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Original Contribution

# Evaluation of pre-induction dynamic arterial elastance as an adjustable predictor of post-induction hypotension: A prospective observational study☆

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## HIGHLIGHTS

- Post-induction hypotension develops frequently, with an incidence as high as 36.5%.
- Although, many studies have identified the predictors of post-induction hypotension, most predictors are not changeable.
- Dynamic arterial elastance measured invasively during deep breathing can predict post-induction hypotension.
- Despite its invasiveness, dynamic arterial elastance is useful, because it is an adjustable parameter.

## ARTICLE INFO

*Keywords:*
Arterial load
Dynamic arterial elastance
General anesthesia
Post-induction hypotension
Pulse pressure variation (PPV)
Stroke volume variation (SVV)

## ABSTRACT

*Study objective:* Dynamic arterial elastance (Eadyn) has been suggested as a functional measure of arterial load. We aimed to evaluate whether pre-induction Eadyn can predict post-induction hypotension.
*Design:* Prospective observational study.
*Patients:* Adult patients undergoing general anesthesia with invasive and non-invasive arterial pressure monitoring systems.
*Measurements:* We collected invasive and non-invasive Eadyns ($n = 38$ in each), respectively. In both invasive and non-invasive Eadyns, pre-induction Eadyns were obtained during one-minute tidal and deep breathing in each patient before anesthetic induction. Post-induction hypotension was defined as a decrease of >30% in mean blood pressure from the baseline value or any absolute mean blood pressure value of <65 mmHg for 10 min after anesthetic induction. The predictabilities of Eadyns for the development of post-induction hypotension were tested using receiver-operating characteristic curve analysis.
*Main results:* Invasive Eadyn during deep breathing showed significant predictability with an area under the curve (AUC) of 0.78 (95% Confidence interval [CI], 0.61–0.90, $P = 0.001$). But non-invasive Eadyn during tidal breathing (AUC = 0.66, 95% CI, 0.49–0.81, $P = 0.096$) and deep breathing (AUC = 0.53, 95% CI, 0.36–0.70, $P = 0.75$), and invasive Eadyn during tidal breathing (AUC = 0.66, 95% CI, 0.41–0.74, $P = 0.095$) failed to predict post-induction hypotension.
*Conclusion:* In our study, invasive pre-induction Eadyn during deep breathing -could predict post-induction hypotension. Despite its invasiveness, future studies will be needed to evaluate the usefulness of Eadyn as a predictor of post-induction hypotension because it is an adjustable parameter.

☆ This study was presented in part at the 24th annual meeting of the Korean Society of Cardiothoracic and Vascular Anesthesiologists, April 10–11, 2021, Seoul, Korea.This study was registered in Clinical Research Information Service (https://cris.nih.go.kr; Identifier: KCT0005525).

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## 1. Introduction

Intraoperative hypotension increases postoperative morbidity and mortality, even if it occurs transiently. [1,2] Among those hypotensive episodes, hypotension after anesthetic induction also frequently develops, with an incidence as high as 36.5%, [3,4] and is mainly caused by anesthetic agents such as propofol. [5] In addition, a study showed hypotension after anesthetic induction was associated with postoperative kidney injury. [5] Many studies have identified the factors related to and the predictors of post-induction hypotension, but most predictors are not changeable. [3,4,6,7]

Until present, parameters showing intravascular volume status, such as inferior vena cava collapsibility index, passive leg raising test, and inferior vena cava to aorta diameter index, have been suggested as adjustable predictors of post-induction hypotension. [8–10] However, a recent study demonstrated that merely optimizing intravascular volume status is insufficient to prevent post-induction hypotension and further illustrated the lack of correlation between stroke volume change and subsequent hypotension after anesthetic induction. [9]

Dynamic arterial elastance (Eadyn), defined as the ratio between pulse pressure variation (PPV) and stroke volume variation (SVV), has been proposed as a functional measure of arterial load by integrating the flow from the heart and the opposing pressure from the arterial system during a respiratory cycle. [11,12] Eadyn has also been suggested to predict blood pressure increase according to fluid loading in preload-dependent patients. In addition, a recent study has suggested that post-induction hypotension seems to be related to arterial dilatation rather than venous dilatation or reduced myocardial contractility. [13] Therefore, we hypothesized that the parameter reflecting pre-induction arterial tone could be associated with blood pressure change after anesthetic induction. Our study aims to evaluate the usefulness of Eadyn as an adjustable predictor of post-induction hypotension using an invasive or non-invasive continuous blood pressure monitoring system (invasive or non-invasive Eadyn, respectively).

