Comparison of Intrabrachial and Finger Blood Pressure in Healthy Elderly Volunteers


This study was performed to compare continuous Finapres (FIN) and intrabrachial (IAP) blood pressure in healthy elderly volunteers. Fifteen elderly subjects (age 71 to 83) without cardiovascular disease and an intraarterial mean (range) systolic and diastolic blood pressure of 162 (122 to 195) and 73 (62 to 88) mm Hg, respectively, participated in the study. A 10-min head-up tilt, 10 min active standing, a 15-sec Valsalva, and a 5-min mental arithmetic were performed in random order. Beat-to-beat values of systolic, diastolic, and mean arterial pressure were analyzed. At rest, FIN underestimated IAP by 16.8 ± 2.6 (SE), 10.8 ± 1.5, and 17.5 ± 1.6 mm Hg for systolic, diastolic, and mean arterial blood pressure, respectively (P < .05). During head-up tilt, FIN overestimated the intraarterial systolic blood pressure response by 7.2 ± 1.6 (SE) mm Hg (P < .05). Group-averaged changes in diastolic and mean arterial IAP were followed closely by FIN. During standing, Finapres closely followed intraarterial diastolic and mean arterial pressure but the increase in systolic blood pressure was higher at the finger as compared to intrabrachial recordings, resembling the results of head-up tilt. During the Valsalva maneuver, maximal responses in systolic, diastolic, and mean arterial pressure were underestimated by FIN by 12.1 ± 3.3 (SE), 6.8 ± 2.7, and 7.1 ± 1.7 mm Hg, respectively (P < .05 for all parameters). During mental arithmetic, FIN underestimated the intraarterial systolic blood pressure response by 6.1 ± 2.7 (SE) mm Hg (P < .05), while diastolic and mean arterial pressure responses were followed correctly by FIN. It is concluded that apart from systolic blood pressure, FIN closely follows intraarterial blood pressure responses for the orthostatic maneuvers and mental arithmetic. During Valsalva, the rapid changes in blood pressure were followed in direction but not in magnitude. Am J Hypertens 1995;8:237–248

KEY WORDS: Finapres, intraarterial pressure, healthy elderly, head-up tilt, standing, Valsalva, mental arithmetic.
ger based on the volume clamp method of Peñáz and the physiocal criteria of Wesseling.4-6 The Finapres device has been shown to provide a useful alternative to continuous IAP measurement in laboratory testing.7-9 However, the pressure transmission between brachial and finger artery, and thus the difference in pressure between the two sites, can be modified by changes in the properties of the vasculature in forearm and hand. Conditions which might change these properties are: hypertension,10,11 old age,11,12 vascular disease,13 vasoconstriction,14-16 cannulation of the radial artery,17 and the use of β-adrenoceptor blocking agents.11 Recently it has been shown that both accuracy and precision of the Finapres device are reduced when a combination of the above-mentioned factors are present.18 However, up to now the accuracy and precision of the Finapres device in healthy elderly clients remains unknown. Therefore, the present study was designed to investigate whether Finapres blood pressure recordings could be a substitute for invasive recordings in the assessment of circulatory responses to standing, head-up tilt, Valsalva maneuver, and mental arithmetic in healthy elderly subjects.

METHODS

Subjects From a group of 87 elderly subjects who had responded to a newspaper announcement, to participate in this study informed consent was obtained in 17 persons between 71 and 83 years of age. One subject gave consent on the condition of being exempted from the mental arithmetic test. A medical history, physical examination, electrocardiography, and a qualitative measurement of urinary glucose were performed to exclude the existence of cardiovascular disease (vascular or cardiac bruit, absent peripheral pulsations, electrocardiographic abnormalities) and diabetes mellitus. One subject was excluded because of an abdominal bruit. Subjects with mild isolated systolic hypertension (systolic blood pressure between 160 and 200 mm Hg, diastolic blood pressure below 90 mm Hg) were not excluded. No subject used cardiovascular medication. No subject had left to right differences of more than 5 mm Hg for either systolic or diastolic blood pressures, as determined by four Riva Rocci Korotkoff (RRK) measurements performed on both arms simultaneously by two observers. In one subject, the brachial artery was cannulated but we failed to obtain a reliable and continuous intraarterial blood pressure signal. Therefore, it was decided to stop the experiment. The clinical characteristics of the remaining 15 subjects are listed in Table 1. The protocol was reviewed and approved by the ethics committees of both participating centers.

