es^{timated} CCO

Comparison of trend performance of esCCO and APCO in kidney transplantation

Submitted by:

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Introduction

Perioperative goal directed therapy (GDT) based on measurement of stroke volume (SV) is expected to improve postoperative outcome[1]. A device that can accurately measure stroke volume (SV) during surgery and that is both minimally-invasive and low cost is ideal. Many methods have been developed to measure SV less-invasively and continuously; pulse contour and intrathoracic impedance methods have been widely used in clinical practice.

Estimated continuous cardiac output (esCCO, Nihon Kohden Corporation, Tokyo, Japan) is a technology that continuously and non-invasively measures SV based on pulse wave transit time (PWTT), and uses only information derived from the electrocardiogram (ECG), pulse oximeter (SpO_2) and blood pressure. With esCCO, continuous SV is available in surgeries where ECG, SpO_2 and blood pressure are measured.

esCCO has been evaluated in a multi-center study involving 7 facilities in Japan. In the multi-center study, Yamada, et. al. used intermittent cold bolus thermodilution (ICO) for initial calibration and compared esCCO with ICO[2]. They concluded that the accuracy of esCCO is clinically comparable to ICO, but commented that esCCO could not be considered self-contained and non-invasive because an invasive method is used for initial calibration[2]. Ishihara, et al. reported on the performance of esCCO calibrated non-invasively with patient's demographic data. The authors suggested that the ability of esCCO to measure trends in cardiac output (CO) is comparable with the arterial pressure-based cardiac output (APCO) by referring to other papers[3].

In this case report, we evaluated the performance of non-invasively measured esCCO to trend changes in SV as compared to APCO (FloTrac/Vigileo, Edwards Lifesciences, Irvine, CA, USA).

Materials and methods

Adult patients scheduled for kidney transplantation and able to provide informed consent were enrolled in the evaluation.

Anesthesia management

The surgery was performed under general and epidural anesthesia. Anesthesia was induced with 2 μ/kg of fentanyl citrate, 2 mg/kg of propofol, and 0.8 mg/kg rocuronium bromide and maintained with continuous infusion of sevoflurane (1.0-2.0%) and remifentanil hydrochloride (0.05-0.5 mcg/kg/min) and intermittent administration of rocuronium bromide. In addition to measurements of ECG, SpO_2 by pulse oximetry, rectal temperature, and end-tidal carbon dioxide ($etCO_2$), radial artery and central venous catheters were inserted after the induction of anesthesia.

Fluid management

The fluid management was guided by the kidney transplantation protocol of our facility. After induction of anesthesia, fluid of 5 mL/kg + amount of bleeding × 3 mL was given until a graft bed was prepared. APCO