## 2. Materials and methods

This prospective observational study was approved by the Institutional Review Board of Samsung Medical Center, Seoul, Korea, on October 14, 2020 (SMC 2020–08–094-002). This study was registered before enrolling the patients at the Clinical Research Information Service (KCT0005525, Principal investigator: Jong-Hwan Lee, Date of registration: October 21, 2020). We obtained written informed consent from all patients before participating in the study and performed all the protocols under the relevant guidelines and regulations.

### *2.1. Patients*

From October 2020 to June 2021, we included adult patients undergoing elective non-cardiac surgery through general anesthesia with continuous blood pressure monitoring in this study. Patients were excluded if they had any of the following characteristics: a wound near the device application site; an abnormal vascular circulation of the hand (based on a satisfactory modified Allen test result); a sign of skin infection; patient with cardiac ejection fraction below 40% or severe cardiopulmonary disease; history of autonomic nerve disease; patient with an implanted pacemaker; patient with difficult airway; a recent history of radial artery catheterization; or a history of peripheral artery disease.

### *2.2. Monitoring and anesthetic induction*

All patients arrived in the operating room were initiated with standard monitoring such as pulse oximetry (Covidien Nellcor, Covidien, USA), 3-lead electrocardiography, bispectral index (BIS) (Quatro sensor, Covidien Ilc, MA, USA), and non-invasive blood pressure measurements. The vital signs were obtained from the monitor (Philips IntelliVue MP70, Philips, USA) in real time. Whereas, the additional continuous blood pressure was monitored using the ClearSight (Edwards Lifesciences, Irvine, CA, USA) or the FloTrac (MHD 6, Edwards Lifesciences, Irvine, CA, USA) system to calculate non-invasive or invasive Eadyn, respectively. The continuous blood pressure monitoring device was applied to the counter arm of the arm with the non-invasive blood pressure cuff. In the experiment for non-invasive Eadyn, the ClearSight finger cuff was applied to the mid-phalanx of the middle finger and connected to the wrist unit, which is plugged into the EV1000 monitor (Edwards Lifesciences, Irvine, CA, USA). [14] The ClearSight system performed physiological recalibrations automatically at regular intervals to keep the finger arteries open and in constant diameter. The pressure in the brachial artery was reconstructed from the pressure signal measured in the finger cuff, demonstrating continuous arterial blood pressure. A radial artery was cannulated after local infiltration of lidocaine in the experiment for invasive Eadyn. The radial artery catheter was connected to the FloTrac transducer plugged into the EV1000 monitor.

Zero pressure was referenced to the intersection of the anterior axillary line at the fifth intercostal space in both the ClearSight and the FlorTrac systems. We used real-time data acquisition software to automatically record hemodynamic data (Vital Recorder, Vital DB). [15] Heart rate, systolic blood pressure (SBP), mean blood pressure (MBP), diastolic blood pressure (DBP), cardiac index, stroke volume, SVV, and PPV were collected immediately before anesthetic induction (baseline) until 10 min after induction. If the baseline MBP differed by >30% compared with the MBP value measured on the morning of the surgery day, the patient was allowed to relax for 10 min.

Anesthesia was induced with propofol (2 mg/kg) and inhaled sevoflurane was started when bispectral index reached 60. Anesthesia was titrated with inhaled sevoflurane to maintain bispectral index of between 40 and 60 in all patients. After loss of consciousness, 0.6–0.8 mg/kg of rocuronium was administered to achieve neuromuscular blockade. Patients' airways were secured by endotracheal intubation as the Train-of-four ratio decreased from 1.0 to 0. Mechanical ventilation was delivered at a tidal volume of 8 mL/kg (predicted body weight) using a mixture of medical air and oxygen at a fresh gas flow rate of 2 L/min, and the respiratory rate was adjusted as needed to maintain normocapnea during the surgery. No additional opioids were used during the study period of 10 min. According to the standardized institutional protocol, nil per os (NPO) was applied from midnight. In the operating room, no fluid was given before anesthetic induction. We infused balanced crystalloids at a rate of 10 mL/kg/h to all patients during the study period.