Measurements All measurements were performed in a temperature-controlled room at 22 to 23°C. Intraarterial pressure (IAP) was measured in the brachial artery of the nondominant arm. After local anaesthesia with a 2% prilocaine hydrochloride solution (Citanest, Astra Pharmaceutica, Rijswijk, The Netherlands), a 20-gauge Teflon catheter (Deseret Medical, Inc. Becton Dickson and Company, Sandy, UT) was inserted and connected with a 180-cm rigid pressure line to a disposable transducer with an integral flush device (Viggo-Spectramed, Bilthoven, The Netherlands). The natural frequencies and damping coefficients of the fluid-filled systems, as measured with the application of a square pressure wave of 100 mm Hg, were 22.8 ± 3.4 (SD) Hz and 0.36 ± 0.16 (SD), respectively. During the experiment, the dynamic characteristics were checked repeatedly with the intraarterial cannula in situ, using the flushing method.19 After the experiments, the intraarterial pressure transducer was calibrated against Finapres, with catheter and flush in situ, to correct for any possible pressure gradient along the catheter-manometer system. Finapres measurements were performed using a Finapres model 5, developed by the Netherlands Organisation for Applied Research (TNO). Cuffs of appropriate size were applied to digit 2 or 3 of the dominant hand.

In the Finapres device, a built-in expert system (Physiocal) was in operation to establish and adjust a proper volume clamp setpoint,5,6 except during the Valsalva maneuver, because the brief interruptions of the blood pressure recording could otherwise mask the very fast blood pressure changes during this procedure. In all subjects, Finapres recordings were started at least 5 min before the start of baseline registrations to stabilize the Finapres registration. In four subjects the finger cuff had to be reapplied between the procedures because of an improper Finapres signal. In one subject, Finapres automatically restarted between two procedures. The Finapres cuff and the intraarterial transducer were kept at the right atrial level during all the maneuvers with a sticker applied on the midaxillary line at the level of the fourth intercostal space as a reference. During the experiments the proper position of the finger was repeatedly checked. Both blood pressure signals were recorded on a four-channel tape recorder (Hewlett Packard, 3964 A FM, CA), together with an event marker.

To assess differences in blood pressure between the two fingers, two Finapres devices were applied at random to a similar finger of the left and right hand before intraarterial cannulation was performed. A 5-min simultaneous registration was performed in the supine position. The maneuvers were performed in random order after at least 10 min of supine rest for
TABLE 1. DEMOGRAPHIC DATA AND SUPINE FIN-IAP BLOOD PRESSURE DIFFERENCES DURING REST

