Use of the Nexfin™ device to detect acute arterial pressure variations during anaesthesia induction

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Editor’s key points

- Continuous measurement of beat-to-beat arterial pressure (AP) during the dynamic phases of anaesthesia facilitates recognition and treatment of acute variations.
- The non-invasive AP monitor Nexfin™ was compared with invasive AP (IAP) measurements during induction of anaesthesia.
- Nexfin™ reliably and quickly detected acute changes in AP, but its accuracy was insufficient to replace IAP monitoring.

Background. Standard non-invasive arterial pressure (AP) measurements are discontinuous. By providing non-invasive beat-to-beat AP measurements, Nexfin™ might limit duration of intraoperative hypotension and hypertension. We assessed the ability of Nexfin™ to detect AP variations by comparing its trending ability with invasive AP monitoring.

Methods. Thirty-one subjects undergoing elective surgery under general anaesthesia were included. During induction, simultaneous pairs of AP measurements were collected every 5 s from the Nexfin™ finger sensor and a homolateral radial artery catheter. Magnitude and time lags of AP variations from baseline to nadir and peak were calculated for both methods. Concordance analysis was performed by the Bland–Altman method (for comparison of repeated measures when appropriate).

Results. Nexfin™ detected 100% of AP changes with the median delays of 0 s (IQR 0 to 7) and 0 s (IQR 0 to 12) for nadir and peak, respectively. Bias (limits of agreement (LOA)) of systolic AP (SAP) variations was −0.5 mm Hg (IQR −31.2 to 30.2) and −9.4 mm Hg (IQR −31.3 to 12.6) from baseline to nadir and from baseline to peak, respectively. For 3479 analysed paired measurements, bias was −3.8 and −8.8 mm Hg for SAP and diastolic AP, with LOA of (−36.0 to 28.5) and (−29.8 to 12.3), respectively.

Conclusions. Nexfin™ detects AP variations accurately and can be a useful warning device during anaesthesia. However, it is not interchangeable with invasive monitoring, given the large LOA between the two measurements.

Clinical trial registration. NCT01658631.

Keywords: anaesthesiology; arterial pressure monitors; monitoring, intraoperative

Accepted for publication: 4 December 2013
**Methods**

**Subjects**

After institutional approval of the Ethics Committee (CPP Ile de France XI, reference 10051) and written informed consent, all consecutive adult patients managed exclusively by E.W. or V.D.-N., undergoing major surgery at Foch Hospital (Suresnes, France) under general anaesthesia and requiring continuous IAP monitoring because of their comorbidities or high haemorrhagic risk, were prospectively included from November 2011 to June 2012. Exclusion criteria were as follows: (i) age under 18, (ii) body weight \( < 40 \) or \( > 180 \) kg, and \( BMI > 35 \) kg \( m^2 \), (iii) history of Raynaud syndrome and related diseases, cardiac arrhythmia, or vascular surgery of upper extremities, (iv) propensity to hand ischaemia in the presence of radial arterial obstruction as evidenced by a positive Allen test (defined clinically as a lack of return of colour within 7 s after the release of ulnar artery compression or by using a Doppler as a lack of palmar arcade flow detection, while the radial artery is compressed).

**Nexfin HD technique**

The Nexfin™ is a non-invasive beat-to-beat AP measurement device based on the so-called ‘vascular unloading’ principle. Finger cuff pressure is continuously adjusted through the systolic AP (SAP) and diastolic AP (DAP) cycle so that the blood volume flowing through the finger arteries is held constant. Thus, cuff pressure is used to indirectly measure finger AP and an algorithm converts the raw beat-to-beat finger AP into brachial AP.12

**Study protocol**

All subjects were orally premedicated with hydroxyzine \( (1 \text{ mg kg}^{-1}) \) 1 h before the induction of anaesthesia. Upon admission in the operating theatre, standard monitoring was applied and a 20 G intra-arterial catheter (Leadercath 20G, Vygon, Ecouen, France) was inserted in the non-dominant arm radial artery under local anaesthesia. The catheter was then connected, using standard low compliant tubing, to a disposable pressure transducer (Edwards Lifesciences, Irvine, CA, USA) and placed at the heart level with the patient in the supine position. The

