NEONATE SLEEP

Validation of a New Noninvasive Method to Measure Blood Pressure and Assess Baroreflex Sensitivity in Preterm Infants During Sleep

Stephanie R. Yiailourou, BSc (Hons); Adrian M. Walker, PhD; Rosemary S.C. Home, PhD

Ritchie Centre for Baby Health Research, Monash Institute of Medical Research, Monash University, Melbourne, Victoria, Australia

Study Objectives: Accuracy and precision of a noninvasive device for continuously measuring blood pressure (BP) (Finometer™, FMS, The Netherlands) during sleep was assessed in preterm infants.

Design: Absolute BP beat-to-beat values, interbeat changes, measurement precision, and baroreflex sensitivity were compared with BP measurements from intraarterial catheters.

Participants: Ten preterm infants (gestational age 27-36 weeks; birth weight 964-2620 gm) were studied in the neonatal intensive care unit.

Measurements and Results: The 2 modes of BP measurement were compared in 2-minute epochs (n = 10-12/infant). Mean arterial pressure, systolic arterial pressure, and diastolic arterial pressure were analyzed beat to beat, and baroreflex sensitivity was assessed using spontaneous sequence analysis. Mean differences for absolute BP (mm Hg) were as follows: mean arterial pressure, 3 (limits of agreement, -1 to 8); systolic arterial pressure, -4 (-8 to 1); and diastolic arterial pressure, 7 (4 to 10). Mean differences and limits of agreement for interbeat changes were essentially 0 for mean arterial pressure, systolic arterial pressure, and diastolic arterial pressure. Precision (+95% confidence intervals, mm Hg) for the Finometer™ were mean arterial pressure ± 7, systolic arterial pressure ± 8, and diastolic arterial pressure ± 6. Precision was greater for the catheter (mean arterial pressure ± 3, systolic arterial pressure ± 4, and diastolic arterial pressure ± 4). Baroreflex sensitivity calculated from the Finometer™ BP was (mean ± SEM, ms/mm Hg) 1.74 ± 0.23 and, from the catheter system, BP was 1.56 ± 0.21 (p value NS).

Conclusions: The Finometer™ provides accurate measurements of beat-to-beat BP and baroreflex sensitivity. The ability to continuously measure BP and baroreflex sensitivity during sleep in infants may provide vital clues into pathologic conditions associated with impaired autonomic control during sleep.

Keywords: Blood pressure, baroreflex, sleep, cardiovascular control

Citation: Yiailourou SR; Walker AM; Home RSC. Validation of a new noninvasive method to measure blood pressure and assess baroreflex sensitivity in preterm infants during sleep. SLEEP 2006;29(8):1083-1088.

INTRODUCTION

CONTINUOUS MEASUREMENT OF BLOOD PRESSURE (BP) IS READILY AVAILABLE IN CLINICAL SETTINGS SUCH AS INTENSIVE-CARE MONITORING OF CRITICALLY ill infants and adults, where it is usually obtained invasively via arterial catheterization. However, continuous measurement of BP is also desirable for the investigation of the cardiovascular system and its autonomic control during sleep, in which arterial catheterization is problematic. In particular, there has been growing interest in studies related to obstructive sleep apnea syndrome1,2 and the sudden infant death syndrome,3,4 in which altered autonomic BP control during sleep may play a crucial role in the pathophysiology of such syndromes.

Autonomic control of the cardiovascular system relies on the baroreflex mechanism for the short-term control of BP variations. Baroreflex sensitivity (BRS) is commonly assessed by power spectral analysis5 or spontaneous sequence analysis6 with both approaches being dependent on accurate, beat-to-beat BP measurement. Because of ethical constraints on arterial catheterization in infants for research purposes, previous assessments of BRS during sleep have relied on noninvasive techniques, such as oscillometry, that allow only intermittent measurements.10-12