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>SBP (mm Hg)</th>
<th>DBP (mm Hg)</th>
<th>MAP (mm Hg)</th>
<th>FIN-IAP (SBP)</th>
<th>RIN-IAP (DBP)</th>
<th>FIN-IAP (MAP)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73</td>
<td>M</td>
<td>173</td>
<td>93.2</td>
<td>134.3</td>
<td>67.4</td>
<td>93.9</td>
<td>-29.3</td>
<td>-17.9</td>
<td>-25.7</td>
<td>No head-up tilt</td>
</tr>
<tr>
<td>2</td>
<td>83</td>
<td>M</td>
<td>167.5</td>
<td>76</td>
<td>158.0</td>
<td>72.9</td>
<td>105.3</td>
<td>-17.1</td>
<td>-14.1</td>
<td>-17.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>75</td>
<td>F</td>
<td>162.5</td>
<td>63.6</td>
<td>168.8</td>
<td>77.4</td>
<td>111.8</td>
<td>-29.2</td>
<td>-16.8</td>
<td>-23.5</td>
<td>Mental arithmetic excluded</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>F</td>
<td>157</td>
<td>56</td>
<td>158.5</td>
<td>65.3</td>
<td>106.3</td>
<td>2.4</td>
<td>-6.6</td>
<td>-11.7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>73</td>
<td>M</td>
<td>165</td>
<td>55.1</td>
<td>171.7</td>
<td>71.0</td>
<td>108.6</td>
<td>-11.3</td>
<td>-5.3</td>
<td>-14.1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>82</td>
<td>M</td>
<td>175</td>
<td>81</td>
<td>135.9</td>
<td>67.8</td>
<td>93.8</td>
<td>-20.0</td>
<td>-13.7</td>
<td>-18.3</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>73</td>
<td>F</td>
<td>155</td>
<td>60.2</td>
<td>171.7</td>
<td>69.7</td>
<td>111.9</td>
<td>-26.3</td>
<td>-9.2</td>
<td>-21.2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>77</td>
<td>F</td>
<td>161.5</td>
<td>64.5</td>
<td>172.3</td>
<td>75.0</td>
<td>118.5</td>
<td>-7.3</td>
<td>-3.7</td>
<td>-13.3</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>73</td>
<td>F</td>
<td>161</td>
<td>61.9</td>
<td>167.7</td>
<td>68.5</td>
<td>108.4</td>
<td>-8.6</td>
<td>-4.7</td>
<td>-10.6</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>71</td>
<td>M</td>
<td>184.5</td>
<td>78.1</td>
<td>121.5</td>
<td>64.5</td>
<td>85.5</td>
<td>-12.3</td>
<td>-9.2</td>
<td>-12.6</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>74</td>
<td>F</td>
<td>156</td>
<td>52.5</td>
<td>135.2</td>
<td>61.8</td>
<td>90.1</td>
<td>-13.7</td>
<td>-0.2</td>
<td>-7.7</td>
<td>Valsalva and standing excluded</td>
</tr>
<tr>
<td>12</td>
<td>81</td>
<td>M</td>
<td>162.5</td>
<td>73.2</td>
<td>165.6</td>
<td>78.1</td>
<td>110.3</td>
<td>-6.3</td>
<td>-12.4</td>
<td>-15.8</td>
<td>Refused to calculate</td>
</tr>
</tbody>
</table>

Mean (SE) (1.0) (M/F) (2.9) (3.5) (5.6) (2.0) (3.4) (2.6)* (1.5)* (1.6)*

All individual blood pressures are the mean of three supine intraarterial 1 min baseline values. SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial blood pressure; FIN-IAP, difference between supine Finapres and intrabrachial blood pressure. * indicates significant difference from zero (P < .05; paired Student t test). During tilt and standing maneuvers, the Finapres cuff and the intraarterial transducer were kept at the right atrial level with a sticker applied on the midaxillary line at the level of the fourth intercostal space as a reference.

Maneuvers The head-up tilt to 60° was performed in 15 sec using an automatic tilt table and sustained for 10 minutes. In one subject, head-up tilt was not performed due to a technical failure. Active standing was performed within 20 sec and sustained for 10 min. The mental arithmetic was performed in the supine position. Subjects performed a 5-min countdown from 4000 in steps of 17. The Valsalva maneuver was performed in the sitting position. Via suitable tubing, a mouthpiece was connected to a manometer and the subjects were instructed to maintain an expiratory pressure of 40 mm Hg during 15 sec. The plastic tube contained a small hole to prevent the subjects from maintaining manometer pressure by closing the glottis.

Data Analysis Extrasystoles, as well as parts of tracings with unstable Finapres signals, were eliminated. An unstable Finapres signal was characterized by frequent physiocras or oscillations resulting in loss of a typical pulsewave. Ultimately, 97.5 ± 3.6 (SD), 97.2 ± 5.1, 97.8 ± 3.7, and 90.7 ± 17.2% of the occurring pulsewaves were included in the analysis for head-up tilt, active standing, Valsalva, and mental arithmetic, respectively. In one subject, the Finapres signal was unstable during the whole mental arithmetic, resulting in exclusion of that registration from further analysis. The registrations of the Valsalva and standing maneuvers of one patient were excluded because of an unstable intraarterial signal. The elderly subjects were not able to stand without using their dominant hand, resulting in height differences between intraarterial transducer, finger cuff, and the heart. For this reason, the first 30 sec of all standing maneuvers were excluded from analysis.

