



HAL
open science

Noninvasive continuous detection of arterial hypotension during induction of anaesthesia using a photoplethysmographic signal: proof of concept

Maxime Coutrot, Jona Joachim, François Dépret, Sandrine Millasseau, Hélène Nougé, Joaquim Matéo, Alexandre Mebazaa, Etienne Gayat, Fabrice Vallée

► To cite this version:

Maxime Coutrot, Jona Joachim, François Dépret, Sandrine Millasseau, Hélène Nougé, et al.. Non-invasive continuous detection of arterial hypotension during induction of anaesthesia using a photoplethysmographic signal: proof of concept. *British Journal of Anaesthesia*, 2019, 122, pp.605 - 612. 10.1016/j.bja.2019.01.037 . hal-03485110

HAL Id: hal-03485110

<https://hal.science/hal-03485110>

Submitted on 20 Dec 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Non-invasive continuous detection of arterial hypotension during induction of anaesthesia using a photoplethysmographic signal: proof of concept

Maxime Coutrot ^{1,2,3}, **Jona Joachim** ^{1,2}, **François Dépret** ^{1,2,3}, **Sandrine Millasseau** ⁴, **Hélène
Nougué** ^{1,2}, **Joaquim Matéo** ^{1,3}, **Alexandre Mebazaa** ^{1,2,3}, **Etienne Gayat** ^{1,2,3}, **Fabrice Vallée**
^{1,2,3,5}

¹Department of Anaesthesiology and Critical Care, Lariboisière Hospital, Assistance
Publique–Hôpitaux de Paris (AP-HP), France

² UMR-S942, Lariboisière Hospital, Paris, France

³ University of Paris Diderot, Paris, France

⁴ Pulse Wave Consulting, Saint Leu La Foret, France

⁵ MEDISIM, Inria Paris-Saclay, Palaiseau, France

Corresponding author:

Maxime Coutrot

Department of Anaesthesiology and Critical Care

Lariboisière Hospital, Assistance Publique-Hopitaux de Paris

2 Rue Ambroise Paré, 75010 Paris, France.

E-mail address: maxime.coutrot@aphp.fr

EDITOR'S KEY POINTS

- Photoplethysmography may be used to assess the dicrotic notch height and perfusion index during anaesthesia
- This study sought to investigate whether relative variations in the photoplethysmographic dicrotic notch height and perfusion index are predictive for intra-operative hypotension during anaesthesia induction.
- A combination of the relative variations in dicrotic notch height and perfusion index showed a high predictive power for intra-operative hypotension.
- Photoplethysmography may be used as additional haemodynamic detection method in patients at risk of intra-operative hypotension during anaesthesia induction.

ABSTRACT

Background. During general anaesthesia, intra-operative hypotension (IOH), defined as a mean arterial pressure (MAP) drop of more than 20%, is frequent and may lead to complications. Pulse oximetry is mandatory in the operating room, making the photoplethysmographic signal and parameters like the relative dicrotic notch height ($Di_{C_{pleth}}$) or the perfusion index (PI) readily available. The purpose of this study was to investigate whether relative variations of $Di_{C_{pleth}}$ and PI could detect intraoperative hypotension during anaesthesia induction, and to follow their variations during vasopressor boluses.

Methods. MAP, $Di_{C_{pleth}}$ and PI were monitored at 1-minute intervals during target control induction of anaesthesia with propofol and remifentanyl. Vasopressor infusion (noradrenaline or phenylephrine) was performed when hypotension occurred according to the decision of the physician.

Results. Sixty-one patients were included. The delta in $Di_{C_{pleth}}$ and PI accurately detected intraoperative hypotension, with areas under the ROC curves (AUC) of 0.83 and 0.86, respectively. The optimal thresholds were -19% (sensitivity 79%, specificity 84%) and 51% (sensitivity 82%, specificity 74%) for $\Delta Di_{C_{pleth}}$ and ΔPI , respectively. There was no difference between the ROC of $\Delta Di_{C_{pleth}}$ and ΔPI ($p=0.22$). Combining both $\Delta Di_{C_{pleth}}$ and ΔPI further improved the hypotension detection power (AUC=0.91) with a sensitivity and specificity of 84%. MAP variations were correlated with $\Delta Di_{C_{pleth}}$ and ΔPI during vasopressor infusion ($r=0.73$ and -0.62 respectively, $p<0.001$).

Conclusion. The relative variation in the $Di_{C_{pleth}}$ and perfusion index derived from the photoplethysmographic signal can be used as a non-invasive, continuous and simple tool to detect intra-operative hypotension, and track the vascular response to vasoconstrictor drugs during induction of general anaesthesia.

KEYWORDS:

General anaesthesia; Arterial hypotension; Pulse oximetry; Intraoperative monitoring; Haemodynamics; Photoplethysmography; Perfusion Index

[ClinicalTrials.gov Identifier: NCT03756935](https://clinicaltrials.gov/ct2/show/study/NCT03756935)

INTRODUCTION

Haemodynamic stability is a major issue in the management of patients during general anaesthesia. Anaesthetic drugs may induce a rapid and deep systemic arterial blood pressure drop, which leads to intra-operative hypotension episodes. Intra-operative hypotension can contribute to complications, such as myocardial infarction, cerebral hypoperfusion or acute kidney injury.¹⁻⁴ These adverse events may induce higher post-surgery mortality risk, result in extended hospital stay, and are thus a source of higher hospital costs.⁵⁻⁷

Standard haemodynamic monitoring in the operating room includes electrocardiography, assessment of the arterial oxygenation saturation by pulse oximetry, and non-invasive blood pressure measurements from an oscillometric blood pressure cuff. The major drawback of the oscillometric cuff is that it measures blood pressure at intermittent intervals only. As the blood pressure may vary quickly, especially during induction of anaesthesia, intra-operative hypotension should be detected in real-time, as even a short hypotensive period may have deleterious consequences on vital organs.^{8,9}