was monitored during fluid challenge to maintain CVP at 15 mmHg without decreasing SV from the time of initiation of suture of grafted kidney to the arterial declamping (artery reperfusion).
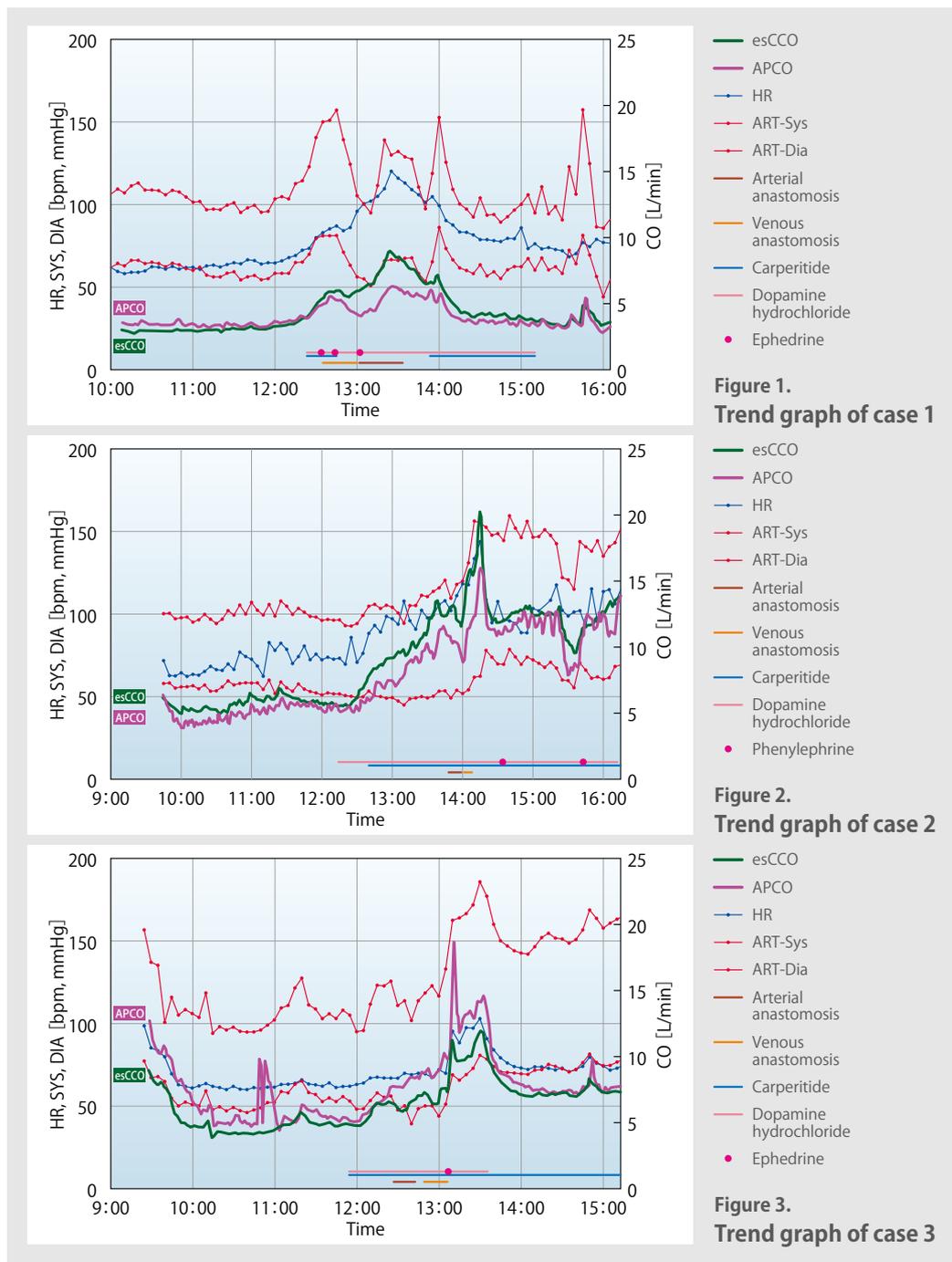
Comparison of esCCO and APCO

esCCO and APCO were compared after induction of anesthesia, before the start of suture of grafted kidney, before artery clamping, and at the end of surgery. esCCO was calibrated non-invasively using information of patient demographics.

Case reports

Case 1:

55 years old female with height of 153 cm and weight

Figure 1.
Trend graph of case 1

Figure 2.
Trend graph of case 2

Figure 3.
Trend graph of case 3

of 42.7 kg. APCO and esCCO were 3.4 L/min and 2.9 L/min after the induction of anesthesia, 5.0 L/min and 5.5 L/min before the initiation of suture of grafted kidney, 6.3 L/min and 8.8 L/min before the artery clamping (artery reperfusion) after the fluid challenge, and 2.9 L/min and 3.4 L/min at the end of the surgery, respectively.

Case 2:
36 years old male with height of 182 cm and weight of 90.5 kg. APCO and esCCO were 3.9 L/min and 5.1 L/min after the induction of anesthesia, 8.7 L/min and 10.1 L/min before the initiation of suture of grafted kidney, 16.0 L/min and 20.0 L/min before the artery clamping (artery reperfusion) after the fluid challenge, and 13.7 L/min and 13.5 L/min at the end of the surgery, respectively.

Case 3:
31 years old male with height of 180 cm and weight of 93.8 kg. APCO and esCCO were 6.5 L/min and 4.7 L/min after the induction of anesthesia, 7.3 L/min and 6.5 L/min before the initiation of suture of grafted kidney, 14.3 L/min and 12.0 L/min before the artery clamping (artery reperfusion) after the fluid challenge, and 7.4 L/min and 7.4 L/min at the end of the surgery, respectively.

As shown in a trendgraph of each case, the measured esCCO shows strong agreement with APCO throughout the surgery in all cases.

Discussion

Perioperative fluid optimization based on SV can lead to reduced hospital stay, reduced occurrence and associated complications of postoperative nausea and vomiting (PONV), and faster postoperative recovery of gastrointestinal function[1]. The only adequately tested and recommended CO monitor for goal directed therapy is oesophageal Doppler, but there are other CO monitors that may be useful and should be evaluated[1].