Both signals were A/D converted at a sampling rate of 100 Hz. A beat-to-beat analysis was performed by a signal analysis program to determine systolic blood pressure, diastolic blood pressure, mean arterial pressure, and the FIN-IAP differences of these parameters. The mean of every measured variable over 1 min just before starting a maneuver was defined as baseline. For each subject, baseline values of head-up tilt, standing, and mental arithmetic were averaged to assess baseline differences between Finapres and intraarterial blood pressure in supine rest. After starting a maneuver, the means of consecutive periods of 3 (during the first minute) or 10 (during minutes 2 to
10) sec were calculated. Differences with the baseline values were calculated. The response provided in the FIN-IAP difference detects possible systematic deviations during a maneuver and should ideally be zero at all times.

**Statistics** Beat-to-beat differences with baseline were averaged for subsequent periods. For the two orthostatic maneuvers three periods were chosen: the first 30 sec (excluded for active standing), 60 to 120 sec, and the last 5 min. These selections were based on previous observations and appeared to be useful to describe the hemodynamic responses (see Figures 2, 4, and 8). For the mental arithmetic, the last 2 min were selected as a single period. Since blood pressure changed rapidly during the Valsalva (Figure 6), 3-sec periods of group-averaged peak changes in blood pressure were selected for this maneuver to compare with baseline.

Apart from this quantitative analysis, qualitative resemblance between the two methods was also evaluated. For this purpose, for head-up tilt, active standing, and mental arithmetic, the directions of the individual blood pressure responses were compared between intraarterial and Finapres blood pressure. An increase or decrease in blood pressure was defined as blood pressure increase or reduction of >5 mm Hg. The number of subjects in which Finapres and intraarterial blood pressure both increased, decreased, or remained constant (so-called “congruent responses”) was counted.

The paired Student t test was used for statistical inference and P < .05 was taken as the level of significance. The abbreviation NS is used when differences were not significant. Unless indicated otherwise, blood pressure responses are expressed as mean ± standard error.

**RESULTS**

**Supine Rest** The group-averaged left-right difference (± SD) as measured simultaneously by two Finapres devices was 4.1 ± 9.6, 1.7 ± 9.1, and 1.3 ± 8.4 mm Hg for systolic, diastolic and mean arterial pressure, respectively (NS). Resting values of intraarterial blood pressures, Finapres blood pressures, and the FIN-IAP differences are shown in Table 1. Finapres significantly underestimated intraarterial systolic blood pressure by 16.8 ± 2.6 mm Hg (P < .001), diastolic blood pressure by 10.8 ± 1.5 mm Hg (P < .001), and mean arterial pressure by 17.5 ± 1.6 mm Hg (P < .001).

**Head-up Tilt** Figure 1 shows the individual tracings of intrabrachial and finger blood pressure for subject 15 (left panel) and subject 10 (right panel), representing the worst and the best Finapres recordings, respectively. In both subjects, diastolic blood pressure fluctuations were remarkably similar for both measurement sites. However, in subject 15 intrabrachial systolic blood pressure fluctuations were less reliably reflected at the finger.

The group-averaged time-course of the responses in intrabrachial blood pressure, Finapres blood pressure, and the FIN-IAP difference during head-up tilt are shown in Figure 2. During the first 30 sec, intrabrachial systolic blood pressure decreased by 3.5 ± 1.2 mm Hg (P < .05). During the second minute and the last 5 min of head-up tilt, intrabrachial systolic blood pressure stabilized at baseline levels. During the first 30 sec of head-up tilt, the systolic FIN-IAP difference was not significantly affected (−2.1 ± 2.5 mm Hg; NS). Thereafter, the FIN-IAP difference gradually increased, resulting in an overestimation of the systolic blood pressure response of 2.9 ± 2.1 (NS) and 7.2 ± 1.6 mm Hg (P < .05) for the second minute.
and last 5 min of head-up tilt, respectively. Intrabrachial diastolic blood pressure gradually increased by 0.9 ± 0.7 (NS), 7.6 ± 1.6 (P < .05), and 8.2 ± 1.3 (P < .05) mm Hg for the three successive periods, respectively. Except for a small FIN-IAP response of -2.5 ± 1.0 mm Hg (P < .05) during the first 30 sec of head-up tilt, accompanied by a reduction of diastolic blood pressure as measured at the finger of 1.6 ± 1.0 mm Hg (NS), the diastolic FIN-IAP difference was not significantly affected by head-up tilt. During the first 30 sec, intrabrachial mean arterial pressure tended to decrease by 2.0 ± 0.9 mm Hg (P = .06). This reduction in mean arterial pressure was more pronounced at the finger and amounted 4.8 ± 1.7 mm Hg (P < .05; FIN-IAP response: -2.8 ± 1.3 mm Hg; P < .05). Thereafter, intrabrachial mean arterial pressure stabilized at baseline levels. During the second minute, mean arterial blood pressure responses were similar at both measurement sites. During the last 5 min, however, mean arterial pressure increased at the finger by 6.6 ± 1.5 mm Hg (P < .05) and significantly differed from the intrabrachial response (FIN-IAP response: 4.4 ± 1.4 mm Hg; P < .05).