A new noninvasive device, the Finapres™ (TNO, The Netherlands) and its portable version, the Portapres™ (FMS, Finapres Medical Systems BV, The Netherlands), have become available for the continuous measurement of BP in adults. The Finapres™ operates via a photoplethysmographic cuff designed for the adult finger and utilizes the volume clamp method of Penaz™ for BP determination. Several studies have assessed the use of the Finapres™ in preterm infants, with application of the adult-sized finger cuff to the infant’s wrist.14-16 but, as yet, validation of this approach is not complete. Of these studies, 2 reported a good agreement between intraarterial catheters and Finapres™/Portapres™ in measurements of systolic (SAP) and diastolic (DAP) arterial pressure.14,15 However, in the most recent study, Andriessen et al.16 concluded that the Finapres™ provided absolute BP measurements of limited accuracy, though the device accurately measured beat-to-beat changes in BP. In addition to agreement concerns relating to absolute accuracy, these previous studies have been limited to a single measurement in each infant, so that the reproducibility (precision) of repeated measurements within a subject is unknown. Furthermore, although the Finapres™ has been used to determine BRS,17 no comparison with arterial-catheter BRS measurements and no assessment of sleep state has been made. Finally, there is currently no information on the measurement accuracy of the Finapres™ for mean arterial pressure (MAP), the value most commonly used in the clinical setting.

Recently, the Finometer™ (FMS, Finapres Medical Systems, The Netherlands), the successor of the Finapres™, has become commercially available. The Finometer™ offers potential utility for recording beat-to-beat BP and contains an algorithm to reconstruct brachial artery pressure waveforms, but, as yet, this has not been validated or evaluated in infants or preterm infants.

Disclosure Statement
This was not an industry supported study. Drs. Home, Yiailourou, and Walker have indicated no financial conflicts of interest.

Submitted for publication January 2006
Accepted for publication March 2006
Address correspondence to: Rosemary SC Horne, PhD, Ritchie Centre for Baby Health Research, Level 5, Monash Medical Centre, 246 Clayton Rd, Clayton, Victoria, Australia 3168; Tel: 61 3 9594 5100; Fax: 61 3 9594 6811; E-mail: rosemary.horne@med.monash.edu.au

SLEEP, Vol. 29, No. 8, 2006
been validated in infants. Using arterial catheter measurements as the gold standard, the aims of this study were to measure BP during sleep using the Finometer™ and assess its capability in a number of key aspects: (1) accuracy of the absolute values and interbeat values of MAP, SAP, and DAP; (2) reproducibility of repeated measurements (precision) within a subject; and 3) accuracy in estimating BRS using spontaneous sequence analysis.

METHODS

The protocol for this study was approved by the Southern Health and Monash University Human Research Ethics Committees. Written parental consent was obtained for all subjects prior to commencement of the study.

Ten preterm infants (6 girls/4 boys) born at 27 to 36 weeks gestational age (mean 31 ± 1 weeks), with birth weights between 964 and 2620 gm (mean 1624 ± 215 gm) and Apgar scores of 2 to 8 (median 5) at 1 minute and 5 to 9 (median 8) at 5 minutes were recruited from the Neonatal Intensive Care Unit, Monash Medical Centre. Infants were studied 1 to 4 days postnatally. All infants were implanted with arterial catheters for intensive care monitoring prior to enrollment. Only infants approximately 1000 gm or larger were included in the selection criteria, because the BP cuff could not be applied appropriately in smaller infants.

Noninvasive BP Measurement (Finometer™)

BP was measured with the Finometer™ cuff placed around the infant’s wrist. In each subject, an appropriate-sized cuff (small, medium, or large) was selected, and 10 to 12 BP measurements were performed, each of 2 minutes duration, with a 2-minute rest period between successive measurements. The cyclic approach of 2 minutes (off-on) was chosen to avoid venous pooling in the infant’s hand. Following the initial start-up calibration, the automatic calibration (Physiocap) was switched off to ensure an uninterrupted recording. All BP measurements were referenced to heart level via the built-in height-correction system.

Infant sleep states were scored as active sleep, quiet sleep, or indeterminate sleep using behavioral observations based on criteria described for preterm infants.18

Invasive BP Measurement (Agilent™ – Catheter system)

BP was also measured directly via a preexisting 3.5 Fr or 5 Fr intraarterial catheter inserted into the umbilical (n = 9) or ulnar artery (n = 1). Decisions on inserting catheters, as well as the connection, zeroing, calibration, and maintenance were made independently by clinical staff for the care of the infant. To prevent clotting, the catheter was routinely flushed with heparinized saline. The catheter was connected to a pressure transducer and referenced to heart level with a fluid-filled manometer tube.

