

## Comparison of noninvasive techniques to measure blood pressure in newborns

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### Abstract

**Objective:** To compare blood pressure measurements in newborn infants using the flush method, pulse oximetry and oscillometry according to Doppler findings.

**Methods:** Noninvasive blood pressure measurements were made using three techniques (flush method, pulse oximetry and oscillometry) in three groups of newborns: 15 normal term infants, 16 stable preterm infants, and 14 critically ill infants. All measurements were video recorded, edited separately, coded and analyzed independently by three neonatologists.

**Results:** Fifty-seven measurements were made using each method. The flush method and pulse oximetry had a better correlation with Doppler findings than oscillometry (correlation coefficients: 0.89, 0.85, 0.71;  $p < 0.01$ ). The difference between measurement means, their standard deviations and the 95% confidence intervals when compared with Doppler findings were:  $-5.2 \pm 7.9$  ( $-21.1:10.7$ ) mmHg for the flush method;  $0.4 \pm 8.9$  ( $-17.5:18.2$ ) mmHg for pulse oximetry; and  $6.4 \pm 16.1$  ( $-25.8:8.6$ ) mmHg for oscillometry. The flush method had a better agreement with Doppler findings for the diagnosis of hypotension than oximetry and oscillometry.

**Conclusions:** The flush method and pulse oximetry seem to be useful techniques to measure systolic blood pressure in newborn infants; oscillometry had the poorest agreement with Doppler findings to detect hypotension.

*J Pediatr (Rio J). 2011;87(1):57-62: Hypotension, systolic blood pressure, newborn infant.*

### Introduction

Blood pressure measurements are essential for the management of newborn infants, particularly when preterm. However, several factors make its measurement and interpretation difficult in this population: the variable arm size, differences in gestational age and weight, and hardly audible Korotkoff sounds.<sup>1,2</sup>

Invasive monitoring is the most accurate blood pressure measurement method, but requires the use of an umbilical artery catheter or peripheral arterial line and is associated with complications, such as infection, vasospasm and thrombus formation.<sup>2-7</sup> At the same time, indirect blood pressure measurement methods have been

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No conflicts of interest declared concerning the publication of this article.

**Suggested citation:** Ribeiro MA, Fiori HH, Luz JH, Piva JP, Ribeiro NM, Fiori RM. Comparison of noninvasive techniques to measure blood pressure in newborns. *J Pediatr (Rio J)*. 2011;87(1):57-62.

Manuscript submitted Aug 05 2010, accepted for publication Oct 15 2010.

doi:10.2223/JPED.2059

shown to be reliable and consistent if recorded under standardized conditions and using a properly functioning sphygmomanometer.<sup>1</sup>

The most important noninvasive monitoring techniques are Doppler ultrasound, oscillometry, the flush method and pulse oximetry.<sup>2,4,5,8-10</sup> Blood pressure measured using a Doppler ultrasound device connected to a mercury sphygmomanometer has a good correlation with invasive blood pressure measurements in newborns.<sup>11</sup>

Oscillometry is widely used in neonatal intensive care units (NICU) because of its practicality.<sup>2,12,13</sup> The device automatically inflates the cuff and, during deflation, measures pulse oscillation and amplitude, determines systolic and mean blood pressure and uses these values to calculate diastolic blood pressure.<sup>4-6,14</sup> However, international studies to evaluate the accuracy and validate the use of oscillometry devices have reported conflicting results.<sup>12,15-17</sup>

The flush method is a technique based on the visualization of return of the blood flow to the distal end of an extremity during deflation of the sphygmomanometer cuff, and it is easy to use in awake infants.<sup>8,10,18</sup> The latest study about this technique was published in Brazil over 25 years ago.<sup>19</sup> Measurements using this method may be limited by severe anemia, edema, hypothermia and blood pressure values below 20 mmHg.<sup>20</sup>

Systolic blood pressure measured by pulse oximetry is characterized by the disappearance and reappearance of the waveform on the monitor screen during cuff inflation, deflation, or both.<sup>21</sup> The few studies with newborn infants using this technique found a good correlation with invasive monitoring.<sup>5,20-22</sup>

A review of the literature in the MEDLINE database did not yield any comparative blinded studies of noninvasive blood pressure measurements using the flush method and pulse oximetry in newborn infants.

