Non-invasive continuous arterial pressure monitoring with Nexfin® does not sufficiently replace invasive measurements in critically ill patients

A. Hohn1,2*, J. M. Defosse1, S. Becker1,3, C. Steffen1, F. Wappler1 and S. G. Sakka1

1 Department of Anaesthesiology and Intensive Care Medicine, University Witten/Herdecke, Hospital Merheim, Cologne, Germany
2 Department of Anaesthesiology, Intensive Care, Palliative Care and Pain Medicine, BG University Hospital Bergmannsheil, Ruhr-University Bochum, Bochum, Germany
3 Department of Anaesthesiology and Intensive Care Medicine, St Johannes Hospital, Troisdorf-Sieglar, Germany

* Corresponding author. E-mail: hohna@web.de

Editor’s key points

- The Nexfin® is a device developed for the continuous non-invasive determination of arterial pressure.
- This study compared the Nexfin® with direct femoral or radial arterial pressure measurements in 25 critically ill patients.
- Limits of agreement were wide, especially in patients with peripheral oedema or those receiving norepinephrine.
- These data do not support the use of the Nexfin® over invasive measurements in ICU.

Background. In this study, we tested the reliability of a non-invasive finger-cuff-based continuous arterial blood pressure monitoring device (Nexfin®, BMEYE, Amsterdam, NL) in critically ill surgical patients.

Methods. Invasive intra-arterial and non-invasive arterial pressure measurements from 25 patients during a 4-h period were compared at five time points. Correlation and linear regression analysis were used and mean bias, precision [so of bias] and limits of agreement (LOA) [bias (2.0 so)] were calculated using the Bland–Altman method.

Results. Eight data pairs were excluded because of error message from the non-invasive technique, and thus a total of 117 data pairs were analysed. Overall, correlation between mean arterial pressure (MAP) was \( r^2 = 0.50 \). Bias, precision, and LOA between invasive and non-invasive MAP were 6 (12) and \(-18 \) to \(+30 \) mm Hg. In patients requiring norepinephrine (83 data pairs), correlation was \( r^2 = 0.28 \) and bias, precision, and LOA were 6 (13) and \(-20 \) to \(+32 \) mm Hg, whereas in patients not receiving norepinephrine (34 data pairs) \( r^2 \) was 0.80 and mean bias, precision, and LOA were 6 (11) and \(-16 \) to \(+28 \) mm Hg. In patients with peripheral oedema (64 data pairs), \( r^2 \) was 0.40 and mean bias, precision and LOA were 7 (15) and \(-23 \) to \(+37 \) mm Hg. In patients without oedema (64 data pairs), \( r^2 \) was 0.86 and mean bias, precision, and LOA were 5 (9) and \(-13 \) to \(+23 \) mm Hg.

Conclusions. Non-invasive blood pressure monitoring with Nexfin® does not seem to be sufficiently accurate to replace intra-arterial invasive blood pressure measurements in critically ill patients.

Keywords: equipment—Finapres; intensive care; monitoring—arterial pressure

Accepted for publication: 31 December 2012

Most critically ill patients need to be monitored by continuous blood pressure measurement. In this context, mean arterial pressure (MAP) is an important haemodynamic value. For example, goals for MAP are defined in managing patients with traumatic brain injury (TBI) or sepsis.1 2 Cerebral perfusion pressure (CPP) in patients with severe TBI should be kept between 50 and 70 mm Hg.1 Therefore, underestimation of MAP may lead to excessive treatment with risk of fluid overload and vasoactive therapy with systemic complications.3 Overestimation of MAP and consecutively CPP may threaten patients with TBI if the ‘true’ CPP is \(<50–60 \) mm Hg.3 4

