Investigation of the agreement of a continuous non-invasive arterial pressure device in comparison with invasive radial artery measurement

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Editor’s key points

- The CNAP™ monitor is a non-invasive arterial pressure (AP) monitor based on the Peñáz principle.
- In this study, the CNAP™ monitor was compared with direct AP readings taken in the same arm.
- The CNAP™ monitor achieved acceptable accuracy for mean AP readings under stable conditions.
- During induction of anaesthesia and hypotension, the monitor did not achieve the authors’ predetermined cut-off values for acceptable percentage error.

Background. Arterial pressure (AP) monitoring should be accurate, easy to use, free of risks, and ideally continuous. The continuous non-invasive arterial pressure (CNAP) device is non-invasive and provides continuous pressure readings. This study was performed to compare the agreement of CNAP and invasive AP monitoring.

Methods. Ninety patients undergoing surgery under general anaesthesia were enrolled. Invasive pressure monitoring was established at the radial artery. CNAP monitoring using a finger sensor recording was begun before induction of anaesthesia. Statistical analysis was conducted with the Bland–Altman method for comparisons of repeated measures.

Results. We obtained 16 843 valid pressure readings from 85 patients. Mean (SD) bias during maintenance of anaesthesia was: systolic AP: 4.2 (16.5) mm Hg; mean AP (MAP): 2.4.3 (10.4) mm Hg; and diastolic AP: 2.5.8 (6) mm Hg. The results of a subgroup analysis of patients who had a mean intra-arterial pressure of <70 mm Hg were as follows: systolic pressure: 2.0.3 (9.7) mm Hg; mean pressure: 2.6.8 (7.6) mm Hg; and diastolic pressure: 2.7.9 (7.2) mm Hg. Bias and percentage error during the induction period were greater in both the main and subgroup analyses, probably due to recalibration being omitted after induction.

Conclusions. The CNAP monitor showed an acceptable agreement and was interchangeable with invasive pressure monitoring for MAP during normotensive conditions. During induction of anaesthesia and when the AP was low, the agreement was less good and interchangeability was not achieved. These results suggest that CNAP is not statistically equivalent to invasive monitoring during all periods of anaesthesia but may be a useful additional AP monitor.

Keywords: anaesthesia, general; apparatus; arterial pressure, hypotension; arterial pressure, measurement; measurement techniques

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During the perioperative period, arterial pressure (AP) should be monitored at frequent intervals or, under some circumstances, continuously. Intermittent monitoring is performed using an oscillometric pressure device and generally referred to as non-invasive AP (NIAP) monitoring. Continuous monitoring is generally conducted invasively using an arterial line. Both methods have a number of risks, although those associated with invasive monitoring cause greater concern. Common complications of invasive monitoring include vessel occlusion (13%), haematoma (12%), abnormal pulse (15%), and rarely blood loss due to unintended disconnection, nerve lesions, necrosis, and fistula formation. A number of studies have reported catheter-related infections. Prolonged use of an automated oscillometric device may cause nerve and skin damage.

Since non-invasive monitoring provides discontinuous readings, the Association for the Advancement of Medical Instrumentation (AAMI) standard states that the AP should be measured every 3–5 min. A number of studies emphasize the importance of continuous perioperative AP monitoring as more than 20% of all hypotensive episodes during surgery are missed by NIAP monitoring and another 20% are detected only after a delay. Prolonged hypotension precedes 56% of perioperative cardiac arrests and is...
associated with a significant increase in the 1 yr mortality rate,13 suggesting that non-invasive monitoring might be insufficient in some cases such as in patients with cardiovascular diseases.

Recently, a new monitor for continuous NIAP (CNAP) monitoring, the CNAP™ Monitor 500, has been introduced. The aim of this study was to compare the agreement between CNAP and invasive AP monitoring during induction and maintenance of general anaesthesia in surgical patients. We hypothesized that the CNAP monitor is interchangeable with invasive AP monitoring and is not associated with serious side-effects.

Methods

The study was registered at clinicaltrials.gov (identifier: NCT01003665). After Institutional Review Board approval and written informed consent, 90 patients undergoing elective major abdominal, vascular, or thoracic surgery were recruited into the study. Inclusion criteria were a clinical indication for intraoperative invasive AP measurement according to our clinical routine (cardiovascular co-morbidities, expected blood loss over 1000 ml, high-risk surgery). Exclusion criteria were age < 18 yr, BMI > 35 kg m⁻², emergency surgery, a positive Allen’s test, and known vascular pathology of the upper limb.

