Anaesthesia in the cardiac catheterization laboratory

Sue Braithwaite[a], Jolanda Kluin[b], Wolfgang F. Buhre[a] and Eric E.C. de Waal[a]

[a]Division of Perioperative and Emergency Care and [b]Department of Cardiothoracic Surgery, University Medical Centre, Utrecht, The Netherlands

Correspondence to Professor Dr Wolfgang Buhre, Division of Perioperative and Emergency Care, University Medical Center, Q 04.2.317, P.O. Box 85500, 6708 GA Utrecht, The Netherlands
Tel: +31 88 7557818; fax: +31 30 2541828; e-mail: w.f.buhre@umcutrecht.nl

Current Opinion in Anaesthesiology 2010, 23:507–512

Purpose of review

Interventions in the cardiac catheterization laboratory (CCL) requiring anaesthetic expertise are becoming routine. These interventions involve a heterogeneous patient population and take place in an offsite location. This review aims to give an insight into anaesthetic issues surrounding certain interventions and the challenges encountered in an offsite location.

Recent findings

Owing to an ageing population with increasing comorbidity, transcatheter interventions are being developed and in certain cases becoming routine alternatives for open heart operations. Percutaneous interventions are also being increasingly performed in adult patients with congenital heart abnormalities. The anaesthetic team plays an important role in these procedures, requiring detailed knowledge of the intervention, the characteristics of the patient population and the ability to work as a team in a complex, multidisciplinary setting.

Summary

Interventions in the CCL have developed to such an extent that dedicated anaesthesia teams are required in order to cope with the complexities of the patient populations, the interventions and the challenges brought by the offsite nature of the CCL.

Keywords

cardiac catheterization laboratory, dedicated anaesthesia teams, offsite anaesthesia, transcatheter aortic valve implantation

Curr Opin Anaesthesiol 23:507–512

0952-7907

Introduction

The increasing scope of interventions in the cardiac catheterization laboratory (CCL) has resulted in an offsite workplace for anaesthesia teams which demands great flexibility in coping with differing patient categories, complications and safety issues. Transcatheter aortic valve implantation (TAVI) is becoming routine practice in elderly patients affected by significant aortic valve stenosis who also have serious comorbidity prohibiting an open heart operation [1–3]. At the other extreme neonatal patients require general anaesthesia to facilitate diagnostic and interventional procedures associated with congenital heart abnormalities.

Anaesthetic challenges relate not only to adapting to this expanding high-risk patient population but also to the prevention and management of the potential life-threatening complications of the catheterization and interventions. This challenge is compounded by the CCL itself, a setting often never designed for the requirements of anaesthesia teams. Unfamiliarity and limitations with the setting can lead to potentially serious safety issues.

Overview of interventions performed in the cardiac catheterization laboratory

Many interventions in the CCL such as percutaneous coronary intervention and electrophysiological procedures are presently carried out by the cardiology team in conscious patients. These procedures will not be covered here.

Transcatheter aortic valve implantation

TAVI is an increasingly routine option for treatment of significant and limiting aortic valve stenosis in a patient population who, owing to advanced age in combination with either extreme comorbidity (logistic EuroSCORE >20) or other factors (e.g. porcelain aorta, previous sternotomy or radiation therapy), are at risk to undergo an open heart operation and traditional aortic valve replacement. The TAVI procedure consists of either retrograde, via the femoral artery, or anterograde, via the apex of the left ventricle (LV), access to the aortic valve annulus. A balloon valvuloplasty of the aortic valve precludes the insertion of a biological aortic valve mounted on a balloon expandable stent. After inflation of the balloon the

Table 1 Guiding the cardiovascular preoperative assessment of patients undergoing TAVI procedures

Preoperative cardiovascular assessment	
Left ventricular function	Systolic, diastolic, recent cardiac failure
Coronary artery disease	+/−
Mitral regurgitation	+/−
Tricuspid regurgitation	+/−
Pulmonary hypertension	+/−
Right ventricular dysfunction	+/−
Atherosclerotic disease	Aorta, carotid arteries, peripheral arteries
Renal function	+/−
Recent stroke	+/−

Table 2 Standard monitoring and procedure-specific equipment for use during a TAVI procedure

