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The Discrepancy between Invasive and Noninvasive Blood Pressure

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ABSTRACT **To clarify the discrepancy between invasive (IBP) and noninvasive (NIBP) blood pressure, we studied the appropriateness of various methods and compared them. All data were collected in simulation studies and from routine clinical work. For IBP monitoring, pressure transducers (DTX or P50, Spectramed, USA) were used. NIBP was monitored in three ways; BP-308 (Colin, Japan) and Dynamap 8100 (Criticon, USA) for the oscillometric method, CBM-2000 (Colin, Japan) for the tonometric method and Finapres (Ohmeda, USA) for the zero transmural pressure method.**

IBP : In our estimation, small invisible air bubbles in the catheter make for a sharp, not dull pressure wave. This phenomenon is explained using frequency response curves. There was more than a 10 mmHg difference in systolic pressures (aortic valve to bifurcation) and much greater difference in distal pressures. With a vasodilating condition, the situation is more complex and it is not so easy to get a true IBP. NIBP : Oscillometric pressure is little affected by peripheral vascular conditions and reflects the central pressure well, however, it is not a continuous pressure monitor. Continuous tonometry pressure was useful only when calibrated with oscillometric pressure. Zero transmural pressure is also an easy continuous method and reveals distal arterial conditions well, but is affected by finger cuff fitness.

In conclusion, there is no reliable method, neither IBP nor NIBP for continuous blood pressure monitoring. However, we recommend the use of one of the continuous methods together with intermittent oscillometric pressure. (Received December 8, 1989 and accepted January 6, 1990)

Key Words : Invasive blood pressure, Noninvasive blood pressure, Blood pressure measurement

1 INTRODUCTION

Automated noninvasive blood pressure (NIBP) monitoring is now very common in operating rooms and intensive care units. Historically, compression cuff size of NIBP was adjusted by invasive blood

Table 1 *Clinically used blood pressure monitoring methods. The underlined methods were discussed in this study.*

NONINVASIVE BLOOD PRESSURE :

AUSCULTATORY METHOD
PALPATORY METHOD
FLUSH METHOD

<u>OSCILLOMETRIC METHOD (BP-308, 8100)</u>
DOPPLER METHOD
<u>TONOMETRIC METHOD (CBM-2000)</u>
<u>ZERO TRANSMURAL PRESSURE METHOD (FINAPRES)</u>

pressure (IBP) values[1]. Even when using standard monitoring methods, we frequently experience a discrepancy between NIBP and IBP. There are many reports dealing with the similarities between them[1)-4)], but no reports have analyzed the discrepancy, especially in the latest models.

We will discuss three aspects of this problem. First is the appropriateness of IBP. Even though using standard blood pressure monitoring methods, pulse wave distortion can frequently be seen. There are instrumental and physiological factors involved in this phenomenon. Next are the characteristics of NIBP. There are many NIBP monitoring methods (Table 1), of which, the latest three automated methods (underlined in Table 1) were studied. Finally we compared NIBP to IBP. Radial arterial pressure as a IBP method, and oscillometric pressure and zero transmural pressure as NIBP methods were tested. Tonometric pressure was excluded from the comparison because we couldn't get an original pressure value without correction with oscillometric pressure.

2 METHODS

2. 1 Simulation study

The simulation study was carried out using a pulse wave simulator (601A, Bio-tek, USA) and function generator (FG-330, Iwatsu, Japan) like a Figure 1. The original and conducted pressure waves were recorded simultaneously in each trace without any electrical or mechanical correction.

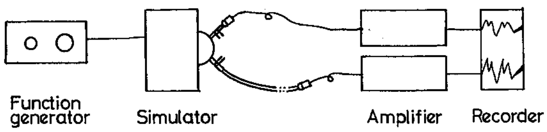

Fig. 1 Illustration of simulation study. No electrical nor mechanical pressure wave correction was made under the 50Hz range.

2. 2 Clinical study

Thirty-eight ASA 1-2 patients, 23 males and 15 females aged 24 to 81 (mean 47) years, who needed IBP monitoring during a wide variety operation, were studied. For IBP monitoring, pressure transducers (DTX or P50, Spectramed, USA) were used. Their frequency responses were checked and corrected by dumping devices. All patients were additionally monitored by two or three NIBP measuring instruments, Dynamap 8100 (Criticon, USA) for oscillometric method, Finapres (Ohmeda, USA) for zero transmural pressure method and CBM-2000 (Colin, Japan) for tonometry method. All pressure outputs were recorded with a polygraph (Nihondenki San-ei, Japan). Peripheral blood flow was measured by laser flow meter (ALF2100, Advance, Japan). All data were collected during our routine work.

