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Effects of Peripheral Vasoconstriction on the Blood Pressure in the Finger, Measured Continuously by a New Noninvasive Method (The Finapres®)

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The authors determined whether vasoconstriction alters the ability of a noninvasive method (Finapres®) of continuously measuring arterial blood pressure in the finger to function accurately. They compared the response of the Finapres® to blood pressures determined simultaneously by an oscillometric technique (Dinamap®) in six anesthetized patients. Vasoconstriction was detected from a photoelectric plethysmogram, which was recorded continuously from an adjacent finger. Vasoconstriction was defined as a decrease in amplitude to less than half of its highest value in one and the same patient. From the 378 paired blood pressure readings obtained in this study, 51% took place in such a vasoconstricted state. The authors found that diastolic and mean blood pressures in the finger were, on the average, 9 mmHg below those in the upper arm and that the systolic pressure was 7 mmHg above that in the upper arm. The authors concluded that the Finapres® keeps functioning well during peripheral vasoconstriction and is a recommendable method to monitor arterial blood pressure in the finger. (Key words: Equipment: Finapres®. Monitoring: arterial blood pressure.

A NONINVASIVE METHOD of continuously measuring arterial blood pressure in the finger was described by Penaz *et al.*[1] Such an instrument has been developed which is easy to use in the clinical setting, by Wesseling *et al.*[2] The device (Finapres,® for *FIN*ger *A*rterial *PRES*sure)** produces a calibrated arterial pressure wave.

A manometer (see "Methods") measures pressure variations in an inflated cuff, which is wrapped around the middle phalanx of a finger. Controlled by a built-in plethysmograph, the cuff pressure is modulated by a pumping mechanism so that the plethysmographic excursions are kept to a minimum. Thus, the transmural pressure remains almost zero and the variations in cuff pressure are identical with finger arterial pressure pulsations. Comparison of the Finapres® with other methods of measuring arterial blood pressure has been performed in other clinical centers by Wesseling *et al.*[2] and Molhoek *et al.*[3] In both studies, which were carried out in awake resting subjects, a good correlation was found.

During anesthesia for surgical procedures, however, reactive vasoconstriction of the peripheral vascular bed in the fingers often may occur.[4–6] Such vasoconstriction results from an increase in smooth muscle tone, which counteracts the intravascular pressure. If this constriction also occurs in the arterial bed under the finger cuff of the Finapres,® less pressure will be needed in that cuff to keep the plethysmographic excursions minimal. Since the Finapres® measures cuff pressure, its readings may be erroneously low during peripheral vasoconstriction. We therefore compared the readings of the Finapres® with upper arm arterial blood pressure during anesthesia for surgical procedures. The occurrence of peripheral vasoconstriction was detected by another photoelectric plethysmogram taken from the end phalanx of an adjacent finger.

Methods

DESCRIPTION OF THE FINAPRES®

The Finapres® includes an inflatable cuff that contains the transducer of an infrared transmission plethysmograph (fig. 1). The cuff is wrapped around the middle phalanx of a finger in such a way that the plethysmograph records the blood volume pulsations under the cuff. The cuff is connected to a source of compressed air. The air pressure in the cuff and the plethysmogram are linked together by an electropneumatic transducer and a fast-reacting servo system. The latter enables the pressure in the cuff to be varied rapidly in such a way that the plethysmographic excursions are minimal. This

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** The device will be commercially available through Ohmeda, Madison, Wisconsin 53707.

indicates that the pressure difference across the arterial wall (the transmural pressure) is kept constant throughout. Thus, cuff pressure follows the arterial pressure pulsations instantaneously. For calibration purposes a special procedure is incorporated,[2] which, guided by the plethysmogram, momentarily brings cuff pressure stepwise to the level at which the finger arteries are just about to collapse. This means that cuff pressure is equal to mean arterial pressure. The calibration procedure is repeated automatically at variable intervals (4–20 heart beats) during the measurement. The end result is that the cuff pressure is at all times identical with intraarterial pressure.

Experimental Procedure

The study was conducted in six female patients, aged 31–72 years (mean 48), undergoing gynecological surgery under general anesthesia. Anesthesia was induced with thiopenthal (4 mg/kg iv) and the trachea intubated following the administration of succinylcholine 1 mg/kg iv. Ventilation was controlled, while a mixture of nitrous oxide and oxygen was inhaled. Narcotics and nondepolarizing neuromuscular blocking drugs were given intermittently as required.

