Comparison of Blood Pressure in Mature and Premature Neonates Using Direct and Indirect Methods of Measurement

Ching-Wen Liu¹,², Shu-Jen Chen¹, Betau Hwang¹

The aim of this study was to evaluate the correspondence of blood pressure (BP) measured using the direct intra-arterial method and indirect oscillometric monitor method. Twenty-three newborns with radial arterial catheters inserted were enrolled in this study. The gestational age (GA) ranged from 25-40 weeks and birth weight (BW) ranged from 700-3,550 g. Direct BP was measured using radial arterial catheters. Indirect BP was concurrently measured from the contralateral forearm using an oscillometric monitor. The systolic BP (SBP), diastolic BP (DBP), and mean BP (MBP) obtained using these two methods were analyzed. Although there was a significant correlation between the pairs of readings for SBP, DBP, and MBP (r = 0.80, 0.70, 0.83, respectively, p < 0.001 for all); the 95% confidence intervals for individual measurements exceeded 20 mm Hg for SBP and DBP, and 15 mm Hg for MBP. SBP, DBP, and MBP obtained using the indirect method of measurement were significantly different from those obtained using the direct method (p < 0.001 for all). The pressure differences and percentage of error were greater in groups of direct MBP > 35 mm Hg, GA > 32 weeks, and BW > 1,500 g than in groups of direct MBP ≤ 35 mm Hg, GA ≤ 32 weeks, and BW ≤ 1,500 g. In conclusion, for MBP, the discrepancy found between these two methods of measurements was clinically acceptable. For SBP and DBP, there was a large variability between these two methods. It is not appropriate to interpret the indirect oscillometric BP readings according to these available normative direct BP values. Direct BP monitoring should be used in newborns in intensive care. Cautious interpretation of oscillometric BP values for newborns in intensive care is mandatory.

Key words: direct intra-arterial blood pressure, indirect oscillometric blood pressure

Blood pressure (BP) measurement is a valuable diagnostic aid in newborns. In practice, the BP of newborns is usually obtained indirectly using the oscillometric technique or occasionally directly by intra-arterial readings. The indirect oscillometric BP monitor is a popular, convenient device found in modern neonatal intensive care units. However, there are no complete normative oscillometric values for premature neonates or newborns in critical condition [1-3]. Most BP values for premature neonates are based on the intra-arterial method [4-9], Doppler method [10], or derived from healthy full-term neonates [11-14]. Furthermore, the question of whether the oscillometric readings reflect the intra-arterial values accurately remains. Some authors doubted the accuracy of the values in sick newborns and found it unreliable in low BP ranges, and unsafe for use in the very low birth weight infants [15, 16]. The purpose of this study is to evaluate the correspondence of BP measured using these two methods, and to assess whether the indirect oscillometric BP could be used instead of the direct intra-arterial BP.

Subjects and Methods

From June 1997 through January 1998, 23 newborns admitted to the neonatal intensive care unit at the Department of Pediatrics, Veterans General Hospital-Taipei with radial arterial catheters inserted were enrolled in this study. Newborns with congenital heart diseases, in shock, or receiving vasoactive agents were excluded.

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Direct BP were measured through 24-gauge radial arterial catheters (Introcan®, 0.7 x 19 mm). The arterial catheter was connected to a Hewlett Packard disposable pressure transducer (1290C, universal quartz) by a polyethylene non-compliant connecting tube (MX 663, 91.4 cm in length and 1.14 mm in internal diameter). To prevent the entrapment of air bubbles and formation of blood clots in the line, the arterial system was kept patent by continuous infusion of heparinized solution (1 u/cc) at a rate of 1-3 ml/hour controlled by a Top-5100 syringe pump. The transducer was connected to a Hewlett Packard omnicare CMS 24 monitor, which showed a continuous waveform of the intra-arterial BP during the study. The zero reference point of the transducer was adjusted at the level of the mid-thorax of the newborns. Prior to each study, the catheter was flushed, and the waveform of the arterial pressure was examined, thus ensuring the absence of air bubbles, blood clots, or the occurrence of any damping.