Routinely, intra-arterial catheters are used for continuous haemodynamic monitoring in the intensive care unit (ICU). However, blood pressure can also be measured continuously and non-invasively with systems based on the volume clamp method.5 6 Although this technology has a long history, there are still some efforts to introduce such systems into clinical practice.7 The Nexfin® device (BMEYE, Amsterdam, NL) measures finger arterial pressure with a mathematical reconstruction for levels of brachial arterial pressure.8 9 As an alternative to invasive arterial pressure monitoring, this system has recently been studied in the setting of anaesthesia and intensive care medicine with inconsistent results.10 14 Recent studies in selected groups of patients undergoing cardiac surgery showed a high accuracy of non-invasive arterial pressure measurements obtained perioperatively by the Nexfin® device.10 13 But so far, there is only one study in an
unselected small ICU population of 10 critically ill patients, which revealed an acceptable correlation between invasive and non-invasive (Nexfin\textsuperscript{®}) arterial pressure measurement.\textsuperscript{11} Thus, the applicability of this system for routine use in critically ill patients remains questionable.

In this study, we tested in a heterogeneous ICU population under clinical conditions whether non-invasively measured MAP obtained by the Nexfin\textsuperscript{®} device is interchangeable with invasively derived MAP.

**Methods**

With approval from the Ethics Committee of the University of Witten/Herdecke (Germany), we enrolled consecutively 25 adult, critically ill patients of the operative ICU at the Hospital Merheim (Cologne, Germany), who had indwelling arterial catheters for haemodynamic management (Table 1) (German Clinical Trials Register: DRKS00004411). Eighteen patients needed continuous norepinephrine infusion to maintain an MAP \( \geq 65 \) mm Hg. Patients with marked haemodynamic instability, fast changes in heart rhythm or blood pressure, cardiac arrhythmia, and clinical ischaemia of the fingers were considered ineligible for non-invasive monitoring. Diagnosis of clinically relevant oedema because of fluid resuscitation and/or capillary leak was made in 10 patients. Diagnosis of oedema was according to the decision of the investigator and oedema were defined clinically relevant if fingers were also affected.

Intensive care management, monitoring, and ventilator settings (Evita XL\textsuperscript{®}, Draeger Medical, Luebeck, Germany) in all mechanically ventilated patients during the study period followed institutional standards and the patients’ individual requirements. Standard monitoring (GE Healthcare, Muencheng, Germany) with electrocardiogram, pulse oximetry, capnography (if required) was established in all patients.

The sites of insertion of the arterial catheter (Leader-Cath, Vygon, Aachen, Germany) were the left or right femoral (8 patients; 18 G, 10 cm) or radial (17 patients; 20 G, 8 cm) artery.

The Nexfin\textsuperscript{®} device was placed on the middle or index finger of the left or right hand at the investigator’s discretion and according to the manufacturer’s recommendations.\textsuperscript{15} The arterial system (CODAN pvb Medical GmbH, Lensahn, Germany) was zeroed to atmospheric pressure at the level of the midaxillary position. The arterial waveform was inspected visually and the system was flushed in regular intervals, and 5 min before each measurement (P0–P4) to assess an adequate resonance frequency.\textsuperscript{16} The Nexfin’s\textsuperscript{®} ‘Heart Reference System’ (HRS) was zeroed to atmospheric pressure at the level of the midaxillary position. The HRS compensates for the hydrostatic difference between the finger and the heart.\textsuperscript{15} According to the manufacturer’s information, Nexfin\textsuperscript{®} performs internal physiologic calibration (Physiocal) automatically in regular intervals. This calibration is to define and maintain the diameter at which the finger artery should be clamped. Each time the patient’s position was changed, the HRS and also the arterial system were re-calibrated.

At the defined time points, systolic, mean arterial and diastolic pressure were read out simultaneously only once from both devices. Five data pairs for each patient at P0 (after calibration of the non-invasive blood pressure), P1 (after 60 min), P2 (after 120 min), P3 (after 180 min), and P4 (after 240 min) comparing both methods were documented.