Table 2 shows the number of subjects with congruent Finapres and intraarterial responses as averaged for each period. Apart from systolic blood pressure, in most subjects Finapres revealed similarly directed responses, as compared with intraarterial recordings.

**Active Standing** In the left panel of Figure 3, the tracings of subject 7 are depicted, representing the worst Finapres registration. The fluctuations in both systolic and diastolic finger pressure are remarkable. In the right panel of Figure 3 the tracings of subject 4 are shown, representing the best case. Finger systolic pressure still fluctuates more than its intrabrachial counterpart, but changes in diastolic pressure were followed closely by the Finapres device. The averaged time-course of the responses in intraarterial blood pressure, Finapres blood pressure, and the FIN-IAP difference during active standing are shown in Figure 4. As stated in the Methods section, the first 30 sec of active standing were excluded from the analysis. On average, intrabrachial systolic, diastolic, and mean arterial blood pressure increased from baseline by 14.9 ± 3.1, 14.8 ± 1.8, and 13.0 ± 2.3 mm Hg, respectively, during the last 5 min (P < .05 for all three parameters). The systolic FIN-IAP difference in-

<table>
<thead>
<tr>
<th>TABLE 2. NUMBER OF SUBJECTS WITH SIMILARLY DIRECTED (CONGRUENT) INTRAARTERIAL AND FINAPRES BLOOD PRESSURE RESPONSES TO ORTHOSTASIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-up tilt (n = 14)</td>
</tr>
<tr>
<td>SBP</td>
</tr>
<tr>
<td>DBP</td>
</tr>
<tr>
<td>MAP</td>
</tr>
<tr>
<td>Standing (n = 14)</td>
</tr>
<tr>
<td>SBP</td>
</tr>
<tr>
<td>DBP</td>
</tr>
<tr>
<td>MAP</td>
</tr>
</tbody>
</table>

*Abbreviations as in Table 1.*
creased significantly during the last 5 min by $5.4 \pm 2.2$ mm Hg ($P < .05$ v baseline). Diastolic and mean arterial pressure responses did not significantly differ between intraarterial recordings and Finapres. Table 2 shows the number of subjects with congruent responses to active standing. Apart from systolic blood pressure, in almost all subjects Finapres revealed similarly directed responses as compared with intraarterial recordings.

Valsalva Maneuver Figure 5 shows the individual tracings of intrabrachial and finger blood pressure during the Valsalva maneuver for subject 7 (worst case, left panel) and subject 2 (best case, right panel). In subject 7, the intrabrachial systolic recovery at 20 to 25 sec after starting the maneuver was not observed at the finger. In all other subjects, the tracings resembled those observed in subject 2, revealing a remarkable resemblance between Finapres and intraarterial blood pressure fluctuations. The courses of the group-averaged responses in intraarterial blood pressure, Finapres blood pressure, and the Fin-IAP difference during the Valsalva maneuver are shown in Figure 6. During the Valsalva maneuver, intrabrachial pressure changes fluctuated from $-37.9 \pm 4.9$ to $27.1 \pm 4.5$, from $-5.6 \pm 1.0$ to $26.6 \pm 2.8$ and from $-17.2 \pm 3.6$ to $19.7 \pm 2.6$ mm Hg for systolic, diastolic, and mean arterial pressure, respectively ($n = 14$, $P < .05$ v baseline for all parameters). These changes were underestimated by Finapres by $8.1 \pm \ldots$
2.5 and 12.1 ± 3.3 for systolic blood pressure, 1.1 ± 1.0 and 6.8 ± 2.7 for diastolic blood pressure, and 2.2 ± 1.1 and 7.1 ± 1.7 mm Hg for mean arterial pressure at the moment of maximal decrease and increase in blood pressure, respectively (P < .05 for maximum increase and decrease in systolic blood pressure, P < .05 at moment of maximum increase in diastolic blood pressure, and P < .05 at moment of maximum increase in mean arterial pressure).