3 RESULTS

3. 1 APPROPRIATENESS OF INVASIVE BLOOD PRESSURE (IBP)

3. 1. 1 Instrumental factors

As shown in Figure 2, the most important factor for measurement was air bubbles, with catheter length and diameter having minor effects on pulse wave distortion. "A" was air-free and air volume was increased to that of "I". Conducted waves are sharp and over 30 mmHg higher than original ones by air bubbles.

3. 1. 2 Physiological factors

Aortic pressure waves were recorded in 10 patients at cardiac catheterization. Figure 3 is the record of an average patient, a 50yr. female with minor mitral regurgitation. The difference in systolic pressure between the aortic valve and bifurcation was +15 mmHg, diastolic was -6 mmHg. Even in aortic pressure there was a significant difference.

On the other hand, distal vascular condition and IBP were recorded in 19 operative patients under general anesthesia. Figure 4 shows the effects of peripheral vascular condition on radial arterial pres-

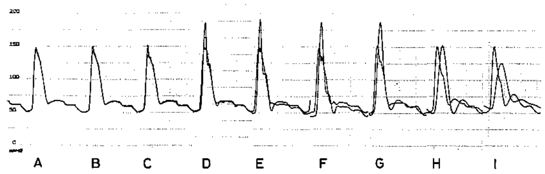

Fig. 2 The effect of air bubbles in the catheter and dome. 100 cm and 30 cm catheters with 3way stopcock were used.
A : air free
B : standard air flush
C : 1 mm air in the catheter
D : 5 cm air in the catheter
E : 10 cm air in the catheter
F : 1 mm air bubble in the dome
G : 3 mm air bubble in the dome
H : air in half of the dome
I : air in the entire dome

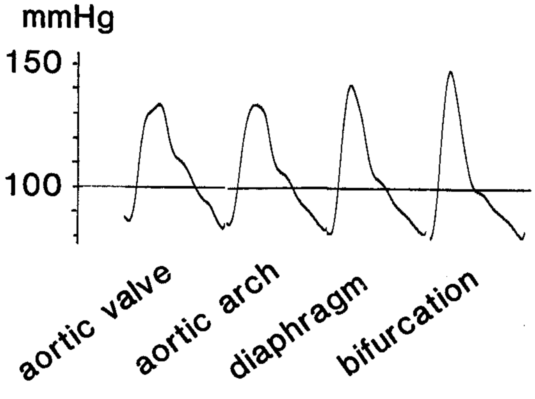

Fig. 3 Aortic blood pressure waves at cardiac catheterization. Patient was 50yr. old with minor mitral regurgitation.

sure under general anesthesia. The left halfe was vasodilated by enflurane anesthesia and the right half was vasoconstricted by dopamine. With wrist grip (increase peripheral vascular resistance), radial pressure increased to oscillometric blood pressure on the left, but had no effect on the right. Similar effects could be seen not only in the radial artery but also the more central brachial artery.

3. 2 CHARACTERISTICS OF NONINVASIVE BLOOD PRESSURE (NIBP)

Oscillometric pressure was not affected by peripheral vascular tonus, so it reflected the central pressure well (Figure 4) but it couldn't give, nor display, continuous pressure. For continuous noninvasive blood pressure monitoring, Finapres and CBM-2000 are commercially available. The pressure of Finapres, a zero transmural pressure method with finger cuff, was affected by finger cuff fitness, distal arterial tonus and blood flow, but the records obtained with Finapres were well reflected by the peripheral circulatory conditions (Figure 5). In CBM-2000, a tonometric method, the original tonometric pressure

