Knowledge of changes of central haemodynamics in patients after cardiac surgery is of crucial importance for optimal therapy. Cardiac output, cardiac index (CI) and other indices characterizing left ventricular performance together with data of systemic and pulmonary vascular resistance give us information about the adequacy of oxygen transport - the most important function of cardio-pulmonary system. Cardiac output and other derived parameters can be measured invasively by Fick method, dye dilution or thermodilution. Fick method and dye dilution are employed mostly in catheterization laboratories and are not suitable for clinical haemodynamic monitoring because of their technical difficulties. Thermodilution (TD) by means of right heart catheterization by Swan-Ganz pulmonary artery catheter is method most frequently used for routine and repeated bedside measurement of cardiac output despite its possible risks and costs. Cardiac output can be estimated non-invasively by Doppler echocardiography but the method is unsuitable for routine monitoring because it is time-consuming and operator-dependent.

Thoracic electrical bioimpedance (TEB) is an attractive alternative providing non-invasive, continuous, real-time, time-unlimited and cheap monitoring of central haemodynamics. Though the technology has been refined in recent years controversies still do exist about its validity in clinical settings. The aim of this study was to determine the correlation and agreement between measurements of CI by means of TEB and TD and thus, in case of good correlation and agreement, indicate possible areas where thermodilution could be interchanged or replaced by bioimpedance.

Material and methods

The population studied were adult patients undergoing elective cardiac surgery at university cardiac surgery centre who had Swan-Ganz pulmonary artery catheter inserted either before induction of anaesthesia or in the course of operation. The decision about the right heart catheterization was upon anaesthesiologist’s consideration based on patient’s history, preoperative status and haemodynamic situation in the course of operation. The study was approved by the institutional Ethics Committee.

A total of 37 patients representing the usual incidence of cardiac procedures were monitored non-invasively by thoracic bioimpedance cardiograph. Ten patients were excluded of the cohort because of cardiac pacing (4), monitored disturbance (3) and low-quality impedance signal (3). Finally 28 patients were enrolled in the study having undergone following procedures: coronary revascularization (CABG - 19, including 1 minimally invasive coronary bypass grafting - MIDCAB), aortic valve replacement (4), mitral valve replacement (1) and combined procedures - aortic
valve replacement with coronary revascularization (3). All patients were in sinus rhythm. All but one were intubated and artificially ventilated at the beginning of the monitoring period and were intentionally extubated no sooner than 4 hours after the arrival at ICU.

The correlation measurements were performed upon the arrival of the patient from operation room to ICU and then after 4, 8, 12 and 20 hours respectively. The value of CI estimators was the average of four consecutive injections of saline solution of room temperature. If any of the trials differed more than 10 percent it was deleted and additional injection was performed. The measurements were processed, stored and printed by the Marquette Electronics Inc. software.

Thoracic electrical bioimpedance measurements were performed in a way of continuous monitoring by noninvasive bioimpedance cardiograph Hotman AH/HHC (Hemo Sapiens, Irvine, CA, USA). Eight solid gel electrodes were applied on the skin at the area of neck and thorax according to the scheme (Fig. 1). The bioimpedance cardiograph displayed the real-time continuous CI estimate as well as other haemodynamic parameters (respiratory rate, heart rate, stroke index, non-invasive blood pressure, end-diastolic index, ejection fraction, left stroke work index, inotropic state index, ejection phase contractility index, thoracic fluid conductivity). All measured data were stored by the cardograph in a form of patient’s record.

From all measured parameters only CI estimates were studied. As the bioimpedance CI estimate results from slightly oscillating reading that is updated every 1 minute the average value of 15 minutes record at corresponding time points was taken as a counterpart to be paired with the thermodilution measurement.

The paired data were processed by Excel 8.0 software (Microsoft). The correlation coefficient r was calculated between the methods and data analysis introduced by Bland-Altmann was performed.