### *2.3. Data acquisition*

Pulse pressure variation (PPV) and stroke volume variation (SVV) were collected before initiating anesthesia in spontaneously breathing patients. In both experiments, patients were first encouraged to breathe in the usual pattern (tidal breathing) and then were instructed to take a deeply forced inspiratory breath followed by slow passive expiration (deep breathing). [16] Each breathing lasted at least one minute. We applied a tightly fitting facial mask with an adjustable pressure-limiting (APL) valve open to check the amount of tidal volume and breathing frequency through capnography. Patients were encouraged to maintain the tidal volume of 6–8 and 10–12 mL/kg (predicted body weight) in tidal and deep breathing, respectively.

Based on the arterial blood pressure, PPV was calculated using the maximum and minimum values for pulse pressure determined over each respiratory cycle as follows: $PPV (\%) = 100 \times (PPmax - PPmin) / [(PPmax + PPmin) / 2]$. The mean value of three consecutive respiratory cycles was used. In comparison, SVV was calculated every 5 sec by the ClearSight and the FloTrac systems and displayed on the EV1000 monitor based on the standard formulae. Then we figured the Eadyns from two different monitoring devices, such as ClearSight and FloTrac systems (non-invasive and invasive Eadyns), respectively, before anesthesia, 5 min, and 10 min after anesthetic induction.

As steady and pulsatile arterial load variables, we calculated total systemic vascular resistance (TSVR = MBP / cardiac output × 80) and net arterial compliance (C = stroke volume / arterial pulse pressure), respectively. [17] Effective arterial elastance (Ea = 0.9 × systolic arterial blood pressure / stroke volume) was also calculated as a variable integrating steady and pulsatile components of an arterial load. [18] Other data such as patients' characteristics, hemodynamic parameters in the ward, comorbidities, and medication history were obtained from our electronic medical record system.

### 2.4. Statistical analysis

Data are presented as the number of patients (%), mean (SD), or median (interquartile range, IQR). Changes in MBP according to anesthetic induction were used as the principal indicator of post-induction hypotension. Post-induction hypotension was defined as a decrease of >30% in MBP from the baseline value or any absolute MBP value <65 mmHg for 10 min after anesthetic induction. [19,20] Induction time was considered as the time after tracheal intubation. If post-induction MBP decreased below 55 mmHg and did not resolve within five minutes, vasoactive drugs were used. [1]

Sample size was calculated based on our pilot study results, in which the incidence of post-induction hypotension was 56%. We considered that a ROC curve with an AUC of at least 0.8 indicates a clinically reliable predictor for post-induction hypotension. Therefore, considering the null hypothesis was 0.5 (fail to discriminate), at least 34 patients were required to detect an AUC difference of 0.3 with a two-sided type I error of 0.05 and a type II error of 0.2 when assuming the incidence of post-induction hypotension was 56%. Considering a drop-out rate of 10%, 38 patients were needed in each experiment.

The ability of baseline non-invasive and invasive Eadyns, baseline MBP, TSVR, C, and Ea during tidal and deep breathing to predict post-induction hypotension was tested using the receiver operating characteristic (ROC) curve analysis. The areas under ROC curves (AUCs) of the patients with post-induction hypotension for those variables were calculated. The general interpretations of a test according to the value of AUC are as follows: AUC = 0.5, no better than chance, a useless test with no prediction possible; AUC = 0.6–0.69, a test with poor predictability; AUC = 0.7–0.79, a fair test; AUC = 0.8–0.89, a test with good predictability; AUC = 0.9–0.99, an excellent test; AUC = 1.0, a perfect test with the best possible prediction. [21] The optimal cut-off values were determined using the Youden index (sensitivity + specificity −1) to maximize both sensitivity and specificity.

Patient characteristics, hemodynamic data, and Eadyn were compared between patients with and without post-induction hypotension using the Student's *t*-test or Mann-Whitney *U* test for continuous variables and the Chi-square test or Fisher's exact test for categorical data. Distribution normality was tested by the Kolmogorov-Smirnov test. All statistical analyses were performed using SPSS 25.0 (IBM Corp., Chicago, IL, USA) and MedCalc for Windows, version 19.4 (MedCalc Software, Ostend, Belgium). A two-sided *P* value <0.05 was considered statistically significant.

## 3. Results

Of the 81 patients screened for eligibility, five patients were excluded (3 patients for cardiopulmonary diseases and 2 for refusing to participate) (Fig. 1). Finally, 38 patients in each experiment were included in this study. No patients showed serious complications according to the study protocol.