After admission to the operation theatre, ECG and pulse oximetry monitors were applied to all patients. An arterial line (transducer: DPT-6000, CODAN pvb Critical Care GmbH, Forstinning, Germany; catheter: 20 G × 3¹/₁₆ in. Arrow Intl, Reading, PA, USA) was placed into the radial artery of the non-dominant side. The damping coefficient and natural frequency of the hydrostatic transducer system were tested using the fast flush test as described by Gardner14 and Kleinmann and colleagues.15 The CNAP system (CNAP™ Monitor 500, CNSystems Medizintechnik AG, Graz, Austria) consists of a double-finger cuff, a pressure transducer mounted on the forearm (Fig. 1), and an NIAP cuff for calibration. The principle of CNAP, the ‘volume clamped method’, was originally developed by Jan Peñáz in the early 1970s. The system uses an infrared transmission plethysmograph for detection of the blood volume and an electro-pneumatic servo control for the cuff pressure adjustment. After invasive AP monitoring had been initiated, the CNAP finger cuffs and NIAP cuff were applied to the same arm. The finger cuff was applied to the index and middle fingers. Calibration time was set to 30 min. The invasive pressure and CNAP transducers were placed on the same level as the anterior axillary line. After calibration of CNAP, data collection of both devices was started using a laptop computer with a software (Datex Ohmeda SE™ Collect; GE Healthcare, Helsinki, Finland) that allowed the export of systolic, diastolic, and mean AP (SAP, DAP, MAP) from both the arterial line and the CNAP with a sampling rate of 100 Hz. Automated artifact detection was performed based on a Matlab script (Matlab 7, The Math Works Inc., Natick, MA, USA). All artifacts caused by calibration, blood gas sampling, and patient repositioning were excluded. Two hundred randomized CNAP and invasive AP readings from each patient were recorded. For each reading, a beat was randomly drawn and the mean of five valid readings before and after this selected value was averaged and considered to be a single data point. Fifty data points during anaesthesia induction (i.e. administration until the first drug during anaesthetic induction until skin incision) and 150 data points during the surgical procedure (from skin incision until skin suture) were randomly identified for analysis.

In 15 patients, we compared the results of capillary blood gas analysis of a sample obtained from a finger used for CNAP monitoring with those of a simultaneous sample from the radial artery to examine tissue oxygenation and metabolism during CNAP measurement. We measured PaO₂, PaCO₂, HCO₃, lactate, and base excess as variables indicating tissue oxygenation and anaerobic glycolysis and potassium as a surrogate indicator of cell damage. The FiO₂ during the sampling period was between 0.3 and 0.5.

Statistical analysis was performed using the Graph Pad software (Prism Version 5, Graph Pad Software, San Diego, CA, USA) and the R language.16 Agreement of IAP with CNAP was tested by Bland and Altman17 analysis for repeated measures.18 19 Bias was defined as the mean difference between invasive AP and CNAP pressure. The limits of agreement (2SD) represent the range in which 95% of the differences between the two methods are found. We followed previous published proposals for the reporting of comparison studies using the Bland–Altman statistic.20 We used the percentage error (PE) (2 SD of bias/[(IAP + CNAP)/2] × 100) as an interchangeability criterion. This was introduced by Critchley for the comparison of different devices measuring cardiac output21 and subsequently recommended for agreement studies.22 We assumed that the predefined PE of 28.3% for cardiac output measurements would not be suitable for a study of AP measurement as it is based on an estimated precision of 20% for the reference method. Therefore, we calculated the precision of invasive AP monitoring (2 × its coefficient of variation) as described elsewhere.22 For determination of the precision, we used 50 consecutive beats averaged from 20 patients for invasive AP and CNAP pressure, respectively, before anaesthesia induction during stable

Fig 1 CNAP™ transducer and finger cuffs mounted on a patient’s forearm.
haemodynamic conditions. This allowed us to calculate the cut-off values for interchangeability, knowing the precision of the reference technique, that is, invasive AP monitoring: $\text{PE} = \sqrt{2 \times (\text{precision IAP})^2}$. To evaluate the performance of the system in the lower normo- to hypotensive range, we performed a subgroup analysis using all data points for which the invasive MAP was $< 70$ mm Hg. A sample size of 85 patients was chosen based on the recommendations of the protocol of the AAMI resulting in a statistical power of 98%. To cover dropouts, 90 patients were included. The mean and so for the AAMI criteria were calculated from the original data, whereas the mean and bias for the Bland–Altman statistics were calculated with respect to repeated measurements. Unless otherwise indicated, data are presented as mean (so). A $P$-value of $< 0.05$ was considered statistically significant.

