Clinical Monitoring and Automatic Detection of Venous Air Embolism

M

Rita Tedim
University of Porto, Portugal

Pedro Amorim
Hospital de Santo António, Centro Hospitalar do Porto, Portugal

Ana Castro
University of Porto, Portugal

INTRODUCTION

Air Embolism is a pathological condition consisting of gas entering the circulation, namely air bubbles entering a vascular system, venous or arterial. Venous Air Embolism (VAE) is a potentially serious situation that may occur as a surgical complication, namely during neurosurgical procedures (Law, 2012). VAE may lead to air bubbles accumulation in the heart, potentially causing a significant reduction in blood flow through the right heart and the lungs. When not detected in time, many complications such as stroke, obstruction of pulmonary blood flow, or cardiovascular collapse may arise (Albin, 2011).

This air bubbles' accumulation is usually caused by the existence of pressure gradients between the right side of the heart and the surgical field, and it is more frequent for the sitting position (incidence of 25%), but may also occur in the prone, supine or lateral positions (incidence ranging between 15% and 25%) (Law, 2012). Clinical studies (Law, 2012; Mirski, 2007) indicate that systemic embolization into the cerebral, pulmonary, and coronary circulations may be catastrophic.

To detect and treat VAE, protocols have been implemented, including placing a precordial Doppler probe or Transesophageal Echocardiography (TEE) for monitoring, the insertion of a right atrium line for air aspiration, and the institution of high flow oxygen (Albin, 2011). The Doppler probe allows real-time monitoring of the heart sounds (Sigel, 1998). During surgical procedures, continuous assessment of the pre-cordial Doppler is the responsibility of the anesthesiologist Changes in heart tones, usually referred to as "mill-wheel murmurs," are characteristic of VAE, and the anesthesiologist has an important role in the detection of these characteristic sounds, and subsequent intervention (Albin, 2011).

A drawback of most current VAE detection methods is the fact that they still rely on the continuous attention of the anesthesiologist to cardiovascular changes, and the Doppler sound beat-to-beat throughout the entire surgical procedure. Since the anesthesiologist has a large number of physiological signals to monitor, some VAE signs may pass unnoticed, especially after the occurrence of false positives (which usually tends to reduce the confidence in the monitoring device, leading to potential disregard of positive alarms). Therefore, the study and development of novel and more reliable and robust methods for automatic detection of VAE is of paramount importance.

This article aims to describe the current clinical methods used in VAE detection, and also, the automatic methods that have been studied to minimize the problems aforementioned.

BACKGROUND

Knowing the physiology of the heart is important to understand how VAE occurs, and what may be done to prevent the problems associated to this event.

Both volume and rate of air accumulation are dependent on the size of the vascular lumen as well as the pressure gradient determining the morbidity and mortality of any episode of VAE (Mirski, 2007). For

DOI: 10.4018/978-1-4666-5888-2.ch544

these reasons surgeries in the head or the brain have a high risk of VAE episodes (negative pressure gradient).

Pathophysiologic pathways are highly dependent on the volume of air accumulated within the right ventricle. If the rate of embolism is high (approximately 5 ml/kg), the probability of air bubble accumulation in the heart is higher. As consequence, the normal blood flow is interrupted. This outflow obstruction may be the result from the inability to decompress the tension of ventricular wall, which leads to heart failure and cardiovascular collapse. When the volumes of VAE are moderate, a decrease in cardiac output, hypotension, myocardial and cerebral ischemia, and even death may occur (Sigel, 1998). At the pulmonary level, an entrainment of air may lead to vasoconstriction, release of inflammatory mediators and bronchoconstriction. Not only negative pressure gradients but also positive pressure insufflation of gas may present a serious VAE hazard (Sigel, 1998).

Main symptoms of VAE include chest pain, dyspnea, coughing (Gan, 1997), tachycardia, cyanosis (Sigel, 1998) and sense of impending death (Avidan, 2008); however such symptoms may only be referred by conscious patients, while VAE occurs mostly during surgery under general anesthesia.

Relating the incidence of VAE with the positioning of the patient, neurosurgical procedures performed in the sitting position have the highest rate of VAE (80% for seated posterior fossa surgery) (Eikaas, 2009).

Neurosurgeries performed in the lateral, supine, or prone positions have an incidence ranging from 15% to 25% (Palmon, 1997).

In human patients, the volume of gas tolerated is unknown, but accidental injections of air of between 100 ml and 300 ml, or 3-5 ml/kg, have been reported to be fatal (Gan, 1997).

In the absence of a high level of suspicion, VAE may be difficult to diagnose because the signs and symptoms are nonspecific and may be transient (Palmon, 1997). In one study of Vesely (2001) 26.7% of the total patients with VAE episodes remained completely asymptomatic at the moment of the event.

DETECTION METHODS

The monitoring devices that are used to detect VAE should be sensitive, easy to use, and noninvasive. The selection depends on the position of the patient, the expertise of the anesthesiologist in using the device, and the medical condition of the patient (Mirski, 2007). The correct selection and use of these devices contribute to an early detection and prompt treatment, factors that limit morbidity and mortality of VAE (Muzzi, 1990).

Direct Clinical Detection Methods

Only two devices are used to detect VAE in a direct way: the Transesophageal Echocardiography (TEE) and the Precordial Doppler. TEE is the most sensitive monitoring device for VAE once it may detect as little as 0.02 ml/kg of air administered by bolus injection. However, it is invasive, expensive, requires expertise and constant vigilance, and the risk of esophageal injury during prolonged use has limited its clinical use (Palmon, 1997). The use of TEE as standard of practice represents only 38% of patients undergoing intracranial procedures, compared with the use of precordial Doppler (Mirski, 2007).

The precordial Doppler is the device with fewer disadvantages, presenting a high sensitivity. For this reason, is the method broadly used to monitor VAE, namely, during neurosurgeries (Schubert, 2006). As the name of the device indicates, it uses the Doppler effect which consists in the change of the frequency of a wave in response to the blood flow relative to the Doppler probe. This is a highly sensitive technique once it was demonstrated that it may detect as little as 0,25 ml of air (0,05 ml/kg) (Law, 2012).

The Doppler probe is usually placed along the right sternal border (between the third and sixth intercostal spaces) since good results were obtained in adults and children, using these landmarks (Eikaas, 2009). Generally, the positioning is confirmed by the injection of some millimeters of saline fluid (Mirski, 2007).

The first discernible evidence of VAE is a change in the character and intensity of the emitted sound (Mirski, 2007) namely the classic mill-wheel murmur, as referred previously (Albin, 2011). This sound reflects the turbulent resonance of normal blood flow passing abruptly through the right cardiac chambers.

Many studies advise the inclusion of the precordial Doppler in the anesthetic plan since it is the most cost effective, easy to use, and least invasive of the high sensitivity monitoring devices (Chan, 1996).