EFFECTS OF PERIPHERAL VASOCONSTRICTION ON THE MEASUREMENT OF BLOOD PRESSURE IN A FINGER

BY
KAREL H WESSELING, JOS J SETTELS, GERARD M A VAN DER HOEVEN, JANNES NIJBOER, MICHELLE W T BUTLJN, AND JOOP C DORLAS

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Effects of peripheral vasoconstriction on the measurement of blood pressure in a finger

KAREL H WESSELING,*‡ JOS J SETTELS,* GERARD M A VAN DER HOEVEN,* IANNES A NIJBOER,† MICHELLE W T BUTIJN,‡ AND JOOP C DORLAS‡

From the *Research Unit, Biomedical Instrumentation TNO, Academic Medical Center, G-1-111, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands and ‡Institute of Anesthesiology, University Hospital, Oostersingel 59, 9713 EZ Groningen, The Netherlands

SUMMARY Using noninvasive techniques only, the fall in mean pressure and the pulse amplification between brachial and finger arterial pressure were measured in six anaesthetised female subjects during surgery. Brachial pressure was measured every 2 min with an oscillometric technique. Finger pressure was measured continuously using an arterial volume clamp method. In addition changes in the degree of peripheral vasoconstriction were established on an adjacent finger with a photographic plethysmograph. On the average finger mean pressure is 10 mmHg below brachial pressure. The difference tends to decrease with increasing constriction. The change in the difference between full constriction and maximal dilatation is 8 mmHg. The average finger to brachial pulse amplitude ratio changes from 110% at maximal dilatation to 170% at full constriction. Finger systolic pressure overshoot is responsible for the pulse wave amplification. On the average it is +7 mmHg and ranges between maximal dilatation and full constriction over 26 mmHg.

The standard error deviation on the volume clamp method could be established at 5% for mean pressure, about equal to that of the oscillometric technique in the literature.

In monitoring intraarterial pressure a registration is usually obtained from a brachial or a radial artery. This pressure serves as a substitute for aortic pressure.

In most cases substitution causes little problems, although it is known that the propagation of the arterial pulse towards the periphery produces distortion of the waveform.1 Distortion includes an amplification of the pulse wave, the disappearance of a clear dicrotic notch and a slight drop in the mean pressure level. The magnitude of the amplification depends on peripheral resistance and on ejection time or heart rate2 and also on the patient's age. The mean pressure drop varies with peripheral resistance.

The recently developed FIN.A.PRES (for finger arterial pressure) sphygmo-tono-meter3 delivers continuous arterial pressure similar in appearance to an intraarterial registration, but obtained noninvasively. It records arterial pressure in a finger, which puts the measurement site even more distal than a radial arterial puncture. This could cause further pulse wave distortion. Since severe constriction of the peripheral vessels in the finger has been observed with photo plethysmography4 enhancement of the variability of pulse wave amplification and mean pressure drop is expected. In addition, arterial vasospasm can be observed in the fingers in Raynaud's phenomenon and similar phenomena have been seen occasionally in anaesthetised patients under severe circulatory stress. At such times finger pressure cannot be measured.

We were particularly interested to see to what degree peripheral constriction affects finger pressure and the reliability and the accuracy of the FIN.A.PRES measurement. We, therefore, decided to study arterial pulse wave amplification and mean pressure drop to the finger. Subjects were taken from category of female surgical patients in which frequent peripheral constriction had been observed. Recording their peripheral constrictional stat correlation could be established.

THE METHOD OF PEÑÁZ

The volume clamp method used in FIN.A.PRES was published by the Czech physiologist Jan Peñáz in 1973.5 His method was further developed6 an prototypes were clinically tested.6 7 The techniqu
provides a full phasic waveform on a continuous basis for hours. The block diagram of Fig 1 shows the major system components. An inflatable wrap-on finger cuff empties the finger vessels except the arteries and unloads the arterial wall. On the inside of the cuff an infrared plethysmograph is mounted. A very fast pneumatic valve varies cuff pressure to follow intraarterial pressure changes including the pulsations. The cuff never occludes the artery.