**Results**

We compared 16 843 valid, paired AP readings from 85 patients. Sometimes induction time was rather short and artifacts occurred due to posture or manipulation. Therefore, the planned number of 50/150-paired readings per patient was not obtained for every patient. From expected 4250 data points from the induction, 157 (3.7%) were missed. Five patients were excluded because of violation of the study protocol with regard to the calibration process.

Patient characteristics are shown in Table 1. The CNAP monitor achieved the AAMI criterion for interchangeability (mean difference $< 5$ mm Hg, SD $< 8$ mm Hg) for MAP during maintenance of anaesthesia $[-4.3 \text{ mm Hg (6.8)}]$. Table 2 shows the PE of all groups for SAP, DAP, and MAP. Measured precision during stable haemodynamics for systolic invasive pressure was 10.4%, for diastolic invasive pressure 12.4%, and mean invasive pressure 13.2%. Measured precision for systolic CNAP under stable conditions was 9%, for diastolic CNAP 9.2%, and mean CNAP 9.6%. The cut-off PE for interchangeability (precision of CNAP is equal to or lower than that of invasive AP monitoring; $\text{PE} = \sqrt{2 \times (\text{precision IAP})^2}$) under the studied conditions was calculated as 14.7% for SAP, 17.5% for DAP, and 18.7% for MAP.

The Bland–Altman plots for SAP, DAP, and MAP were calculated for induction of anaesthesia (Fig. 2) and maintenance (Fig. 3). For SAP during induction, the bias (so of bias) was $-3.3 \pm 16.5$ mm Hg (limits of agreement: $-43$ to 36 mm Hg) with a PE of 25.5%, reflecting a slight overestimation of SAP with CNAP. For DAP during induction, the bias was $-10.8 \pm 10.7$ mm Hg (limits of agreement: $-35$ to 14 mm Hg) with a PE of 24.8%, corresponding with an overestimation of DAP with CNAP. For MAP during induction, the bias was $-10.2 \pm 11.3$ mm Hg (limits of agreement: $-36$ to 15 mm Hg) with a PE of 24.7%, reflecting an overestimation of MAP with CNAP. For SAP during maintenance of anaesthesia, the bias was $4.2 \pm 10$ mm Hg (limits of agreement: $-27$ to 35 mm Hg) with a PE of 16.6%, showing a slight underestimation of SAP with CNAP. For DAP during maintenance of anaesthesia, the bias was $-5.8 \pm 6$ mm Hg (limits of agreement: $-23$ to 12 mm Hg) with a PE of 18%, corresponding with an overestimation of DAP with CNAP. For MAP during maintenance of anaesthesia, the bias was $-4.3 \pm 6.8$ mm Hg (limits of agreement: $-24$ to 15 mm Hg) with a PE of 15.8%, showing an overestimation of MAP with CNAP. Thus, for MAP, the CNAP monitor fulfilled the PE interchangeability criterion during maintenance of anaesthesia under stable conditions.

Figures 4 and 5 show the Bland–Altman plots of the subgroup analysis of all included measurements with a mean invasive AP of $< 70$ mm Hg, considered to represent the lower normo- to hypotensive range. For anaesthesia induction, 778 (19%) data points from 59 patients were selected and for the maintenance, 2462 (19.3%) data points from 70 patients were included in the subgroup analysis. For SAP during induction, the bias was $-7.2 \pm 16$ mm Hg (limits of agreement: $-39.7$ to 25.3 mm Hg) with a PE of 21.9%, reflecting a moderate overestimation of systolic pressure by the CNAP. For DAP, the bias was $-13.6 \pm 10.1$ mm Hg (limits of agreement: $-35$ to 7.9 mm Hg) with a PE of 35%, reflecting a distinct overestimation of diastolic pressure by the CNAP. For MAP, the bias was $-12.8 \pm 11.6$ mm Hg (limits of agreement: $-36.6$ to 11 mm Hg) with a PE of 32.9%, again reflecting an overestimation of mean pressure by the CNAP. For SAP during maintenance of anaesthesia in the hypotensive

![Table 1](https://example.com/Table1.png)