In this study, blinded examiners compared the measurements of systolic blood pressure using the flush method, oscillometry and pulse oximetry with the systolic blood pressure measured using Doppler ultrasound and a mercury sphygmomanometer.

## **Patients and methods**

This cross-sectional study was conducted from December 2006 to April 2007 in the NICU and rooming-in ward of Hospital São Lucas of Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS), Porto Alegre, Brazil. Study patients were divided into three groups: normal newborn infants - birth weight greater than 2,000 g and gestational age  $\geq$  35 weeks (group 1); stable preterm newborn infants - current weight below 1,800 g (group 2); and clinically unstable preterm newborn infants (group 3). Infants in group 3 were

included if they met at least one of the following criteria: continuous positive airway pressure with inspired oxygen fraction greater than 0.3 or mechanical ventilation; septic shock; symptomatic congenital heart disease; postoperative recovery after cardiac surgery; necrotizing enterocolitis; signs of active bleeding; renal insufficiency; and grade III and IV intracranial hemorrhage. Newborn infants were excluded if they had venous or arterial lines in both upper extremities or if their parents or guardians did not grant informed consent.

All the blood pressure measurements in newborn infants were made by one of the authors in a well-lit room. The newborn infants were placed in supine position, and the examiners waited until they were quiet. No sedation drug was used, except for the critically ill infants that had a clinical prescription for it. Heart beats and oxygen saturation for each newborn infant were recorded continuously during measurements.

The use of a cuff bladder followed international guidelines.<sup>14</sup> Its width was about 40% of mean arm circumference and covered 80 to 100% of that circumference. The cuff was placed in the right arm and connected to a desktop mercury sphygmomanometer (Premium, Glicomed®, São Paulo, Brazil).<sup>14</sup> The flush method and pulse oximetry measurements were made with double tube latex-free neonatal cuffs (Classic-cuf, Critikon Vital Aswers®, Atlanta, USA), and the oscillometry measurements, with single tube cuffs (Classic-cuf, Datascope®, New Jersey, USA).

Doppler ultrasound measurements of blood pressure were made at the same time as each method under test. A portable transducer (DV-10, Microem®, Ribeirão Preto, Brazil) with conducting gel was placed on the cubital fossa, and slight pressure was applied to obtain an audible sound. The systolic blood pressure value was determined by the onset of shift signals generated by the movement of the brachial artery.

In the flush method, the examiner gently compressed the infant's hand with enough force to make the skin look pale. After that, the cuff was inflated to 90 mmHg, as previously described.<sup>10</sup> In case pulse was still audible using Doppler ultrasound at this pressure, the cuff was further inflated up to 10 mmHg above the value at which the pulse disappeared. The newborn's hand was immediately released and the cuff pressure was reduced 4 to 6 mmHg at 3 to 5 s intervals until zero was reached in the sphygmomanometer. During release, the hand was carefully observed and, when any change in skin color was seen (flush), the pressure reading in the mercury sphygmomanometer was recorded.

To measure blood pressure using pulse oximetry, the pulse oximetry sensor (DX2515, Dixtal®, Manaus, Brazil) was connected to the newborn's hand and the same cuff inflating and deflating procedures described for the flush method were repeated. When the pulse signal was seen

on the oximeter screen again, the pressure reading on the mercury sphygmomanometer was recorded.<sup>21</sup>

To measure blood pressure using oscillometry, a noninvasive automatic device (Accutorr Plus· Datascope®, Mahwah, NJ), recently validated for use in pediatrics, was used. For the simultaneous measurement with Doppler ultrasound, the oscillometry monitor and a desktop mercury sphygmomanometer were connected to a single tube cuff using a three-way stopcock (Luer Lock, Elcam Medical®, Bar'Am, Israel).

Blood pressure measurements using Doppler ultrasound were made at the same time as the other techniques in the following order: 1) flush method; 2) pulse oximetry; 3) oscillometry. Measurements were made at intervals of at least 2 min between each other. This sequence was adopted to reduce newborn handling and to facilitate measurements and recordings. One blood pressure measurement using each method was made for each newborn infant. For some critically ill newborn infants, sequential measurements using all methods were made at an interval of 1 to 2 h.