The indirect BP was measured over the contralateral forearm with the Hewlett Packard omnicare CMS 24 monitor. The circumference of the mid-portion of the forearm was measured. The selection of BP cuff size was according to the recommendation of the manufacturer. Cuff sizes #1, #2, #3, and #4, corresponding to cuff width 2.3 cm, 3.0 cm, 3.9 cm, and 4.2 cm, were used for newborns with limb circumferences of 3.1-5.7 cm, 4.3-5.2 cm, 5.8-10.9 cm, and 7.1-13.1 cm, respectively. The newborns were quiet and in a supine position during the measurement. Direct and indirect systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean blood pressure (MBP) were obtained at 1-hour intervals simultaneously until removal of radial arterial catheter or occurrence of damping wave.

Statistical package for the Social Science for Windows program was used for all the statistical analyses. Data were presented as mean ± SD. To determine the relationship between the direct and indirect BP values, linear regression analysis, Pearson correlation coefficient, and 95% confidence intervals for mean and individual measurements were done for the following pairs of data: (1) direct SBP vs. indirect SBP, (2) direct DBP vs. indirect DBP, (3) direct MBP vs. indirect MBP. In addition, the pressure differences (indirect BP minus direct BP) measured by two different methods were compared by the paired-samples Student’s t test. For each pair of measurements, the pressure differences were plotted against direct BP values. The measured BP data were analyzed initially in the whole sample. The pressure differences and percentage of error (pressure difference divided by direct BP) were further analyzed by the independent-samples Student’s t test in the following groups: (1) direct MBP ≤ 35 mm Hg vs. direct MBP > 35 mm Hg, (2) gestational age (GA) ≤ 32 weeks vs. GA > 32 weeks, and (3) birth weight (BW) ≤ 1,500 g vs. BW > 1,500 g. A two-tailed p value less than 0.05 was considered significant.

Results

Population Characteristics

The study population consisted of 23 newborns with GA from 25 to 40 weeks (median, 34 weeks) and BW from 700 to 3,550 g (2,015 ± 1,004 g). There were 16 boys (69.6%) and 7 girls (30.4%). The age at study ranged from 1 hour to 4 days and 7 hours (median, 13 hours). Fifteen patients (65.2%) suffered from hyaline membrane disease, and other diseases included four with sepsis (17.4%), three intraventricular hemorrhage with or without hydrocephalus (13%), three perinatal asphyxia (13%), three hyperbilirubinemia (13%), two persistent pulmonary hypertension (8.7%), two necrotizing enterocolitis (8.7%), two meconium aspiration syndrome (8.7%), one meningitis (4.4%), and one imperforate anus (4.4%). Of the 23 newborns, four (17.4%) received high frequency oscillometric ventilation, 12 (52.2%) used conventional mechanical ventilation, and five (21.7%) received continuous positive airway pressure. A total of 1,139 pairs of simultaneous measurements for SBP, DBP, and MBP were collected. The average number of measurements for each patient was 49.5 ± 23.7 (range, 10-99). The average ratio of cuff width to circumference of forearm was 0.44 ± 0.04 (range, 0.39-0.51).

Correlation of Direct and Indirect BP Values

Figure 1 illustrates the relationship of direct and indirect values for SBP, DBP, and MBP. The Pearson correlation coefficient r between two methods were 0.80, 0.70, 0.83 for SBP, DBP, and MBP, respectively, and the linear correlation was statistically significant (p < 0.001 for all). Also shown are the linear regression equations, 95% confidence intervals for mean (indicating that for a given direct value, 95% probability of the mean of multiple indirect measurements will be within the range) and for individual measurements (indicating that for a given direct value, 95% probability of indirect measurement will be within the range). Although the 95% confidence intervals for the mean was less, the 95% confidence intervals for individual measurements were of great range, exceeding 20 mm Hg for SBP and DBP, and 15 mm Hg for MBP, respectively.
Figure 1. The relationship between direct and indirect blood pressure data. The Pearson correlation coefficient, linear regression equation, linear regression line (central solid line), 95% confidence intervals for mean (dotted lines near the regression line), and 95% confidence interval for individual data (dotted lines far from the regression line) were shown. SBP: systolic blood pressure, DBP: diastolic blood pressure, MBP: mean blood pressure.