Digital photoplethysmography is a non-invasive signal produced by light absorption variations due to pulsatile blood volume variations. Similarities in the photoplethysmographic and invasive blood pressure waveforms have been described since the 1940s.^{10, 11} Indices derived from photoplethysmographic signals have been used successfully to characterise the cardiovascular status in patients. Dic_{pleth} , representing the relative height of the dicrotic wave compared to the maximum peak of the waveform (Figure 1, Panel A), has been described as the amount of reflected wave, dependent of the vascular tone. Reduction in Dic_{pleth} has been shown to be related to the reduction of vascular tone due to vasodilator drugs such as salbutamol or glyceryl trinitrate.¹²

The perfusion index (PI) represents the ratio of the pulsatile light absorption (i.e the amount of blood ejected at each systole) on the continuous absorption (corresponding to the non-pulsatile vessels, bones and soft tissues) (Figure 1, Panel A). The perfusion index has been described as a reliable tool for vascular tone assessment and monitoring.^{13 14} As $Di_{C_{pleth}}$ and PI are both related to vascular tone and are easily derived from the photoplethysmographic signal, we aimed to explore whether the combined analysis of $Di_{C_{pleth}}$ and PI variations would allow for early detection of intra-operative hypotension during the induction of general anaesthesia.

MATERIAL AND METHODS:

Patients

We conducted a single-centre, prospective and observational study in the neuroradiology unit of the department of Anaesthesiology and Intensive Care of Lariboisière University Hospital (Paris, France). The study has been approved by local ethics committee (n°CE SRLF 11-356). Inclusion criteria were patients with age over 18-year-old undergoing elective neuroradiological procedures. All patients were included after oral informed consent was obtained. Exclusion criteria from the study were cardiac arrhythmia (i.e auricular fibrillation) and pregnancy. The study was registered in ClinicalTrials.gov (NCT03756935).

Anaesthesia protocol

Before induction of anaesthesia, standard monitoring was initiated with electrocardiography, non-invasive brachial arterial blood pressure measurements (PHILIPS FRANCE, Suresnes, France) set to inflate every minute and digital pulse oximetry (PHILIPS FRANCE, Suresnes, France) placed on the second finger of the contralateral side to the blood pressure cuff. Bispectral index (BIS; BIS™quatro sensor, Medtronic France, Boulogne-Billancourt, France) and neuromuscular blockade monitoring (TOF Watch®, ALSEVIA PHARMA, Paris, France) were also used to monitor anaesthesia. All monitoring parameters were available on a PHILIPS Intellivue MP 60 monitor (PHILIPS FRANCE, Suresnes, France).

Induction of anaesthesia was conducted according to our local standard of care with Target Controlled Anaesthesia (TCA) using remifentanil and propofol with a starting dose of 5 ng mL⁻¹ and 5 µg mL⁻¹, and adjusted to reach a BIS between 40 and 60. After the BIS decreased below 60 and loss of consciousness was observed, neuromuscular blockade was conducted by intravenous injection of 0.5 mg kg⁻¹ of atracurium. Patients were then mechanically

ventilated with tracheal intubation via direct laryngoscopy (end-tidal volume = 6 mL kg⁻¹ of ideal body weight, positive end-expiratory pressure = 5 cmH₂O, respiratory rate and oxygen fraction to reach an end-tidal CO₂=4.7 kPa and an O₂ saturation >95%).

In agreement with our local protocol for neuroradiological patients, arterial pressure was measured every minute during induction and every 5 minutes after tracheal intubation and stabilization. The anaesthetist in charge of the patient could at any time modify the frequency of the measurements, and treat hypotensive episodes with fluid load and/or vasopressor administration (phenylephrine and/or noradrenaline). After induction, some patients were subjected to invasive and continuous blood pressure monitoring, following our standard department management guidelines or by decision of the anaesthetist in charge of the patient.

Data collection

All monitoring parameters and curves displayed on the monitor were recorded on a computer with ixTrend© software (ixellence, Wildau, Germany). Haemodynamic parameters (heart rate, systolic arterial pressure [SAP], mean arterial pressure [MAP] and diastolic arterial pressure [DAP]), and photoplethysmographic parameters (DiC_{pleth}, PI and SpO₂) were then retrospectively sampled every minute during induction. The induction period was arbitrarily defined from pre-oxygenation to 3 minutes after connection to mechanical ventilation. "Baseline" values were obtained by averaging of the two measures (1 minute apart) prior to the anaesthetic drug injection during the preoxygenation period.

We defined "pre-pressor" values as the measures prior to the vasopressor bolus during intra-operative episodes. "Peak-pressor" values were defined as the maximum effects of vasopressor bolus, when the highest MAP was reached. In agreement with most studies,

intra-operative hypotension was defined as a MAP drop of more than 20% from baseline MAP.¹⁵

DiC_{pleth} and perfusion index measurements

DiC_{pleth} was obtained from the recorded photoplethysmographic waveforms by an operator who was blinded from arterial blood pressure values. The DiC_{pleth} was defined as the ratio of the height of the dicrotic notch (from nadir point of the complex to the notch) to the height of the systolic peak (from same nadir point of the complex to the pic), measured at end-expiratory time in patients under mechanical ventilation (average of 3 consecutive complexes) (Figure 1, Panel B). The perfusion index was provided by the manufacturer and is calculated as the ratio of the pulsatile component of the photoplethysmographic signal and the continuous component.

We calculated the Δ MAP, Δ DiC_{pleth}, and Δ PI during the induction period as their relative variations (in percent) from their baseline values. During vasopressor boluses, respective parameter variations were calculated between “pre-pressor” and “peak-pressor” measurements.

DiC_{radial} measurements

In patients with invasive monitoring during maintenance of anaesthesia, DiC_{radial} was also measured from the arterial pressure signal using the same methodology as DiC_{pleth}. The last 3 heart beats of the end-expiratory period were used to calculate DiC_{radial}, from the height of the dicrotic notch to the height of the systolic peak. In those patients, DiC_{pleth}, DiC_{radial} and their relative variations (Δ DiC_{pleth} and Δ DiC_{radial}) during vasoconstrictors administration were also analysed.