This requires a high rate of change of cuff pressure which can only be achieved by an electronic servo system. When finger pressure increases the finger arteries distend. This causes more light from the plethysmograph to be absorbed, hence its output decreases. This is detected by comparison with a constant set point (C1, in the block diagram) and amplified in the proper phase to drive a pneumatic valve. The valve passes more air into the cuff thereby increasing cuff pressure. The increasing cuff pressure opposes the initial distension of the artery; and similarly for decreasing intraarterial pressures. Thus the arterial wall is floated between the opposing intraarterial and cuff pressures precisely balanced by the servo. Finger arterial pressure is read indirectly by recording cuff pressure with a manometer.

If during arterial vasospasm the arteries in the finger are fully contracted with zero lumen, they no longer pulsate and the arterial wall cannot be floated. In such cases the method breaks down and finger pressure measurement is not possible.

Methods

The study was conducted in six female patients, aged 31 to 71 years who underwent gynaecological surgery under general anaesthesia. Induction was done with 4 mg·kg⁻¹·BW thiopentone, and intubation followed the administration of 1 mg·kg⁻¹·BW succinylcholine. The patients were maintained on an automatic ventilator supplying a N₂O:O₂ mixture. Further intermittent doses of a narcotic analgesic and muscle relaxant were supplemented as required. Other inhalation anaesthetics were avoided.

Since brachial arterial cannulation was not indicated for this type of operation, proximal systolic, diastolic and mean blood pressure were obtained by an oscillometric technique (DINAMAP, model 845) on the right upper arm every 2 min. The precise periods of these measurements were recorded by a light reflection plethysmograph distal of the oscillometric cuff (timer pleth). Occasional time markers were also recorded. A continuous distal pressure signal was obtained by means of a FIN.A.PRES prototype from the middle finger of the left arm, thus allowing simultaneous readings with the two methods. A further light reflection plethysmograph was mounted on a finger adjacent to the finger cuff to monitor peripheral constriction (constriction pleth). The photo reflection plethysmographs consisted of a CO₂ photoconductor and a concentrically illuminating incandescent lamp. This instrument is very light weight and has excellent sensitivity in the near infrared. The passband extends from 0.5 to 15 Hz including electronics. Heat dissipation is much less than 1 W and does not affect the skin circulation. The plethysmographs were attached to the skin with a small contact pressure to assure good contact and an undisturbed plethysmographic wave shape. The output being expressed as mm on a 50 mm wide strip chart recorder with a precision of 0.5 mm or 1% of full scale. All continuous signals were displayed on a Schwarzer multi-channel chart recorder at 15/16 IPS tape speed for later evaluation. Each DINAMAP reading and clock time was printed automatically.

Each patient was informed about the additional non-invasive procedures and gave her consent. Approval by the Groningen Medical Ethics Committee for this study was requested and obtained.

Upon play back all continuous signals were recorded on an 8 channel Gould Brush model 200. Systolic, diastolic and mean pressure levels from the continuous finger pressure signal were derived on a
heat-to-beat basis via a computer and fed to three additional registration channels.

The corresponding oscillometric readings were manually entered and synchronised with the timer using occasional marker verification. Every 2 min as indicated by the timer pletth the finger systolic, diastolic and mean pressures were taken, averaged over four beats, and the peak-to-peak amplitude of the constriction pletth was measured. Approximately 60 sets of samples were tabulated for each patient. Trend charts of the pressure levels at the two sites and of the peripheral constriction pletth amplitude were plotted for each individual patient for visual inspection.

During the measurement the finger was fixed at a constant height above mi brachial, varying between patients from 0 to 16 cm (average 8 cm). Correction was performed by adding 0.75 times the height difference in cm to all finger pressures in mmHg. The brachial systolic, diastolic and mean pressure levels were averaged per patient and the standard deviation computed. For each pressure level and patient the paired difference (finger-brachial) statistics were also computed. Pulse wave amplification was computed as a percentage of the ratio of finger to brachial pulse pressure (systolic-diastolic).