<table>
<thead>
<tr>
<th>Table 1 Characteristics of all 85 included patients. abd, abdominal surgery; thor, thoracic surgery; vasc, vascular surgery. Values are mean (range), mean (so), or absolute numbers</th>
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<tbody>
<tr>
<td>Age (yr)</td>
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<td>Gender (M/F)</td>
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<td>BMI (kg m$^{-2}$)</td>
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<tr>
<td>ASA (I/II/III/IV)</td>
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<td>Surgery (abd/thor/vasc)</td>
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![Table 2](https://example.com/Table2.png)

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<th>Table 2 $\text{PE (2 so of bias)/(IAP+CNAP)/2} \times 100$ as an interchangeability criterion. SAP, systolic arterial pressure; DAP, diastolic arterial pressure; MAP, mean arterial pressure; hypotension: all data with IAP mean under 70 mm Hg. *Fulfilled interchangeability criteria</th>
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<tr>
<td><strong>Calculated PE for interchangeability (%)</strong></td>
</tr>
<tr>
<td>SAP</td>
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<td>DAP</td>
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<td>MAP</td>
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subgroup, the bias was $-0.3$ (9.7) mm Hg (limits of agreement: $-23$ to $22.4$ mm Hg) with a PE of 21%. For DAP, the bias was $-7.9$ (7.2) mm Hg (limits of agreement: $-24.8$ to $9$ mm Hg) with a PE of 26.5%, reflecting a moderate overestimation of diastolic pressure by the CNAP. For MAP, the bias was $-6.8$ (7.6) mm Hg (limits of agreement: $-24.3$ to $10.8$ mm Hg) with a PE of 22.3%, reflecting a moderate overestimation of mean by the CNAP. The apparent trend in the plots is a numerical artifact due to limiting the distribution of mean intra-arterial pressure values to $<70$ mm Hg.

Capillary and arterial blood gas analysis from 15 patients after 25 min of tourniquet time is shown in Table 3. We found significant differences for $P_{O_2}$ (32.1 vs 14.8 kPa, $P<0.05$), potassium (3.9 vs 4.2 mmol litre$^{-1}$, $P<0.05$), and lactate (0.8 vs 1.5 mmol litre$^{-1}$, $P<0.05$).

Fifty-four patients (64%) received cafedrine/theodrenaline (Akrinor, AWD, Dresden, Germany) with a mean dosage of 100 mg cafedrine and 5 mg theodrenaline. Fifteen patients (18%) received an intermittent norepinephrine infusion with a mean dosage of 5.3 μg min$^{-1}$.

**Discussion**

We investigated the agreement and interchangeability of the CNAP monitor when compared with intra-arterial pressure monitoring during anaesthesia induction and maintenance. The main findings of our study were: (i) CNAP showed an agreement with invasive AP measurement under some clinical conditions; (ii) interchangeability criteria defined by the PE and the AAMI criteria were met for MAP during anaesthesia maintenance; (iii) agreement during anaesthesia induction was less than for maintenance; (iv) agreement was less for hypotensive conditions; and (v) blood gas analyses showed minor changes with no clinically evident harmful side-effects due to the use of finger cuffs.

An ideal AP monitor for perioperative care should be non-invasive, provide continuous measurements, give good agreement with intra-arterial monitoring, and ideally be interchangeable with intra-arterial monitoring without additional risks. The difficulty in evaluating the agreement of an AP monitor when compared with intra-AP monitoring is that there exists no international standard. The often-cited AAMI standard$^{10}$ for the evaluation of NIAP devices clearly states that monitors measuring AP on the finger are not covered and if intra-arterial measurements are compared with non-invasive devices, the radial artery should not be used as the reference device, since a systematic bias has to be expected. This problem has been reported in previous work on this topic.$^{13}$ The systematic bias between intra-arterial and non-invasive AP measurement is also
considered by the AAMI standard in a meta-analysis that reported absolute differences of 0.68–13.4 and 0.8–18 mm Hg for SAP and DAP, respectively. For ethical reasons, intra-arterial pressure measurement in the subclavian, axillary, or brachial arteries was not appropriate in our study. The bias that we observed in SAP and DAP between CNAP and intra-arterial pressure lies within the above-mentioned range, during induction (3.5 and 10.9 mm Hg, respectively) and maintenance (4.2 and 5.7 mm Hg, respectively).

Intra-arterial pressure was measured at the radial artery while the CNAP was calibrated to pressure measured non-invasively at the brachial artery. This may account for the fact that the observed agreement is best for MAP. The analysis of the PE also demonstrated that of systolic, mean, and diastolic pressure, mean pressure was most reliably estimated by CNAP.

