



## Comparing a non-invasive hemodynamic monitor with minimally invasive monitoring during major open abdominal surgery

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### Abstract

As part of the enhanced recovery after surgery (ERAS) protocol, the goal-directed fluid management with hemodynamic monitoring can effectively guide perioperative fluid use and significantly improve the outcomes in high-risk patients undergoing major surgeries. Several minimally invasive and non-invasive monitoring devices are commercially available for clinical use. As part of an internal evaluation, we reported the results from three different hemodynamic monitoring devices used in a patient undergoing a major abdominal surgery.

**Keywords:** enhanced recovery after surgery, non-invasive hemodynamic monitoring, goal directed therapy

### INTRODUCTION

Intraoperative hemodynamic monitoring used can effectively guide the use of fluid resuscitation with the goal of reducing length of stay<sup>[1-3]</sup>. Non- or minimally-invasive methods of determining cardiac output (CO) may allow guided fluid therapy in a goal-directed fashion and mitigate the risks inherent in insertion of a central line and/or pulmonary arterial catheter. In this case report, we present a comparison of hemodynamic measurements made during a routine surgical case, as measured by three non- and minimally- invasive hemodynamic methods as part of the product evaluation: the Vigileo/FloTrac system (Edwards Lifesciences Corporation, Irvine, California), the Cardio-Q ODM (Deltex Medical Limited, Chichester, West Sussex), and the Nexfin (BMEYE B.V., Amsterdam, The Netherlands) (**Fig. 1**). The purpose of this case report is to examine the measurements obtained from all three devices, with the goal of further understanding their ability to measure CO, as well as their ability to trend

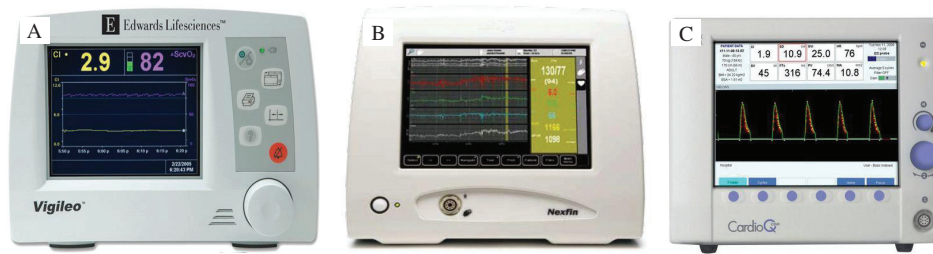
hemodynamic changes and guide fluid resuscitation therapy.

### CASE REPORT

A 72 year old, 72 kg man presented with right upper quadrant pain. Subsequent evaluation led to discovery of a gallbladder mass with portal vein lymphadenopathy. He was brought to the operating room for an elective laparoscopic converted to open cholecystectomy with liver resection and portal vein lymphadenectomy. The patient was placed in the supine position with arms abducted at near ninety degrees from the body. After an uneventful intravenous induction with 100 mcg of fentanyl, 60 mg of lidocaine, 140 mg of propofol, and 100 mg of rocuronium, a right radial arterial line was placed and connected to a FloTrac/Vigileo monitor. The Nexfin finger cuff was then placed on the middle phalanx of the right middle finger. Finally, an esophageal Doppler monitor was used. All three monitors were placed, calibrated, and programmed per their

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**Fig. 1** Pictures of the three hemodynamic monitoring devices used in this report. A: Vigileo/FloTrac system (Edwards Lifesciences Corporation, Irvine, California); B: the Nexfin (BMEYE B.V., Amsterdam, The Netherlands); C: the Cardio-Q ODM (Deltex Medical Limited, Chichester, West Sussex),

respective manufacturer recommendations. Averaging times for the three monitors were programmed as follows: FloTrac/Vigileo, 20 seconds; Nexfin, 5 beats; Cardio-Q ODM, 10 beats. The monitors were run for 30 minutes prior to incision; during the case, the cardiac index (CI), FloTrac/Vigileo and Nexfin stroke volume variation (SVV), left arm non-invasive blood pressure, arterial line blood pressure, and Nexfin non-invasive blood pressure were recorded in the anesthesia record in fifteen minute intervals. Additionally, the Cardio-Q ODM transducer was refocused every fifteen minutes or more frequently to maintain an optimized signal. Key surgical events were noted with the time of the event.