**Statistics**

Data were tested for normality by Kolmogorov–Smirnov test. All data normally distributed are given as mean (so). Data from the two different methods were analysed using correlation and linear regression analysis. Bias and precision [so of bias] and also limits of agreement (LOA) [bias (2.0 so)] were calculated according to the statistical method of Bland and Altman with a specific calculation for repeated measures in the same subject.\textsuperscript{17, 18} According to the recommendations of the Association for the Advancement of Medical Instrumentation, a difference of 5 mm Hg in MAP was considered relevant.\textsuperscript{19} With a standard deviation (so) of 12 mm Hg, this difference could be detected with 110 comparative data points (5 measurements in 22 patients each), using standard statistical errors (\( \alpha=0.05; \beta=0.15 \). Postulating a 10% failure rate of the non-invasive device, we included 25 patients in the study.

Analysis of variance (ANOVA) for repeated measures was used for comparison of differences in mean bias, precision, and LOA at different time points (P0–P4).

Statistical calculations were performed with SPSS\textsuperscript{®} for Windows (IBM SPSS\textsuperscript{®} Statistics, Version 20, IBM Germany, Ehningen, Germany) and MedCalc\textsuperscript{®} (Version 12.3.0.0, Mariakerke, Belgium).

**Results**

A total of 125 data pairs from 25 critically ill patients (7 women and 18 men) were collected. Mean age of all patients was 63 (18–82) years, average height was 173 (10) cm, and average weight was 76 (14) kg. Mean Simplified Acute Physiology Score (SAPS) II was 41 (17) and mean maximum dosage of norepinephrine during the study period was 0.13 (0.11) \( \mu \text{g} \text{kg}^{-1} \text{min}^{-1} \). Because of missing data from one patient, mean dosage of norepinephrine could only be calculated for 17 patients. For one patient (23) there was no information about peripheral oedema. Internal error messages (‘access violation’ [2x], ‘low cuff pressure’ [5x], ‘physiocal off’ [1x]) from the non-invasive device indicated invalid data and eight data pairs of eight different patients had to be excluded. Thus, final data analysis was performed for 117 data pairs.

