REVIEW

Anaesthesia for minimally invasive cardiac procedures in the catheterization lab

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Purpose of review
The share of cardiac procedures performed in settings involving nonoperating room anaesthesia (NORA) continues to grow rapidly, and the number of publications related to anaesthetic technique in cardiac catheterization laboratories is substantial. We aim to summarize the most recent evidence about outcomes related to type of anaesthetic in minimally invasive cardiac procedures.

Recent findings
The latest studies, primarily focused on transcatheter aortic valve replacement (TAVR) and transcatheter mitral valve repair (TMVr), demonstrate the need for reliable monitoring and appropriate training of the interdisciplinary teams involved in this high-risk NORA setting.

Summary
Inappropriate sedation and concurrent inadequate oxygenation are main risk factors for claims involving NORA care. Current evidence deriving from TAVR shows that procedural sedation is associated with shorter length of stay and lower mortality.

Keywords
cardiac catheterization, minimally invasive cardiac procedures, nonoperating room anaesthesia, procedural sedation, transcatheter aortic valve replacement, transcatheter mitral valve repair

INTRODUCTION

Driven by rapid and continuous development of new devices and procedures to serve patients at increased surgical risk, the share of procedures performed in nonoperating room anaesthesia (NORA) settings continues to grow steadily. One of the most frequent settings is the cardiac catheterization laboratory. The number of publications reporting on anaesthetic techniques for minimally invasive cardiac procedures is staggering. A recent analysis of more than 12 million cases from the United States National Anaesthesia Clinical Outcome Registry (NACOR), comparing NORA procedures with procedures performed in operating rooms, confirmed that the majority of patients receiving NORA are older than 50 [1]. Previous studies also reported that patients in this setting tend to be older and have more comorbidities [2]. Although early studies suggested similar morbidity and mortality rates for operating room and NORA settings, current data show significantly lower morbidity and mortality in NORA settings (0.02 versus 0.04% for operating room procedures) [1].

Amongst all NORA procedures, cardiology procedures appear to have the highest risk of complications, which result in haemodynamic instability and an increased risk of death (0.05%) [1]. Frequent need for anticoagulation, reduced preload or afterload, decreased coronary perfusion pressure, guidewire-induced arrhythmias, pericardial effusion and pulmonary oedema are among the scenarios to be recognized and treated immediately [3]. The paediatric population and adults with congenital heart disease (ACHD) bring additional complexity to the organizational setting and the cardiopulmonary physiology to be managed in catheterization labs.

The SARS-COVID-19 pandemic certainly added another layer of complexity to the increased need

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KEY POINTS

- The cardiac catheterization laboratory is one of the riskiest settings for minimally invasive cardiac procedures.
- The risk is exacerbated further in adult and paediatric congenital heart disease patients.
- Improved techniques and an experienced cardiologist allow for minimal or medium sedation levels, assuming that appropriate resources for escalation of anaesthesia care are readily available.
- Reliable monitoring and appropriate training of the interdisciplinary teams involved is crucial.

for minimally invasive cardiac procedures in the catheterization lab, as well as other innovative approaches in this patient cohort and setting, such as preinterventional assessment with telemedicine [4▪,5].

With this review, we aim at providing a concise summary of the latest evidence concerning outcomes related to anaesthetic management of minimally invasive cardiac procedures in this high-risk setting, and their impact on postoperative outcomes. We will focus on general considerations, transcatheter aortic valve replacement (TAVR), transcatheter mitral valve repair (TMVr) and issues specific to the paediatric population, concluding with organizational issues.

GENERAL CONSIDERATIONS

Within a very short period, closed claims related to NORA cases increased dramatically [2], confirming the need for vigilant teams, reliable monitoring and appropriate training in this setting [6–8]. Analysing data from the American Society of Anesthesiologists Closed Claims Database, Metzner *et al.* [2] identified inappropriately deep sedation and concurrent inadequate oxygenation as main risk factors for claims related to NORA care. In addition to the older age of patients and the complexity of their diseases, NORA environments are frequently more remote, and they have a relative lack of qualified staff compared with operating room settings [1]. Physical distance from the operating room environment can be a challenge during management of emergencies when valuable time may be lost waiting for back-up personnel and equipment. Being prepared and ensuring that monitoring and materials are state of the art is thus important [1].