ECG and capnogram were monitored continuously. Arterial blood pressure was measured every 2 min by an oscillometric technique (Dinamap 845®). In the contralateral arm, finger blood pressure was measured continuously by the Finapres®. Its cuff, containing the plethysmographic transducer, was applied around the middle phalanx of the middle finger. From the end phalanx of an adjacent finger, another photoelectric plethysmogram was recorded continuously to detect the occurrence of vasoconstriction in the hand.

The continuous signals were stored on a HP® model 3968A eight-channel instrumentation tape recorder. The Dinamap® readings were printed automatically for each measurement. All patients were informed about the additional noninvasive procedures and gave their consent. Approval by the Medical Ethics Committee also was obtained.

Data Acquisition and Analysis

Upon playback of the tapes, all continuous signals were recorded in a calibrated way. The Dinamap® values, read every 2 min, were manually entered and consecutively plotted (in mmHg) together with the corresponding readings from the Finapres®, which were averaged over four consecutive beats. For the concurrent systolic, diastolic, and mean pressure values, the paired differences (finger–branchial) were averaged and the range and standard deviation computed per patient.

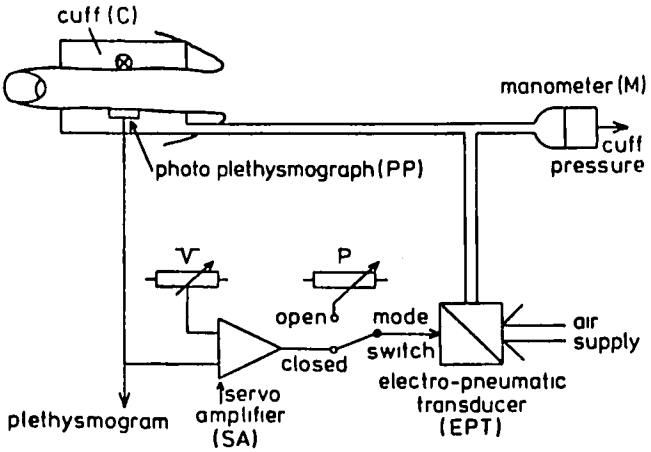

FIG. 1 Block diagram of the Finapres.® The manometer reads the pressure variations in the cuff, brought about by a source of pressed air. The air supply is regulated by an electropneumatic transducer and a fast-reacting servo-amplifier, guided by a plethysmogram taken from beneath the cuff. By the mode switch the instrument can be placed in the open mode for the calibration procedure. P = potentiometer to find the calibration pressure that has to be relayed to V as reference level for the servo-amplifier.

Approximately 60 sets of readings thus were tabulated for each patient.

Vasoconstriction, as detected from the plethysmogram of the adjacent finger, was defined as a decrease in amplitude to less than half of its highest amplitude in one and the same patient. The frequency of occurrence was expressed as the percentage of readings in which such a vasoconstriction was found. An example of the computer plot of all data for one patient is given in figure 2.

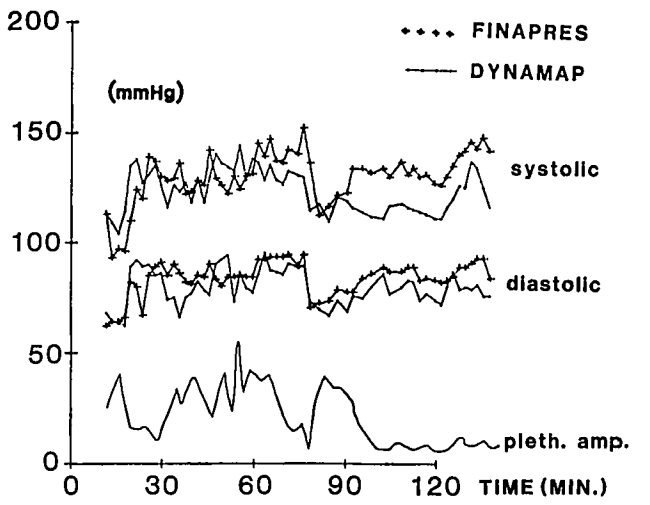

FIG. 2. Computer plot of simultaneously recorded blood pressure values (in mmHg) and amplitude of the end-phalanx plethysmogram (in mm) in patient no. 445.

TABLE 1. Frequency of Vasoconstriction

Patient Code	n	% Vasoconstriction
443	63	80
444	55	50
445	58	55
446	61	30
447	64	20
448	77	72
Total	378	51%

n = number of readings in each patient; % vasoconstriction = percentage of the readings in which vasoconstriction was found.

Results

Peripheral vasoconstriction occurred in all patients and was found in 51% of the 378 readings (table 1).