In both experiments, there was no difference in patient characteristics and hemodynamic data between patients with and without post-induction hypotension except lowest MBP and MBP decrement during the study period (Tables 1 and 2). Also, of 13 patients who had hypertension in the current study, 7 patients were treated with PRN antihypertensive medication due to high blood pressure on the morning of surgery, whereas none of the patients were treated with vasoactive drugs before surgery. Among all calculated arterial load variables, only invasive Eadyn during deep breathing is greater in the patients with post-induction hypotension than in the patients without post-induction hypotension (Tables 1 and 2).

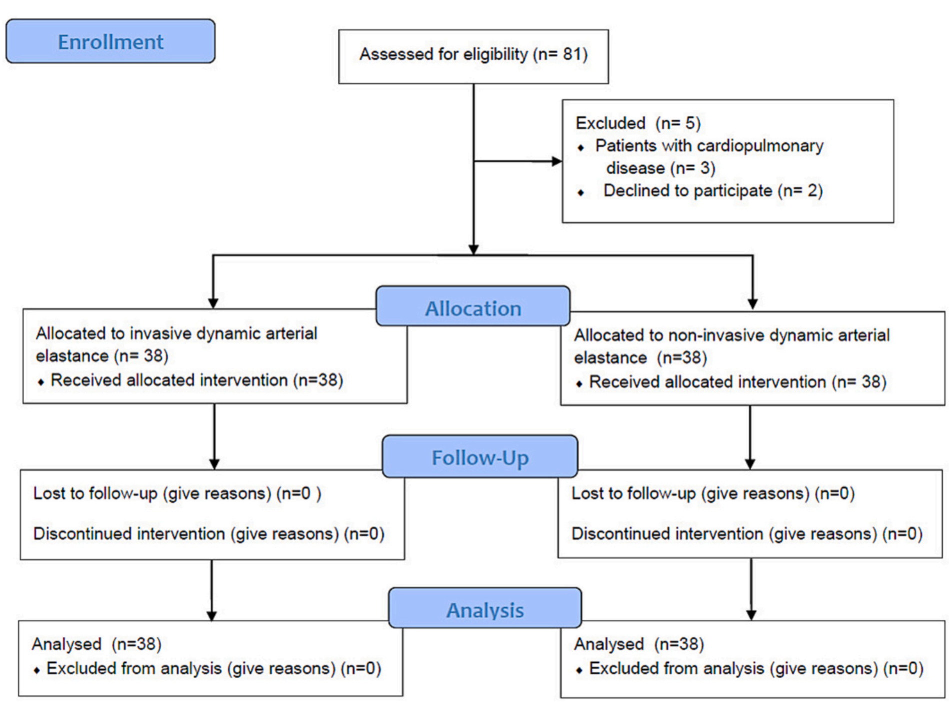


**Fig. 1.** Consort flow diagram. Eadyn, dynamic arterial elastance.

**Table 1**
Comparison of patient characteristics, hemodynamic data, and dynamic arterial elastance extracted from Flotrac™ (invasive monitoring device) in patients who developed post-induction hypotension (PIH) and who did not.