Results

Together 128 pairs of CI estimates (thermodilution/bi-impedance) were obtained (25, 26, 27, 26 and 24 at each time point respectively). The range of readings was 1.3 - 6.7 l/min·m² (TEB) and 1.8 - 5.6 l/min·m² (TD). A correlation was sought between TD and TEB readings. The correlation coefficient r calculated for all pairs of data obtained was 0.26, p<0.05 (Fig. 2). Then a correlation was sought between specific subsets of data. The correlation coefficient for CABG patients only was r = 0.30, p<0.05. On the same basis correlation was determined between paired measurements at specific time points 1-5. In these subsets r was determined 0.25; 0.33; 0.23; 0.34; 0.21; p<0.05 respectively, indicating thus the best between-method correlation in measurements 12 hours after the end of open-heart surgery.

A data analysis that was introduced in 1986 by Bland and Altman and since then has been widely used as the only correct procedure in determining the agreement between two methods, neither one of which is absolutely precise, was performed. The distribution of all data in Bland-Altman’s plot display bias 0.07 ± 1.1 min·m² with precision (SD) ± 1.1 min·m². The 95% limits of agreement defined as ± 2 SD were -2.27 - 2.13 l/min·m² (Fig. 3).

Discussion

Though the changes of impedance synchronous with cardiac cycle were noticed already by Vogt (1888) and Cremer (1907), the theoretical grounds were laid and first modern devices for measurement of thoracic electrical bioimpedance were constructed in U.S.A. in late 60-ties for the purpose of N.A.S.A. Nyboer in the beginnings of 50-ties described first equation for computation of stroke volume which was later modified by Kubik in 60-ties.

where LVET = left ventricular ejection time, dZ/dt = maximal velocity of change of impedance during systole (Ohm/s).

In 1981 Sramek presented a new equation for computation of SV which eliminated blood resitivity and thoracic length:

where VET = physical volume of electrically participative tissue calculated from sex, height and weight correlated to age, VE = ventricular ejection time. IC = index of contractility (1). Sramek’s formula was later modified by Bernstein (1986) who introduced correction factor delta to eliminate some disproportions in patients with borderline weight.

Thoracic bioimpedance is an electrically nonhomogenous volume conductor. High-frequency electrical current of low intensity (50 - 100 kHz, 0.2 - 5 mA) is distributed via two pairs of electrodes on the surface of the patient’s trunk and the level of diaphragm. Both the basic level of impedance and its dynamic changes are measured by two pairs of sensing electrodes situated inside the electrical field. The dynamic impedance changes are synchronous with heart rate and are caused pre- dominantly by changes of descending thoracic aorta throughout the heart cycle. Descending thoracic aorta due to its longitudinal orientation is the main electrical current pathway in thorax. Changes of its impedance are caused by changes of its volume thus reflecting the cyclic intravascular changes of pressure originated in heart performance. Second contribution to the dynamic impedance signal dZ is the change of flowing blood conductivity with regard to its velocity. At the moment of highest velocity (systole) the blood displays the highest conductivity that is caused by most of the erythrocytes being aligned parallel to the stream.

The devices for measurement of thoracic electrical bioimpedance have been substantially improved in the course of development. The dramatic onset of hardware and software sophistication enabled the modern bioimpedance cardiographs to be constructed as compact, easy-to-handle multifunctional devices suitable for longitudinal real-time bedside monitoring of central haemodynamics.

One of the most favourable techniques is frequently employed by investigators in anaesthesiology, gynaecology or nephrology. On the other hand, serious controversies still do exist about the validity of bioimpedance measurements in clinical conditions. The ongoing efforts of investigators are motivated by the need of a device performing reasonably precise, non-invasive and cheap measurements. Works with different results were published comparing TEB with other modalities of cardiac output estimation in experimental model as well as in various patients populations.

The first trials were performed mostly on healthy volunteers confirming thus the basic concepts of the method a number of authors tried to validate bioimpedance cardiography in various clinical conditions against proven methods of CO estimation. The population for these studies was therefore recruited among those patients whose diagnosis, medical history and risk factors were documented by Kubit in 60-ties.

The use of TEB in patients undergoing cardiac surgery is another appealing issue. The candidates for open-heart surgery - CABG predominantly - form relatively uniform group of patients who are well diagnosed, treated according to routine schemes and frequently with the use of pulmon- ary artery catheter. Hypothetical replacement of TD by TEB, if allowed under certain conditions, would mean a considerable diminishment of invasive burden as well as decrease of costs. However, the results of several studies are deeply controversial. Deoors reports poor agreement in her
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\[ SV = \rho \times \left( \frac{L}{Z_0} \right)^2 \times LVET \times \left( \frac{dZ}{dt} \right) \]

where LVET = left ventricular ejection time, dZ/dt = maximal velocity of change of impedance during systole (Ohm/s).

