# Use of Impedance Cardiography in Anaesthesia and Intensive Care in Children

PhD thesis

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## 1. Introduction

The evaluation of the haemodynamic state of the patient during anaesthesia and intensive care is essential. The primary goal of haemodynamic monitoring is to determine the adequacy of oxygen delivery, as the most important function of the circulation is to provide transport of oxygen and substrates to and from the tissues. Cardiac output (CO) is considered the most important factor in oxygen delivery. The use of thermodilution (right heart catheterisation, pulse contour cardiac output) to measure cardiac output is the 'gold standard' technique but it is invasive, especially in children. The convergence of escalating concerns over the safety of invasive haemodynamic monitoring and the developments in microprocessors and signal analysis technology has culminated in a renewed interest in some of the noninvasive monitoring methods. One of them is impedance cardiography (ICG) has been used to measure CO for decades. ICG technology converts the time-varying measurements of thoracic impedance (Z) into waveform. The rate of the change of impedance (dZ/dt) is an image of the aortic blood flow, and its maximum ($dZ/dt_{max}$) is proportional to the aortic peak flow. The stroke volume is calculated by the following expression:

$$SV=\rho \cdot (l^2 \cdot Z_0^{-2}) \cdot dZ \cdot dt_{max}^{-2} \cdot LVET$$

where SV=stroke volume (ml), ρ=resistivity of blood (Ωcm), l=inner distance between the voltage detecting electrodes (cm), $Z_0$= baseline thoracic impedance (Ω), $dZ \cdot dt_{max}^{-2}$ = maximum rate of change of impedance during systole (Ω/s) and LVET= left ventricular ejection time (ms) .

Using ICG to measure stroke volume non-invasively on a beat to beat basis showing trends helps in clinical decision making. The instrument (ICG-M401) used in our study was tested by Pianosi who compared impedance measurements of CO with carbon dioxide rebreathing measurement of CO in healthy children and children with cystic fibrosis during exercise. He found that ICG provided reliable estimation of CO with good correlation of indirect Fick ($CO_2$) method. ICG is not applicable and reliable in certain clinical situations, such as open heart surgery, thoracic surgery, severe lung injury, but as as a non invasive method can be a good alternative of invasive techniques in paediatric anaesthesia and intensive care.

## 2. Aims

**2.1.** Laparoscopy is widely used in paediatric surgery for the diagnosis and treatment of many surgical conditions. However, proper haemodynamic monitoring during these operations is not easy. Data are limited of the intraoperative and postoperative changes related to pneumoperitoneum (PP) in children. The aim of the present study was to evaluate whether ICG as a non invasive method is applicable to track the trends in cardiovascular parameters during laparoscopy in children.

**2.2.** The induction of general anaesthesia with propofol and fentanyl is safe and widely used in paediatric practice, however is often associated with a decrease in blood pressure and cardiac output. Trendelenburg positioning is often the first clinical step to treat heamodynamically unstable patients when hypovolaemia is suspected. Data are limited with respect to the cardiovascular effects related to head-down tilt in children. The objective of our study was to determine with the use of impedance cardiography whether Trendelenburg positioning would prevent or attenuate the decrease in blood pressure and cardiac output caused by intravenous induction of anaesthesia with propofol and fentanyl in children.

**2.3.** Continuous mechanical ventilation with positive end expiratory pressure (PEEP) is part of the routine management of gas exchange disturbances in intensive care. It has been widely accepted that increases in airway pressure ($P_{aw}$)

induced by PPV can decrease cardiac output. Data are limited with respect to the haemodynamic changes related to PEEP in children, especially with normal, or improving lung function.

The objective of our study was to evaluate the relationship between CO and $P_{aw}$ with the use of impedance cardiography, and CO and $S_{cv}O_2$ in ventilated paediatric patients without pulmonary disease.

## 3. Materials and methods

Impedance cardiography was performed in all of the studies (with 12 electrodes and a phono head) using ICG-M401 impedance cardiograph (Askit Ltd, Budapest, Hungary). Three 8-second impedance measurements were made during the last minute of each period, and averaged to provide a single value for SV. All ICG measurements were performed during spontaneous and mechanical ventilation where pulmonary pathology was absent. Even applying PEEP there is a strong correlation between the results of ICG and of invasive methods (dye dilution, thermodilution), in adults and paediatric patients under mechanical ventilation.