Physiologic Recordings

Physiologic variables measured for routine clinical monitoring of vital functions during intensive care were recorded and displayed on a patient-monitoring device (Agilent™ monitor, Agilent Technologies, MA). Measurements included BP (3.5-5 Fr catheter), electrocardiogram, and respiration (Kendall Kittycal™ Foam Prewired Neonatal/Pediatric Monitoring Electrodes, The Ludlow Company, Chicopee, MA) and oxygen saturation (Dolphin TM, 2000 Oximetry Sensors, OSS Medical, Singapore). Signals, including Finometer™ BP measurements, were digitized using a 16-channel Powerlab system (ADInstruments, Sydney, Australia) at a sampling frequency of 400 Hz and stored on a personal computer running a specialized program for data storage, analysis, and signal display (Chart 5.0, ADInstruments).

Data Analysis

Absolute BP Beat-to-Beat Values

Absolute beat-to-beat values of MAP, SAP, and DAP were obtained and matched by peak detection using Chart 5.0 software (ADInstruments) for both the Finometer™ (MAPf, SAPf, and DAPf) and catheter-system (MAPc, SAPc, and DAPc) BP measurements. Any sections within the 2-minute epoch containing movement artifact were excluded from further analysis. The difference between the catheter-system and the Finometer™ MAP, SAP, and DAP measurements were calculated for each beat, and a mean value was calculated for each 2-minute recording for each subject. Mean values were calculated for each subject; data was tested for normality using Kolmogorov-Smirnov test and compared using Bland-Altman analysis.19

Interbeat Differences

Inter-beat differences between the Finometer™ and catheter system were compared by calculating the change in BP from one beat to the next and determining the difference between both systems for each beat. Values were compared using Bland-Altman analysis for each subject.

Measurement Precision

Precision (reproducibility) was estimated using the method of Youden20 as the 95% confidence interval (CI) of a single estimate:

\[ CI = 2S \]

And,

\[ S = \sqrt{\frac{\sum d^2}{2(n-1)}} \]

Where, \( S \) equals the standard deviation of single estimate, \( d \) equals the difference of extremes of replicate measurements, and \( n \) is the number of replicates.

The number of replicate measurements (n) for the Finometer™ required to obtain an estimate with precision equal to that of the catheter system was calculated as:

\[ n = \sqrt{\frac{Sf}{Sc}} \]

Where \( Sf \) is the standard deviation of a single estimate for the Finometer™ and \( Sc \) is the standard deviation of a single estimate for the catheter system.

BRS Assessment

BRS was assessed using spontaneous sequence analysis.7,9 Paired MAP and heart period (obtained from the electrocardiogram signal) sequences characterized by an increase or decrease of at

SLEEP, Vol. 29, No. 8, 2006
least 1 mm Hg during 3 or more consecutive beats were identified during each 2-minute epoch. BRS was calculated as the slope of the linear regression of MAP and the proceeding heart period for each sequence and averaged for each 2-minute epoch. Baroreflex sequences were defined by changes in MAP and heart period proceeding in the same direction, ie, sequences having positive slopes. A mean BRS was calculated for each infant for both Finometer™ and catheter-system MAP measurements. A paired Student’s t test was used to compare BRS estimates both within each infant and for pooled subject means.

RESULTS

A typical example of simultaneous BP signals recorded by the catheter and Finometer™ systems is presented in Figure 1. Of the 10 infants studied, 1 infant was excluded (infant 3) because the mean catheter-system BP measurements for this infant were more than 2 SDs above the pooled subject mean, suggesting a zeroing error in this system.

A total of 101 2-minute epochs of simultaneous Finometer™ and catheter-system BP measurements were made. Of these, 58 epochs were analyzed free of movement artifacts, 55 epochs were recorded in active sleep, 1 in quiet sleep, and 2 in indeterminate sleep. Measurements in different sleep states were combined, and a total 11,637 paired beats were analyzed. BRS was assessed in 8 of 10 infants because 1 infant (infant 5) was excluded from BRS assessment related to a poor electrocardiogram signal.