Statistical analysis

Values were expressed as median and interquartile range [25th; 75th percentiles]. Changes of the parameters were analysed using Wilcoxon rank test. Concordance percentages between delta Δ MAP, and Δ Dic_{pleth} and Δ PI were calculated during induction period. Areas under the curve (AUC) of Receiver Operating Characteristic (ROC) curve (with 95% confidence interval) of Δ Dic_{pleth} and Δ PI to detect a hypotensive episode were estimated and eventually compared using DeLong test. Youden method was used to determine the optimal Δ Dic_{pleth} and Δ PI cut-off values to detect hypotensive episodes. ROC curve of combination of Δ Dic_{pleth} and Δ PI was built using logistic model. Correlation tests were performed using Spearman test. P<0.05 was considered as statistically significant.

The primary aim of the study was to estimate the AUC of the ROC curve of both Δ Dic_{pleth} and Δ PI to track hypotension during induction. Sample size was determined with an expected AUC at 0.85, an expected incidence of hypotension of 80% and the width of the confidence interval of 1. With a power of 80%, the number of patients to include was then 62.¹⁶ Secondary objective was to evaluate AUC of the ROC curve for the combination of Δ Dic_{pleth} and Δ PI.

Statistical analysis was performed using Prism 6.00© (Graphpad Software, Inc, La Jolla, CA, USA) and R 3.3.0 software (R foundation for Statistical Computing, Vienna, Austria).

Patients who had non-measurable Dic_{pleth} at baseline before induction of anaesthesia were excluded from the analysis.

RESULTS

Patients

From November 2014 to May 2015, 65 patients were included in the study. Before induction of anaesthesia, $Di_{C_{pleth}}$ was non-measurable in 4 patients (6.2%) due to the absence of detectable dicrotic notch on the photoplethysmographic signal (class IV waveform according to Dawber et al.).¹⁷

Characteristics of the 61 remaining patients are listed in Table 1. Most patients were ASA II, with a mean age of 54 [39; 64] years. Arterial hypertension, smoking, and dyslipidaemia were the most common co-morbidity encountered. Reason for Neuroradiology procedures was mainly aneurysm or arteriovenous malformation scheduled embolization.

Evolution of MAP, $Di_{C_{pleth}}$ and perfusion index during the induction period

Median duration of anaesthetic induction was 11 [10; 13.5] minutes. Overall, we recorded 720 haemodynamic data points: 61 at baseline values, and 659 after anaesthetic injection, hence representing 659 variations from baseline. The MAP baseline value was 86 [79; 93] mmHg giving an individual limit of intra-operative hypotension at 69 [62; 74] mmHg. MAP decreased to 54 [48; 60] mmHg before laryngoscopy, and rose to 72 [64; 82] mmHg after tracheal intubation. The mean MAP on the overall induction period was 70 [64; 71] mmHg.

Fifty-four patients (88%) suffered from at least one hypotensive episode during anaesthesia induction, representing 323 measurements (49% of haemodynamic points). Twenty-eight patients (46%) received one bolus of vasopressor during induction (2 phenylephrine and 26 noradrenaline). $Di_{C_{pleth}}$ was at 0.54 [0.45; 0.65] at baseline, dropped to 0.36 [0.19; 0.45] ($p < 0.001$) and increased to 0.46 [0.41; 0.56] after tracheal intubation. PI baseline values were 1.7 [0.9; 3] and increased to 4.4 [2.8; 6.6] ($p < 0.001$) before laryngoscopy, and then

decreased to 3.6 [2.1; 5.4] after tracheal intubation. A visual representation of Δ MAP, Δ Dic_{pleth} and Δ PI over induction time is described in Figure 2. We found 89% concordance between Δ Dic_{pleth} and Δ MAP and 90% between Δ PI and Δ MAP (Supplemental file 1).

Diagnosis performances of Δ Dic_{pleth} and Δ PI for detection of arterial hypotension

Figure 3 represents ROC curves to assess Δ Dic_{pleth} and Δ PI performances to detect hypotensive episodes. Diagnosis performances values of Δ Dic_{pleth} and Δ PI are summarized in Table 2. The best threshold value of Δ Dic_{pleth} and Δ PI for detecting intra-operative hypotension were -19% and 51%, respectively. AUC of Δ Dic_{pleth} and Δ PI were not significantly different ($p=0.22$).-Combining Δ Dic_{pleth} and Δ PI to detect hypotensive episodes improved the detection performance with an AUC of ROC curve (0.91, (95%CI 0.88-0.95, $p<0.001$) statistically better than Δ Dic_{pleth} and Δ PI separately ($p=0.026$ and $p<0.001$, respectively) (Table 2, Supplemental file 2 and 3).

Evolution of MAP, Dic_{pleth} and PI during vasoconstrictor administration

Twenty-eight patients (46%) received a bolus of vasopressors during induction (2 phenylephrine and 26 noradrenaline). After vasopressors, MAP increased from 59 [50; 67] mmHg to 76 [68; 79] mmHg (relative variation: 30 % [14; 45], $p<0.001$). Dic_{pleth} increased from 0.34 [0.25; 0.39] to 0.48 [0.35; 0.55] (relative variation: 44% [17; 63], $p<0.001$) and PI decreased from 4.0 [3.3; 5.4] to 3.2 [1.8; 5.4] (relative variation: -28% [-44;-13], $p<0.001$). Δ Dic_{pleth} and Δ PI under the effect of vasopressors were strongly related to Δ MAP ($r=+0.73$, 95%CI 0.48-0.87, $p<0.001$ and $r = -0.62$ 95%CI -0.81 to -0.32, $p<0.001$; respectively) (Supplemental file 4).