**3.1.** 30 boys scheduled for elective laparoscopic varicocelectomy were enrolled in the study. The ICG was used in continuous monitoring mode. After induction, the abdomen was insufflated with $CO_2$ to the desired intra-abdominal pressure (IAP) of 12-13 mmHg and this was maintained automatically. The values of heart rate (HR), mean arterial blood pressure (MABP), $ETCO_2$, peak inspiratory airway pressure (PIP), stroke volume (SV), stroke volume index (SVI), CO, cardiac index (CI), systemic vascular resistance (SVR) and systemic vascular resistance index (SVRI) were recorded every minute. The course of anaesthesia was divided into 4 periods (T1-4):T1, before induction; T2, between induction and incision; T3, during insufflation; T4, after desufflation of PP until awake.

**3.2.** Thirty ASA I children of both sexes scheduled for elective minor orthopaedic surgery were enrolled in the study.. Anaesthesia was induced with fentanyl (1.5 $\mu g \cdot kg^{-1}$) and propofol (3 $mg \cdot kg^{-1}$) and the appropriate size laryngeal mask airway (LMA) was inserted. Beside the haemodynamic variables of SVI and CI the Heather Index (HI) was measured, which represents a direct reflection of acceleration expressed as $\Omega \cdot s^{-2}$ for aortic ejection and thus contractility. Patients were allocated to one of two positions using computer generated numbers: 20° head-down tilt (head-down group, HDG, n=15) or supine (supine group, SG, n=15). During the course of anaesthesia in each group, the values of HR, MABP, $ETCO_2$, SVI, CI, SVRI and HI were recorded before induction (B) and three ($A_3$) five ($A_5$) and eight ($A_8$) minutes after LMA insertion. Surgery was started after the last recording ($A_8$).

**3.3.** Twelve children requiring mechanical ventilation in the Paediatric Intensive Care Unit were enrolled in the study. None of the patients had pulmonary diseases. Baseline PEEP was set to 5 $cmH_2O$. All patients had a central venous catheter via the subclavian approach as a routine part of their management. The locations of cathetertips were in the lower part of the superior vena cava as confirmed by chest X-ray.

The study protocol was as follows: After a 5 min resting period with PEEP 5 $cmH_2O$ ($P_{b5}$) with stable ventilatory and circulatory condition the following end-expiratory pressures were applied for 5 mins consecutively: PEEP 10 $cmH_2O$ ($P_{i10}$); PEEP 15 $cmH_2O$ ($P_{i15}$); PEEP10 $cmH_2O$ ($P_{d10}$) and PEEP 5 $cmH_2O$ ($P_{d5}$). Central venous oxygen saturations were measured from venous sample with a blood-gas analyser.

**3.4. Statistical analysis:** Measured variables were expressed as mean ± SD. Analysis of variance (ANOVA) for repeated measures was used to compare time effects. Posthoc paired samples t-tests with Bonferroni correction and independent samples t test were performed for the haemodynamic variables within and between groups. A p-level< 0.05 was regarded as statistically significant.

### 4. Results and conclusions

**4.1.** The average IAP was 12.4±2.1 mmHg. The average insufflation time was 16±4.5 min. After the induction of anaesthesia HR, MABP and CI decreased, the SVI remained unaffected. The decrease in CI was 11% (T1: 3.0±0.5 vs. T2: 2.7±0.5 $l \cdot min^{-1} \cdot m^{-2}$, p<0.001), caused mainly by the decrease in HR. The insufflation resulted in a significant decrease in stroke volume (T2: 32.8±5.2 vs. T3: 27.4±4.8 $ml \cdot m^{-2}$, p<0.001) and a further reduction in CI (T2: 2.7±0.5 vs. T3: 2.2±0.5 $l \cdot min^{-1} \cdot m^{-2}$, p<0.001). Total reduction in CI was 25%. Following PP HR did not change. The MABP and the SVR increased significantly. After desufflation the CI, SVI increased and the SVRI decreased significantly, but only the SVI returned to the baseline values.