Agreement and interchangeability of CNAP when compared with intra-arterial monitoring was less good for the induction period. We suggest that changes of vascular tone produced by anaesthetic drugs contributed to this discrepancy. The calibration interval of CNAP based on NIAP was set to 30 min for both study periods. A recalibration after drug administration may lead to a better agreement and should be indicated for the use of CNAP.

A subgroup analysis for mean intra-arterial pressure of <70 mm Hg was performed to clarify the performance of the system in haemodynamic conditions where treatment of hypotension is clinically recommended. For the induction period, bias and PE were worse than those observed in the overall data analysis for the reasons mentioned above. For the maintenance period, there was no clinically significant difference in bias in the subset when compared with the full set of observations, but the PE and the limits of agreement were greater. A trend to overestimate the AP with CNAP when compared with intra-arterial pressure monitoring was present in the subset. Therefore, intervention when using CNAP monitoring should be considered at greater MAP levels than might be considered appropriate with intra-arterial pressure monitoring.

Two other groups have evaluated the CNAP monitor recently. Jeleazcov and colleagues\textsuperscript{23} concluded that CNAP provides comparable AP values with those provided by intra-arterial monitoring and detected intraoperative hypotension and rapid changes of pressure in more than 80% of subjects. The values for bias reported in this study were very similar to those which we observed. The authors reported that the MAP recorded by CNAP gave the best agreement with invasive AP which is in accordance with our data. Biais and colleagues\textsuperscript{24} compared CNAP and intra-arterial monitoring in 25 patients undergoing vascular surgery. The agreement measured by the Bland–Altman

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**Fig 3** Bland–Altman plots for repeated measurements from 85 patients for SAP, DAP, and MAP during maintenance of general anaesthesia.
statistics was close to our data. In contrast to our statistical analysis, the necessary correction for repeated measurement was not used in either of these studies. Thus, two earlier studies demonstrated acceptable agreement of intra-arterial pressure monitoring and CNAP; our more sophisticated statistical analysis supports these results.

Intra-arterial pressure measurement and CNAP were, apart from mean pressure during anaesthetic maintenance, not statistically equivalent. As discussed above, the reason may be the calibration to non-invasive AP measurements. Non-invasive measurements are standard in routine clinical practice. However, there are major differences regarding the measurement technique and agreement compared with intra-arterial pressure measurement. Bias may be introduced by increasing age and co-morbidity such as diabetes resulting in a loss of compliance of the artery walls. van Ittersum and colleagues described differences between the sphygmomanometer and an oscillometric AP measurement device dependent on the presence of diabetes. van Popele and colleagues described arterial stiffness as a cause for disagreement between an oscillometric AP monitor and a sphygmomanometer. The influence of different APs on non-invasive APs when compared with intra-AP was shown by Manios and colleagues in the setting of hyperacute stroke. Non-invasive measurements underestimated systolic pressure measured intra-arterially by up to 19.8 mm Hg. Results from obese patients indicate moderate differences between intra-arterial and continuous NAP measured at the wrist, while there were clinically important differences between oscillometric AP measurements performed on the upper arm and intra-arterial pressure measurements. Compared with intra-arterial pressure monitoring, only 84% of MAP, 75% of DAP, and 61% of SAP measurements performed non-invasively fell within a range of ± 15 mm Hg.

A second confounder is the difference between pulse pressure level and pulse wave shape at different locations in the artery. In this study, calibration measurement was performed on the brachial artery, the invasive measurement at the radial artery, and CNAP at the finger. Finger DAP is less than intra-arterial pressure. A simple single resonance model can describe the pulse wave distortion between the brachial artery and finger arteries. Bos and colleagues described the reconstruction of brachial artery pressures from finger pressure measurements. Guelen and colleagues compared invasive brachial artery pressure with non-invasive finger measurements. In this study, the Finapres system showed poor correlation with invasive pressure. Technical improvements including the adaptation of brachial...
pulse curve to the finger arterial curve with ‘waveform filtering’ and ‘return to flow’ calibration improved the agreement to the extent that the device fulfilled AAMI standard.