Overall, correlation between mean arterial pressure (MAP) determined invasively and non-invasively (Nexfin\textsuperscript{®}) was \( r^2=0.50 \) (Fig. 1, Table 2). Bias, precision and LOA between invasive and non-invasive MAP were 6 (12) and –18 to +30 mm Hg (Fig. 2). In patients with continuous norepinephrine administration (83 data pairs), \( r^2 = 0.28 \) for MAP. Bias,
<table>
<thead>
<tr>
<th>Patient</th>
<th>Diagnosis</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>SAPS II</th>
<th>Oedema</th>
<th>Max. norepinephrine (µg kg⁻¹ min⁻¹)</th>
<th>Ventilation</th>
<th>Site of arterial cannulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Subarachnoidal haemorrhage, sepsis</td>
<td>Male</td>
<td>59</td>
<td>170</td>
<td>70</td>
<td>29</td>
<td>+</td>
<td>0.17</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>2</td>
<td>Hepatic surgery</td>
<td>Male</td>
<td>69</td>
<td>168</td>
<td>85</td>
<td>21</td>
<td>–</td>
<td>0.16</td>
<td>Spon.</td>
<td>Radial</td>
</tr>
<tr>
<td>3</td>
<td>Traumatic brain injury</td>
<td>Male</td>
<td>54</td>
<td>180</td>
<td>70</td>
<td>49</td>
<td>–</td>
<td>0.20</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>4</td>
<td>Traumatic brain injury with intracerebral haemorrhage</td>
<td>Male</td>
<td>71</td>
<td>185</td>
<td>95</td>
<td>73</td>
<td>+</td>
<td>0.12</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>5</td>
<td>Multiple organ failure after Whipple operation</td>
<td>Male</td>
<td>71</td>
<td>170</td>
<td>65</td>
<td>43</td>
<td>+</td>
<td>0.01</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>6</td>
<td>Intracerebral haemorrhage, cerebral oedema</td>
<td>Female</td>
<td>82</td>
<td>165</td>
<td>60</td>
<td>53</td>
<td>–</td>
<td>0.04</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>7</td>
<td>Multiple trauma</td>
<td>Male</td>
<td>18</td>
<td>195</td>
<td>75</td>
<td>45</td>
<td>+</td>
<td>0.09</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>8</td>
<td>Intracerebral haemorrhage</td>
<td>Male</td>
<td>71</td>
<td>175</td>
<td>90</td>
<td>63</td>
<td>–</td>
<td>0.08</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>9</td>
<td>Subarachnoidal haemorrhage</td>
<td>Female</td>
<td>61</td>
<td>179</td>
<td>100</td>
<td>24</td>
<td>–</td>
<td>0.05</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>10</td>
<td>Intracerebral haemorrhage, subdural haematoma</td>
<td>Female</td>
<td>79</td>
<td>155</td>
<td>50</td>
<td>56</td>
<td>–</td>
<td>None</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>11</td>
<td>Haemorrhagic shock</td>
<td>Male</td>
<td>42</td>
<td>180</td>
<td>100</td>
<td>86</td>
<td>–</td>
<td>0.07</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>12</td>
<td>Hemihepatectomy, massive transfusion</td>
<td>Female</td>
<td>66</td>
<td>159</td>
<td>90</td>
<td>33</td>
<td>–</td>
<td>0.08</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>13</td>
<td>Acute respiratory failure</td>
<td>Male</td>
<td>72</td>
<td>165</td>
<td>67</td>
<td>40</td>
<td>–</td>
<td>0.23</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>14</td>
<td>Intracerebral haemorrhage</td>
<td>Female</td>
<td>58</td>
<td>165</td>
<td>55</td>
<td>21</td>
<td>–</td>
<td>0.05</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>15</td>
<td>Penetrating traumatic brain injury</td>
<td>Male</td>
<td>37</td>
<td>185</td>
<td>80</td>
<td>17</td>
<td>–</td>
<td>None</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>16</td>
<td>Intracerebral haemorrhage</td>
<td>Male</td>
<td>57</td>
<td>175</td>
<td>70</td>
<td>31</td>
<td>+</td>
<td>0.11</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>17</td>
<td>Traumatic subarachnoidal haemorrhage</td>
<td>Male</td>
<td>76</td>
<td>170</td>
<td>65</td>
<td>36</td>
<td>+</td>
<td>None</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>18</td>
<td>Lung surgery because of cancer</td>
<td>Male</td>
<td>60</td>
<td>171</td>
<td>80</td>
<td>12</td>
<td>–</td>
<td>No dosage</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>19</td>
<td>Intracerebral haemorrhage, cerebral infarction</td>
<td>Female</td>
<td>68</td>
<td>160</td>
<td>69</td>
<td>31</td>
<td>+</td>
<td>0.06</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>20</td>
<td>Intracerebral haemorrhage</td>
<td>Male</td>
<td>62</td>
<td>175</td>
<td>80</td>
<td>35</td>
<td>+</td>
<td>None</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>21</td>
<td>SIRS after orthopaedic surgery</td>
<td>Male</td>
<td>84</td>
<td>186</td>
<td>65</td>
<td>57</td>
<td>–</td>
<td>0.50</td>
<td>PCV</td>
<td>Femoral</td>
</tr>
<tr>
<td>22</td>
<td>Traumatic subdural haemorrhage</td>
<td>Male</td>
<td>79</td>
<td>180</td>
<td>90</td>
<td>41</td>
<td>+</td>
<td>None</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>23</td>
<td>Subarachnoidal haemorrhage</td>
<td>Male</td>
<td>57</td>
<td>170</td>
<td>98</td>
<td>43</td>
<td>No data*</td>
<td>0.17</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>24</td>
<td>Sepsis, pneumonia</td>
<td>Male</td>
<td>56</td>
<td>170</td>
<td>78</td>
<td>57</td>
<td>+</td>
<td>0.07</td>
<td>PCV</td>
<td>Radial</td>
</tr>
<tr>
<td>25</td>
<td>Intracerebral haemorrhage</td>
<td>Female</td>
<td>76</td>
<td>160</td>
<td>65</td>
<td>35</td>
<td>–</td>
<td>None</td>
<td>PCV</td>
<td>Radial</td>
</tr>
</tbody>
</table>
precision and LOA were 6 (13) and −20 to +32 mm Hg. Correlation ($r^2=0.80$) was higher in patients without norepinephrine infusion (34 data pairs). In these patients, bias, precision and LOA were 6 (11) and −16 to +28 mm Hg. In patients with clinically relevant oedema of the fingers (49 data pairs), correlation was $r^2=0.40$ and bias, precision and LOA were 7 (15) and −23 to +37 mm Hg. Correlation was higher in patients without oedema (64 data pairs), with $r^2=0.66$ and bias, precision and LOA of 5 (9) and −13 to +23 mm Hg. Correlation between invasive and non-invasive systolic arterial pressure (SAP) was $r^2=0.35$ and precision, bias and LOA were −9 (25) and −58 to +41 mm Hg. Average blood pressures [mean (SD)] and mean bias, precision and LOA of MAP and SAP at the different times (P0–P4) and also results from the ANOVA for repeated-measures are summarized in Table 3. We found a significant difference ($P<0.01$) of mean bias and precision between P0–P4. ANOVA in non-invasive MAP, revealed non-significant ($P=0.08$) differences between P0 and P4 but we found a significant ($P=0.03$) linear trending over the study period.