Evolution $D_{C_{pleth}}$ and $D_{C_{radial}}$ during vasoconstrictor administration

During maintenance of anaesthesia, 48 boluses of noradrenaline were administered to 10 patients (5 [4; 6] boluses per patient) under invasive blood pressure monitoring. $D_{C_{pleth}}$ was non-measurable in 2 haemodynamic points which were excluded from the analysis. MAP increased from 70 [63; 77] mmHg to 88 [77; 98] mmHg (relative variation 26% [19; 34], $p < 0.001$). $D_{C_{pleth}}$ increased from 0.28 [0.17; 0.36] to 0.39 [0.25; 0.46], and $D_{C_{radial}}$ from 0.32 [0.21; 0.39] to 0.40 [0.31; 0.49] (respective relative variations 34% [20; 71], $p < 0.001$ and 27% [14; 46], $p < 0.001$). $D_{C_{pleth}}$ and $D_{C_{radial}}$ and their relative variations were strongly correlated during vasoconstrictor administration ($r = 0.87$ 95%CI 0.83-0.90 and $r = 0.92$ 95%CI 0.85-0.95) (Supplemental file 5).

DISCUSSION

In our study, we describe during induction of anaesthesia the variations of two parameters issued from photoplethysmographic curves, namely $D_{C_{pleth}}$ and PI, and their performance to detect intra-operative hypotension under the vasoactive effects of anaesthetic drugs. ΔMAP and $\Delta D_{C_{pleth}}$ vary in parallel during induction of anaesthesia, while ΔMAP and ΔPI vary inversely, with good concordance (89% and 90% respectively). Our study also found correlations between variations of $D_{C_{pleth}}$ and MAP on one hand, and PI and MAP on the other hand, under the influence of vasoconstrictors. The main result of our study is that $\Delta D_{C_{pleth}}$ and ΔPI were accurate and presented similar performances to detect intra-operative hypotension induced by general anaesthesia. Moreover, a combined analysis of these two parameters enhanced diagnostic performance for detecting intra-operative hypotension under actions of vasoactive effect of anaesthetics.

Dicrotic waveform variations have been described on invasive ABP and photoplethysmographic curves with changes of haemodynamic status in various clinical conditions. At the aortic level, the dicrotic notch represents the closure of aortic valve, i.e the end-systolic pressure, which is then followed by the dicrotic wave and the aortic elastic recoil (Windkessel effect). End-systolic pressure is dependent on afterload, which can vary quickly with changes in vascular tone, as during induction of anaesthesia due to the vasoactive effect of anaesthetic drugs.¹⁸ A linear relationship has been described between central dicrotic notch pressure and MAP.¹⁸ A similar relationship at the photoplethysmography level has been suggested between $D_{C_{pleth}}$ and MAP.¹⁰ But to our knowledge, no study quantified $D_{C_{pleth}}$ variations to detect arterial hypotension. The photoplethysmography curve represents the pulsatile variations of light absorption measured on a tissue. It is an indirect measurement of arteriolar dilatation and hence of

arteriolar transmural pressure variations at each cardiac cycle. It seems that ABP and photoplethysmographic waveforms have the same determinants as confirmed in a sub-analysis we performed that shows high correlation between dicrotic notch height on the photoplethysmographic signal and radial invasive ABP (ESM 5). Indeed a transfer function has been previously described between invasive ABP and photoplethysmographic curves.¹⁹ This suggests that Dic_{pleth} could be used as a surrogate parameter for the non-invasive and continuous monitoring of MAP during induction of anaesthesia. Furthermore, as the dicrotic notch pressure at the aortic level, Dic_{pleth} , could be used to assess vascular tone and MAP variations under vasoactive drugs effect as reported in several previous studies.^{11 12} Our results confirm this hypothesis, as we found a strong correlation between ΔDic_{pleth} and ΔMAP under the action of vasoconstrictors. A drop of 19% of Dic_{pleth} had good performances to detect intra-operative hypotension with a sensitivity of 79% and a specificity of 84%.

PI represents the ratio between pulsatile and continuous components of light absorption. Lima et al. showed a strong correlation between PI and core-to-toe temperature gradient, a parameter strongly dependent on vascular tone.¹⁴ Some studies have described increase of PI during reduction of vascular tone due to sympathectomy during the onset of peripheral or epidural anaesthesia.^{20 21} PI has also been described to increase with vasoconstriction induced by central hypovolemia during lower body negative pressure.²² Most available pulse oximeter in operating room already displays PI. Our results showed a negative correlation between ΔPI and ΔMAP under vasopressors. ΔPI was also accurate to detect intra-operative hypotension, but was probably less reliable than ΔDic_{pleth} to inform about the depth of hypotension, probably because of the complex influence of vascular tone and stroke volume on PI. Finally, our results suggest that combining both parameters could improve the detection of hypotension with a specificity and sensitivity of 84%.

Our study has some limitations. On first, our study included mainly ASA I or II patients, for neurosurgical or neuroradiology elective procedures. None of them had cardiac failure or severe arterial diseases. However, most of patients in our study were free of medication that may influence arterial compliance and proprieties. Our results need to be validated in patients with higher ASA score and cardiovascular risk. However, patients with higher ASA status are more likely to require continuous invasive ABP monitoring and hence will not require such a simple and easy alternative to detect intra-operative hypotension.

Secondly, we used the standard intermittent oscillometric method for ABP measurements which might be less reliable than invasive ABP.^{23 24} A study comparing the performance of $\Delta\text{Dic}_{\text{pleth}}$ and ΔPI to detect hypotension based on accurate continuous ABP reference would be useful. Our patients did not have cardiac output monitoring. In further studies, it would be useful to study relationships between PI, MAP and stroke volume to evaluate the influence of stroke volume on PI variations. These interconnected parameters are complex and a potential drop of stroke volume may influence variations of PI by other mechanisms than changes in vascular tone alone as during induction of anaesthesia. Finally, all the patients received total intravenous anaesthesia (propofol and remifentanyl), and the vasoconstrictor drugs used were noradrenaline and phenylephrine. Our result may not be similar with other drugs, such as Ephedrine. Also our study is based on fingertip photoplethysmographic signals. As photoplethysmographic waveforms contour depend on measurement site, our conclusion might not be applicable if photoplethysmographic signals are recorded from another site.^{25,26}

The relative height of the dicrotic notch and the perfusion index, both measured from a standard pulse oximetry signal (photoplethysmography signal), could be used to detect hypotensive episodes during induction of anaesthesia. The combined analysis of the

variations of these two indices could represent a new non-invasive, simple and easy-to-use tool to follow arterial blood pressure variations during general anaesthesia.