The postulated increase in amplification with peripheral constriction was investigated by computing linear least squares regressions for each patient. To establish if changes in amplification were mainly affecting systolic or diastolic levels, the finger-brachial pressure differences for these levels were also regressed upon the simultaneous constriction pletth amplitude. A possible variation of the brachial-to-finger mean arterial pressure drop with degree of peripheral constriction was similarly investigated by regression analysis.

Results

No periods of finger arterial spasm occurred and finger pressure could be measured without interruption throughout each of the six operations.

The brachial (proximal) pressure levels averaged for each patient ranged from 118 to 134 mmHg (systolic), 76 to 94 mmHg (diastolic) and from 92 to 107 mmHg for mean pressure. Typical within patient standard deviations were 13, 9 and 10 mmHg, respectively, and neither very high nor very low blood pressures occurred during the operations.

The paired pressure differences (finger-brachial) are listed in Table 1 with their standard deviations. Overall, diastolic and mean finger pressures underestimate brachial pressures by 9 to 10 mmHg. Systolic pressures on the other hand are higher in the finger than in the brachial artery.

The trend chart for patient 445 (Fig 2) illustrates the

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![Graph](image)

FIG 2 The trend charts of patient 445 are from above: S, finger (FINAPRES) and brachial (DINAMAP) systolic pressures; D, diastolic pressures; PL, adjacent fingers, mean pressures. At 25 and 75 min into the operation and also during the last 40 min prolonged constrictions are present.

various measured pressure levels and the amplitude of the plethysmogram and their course during an operation. Typically, the constriction pleth amplitude is rather large during the first part of the operation (periphery dilated) and of decreased amplitude near the end (periphery constricted). Proximal (brachial) and distal (finger) mean pressures follow each other quite well. The same is true for the diastolic levels.
Systolic levels deviate more systematically from each other when the constriction pleth is of small amplitude. Clearly, most of the increase in amplification with peripheral constriction is due to peripheral systolic pressure increase. To a lesser extent increases can be noted in the mean and diastolic levels. Scattergrams (fig 3) and linear regressions of these phenomena for the same patient emphasise the effects seen. The pulse amplification and the systolic differences correlate best with constriction pleth amplitude ($r = -0.52$ and $-0.54$). The correlation coefficient for the amplification of $-0.52$ improves to $-0.69$ by removing six outliers in the scattergram. However, only a small fraction of the vertical scatter in the diagrams is explained by the regression.

The tendency in all variables in all patients except one was to decrease with increasing constriction pleth amplitude. The significance of this tendency can be judged from the correlation coefficients listed in table 2. All six of the systolic and amplification regressions are significant at $p<0.05$, a further 2 diastolic and 3 mean regressions are also significant. Since the horizontal constriction pleth scale is arbitrary it makes no sense to specify regression slopes. A more useful quantity is the maximal change in pressure difference from full dilatation to full constriction. Averaged over all six subjects it is 26 mmHg for the systolic level and 5 mmHg for diastolic and 8 mmHg for the mean level. Pulse wave amplification changes from 110% to 170%. The predominance of systolic over diastolic changes was predicted. Using a one tailed Wilcoxon matched pair signed rank test it is significant at $p = 0.025$.

Fig 4 shows a 1 min record of finger pressure and

![Graphs showing scattergrams and regression lines for systolic, diastolic, and mean pressure differences.](image)

**Fig 3** In the four scattergrams the paired systolic, $\Delta S$, diastolic, $\Delta D$, and mean, $\Delta M$, pressure differences (finger-brachial) and the pulse wave amplification, $A$, were plotted vertically versus the simultaneous constriction plethysmographic amplitude, $PL$, horizontally. The smaller the plethysmogram (to the left) the more the periphery is constricted.