The total surgical duration was nine hours and forty-five minutes. General anesthesia was maintained with sevoflurane. Tidal volumes were maintained from 6 to 8 mL/kg. When allowable, fluid resuscitation was guided by SVV increasing beyond 10%, as measured by the FloTrac/Vigileo monitor. During periods of rapid blood loss, fluid resuscitation was guided by SVV in conjunction with visual estimation of blood loss. Total blood loss was 2,200 mL; total urine output over the case duration was 790 mL; fluid resuscitation was provided with crystalloid (2,800 mL), hydroxyethyl starch colloid (2,000 mL), and packed red blood cells (900 mL).

## DISCUSSION

This case provides a real world comparison between the Nexfin monitor, a completely non-invasive CO monitor, with other methods of minimally invasive CO measurement, the FloTrac/Vigileo monitor and Cardio-Q ODM as part of the internal product evaluation.

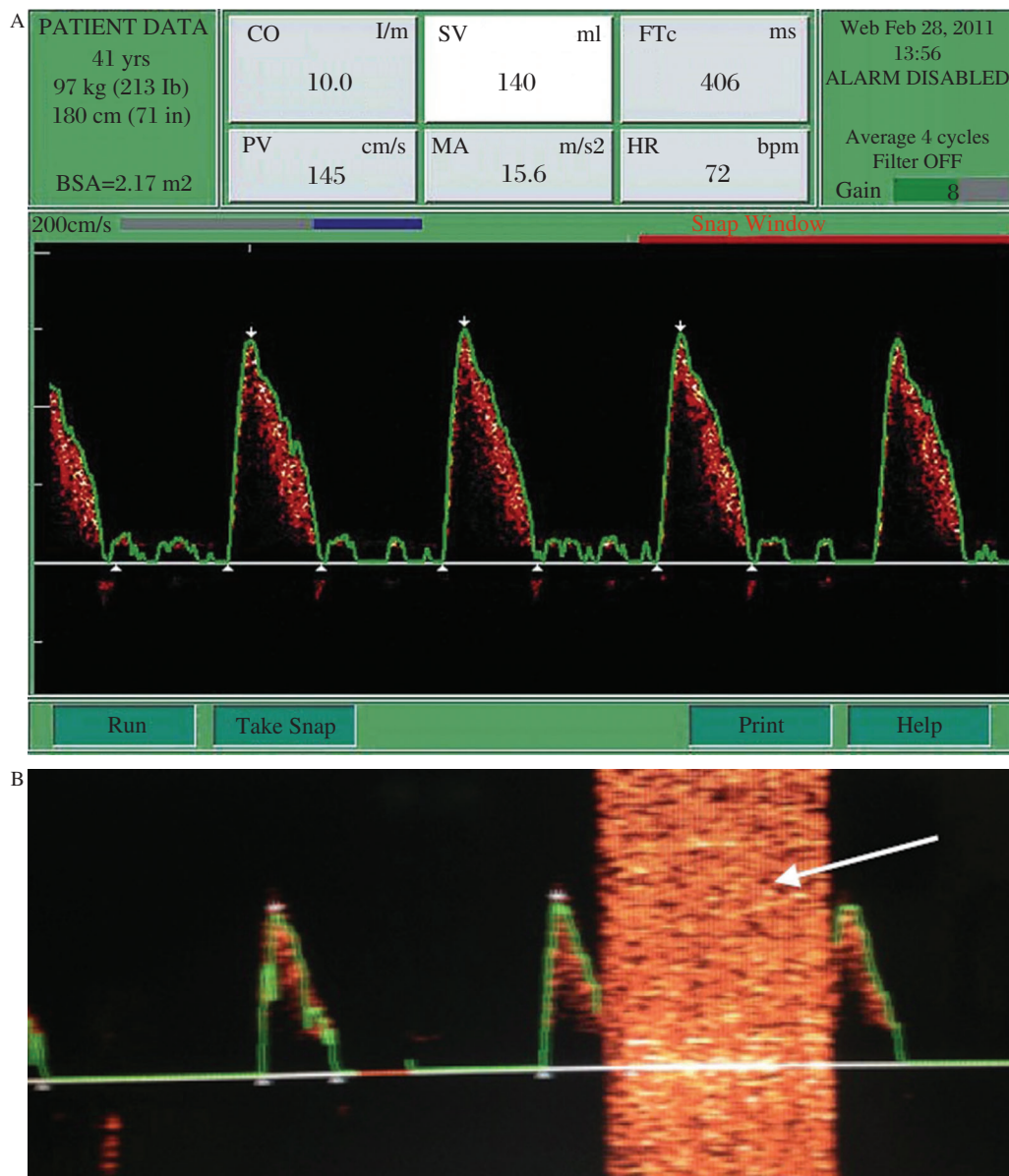
Unlike the FloTrac/Vigileo and Cardio-Q ODM, which require an arterial line and an esophageal placed ultrasound transducer respectively, the Nexfin monitor is non-invasive by utilizing external pressure to negate any plethysmographic changes in the measured finger,