AUTHORS CONTRIBUTION:

Study design and supervision: MC, JM, FV

Data collection: MC, JJ, FD, FV

Data analysis and interpretation: MC, SM, HN, EG, FV

Drafting and writing paper: MC, SM, EG, FV

Revision and approval for final manuscript: MC, JJ, FD, SM, HN, JM, AM, EG, FV.

Acknowledgements:

The authors thank all the paramedical staff of the operating room, the doctors of Neuroradiology as well as the whole clinical research team of the "*Le Temple*".

Disclosure:

Alexandre Mebazaa has received speaker honoraria from Abbott, Novartis, Orion, Roche and Servier and fee as member of advisory board and/or steering committee from Cardioentis, Adrenomed, MyCartis, ZS Pharma and Critical Diagnostics. Etienne Gayat has received consulting fees from Magnisense, research support from Sphingotec, Deltex Medical and Retia Medical. Fabrice Vallée has received research support from Radiometer, Deltex Medical and Retia Medical. Sandrine Millasseau has received consulting fees from Alam Medical, AtCor Medical, Mesi Medical and Omron.

Funding: None

REFERENCES:

1. Lienhart A, Auroy Y, Péquignot F, Benhamou D, Warszawski J, Bovet M, et al. Survey of anesthesia-related mortality in France. *Anesthesiology* 2006; **105**: 1087–97
2. Nair BG, Horibe M, Newman S-F, Wu W-Y, Peterson GN, Schwid HA. Anesthesia information management system-based near real-time decision support to manage intraoperative hypotension and hypertension. *Anesth Analg* 2014; **118**: 206–14
3. Futier E, Lefrant J-Y, Guinot P-G, Godet T, Lorne E, Cuvillon P, et al. Effect of Individualized vs Standard Blood Pressure Management Strategies on Postoperative Organ Dysfunction Among High-Risk Patients Undergoing Major Surgery: A Randomized Clinical Trial. *JAMA* 2017; **318**: 1346–57
4. Wesselink EM, Kappen TH, Torn HM, Slooter AJC, van Klei WA. Intraoperative hypotension and the risk of postoperative adverse outcomes: a systematic review. *Br J Anaesth* 2018; **121**: 706–21
5. Willingham MD, Karren E, Shanks AM, O'Connor MF, Jacobsohn E, Kheterpal S, et al. Concurrence of Intraoperative Hypotension, Low Minimum Alveolar Concentration, and Low Bispectral Index Is Associated with Postoperative Death. *Anesthesiology* 2015; **123**: 775–85
6. Reich DL, Hossain S, Krol M, Baez B, Patel P, Bernstein A, et al. Predictors of Hypotension After Induction of General Anesthesia. *Anesth Analg* 2005; **101**: 622–8
7. Kork F, Balzer F, Krannich A, Weiss B, Wernecke K-D, Spies C. Association of comorbidities with postoperative in-hospital mortality: a retrospective cohort study. *Medicine (Baltimore)* 2015; **94**: e576
8. Walsh M, Devereaux PJ, Garg AX, Kurz A, Turan A, Rodseth RN, et al. Relationship between intraoperative mean arterial pressure and clinical outcomes after noncardiac surgery: toward an empirical definition of hypotension. *Anesthesiology* 2013; **119**: 507–15
9. Ng JLW, Chan MTV, Gelb AW. Perioperative stroke in noncardiac, nonneurosurgical surgery. *Anesthesiology* 2011; **115**: 879–90
10. Millasseau SC, Kelly RP, Ritter JM, Chowienczyk PJ. Determination of age-related increases in large artery stiffness by digital pulse contour analysis. *Clin Sci Lond Engl* 1979 2002; **103**: 371–7
11. Millasseau SC, Ritter JM, Takazawa K, Chowienczyk PJ. Contour analysis of the photoplethysmographic pulse measured at the finger. *J Hypertens* 2006; **24**: 1449–1456
12. Chowienczyk PJ, Kelly RP, MacCallum H, Millasseau SC, Andersson TL, Gosling RG et al. Photoplethysmographic assessment of pulse wave reflection: blunted response to endothelium-dependent beta2-adrenergic vasodilation in type II diabetes mellitus. *J Am Coll Cardiol* 1999; **34**: 2007–14