Figure 2. The distribution of the pressure differences against the direct blood pressure data. The mean difference (central solid line) and 95% confidence intervals for individual data (dotted lines) are presented. SBP: systolic blood pressure, DBP: diastolic blood pressure, MBP: mean blood pressure.
**Discrepancy between Direct and Indirect BP Values**

For SBP, DBP and MBP, the pressure difference was 7.3 ± 6.4 mm Hg, -5.0 ± 6.9 mm Hg and -1.6 ± 5.0 mm Hg, respectively. (p<0.001 for all). Figure 2 displays the pressure differences against the direct SBP, DBP, and MBP values. The 95% confidence intervals are also shown in each figure. The pressure difference more than 10 mm Hg occurred in 30.3% measurements for SBP, 21.2% for DBP, and 5.6% for MBP.

**Comparison between Different direct MBP, GA, BW Groups**

The pressure differences and percentage of error among different groups are listed in Tables 1 and 2. The pressure differences was significantly greater in the groups of direct MBP > 35 mm Hg, GA > 32 weeks, and BW > 1,500 g than in groups of direct MBP ≤ 35 mm Hg, GA ≤ 32 weeks, and BW ≤ 1,500 g (p < 0.001 for all). When the percentage of error was calculated, similar results were also found, although it was not statistically significant in comparing SBP.

**Table 1. Comparison of pressure differences between different direct MBP, GA, and BW groups**

<table>
<thead>
<tr>
<th>direct MBP</th>
<th>direct MBP</th>
<th>GA</th>
<th>GA</th>
<th>BW</th>
<th>BW</th>
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<tr>
<td>≤35mmHg</td>
<td>&gt;35mmHg</td>
<td>≤32 weeks</td>
<td>&gt;32weeks</td>
<td>≤1500g</td>
<td>&gt;1500g</td>
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<tr>
<td>ΔP</td>
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<tr>
<td>SBP</td>
<td>4.9±6.7</td>
<td>7.6±6.3</td>
<td>6.2±7.2</td>
<td>8.0±5.8</td>
<td>6.3±6.6</td>
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<tr>
<td></td>
<td>(p&lt;0.001)</td>
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<tr>
<td>DBP</td>
<td>-0.5±5.5</td>
<td>-5.5±6.8</td>
<td>-1.6±5.1</td>
<td>-7.1±7.0</td>
<td>-2.6±5.2</td>
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<td>(p&lt;0.001)</td>
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<tr>
<td>MBP</td>
<td>0.6±3.1</td>
<td>-1.9±5.2</td>
<td>0.1±4.0</td>
<td>-2.6±5.4</td>
<td>-0.5±3.8</td>
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<td>(p&lt;0.001)</td>
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SBP: systolic blood pressure, DBP: diastolic blood pressure, MBP: mean blood pressure, GA: gestational age, BW: birth weight, ΔP: (indirect-direct) blood pressure difference.

**Discussion**

The relationship between direct and indirect BP measurements has been studied by several authors. In previous reports, the direct BP readings were obtained from the umbilical artery [15, 17-19], radial artery, dorsalis pedis [20], or mixed different arterial sources [16, 21-24]. The corresponding indirect BP readings were obtained from brachial or femoral artery [15, 17-25]. The amplification of blood pressure from the aorta to peripheral artery is a well-known phenomenon; this may contribute to the pressure difference if one measured site was distal to another [26]. In our study, we measured at the radial artery for direct BP and at the contralateral forearm for indirect BP to avoid such unwarranted error, since BP differences between the left and right extremities are negligible [27]. Although some papers included data from patients with heart anomalies [22, 23], we excluded newborns with congenital heart diseases because the presence of left ventricular outflow tract obstruction or significant shunt through a patent ductus arteriosus may result in BP difference between these two sides [28].

In our study, a significant correlation between direct and indirect BP readings was demonstrated, especially for MBP which gave the best correlation with a r value of 0.83. Previous observations also showed correlation with a r value varying from 0.49 to 0.99 in newborns and 0.63 to 0.99 in children [15-18, 20-24]. Friesen et al concluded the oscilometric method is an accurate noninvasive method for monitoring BP in infants [21]. However, it should be noted that the high correlation of the two methods does not mean close agreement between them. Our results revealed that data obtained using the indirect method was significantly different from those measured using the direct method.

