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Blood pressure monitoring in the newborn

The association of cerebral palsy and cerebral ischaemic lesions such as periventricular leucomalacia is now clearly established.[1–4] Such lesions are likely to be caused by changes in cerebral perfusion. The hypothesis that cerebral perfusion is 'pressure-passive' in some newborn infants is becoming increasingly widely held and in these infants changes in systemic blood pressure are likely to be directly transmitted to the cerebral circulation.

If we accept this point of view, and there is increasing evidence that we should,[5–7] it is clear that close monitoring of blood pressure is a prerequisite for successful neonatal intensive care. But important questions arise: what method is best? what is the normal range of blood pressure? The purpose of this annotation is to provide answers.

Methods for measuring blood pressure

The requirements for successful blood pressure monitoring are that the method should be easy to set up, reliable, and give continuous information or enable measurements to be made at frequent intervals with minimal disturbance to the baby. Non-invasive and invasive methods are available.

NON-INVASIVE METHODS

The four methods available are the traditional mercury sphygmomanometer and three automatic methods: the Arteriosonde (a Doppler technique), the Infrasonde, and the oscillometric monitor (such as the Dinamap (Critikon)). Each of these methods has serious shortcomings. Traditional flush techniques and methods relying on palpation and auscultation are not sufficiently accurate and just not practical for the small sick infant.[8] Of the three automatic devices available, only the oscillometric type is now in widespread use.

The Doppler method (Arteriosonde) involved the use of a fairly large and clumsy transducer which was placed under a cuff and over the brachial artery. In a neonatal study a correlation coefficient of no better than 0·80 was obtained when compared with measurements from an arterial catheter.[9] This technique has also caused a transient radial nerve palsy in small infants due to pressure by the transducer on the radial nerve which accompanies the brachial artery along the inner aspect of the humerus.[10] The cumbersomeness of this technique has undoubtedly contributed to its failure to gain wide popularity.

The Infrasonde derived its signal in the following way. When an inflated cuff was placed around the limb and deflated, blood passed from the vessel segment under the deflating cuff into the distal portion of artery which was collapsed. This collapsed section fluttered as blood passed into it and this fluttering gave rise to low frequency (infrasonic) vibrations that disappeared when the cuff pressure fell below the diastolic pressure. In a study of children aged between 4 days and 14 years, this device was compared with simultaneous intra-arterial measurements: the authors concluded that although systolic measurements were as good as those obtained by a mercury sphygmomanometer, diastolic measurements were not.[11] I am not aware of any good studies to correlate this technique with invasive blood pressure measurements in very small infants. One problem was that the error in the method was variable—that is, not systematic.

The most popular of the indirect methods is currently the Dinamap oscillometric monitor. The basis for this device is that the arterial wall oscillates when blood flows in pulsatile fashion through a vessel. These oscillations are transmitted to a cuff placed around the limb. As the pressure within the cuff is reduced, the pattern of oscillations changes. When arterial pressure is just above the cuff pressure there is a rapid increase in the amplitude of the oscillations and this is taken as systolic pressure. The point at which the amplitude of the oscillations is maximal coincides with the mean arterial pressure. Diastolic pressure is recorded when there is a sudden decrease in oscillations.[12]

The oscillometric method has serious problems associated with it. Firstly, the regular automatic inflation of the cuff disturbs infants whose clinical condition is unstable and who are being handled as little as possible. Secondly, although several studies of newborn infants have reported the method to be reliable and accurate,[8] the most telling observations have been made by Diprose and colleagues.[13] These authors studied very low birthweight infants and showed that the Dinamap consistently over read systolic and diastolic blood pressures when the infants were hypotensive. Thus the instrument became most unreliable when accurate measurement was of the greatest importance— and there is no reason to believe that other oscillometric monitors perform any better.

The oscillometric method has been enthusiastically promoted. Its popularity is mainly due to its convenience and ease of use. As stated above, however, it is inaccurate when sick infants of very low birth weight are being monitored and this caveat must be borne in mind during neonatal intensive care.