13. van Genderen ME, Bartels SA, Lima A, Bezemer R, Ince C, Bakker J, et al. Peripheral Perfusion Index as an Early Predictor for Central Hypovolemia in Awake Healthy Volunteers. *Anesth Analg* 2013; **116**: 351–6
14. Lima AP, Beelen P, Bakker J. Use of a peripheral perfusion index derived from the pulse oximetry signal as a noninvasive indicator of perfusion. *Crit Care Med* 2002; **30**: 1210–1213
15. Bijker JB, van Klei WA, Kappen TH, van Wolfswinkel L, Moons KGM, Kalkman CJ. Incidence of intraoperative hypotension as a function of the chosen definition: literature definitions applied to a retrospective cohort using automated data collection. *Anesthesiology* 2007; **107**: 213–20
16. Obuchowski NA. Sample size calculations in studies of test accuracy. *Stat Methods Med Res* 1998; **7**: 371–92
17. Dawber T, Emerson TJ, McNamara P. Characteristics of the dicrotic notch of the arterail pulse wave in coronary heart disease. *Angiology* 1973; **24**: 244–55
18. Hébert JL, Lecarpentier Y, Zamani K, Coirault C, Daccache G, Chemla D. Relation between aortic dicrotic notch pressure and mean aortic pressure in adults. *Am J Cardiol* 1995; **76**: 301–6
19. Millasseau SC, Guigui FG, Kelly RP, Prasad K, Cockcroft JR, Ritter JM, et al. Noninvasive assessment of the digital volume pulse. Comparison with the peripheral pressure pulse. *Hypertension* 2000; **36**: 952–6
20. Ginosar Y, Weiniger CF, Meroz Y, Kurz V, Bdolah-Abram T, Babchenko A, et al. Pulse oximeter perfusion index as an early indicator of sympathectomy after epidural anesthesia. *Acta Anaesthesiol Scand* 2009; **53**: 1018–26
21. Galvin EM, Niehof S, Verbrugge SJ, Maissan I, Jahn A, Klein J, et al. Peripheral Flow Index Is a Reliable and Early Indicator of Regional Block Success. *Anesth Analg* 2006; **103**: 239–43
22. Lima A, Van Genderen M, Klijn E, Bartels S, Van Bommel J, Bakker J. Perfusion index as a predictor for central hypovolemia in humans. *Crit Care* 2011; **15**: P69
23. Sheshadri V, Tiwari AK, Nagappa M, Venkatraghavan L. Accuracy in Blood Pressure Monitoring: The Effect of Noninvasive Blood Pressure Cuff Inflation on Intra-arterial Blood Pressure Values. *Anesth Essays Res* 2017; **11**: 169–73
24. Nakagomi A, Okada S, Shoji T, Kobayashi Y. Comparison of invasive and brachial cuff-based noninvasive measurements for the assessment of blood pressure amplification. *Hypertens Res Off J Jpn Soc Hypertens* 2017; **40**: 237–42
25. Allen J, Murray A. Age-related changes in the characteristics of the photoplethysmographic pulse shape at various body sites. *Physiol Meas* 2003; **24**: 297–307

26. Cannesson M, Desebbe O, Rosamel P, Delannoy B, Robin J, Bastien O, et al. Pleth variability index to monitor the respiratory variations in the pulse oximeter plethysmographic waveform amplitude and predict fluid responsiveness in the operating theatre. *Br J Anaesth* 2008; **101**: 200–6

Table 1- Patient characteristics

Patients (n)		61
Male, n (%)		22 (36)
Age (years)		54 [39-64]
BMI (kg m ⁻²)		25 [21-28]
ASA, n (%)	1	15 (25)
	2	44 (72)
	3	2 (3)
	4	0 (0)
Comorbidities n (%)	Arterial hypertension	20 (33)
	Smoking	23 (38)
	Dyslipidaemia	6 (10)
	Diabetes mellitus	2 (3)
	STEMI	0 (0)
	Heart failure	0 (0)
	Intracranial hypertension	2 (3)
Treatments n (%)	Beta-blockers	11 (18)
	Renin Blockers of renin angiotensin system	10 (16)
	Calcium blockers	5 (8)
Procedures	Aneurism embolisation	47 (77)
	Arteriovenous malformation embolisation	12 (20)
	Other	2 (3)
Baseline haemodynamic parameters		
SAP (mmHg)		127 [116-137]
DAP (mmHg)		73 [66-80]
MAP (mmHg)		86 [79-93]
HR (bpm)		67 [61-78]
Di _{C_{pleth}}		0.54 [0.45-0.65]
PI		1.7 [0.9-3.0]

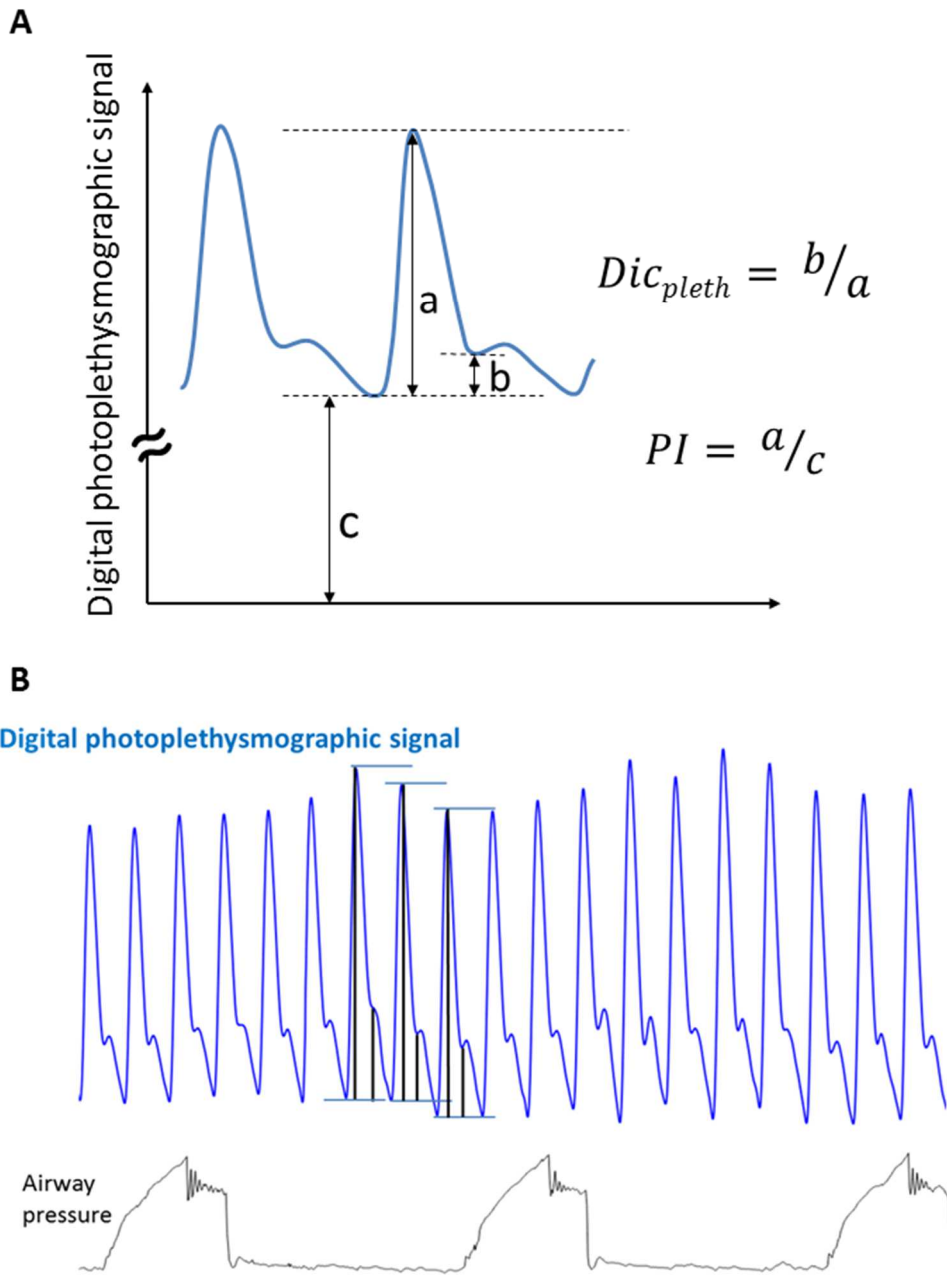
Data are expressed as mean [25-75] IQ or number and percentage. BMI: body mass index; ASA: American Society of Anesthesiologists; STEMI: ST-Elevation Myocardial Infarction; SAP: systolic arterial pressure; DAP: diastolic arterial pressure; MAP: mean arterial pressure; HR: heart rate, Di_{C_{pleth}}: relative dicrotic notch height; PI: perfusion index.