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**Fig 1** Flow chart. Each stored AP value represents an average of all AP values measured over the previous 5 s period.
transducer was first zeroed to ambient air pressure, and the line was subsequently flushed with a 300 mm Hg pressurized bag of normal saline to remove air bubbles. To test the adequacy of the pressure monitoring system, a rapid flush test was performed as described by Gardner and Kleinman and colleagues. With this test, an under-damped (extra oscillations) or over-damped (slowed upstroke and loss of oscillations) pressure system can be identified. The IAP measurement was checked for quality by visually inspecting the waveform.

Continuous NIAP was measured on the same arm with the Nexfin™ device. After choosing the appropriate size, the Nexfin™ finger cuff was applied to the middle phalanx of the second or third finger. The heart reference system was placed at the heart level to measure and correct the hydrostatic pressure difference between the finger and the heart. Then, the finger cuff and the heart reference system were connected to a wrist-processing unit, which was in turn connected to the device. The automatic calibrating procedure of the Nexfin™ device was started, and frequently activated at the start of the measurement. IAP transducer and Nexfin™ were linked via an analogue input to a monitoring system (S5™ monitor; Datex-Ohmeda, Helsinki, Finland) allowing simultaneous measurements of NIAP and IAP signals. Finally, the monitoring system was connected via an RS 232 port, to the ToolBox 95 version 4.8 recording system.

When a stable signal was detected by both AP measurement methods, anaesthesia was induced either manually [sufentanil (0.2–0.5 µg kg⁻¹) and propofol (2–4 mg kg⁻¹)] or by using propofol and remifentanil target-controlled infusion. Tracheal intubation was facilitated by a non-depolarizing neuromuscular blocking drug (atracurium 0.5 mg kg⁻¹), and mechanical ventilation was started using the volume-controlled mode. Oxygen–air mixture and ventilation variables were adjusted to maintain pulse oximeter oxygen saturation >96% and end-tidal carbon dioxide partial pressure between 4.39 and 5.06 kPa. Vasoactive drugs were used in order to maintain mean AP (MAP) >65 mm Hg.

Recorded data and analyses

Paired values of SAP, DAP, and MAP obtained by both methods were recorded from 1 min before the induction to 10 min after tracheal intubation. Each stored AP value represented an average of all AP values measured over the previous 5 s period. Signals recorded during Nexfin™ recalibration were not taken into account. Arterial line recordings were visually inspected for any artifacts such as damping or flushing and artifacts were manually removed.

The precision of IAP monitoring was calculated as described previously (2 × coefficient of variation of n averaged measurements/s/n)¹⁷ using the 1 min measurements preceding induction of anaesthesia.

For each subject and for each method, we determined (i) baseline values of SAP, MAP, and DAP as the 30 s average of their values recorded immediately before induction, and (ii) the minimal (nadir) and maximal (peak) values of AP observed during induction. This allowed calculating differences between the methods concerning (i) values of ΔAP nadir (i.e. difference between baseline and nadir) and ΔAP peak (i.e. difference between peak and nadir), and (ii) time to reach nadir and peak pressures (T nadir and T peak, respectively).

Statistical analysis

Comparison of trending analysis ability of both AP measurement methods was performed using a five-pronged strategy.

Four-quadrant plot¹⁸ permits the calculation of the percentage of concordance between changes in AP.

Bias and limits of agreement (LOA) were defined as the mean difference between IAP and Nexfin™ measurements and as the range within which 95% of these differences are expected to lie, respectively. The standard Bland–Altman approach¹⁹ was used to analyse agreement for individual AP nadir, AP peak, ΔAP nadir, and ΔAP peak values. The Bland–Altman approach for repeated measurements,²⁰ which is appropriate and usable for analyses of unequal number of

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<td>Ephetrine</td>
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collected points, was used to study agreement between all paired values \( n = 3479 \).