The main variables were blood pressure measured using the flush method, systolic blood pressure measured using oscillometry, and systolic blood pressure using pulse oximetry. The independent variable was systolic blood pressure measured using Doppler ultrasound. All blood pressure values were recorded in mmHg. Secondary variables were hypotension and measurement time for each method. Hypotension was defined as Doppler ultrasound systolic blood pressure measurements below 2 standard deviations of mean values recommended for term newborn infants<sup>1</sup> and below the 10th percentile of the values for preterm infants.<sup>11</sup>

All measurements were video recorded and the images were edited, coded and randomly recorded in DVD to avoid identification of the measurements made. For all measurements, the mercury sphygmomanometer was video recorded with audio to enable the detection of the Doppler ultrasound signals. In the flush method, recordings focused on the newborn's hand during measurement; for the pulse oximetry, the oximeter display was focused. DVD recordings were evaluated by three neonatologists that did not participate in measurements. Systolic blood pressure for each method was defined as the mean values determined by the examiners. This study was approved by the Ethics and Research Committee of PUCRS and, before patient inclusion in the study, parents or guardians signed an informed consent term.

Sample size for 45 measurements for each method (15 in each group of patients) was calculated for a 90% power to detect a difference of at least  $5 \pm 4$  mmHg between techniques. The level of significance was set at  $p < 0.05$ .

The PASW® 17.0 for Windows was used for statistical analyses. Continuous variables were expressed as mean

and standard deviation. The Pearson linear regression was used to determine the correlations between blood pressure values using Doppler ultrasound and the methods under test. The Bland-Altman plot<sup>24</sup> was used to determine the limits of agreement between the techniques evaluated and Doppler ultrasound. To detect differences between non-normally distributed variables, the Kruskal-Wallis test was used. A chi-square test was used for categorical variables. The intraclass correlation coefficient (ICC) was calculated to evaluate interobserver agreement.

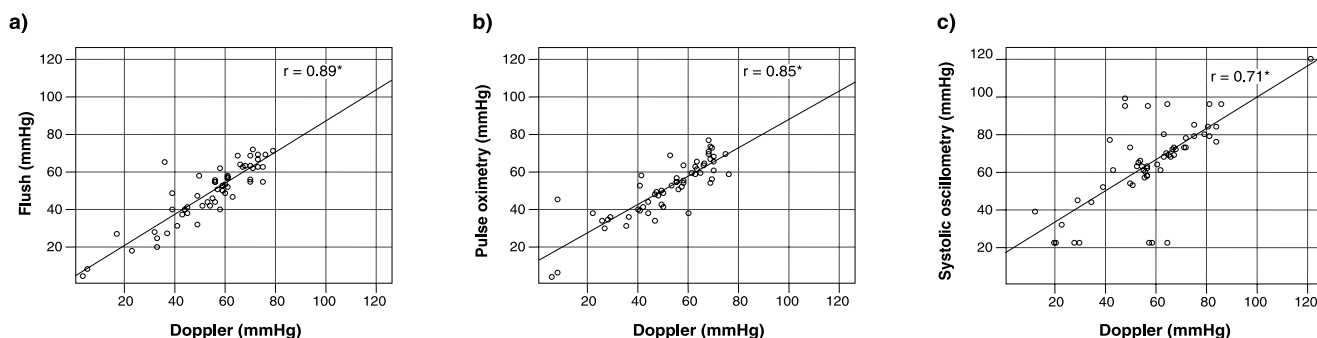
## Results

Fifty-seven measurements were made in 44 newborn infants, 15 in 15 normal term infants, 18 in 16 stable preterm infants and 24 in 14 critically ill infants. A preterm newborn was included in two groups: when critically ill, in group 3, and when stable, in group 2. Mean gestational age and birth weight were  $38 \pm 2$  weeks and  $2,970 \pm 636$  g in group 1,  $31 \pm 3$  weeks and  $1,269 \pm 361$  g in group 2 and  $30 \pm 4$  weeks and  $1,351 \pm 852$  g in group 3.