**Mental Arithmetic** In the left panel of Figure 7, the tracings of subject 9 are depicted, representing the worst Finapres registration. Apart from the frequent extrasystoles during the second minute of mental arithmetic, 30 sec after starting the stress test a considerable drop in pulse pressure was observed at the finger but not in the brachial artery. The right panel shows the tracings of subject 1, representing one of the best Finapres recordings. Almost any change in intrabrachial blood pressure can be seen at the finger. The time-course of the group-averaged blood pressure responses during the mental arithmetic are shown in Figure 8. The intraarterial systolic, diastolic, and mean arterial pressure gradually increased by 18.0 ± 2.9, 9.5 ± 1.2, and 14.1 ± 2.1 mm Hg, respectively (P < .001 for all parameters). Finapres underestimated the intraarterial systolic blood pressure response by 6.1 ± 2.7 mm Hg (P < .05). Neither dia-
Systolic and Diastolic Blood Pressure  Finapres underestimates both the systolic and diastolic blood pressure in this group, for systolic blood pressure by 16.8 (SD, 10.3) mm Hg and for diastolic blood pressure by 10.8 (SD, 5.9) mm Hg. It has been shown that in the same group of subjects, the RRK technique underestimates systolic blood pressure but overestimates diastolic blood pressure by 6.3 (SD, 4.3) mm Hg and 3.4 (SD, 4.3) mm Hg, respectively.23 Thus, intraarterial blood pressure was underestimated.
more by Finapres than by the RRK method. This is especially the case for systolic blood pressure, a parameter that is of importance in the elderly since isolated systolic hypertension has been associated with an increased risk for cardiovascular morbidity in this age group. Therefore, Finapres should not be used to determine absolute blood pressure levels in the elderly. In the large epidemiologic studies, the RRK method has been used to define cut-off points for treatment of hypertension. Therefore, the RRK method is recommended to determine absolute blood pressure levels in the elderly.

Responses to Hemodynamic Stress The continuous noninvasive measurement of blood pressure responses to orthostatic stress, Valsalva strain, or mental arithmetic can only be carried out with Finapres. Does the Finapres measurement produce a reasonably accurate image of true intraarterial responses? This depends on the setting in which the Finapres device is used. In a clinical setting, qualitative aspects of the responses are probably of more importance, while in physiologic research quantitative aspects are of more interest. Both aspects will be discussed.

Response to the Orthostatic Stress of Head-Up Tilt
The group-averaged intraarterial responses to head-up tilt in our study are: no change in systolic blood pressure and increases of approximately 9 mm Hg in diastolic and 3 mm Hg in mean arterial pressure. Systolic and, to a minor degree, also mean arterial pressure responses are overestimated by Finapres. In (patho)physiologic research, these differences between intraarterial and Finapres responses can be confusing, especially for systolic blood pressure. However, in a clinical setting these small differences are less important and the qualitative resemblance between both methods is of more relevance. Apart from systolic blood pressure, Finapres can still be used to detect a pathologic blood pressure response to head-up tilt in patients over 70 years of age.

Responses to the Orthostatic Stress of Standing
Standing causes larger blood pressure increments than head-up tilt. With errors the same and responses larger during standing as compared with head-up tilt, the relative differences between both waveforms are smaller for standing. Therefore, blood pressure responses are more reliably recorded by Finapres during standing than during head-up tilt and can be used in (patho)physiologic research on blood pressure responses to standing in this age group. Apart from systolic blood pressure, the direction of the blood pressure response was equal for both methods in most subjects. Therefore, Finapres is a useful device in the clinical setting to detect a pathologic blood pressure response to standing in the aged.