| | Without PIH ($n$ = 28) | With PIH ($n$ = 10) | $P$ |
|---|---|---|---|
| **Baseline characteristic** | | | |
| Age (years) | 57 (43, 69) | 61 (58, 65) | 0.636 |
| Male sex | 13 (46.4) | 5 (50.0) | >0.999 |
| Body mass index (kg·m$^{-2}$) | 24.1 (21.0, 28.2) | 25.0 (23.3, 26.0) | 0.935 |
| ASA class 1 / 2 / 3 | 4 / 22 / 2 | 1 / 9 / 0 | 0.833 |
| History of Hypertension | 7 (25.0) | 5 (50.0) | 0.235 |
| History of Diabetes | 3 (10.7) | 1 (10.0) | >0.999 |
| Baseline SBP (mmHg) | 149 (138, 155) | 153 (136, 179) | 0.368 |
| Baseline MBP (mmHg) | 99 (91, 107) | 104 (98, 106) | 0.482 |
| Baseline Heart rate (beat·min$^{-1}$) | 76 (63, 82) | 81 (62, 96) | 0.334 |
| Baseline Cardiac index (L·min$^{-1}$·m$^{2}$) | 3.2 (2.7. 4.1) | 3.4 (2.7, 3.8) | 0.858 |
| Baseline Stroke volume (mL) | 74 (61, 88) | 78 (49, 84) | 0.782 |
| Baseline Pulse pressure variation | 8 (5, 9) | 9 (7, 12) | 0.209 |
| Baseline Stroke volume variation | 9 (6, 11) | 9 (6, 12) | 0.833 |
| Propofol used (mg) | 120 (110, 138) | 115 (100,133) | 0.442 |
| **Arterial load variables** | | | |
| **Tidal breathing** | | | |
| Total systemic vascular resistance | 1527 (1156, 1767) | 1626 (1277, 1821) | 0.546 |
| Net arterial compliance | 1.05 (0.79, 1.20) | 0.89 (0.72, 0.99) | 0.088 |
| Effective arterial elastance | 1.80 (1.45, 2.16) | 1.92 (1.66, 2.67) | 0.368 |
| Dynamic arterial elastance | 0.78 (0.70, 1.07) | 0.93 (0.78, 1.38) | 0.151 |
| **Deep breathing** | | | |
| Total systemic vascular resistance | 1383 (1048, 1700) | 1447 (1251, 1724) | 0.590 |
| Net arterial compliance | 1.10 (0.79, 1.32) | 0.85 (0.75, 0.96) | 0.151 |
| Effective arterial elastance | 1.60 (1.34, 2.19) | 1.93 (1.73, 2.42) | 0.272 |
| Dynamic arterial elastance | 0.78 (0.55, 0.92) | 1.00 (0.97, 1.13) | 0.009 |
| **Intraoperative Variables** | | | |
| Lowest MBP during study period (mmHg) | 80 (75, 86) | 65 (55, 72) | < 0.001 |
| MBP decrement during study period (mmHg) | 19 (12, 25) | 35 (32, 42) | < 0.001 |
| Rescue medication during study period | 0 | 1 (10.0) | 0.263 |

Data are presented as median (25th percentile, 75th percentile) or frequency (percent). ASA, American society of anesthesiologist; MBP, mean blood pressure; Percentage of decrease in MBP is calculated by the difference between the first MBP measured in the operating room and the lowest MBP during study period. Intraoperative MBP fluctuation is calculated by the difference between the highest MBP and the lowest MBP.

**Table 2**
Comparison of patient characteristics, hemodynamic data, dynamic arterial elastance extracted from Clearsight™ in patients who developed post-induction hypotension (PIH) and who did not.

| | Without PIH ($n$ = 22) | With PIH ($n$ = 16) | $P$ |
|---|---|---|---|
| **Baseline characteristic** | | | |
| Age (years) | 40 (29, 45) | 41 (25, 51) | 0.651 |
| Male sex | 10 (45.5) | 11 (68.8) | 0.197 |
| Body mass index (kg·m$^{-2}$) | 23.8 (21.4, 25.3) | 23.9 (22.5, 25.1) | >0.999 |
| ASA class 1 / 2 | 21 / 1 | 14 / 2 | 0.562 |
| History of Hypertension | 1 (4.5) | 0 | >0.999 |
| History of Diabetes | 0 | 0 | |
| Baseline SBP (mmHg) | 123 (115, 132) | 128 (113, 135) | 0.651 |
| Baseline MBP (mmHg) | 94 (87, 100) | 97 (84, 104) | 0.609 |
| Baseline Heart rate (beat·min$^{-1}$) | 70 (62, 83) | 79 (69, 94) | 0.162 |
| Baseline Cardiac index (L·min$^{-1}$·m$^{2}$) | 3.9 (3.3. 4.6) | 3.8 (2.8, 4.5) | 0.455 |
| Baseline Stroke volume (mL) | 99 (85, 104) | 82 (70, 93) | 0.039 |
| Baseline Pulse pressure variation | 13 (10, 15) | 14 (10,20) | 0.196 |
| Baseline Stroke volume variation | 10 (8, 13) | 11 (9, 14) | 0.467 |
| Propofol used (mg) | 135 (110, 150) | 125 (110, 148) | 0.529 |
| **Arterial load variables** | | | |
| **Tidal breathing** | | | |
| Total systemic vascular resistance | 1047 (969, 1437) | 1090 (972, 1350) | 0.859 |
| Net arterial compliance | 1.86 (1.47, 2.13) | 2.02 (1.69, 2.23) | 0.375 |
| Effective arterial elastance | 1.13 (1.05, 1.42) | 1.33 (1.06, 1.65) | 0.174 |
| Dynamic arterial elastance | 1.00 (1.00, 1.20) | 0.96 (0.87, 1.00) | 0.091 |
| **Deep breathing** | | | |
| Total systemic vascular resistance | 1001 (926, 1278) | 1007 (845, 1233) | 0.544 |
| Net arterial compliance | 1.82 (1.61, 2.13) | 2.13 (1.75, 2.25) | 0.132 |
| Effective arterial elastance | 1.17 (1.00, 1.29) | 1.32 (1.16, 1.57) | 0.063 |
| Dynamic arterial elastance | 1.21 (1.08, 1.33) | 1.21 (1.00, 1.39) | 0.745 |
| **Intraoperative Variables** | | | |
| Lowest MBP during study period (mmHg) | 75 (72, 79) | 64 (59, 68) | < 0.001 |
| MBP decrement during study period (mmHg) | 17 (11, 26) | 31 (24, 33) | < 0.001 |
| Rescue medication during study period | 0 | 0 | |