Standard monitoring	
5 lead ECG	
Arterial line	PPV
Central venous line	CVP
Transoesophageal echocardiography	FAC, LVEDA, valve function pre and post AV implantation
Temperature probe	
Urine catheter	
ACT monitor	ACT > 250 s during procedure
Procedure-specific equipment	
Large-bore i.v. access	
Rapid infusion-warming device	
Pacemaker	
Cell saver	
Heated blanket device	
External defibrillation pads	

ACT, activated coagulation time; AV, aortic valve; CVP, central venous pressure; FAC, fractional area change; i.v., intravenous; LVEDA, left ventricle end-diastolic area; PPV [6], pulse pressure variation.

biological aortic valve expands and spans the aortic valve annulus, pushing the native aortic valve to the side in a redundant, permanently open, position.

In the majority of cases TAVI is performed under general anaesthesia. A possible alternative is the use of local anaesthesia with sedation for the transfemoral approach. With both anaesthetic techniques, detailed cardiovascular preoperative assessment of the patient is vital [4••] (see Table 1). Determination of renal function is relevant owing to the potential nephrotoxicity of intravenous fluoroscopic contrast in patients with compromised renal function. Further investigations relevant to the intervention itself include measurement of the aortic valve annulus, distance between the aortic valve and the coronary ostiae and screening the extent of possible atherosclerotic arterial disease both peripherally in the femoral and iliac vessels and centrally in the ascending aorta and aortic arch.

We routinely perform a case conference with all medical specialties involved to detail the approach, the specific problems anticipated for each patient and what the course of action should be in the case of an acute life-threatening complication during the procedure. Such preprocedure meetings can greatly facilitate teamwork during the actual procedure and avoid delay and confusion during possible crisis situations [5••].

Anaesthesia technique for TAVI procedures

In our centre, both transfemoral and transapical AVI procedures are performed under general anaesthesia according to a fast-track protocol. Before induction, large-bore intravenous access is obtained, a rapid infusion-warming device connected, and an arterial line introduced. Owing to the lack of waste gas-scavenging systems in the CCL, a total intravenous anaesthesia technique is performed with propofol and remifentanil. After induction, central venous access is obtained, a transoesophageal echo (TEE) probe introduced and external defibrillation pads are placed.

The temperature of the patient is maintained with heated blankets and air-warming devices. Cell-saving equipment is readied for use and a perfusionist is on standby with extracorporeal circulation equipment (see Table 2).

In both approaches, a pacing wire is first introduced and connected to a pacemaker under the control of the anaesthesiologist. The pacing wire is subsequently tested to affirm that rapid ventricular pacing can be initiated. The native aortic valve is dilated by balloon valvuloplasty and the transcatheter aortic valve subsequently placed under the conditions of rapid ventricular pacing and a cessation of ventilation. These conditions ensure minimal displacement of the aortic valve annulus and must be initiated and terminated according to clear commands. Correct placement of the aortic valve is confirmed by fluoroscopy and TEE, the catheters are withdrawn and, in the case of transapical access, an intercostal nerve block is performed.

During the procedure, haemodynamic monitoring of preload and ventricular function is facilitated by TEE, performed by a cardiologist or anaesthesiologist experienced and certified in the technique.

Procedure-specific complications [7••] consist of massive blood loss due to damage to femoral and iliac arteries or the left ventricular apex, depending on the approach. Other complications requiring immediate surgical intervention include aortic dissection, embolization of the new aortic valve and acute refractory left ventricular failure (see Table 3). Such critical complications may demand the institution of extracorporeal bypass and subsequent open heart operation requiring teamwork between surgical, anaesthetic and perfusion teams.

Recently, hybrid operating theatres have been developed in order to facilitate direct open heart operations with use

Table 3 Showing complications of transfemoral and transapical implantations of the Edwards Sapien valve