Absolute BP

The ranges of BP (mm Hg) measured by the catheter system (c) and the Finometer™ (f) were 34 to 46 (MAPc) versus 39 to 47 (MAPf), 45 to 62 (SAPc) versus 46 to 61 (SAPf), and 23 to 43 (DAPc) versus 31 to 45 (DAPf). Mean differences (± SEM) and limits of agreement for MAP, SAP, and DAP are presented in Tables 1, 2, and 3, respectively. MAP estimates corresponded most closely with a difference between measurements averaging 3 mm Hg and close limits of agreement (-1 to 8) (Figure 2a). SAP differed by ~4 mm Hg, with limits of agreement of -8 to 1 mm Hg (Figure 2b). DAP differed by 7 mm Hg, with limits of agreement of 4 to 10 mm Hg (Figure 2c).

Interbeat BP

Mean differences and limits of agreement for the interbeat changes recorded by the 2 systems were essentially 0 (< 0.01 mm Hg) for each of MAP, SAP, and DAP.
Precision of BP Measurements

The precision (95% CI, mm Hg) for each of the measurements was MAPc (-1 to 4) versus MAPf (-3 to 10), SAPc (-2 to 6) versus SAPf (-4 to 11), and DAPc (-2 to 5) versus DAPf (-3 to 9).

Numbers of replicates required for the Finometer™ to measure with a precision equal to that of the catheter were 5, 3, and 3 for MAP, SAP, and DAP, respectively.

Baroreflex Sensitivity

BRS data are presented in Table 4. There was no difference between the mean BRS calculated for the Finometer™ (1.74 ± 0.23) and the catheter system (1.56 ± 0.21, p = 0.2). The number of ramps identified to calculate BRS estimates in the catheter system (n = 713) was not different than that in the Finometer™ (n = 679).

DISCUSSION

Our study has demonstrated that the Finometer™ is a useful tool that can measure BP accurately and with high precision in preterm infants during sleep using the adult finger cuff placed around the wrist of the infant. Our findings support those of earlier workers,14,15 who found close agreement between Finometer™ and catheter estimates of SAP and DAP. Our data extend these validations to include MAP estimates. In addition, we have demonstrated that the Finometer™ accurately reconstructs the beat-to-beat BP profile, allowing its application to assess interbeat changes in BP and BRS estimates in the time domain. This is also the first study to assess the precision of single measurement versus repeated measurements of BP within an infant, and we have calculated the number of replicate measurements of BP to match the precision of the Finometer™ to that of the Agilent™ catheter system.

The Finometer™ closely determined MAP, with the mean difference between arterial catheter and Finometer™ measurements being only 3 mm Hg, a difference not considered to be clinically significant in preterm infants with BP typically in the range of 25 to 45 mmHg. This is the first study to compare MAP values between a catheter system and the Finometer™, which is important because, in long-term BP catheter recordings, MAP is least affected by loss of catheter patency and is more reliable than systolic and diastolic pressures.21 Absolute BP values of the Finometer™ underestimated SAP by a mean of -4 mm Hg and overestimated DAP by a mean of 7 mm Hg, indicating that the Finometer™ underestimates pulse pressure, although MAP accuracy is maintained. Our findings are similar to those of Harrington et al,15 who analysed 5-minute epochs of BP in term neonates in intensive care and also found that the Portapres™ underestimated SAP (-2 ± 4 mm Hg) and overestimated DAP by a mean of 7 mm Hg, indicating that the Finometer™ underestimates pulse pressure, although MAP accuracy is maintained. Our findings are similar to those of Harrington et al,15 who analysed 5-minute epochs of BP in term neonates in intensive care and also found that the Portapres™ underestimated SAP by a mean of -4 mm Hg and overestimated DAP by a mean of 7 mm Hg, indicating that the Finometer™ underestimates pulse pressure, although MAP accuracy is maintained.