In kidney transplantation, it is necessary to keep blood pressure and CO at adequate levels to maintain good kidney perfusion in order to prevent ischemic reperfusion injury after the grafted kidney is sutured. In our facility, we use APCO to less-invasively measure CO for fluid management. In Japan, APCO is widely used to monitor SV during surgeries because: (1) the accuracy of APCO has been shown to be clinically acceptable[4], (2) it is less-invasive, and (3) it is easy to use.

In these case reports, we compared APCO and esCCO during kidney transplantation in patients where hemodynamics changed significantly. These cases show the performance of esCCO to track changes in CO when compared to APCO (**Fig.1-3**).

esCCO non-invasively estimates CO based on PWTT, which is calculated as the time measured from a peak of ECG R-wave to a rise point of pulse wave measured by pulse oximetry[2]. The principle of esCCO is based on combination of the Windkessel model[5] and PWTT to estimate CO non-invasively [6, 7]. For details, refer to Appendix.

Multiple regression analysis was used to formulate the patient information CO calibration using patient demographic data, including age, gender, height, and body weight as well as blood pressure, heart rate and PWTT at the corresponding time-points[3]. esCCO calibrated with patient's demographic data is totally non-invasive, so it is expected that the application of esCCO may be expanded to a broader clinical population.

The pulse contour and impedance methods are well established as less-invasive measurements of SV, and APCO is especially popular, based partly on reports demonstrating better accuracy of APCO compared to impedance method. APCO is based on the pulse contour analysis, and the principle of esCCO is based on PWTT. While APCO requires radial artery catheterization, esCCO can be non-invasively measured only by measuring ECG, SpO_2 and blood pressures without additional sensors. Perioperative SV monitoring is believed to improve the quality of care in patients undergoing surgery; esCCO can provide flow-related parameters such as SV and CO as derived by routinely measured parameters and be useful to guide intraoperative goal directed fluid therapy.

To establish the clinical benefits of esCCO in GDT, we will continue to evaluate esCCO, focusing on the fluid responsiveness of esCCO.

Appendix: Theoretical background

PWTT measures the time from the peak of the ECG R-wave to the point where the pulse oximeter wave reaches to the periphery, which is defined as the time when the differentiated pulse wave reaches 30% of its peak amplitude and described as PWTT by Ochiai et al[6] (**Fig.4**). PWTT is a sum of pre-ejection period (PEP), pulse wave transit time from ascending aorta through radial artery (PWTT1) and pulse wave transit time from PWTT1 through to the peripheral measurement site (PWTT2).

Theoretically, each of the time components have an inverse correlation with SV[8], so a linear approximation can be considered. Thus, SV is expressed by the following linear regression equation:

$$SV = \alpha' \times (PEP + PWTT1 + PWTT2) + \beta'$$
$$= \alpha' \times PWTT + \beta'$$

At least 2 pairs of SV and PWTT are needed to calculate α' and β', and both should be collected when SV changes. However, it is not practical to change SV for calibration[8]. The following equation completes calibration with a single SV measurement, as shown to be the most accurate in an animal study[8]:

$$SV = K \times (\alpha \times PWTT + \beta)$$

, where α is a fixed value and K and β are individualized for each patient.

Figure 4.
Components of PWTT
PWTT = PEP + PWTT1 + PWTT2
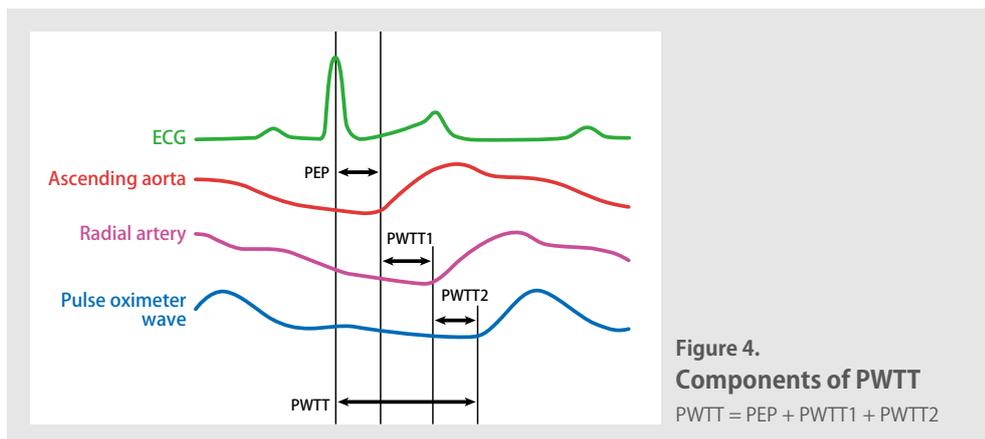
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