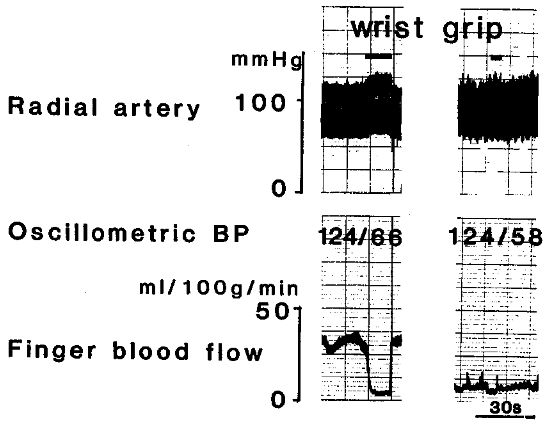

Fig. 4 The effects of peripheral vascular condition on radial arterial pressure under general anesthesia. The left half was vasodilated by enflurane anesthesia and the right half was vasoconstricted by dopamine. With wrist grip (increase peripheral vascular resistance), radial pressure increased to oscillometric blood pressure on the left, but had no effect on the right.

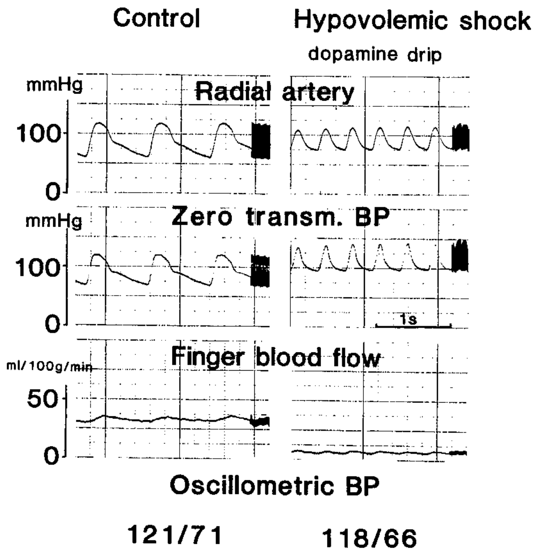

Fig. 5 Simultaneously traced pressure and flow waves under general anesthesia. Zero transmural blood pressure was mostly affected by peripheral circulatory conditions.

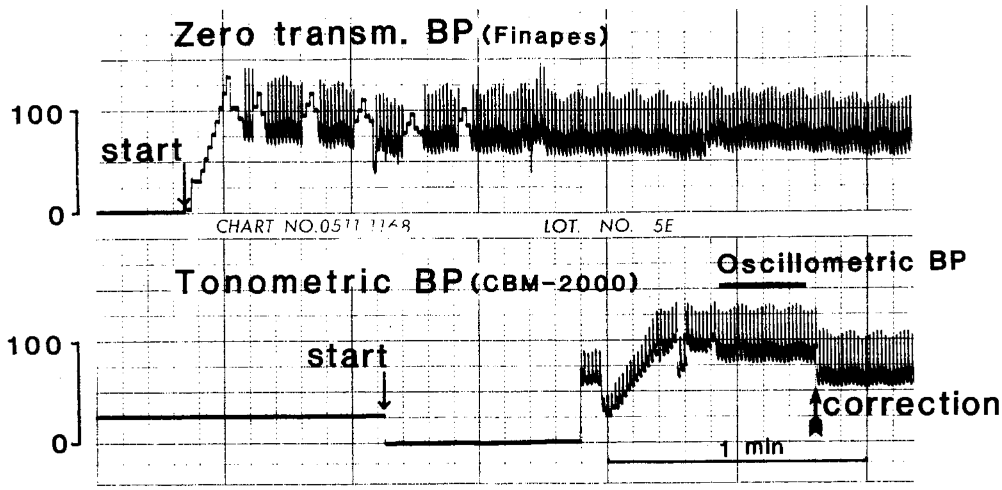

Fig. 6 Output pressure waves from Finapres and CBM-2000 at the starting phase. Self-calibration was done in Finapres, but CBM-2000 needed correction by oscillometric pressure.