The drawn lines are the regressions. Since the horizontal scale is arbitrary no regression coefficients are given. The correlation coefficients are not dependent on scale factors and are: $-0.52$ for amplification, $-0.54$ for systolic, $-0.35$ for mean and $-0.15$ for diastolic. All except diastolic are significant for this patient ($p=0.01$).
constriction phleth. Three abrupt constrictions each lasting about 10 s can be seen; two are fully shown. The parallel increase in the systolic and diastolic pressures and in pulse pressure are clearly visible. Sometimes, abrupt constrictions lasted longer than 10 s. The number of constrictions in each patient ranged from 0 to 30. The total number of constrictions was 109. In 98 cases (90%) the constriction was associated with a clear rise in systolic pressure.

Discussion

VASOSPASM

The fact that arterial vasospasm in the fingers did not occur during any of the six operations, allowing uninterrupted monitoring of finger pressure, is encouraging and seems to answer the reliability question posed in this paper. Statistically, however, a vasospasm rate of 0 out of 6 cases only allows the establishment of the population vasospasm rate to be less than 40% (95% confidence). Clearly, a much larger study is needed to settle this question.

CONTRACTION PLETHYSMOGRAPH

We measured a decreased plethysmographic pulsation under conditions of an increased arterial pressure pulse. The opposite is expected at first sight. A detailed understanding of what precisely is observed with a photo-reflection plethysmograph is still lacking,9,10 but the following seems correct. Due to the good penetration depth of the infrared plethysmograph, pulsations should be visible from the small arteries, arterioles, capillaries, venules and small veins throughout the skin. The arteries are not seen by the reflection plethysmograph, since their anatomical location is deep down in the tissue and their visibility is blocked by more superficial vessels.9

The arterioles are exposed to the increased pulse pressure but their total volume has been decreased due to constriction of the smooth muscle which results in a smaller plethysmogram. In addition, vessels with a high smooth muscle tone become viscous (ie sluggish) and lose their ability to pulsate at cardiac rhythm which again results in a smaller plethysmogram. Downstream of the capillaries no significant
constriction takes place. However, venous pulsations decrease due to the decreasing pulsatile inflow caused by arteriolar constriction. The capillaries probably also pulsate but even substantial increases in diameter would not let more red blood cells in, thus capillary pulsations and their changes remain invisible. Although constriction appeared at times to be virtually complete, finger arterial pressure could still be measured. This suggests that peripheral constriction is not accompanied by a similar constriction of the arteries in the cuffed finger, under the conditions of this study.

Many of the abrupt peripheral constrictions (fig 4) last about 10 s. The associated increases in finger pressure have the same duration. Such 10 s oscillations in blood pressure can be triggered by pain, handgrip, breath holding, talking, or by taking a deep breath. They are believed to be generated by a damped resonance in the baroreflex control of peripheral resistance.12 13 It was shown by Shoukas and Sagawa14 that the rate of change of resistance is sufficiently high for the purpose, and that the rate of change of arterial and venous tone is an order of magnitude slower. Thus arterial constriction is not only not seen by the reflecting plethysmograph but plays no role during the abrupt constrictions.

AMPLIFICATION EFFECT

The amplification of the pulse wave towards the periphery in the human arterial system has been described by Kroeker and Wood15 and by O'Rourke et al.16 and in the arm by O'Rourke.2 The amplification is principally caused by reflection of the pulse wave at the resistance vessels and increases with increasing peripheral resistance.1 17 This is clearly demonstrated in our data. The principal effect of peripheral reflection of the pulse wave is an increase in systolic pressure. The diastolic pressure level is virtually unaffected by reflection.1 17 This is also confirmed here.

According O'Rourke et al.16 amplification is reduced in older patients. However, this effect shows large interindividual variability and could not be established in our sample of patients.