	Edwards Sapien valve SOURCE registry, transfemoral AVI, Europe, $n = 463$	Edwards Sapien valve SOURCE registry, transapical AVI, Europe, $n = 575$	CoreValve ReValving device (^{18}F Expanded Registry) $N = 1243$ [8]
Procedural success	436 (95.6%)	523 (92.9%)	98%
Valve migration	0	3 (0.5%)	NA
Valve malposition	8 (1.7%)	8 (1.4%)	NA
Aortic regurgitation > grade 2	15 (3.2%)	34 (5.9%)	> grade 3: 0.8%
Coronary obstruction	3 (0.7%)	3 (0.5%)	NA
Conversion to surgery	8 (1.7%)	20 (3.5%)	NA
30-day follow-up:			
Death	29 (6.3%)	59 (10.3%)	6.7%
Stroke	11 (2.4%)	16 (2.6%)	1.7%
Renal failure requiring dialysis	23 (5%)	69 (11.7%)	NA
Permanent pacemaker required	31 (6.7%)	42 (7.3%)	12%
Vascular complications (access related)	83 (17.9%)	14 (2.4%)	NA
Vascular complications (non-access related)	5 (1.1%)	7 (1.2%)	NA

Update from the SOURCE registry. Proceedings of the 21st Annual Scientific Sessions in Transcatheter Cardiovascular Therapeutics, 21–25 September, 2009, San Francisco, California, and implantations of the CoreValve ReValving device with use of the ^{18}F delivery system [8]. NA, not available.

of cardiopulmonary bypass in the same location as cardiac catheterization [9]. If the two locations remain distinct, however, transport and relevant logistical problems will have to be negotiated to transfer the patient to the operating theatre. Meticulous planning is essential in order to facilitate this process.

The most common complication not requiring immediate intervention is the risk of stroke due to embolization of calcified plaques in the ascending aorta or aortic valve annulus. Early evaluation of neurological status is essential, requiring emergence from general anaesthesia as soon as possible.

Percutaneous mitral valve interventions

The percutaneous approach to mitral valve repair in mitral regurgitation or commissurotomy in mitral valve stenosis shares the same advantages as TAVI in relation to open heart operations in that sternotomy, implementation of extracorporeal circulation and cross-clamping of the aorta are avoided. While catheter-based commissurotomy results have become comparable with short- and long-term results of surgical commissurotomy for mitral stenosis [10], results of percutaneous interventions for mitral regurgitation have lagged behind. The complex multifactorial pathogenesis and anatomical variations in mitral regurgitation have led to the limited success of percutaneous interventions [11]. In edge-to-edge repair, a clip is placed between the free leaflets of the mitral valve, creating a double-orifice mitral valve in a bow-tie configuration, comparable to an Alfieri stitch [12]. The clip is introduced via the femoral vein to the right atrium and via a septal puncture to its position between the anterior and posterior mitral valve leaflet margins. General anaesthesia is required for these procedures to facilitate the use of transoesophageal echocardiography in guiding positioning of the valve clip.

Acute and life-threatening complications of these procedures can include embolization of the mitral valve clip and cardiac tamponade.

Coronary angiography and percutaneous coronary intervention in patients in cardiogenic shock

The vast majority of percutaneous coronary diagnostic and intervention procedures occur without the presence of an anaesthesia team. However, performing the procedure in patients in cardiogenic shock following an ischaemic event often requires endotracheal intubation, not only to secure the airway but also to ensure optimal oxygenation and ventilation. Positive pressure ventilation may also aid a failing LV by reducing LV afterload. Anaesthesia is also required in patients who have suffered an out-of-hospital cardiac arrest, for the institution and maintenance of systemic hypothermia for cerebral protection [13].

In cases of cardiogenic shock secondary to ischaemia it may be appropriate to discuss the implantation of an intra-aortic counterpulsation device to optimize coronary perfusion and to decrease the afterload of the failing LV [14]. In cardiogenic shock refractory to inotropic therapy, percutaneous implantation of ventricular assist devices such as the Impella, Tandem Heart or, most recently, the PulseCath device may be considered.

The role of anaesthesia teams in the care of patients in cardiogenic shock differs from the other interventions in the CCL owing to the acute nature of the situation. This can lead to less than optimal conditions for effective and safe patient care and teamwork. It is therefore vital that in centres offering an acute coronary interventional service that anaesthetic equipment and drugs are stored in close proximity to the CCL and are able to be quickly installed and utilized.

Percutaneous diagnostic and intervention techniques in adult patients with congenital heart disease (GUCH)

The population of adult patients with congenital heart disease is steadily growing owing to advances in the diagnosis and treatment of a number of congenital heart abnormalities [15•]. A proportion of this population requires ongoing interventions to treat or palliate either the chronic side effects of previous surgical treatment or the chronic effects of the congenital heart abnormality itself. Catheterization may be necessary for diagnostic purposes in a presurgical work-up or for interventional procedures. General anaesthesia is often required for the prolonged, complex interventions or for patients who have associated learning difficulties as a part of a syndrome associated with the congenital heart abnormality.