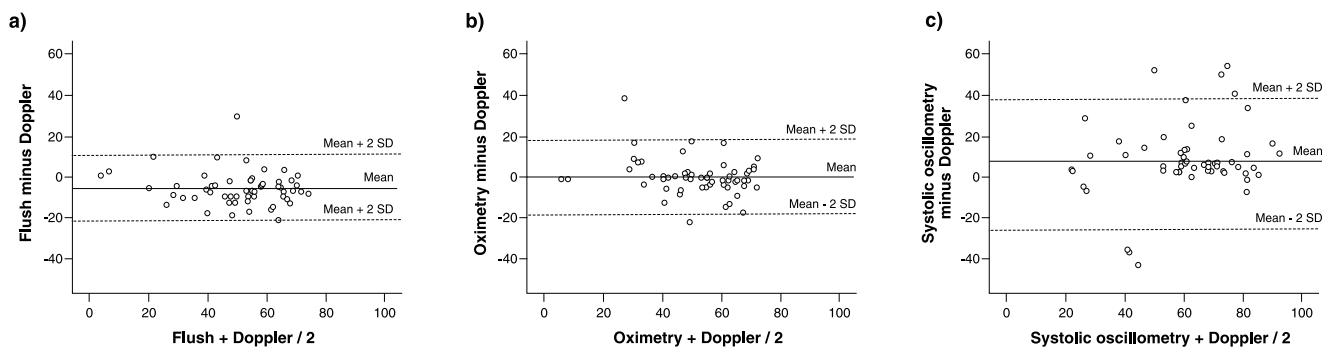
Median age (interquartile range) at time of blood pressure measurements was 2 d (8 h to 4 d) for normal newborn infants, 11 d (5 to 16 d) for stable infants, and 20 d (1.4 to 39 d) for critically ill infants. The left arm was used in 14 (24.6%) blood pressure measurements. Hemoglobin values below 9 g/dL were found in 5 (35.7%) of the critically ill newborns, and 13 (54.2%) measurements were made in this group. There were no difficulties in measuring blood pressure in these newborns. No infant had hypothermia or edema of extremities during measurements.

All methods had a good correlation with Doppler ultrasound findings, and the flush method and pulse oximetry had the best correlation (Figure 1). There was good agreement between systolic blood pressure values obtained using Doppler ultrasound, blood pressure values using the flush method, and systolic blood pressure values using pulse oximetry, whereas systolic blood pressure values using oscillometry had the greater dispersion (Figure 2). Mean differences between Doppler ultrasound findings and the other methods were  $-5.2 \pm 7.9$  (95%CI,  $-21.1:10.7$ ) mmHg for the flush method,  $0.4 \pm 8.9$  (95%CI,  $-17.5:18.2$ ) mmHg for pulse oximetry and  $6.4 \pm 16.1$  (95%CI  $-25.8:38.6$ ) mmHg for oscillometry ( $p < 0.001$ ). In group 3, data showed a difference of  $-3 \pm 10$  (95%CI  $17:24$ ) mmHg for the flush method,  $4 \pm 10$  (95%CI  $16:24$ ) mmHg for pulse oximetry and  $8 \pm 17$  (95%CI  $26:42$ ) mmHg for oscillometry.

Pulses were determined using Doppler ultrasound for all patients. Blood pressures could not be measured using oscillometry in 7 (12.3%) patients, two with normal blood pressure. In 11 cases, systolic blood pressure measurements made in newborns with hypotension had values of  $< 45$  mmHg when using Doppler ultrasound; using oscillometry, pressure



**Figure 1** - Linear regression comparing Doppler ultrasound findings and a) the flush method; b) pulse oximetry; and c) systolic blood pressure using oscillometry ( $r$  = Pearson linear correlation coefficient; \* $p < 0.01$ )



**Figure 2** - Limits of agreement (Bland-Altman plot) of the comparison of Doppler ultrasound findings with: a) the flush method; b) pulse oximetry; and c) systolic blood pressure using oscillometry (SD = standard deviation)

was not detected in four measurements and, in other four measurements, the device showed values greater than 55 mmHg. Blood pressure measurements using the flush method and pulse oximetry were made for all patients.