Data are presented as median (25th percentile, 75th percentile) or frequency (percent). ASA, American society of anesthesiologist; MBP, mean blood pressure; Percentage of decrease in MBP is calculated by the difference between the first MBP measured in the operating room and the lowest MBP during study period. Intraoperative MBP fluctuation is calculated by the difference between the highest MBP and the lowest MBP.

### 3.1. *Experiment for invasive Eadyn as a predictor of post-induction hypotension*

Post-induction hypotension was developed in 10 patients (26.3%), and one patient required an intravenous injection of ephedrine to resolve hypotension during the study period. In the ROC curve analysis (Fig. 2 and Table 3), Eadyn during deep breathing showed a significant predictability with an AUC of 0.78 (95% CI, 0.613–0.895; $P$ = 0.001). A value of pre-induction Eadyn during deep breathing over 0.92 predicted post-induction hypotension after anesthetic agent administration with a sensitivity of 80.0% and a specificity of 78.6%.

### 3.2. *Experiment for non-invasive Eadyn as a predictor of post-induction hypotension*

Sixteen patients (42.1%) experienced post-induction hypotension, but no rescue medication was needed to resolve hypotension. In ROC curve analysis, no parameter can predict the development of post-induction hypotension regardless of the breathing method (Table 3).

## 4. Discussion

In the present study, the pre-induction invasive Eadyn derived from the FloTrac system during deep breathing could predict post-induction hypotension with a fair prediction power. But all other arterial load variables, including invasive Eadyn during tidal breathing and non-invasive Eadyn from the ClearSight system, failed to predict post-

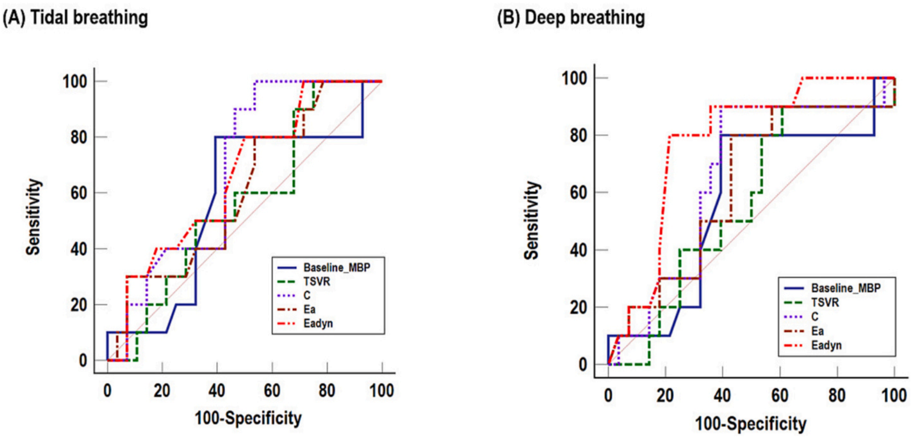


**Fig. 2.** Comparison of receiver operating characteristic (ROC) curves of baseline mean blood pressure (MBP), total systemic vascular resistance (TSVR), net arterial compliance (C), effective arterial elastance (Ea), dynamic arterial elastance (Eadyn) to predict post-induction hypotension in (A) Tidal breathing and (B) Deep breathing.

induction hypotension.