INVASIVE MEASUREMENT

The most widely used method is by means of an umbilical arterial catheter connected to a blood pressure transducer by rigid low compliance pressure tubing. Insertion of the catheter is relatively straight forward. The precise method of insertion is a matter of personal preferences and techniques of insertion and fixation of the catheter are well described in standard neonatal texts.[14]

Some theoretical considerations

There are some theoretical considerations which are of practical importance. The pressure, P, measured by the transducer has three components:

$$P=P_s+P_k+P_r$$

where P_s is the static component, P_k is the kinetic component, and P_r is the reference level component.[15]

When a catheter is introduced into the lumen of a vessel, the observer wants to know what the pressure at the tip of the catheter is. If there is no flow the pressure will be the same in all directions. This is the static component, P_s, and the direction in which the catheter opens (that is, whether it has a hole at the end or at the side) is of no importance.

When flow occurs the blood develops kinetic energy, giving rise to a kinetic pressure component, P_k. The pressure sensed (P_s+P_k) will vary according to the relationship of the catheter opening to the direction of flow. If an end hole catheter is used, the kinetic energy effect is maximal because flow is straight into the catheter. The size of the kinetic energy component ($\frac{1}{2}d.v^2$, where d is the density of blood and v is the velocity) is given by Bernoulli's theorem and is proportional to the square of the blood velocity. Assuming a high mean aortic blood velocity of 40 cm/second, the size of this kinetic pressure component is only 0·6 mm Hg, which is less than 2% of the total mean pressure. During systole, the flow velocity increases to a peak which is approximately three times the mean and P_k increases to 5·7 mm Hg or about 10% of the total systolic pressure. Similarly, P_k will also increase as cardiac output increases. A side hole catheter—where the opening of the catheter is at right angles to the direction of flow—minimises this artifact. Against this theoretical advantage of a side hole catheter, however, must be set the more practical one that these catheters tend to become blocked by blood clot more quickly than end hole catheters.

The reference level component, P_r, is due to the difference in height between the two ends of the catheter. P_r will be zero if the transducer is placed at the same level as the catheter opening.

A further theoretical consideration when selecting a transducer is to choose one with a frequency response which will provide a reasonable representation of the arterial pressure wave. The number of harmonics required relate to the shape of the signal and the accuracy required. For arterial pressure, reproduction using at least seven, and preferably 10, harmonics will give sufficient accuracy.[15] The fundamental frequency of the blood pressure wave is the pulse rate, which is less than 4 Hz, and an arterial pressure transducer for neonatal use has therefore to be able to record at $4\ Hz\times7=28$ Hz. This may be compared with a system intended for adult use, which has to achieve only half of this frequency response.

Two sources of error are particularly noteworthy. A catheter of too small diameter will act as a low pass filter with loss of higher frequencies resulting in under reading particularly of systolic pressures. Another frequent and substantial source of error is the introduction of small air bubbles. Their effects may be explained in terms of the concepts of resonant frequency, underdamping, and overdamping. A perfect transducer should represent a perfectly sinusoidal pressure waveform of any frequency. As with all mechanical systems, a catheter transducer system will resonate at a particular frequency, that is, the amplitude of a measured waveform of that frequency will be selectively increased rather than being truly represented. If a system is to be useful for the practical measurement of arterial blood pressure, the resonant frequency should be as high as possible and beyond the range of frequencies of interest. Thus in the above example, it should be several times greater than 28 Hz. If overdamping or underdamping or resonance occurs, the high harmonics of the signal will be most affected and there will be greater error in the measurement of systolic and diastolic pressures than in the measurement of mean arterial pressure.[13] In a resonating system, systolic and diastolic pressures will be too high and too low respectively. The effect of an underdamped system will be the same,[16] whereas an overdamped system will result in the systolic reading being too low and the diastolic reading being too high. This constitutes another reason for clinicians placing more weight on the mean than on systolic or diastolic pressures.