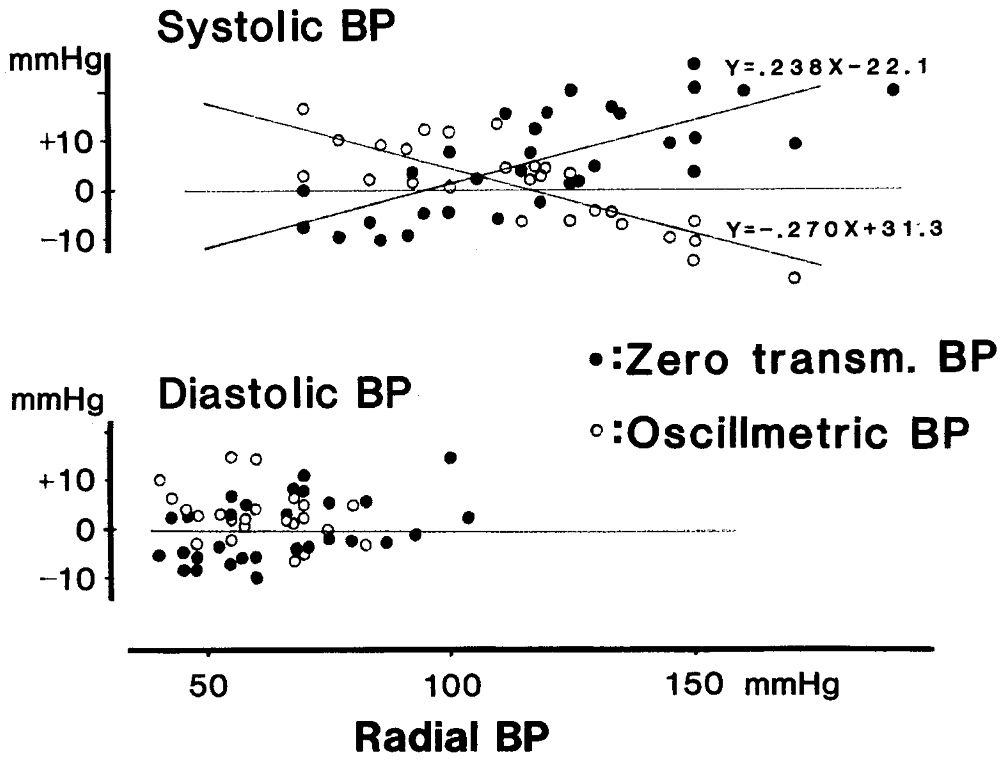

Fig. 7 Comparison of radial arterial pressure, zero transmural blood pressure and oscillometric blood pressure. There was a significant difference ($p<.001$) between the two groups in systolic blood pressures, but not in diastolic.

value was not so reliable. However, it is clinically useful with intermittent self correction with oscillometric pressure (Figure 6).

3. 3 COMPARISON OF NIBP AND IBP

As shown in Figure 7, high systoric pressure was significantly underestimated and low systolic pressure was overestimated in oscillometric pressure compared with the radial arterial pressures ($Y=.238X-22.1$, $r=.86$). On the contrary, zero transmural pressure had the reverse tendency ($Y=-.270X+31.3$, $r=.81$). The difference between the two groups was significant ($p<.001$). Measurements for diastolic pressure were not so different.

4 DISCUSSION

4. 1 APPROPRIATENESS OF INVASIVE BLOOD PRESSURE

4. 1. 1 Instrumental factors

There is much misunderstanding about the steep pressure wave phenomenon. Why do air bubbles make a wave sharpen, not dull? The answer is in Figure 8[5]. There are the frequency response curves through the catheter and domes. With an air-free normal condition, the curve is almost flat in the range of pressure wave frequency, usually under 20Hz. However, small air bubbles decrease not only the peak gain amplitude, but also its frequency, and finally the peak of this curve comes into the range shown by crosshatched area. This is the reason for high conducted pressure waves by air bubbles. There is no peak with large air bubbles, as only they decrease the wave height.

4. 1. 2 Physiological factors

Under normal or vasoconstricted conditions, the distal arterial pressure is higher than the central. On the other hand, vasodilation will make the distal arterial pressure lower than the central. From these results we would like to propose the next schema (Figure 9)[6]. What is true IBP? Aortic pressure just past the aortic valve is most reliable, but clinically it is very difficult to get. How do we get central pressure values near the aortic or large arteries? From our data and Pauca et al[7] it is possible to estimate the central pressure from IBP with distal artery occlusion like wrist grip.