The Wilcoxon rank test was used to compare times to reach nadir and peak pressures.

The polar plot approach was also used. In this method, first proposed to describe trending ability of cardiac output monitors,\(^{21}\) the bias becomes the mean of the polar angles, the Bland and Altman horizontal limit lines are replaced by radial LOA, and the 30\(^{\circ}\) radial sector lines provide envelopes within which most of the data points should lie if acceptable trending ability exists.

Time point analysis to check deviation over time, from 1 min before induction, that is, \( T - 1 \), to 9 min after, that is, \( T9 \), was performed using analysis of variance (ANOVA) for repeated measurements.

Finally, as described by Ilies and colleagues,\(^{22}\) the percentage error (PE) initially developed for cardiac output monitoring device comparison was adapted and used as an interchangeability criterion between IAP and NIAP values.\(^{17,23}\)

Results are expressed as median (first quartile–third quartile), mean (SD), or counts and percentages. A two-sided \( P \)-value of 0.05 was considered significant. All analyses were performed with R 2.13.0 statistical software (R Foundation for Statistical Computing, Vienna, Austria).

**Results**

Thirty-eight subjects were included in the study. As reported in the flow chart (Fig. 1), the data for seven subjects were excluded from the analysis because of technical or operational problems.\(^{24}\) In two subjects, the finger cuff malfunctioned and could not inflate; in another, we were unable to obtain a reliable photoplethysmographic signal, despite multiple attempts with different sized cuffs on different fingers; in two subjects, radial artery catheterization was impossible; finally, for two patients, there was a recording system dysfunction. Thus, data from 31 subjects (14 males, median age 63 yr, range (24–89 yr)) were available for analysis. The main characteristics of these subjects and vasoactive drug requirements are reported in Table 1. No complications related to the use of the Nexfin\(^{\text{TM}}\) device or to radial artery catheterization were observed over the study period.

We expected to obtain 4092 pairs of data, but actually acquired only 3925 pairs because of minor deviations from
protocol (Fig. 1). Four hundred and forty-six pairs of measurements were deleted because of artifacts (11.3%): removals of 326 (8.3%) and 120 (3%) pairs of measurements were related to Nexfin™ recalibration and to damping and flushing of the arterial catheter, respectively (Fig. 1). Thus, a total of 3479 valid pairs of simultaneous Nexfin™ and IAP measurements were analysed. The median number of paired measurements per subject was 106 (87.5–132).

Values of precision for IAP monitoring were 5.4%, 5.1%, and 7.1% for SAP, MAP, and DAP, respectively.

As displayed using the four-quadrant concordance plot in Figure 2, the percentage of concordance between changes in invasive and non-invasive SAP and DAP was 100%.

Bias and LOA between the two methods for individual nadir values were −1.3 mm Hg (−28.1 to 25.4) for SAP, −7 mm Hg (−23.5 to 9.7) for DAP, and −4.3 mm Hg (−23.2 to 14.5) for MAP. Concerning peak values, bias and LOA for SAP, DAP, and MAP were −10.2 mm Hg (−60.4 to 39.9), −12.6 mm Hg (−47 to 21.8), and −12.6 mm Hg (−49.7 to 24.6), respectively. Times to reach nadir and peak with the two methods were similar (P = 0.2 and 0.58, respectively). The median time lags between both methods to reach nadir and peak values were, respectively, 0 s (−13 to 7) and 0 s (−5 to 12); they are pictured by box plot representation in Figure 3. Agreement for individual values of AP variation magnitude (ΔSAP, ΔMAP, and ΔDAP) obtained by the two methods during induction of general anaesthesia is displayed by the Bland–Altman graphical representation in Figure 4 (Fig. 4a for nadir variations and Fig. 4b for peak variations). Finally, bias and LOA between the two methods over all pairs of measurements of SAP, MAP, and DAP are depicted in the modified Bland–Altman plots for repeated measurements (Fig. 5).