We also investigated possible side-effects due to the finger tourniquet at 30 min. Differences between capillary and arterial blood gas analyses were small: 0.7 mmol litre\(^{-1}\) for lactate, 0.3 mmol litre\(^{-1}\) for potassium, and 17.3 kPa for \(P_{O_2}\) with an \(F_{I_O_2}\) above 0.3. All variables were within the normal physiological range. Therefore, tissue damage through cell necrosis or anaerobic metabolism seemed probably unlikely. No patient complained about pain or paraesthesia in the fingers after the procedure.

Nevertheless, the incidence of metabolic or physical damage due to the finger tourniquet may be low and therefore not detected by our group size or subclinical and only detectable by invasive techniques such as microscopic analysis of tissue samples.

Our study has some limitations: (i) ipsilateral measurement of intra-arterial pressure may possibly bias CNAP readings. Contralateral measurement could also have led to bias due to differences in AP between the arms and the influence of patient’s repositioning during surgery and the height of the measuring point. (ii) The effects of temperature of the fingers on CNAP were not evaluated. Nevertheless, body temperature remained above 35.5°C due to external warming. (iii) The calibration interval of 30 min may have contributed to inaccuracy in CNAP readings developing over the time. After administration of anaesthetics during induction, changes of the vascular tone may have affected the agreement of the device with intra-arterial values, especially as no recalibration was performed. So far, no data are available investigating the optimal calibration interval in the course of general anaesthesia. This important question requires further studies. (iv) Response time of the system and the magnitude of changes were not studied. A different study design should clarify this issue. (v) Recalibration after repositioning of patients was not performed and may also contribute to bias.

In conclusion, MAP measured with CNAP agreed with invasive arterial measurements under stable conditions with the advantages of beat-to-beat readings, a rapid indication of AP trend, and a visual representation of the pulse wave. Therefore, we think CNAP may be a potentially valuable monitor for patients in whom there is not an absolute need for invasive pressure monitoring, but beat-to-beat AP measurement would be of value. Nevertheless, at the moment, it cannot replace the precision of intra-arterial pressure measurement during hypotension and during fast changes of vascular tone.

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Fig 5 Bland–Altman plots for repeated measurements from 70 patients for SAP, DAP, and MAP during maintenance of general anaesthesia. Subgroup analysis for all measurements under a mean invasive AP <70 mm Hg.
Table 3 Arterial (art) and capillary (cap) blood gas analyses after 25 min of finger tourniquet from 15 patients. (BE, base excess; lac, lactate; gluc, glucose). Data are means (sd). *P < 0.05 between arterial and capillary measurement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Arterial</th>
<th>Capillary</th>
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<tr>
<td>pH</td>
<td>7.38 (0.05)</td>
<td>7.37 (0.06)</td>
</tr>
<tr>
<td>$\text{PCO}_2$ (kPa)</td>
<td>5.5 (0.8)</td>
<td>5.6 (1.2)</td>
</tr>
<tr>
<td>$\text{PO}_2$ (kPa)</td>
<td>32.1 (6.1)</td>
<td>14.8 (10.1)*</td>
</tr>
<tr>
<td>$\text{K}^+$ (mmol litre$^{-1}$)</td>
<td>3.9 (0.3)</td>
<td>4.2 (0.4)*</td>
</tr>
<tr>
<td>Gluc (mmol litre$^{-1}$)</td>
<td>6.5 (1.7)</td>
<td>6.1 (1.5)</td>
</tr>
<tr>
<td>Lac (mmol litre$^{-1}$)</td>
<td>0.8 (0.2)</td>
<td>1.5 (0.4)*</td>
</tr>
<tr>
<td>BE (mmol litre$^{-1}$)</td>
<td>−1.0 (1.8)</td>
<td>−1.0 (3.9)</td>
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during anaesthesia induction. The tendency for CNAP to overestimate MAP and DAP in clinical practice is a potential limitation on the use of this monitor. Future, technical improvements may increase the performance of the monitor. Pulse wave reconstruction of the brachial artery and correction of distortion by known algorithms and improved calibration methods are avenues for further development.

Declaration of interest

All physicians involved in this study were staff members of the Department of Anaesthesiology and Intensive Care Medicine, University-Hospital Schleswig-Holstein, Campus Kiel, Germany, and the Department of Anaesthesiology, Emergency and Intensive Care Medicine, University Medical Centre, Göttingen, Germany. R.H. has received an unrestricted grant from CNSystems, Graz, Austria. Monitoring, equipment, and medication used within the study were those routinely used for anaesthesia in our hospital. CNSystems, Graz, Austria, supplied the CNAP™ Monitor. The support from CNSystems was not dependent on the results of the study.

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