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The use of TEB in patients undergoing cardiac surgery is another appealing issue. The candidates for open-heart surgery - CABG predominantly - form relatively uniform group of patients who are well diagnosed, treated according to routine schemes and frequently with the use of pulmo-
nary artery catheter. Hypothetical replacement of TD by TEB, if allowed under certain conditions, would mean a considerable diminishment of invasive burden as well as decrease of costs. However, the results of several studies are deeply controversial. Douros reports poor agreement in her

![Fig. 1](placement of TEB electrodes (black - current electrodes, white - sensing electrodes)).

From all measured parameters only CI estimates were studied. As the bioimpedance CI estimate results from slightly oscillating reading that is updated every 1 minute without the heart cycle. Descending thoracic aorta due to its situation inside the electrical field. The dynamic impedance changes are measured by two pairs of sensing electrodes on the surface of the neck and at the level of diaphragm. Both the basic level of impedance and its dynamic changes are measured by two pairs of sensing electrodes situated inside the electrical field. The dynamic impedance changes are synchronous with heart rate and are caused predominantly by changes of descending thoracic aorta throughout the heart cycle. Descending thoracic aorta due to its longitudinal orientation is the main electrical current path way in thorax. Changes of its impedance are caused by changes of its volume thus reflecting the cyclic intravascular changes of pressure originated in heart performance. Second contribution to the dynamic impedance signal dZ is the change of flowing blood conductivity with regard to its velocity. At the moment of highest velocity (systole) the blood displays the highest conductivity that is caused by most of the erythrocytes being aligned parallel to the stream.

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Typically, patients undergoing diagnostic catheterization, open-heart surgery or staying at the ICU from various reasons were studied. The majority of these studies found an overall good correlation between methods (r = 0.65 - 0.9) and low bias values with varying values of precision. Shoemaker documented in multicenter trial the use of TEB in series of high-risk surgical patients with possibility of tracking the typical patterns of survivors vs. non-survivors via longitudinal bioimpedance cardiography monitoring (1, 2).

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series of 34 elective cardiac surgery patients (CABG, mitral valve replacement, combined valve and coronary surgery) be- ing monitored for 22 hours after operation (14). Thomas discourages the use of TEB in the first 12 hours af- ter cardiac surgery (15). Similar negative conclusions were published by Spahn and Sageman (16, 17) whereas good cor- relation was experienced by Ferraro, Hruska. Schwann and recently in a multicenter COST study (18 - 20). Despite controversial opinions on validity of TEB in clini- cal settings there is an agreement in defining the areas where TEB due to its inherent drawbacks is unsuitable for use. These are sepsis, tachycardia over >180/min, extreme obesity or height, excessive patient movement, dilatation of aorta, LBBB (21). Patients with atrial or mitral valve re- gurgitation are falsely underestimated because only forward flow is taken into consideration. The effect of improper po- sition of lower pair of sensing electrodes on the CO esti- mate was demonstrated by Jewkes (22). On the other hand, it has to be reminded that thermodi- lution is not a reference method and bears a lot of inherent inaccuracy as well (23). It is known for underestimating in low-flow states. In general, the flow-dependent relation bet- ween the two methods remains unclear. While overestimation by TEB in low-flow states is claimed by some (12) and also in highflow states by others (22), a systematic underestimation was also reported (16). We found almost linear underestima- tion at low flow and overestimation at high flow (Fig. 4).

![Fig. 4: Low-flow vs. high-flow TEB readings - relation to si- multaneous TD: low-flow TEB underestimated TD whereas high-flow TEB overestimates TD (r = 0.87, p<0.05; n = 128).](image)

In our experience, transthoracic electrical bioimpedan- ce monitoring can be easily accomplished providing com- fortable real-time information and unlimited longitudinal record. Care has to be taken of correct placement of lower pair of sensing electrodes because the level of diaphragm lays more cranial in supine patients than it might by expec- ted. Patients who were 100 % paced (via epicardiovascular electrode placed at the time of operation) were not suitab- le candidates for TEB monitoring because aberrant QRS formation disabled correct detection of systole and led to erroneous CI estimate. Three MDCAB patients were ex- cluded from the study because of restlessness and motoric disturbances commonly seen after this type of procedure.