Polar plot results are as follows: polar concordance rate at 30° was 88%, mean angular bias for ΔSAP and ΔDAP were 12° (18) and 4° (17), respectively, and radial LOA were −19° to 35° for ΔSAP and −22° to 23° for ΔDAP (Fig. 6).

Bias and LOA of SAP, MAP, and DAP at the different time points (T–1 to T9) and also results from ANOVA for repeated-measures are displayed in Table 2. We found no significant difference of the mean bias between T–1 and T9.

PE values were, respectively, 34%, 37%, and 32% for SAP, DAP, and MAP.

**Discussion**

Our high vasoactive drug requirement rate (58.1% and 9.7% for ephedrine and phenylephrine, respectively) demonstrates that even among low-risk patients (87% ASA I and II), acute AP variations are common during induction of general anaesthesia. In this context, Nexfin™ was reliable in detecting AP variations rapidly and thus, might be a useful warning device during general anaesthesia. However, Nexfin™ is not precise enough to measure the magnitude of AP variations accurately and cannot be considered interchangeable with a radial artery catheter for AP measurements during induction of general anaesthesia, given the large LOA between the two types of device.

Acute periods of unstable AP are particularly important in anaesthesia practice as several studies have shown that their early detection and management can impact patient outcome. By providing continuous AP monitoring, Nexfin™ can reduce this delay, but its ability to detect AP variations has never been compared with the gold standard method of AP monitoring, that is, IAP. Indeed, since its commercialization, the Nexfin™ device has been validated during adult anaesthesia by Martina and colleagues and Fischer and colleagues on 9000 and 220 measurements, respectively. However, these studies were performed during periods of relative haemodynamic stability: in the first study, AP values from acute unstable periods were combined with data obtained from prolonged stable periods and the second study was performed in an intensive care unit. For these reasons, we were interested in investigating the trending ability of Nexfin™.

As reflected by four-quadrant plot and 30° polar concordance rates, Nexfin™ reliably detects AP changes and correctly assesses their direction. Furthermore, Nexfin™ instantly viewed these variations, as shown by the <1 s detection time-lag with the arterial line. Finally, feasibility and safety of the Nexfin™ device seems to be satisfactory as we report a lower failure rate of Nexfin™ than in previous studies and no complications related to its use.

However, concerning variation magnitude detection, although bias values were acceptable, LOA between the reference method and Nexfin™ were too wide to be considered as suitable for clinical practice. Moreover, using the limits of the
polar approach proposed by Critchley and colleagues for evaluating devices measuring cardiac output, we report a high angular bias and large radial LOA. However, using Critchley’s limits can be questioned.

Interestingly, concerning agreement between the two methods over all pairs of measurements, our results do not confirm those of Martina and colleagues and Fischer and colleagues. Indeed, width of agreement limits do not allow Nexfin™ to fulfil AAMI validation criteria. Furthermore, the PE for SAP, MAP, and DAP was also too high to conclude that there was interchangeability between Nexfin™ and IAP. Unlike a recent study from Hohn and colleagues evaluating Nexfin™ in critically ill patients, we did not show any effect of measurement time on Nexfin accuracy. As explained above, these discrepancies might be due to different study periods. In our study, haemodynamic instability and sudden changes in vascular tone could have required further recalibration of the Nexfin™ device, thus increasing the relative imprecision of this non-invasive technique. Indeed, Nexfin™ ‘Physiocal’ software is in charge of calibrations and periodic adjustment to vasomotor changes, but it is based on an algorithm. Furthermore, two other studies have previously reported such an effect of haemodynamic disturbances and vasoactive drug requirements on accuracy of continuous non-invasive finger AP monitoring. Ilies and colleagues have already reported that the PE of Cnap™, another NIAP monitoring device based on the ‘volume clamp method’, was much higher during the unstable period of anaesthesia induction than during maintenance of anaesthesia. More recently, Hohn and colleagues showed a low accuracy of Nexfin™ monitoring in critically ill patients since they reported that bias, precision, and LOA between invasive and non-invasive MAP were 6 (12) and −31.3 mm Hg with similar results whether patients received norepinephrine infusion or not.