Among the possible mechanisms for developing post-induction hypotension, such as reduced myocardial contractility, venodilation, and arterial dilation, [13,22–24] we focused on the arterial system. An increase in preload by fluid loading or by elevating the legs has been generally suggested to manage propofol-induced hypotension during anesthetic induction because the main cardiovascular effect of propofol is the decrease in cardiac preload due to venodilation. [22] But, a previous study showed that fluid optimization before anesthetic induction alone is not enough to reduce the incidence of post-induction hypotension. [9] And Saugel and colleagues suggested that post-induction hypotension may be caused by arterial dilation rather than venodilation or reduced myocardial contractilit. [13] Therefore, in this study we evaluated Eadyn as a predictor for post-induction hypotension, which has been suggested as a sensitive and easy-to-use indicator reflecting arterial load. [25,26]

Invasive Eadyn during deep breathing was the only parameter that showed predictability to develop post-induction hypotension with fair prediction power (AUC = 0.78). It may be challenging to immediately apply Eadyn because of its invasiveness. However, predictors of post-induction hypotension demonstrated in the previous studies were not usually adjustable and some predictors even required advanced skills for ultrasonography. [3,4,6,7] Given that clinicians can easily change Eadyn by using fluid loading or vaso-active drugs, pre-induction Eadyn can be considered as a parameter which can lead to a preventive management of post-induction hypotension.

In contrast to our hypothesis, non-invasive Eadyn from ClearSight system failed to predict post-induction hypotension regardless of the breathing patterns. These results appear disappointing because non-invasive techniques can be more easily applied to awake patients than invasive methods. In line with our results, previous studies in critically ill patients with the potential of abnormal vascular tone [27] or surgical patients with elevated systemic vascular resistance [28] showed unreliable continuous arterial blood pressure from ClearSight system using the volume clamp method. Due to the fact that we collected PPV and SVV immediately before anesthetic induction in surgical patients whose sympathetic nervous system can be increased due to psychological stress, [29] the accuracy of the arterial pressure measured by the ClearSight system might have been affected. Also, an increased time lag for recalibration, mainly due to abrupt hemodynamic changes during anesthetic induction, may have raised the possibility of blood pressure imprecision measured by the ClearSight system. [30,31]

In our study, post-induction hypotension could be predicted by invasive Eadyn only during deep breathing. The prediction of hypotension after anesthetic induction is meaningful only if it can be measured before anesthetic induction in awake patients with spontaneous breathing activity. But there have been controversial results for the usefulness of dynamic indices, including PPV, SVV, and Eadyn, in spontaneous breathing patients. [11,15,32–34] During spontaneous breathing, the magnitude of the cyclic flow change can be insufficiently large to detect the variation of dynamic indices, [35] which can lead to an unreliable value of dynamic indices. However, other dynamic indices such as PPV and SVV have shown better predictability when deep breathing is applied to the patient than tidal breathing. [15,36,37] Thus, an appropriate magnitude of cyclic flow change seems essential when using invasive Eadyn as a predictor of post-induction hypotension.

This study has several limitations. First, there was a potential risk of selection bias because only relatively healthy patients with minimized confounders were enrolled. In this regard, patients with decreased left ventricular function are not included in this study. However, the discrepancy between cardiac output extracted from pulmonary artery catheter and from FloTrac sensor is known to increase in patients with moderately reduced cardiac function [38] This suggests that caution is needed when interpreting the dynamic indices extracted from FloTrac sensor in patients with reduced cardiac function. Therefore, it would be hard to conclude whether invasive Eadyn during deep breathing can predict post-induction hypotension in cardiovascular compromised patients who are likely to develop hemodynamic instability after anesthetic induction. Second, we did not use the Acumen Hypotension Prediction Index software (Edwards Lifesciences, Irvine, CA, USA), which allows the automated calculation of Eadyn. Since we measured PPV and SVV using different monitoring systems, there is a possibility that a time difference may occur in those measurements. On the contrary, it is possible to escape the risk of mathematical coupling for the same reason. Third, although we had made an effort to maintain breathing activity regularly way using capnography monitoring, intrathoracic pressure might not be precisely controlled according to breathing patterns. So, it is possible that PPV and SVV, elements of Eadyn, were affected by irregular variations in the intrathoracic pressure. But PPV and SVV are affected by breathing activity to the same extent. A previous study has reported that Eadyn can predict arterial pressure response to fluid administration in spontaneously breathing patients. [33] Fourth, the results of the current study were based on the power analysis from our pilot data, which showed a relatively high incidence of post-induction hypotension of 56%. However, the actual incidences of post-induction hypotension in our experiments for invasive and non-invasive Eadyns were 26.3% and 42.1%, respectively. Although our power analysis was based on the results of our pilot study, it would be hard to exclude the possibility that we overestimated the risk of post-induction hypotension, which resulted in an underpowered