Doppler ultrasound showed hypotension in 18 measurements made in group 3. Hypotension was also found in the same 18 cases when the flush method was used, in 16 (89%) using pulse oximetry, and in only 9 (50%) when using oscillometry.

Interobserver variation was similar for the three examiners when using the flush method (ICC = 0.92, 95%CI 0.88:0.95), oximetry (ICC = 0.96, 95%CI 0.87:0.95) and Doppler ultrasound (ICC = 0.90, 95%CI 0.87:0.92).

Mean measurement time for oscillometry ( $44 \pm 28$  s) was shorter than for the flush method ( $73 \pm 40$  s) and pulse oximetry ( $61 \pm 32$  s) ( $p < 0.01$ ).

## Discussion

This is the first blinded study using video recordings to compare noninvasive blood measurement methods for newborn infants. The flush method had a better agreement with Doppler findings than oximetry and oscillometry when measuring blood pressure in newborn infants.

Oscillometry has been widely used in the NICU because it is an easy and fast method to measure blood pressure. However, our study demonstrated that systolic blood pressure measured using this technique overestimated the values obtained using Doppler ultrasound for the lowest blood pressure values. Other authors had already reported similar findings for preterm and very low birth weight newborns.<sup>3,11,25</sup> Moreover, oscillometry was unable to measure blood pressure in 12% of the patients. This technique was unreliable due to its inaccuracy, as reported

in other studies.<sup>3,5,11,21,26</sup> In addition, only two oscillometry devices have been validated for use in pediatrics, one of which was used in this study.<sup>23,27</sup> However, no oscillometry device has been validated for use in neonatology.

At the same time, blood pressure measured using the flush method has a good correlation and very close values to those found when using Doppler ultrasound, which suggests that the values obtained using the flush method represent systolic blood pressure, as reported in several studies, and not mean blood pressures, as reported in others.<sup>8,10,19,20</sup> These differences might be assigned to small variations in blood pressure measurement techniques when using the flush method. In our study, cuff deflations occurred every 3 to 5 s, whereas in studies that found that the measurements made using the flush method represented mean blood pressure, deflation was continuous, which might have led to a delay in readings.

The high agreement of the flush method and Doppler ultrasound in detecting hypotension, even at extremely low values, suggests that this technique is appropriate to monitor blood pressure. In our study, the limitations described by other authors for this method have not been found, maybe due to the fact that no infants with hypothermia or edema of the extremities were included.<sup>20</sup>

Pulse oximetry detected blood pressure values very close to those obtained when using Doppler ultrasound, as in other studies.<sup>5,11,21</sup> When compared with the flush method, variability was similar, but Doppler ultrasound detected a greater percentage of hypotension than pulse oximetry. One of the possible disadvantages of the flush method and pulse oximetry is the fact that both require a few more seconds for its performance than oscillometry, but this delay seems to be of little significance in practice.

Some limitations of our study were associated with its methods. To avoid excessive handling, we made only one measurement per technique in each newborn infant, which is usual in clinical practice. Nonsignificant differences in successive blood pressure measurements have been described when using oscillometry.<sup>28</sup> Invasive blood pressure measurements were not used as the criterion standard because the purpose of this study was to compare noninvasive techniques to measure blood pressure in newborn infants. Therefore, it would be unethical, due to risks, to perform that procedure in normal or clinically stable newborns. Moreover, this study did not include a larger number of extremely preterm infants, particularly not in the first hours of life or when they had severe hypotension.

The agreement between blood pressure measurements using oscillometry and Doppler findings was poorer than that obtained for the flush method and pulse oximetry in the diagnosis of hypotension. The flush method seems to be a simple alternative, easy to learn and to apply, and requires only a sphygmomanometer for its performance.

It is easily adapted to different conditions and settings, such as the office, outpatient services and hospitals that lack the equipment necessary for neonatal intensive care. This technique may be useful when blood pressure is not detected using oscillometry, a not infrequent situation, particularly in newborns with hypotension.

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