Although radial arterial blood pressure measurement is most often used for TAVR procedures, Cook *et al.* [9] evaluated the feasibility of transducing blood pressure from the side-port of the femoral artery sheath. This approach was used only in patients receiving sedation, and did not affect 30-day mortality or length of hospital stay [9].

A Cochrane analysis studying the efficacy of midazolam for anxiolysis during diagnostic or therapeutic procedures revealed relatively low-quality evidence in support of the drug [10]. A recent single-centre study evaluating diagnostic cardiac catheterization showed that the judgement of experienced cardiologists enables well tolerated operator-directed sedation, which is a widely established practice in selected patients undergoing invasive cardiac diagnostic procedures [11]. Another trial in patients undergoing coronary interventions demonstrated that a combination of benzodiazepines and opioids can increase patient compliance, reduce pain and decrease the incidence of radial artery spasm [12], as supported by a scientific statement from the American Heart Association [13]. It is important to note that the authors warned about the availability of 'appropriate staffing and monitoring', as well as 'individualized [clinical decision making] based on patient factors' when combining benzodiazepines and opioids [12]. In more complex cases managed by trained anaesthesia personnel, propofol and short-acting analgesics appear to be appropriate. Studying patients undergoing moderate sedation for transoesophageal echocardiography (TOE), Sruthi *et al.* [14] found a combination of propofol and ketamine to be preferable to dexmedetomidine for sedation, given the faster onset, more stable haemodynamics and fewer postprocedural complications of the combination. Although this study was performed for a specific procedure, the results may apply to similar procedures in the cardiac catheterization lab.

There is an increasing trend towards a minimalistic approach to procedures in the catheterization lab. TAVR will be discussed separately, but several studies have recently demonstrated the efficacy of procedural sedation for procedures historically performed under general anaesthesia, such as percutaneous closure of the left atrial appendage (LAA). Chan *et al.* [15] described the feasibility of procedural sedation using fentanyl and midazolam in 11 patients undergoing TOE-guided LAA closure. Further studies have shown good device placement, no increase in peri-procedural complications, a relatively low rate of conversion to general anaesthesia (0–2.6%) and shorter postprocedural monitoring requirements, including same-day discharge [16,17,18▪]. A combination of local anaesthesia, both at the puncture site and topical oral anaesthesia for the TOE probe, in combination with

midazolam, fentanyl and a propofol infusion, was utilized. The authors acknowledged the need for trained providers to administer sedation and that 'the team has to be prepared for speedy conversion to general anaesthesia if necessary [16]'.

It is also important to note that analgo-sedation can redistribute blood volume towards the body's periphery, thereby lowering core temperature. While involving some additional costs [19], forced air warming during cardiac catheterization is advisable, at least prior to and after the procedure (paused during the intervention given the potential interference with electrocardiogram monitoring) [20].

Finally, a randomized controlled trial of sedation utilizing high-flow nasal oxygen at 50 l/min and a 50 : 50 oxygen-to-air ratio compared with the standard 8 l/min via facemask during implantation of cardiac electronic devices, showed no superiority for high-flow nasal oxygen delivery [21]. Although assessed in a specific cohort, this finding most likely applies to other minimally invasive cardiac procedures in the catheterization lab.