Indirect SBP was always higher than corresponding direct SBP by a value of 7.3 ± 6.4 mm Hg, whereas the pressure difference was -5.0 ± 6.9 mm Hg and -1.6 ± 5.1 mm Hg for DBP and MBP, respectively. Only the MBP fit the criteria for BP monitoring device, in which the average difference should be within ±5 mm Hg and SD within ±7 mm Hg [29]. Furthermore, as shown in Figures 1 and 2, although the 95% confidence intervals for the mean was narrow, the 95% confidence intervals for...
individual measurements were wide, approximately having a range of 20 mm Hg for SBP and DBP, 15 mm Hg for MBP. Discrepancies of more than 10 mm Hg occurred in 30.3% of SBP readings, 21.2% of DBP, and only 5.6% of MBP. These observations imply that there is considerable individual variability and single readings may be inaccurate, although the average of multiple readings may give a more accurate assessment. Such a discrepancy in BP measurement may cause problems in clinical interpretation for newborns in intensive care, since the oscillometric BP standards are not complete. Obviously, it is also dangerous to interpret the indirect oscillometric BP readings according to the available normative direct BP values.

The observed BP discrepancy between two methods in our study may be attributed to the following reasons. First, the mechanisms of direct intra-arterial BP monitoring and indirect oscillometric device were different in nature. The former gives the beat-to-beat (ie, real-time) BP change. The latter displays the BP data after the inflation-deflation cycle and gives an average BP change, in which several heart cycle has occurred. In addition, the cuff used in oscillometric device deflated in several mm Hg increments, rather than a single 1 mm Hg increment [24]. Second, the cuff width to limb circumference ratio may be an associated factor. The BP reading may be erroneously high, if the cuff is too narrow; or erroneously low, if it is too wide. In our study, the average ratio was 0.44 ± 0.04 (range, 0.39-0.51). Our ratio is compatible with the recommendation of the American Heart Association that the width of the inflatable bladder be more than 40% of the circumference of the mid-point of the limb [30]. It is also similar to the findings of Sonesson et al in an umbilical arteries study that showed more accurate MBP measurements were recorded with a cuff width to arm circumference ratio of 0.44-0.55 [19]. Whereas it was contrary to the observation by Kimble et al in which there was a sharp increase in the mean error when the ratio fell below 0.45, a less dramatic increase when it exceeded 0.70, and an error of -0.2 ± 3.8 mm Hg when the ratio was between 0.45 and 0.70 [17]. Pilossof et al evaluated infants with congenital heart defects after operation who required an indwelling radial arterial catheter or femoral arterial catheter, and they suggested the best correlation between oscillometric and direct BP measurements was obtained with a ratio of 0.38-0.41 [23]. Moreover, in comparing with umbilical BP, Briassoulis stated that changing the cuff size did not reduce inherent errors in the oscillometric method, in which both of the recommended cuff size and the larger size cuff were used [24]. We were unable to analyze or verify this result due to lack of data. Further investigation is required to establish the role of cuff width in our population.

In comparing MBP ≤ 35 mm Hg vs. MBP > 35 mm Hg group, GA ≤ 32 weeks vs. GA > 32 weeks group, and BW ≤ 1,500 g vs. BW > 1,500 g group, both the pressure differences and the percentage of errors were larger in the groups of MBP > 35 mm Hg, GA > 32 weeks, and BW > 1,500 gm. We agree with the research by Diprose et al which showed that the oscillometric device fails to detect hypotension in very low birth weight infants and the data from Chia et al which showed that the Dinamap oscillometric BP monitor is unreliable for clinical use for sick neonates when intraarterial MBP is 35 mm Hg or below [15, 16]. However, we also found this false estimation tends to be larger in higher MBP, higher GA, and higher BW groups. As outlined above, the possible cause of the variation among our data and their data is that they combined the umbilical artery and peripheral artery as the direct arterial BP source, while we only measured the radial artery for direct BP.

In conclusion, although there was a significant linear correlation between the direct and indirect readings for SBP, DBP, and MBP, the BP data obtained by the indirect method was significantly different from those of direct method. Only the discrepancy for MBP was clinically acceptable. There was large variability in the differences for SBP and DBP. Therefore, this study suggests that it is inappropriate to interpret the indirect oscillometric BP readings according to the available normative direct BP values. Direct BP monitoring should be used to measure BP in newborns in intensive care. Cautious interpretation of indirect oscillometric BP data is mandatory until its own complete normative BP reference in newborns is available.

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