Challenges to the anaesthesiologist include gaining a full understanding of an often complex and possibly previously manipulated circulation. Patients presenting for the catheterization owing to a worsening in their condition are often in a less than optimal haemodynamic state. Effects of general anaesthesia and mechanical ventilation on preload, pulmonary vascular resistance and systemic vascular resistance and consequences for the haemodynamic state must be carefully considered. Uncooperative patients present a separate challenge as a gradual induction may not be feasible and preprocedure sedation with the associated side effects on oxygenation and ventilation may be contraindicated. Most commonly, a balanced anaesthesia technique is used in these patients. Importantly, in patients with previous right heart exclusion procedures (Fontan circulation) the avoidance of pulmonary hypertension is vital.

Percutaneous diagnostic and intervention techniques in the paediatric population

Owing to the nature of the paediatric population, heart catheterization almost always requires the presence of anaesthesia teams. Preanaesthesia screening of the patient must involve a detailed analysis of the (suspected) abnormality and consideration must be given to the possible effect of anaesthetic drugs on systemic and pulmonary vascular resistance and the consequences this may have on shunts, preload, systemic flow and pulmonary flow. During the catheterization, attention must be paid to the effects that the maintenance of anaesthesia, mechanical ventilation and inspired oxygen concentrations have on the measurement of flow, pressures and shunts. A detailed review of catheterization, interventional cardiology and ablation techniques for children has recently been published [16••].

Specific complications of catheterization in the paediatric population include insidious blood loss via the introducer sheaths, which is poorly tolerated in patients with small circulating volumes. More acute blood loss may occur in the case of damage to or perforation of major vessels, necessitating rapid infusion of blood products.

General cardiac catheterization-specific complications

A number of complications are inherent to the process of catheterization itself. In all patients radiocontrast agents are used to enable visualization of the relevant anatomy. Contrast agents have the potential to induce anaphylactoid or anaphylactic reactions upon intravascular injection [17], ranging from nausea and vomiting with localized urticaria to anaphylactic shock. The risk of severe complications is 0.03%. The most significant risk factor for the development of an adverse reaction to a contrast agent is a previous adverse reaction, and it is recommended to premedicate these patients with corticosteroids and antihistamine agents. Treatment of any adverse reaction depends on severity and includes ABC stabilization with potential use of oxygen, bronchodilators, intramuscular or intravenous epinephrine and eventual aggressive intravenous fluid therapy [18].

Complications may also arise in the CCL as a result of the positioning of the patient. In order to obtain an undisturbed lateral view of the thorax the patient's arms must be positioned above the head. This may lead to brachial plexus injury due to excessive stretch. Care must be taken to position and secure the arms in a manner in which such stretch is avoided.