**Discussion**

The results of this study show that non-invasive blood pressure monitoring with a finger cuff-based system (Nexfin®) cannot replace intra-arterial blood pressure monitoring in ICU patients.

**Table 2** Correlation, bias, precision [SD of bias] and limits of agreement (LOA) [bias (2.0 SD)] between invasive and non-invasive measurement. n, pairs of simultaneous measurement; LOA, limits of agreement; MAP, mean arterial pressure; SAP, systolic arterial pressure. For one patient* information about oedema was missing. Therefore, only a total of 113 (49+64) data pairs were analysed.

<table>
<thead>
<tr>
<th></th>
<th>$r^2$</th>
<th>Bias (mm Hg)</th>
<th>Precision (mm Hg)</th>
<th>LOA (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAP all patients (n=117)</td>
<td>0.50</td>
<td>+6</td>
<td>12</td>
<td>−18 to +30</td>
</tr>
<tr>
<td>MAP patients with norepinephrine (n=83)</td>
<td>0.28</td>
<td>+6</td>
<td>13</td>
<td>−20 to +32</td>
</tr>
<tr>
<td>MAP patients without norepinephrine (n=34)</td>
<td>0.80</td>
<td>+6</td>
<td>11</td>
<td>−16 to +28</td>
</tr>
<tr>
<td>MAP patients with oedema (n=49)*</td>
<td>0.66</td>
<td>+7</td>
<td>15</td>
<td>−23 to +37</td>
</tr>
<tr>
<td>MAP patients without oedema (n=64)*</td>
<td>0.35</td>
<td>−9</td>
<td>25</td>
<td>−58 to +41</td>
</tr>
<tr>
<td>SAP all patients (n=117)</td>
<td>0.35</td>
<td>−9</td>
<td>25</td>
<td>−58 to +41</td>
</tr>
</tbody>
</table>

**Fig 1** Correlation and linear regression for MAP of all measurements (n=117) in 25 patients. MAP Inv, invasively measured mean arterial pressure; MAP Nexfin®, mean arterial pressure measured by the Nexfin® device. Dashed line, line of identity; bold line, regression line.
critically ill patients. Mean difference in MAP between the two methods was 6 (12) mm Hg (LOA of −18 to +30 mm Hg) with $r^2=0.50$. Also in different subgroups of patients, with or without norepinephrine infusion and with or without oedema of the fingers, results for bias and precision did not reach acceptable levels (5 ± 8 mm Hg), according to the Association for the Advancement of Medical Instrumentation (Table 2).\(^{19}\) Although these limits are primarily applied when comparing non-invasive intermittent with invasive methods, they seem to be widely accepted for comparison of blood pressure measurements with different devices. Overall, MAP was overestimated by non-invasive measurement with Nexfin\(^{®}\) just as in the different subgroups. There was also a significant difference ($P<0.01$) in mean bias and precision at the different time points (P0–P4) (Table 3).