*Conclusion:* We found significant decrease in CI after induction of anaesthesia, partly the result of the decrease in heart rate as SVI did not greatly change. However during PP a significant reduction in SVI and CI and increase in SVRI and MABP was observed. ICG is a reliable method to cover heamodynamic trends during PP in children.

**4.2.** Baseline haemodynamic variables were not significantly different between the groups. After induction of anaesthesia, a significant ($p<0.05$) decrease in HR (32% in HDG and 16% in SG at $A_3$), MABP (25% HDG and 23% SG at $A_3$) and CI (24% HDG and 16% SG at $A_3$) were recorded in each group compared with baseline (B). The reduction in HR was more pronounced in the HDG at $A_3$ (66±13 vs. 78±17 beat · $min^{-1}$ respectively, p=0.039). The differences in CI and MABP between the groups were not significant. SVI did not change in the supine group while statistically but not clinically significant SVI elevation was observed in the HDG at $A_3$ as compared to the baseline (38.8±5.4 at B vs 42.9±6.4 ml · $m^{-2}$ at $A_3$ p=0.021). No significant differences in SVRI were found between and within the groups, while induction resulted in a significant decrease in HI in each group. After induction, the end-tidal $CO_2$ concentrations in the HDG were higher than those is SG, and the differences were significant at $A_3$ and $A_5$ but not at $A_8$.

*Conclusion*: After intravenous induction of anaesthesia using propofol and fentanyl, a 20° Trendelenburg positioning compared with supine did not clinically attenuate haemodynamic changes. Many studies have demonstrated substantially reduced systemic vascular resistance, reduced sympathetic nervous system activity resulting in venodilatation and thus decreasing venous return. Some studies found that propofol causes a significant reduction in myocardial contractility. In our study no clinically important changes in SVRI were observed after induction while the significant decrease in HI suggests direct myocardial depression. This reduced myocardial contractility may have contributed to CI decrease in our patients rather than the decreased systemic vascular resistance.

**4.3.** Increasing the $P_{aw}$ did not result in significant changes in SVI and CI at $P_{i10}$ and $P_{i15}$ compared to $P_{b5}$ as a baseline. PEEP reduction ($P_{d5}$) resulted in a statistically significant increase in SVI as compared to $P_{i15}$ (26±5.1 at $P_{i15}$ vs 30.3±4.2 ml · $m^{-2}$ at $P_{d5}$). The increase in CI was significant at $P_{d5}$ (2.8±0.6 at $P_{i15}$ vs 3.2±0.5 l · min · $m^{-2}$ at $P_{d5}$). CVP increased significantly after PEEP elevation (7.6±1.6 at $P_{b5}$ vs 8.8±1.5 at $P_{i10}$ than 11±1.7 mmHg at $P_{i15}$) and returned to the baseline when PEEP decreased. CI, HR, MAP and $ETCO_2$ did not change significantly. CO, HR, MAP and $ETCO_2$ did not change significantly. The values of $S_{cv}O_2$ decreased non-significantly after PEEP elevation

*Conclusion:* High PEEP levels in ventilated children without pulmonary pathology did not result in significant haemodynamic changes. Our findings suggest that normovolaemic children with normal lung compliance can compensate the negative effects of elevated PEEP on venous return. Oxygen demand remained unchanged during the study. The constant values of $S_{cv}O_2$ are in line with the lack of significant changes in CO as measured by ICG.

## 5. New observations

**5.1.** Our findings suggest, that significant haemodynamic changes occurring in healthy children caused by peritoneal insufflation can be monitored by impedance cardiography. Impedance cardiography can be a useful method to monitor trends in cardiac function.

**5.2.** Using ICG to determinate cardiac output, we found that (a) reduced myocardial contractility can be detected and partly is responsible for the decrease in cardiac output following propofol-fentanyl induction of anaesthesia, and (b) a 20° head-down tilt does not prevent a decrease in cardiac output after induction of anaeshesia using a combination of propofol and fentanyl in healthy children.