The paired pressure differences (finger–brachial), averaged for each patient, are listed in table 2. All diastolic and mean pressure differences except one are negative, while all systolic pressure differences except one are positive. The values averaged over the 378 readings show that diastolic and mean pressures in the finger are 9–10 mmHg below those in the upper arm and that the systolic pressure in the finger is found to be 7 mmHg above that in the upper arm.

Furthermore, the operation of the apparatus was simple, although the finger cuff containing the plethysmographic transducer had to be applied with great accuracy, because a good plethysmogram is essential for the functioning of the Finapres®. During the first 10–30 min after application, the tip of the finger showed a slightly congested appearance, but this reverted to normal during continued measuring. There were no complications or discomforts due to the use of the apparatus.

Discussion

Several authors demonstrated that a decrease in amplitude of the normal finger plethysmogram should be interpreted as a sign of peripheral vasoconstriction to stressful stimuli.[4–6] Although the amplitude is a relative value, there is a clear correlation between changes in the amplitude of a continuously recorded plethysmogram and the changes in the degree of vasoconstriction.[7] Therefore, vasoconstriction was defined arbitrarily in our study as a decrease in amplitude to less than half of its highest value. Since such a vasoconstriction occurred very frequently in our study, it follows that 51% of the pressure readings took place in the vasoconstricted state.

As reference for the Finapres® readings, Dinamap® measurements of blood pressure in the upper arm were used. The Dinamap® is widely used in clinical practice and is capable of producing reliable trend information during anesthesia.[8,9] Yelderman and Ream even concluded that the mean difference over many determinations is less than 1.5% of mean arterial blood pressure.[10]

In our study, mean blood pressures in the finger averaged 10 mmHg (range 4–15) below those in the upper arm. This is not grossly at variance with the 6 mmHg (0–15 mmHg) reported by Molhoek *et al.*,[3] who compared the Finapres® with invasive brachial artery pressure measurements in 21 patients suspected of having hypertension. The negative pressure differences agree with the normal decrease in mean pressure of 3–5 mmHg from the aorta to arteries as small as 3 mm in

TABLE 2. Paired Pressure Differences (Finapres®–Dinamap®), Averaged for each Patient

	Systolic			Diastolic			Mean			
Pat.	$\bar{p}$	m	s	$\bar{p}$	m	s	$\bar{p}$	m	s	n
443	127	−3.3 (+16 to −24)	9.5	91	−14.2 (+2 to −30)	5.6	103	−15.3 (−5 to −24)	4.5	63
444	125	4.3 (+27 to −35)	11.8	76	−10.5 (0 to −33)	7.0	96	−14.3 (−1 to −31)	7.2	55
445	122	6.5 (+23 to −25)	12.2	78	4.2 (+20 to −22)	7.5	97	−3.8 (+5 to −20)	6.5	58
446	118	9.9 (+37 to −23)	12.4	79	−10.3 (+6 to −27)	7.3	92	−8.6 (+8 to −35)	8.5	61
447	134	18.0 (+50 to −24)	14.5	94	−18.2 (−5 to −45)	8.8	107	−10.8 (+8 to −32)	10.1	64
448	133	4.1 (+23 to −15)	7.4	85	−5.5 (+2 to −14)	3.6	98	−5.7 (+4 to −21)	4.9	77
Mean	127	7.0	11.0	84	−9.1	7.0	99	−10.0	7.0	Total 378

Pat. = patient code number; $\bar{p}$ = average Dinamap® pressure during the operation, m = mean difference and range in mmHg; s = standard deviation of the difference; n = number of readings.

diameter and with a decrease of 15 mmHg to the very small arteries at the beginning of the arterioles.[11]

The diastolic pressure difference between upper arm and finger was found by Molhoek *et al.*[3] to be −6 mmHg (+1 to −12). Wesseling *et al.*,[2] using the Riva-Rocci-Korotkov method at the upper arm in 10 healthy volunteers, did not find a significant difference but a range of +13 to −16 mmHg. The diastolic pressure difference of −9 mmHg (+4 to −18) found in our study, therefore, does not indicate that frequent vasoconstriction reactions lead to lower readings of the Finapres® either.

For systolic pressure differences along an arm (in our study +7 mmHg, range −3 to +18), more variable results were reported in the literature. Molhoek *et al.*[3] and Wesseling *et al.*[2] both found a negative difference in their awake resting subjects (Molhoek −6 mmHg, range −26 to +14). Nielsen *et al.*,[12] on the contrary, using simultaneous intraarterial measurements, reported a positive systolic difference from the proximal to the distal aspects of the arterial tree.