thereby reconstructing the arterial waveform externally. Calculation of the stroke volume (SV) and CO is based on pulse contour algorithms<sup>[4,5]</sup>. Utilizing a proprietary transfer function based on a clinical database that accounts for age, gender, height, and weight, this finger arterial pressure waveform is used to reconstruct a brachial arterial waveform which is then used as a substitute for aortic pressure.

Whereas the FloTrac/Vigileo monitor has found widespread intraoperative use due to its robustness in patients without cardiac rhythm and valvular abnormalities, the use of the Cardio-Q ODM has been more limited due to its susceptibility to electrocautery noise (**Fig. 2**). In our experience, the frequency with which electrocautery is used by surgeons is often high enough to prevent measurement, and often negates the usefulness of this monitor as periods of extensive electrocautery use often coincide with significant hemodynamic changes for which these monitors are used. Intraoperative fluid resuscitation in this case was guided by SVV when possible (maintaining SVV below 10%), and in conjunction with visual estimation during periods of brisk blood loss. Here, we focus our discussion on comparing the performance of the Nexfin device, with the Vigileo/FloTrac and Cardio-Q ODM systems, in regards to measurements of mean arterial pressure, cardiac output, and stroke volume variation.

### Mean arterial pressure

Throughout the surgery, the Nexfin estimated a consistently higher mean arterial pressure (MAP) than either the FloTrac/Vigileo monitor or Cardio-Q ODM. However, Nexfin MAP trended consistently with both the arterial line and blood pressure cuff, and response time to changes in MAP were not measurably different between devices, suggesting the likelihood of a measurement bias due to device positioning, or calibration error. Correlations between the Nexfin and peripheral arterial blood pressure measurements have been