Moreover, correlation between two methods of CI estimation was poor what is expressed in r = 0.2, p>0.05. The result did not change significantly when CABG pati- ents were studied solely (r = 0.30, p<0.05) or only mea- surements from specific time points were examined separately (r = 0.21 - 0.34, p<0.05).

Bland and Altman introduced their statistical method in 1986 as the only correct tool in determining the agreement of two methods of which neither one is absolutely precise. The differences in readings by TD and TEB were plotted against the average of both methods. The between methods bias was very low, 0.07 l/min/m². The precision however was ±1.1 l/min/m². The 95% limits of agreement were -2.27 - 2.13 l/min/m², what represents interval unacceptable for clinical purposes. It is evident that TEB technology encounters distinct problems in open-heart surgery patients. An acute dysba- lance in thoracic fluid content after cardiac-pulmonary by- pass may be the leading cause. Different patterns of thoracic resistance in patients operated with or without cardiac-pulmonary bypass, which were expressed shortly af- ter cardiac surgery, were documented in the work of Mattar (24). The structural and functional changes of thorax, amount of fluid in pericardial and pleural cavities together with presence of chest tubes make the correct bioimpedan- ce calculation difficult. Transient pathological situations as arrhythias, low-flow or high-flow states and artificial ventilation - the influence of which is poorly understood - are frequently present after open-heart surgery.

**Conclusion**

Transthoracic electrical bioimpedance though contro- versially accepted is an established method for non-invasive monitoring of central haemodynamics. The bioimpedance cardiographs have been subject to continuous refinement of calculation algorithm. Newly released monitors are awai- ted for clinical evaluation. As numerous studies were per- formed in various clinical subsets using different types of bioimpedance cardiographs and employing different for- mulas (Kubiczek, Szramek, Sramek-Bernstein) further tech- nological improvement as well as clearly defined areas of clinical application still have to be sought. If justified by comparison study it would be very attractive modality due to its non-invasiveness, continuous realtime estimate and low costs in situations where information on central haute- modynamics was needed but invasive approach was dis- couraged from multiple reasons. At this moment, however, our data cannot support this hypothesis.