**Table 3**
Comparison of areas under ROC curves (AUCs) of arterial load variables extracted from Flortrac™ (Invasive monitoring) and Clearsight™ (Non-invasive monitoring).

| Invasive arterial load variables | AUC | P† | SE (%) | SP (%) |
|---|---|---|---|---|
| **Tidal breathing** | | | | |
| Total systemic vascular resistance (dyns·cm$^{-5}$) | 0.57 (0.41–0.74) | 0.394 | 37.5 | 86.4 |
| Net arterial compliance (mLmmHg) | 0.68 (0.51–0.82) | 0.210 | 31.3 | 100 |
| Effective arterial elastance (mmHg/mL) | 0.61 (0.44–0.76) | 0.163 | 62.5 | 68.2 |
| Dynamic arterial elastance | 0.66 (0.49–0.81) | 0.096 | 80.0 | 50.0 |
| **Deep breathing** | | | | |
| Baseline mean blood pressure (mmHg) | 0.59 (0.42–0.75) | 0.411 | 70.0 | 53.6 |
| Total systemic vascular resistance (dyn s cm$^{-5}$) | 0.56 (0.39–0.72) | 0.550 | 90.0 | 39.3 |
| Net arterial compliance (mLmmHg) | 0.66 (0.49–0.81) | 0.108 | 90.0 | 60.7 |
| Effective arterial elastance (mmHg/mL) | 0.62 (0.45–0.78) | 0.232 | 80.0 | 57.1 |
| Dynamic arterial elastance | 0.78 (0.61–0.90) | <0.001 | 80.0 | 78.6 |
| **Non-Invasive arterial load variables** | **AUC** | **P†** | **SE (%)** | **SP (%)** |
| **Tidal breathing** | | | | |
| Total systemic vascular resistance (dyns cm$^{-5}$) | 0.52 (0.35–0.68) | 0.861 | 87.5 | 31.8 |
| Net arterial compliance (mL/mmHg) | 0.59 (0.41–0.74) | 0.360 | 100 | 22.7 |
| Effective arterial elastance (mmHg/mL) | 0.63 (0.46–0.78) | 0.175 | 62.5 | 68.2 |
| Dynamic arterial elastance | 0.66 (0.49–0.81) | 0.096 | 50.0 | 86.4 |
| **Deep breathing** | | | | |
| Baseline mean blood pressure (mmHg) | 0.58 (0.41–0.74) | 0.394 | 93.8 | 27.3 |
| Total systemic vascular resistance (dyn s cm$^{-5}$) | 0.56 (0.39–0.72) | 0.552 | 75.0 | 45.5 |
| Net arterial compliance (mL/mmHg) | 0.65 (0.47–0.79) | 0.111 | 56.2 | 72.7 |
| Effective arterial elastance (mmHg/mL) | 0.68 (0.51–0.82) | 0.043 | 56.3 | 77.3 |
| Dynamic arterial elastance | 0.53 (0.36–0.70) | 0.750 | 50.0 | 68.2 |

Data are presented as Area Under the Curve (AUC) (95% Confidence interval). SE, sensitivity; SP, specificity. †, The *P*-value is the significance of the ROC curve.

study. Last, although our study demonstrates the potential of dynamic arterial elastance as a predictor of post-induction hypotension, additional research is warranted to show whether it is actually adjustable with fluid administration or vasoactive drugs and consequently reduce the incidence of post-induction hypotension.

In conclusion, we showed that the augmented invasive Eadyn using deep breathing could predict post-induction hypotension with a fair prediction power. Although it will be hard to apply invasive Eadyn to patients immediately because of its invasiveness, future studies will be needed to evaluate the usefulness of Eadyn to predict and avoid post-induction hypotension, considering it can be adjustable according to the clinician's treatment.

## Assistance with the study

None.

## Author's contributions

Oh EJ: This author helped data collection, data and statistical analysis, drafting the manuscript, and revising the manuscript.

Min JJ: This author helped conception of the idea, drafting the manuscript, and revising the manuscript.

Choi EA and Kwon E: This author helped data collection.

Lee J-H: This author helped conception of the idea, study design, data collection, data and statistical analysis, drafting the manuscript, and revising the manuscript.

## Declaration of Competing Interest

The authors have no commercial, proprietary, or financial interests in the products or companies described in this article.

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