Our findings are similar to those of Harrington et al,15 who analysed 5-minute epochs of BP in term neonates in intensive care and also found that the Portapres™ underestimated SAP by a mean of -4 mm Hg and overestimated DAP by a mean of 7 mm Hg, indicating that the Finometer™ underestimates pulse pressure, although MAP accuracy is maintained. Our findings are similar to those of Harrington et al,15 who analysed 5-minute epochs of BP in term neonates in intensive care and also found that the Portapres™ underestimated SAP by a mean of -4 mm Hg and overestimated DAP by a mean of 7 mm Hg, indicating that the Finometer™ underestimates pulse pressure, although MAP accuracy is maintained.

In our study,
The maximum individual differences for SAP and DAP were similar to those of Andrissen et al,16 but the differences for MAP were much less (-1 to 7, Table 1).

The FinometerTM tracked interbeat changes in MAP, SAP, and DAP with high agreement, compared with the arterial catheter, with mean differences of 0 and limits of agreement also 0. In support of our data, Andrissen et al16 achieved similarly accurate beat-to-beat changes for SAP and DAP. Importantly, that the FinometerTM described by Youden,17 Hg, respectively. Importantly, using the precision calculation for MAP, the 95% CI was -1 to 4 mm Hg versus -3 to 10 mm Hg for replicate measurements, the FinometerTM catheter system is uncertain, but it may represent a greater intrinsic source of greater precision of the catheter system. The source of greater precision of this new technology in detecting rapid changes in BP, which can accurately track beat-to-beat changes in BP supports the use of this technology in detecting rapid changes in BP, which are essential when assessing autonomic cardiovascular control. Furthermore, our study has shown that BRS in the time domain are essential when assessing autonomic cardiovascular control. Consequently, our study has shown that BRS in the time domain can accurately track beat-to-beat changes in BP supports the use of this new technology in detecting rapid changes in BP, which are essential when assessing autonomic cardiovascular control. Furthermore, our study has shown that BRS in the time domain can accurately assessed from FinometerTM BP measurements, because there was no difference compared with BRS derived from arterial-catheter measurements. The BRS values we obtained from spontaneous sequence analysis (arterial catheter: 1.56 ± 0.21 ms/mm Hg; FinometerTM: 1.74 ± 0.23 ms/mm Hg) are similar to those previously reported for preterm infants at similar gestational ages (1.80 ± 0.14 ms/mm Hg) using the technique of spontaneous sequence analysis.22

A novel approach of our study was to estimate the precision of each method by calculating the 95% CI for a single estimate. The precision of the catheter system was somewhat greater than the FinometerTM because the 95% CIs were less; for example, for MAP, the 95% CI was -1 to 4 mm Hg versus -3 to 10 mm Hg, respectively. Importantly, using the precision calculation described by Youden,17 we have shown that, with 5 or fewer replicate measurements, the FinometerTM precision is equal to that of the catheter system. The source of greater precision of the catheter system is uncertain, but it may represent a greater intrinsic stability of the measurement system or a lesser sensitivity to physiologic BP changes. Alternatively, the lesser precision of the FinometerTM could be due to the displacement of the cuff between replicated measurements. Because the majority of measurements were recorded during active sleep, the position of the cuff on the wrist could have altered due to the characteristic body movements of this state. Therefore, during a research study, this could be rectified by ensuring that the wrist with the BP cuff is kept still or is confined to 1 position as the infant sleeps.

Despite the overall good agreement between methods of measurement, we did observe variation in mean differences and 95% limits of agreement between subjects, with the FinometerTM both underestimating and overestimating absolute BP in some infants. This variation may have been due to a poor-fitting cuff in these particular infants. The inflatable cuff operates to clamp the diameter of the artery constant by opposing pulsatile changes occurring during each heart beat. Any change is counteracted by a fast pressure servo controller that increases or decreases pressure accordingly in the inflatable bladder. If the BP cuff is too large, this could lead to an overestimation of BP caused by a pressure gradient over the air bladder due to overinflation. Conversely, if the cuff is too small or wrapped too tightly, this could result in an underestimation of BP. This may explain the overestimation of BP in infant 1, who had the lowest birth weight (964 gm) of all infants studied. Despite using the smallest cuff on this infant, the FinometerTM overestimated DAP by 13 mm Hg, which may suggest that the cuff was too large. Other authors have also reported considerable variation in bias between subjects and have questioned whether or not it is acceptable to pool individual BP