In our study, we tested non-invasive blood pressure monitoring with Nexfin\(^{®}\) in a routine clinical setting against patients with indwelling femoral or radial arterial catheters. The accuracy of peripheral invasive blood pressure in comparison with more central (aortic, femoral, or both)
measurements has been evaluated with inconsistent results in several studies with patients undergoing cardiac surgery.\textsuperscript{20–25} In a selected group of critically ill patients, one study revealed that radial artery pressure underestimated central (femoral) pressure in hypotensive septic patients receiving high-dose vasopressor therapy.\textsuperscript{26} A recent study in 55 critically ill patients showed that measurements of MAP in radial or femoral arteries are clinically interchangeable.\textsuperscript{27}

The lower correlation and higher difference between both techniques in patients with clinically relevant oedema and those with continuous norepinephrine administration may be because of a reduced peripheral blood flow, affecting the non-invasive measurements. The lowest mean bias and highest precision was found in patients without clinically relevant oedema. Possibly, critically ill patients before manifestation of general oedema, for example on admission to hospital, during major surgery or in the early postoperative period, may be more suitable for non-invasive blood-pressure with a finger cuff-based system. Our results are in accordance with a very recent study that also revealed a low accuracy of non-invasive MAP from Nexfin\textsuperscript{w} in critically ill patients.\textsuperscript{28}

Interestingly, we found a significant linear trending ($p=0.03$) of non-invasive MAP over the study period. One could assume that for a longer study period, ANOVA of non-invasive MAP may also have revealed significant differences. If accuracy of the non-invasive device decreases with the measurement time, this could be a further limitation of this method for the long-term use in the ICU.

In one patient (#24), there was a notably high difference over the whole study period between the two methods. We included these measurements in our analysis because there was no error message from the non-invasive device. But even if these five data pairs were completely excluded, results did not reach acceptable limits with mean bias 4 (10) mm Hg and an $r^2$ of 0.67.

With respect to systolic arterial pressure (SAP), we also found a low correlation and high difference between both the methods. However, these results have to be interpreted carefully. As we did not standardize measurements at the different time points (P0–P4) to the respiratory cycle and did not calculate averages of SAP over a defined period, effects from systolic pressure variation are possible. Furthermore, the measurement of SAP is affected by inadequate dynamic response characteristics.\textsuperscript{16}

There are several limitations to our study. We analysed a heterogeneous population and thus, the number of patients in the subgroups may be too low to give final explanation for the low correlation between the two methods. It might be that other factors than clinically assessed oedema or administration of norepinephrine may have a significant impact on non-invasive blood pressure measurements. In addition, clinical diagnosis of oedema was made by the investigator and because of missing formal criteria there is a chance of an observer bias in this subgroup. Therefore, further studies, with different defined subpopulations of critically ill patients, should investigate the reliability of continuous non-invasive blood pressure monitoring in the ICU.

Furthermore, we used a non-standardized reference method as data from radial and from femoral arterial measurements were included. However, for measurements of MAP in critically ill patients, the use of radial and femoral arterial seems to be interchangeable and our approach was consistent with routine clinical practice.\textsuperscript{27}

In conclusion, non-invasive blood pressure monitoring with Nexfin\textsuperscript{w} does not seem to be sufficiently accurate to replace intra-arterial invasive blood pressure measurements in critically ill patients. This method cannot generally be recommended for use in the ICU. Further studies should investigate, which groups of critically ill patients may be suitable for non-invasive monitoring.

**Acknowledgement**

BMEYE B. V. (Amsterdam, the Netherlands) kindly provided the Nexfin\textsuperscript{w} device during the study period.

**Declaration of interest**

S.G.S. has received compensation for giving lectures and is a member of the medical advisory board of Pulsion Medical Systems, Feldkirchen, Germany.

**Funding**

This study was supported by institutional and departmental sources.

**References**

7. Forghark IR. Continuous direct and indirect blood pressure measurement (Finapres) in the critically ill. Anaesthesia 1991; 46: 1050–5