From a practical point of view, the dicrotic notch on the downward slope of the waveform on the

Table *Mean blood pressure, birth weight, and postnatal age. Results (in mm Hg) are given as 10th percentile (mean)**

Birth weight (g)	*Postnatal age (hours)*								
	3	*12*	*24*	*36*	*48*	*60*	*72*	*84*	*96*
500	23 (35)	24 (36)	25 (37)	26 (38)	28 (39)	29 (41)	30 (42)	31 (43)	33 (44)
600	24 (35)	25 (36)	26 (37)	27 (39)	28 (40)	29 (41)	31 (42)	32 (44)	33 (45)
700	24 (36)	25 (37)	26 (38)	28 (39)	29 (42)	30 (42)	31 (43)	32 (44)	34 (45)
800	25 (36)	26 (37)	27 (39)	28 (40)	29 (41)	31 (42)	32 (44)	33 (45)	34 (46)
900	25 (37)	26 (38)	27 (39)	29 (40)	30 (42)	31 (43)	32 (44)	34 (45)	35 (47)
1000	26 (38)	27 (39)	28 (40)	29 (41)	31 (42)	32 (43)	33 (45)	34 (46)	35 (47)
1100	27 (38)	27 (39)	29 (40)	30 (42)	31 (43)	32 (44)	34 (45)	35 (46)	36 (48)
1200	27 (39)	28 (40)	29 (41)	30 (42)	32 (43)	33 (45)	34 (46)	35 (47)	37 (48)
1300	28 (39)	29 (40)	30 (41)	31 (43)	32 (44)	33 (45)	35 (46)	36 (48)	37 (49)
1400	28 (40)	29 (41)	30 (42)	32 (43)	33 (44)	34 (46)	35 (47)	36 (48)	38 (49)
1500	29 (40)	30 (42)	31 (43)	32 (44)	33 (45)	35 (46)	36 (48)	37 (49)	38 (50)

*Data obtained by birthweight specific regression for mean arterial pressure on postnatal age using data from 131 infants.[18]

visual display unit is most sensitive to changes in the higher harmonics. If the dicrotic notch becomes distorted—it is usually absent when overdamping occurs—the presence of an air bubble in the catheter transducer system should be suspected.

Some other practical considerations

There are some contentious areas: should the tip of the catheter be in a mid-thoracic position or below the origins of the renal arteries? How long should a catheter be left in situ? What are the indications for its removal?

A straw poll of 26 neonatal intensive care units in the United Kingdom showed that 18 favoured a high position whereas five preferred the catheter tip to be below L2, the level of the origins of the renal arteries, two used a high position for infants below 1000 g and a low position for infants above 1000 g, and one centre was conducting a randomised trial to compare the two positions. At Liverpool Maternity Hospital the tip of the catheter is usually sited just above the level of the diaphragm—unless the radiograph performed to check its position shows it to be in the abdominal aorta, in which case it is pulled back to L3/4. Our only absolute indication for catheter removal is ischaemia of the lower limbs or buttocks which does not improve after infusion of plasma. We have no set time limit for removal of a catheter.

Measurements of blood pressure from umbilical arterial catheters have been shown to correlate well with those measured from peripheral arteries.[17]

There are transducers that have pressure domes for multiple use and that are able to withstand chemical sterilisation a number of times. Because this is awkward and time consuming, disposable domes have increased in popularity. Nowadays completely disposable transducers are available. These may be packed with a complete set of lines and flushing devices and are to be recommended for those nurseries where blood pressure monitoring is only undertaken intermittently and where the prospect of assembling a complicated reuseable system may be daunting.

Normal ranges of blood pressure

There is a paucity of data for the very low birthweight infant. Blood pressure data from 131 infants who had peripheral or umbilical arterial lines with end holes and who were admitted to Mersey regional neonatal intensive care unit have been recently collected.[18] Birthweight specific regression for mean arterial pressure on postnatal age was calculated using data from survivors unaffected by drugs. These data are reproduced in the table. The 10th percentile in this study was similar to previously published normal data for blood pressure in infants below 1000 g.[19]

Conclusions

Close monitoring of blood pressure and the correction of hypotension have become an important and essential part of modern neonatal intensive care. Non-invasive techniques for blood pressure measurement are particularly unreliable in small sick infants. Such children should have their blood pressure monitored by means of a transducer attached to an intra-arterial catheter wherever possible. The measurement of mean arterial pressure is less prone to error than systolic or diastolic pressures.

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