---

### Table 3—Mean DAP Values Measured by the Catheter System and the FinometerTM for 9 Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>DAPc</th>
<th>DAPf</th>
<th>D_{DAP}</th>
<th>Limits of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>42</td>
<td>13</td>
<td>7 to 20</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>39</td>
<td>6</td>
<td>4 to 8</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>42</td>
<td>3</td>
<td>1 to 5</td>
</tr>
<tr>
<td>5</td>
<td>33</td>
<td>43</td>
<td>10</td>
<td>7 to 13</td>
</tr>
<tr>
<td>6</td>
<td>33</td>
<td>45</td>
<td>12</td>
<td>7 to 17</td>
</tr>
<tr>
<td>7</td>
<td>40</td>
<td>44</td>
<td>4</td>
<td>-2 to 10</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>31</td>
<td>1</td>
<td>-1 to 3</td>
</tr>
<tr>
<td>9</td>
<td>23</td>
<td>32</td>
<td>9</td>
<td>6 to 11</td>
</tr>
<tr>
<td>10</td>
<td>27</td>
<td>35</td>
<td>8</td>
<td>4 to 13</td>
</tr>
<tr>
<td>Mean ± SEM</td>
<td>32 ± 2</td>
<td>39 ± 2</td>
<td>7 ± 1</td>
<td>4 to 10</td>
</tr>
</tbody>
</table>

Diastolic arterial pressure (DAP) values, in mm Hg, were measured by the catheter system (MAPc) and the FinometerTM (MAPf). D_{DAP} represents the mean difference and limits of agreement between each method of measurement.

### Table 4—Determinates of BRS Estimates for 8 Infants for the Catheter and FinometerTM Systems

<table>
<thead>
<tr>
<th>Infant</th>
<th>Gestational age, wk</th>
<th>Catheter</th>
<th>FinometerTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>1</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>1.64 ± 0.09</td>
<td>2.22 ± 0.68</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
<td>2.30 ± 0.75</td>
<td>2.70 ± 0.59</td>
</tr>
<tr>
<td>6</td>
<td>27</td>
<td>1.63 ± 0.38</td>
<td>2.09 ± 0.47</td>
</tr>
<tr>
<td>7</td>
<td>33</td>
<td>1.86 ± 0.72</td>
<td>0.91 ± 0.13</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
<td>2.28 ± 0.59</td>
<td>1.90 ± 0.51</td>
</tr>
<tr>
<td>9</td>
<td>28</td>
<td>1.23 ± 0.15</td>
<td>1.70 ± 0.27</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>1.01 ± 0.12</td>
<td>1.66 ± 0.27</td>
</tr>
<tr>
<td>Mean ± 1</td>
<td>1.56 ± 0.21</td>
<td>1.74 ± 0.23</td>
<td></td>
</tr>
</tbody>
</table>

The mean baroreflex sensitivity (BRS) ± SEM is presented in ms/mm Hg.

---

SLEEP, Vol. 29, No. 8, 2006
quiet sleep, we anticipate that any differences in the measurement
be examined. However, because physiologic variability is less in
were made in this state, and potential sleep-state effects could not
time in active sleep, the majority of our measurements (55/58)
be representative of population estimates. A second limitation was
adequate repeated measurements in each subject and normally
distributed data, we are confident that a pooled comparison will
mean differences were
distributed. Therefore, in a research setting with
{}1088

Acknowledgments

We would like to thank the medical and nursing staff at the
Neonatal Intensive Care Unit, Monash Medical Centre, and all
of the parents who volunteered their infants for participation in
the study. This project was supported by the National Health and
Medical Research Council of Australia.