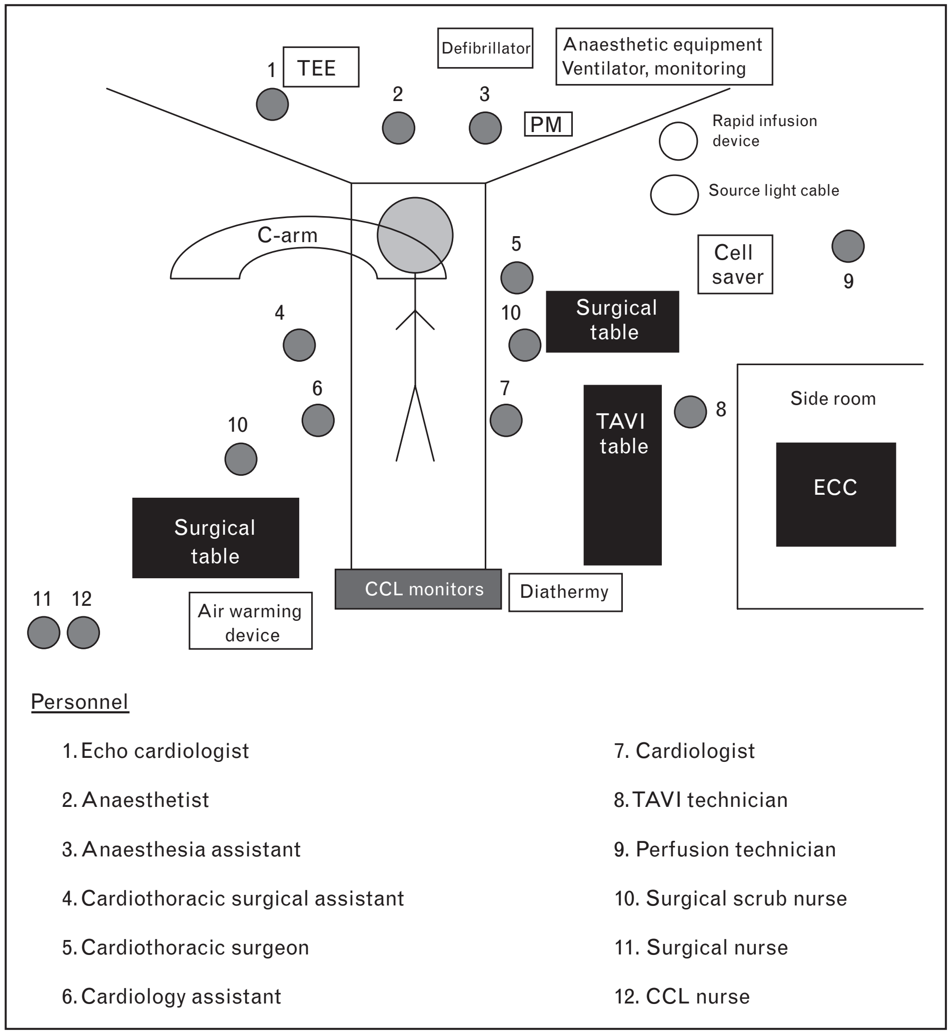
Temperature management of the patient is also an important issue in the CCL, with hypothermia being a poorly tolerated complication in patients with compromised cardiac function due to shivering and subsequent demands on oxygen consumption. Heated mattresses and warm air blankets may be of great value, especially in the paediatric population.

Limitations of the cardiac catheterization laboratory to anaesthesia

Highlighting certain limitations and differences that the CCL may have in comparison with a standard operating room with respect to certain anaesthetic considerations is important [19,20]. Access to the airway of the patient may be extremely limited by the presence of the large C-arm of the fluoroscopy equipment. While this can often be pushed to the side during induction, access to the airway may be extremely limited during the procedure and may also necessitate extended ventilation tubing. Care must be taken to ensure that manipulation of the C-arm does not dislocate the ventilation tubing or airway device.

Central venous access may be difficult to obtain as the CCL table can often not be placed in the Trendelenburg

Figure 1 Plan showing the positioning of medical personnel and equipment during a transapical TAVI procedure



CCL, cardiac catheterization laboratory; ECC, extracorporeal circulation; PM, pacemaker; Surgical table, sterile surgical table; TAVI table, sterile table with specialized equipment facilitating TAVI procedure; TAVI, transcatheter aortic valve implantation; TEE, transoesophageal echo.

position. Access may be facilitated by the use of ultrasound. Connections to pressure lines and intravenous pumps may also have to be extended to allow for the lack of space in the vicinity of the patient due to the C-arm.

Potential lack of space around the patient also limits the work environment of the anaesthetic team. During procedures requiring a multidisciplinary approach, such as TAVI, a clear plan must be made in which teams should be positioned (Fig. 1) and in which equipment may be installed. Such issues are greatly improved by the development of hybrid operating rooms which cater for the increased amount of staff present and equipment necessary during such procedures.

Conclusion

Anaesthesia in the CCL remains challenging owing to the nature of the environment, the diverse patient population and the ever evolving interventions which may be carried out. The often complex nature of the patient and the intervention demand meticulous planning on behalf of the anaesthesiologist to ensure a reasonable plan for the anaesthesia, monitoring, venous access, additional equipment required and potential complications of the procedure. In the majority of cases, the formulation of a plan by all medical teams involved detailing the planned intervention and potential emergency actions in the event of complications may greatly improve communication and teamwork during the procedure itself.

Acknowledgement

The authors have no conflicts of interest.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:
- • of special interest
- •• of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 537–538).