Comparing intrabrachial and intraradial artery pressure in two volunteers, a systolic difference of +6 and +13 mmHg, respectively, was found. In two textbooks,[11,13] it is concluded that pulse pressure increases from the central to the peripheral arterial bed, mainly due to a rise in systolic pressure. The increase in systolic pressure is attributed to a summation of arriving and reflected pressure waves. However, this summation varies greatly with age, level of mean blood pressure, distensibility of the vascular walls, and also with the degree of peripheral vascular resistance.[14] A marked enhancement of the increase in pulse pressure along an arm is reported in circumstances that are associated with peripheral vasoconstriction.[15]

It is caused by a further increase in the reflected pressure wave from the constricted peripheral vascular bed.[16] Therefore, the positive difference in systolic pressure in our patients is consistent with the other reports. The wide range of the pressure differences must be due to the variations in peripheral vascular resistance occurring in each patient.

The fact that the Finapres® did not give excessively low readings in our patients can be explained by the external pressure exerted locally by the inflated cuff. We found that this pressure prevents constrictive reactions in the vascular bed under the cuff (unpublished). Therefore, if peripheral vasoconstriction occurs, as indicated by the plethysmogram taken from the adjacent finger, the plethysmogram controlling the Finapres® is not affected so that the Finapres® actually gives the true arterial blood pressure in the finger.

On the other hand, if such a change in vascular resistance in the rest of the hand occurs, it will particularly affect systolic pressure in the distal aspects of the arm.

The resulting difference in pulse pressure along the arm gradually will decrease from the terminal vascular bed to the aorta, so that the effect still will be present in the radial artery. Since this is the most distal site accessible for invasive blood pressure measurement, the pressure at this site should be used to give reference values in a further study to determine the accuracy and precision of the Finapres.®

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References

1. Penáz J, Voigt A, Teichmann W: Beitrag zur fortlaufenden indirekten Blutduckmessung. Zeitschr für innere Med 31:1030–1033, 1976
2. Wesseling KH, de Wit B, Settels JJ, Klawer WH: On the indirect registration of finger blood pressure after Penáz. Funkt Biol und Med 1:245–250, 1982
3. Molhoek PG, Wesseling KH, Arntzenius AC, Settels JJ, van Vollenhoven E, Weeda HWH: Initial results of noninvasive measurement of finger blood pressure according to Penáz. Automedica 4:241–246, 1983
4. Dorlas JC: Plethysmography in clinical measurement, Measurement in Anaesthesia, Vol 9, Boerhaave Series. Leiden, Leiden University Press, 1974, pp 165–169
5. Johnstone M: Digital vasodilatation—a sign of anaesthesia. Br J Anaesth 46:414–419, 1974
6. Otteni JC, Sauvage MR, Gauthier-Lafaye JP: Surveillance continue de la circulation peripherique par photoplethysmografie digitale. Cahier d'Anesth 18:735–756, 1970
7. Nijboer JA, Dorlas JC, Mahieu HF: Photo-electric plethysmography—some fundamental aspects of the reflection and transmission method. Clin Phys Physiol Meas 2:202–215, 1981
8. Broeke van den JJ, Karliczek G: Dinamap—eine neue automatische Blutdruckmessung (Ergebnisse von Vergleichmessungen). Prakt Anästh Wiederbeleb Intensivther 14:533–536, 1979
9. Hutton P, Dye J, Prys-Roberts C: An assessment of the Dinamap 845. Anaesthesia 39:261–267, 1984
10. Yelderman M, Ream AK: Indirect measurement of mean blood pressure in the anesthetized patient. ANESTHESIOLOGY 50:253–256, 1979
11. Guyton AC: The systemic circulation, Textbook of Medical Physiology. Philadelphia, WB Saunders, 1981, 19, pp 219–231
12. Nielson PE, Barras JP, Holstein P: Systolic pressure amplification in the arteries of normal subjects. Scand J Clin Lab Invest 33:371–377, 1974
13. McDonald DA: Blood flow in arteries, 2nd edition. London, E Arnold, 1974, p 356
14. O'Rourke MF: The arterial pulse in health and disease. Am Heart J 82:687–702, 1971
15. Rowell LB, Brengelmann GL, Blackmon JR, Bruce RA, Murray JA: Disparities between aortic and peripheral pulse pressure induced by upright exercise and vasomotor changes in man. Circulation 37:954–965, 1968
16. O'Rourke MF, Taylor MG: Vascular impedance of the femoral bed. Circ Res 18:126–139, 1966