The accuracy of our reference method, IAP, should also be discussed. When using this method, an awareness and understanding of the common sources of errors—primarily resonance, damping, and errors of zeroing and levelling—and how to detect and to prevent these errors is important to ensure accurate and useful measurement. In our study, several steps were taken in order to limit these sources of error: use of a high-frequency transducer and stiff, non-compliant, 100 cm, and large diameter tubing; direct connection of the tubing to the cannula; careful flush of air bubbles from the system before data collection; regular square wave tests (i.e. fast flush tests) for each patient, ensuring the signal was interpretable; and choice of the widely used midpoint of the right atrium reflecting cardiac preload as the reference level.

Fig 4 Bland–Altman graphical representation of agreement for individual values of ΔAP nadir and ΔAP peak between invasive and non-invasive measurements during induction of general anaesthesia. (a) Agreement of the ΔAP nadir values and (b) agreement of ΔAP peak values. The green continuous line represents the bias and the dashed pink lines the upper and lower LOA, respectively. Dashed green lines represent LOA recommended by AAMI for validation of NIAP devices.
Paying attention to these precautions, we found that IAP monitoring was precise. Nevertheless, the use of the radial artery catheter as reference method still results in a major limitation. Indeed, whereas our reference method measures radial AP, the Nexfin™ device has an algorithm software that allows the real-time conversion of measured finger AP into a reconstructed brachial artery waveform. However, from the brachial to the radial measurement site, narrowing of arteries has been shown to enhance AP reflection, which results in an increase in SAP and a decrease in DAP. 30 This so-called pulse pressure amplification phenomenon could have biased our results. For this reason, the AAMI standard for the evaluation of NIAP devices clearly states that if IAP measurements are compared with non-invasive finger devices, the radial artery should not be used as the reference device, since a systematic bias has to be expected.2 However, for ethical reasons, IAP measurement in the subclavian, axillary, or brachial arteries was not possible in our study.

In conclusion, our study shows that the Nexfin™ device detects AP variations reliably and quickly and could be a useful warning device during induction of general anaesthesia. Thus, Nexfin™ might limit duration of hypotensive or hypertensive events and play a role in the case of impossible arterial catheterization for anatomical, technical, or organizational reasons, which accounted for 5% of cases in our study. However, the accuracy of Nexfin™ measurements of AP variation magnitude is not to consider this device interchangeable with IAP monitoring. Finally, Nexfin™ does not satisfy AAMI validation criteria during acute periods of unstable AP.

**Authors’ contributions**

E.W.: patient recruitment, data collection, and writing up of the first draft of the paper. E.G.: study design, data analysis, and writing up of the first draft of the paper. V.D.-N.: patient recruitment and data collection. M.L.G.: patient recruitment and data collection. M.F.: study design and writing up of the
Table 2 Absolute values, bias, and LOA of IAP and NIAP (n = 325) at different time points after calibration. SAP, systolic arterial pressure; DAP, diastolic arterial pressure; MAP, mean arterial pressure; LOA, limits of agreement; T = 1, 1 min before induction; T0, beginning of induction; T1–9, 1, 2, 3, 4, 5, 6, 7, 8, and 9 min after the beginning of induction. Results are presented as mean(SD). Statistical analysis used ANOVA for repeated measurements of AP and for bias. Sixteen data pairs are missing: three were manually removed due to artifacts and 13 were not recorded due to minor deviation protocol (see Fig. 1 and the Results section).

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final draft of the paper. All authors have approved the version to be published. M.F. has accepted direct responsibility for the manuscript.

**Declaration of interest**

None declared.

**Funding**

Support was provided solely from institutional and departmental sources.

**References**


Handling editor: H. C. Hemmings