Responses to the Valsalva Maneuver
The blood pressure responses to Valsalva strain measured in the brachial artery and the finger are each others' counterpart. Each detail in one response can be observed in the other. Although this is clinically important, on closer inspection finger pressure response seems somewhat damped with respect to intraarterial values, resulting in a 20% underestimation of blood pressure responses. As we did not include a group of young subjects, we cannot definitely conclude that the findings in these elderly subjects are related to age. However, in a previous study it has been shown that the fast fluctuations in blood pressure during a Valsalva maneuver are not underestimated in a group of young subjects. This discrepancy suggests that the quantitative difference between intraarterial and Finapres measurement of blood pressure responses to Valsalva, as found in the present study, is caused by age-related changes in the cardiovascular system. In a clinical setting, these quantitative differences are of minor importance, especially when age-controlled reference values are obtained with Finapres.

Responses to Mental Arithmetic During mental arithmetic all three blood pressure parameters increased substantially. Intrabrachial responses in diastolic and mean arterial pressure were well followed by Finapres, both quantitatively and qualitatively. Although the directions of systolic blood pressure responses were the same for both methods in most subjects, the systolic responses appeared somewhat damped in the finger, resulting in a quantitative underestimation of the systolic blood pressure response. Although clinically not relevant, this small underestimation might result in misunderstanding when the Finapres device is used in physiologic research.

To conclude apart from systolic blood pressure, blood pressure responses to various stressors in elderly subjects are qualitatively comparable when measured intraarterially and with Finapres. Thus, in a clinical setting the device is useful to detect a qualitatively abnormal cardiovascular reflex control in patients over the age of 70 years. Quantitatively, small differences between intrabrachial and Finapres blood pressure responses can occur, especially when blood pressure fluctuates substantially within a short period of time. These quantitative differences were most pronounced for systolic blood pressure responses.

Causes of Finger to Brachial Pressure Differences
The intraarterial blood pressure measurement was performed in the brachial artery because this site most closely resembles the measurement site of noninvasive blood pressure measurement techniques. The possibility of comparing the present results with data obtained by others in healthy young subjects
<table>
<thead>
<tr>
<th>Study</th>
<th>Systolic Blood Pressure</th>
<th>Mean Arterial Blood Pressure</th>
<th>Diastolic Blood Pressure</th>
<th>n</th>
<th>Age</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kurki et al (1987)</td>
<td>-4.8 ± 8.7</td>
<td>0.3 ± 7.6</td>
<td>1.5 ± 5.8</td>
<td>50</td>
<td>24–83</td>
<td>Vascular disease included; IA measurement site: radial artery</td>
</tr>
<tr>
<td>Imholz et al (1990)</td>
<td>1.9 ± 10.6</td>
<td>-3.7 ± 8.3</td>
<td>-3.2 ± 7.2</td>
<td>11</td>
<td>22–40</td>
<td>Healthy; IA measurement site: brachial artery</td>
</tr>
<tr>
<td>Imholz et al (1988)</td>
<td>-1 ± 9.6</td>
<td>-9 ± 6.8</td>
<td>-4 ± 6.1</td>
<td>15</td>
<td>25–61</td>
<td>Hypertension; IA measurement site: brachial artery</td>
</tr>
<tr>
<td>Parati et al (1989)</td>
<td>1.2 ± 5.4</td>
<td>2.9 ± 5</td>
<td></td>
<td>24</td>
<td>25–64</td>
<td>Hypertension included; IA measurement site: radial artery</td>
</tr>
<tr>
<td>Molhoek et al (1984)</td>
<td>-6 ± 11</td>
<td>-6 ± 6</td>
<td></td>
<td>21</td>
<td>18–78</td>
<td>Hypertension included; IA measurement site: radial artery</td>
</tr>
<tr>
<td>Bos et al (1992)</td>
<td>-15.7 ± 5.8</td>
<td>-20.2 ± 3.6</td>
<td>-13.5 ± 3.6</td>
<td>12</td>
<td>52–79</td>
<td>Hypertension, cardiovascular medication, cardiovascular disease</td>
</tr>
<tr>
<td>This study</td>
<td>-16.8 ± 10.3</td>
<td>-17.4 ± 6.2</td>
<td>-10.8 ± 5.9</td>
<td>15</td>
<td>71–83</td>
<td>Healthy; IA measurement site: brachial artery</td>
</tr>
</tbody>
</table>

IAP, intraarterial.