**References**

1. Shoemaker WC, Wo CC, Bishop MII et al. Multiorgan failure of a new thoracic elec- trical bioimpedance device for cardiac output estimation. Crit Care Med 1994;22(12):1915-22.
2. Shoemaker WC, Wo CC, Bishop MII et al. Noninvasive physiological monitoring of high-risk surgical patients. Arch Surg 1996;131(7):737-72.
3. Bishop MII, Shoemaker WC, Shuldan J, Wo CC. Noninvasive cardiac output mon- itoring in patients with acute pancreatitis. Crit Care Med 1994;22(6):983-8.
4. Bolenderh R, Cianfarani N, Costacurta G, Bartolini A, Pierau A. Comparison of impedance cardiography with thermodilution and direct Fick methods for non- invasive measurement of stroke volume and cardiac output during intermittent exercise in patients with ischemic cardiomyopathy. Am J Cardiol 1996;78(15):1295-301.
5. Spahn RD, McCreary RJJ, Tanam KL, Khanvirk AD. Bioimpedance hemodyna- mics compared to pulmonary artery catheter monitoring during orthotopic liver transplantation. J Transplant 1995;24:1226-30.
6. Nieslach B, Wimmer E, Dang-Ho N. Noninvasive de- termination of cardiac output by Doppler echocardiography and electrical bio- impedance. Br Heart J 1995;74:587.
7. Talarico G, Saino A, Costante G. Valutazione non invasiva dellindice cardiaco ed el- la frizione di sussiecia nella cardiopatia ischemica. Confronto tra bioimpedenza e ultrasonografia. Minoria Cardiologica e Toracologica 1995;7(1):49-58.
8. Cao G, Moller G, Bloman J, Neudorfer I, Almlof P. Determination of car- diac output during cardiac surgery using Fick equation. Electrical bioimpedance and thermodilution. Crit Care Med 1990;18(5):544-6.
9. Clark TV, Norman K, Reynolds C, Conigrave D, Maxwell RJ. Cardiac output measurement in critical care patients: Thoracic Electrical Bioimpedance versus thermodilution. Thorax 1993;48(11):110-20.
10. Winkler O, Boeckhoutsoon H, Faha P, Nebuch G, Baudt J. Registration of thoracic electrical bioimpedance for early diagnosis of rejection after heart trans- plantation. Heart Lung 1993;12:532-4.
11. Atallah MM, Demain AD. Cardiac output measurement: lack of agreement bet- ween thermodilution and thoracic electric bioimpedance in two clinical settings. J Clin Anesth 1995;7:53-5.
12. Wise R, Colowick I, Cain D, Granger W, Winslow J. Effectiveness of thoracic electrical bioimpedance in cardiac surgery: Clinical validation. Cardiothorac Anesth 1995;9(1):48-53.
13. Spahn DR, Amundsen DE. Thoracic electrical bioimpedance measurement of cardiac output in postoperative coronary bypass patients. Crit Care Med 1993;21(3):572-4.
14. Saniger L, El Adi M, Madalena G et al. Unila della bioimpedenza nel monito- raggio del paziente in modo di pesa immobile di cardiochirurgia: comparazione con la termodiluzione. Cardiochir 1995;39(3):77-85.
15. Hukay K, Senak J, Hrubátko D et al. Komplexe vorzeitige veränderungen der thoraxleitungswiderstände im kardiologischen und thoraxleistungssystem. Z Kardiologie 1995;2(5):303-4.
16. Schown WN, Nagi D, McNally S, Tryamaj M, Aud F. Intracoronary compari- son of a new thoracic bioimpedance device to thermodilution and echocardiography for the determination of cardiac output. Anesth Analg 1997;84, SCA1-SCA127.
17. Schwan NM, Nagi D, McNally S, Tryamaj M, Aud F. Intracoronary compari- son of a new thoracic bioimpedance device to thermodilution and echocardiography for the determination of cardiac output. Anesth Analg 1997;84, SCA1-SCA127.
18. Fournier A, Dalgletch Y, Berthoud P. Comparison of thoracic electrical bioimpedance and thermodilution for the measurement of cardiac index in patients with severe se- psis. Br J Anaesth 1991;67(1):56-62.
19. Jenkins C, Bear FW, Yeoward M, Sanders DJ, Fous P. Noninvasive measurement of cardiac output by thoracic electrical bioimpedance: a study of reproducibility and comparison with thermodilution. Br J Anaesth 1997;78(6):784-9.
20. Benevento G, Immuntorre M, Nicoletto C, Lovigno C, Di Nardo L. Clinical and Computerized Medicine in Cardiac Surgery, 2nd ed. Philadelphia: W B Saunders, 1993:213-34.
21. Mattar J, Bucinat MD, Hedge E, Tucci SR, Biassoni A, Raffini A. Application of bolus noninvasive method of body impedance analysis to assess changes in pre and postoperative period of cardiac surgery. Presented at VII. World Congress of Cardiology, Rio de Janeiro, 1998.

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Our data cannot support this hypothesis. Others have assumed that invasive monitoring is needed but invasive approach was discouraged from multiple reasons. At this moment, however, low costs in situations where information on central hemodynamics can be easily accomplished providing comparable accuracy to thermodilution is a reference method and bears a lot of inherent problems in open-heart surgery patients. An acute dysrhythmias, low-flow or high-flow states and artificial pass may be the leading cause. Different patterns of cardiac output after open-heart surgery. An acute dysrhythmias, low-flow or high-flow states and artificial pass may be the leading cause. Different patterns of cardiac output after open-heart surgery. Nevertheless, correlation between two methods of CI estimation was poor what is expressed in r = 0.2; p<0.05. The result did not change significantly when CABG patients were studied solely (r = 0.30, p<0.05) or only measurements from specific time points were examined separately (r = 0.21; 0.34, p<0.05).

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