1 Rodés-Cabau J, Dumont E, De LaRochellière R, *et al.* Feasibility and initial results of percutaneous aortic valve implantation including selection of the transfemoral or transapical approach in patients with severe aortic stenosis. Am J Cardiol 2008; 102:1240–1246.

2 Tamburino C, Capodanno D, Mulè M, *et al.* Procedural success and 30-day clinical outcomes after percutaneous aortic valve replacement using current third-generation self-expanding core valve prosthesis. J Invasive Cardiol 2009; 21:93–98.

3 Vahanian A, Alfieri OR, Al-Attar N, *et al.* Transcatheter valve implantation for patients with aortic stenosis: a position statement from the European Association of Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI). Eur J Cardiothorac Surg 2008; 34:1–8.

4 Billings FT, Kodali SK, Shanewise JS. Transcatheter aortic valve implantation:
•• anesthetic considerations. Anesth Analg 2009; 108:1453–1462.
Excellent recent review detailing the TAVI procedure, anaesthetic considerations and the role of TEE.

5 Covello RD, Maj G, Landoni G, *et al.* Anesthetic management of percutaneous
•• aortic valve implantation: focus on challenges encountered and proposed solutions. J Cardiothorac Vasc Anesth 2009; 23:280–285.
Good overview of the TAVI procedure with insight into the authors' clinical experiences.

6 Marik PE, Cavallazzi R, Vasu T, Hirani A. Dynamic changes in arterial waveform variables and fluid responsiveness in mechanically ventilated patients: a systemic review of the literature. Crit Care Med 2009; 37:2642–2647.

7 Zajarias A, Cribier AG. Outcomes and safety of percutaneous aortic valve
•• replacement. J Am Coll Cardiol 2009; 53:1829–1836.
Nice oversight of the complications of specific TAVI approaches and devices used.

8 Laborde JC. Transcatheter aortic valve implantation with the CoreValve ReValving Device. Paper presented at: Transcatheter Cardiovascular Therapeutics; October 12, 2008; Washington, DC.

9 Nollert G, Wich S. Planning a cardiovascular hybrid operating room: the technical point of view. Heart Surg Forum 2009; 12:E125–E130.

10 Rifaie O, Abdel-Dayem MK, Ramzy A, *et al.* Percutaneous mitral valvotomy versus closed surgical commissurotomy. Up to 15 years of follow-up of a prospective randomized study. J Cardiol 2009; 53:28–34.

11 Mack MJ. Percutaneous treatment of mitral regurgitation: so near, yet so far! J Thorac Cardiovasc Surg 2008; 135:237–239.

12 Brinkman WT, Mack MJ. Transcatheter valve interventions. Surg Clin North Am 2009; 89:951–966.

13 Arrich J, Holzer M, Herkner H, *et al.* Hypothermia for neuroprotection in adults after cardiopulmonary resuscitation. Cochrane Database Syst Rev 2009; 7:CD004128.

14 Sjauw KD, Engström AE, Vis MM, *et al.* A systemic review and meta-analysis of intra-aortic balloon pump therapy in ST-elevation myocardial infarction: should we change the guidelines? Eur Heart J 2009; 30:459–468.

15 Cannesson M, Collange V, Lehot JJ. Anesthesia in adult patients with
• congenital heart disease. Curr Opin Anaesthesiol 2009; 22:88–94.
Good overview of the long-term sequelae of congenital heart disease and the consequence for anaesthesia.

16 Hollinger I, Mittnacht A. Cardiac catheterization laboratory: catheterization,
•• interventional cardiology, and ablation techniques for children. Int Anesthesiol Clin 2009; 47:63–99.
Excellent, detailed overview of catheterization techniques, complications and relevant anaesthetic considerations in the paediatric population.

17 Nayak KR, White AA, Cavendish JJ, *et al.* Anaphylactoid reactions to radiocontrast agents: prevention and treatment in the cardiac catheterization laboratory. J Invasive Cardiol 2009; 21:548–551.

18 Riou B. Anaphylaxis and anesthesia. Anesthesiology 2009; 111:1141–1150.

19 Metzner J, Posner KL, Domino KB. The risk and safety of anesthesia at remote locations: the US closed claims analysis. Curr Opin Anaesthesiol 2009; 22:502–508.

20 Haas S, Richter HP, Kubitz JC. Anesthesia during cardiologic procedures. Curr Opin Anaesthesiol 2009; 22:519–523.