caused by arteriosclerosis may be the underlying factor."

**Summary**

In 26 younger and 26 older men, a volume pulse of extracranial circulation was recorded from forehead and occiput by means of impedance plethysmography in supine position, during 5 min. of 45° tilted-up position, and during 2 min. of 15° tilted-down position. Decrease of the pulse amplitude in tilted-up position and increase in tilted-down position was much greater in the older group, indicating impairment of postural circulatory adjustment with age. The changes of the peak time (decrease in tilted-up, increase in tilted-down position) were also significantly greater in the older men. The postural circulatory changes in a group of 18 patients with coronary disease were significantly different from the response of the group of healthy older men of identical mean age. Instead of the pronounced decrease, there was a slight increase of the amplitude in tilted-up position, and in tilted-down position, the increase of amplitude in coronary patients was less pronounced. It is suggested that this is due to vascular hyperactivity in the coronary patients.
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in un gruppo de 18 patientes con morbo coronari differava significativamente ab le responsa del gruppo de normal masculos con le medesme etate medie. In loco del pronunciate reduction in normales, il occurreva un leve augmento del amplitude in inclination in alto. In declination in basso, le augmento del amplitude in patientes coronari esseva minus pronunciate. Es suggerite que isto se explica per hyperactivitate vascular in le patientes coronari.

REFERENCES

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