(Table 3) formed a second reason to measure intraarterial pressure in the brachial artery. Intraarterial and Finapres blood pressure were not measured at the same arm, to exclude possible effects of intraarterial cannulation on the blood pressure measured in the finger. A possible error induced by blood pressure differences between the left and right arm is negligible because left-right differences, assessed by simultaneous auscultatory measurements, were less than 5 mm Hg in all subjects. Furthermore, simultaneous registration of finger pressure did not show a significant left-right difference. Thus, left-right differences cannot explain the difference between intraarterial and finger pressure.

Differences between intraarterial and Finapres blood pressure can result from an inaccurate reflection of finger blood pressure by the Finapres device or from a real difference in blood pressure between the brachial and finger arteries. We cannot exclude the possibility that Finapres inaccurately reflected actual digital blood pressure in this group of aged subjects. Since we did not measure blood pressure in the digital artery directly, we will restrict our further discussion to a (patho)physiologic explanation of the differences found between Finapres and intrabrachial pressure.

The intraarterial measurement site was more proximal than the Finapres measurement site. On its way to the periphery, the shape of the arterial pulsewave can be changed by amplification, and by the pressure gradient along the arterial tree. The arteriolar reflection, which mainly affects the systolic pressure, increases with increasing vasoconstriction, whereas it decreases with vasodilation. The reflected wave is superimposed on the forward travelling wave, and will thus add to the systolic pressure when the incoming wave is still in its systolic phase at a given measurement site. When the pulse wave velocity is high, the reflected wave travels back at a high speed, and will increase the systolic pressure at more...
centrally located measurement sites. Thus, increases in pulsewave velocity, as in hypertension or old age, lead to a reduction of pulsewave amplification, and smaller systolic pressure differences between central and peripheral measurement sites.

The pressure gradient along the vascular tree causes the finger pressure to be below the mean radial or brachial pressure. From Poiseuille’s equation it can be derived that this pressure gradient is greater when the flow increases or when the diameter of the arterial segment between the two measurement sites decreases. The decrease in arterial diameter might be expected to cause the lower finger pressure that has been observed in patients with vascular disease, with vasoconstriction due to cannulation of the radial artery, and in those using ß-adrenoceptor blocking agents. The above-mentioned factors that determine differences between brachial and finger blood pressure can be applied to explain the differences between intrabrachial and Finapres blood pressure observed in this study.

During supine rest, all Finapres blood pressure parameters were considerably lower than the corresponding intraarterial parameters, differing from most other reports (see Table 2). Systolic blood pressure was more underestimated than diastolic blood pressure. The discrepancies with FINAP differences as reported in the literature can be explained by an increased pressure gradient between brachial and finger artery combined with a decreased pulse pressure amplification in these elderly subjects. The increased pressure gradient may be due to age-related changes in the vascular wall resulting in an increased vascular resistance.

Vasoconstriction causes a greater amplification and vasodilatation diminishes amplification with systolic blood pressure principally affected. This may be a reason for the larger effect of vasoconstriction upon head-up tilt or standing on systolic than on diastolic levels. Mental arithmetic is associated with forearm vasodilatation. The resulting reduction in amplification could explain the tendency of mental arithmetic to increase the difference in systolic blood pressure between the two measurement sites.

Conclusion For the noninvasive estimation of the levels of systolic and diastolic blood pressure in elderly subjects, the Finapres should not be used, but the RRK method should be used instead. In comparison with intraarterial measurements, blood pressure responses to circulatory stimuli as recorded with Finapres are similar in appearance and direction but not in magnitude. The qualitative performance of the Finapres allows it to be used in the clinical setting to evaluate cardiovascular reflex control in patients over 70 years of age. In physiologic research, small quantitative differences between intraarterial and finger blood pressure responses may potentially be confounding. The investigator should keep in mind that in the elderly fast fluctuations in brachial blood pressure are underestimated at the finger and that systolic blood pressure responses at the finger do not always reflect intrabrachial systolic responses.

Taking into account the advantages of a noninvasive blood pressure device and its ease of use, we believe that Finapres is a feasible tool to measure blood pressure responses in the elderly and is a good substitute for intraarterial measurements unless a high degree of precision is required.

ACKNOWLEDGMENTS

The authors express their gratitude to Wouter Wieling, Department of Medicine, Academic Medical Centre, Amsterdam, The Netherlands, for critically reading the manuscript and to Derk P. Veerman for his help in analyzing the data.

REFERENCES

11. Takahashi H, Yoshimura M, Nishimura M, et al: Mea-