References

blood pressure in children with sleep-disordered breathing.[see
2. Suzuki M, Guillemiault C, Otsuka K, Shiomi T. Blood pressure
"dipping" and "non-dipping" in obstructive sleep apnea syndrome
Southall DP. Cardiac and respiratory patterns in normal infants and
victims of the sudden infant death syndrome. Sleep 1988;11:413-
24.
4. Harper RM, Woo MA, Alger JR. Visualization of sleep influences
on cerebellar and brainstem cardiac and respiratory control
5. Galland BC, Reeves G, Taylor BJ, Bolton DP. Sleep position,
autonomic function, and arousal. Arch Dis Child Fetal Neonatal Ed
1998;78:F189-94.
Mulder G. Assessment of baroreceptor reflex sensitivity by means
7. Bertinieri G, Di Rienzo M, Cavallazzi A, Ferrari AU, Pedotti A,
Mancia G. Evaluation of baroreceptor reflex by blood pressure
monitoring in unanesthetized cats. Am J Physiol 1988;254:H377-
83.
8. Blaber AP, Yamamoto Y, Hughson RL. Methodology of spontaneous
baroreflex relationship assessed by surrogate data analysis. Am J
of heart rate during the wake-sleep cycle in rat. Sleep 2001;24:753-
8.
10. Chong A, Murphy N, Matthews T. Effect of prone sleeping on

SLEEP, Vol. 29, No. 8, 2006

1088

Noninvasive Blood Pressure Measurement In Infants—Yiallourou et al

of heart rate during the wake-sleep cycle in rat. Sleep 2001;24:753-
8.
10. Chong A, Murphy N, Matthews T. Effect of prone sleeping on

SLEEP, Vol. 29, No. 8, 2006

1088 Noninvasive Blood Pressure Measurement In Infants—Yiallourou et al

values. However, as evident from our Bland-Altman analysis,
in particularly for MAP (Figure 2a), the majority of individual
subject differences are close to 0, and mean differences were
normally distributed. Therefore, in a research setting with
adequate repeated measurements in each subject and normally
distributed data, we are confident that a pooled comparison will
be representative of population estimates. A second limitation was
that because preterm infants spend the majority of their sleeping
time in active sleep, the majority of our measurements (55/58)
were made in this state, and potential sleep-state effects could not
be examined. However, because physiologic variability is less in
quiet sleep, we anticipate that any differences in the measurement
systems would be less in this state.

In summary, our study has found that the Finometer™ is a useful
tool to measure both absolute and beat-to-beat changes in BP in
infants during sleep with the adult-sized finger cuff placed around
the wrist. The continuous noninvasive measurement of BP will
provide new opportunities to study the maturation of baroreflex
control of BP in infants and may provide important insights into
a number of infant sleep-related problems such as sudden infant
death syndrome, which has been proposed to result from a failed
baroreflex response to profound hypotension.23

Acknowledgments

We would like to thank the medical and nursing staff at the
Neonatal Intensive Care Unit, Monash Medical Centre, and all
of the parents who volunteered their infants for participation in
the study. This project was supported by the National Health and
Medical Research Council of Australia.

References

blood pressure in children with sleep-disordered breathing.[see
2. Suzuki M, Guillemiault C, Otsuka K, Shiomi T. Blood pressure
"dipping" and "non-dipping" in obstructive sleep apnea syndrome
Southall DP. Cardiac and respiratory patterns in normal infants and
victims of the sudden infant death syndrome. Sleep 1988;11:413-
24.
4. Harper RM, Woo MA, Alger JR. Visualization of sleep influences
on cerebellar and brainstem cardiac and respiratory control
5. Galland BC, Reeves G, Taylor BJ, Bolton DP. Sleep position,
autonomic function, and arousal. Arch Dis Child Fetal Neonatal Ed
1998;78:F189-94.
Mulder G. Assessment of baroreceptor reflex sensitivity by means
7. Bertinieri G, Di Rienzo M, Cavallazzi A, Ferrari AU, Pedotti A,
Mancia G. Evaluation of baroreceptor reflex by blood pressure
monitoring in unanesthetized cats. Am J Physiol 1988;254:H377-
83.
8. Blaber AP, Yamamoto Y, Hughson RL. Methodology of spontaneous
baroreflex relationship assessed by surrogate data analysis. Am J
of heart rate during the wake-sleep cycle in rat. Sleep 2001;24:753-
8.
10. Chong A, Murphy N, Matthews T. Effect of prone sleeping on

SLEEP, Vol. 29, No. 8, 2006

1088 Noninvasive Blood Pressure Measurement In Infants—Yiallourou et al