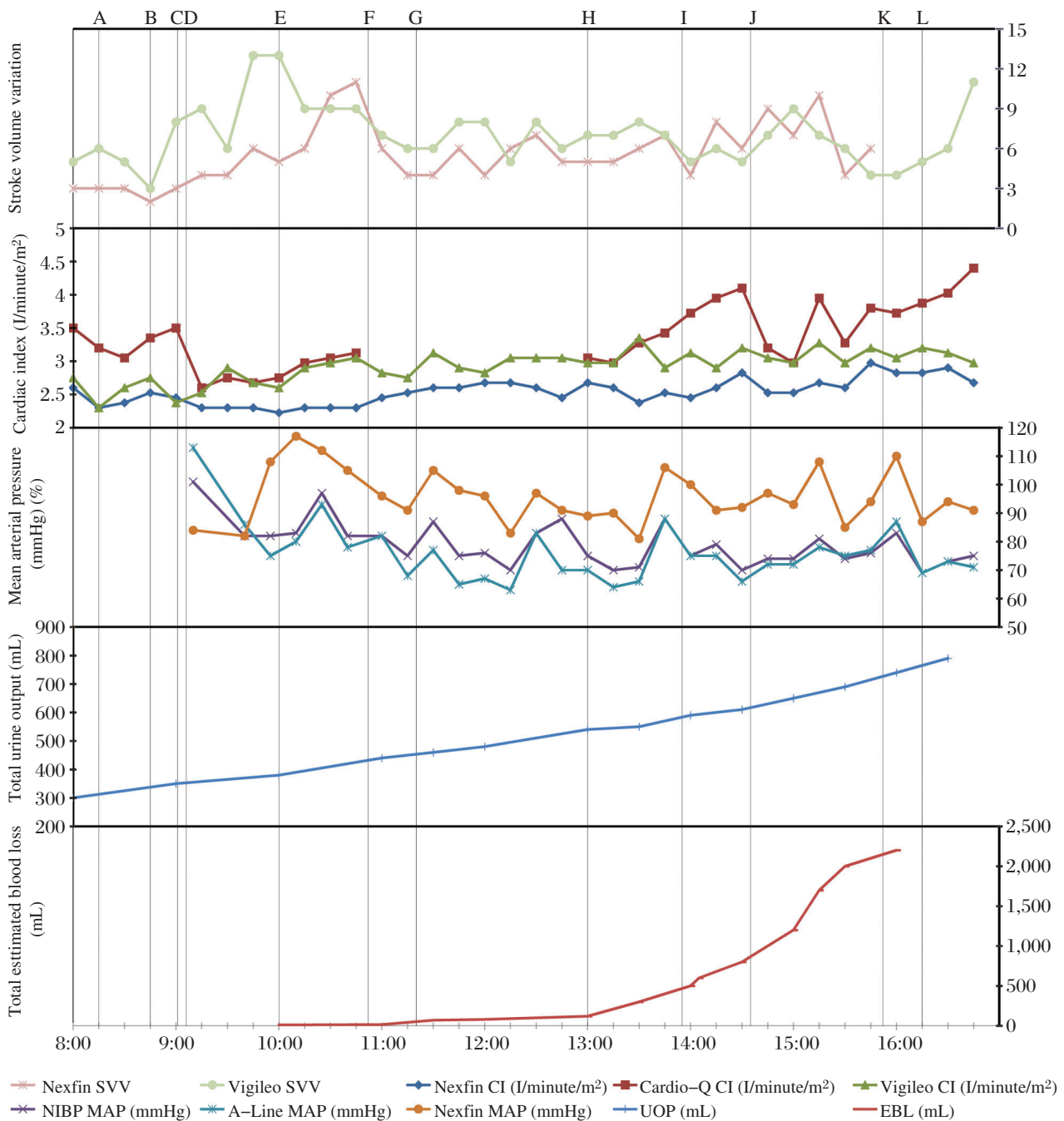


**Fig. 2 A:** An example of Cardio-Q ODM Doppler signal. CO: cardiac output; SV: stroke volume; FTc: flow time corrected; PV: peak velocity; MA: mean acceleration; HR: heart rate. **B:** An example of electrocautery interference (arrow) with the Cardio-Q ODM signal.

demonstrated in adult<sup>[6]</sup> and pediatric cardiac surgeries<sup>[7]</sup>; however, this correlation may not translate to the adult abdominal case. Although blood pressure correlation has been demonstrated between the Nexfin and manual<sup>[8]</sup> and automatic non-invasive cuff measurements<sup>[9]</sup> in non-operative environments, bias may be introduced secondary to surgical factors such as positioning. Additionally, the nature of the noninvasive and minimally invasive systems can create questionable results during extreme vasoconstriction, conditions seen with Reynaud's disease or shock as cited by the manufacturer. The degree to which measurements are sensitive to less severe vaso-constrictive conditions that may be seen in the operating room such as distal hypothermia is unknown.