BRACHIAL-TO-FINGER PRESSURE DIFFERENCES

The mean pressure in the finger averaged 10 (range 4 to 15) mmHg below brachial mean pressure levels (table 1). This is not grossly at variance with the 6 (range 0 to 15) mmHg reported by Molhoek et al17 for the Peñáz method. Similar pressure differences of 8 mmHg in 119 normotensive and 16 mmHg in 76 hypertensive patients were measured by Nakayama and Azumi18 using a different technique. Systolic pressure differences (finger-brachial) seem to be much more variable. They average +7 (range -3 to +18) mmHg in the present study. Molhoek et al17 observed 6 (range -26 to +14) mmHg. Nakayama and Azumi18 found averages of -15 in normotensive and -28 mmHg in hypertensive subjects. Weaver and Bohr19 using an occluding cuff and flow detection found an average of -19 (range -5 to -31) mmHg in 75 normal subjects ages 16 to 65 years. Nielsen et al20 found +9 mmHg in a young and +0.8 mmHg in an older patient group. These values, thus, depend on age, blood pressure level and technique used in addition to the degree of peripheral constriction.

ERROR ANALYSIS

Although the systolic pressure differences between brachial and finger regresses significantly upon the constriction plesh amplitude, an average correlation coefficient of about 0.5 means that only 25% of the observed variance is explained by constriction. The remaining 75% is "error" variance. For diastolic and mean pressure the explained variance is even less, in fact it is negligible. We could, therefore, use the pressure difference analysis of table 1 as an approximate error analysis for comparison of the two different techniques embodied in the DINAMAP and FIN.A.PRES instruments. Partitioning of the error between the two methods is based on independent information from several authors reporting on the precision of DINAMAP's mean pressure estimates. Ramsey21 reported an average overestimate of mean pressure of -0.23 mmHg and a standard deviation, SD, of the error of 4.2 mmHg in over 600 comparisons in 28 patients. Yelderman and Reins22 reported and overestimate of 1.4 mmHg and an error SD of 6.2 mmHg in a patient group of similar size. Francoual et al23 in a study with about 140 comparisons from 20 patients did not report these statistics, but published scattergrams from which we estimated an error range of about 60 mmHg although most of the errors lie within a 30 to 40 mmHg band. A slight overestimate of intraarterial pressures of about 2 to 4 mmHg is perhaps also present. Assuming an error range equal to 5 to 6 standard deviations, an error SD of between 5 and 10 mmHg follows. Van de Broeke en Karlikz22 reported a DINAMAP overestimation of mean pressure for levels below 100 mmHg which turned into an underestimate above that level. Diastolic is constantly overestimated by about 6 mmHg. The error standard deviation is about 9 mmHg. From these results we can conclude a DINAMAP overestimate of intraarterial pressures of 1 to 4 mmHg and an error SD of 4 to 9 mmHg. Since the technique is automatic, obviating human observer error, and since cuff application was performed with care and the clinical state of the patients was similar (no shock cases) we may assume that our errors using DINAMAP do not differ markedly from those in the studies cited. Since DINAMAP and FIN.A.PRES each use a different
Finger blood pressure and vasoconstriction

technique their errors are probably independent. This means that the variances can be added to deliver the total error variance of the comparison, while mean errors are linearly added.

Thus, the underestimate of finger mean pressure of 10 mmHg on the average, reduces to 6 or 9 mmHg in view of a DINAMAP overestimate. Subtraction of a DINAMAP variance of $5^2$ (mmHg$^2$) from the observed variance of $7^2$ (mmHg$^2$) results in a FIN A PRES variance of $e^2 = 49 - 25 = 24$ (mmHg$^2$). Hence the FIN A PRES error SD has a probable value of 5 mmHg and is essentially equal to DINAMAP’s.

Therefore, with regard to FIN A PRES precision, our second question posed, we obtain an error SD of 5 mmHg for mean pressures which is as good as can be obtained with other modern indirect methods. The average underestimate of mean pressure in the finger, compared with the contralateral brachial Pressure, of 6 to 9 mmHg cannot be ignored but must be compensated for. By positioning the measured finger about 10 cm below heart level (tricuspid valve) a hydraulic compensation is automatically obtained.

Pressure changes due to peripheral constriction explain only a small fraction of the error variance and can be ignored for all practical purposes. The only exception is perhaps its effect on finger systolic pressure. In abrupt constrictions the effect is easily noticed. For slow trends in constrictional state an approximate “mental” correction may often suffice.

References