TRANSCATHETER AORTIC VALVE REPLACEMENT

Initially, management of TAVR included general anaesthesia, TOE and multiple invasive monitors, followed by a multiple-day hospital stay. Now, however, more and more centres are switching to monitored anaesthesia care with light to moderate sedation. Hyman *et al.* [22] showed in 2017 that procedural sedation for TAVR is associated with a shorter hospital stay and lower risk of in-hospital and 30-day mortality in comparison to general anaesthesia. An analysis of more than 120 000 patients from the transcatheter valve therapy (TVT) Registry who received TAVR in the period 2016–2019 revealed an increase from 33 to 64% of cases performed under procedural sedation [23]. Procedural sedation thereby was associated with a significantly shorter stay in hospital and lower risk of in-hospital and 30-day mortality in comparison to general anaesthesia [23]. Other studies show similarly beneficial results [24▪]. Another study from 2021 confirmed the shorter hospital stay for that pathway but did not show a difference for in-hospital or 30-day mortality rate [25▪▪]. Data from the Swiss TAVR registry also show a favourable outcome after procedural sedation and local anaesthesia compared with general anaesthesia, as well as an increase in mortality when patients must undergo general anaesthesia [26].

In late 2020, a group from Cleveland showed that omitting TOE during TAVR is efficient and does not compromise safety or outcome [27▪].

Several recently published studies demonstrate additional advantages of using procedural sedation versus general anaesthesia. In a retrospective, single-centre study, Maier *et al.* [28] showed a reduced risk of postoperative delirium in patients who received sedation, thus reducing a source of significant potential morbidity and mortality. Mukhdad *et al.* [29] investigated the incidence of postoperative dysphagia after isolated TF-TAVR and found that use of general anaesthesia with endotracheal intubation had a significantly higher risk than procedural sedation (7 versus 0%, $P = 0.04$). As the minimalist approach spares the use of an endotracheal tube and TOE, both of which can cause dysphagia, these results are not surprising.

The Vancouver 3M (Multidisciplinary, Multimodality, but Minimalist) clinical pathway published in 2019 was developed with the goal of next-day discharge home after TAVR [30▪▪]. The minimalistic peri-procedural approach includes TAVR in a dedicated catheterization lab or hybrid operating room, local anaesthesia with no or minimal sedation, transthoracic echocardiography (TTE), percutaneous vascular access and closure, radial artery blood pressure monitoring and temporary pacemakers, but no pulmonary arterial or urinary catheter [30▪▪]. Four-hour postprocedural bed rest is followed by nurse-led mobilization to baseline and early return to baseline hydration and nutrition [30▪▪]. With their prospective study including some 1400 patients in various centres, the authors concluded that the 3M approach is feasible and well tolerated for a centre of any size [30▪▪].

Additional measures – such as ultrasound guidance [31] for vascular access, fascia iliaca blocks for transfemoral TAVR [32] or cervical plexus blocks for transcarotid TAVR [33] – have been shown to be feasible and well tolerated.

Studies to date have compared these regional anaesthesia-supplemented procedural sedation techniques with general anaesthesia; the benefit compared to standard local anaesthesia by the cardiologist remains to be assessed. In addition, Sanders *et al.* [34] demonstrated that procedural sedation is possible for the transcaval approach to TAVR, and recommended its use over general anaesthesia. Various sedation regimens have also been investigated, with both propofol and dexmedetomidine administration revealing no difference in major complications, in-hospital mortality, vasopressor requirements or cost [35].

Although some small single-centre studies claim that minimally invasive percutaneous cardiac procedures in the catheterization lab are feasible without trained anaesthesia providers [36], both the patient cohort and the setting are among the

environments at highest risk during NORA [1]. Mayr *et al.* [37] showed that vasopressor support was needed in almost 50% of patients during TAVR, and critical adverse events occurred in almost 10%, even in highly specialized high-volume centres. In addition, a recent propensity-matched cohort study in hospitals participating in the American College of Surgeons National Surgical Quality Improvement Program, and comparing patients undergoing TAVR with patients receiving a surgical aortic valve, showed a significantly lower blood transfusion rate in TAVR [38].

Involving anaesthesia specialists in the care team is prudent – not only for patient safety, but also for patient comfort and efficacy of care – and is reflected in the current guidelines [39].

