Foundation of tissue oxygenation: optimizing systemic blood flow by trans-oesophageal Doppler (TED) monitoring

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Introduction

Systemic blood flow is a key link in the chain of oxygen transfer from alveoli to mitochondria and is therefore one of the main determinants of tissue oxygenation. Impaired systemic blood flow is known to readily compromise oxygen delivery and hence, maintenance of an adequate cardiac output (CO) is considered pivotal in maintaining an adequate tissue oxygenation. Clinically, thermodilution techniques, which require insertion of a pulmonary artery catheter, are considered the golden standard for determinations of CO. Major risks, high costs and a considerable time needed for PAC insertion usually limit the use of this technique to patients with high risk of haemodynamic instability. Alternative techniques such as pulse contour analysis or transoesophageal echocardiography are also either invasive or require expert operators, so that CO is most often not assessed at all in patients at risk of developing tissue hypoxia. In these patients, transoesophageal Doppler (TED) ultrasound of the descending aorta may offer a promising alternative. The technique is minimally invasive, is easy to learn, allows quick and continuous assessment of CO and does not require a sterile environment, making TED technology suitable for routine clinical use.

Technical principles

The TED probe is inserted into the oesophagus similar to a gastric tube and subsequently aligned with the descending aorta. Emitted ultrasound waves (typically with frequencies of 4 to 5 MHz) are scattered by erythrocytes travelling in the ultrasound beam and partially reflected back to the probe. A change in the frequency of waves (in this case ultrasound waves) reflected by moving objects (here: erythrocytes) is known as Doppler effect, and the shift between emitted and perceived frequency is directly proportional to velocity of the moving object. This principle allows to calculate descending aortic blood flow velocity and to plot blood flow velocity (cm sec^{-1}) against time (sec). The area under the systolic portion of this curve (cm $sec^{-1} \cdot sec$) corresponds to the distance (cm) the blood column has moved forward in the aorta during systole. Multiplying this distance (cm) with aortic cross sectional area (cm^2) yields descending aortic stroke volume (cm^3), from which systemic stroke volume and hence CO can be estimated assuming a constant distribution of blood flow between the descending aorta (~70%) and the coronary and brachiocephalic arteries (~30%).

Limitations and clinical validity

Note that we basically have two unknowns in the computation of CO: aortic diameter and distribution of blood flow. Depending on the device, aortic diameter is either estimated with integrated M-mode ultrasound, or systemic stroke volume is calculated using a validated nomogram based on patient's age, height and weight. Technical limitations mainly derive from the assumptions needed to translate blood flow velocity to CO and may prevent the technique from measuring exact absolute CO values. Indeed, various studies suggest that, while TED does not systemically under- or overestimate CO, individual CO values can considerably differ from values obtained with reference methods. However, trend monitoring should generally be possible despite these limitations as long as the basic conditions, i.e. aortic diameter and blood flow distribution, remain constant. This has been confirmed by numerous studies which have shown that TED reliably follows CO changes over time. Therefore, while TED may not be an ideal technique when exact absolute values of CO are required, it is useful especially as a non-invasive and continuous technique for trend monitoring of CO. However, it is important to realize that changes of the basic condition, e.g. sudden changes of aortic diameter and blood flow distribution due to acute hemorrhage, may likely lead to inconsistent or even misleading CO readings.

Hemodynamic optimization

In clinical practice, non-invasive monitoring of CO changes may be useful for early detection and management of hemodynamic deterioration. Herein, TED also aids the clinician by measuring time-related and accelerometric parameters that allow indirect assessment of preload, afterload and myocardial contractility, which are however beyond the scope of this abstract. In addition, TED can be used to optimize CO in patients without obviously impaired systemic blood flow. Herein, especially the role of TED to optimize fluid load has been well defined in the literature. Since the normal, not hypervolaemic hart operates on the ascending limb of the Starling curve, a fluid bolus will result in an increased stroke volume. In contrast, absence of an adequate increase suggests that the hart operates on the flat portion of the Starling curve and that further filling will result in volume overload. In this context, an increase is generally considered adequate if it exceeds 10% following a colloid bolus of 3 ml kg^{-1} bodyweight. Thus, using TED together with the Starling principle allows to optimize preload while avoiding hypervolaemia. A total of 10 studies using TED guided volume management strategies in perioperative and trauma patients conclusively report beneficial effects in the Doppler-guided groups. TED managed patients required fewer days on an intensive care unit and were earlier medically fit for discharge from hospital. Moreover, these studies demonstrate that Doppler-guided fluid replacement reduces the risk of postoperative complications and morbidity. Reductions in the incidence of postoperative nausea as well as a shorter time to recovery of gut function and resumption of enteral nutrition have also been reported in the volume-optimized groups. While none of the studies have actually investigated the influence of TED guided volume management on tissue oxygenation, it is likely that the observed improvement in outcome is ultimately due to improvements in tissue microcirculation and oxygenation. In contrast to the well described beneficial effects of TED guided volume management in perioperative patients, studies assessing the ability of TED to guide hemodynamic management in other patient populations or with inotropic and vasoactive drugs are lacking.

Conclusions

Transoesophageal Doppler measurements of descending aortic blood flow velocity is a minimally invasive, easy to learn and quick method for continuous trend monitoring of CO. Various studies have demonstrated a reduced postoperative morbidity and shorter length of hospital stay in perioperative patients managed with TED, however further studies are needed to determine the role of TED in guiding inotropic and vasoactive therapies and to asses the influence of TED guided hemodynamic management on tissue oxygenation.

References

An extended list of references can be obtained from the author.