Table 2- Diagnostic performances for $\Delta\text{Dic}_{\text{pleth}}$, ΔPI and $\Delta\text{Dic}_{\text{pleth}}$ and ΔPI combination to detect IOH episodes.

	$\Delta\text{Dic}_{\text{pleth}}$	ΔPI	$\Delta\text{Dic}_{\text{pleth}} + \Delta\text{PI}$
AUC ROC	0.83 (95%CI 0.80-0.86)	0.86 (95%CI 0.80-0.86)	0.91 (95%CI 0.88-0.95)
P-value	<0.001	<0.001	<0.001
Threshold value	-19%	51%	NA
Sensitivity (%)	79	82	84
Specificity (%)	84	74	84
PPV (%)	79	71	79
NPV (%)	84	85	89

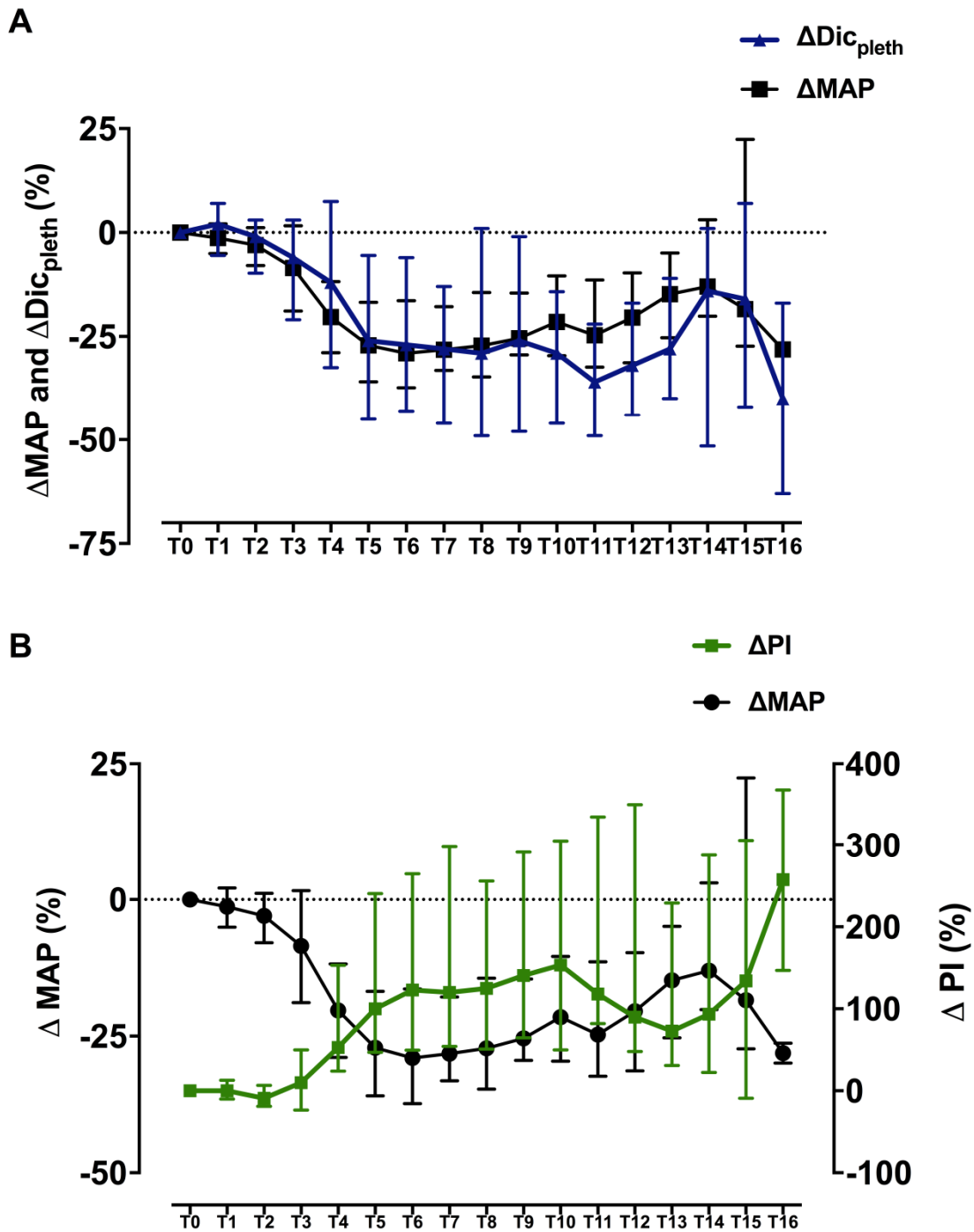
$\Delta\text{Dic}_{\text{pleth}}$: relative variation of $\text{Dic}_{\text{pleth}}$ from baseline; ΔPI : relative variation of perfusion index from baseline; AUC ROC: Area under the curve of receiver operating characteristic; PPV: Positive predictive value; NPV: Negative predictive value