**5.3.** Using ICG to determine cardiac output, we found that short-term PEEP elevation from 5 up to 15 $cmH_2O$ does not cause a significant decrease in CI in ventilated normovolaemic children without lung injury. The unchanged values of $S_{cv}O_2$ indicate that changes in $P_{aw}$ did not influence the balance of oxygen supply and demand.

## 6. The thesis is based on the following papers

**1**. **Kardos A,** Vereczkey G, Pirot L, Nyiradi P, Melker R. Use of impedance cardiography to monitor haemodynamic changes during laparoscopy in children. *Paed Anaesth* 2001; **11**:175-179. **IF**: **0.88**

**2**. **Kardos A,** Vereczkey G, Szentirmai C. Haemodynamic changes during positive pressure ventilation in children. *Acta Anaesthesiol Scand* 2005; **49**:649-653. **IF: 1.837**

**3**. **Kardos A,** Foldesi C, Nagy A, Saringer A, Kiss A, Kiss G, Marschalko P, Szabo M. Trendelenburg positioning does not prevent a decrease in cardiac output after induction of anaesthesia with propofol in children *Acta Anaesthesiol Scand* 2006; **50**:869-874.
**IF**: **1.863**

## 7. Other papers and abstracts

**1. Kardos A** , Kiss A, Mekler R. Harmadfokú AV blokkal, miokardiális és hepatocelluláris érintettséggel járó infectio öt hónapos csecsemőnél. *Pediáter* 1999; **8**: 159-162.

**2**. Szentirmai Cs, **Kardos A.** Súlyos koponyasérültek kezelése. *Gyermekaneszteziológia és Intenzív Terápia,* 2003 ;**3**:13-23

**3**. Máté M, **Kardos A**.  A parapneumoniás folyadékgyülem kezelése fibrinolysissel. *Gyermekaneszteziológia és Intenzív Terápia,* 2003;**3**:24-30

**4**. Vatasescu R, Shalganov T, **Kardos A**, Jalabadze K, Paprika D, Gyorgy M, Szili-Torok T. Right Diaphragmatic Paralysis Following Endocardial Cryothermal Ablation of Inappropriate Sinus Tachycardia. *Europace*  2006 ;**8**:904-6.

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**6**. Kiss A, Polovitzer M, Merksz M, **Kardos A**, Schaffer P, Apor A, Huttl K. Treatment of posttraumatic high-flow priapism in 8-year-old boy with percutaneous ultrasound-guided thrombin injection. *Urology*. 2007;**69**:779.e7-9.

**7**. **Kardos A**, Foldesi C, Ladunga K, Toth A, Szili-Torok T. Pulmonary vein isolation without left atrial mapping.*Indian Pacing Electrophysiol J*. 2007 1;**7**:142-7.

**8.** Bauernfeind T, **Kardos A**, Foldesi C, Mihalcz A, Abraham P, Szili-Torok T. Assessment of the maximum voltage-guided technique for cavotricuspid isthmus ablation during ongoing flutter. *J Interv Card Electrophysiol*. 2007 ; **19**:195-199.

**9. Kardos A**, Stegeman B, Foldesi C, Mihalcz A, Csakany L, Szili-Torok T. Comparison of coupled and paired pacing for rapid rate control during atrial fibrillation. *JAAC* 2007; 49 (Supplement A); 13A:903-241.

**10. Kardos A,** Kornyei L, Foldesi C, Szili-Torok T. Cryomapping offers advanteges for ablation near to the atrioventricular junction in paediatric patients. *Europace* 2007; 9 (Supplement 3) 39.

**11.** Foldesi C**, Kardos A**, Mihalcz A, Szili-Torok T. Electrophysiology study before cardiac resynchronisation device implantation: pre-implant coronary sinus canulation offers advantages for cardiac resynchronization procedural outcome. *Europace* 2007; 9 (Supplement 3) 338.

**12.** Bauernfeind T, **Kardos A**, Foldesi C, Mihalcz A, Szili-Torok T. Assessment of the maximum voltage-guided technique for cavotricuspid isthmus ablation during ongoing atrial flutter. *Europace* 2007; 9 (Supplement 3) 754.