4. 2 CHARACTERISTICS OF NONINVASIVE BLOOD PRESSURE (NIBP)

Oscillometric pressure is occlusive pressure principally and supposed to be influenced mainly by cen-

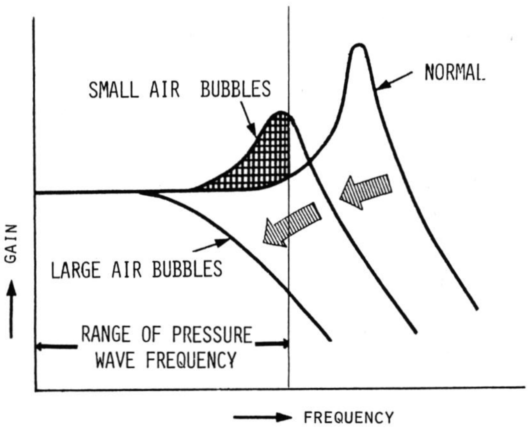

Fig. 8 Frequency response curves through catheter and domes. Range of pressure wave frequency is usually 0-20Hz. This schema shows how air bubbles make the wave steep rather than rounded.

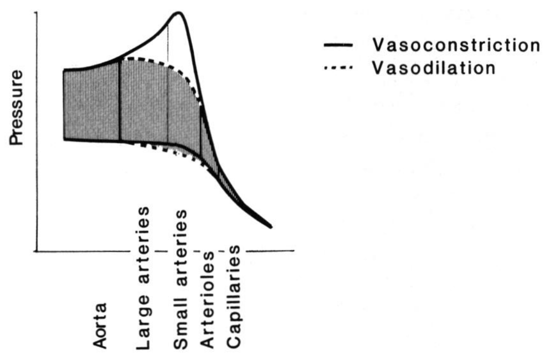

Fig. 9 Proposed schema of arterial pressure under two conditions. Following peripheral vasodilation, distal arterial pressure will close to the capillary pressure. So the distal arterial pressure, like the radial pressure, will be lower than the central arterial pressure.

tral pressure. Clinically it reveals the most reliable pressure values, but is not continuous. Another two methods can trace the waves continuously in displays but their values are less reliable than oscillometric, so they need to be supplemented by a trustworthy method like oscillometric pressure.

4. 3 COMPARISON OF NIBP AND IBP

Oscillometric pressure reflects more of the central pressure like aortic pressure. On the other hand, zero transmural pressure reflects distal finger pressure more. IBP of the radial artery has a tendency, as shown in Figure 9, that vasoconstriction and vasodilation correspond to high and low blood pressure. From these facts we found that oscillometric pressure reflect for the pressure of the aorta or large arteries, radial artery pressure the large or small arteries, and zero transmural pressure the pressure of the small arteries or arterioles.

5 CONCLUSIONS

For continuous blood pressure monitoring, there is no reliable method, neither IBP nor NIBP. However, we recommend the use of one of the continuous methods together with intermittent oscillometric pressure.

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観血および非観血的血圧測定値の差異について

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観血的血圧と非観血的血圧の差異を明確にするため，これらの方法の正当性についてシミュレーション実験およびこれらの血圧測定を必要とした臨床例について比較検討を行なった．観血的血圧測定には血圧トランスデューサ(DTX or P50, Spectramed, USA)を，非観血的血圧測定には最近用いられてきている3種類の方法を用いた．オシロメトリック法にはBP-308(Colin, Japan）またはDynamap 8100(Criticon, USA）を用い，トノメトリー法にはCBM-2000(Colin, Japan)，無負荷動脈法にはFinapres(Ohmeda, USA)を使用した．

観血的血圧：カテーテル内の気泡は我々の予想に反し波形を尖らせることを示すと共に，周波数応答曲線を用いこの現象を説明した．また大動脈内でも起始部と分岐部で10 mmHg以上の差があることを示し，観血的測定法が絶対的なものでないことを強調した．

非観血的血圧：オシロメトリック法は連続的血圧表示はできないが，末梢血管の変化に影響されず中心血圧をよく反映していた．主に橈骨動脈で測定するトノメトリー法は連続血圧表示が可能だが，絶対値の信頼性にかけるためオシロメトリック法と併用することでこの問題を解決している．もう一つの連続血圧表示可能な無負荷動脈法は指にカフを巻いて測定する簡便な方法で，より末梢の圧を反映する．

結論として信頼できる連続血圧をモニターするよい方法はなく，オシロメトリック法と他の3者の併用が望ましいといえる．