TRANSCATHETER MITRAL VALVE REPAIR

Transcatheter mitral valve repair recently emerged as an alternative to surgical mitral valve repair in inoperable patients with primary mitral regurgitation [40]. Available evidence on TMVr for the treatment of secondary mitral regurgitation is controversial [41,42]. Although the Multicentre Study of Percutaneous Mitral Valve Repair MitraClip Device in Patients With Severe Secondary Mitral Regurgitation (MITRA-FR) trial showed comparable rates of death and heart failure hospitalizations at 1 year in patients with TMVr or medical treatment [41], TMVr resulted in lower rates of death and heart failure hospitalizations compared with optimal medical treatment at 2 years in the Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients with Functional Mitral Regurgitation (COAPT) [42].

Compared with TAVR, TMVr requires periprocedural guidance by TOE, performed more and more often by a highly specialized structural imager/interventional echocardiographer [43]. Although general anaesthesia is therefore traditionally the preferred approach, and current consensus suggests periprocedural management by cardiac anaesthesiologists [44], recent data indicate the feasibility of procedural sedation in selected patients [45], enabling same-day discharge without major complications [46]. Future studies will have to confirm this approach.

PAEDIATRIC PATIENTS

The care of both adult and paediatric patients with CHD presents a further challenge. Finnerty and Griffin [47▪] recently published a review outlining the anaesthetic considerations in adult congenital heart disease (ACHD) for a range of procedures in the catheterization lab. They noted the increased complexity and frequency with which treatments occur. The anaesthesiologist must have an understanding of the procedures and their possible complications; for example, should be aware that deployment of a percutaneous pulmonary valve can compress the left main coronary artery, that endovascular treatments can be difficult due to altered anatomy, and that leadless pacemakers do not respond to magnet placement and, if necessary, require preprocedure reprogramming [47▪].

Several genetic syndromes are associated with both orofacial and cardiac anomalies, and the treating anaesthesiologist must bear in mind the increased risk of difficult airways and act accordingly. A consensus statement on anaesthesia and sedation practice for the paediatric congenital cardiac catheterization laboratory, published in 2016, reiterates this risk [48]. Particular care and expertise are required when caring for the paediatric CHD patient, as these children are among the NORA patients at highest risk of dying (mortality 0.08%) [49]. The CRISP score can be used to determine the risk of a serious adverse event [50,51]. Adequate expertise and experience in the treating anaesthesia team, as well as interdisciplinary teamwork and good periprocedural planning, are mandatory.

ORGANIZATIONAL ISSUES

Patient and procedure-related complications can result extremely quickly in deleterious outcomes if they are not managed with the utmost care. Catheter-based cardiac procedures in the catheterization lab require involvement of highly trained staff and well established teams [6,31,52]. Such training includes familiarity with technical aspects of the procedures and devices and extensive experience in cardiac anaesthesiology in case of a need for surgical conversion and haemodynamic management. Good interpersonal skills are also of high importance to assure interaction across medical specialties [53–56,57▪▪].

Older and medically complex patients undergoing catheter-based cardiac procedures in the catheterization laboratory add another layer of difficulty for the treating teams [58]. Evidence from the operating room setting shows that the allocation of the right anaesthesiologist affects team performance; this principle potentially applies to the NORA setting as well [59]. Apart from technical expertise, staff providing anaesthesia in decentralized high-risk settings must be selected and trained appropriately [52,60].

CONCLUSION

Current evidence deriving from TAVR shows that procedural sedation is associated with a shorter length

of stay, and possibly lowers mortality. Teams responsible for minimally invasive cardiac procedures in the catheterization laboratory must be highly trained in both technical and interpersonal issues. Although rapid developments in minimally invasive techniques allow for lighter sedation, patient- and procedure-related complications are potentially deleterious. Given the significant increase in closed claims in the cardiac NORA setting, we advocate for going beyond the current standard of care to include state-of-the art equipment and monitoring, and highly trained staff to handle minimally invasive cardiac procedures in the catheterization lab.

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