### Cardiac output

It has been shown that measured CO can differ substantially depending on the method of determining CO, with variations as large as 41.3%, 42.1%, and 39% for arterial pulse contour analysis, esophageal Doppler, and Nexfin respectively, versus thermodilution<sup>[10,11]</sup>. These figures exceed the  $\pm 30\%$  criteria suggested by Critchley and Critchley<sup>[12]</sup>. For the purposes of intraoperative management, however, the ability to identify trends in CO may in itself be of use in guiding fluid resuscitation. In this regard, the Nexfin monitor was able to display CI changes in the same direction as the FloTrac/Vigileo and Cardio-Q at several points (**Fig. 3**), displaying a drop after induction, and



**Fig. 3** Stroke volume variation (SVV); cardiac index (CI); mean arterial pressure (MAP) from non-invasive blood pressure cuff (NIBP), arterial line (A-Line), and Nexfin; total urine output; and estimated blood loss plotted versus time. Surgical events are marked by vertical bars as follows: A, phenylephrine administered; B, oral-gastric tube placed, ephedrine administered; C, surgical incision; D, abdominal insufflation, patient positioned in reverse Trendelenburg; E, phenylephrine administered; F, conversion from laparoscopic to open case, phenylephrine administered, loss of Cardio-Q monitor signal due to electrocautery interference; G, phenylephrine administered; H, end of extensive electrocautery use, Cardio-Q monitor reinitialized; I, significant portal vein bleeding noted by surgeon; J, vaso-active medication given; K, patient returned to level, supine position; L, abdominal wall closure.

increases after each dose of vaso-constrictive medication (markers A, E, and G); marker J shows a drop in output with all three measurement techniques, due to rapid surgical blood loss. Although a recent study demonstrated that earlier FloTrac system did not accurately track

changes in CO following the administration of phenylephrine, a predominantly  $\alpha_1$ -adrenergic receptor agonist<sup>[13]</sup>, newer version has been developed to track the change well. The Nexfin has been known to be insensitive to vasopressor administration<sup>[14]</sup>.

## Stroke volume variation

Stroke volume variation has been shown to be efficacious in predicting fluid responsiveness<sup>[15]</sup>, and in this regard may serve as an intraoperative tool to guide fluid resuscitation. The top panel of **Fig. 3** compares SVV as determined by the FloTrac/Vigileo and Nexfin monitors, demonstrating increase with surgical blood loss, and decrease with fluid resuscitation, and demonstrates correlation between SVV and Nexfin-determined CI. During this case, increasing trends in SVV were associated with decreasing trends in CI, and vice versa.

Prior work has questioned the efficacy of minimally invasive cardiac output monitoring versus clinical observation<sup>[16]</sup>; but the data was from 2006-2007 ICU patients who are very different from patients in the operating room. Furthermore, the technology has improved significantly since then. In this case, and intraoperatively in general, we believe that the value of SVV can be used safely and effectively to determine fluid responsiveness and guide fluid therapy. However, when SVV/PPV is between 9-13% (gray zone), there are about 25% of the cases for whom SVV/PPV may not accurately predict the volume responsiveness under general anesthesia<sup>[17]</sup>. For those instances, stroke volume change can be used to predict volume responsiveness. The averaging times were different in all the three devices that may show the delayed response.

Additionally, the value of intraoperative SVV must also be interpreted within the surgical context. This particular case involved surgical manipulation in close proximity to the inferior vena cava, very likely with alternating compression and decompression. The subsequent effect on cardiac preload can theoretically bias measurements of SVV, and any fluctuation must also account for this or any other surgically induced bias.

In conclusion, during operative situations where objective determination of CO is critical to clinical decision-making, non- or minimally-invasive methods of CO may provide measurements that correlate within approximately 40% of thermodilution measurements via a pulmonary arterial catheter. However, in surgical situations where objective measurement is unnecessary, where the risks of pulmonary artery placement outweigh the utility of thermodilution measurements, or where CI or SVV trends alone provide utility in guiding goal-directed fluid management, the Nexfin monitor may provide useful hemodynamic information regarding fluid responsiveness for clinical decision making in a completely non-invasive fashion and it is comparable to that obtained by Vigileo/FloTrac and Cardio-Q ODM monitors.

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