Figure 1- Definition of Dic_{pleth} and PI (panel A) and an example of Dic_{pleth} measurement on a real-life photoplethysmographic curve (panel B)



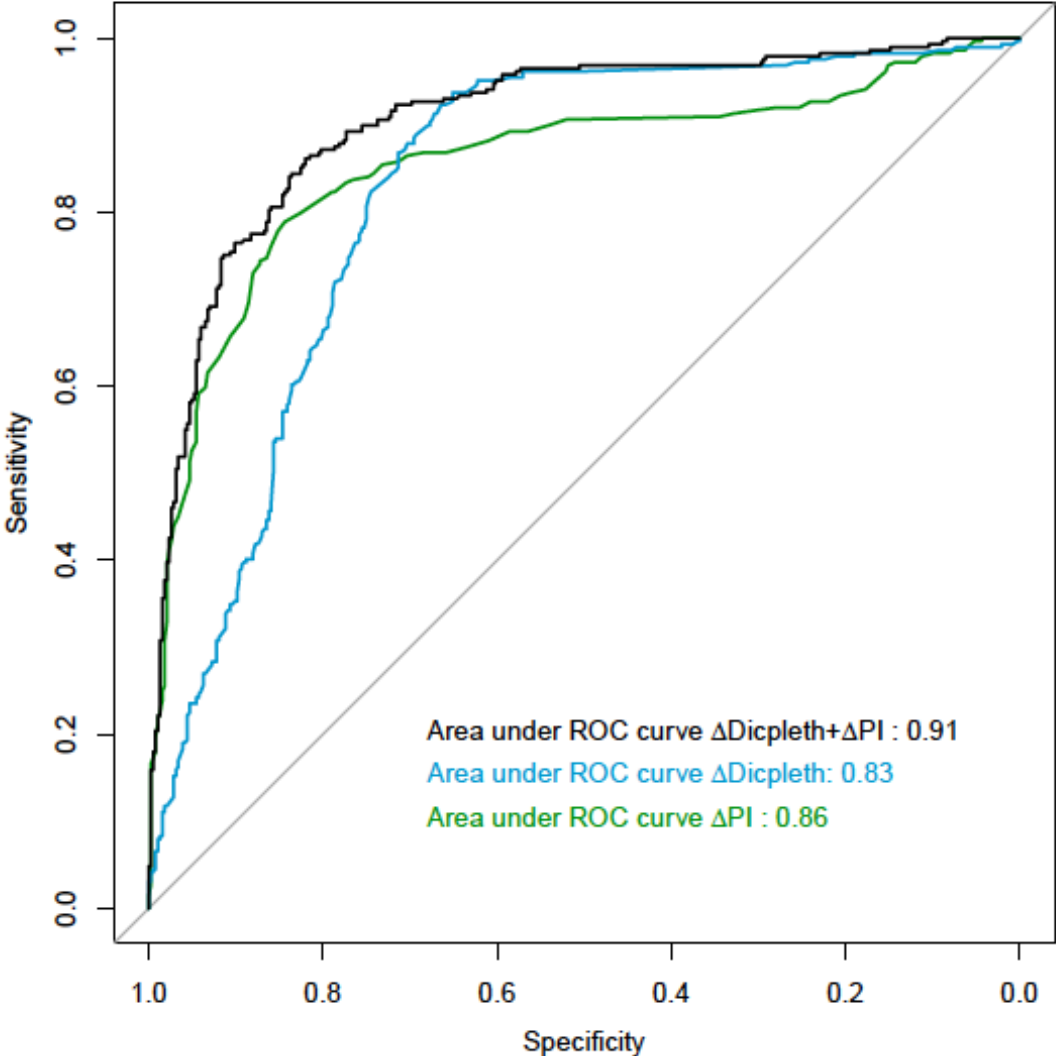
Dic_{pleth} : relative dicrotic notch height on the digital photoplethysmographic signal (calculated as b/a ratio, by averaging the values of 3 consecutive complexes, at end-expiratory time); PI: perfusion index (given by the manufacturer, representing the a/c ratio). a = amplitude of the pulsatile component of the digital photoplethysmographic signal. It can also be described as the height of the systolic peak; b = height of the dicrotic notch; c = amplitude of the steady state component of the digital photoplethysmographic signal.

Figure 2- Median Δ MAP and Δ DiC_{pleth} (panel A) and median Δ MAP and Δ PI (panel B) during induction of anaesthesia



Δ DiC_{pleth} : relative variation of DiC_{pleth} from baseline; Δ PI : relative variation of perfusion index from baseline ; Δ MAP: relative variation of MAP from baseline. The figure represents Δ MAP and Δ DiC_{pleth} evolution during the 16 min period of induction of anaesthesia. Median MAP and DiC_{pleth} variation from baseline are represented at each minute (T"x" , at "x" min from T0) from the beginning of the induction (T0).

Figure 3- Receiver operator characteristic curves for Δ PI and Δ Dic_{pleth} performance to detect IOH.



Δ PI: relative variation of perfusion index; Δ Dic_{pleth}: relative variation of Dic_{pleth}; Δ MAP: relative variation of mean arterial pressure; IOH: intra operative hypotension ROC: receiver operating characteristic