Recent advances in cardiac anaesthesia

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ABSTRACT

The speciality of cardiac anaesthesia has rapidly evolved over the past few decades with advances in technology, including artificial intelligence (AI), newer devices, techniques, imaging, pain relief and a better understanding of the pathophysiology of disease states. Incorporation of the same has led to improved patient outcomes in terms of morbidity and mortality benefits. With the advent of minimally invasive surgical methods, minimising the dose of opioids and ultrasound-guided regional anaesthesia for pain relief, enhanced recovery after cardiac surgery has been made possible. Perioperative imaging including 3D transoesophageal echocardiography, newer devices and drugs and AI algorithms will play a significant role in cardiac anaesthesia. This review briefly addresses some of the recent advances that the authors believe can impact the practice of cardiac anaesthesia.

Key words: Anaesthesiology, artificial intelligence, recent advances

INTRODUCTION

Advances in the practice of cardiac anaesthesia have led to the identification of gaps in knowledge requiring a focus on perioperative care including longer-term outcomes. Adopting the use of various types of data, novel analytical techniques and innovative approaches to the conduct of research will ultimately benefit patients. With the advent of minimally invasive cardiac surgery (MICS), minimising the dose of opioids and ultrasound-guided regional anaesthesia for pain relief have made enhanced recovery after cardiac surgery (ERACS) possible. Perioperative imaging including 3D transoesophageal echocardiography (TEE), newer devices and medications, big data analytics and machine learning generated algorithms will be essential for safe cardiac anaesthesia. A few, like MICS with problems of lung isolation, and leadless pacemakers have anaesthetic implications, whereas others like artificial intelligence (AI)-enhanced software improve imaging which can result in the faster interpretation of findings for better perioperative management. Medical therapies such as dilators and diuretics have significantly contributed to the reduction in mortality and exacerbations of heart failure. Some of the aspects such as regional analgesia, emerging drugs and technologies, AI in cardiac anaesthesiology, advances in imaging and MICSs and anaesthesia that have had an impact on clinical practice are described in this review.

REGIONAL ANALGESIA

Pain following cardiothoracic surgeries is considered most severe and methods to relieve the same include regional techniques which can be divided into neuraxial and non-neuraxial including fascial plane

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nerve blocks excluding infiltrative methods[1] [Table 1]. The anterior divisions of the 2nd–6th intercostal nerves supply most of the anterior chest wall.

Paravertebral block

This block is used for thoracotomy, minimally invasive and robotic surgeries and for midline approach bilaterally. Single-shot multi or single-level block using a catheter can be performed. Ultrasound guidance increases success rates[2] [Figure 1].

Parasternal intercostal block

This block involves bilateral injections of local anaesthetic in the second to sixth intercostal spaces prior to the placement of sternal wires.[3] [Figure 2].

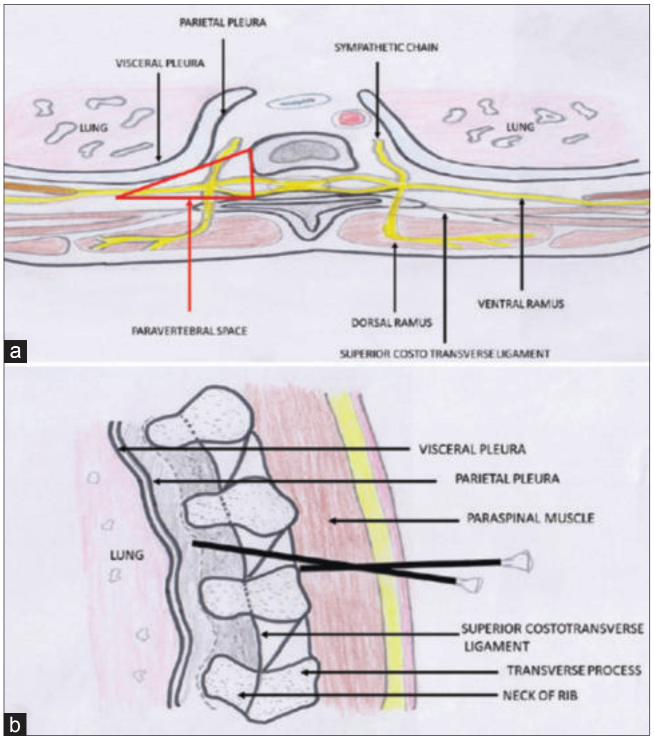

Figure 1: (a) Paravertebral space and its boundaries. (b) Sagittal section—needle walking over the transverse process after piercing superior costotransverse ligament. (Adapted from the primary author's previous publication[1])

Fascial plane blocks

These blocks comprised of pectoralis nerve block, serratus anterior plane block, pesto-intercostal fascial plane block and transverse thoracic muscle plane block [Figures 3-5]. The drawback is that bilateral blocks are needed for midline incisions.

With the implementation of ERACS protocols, the use of regional blocks has found extensive application by ultrasound-guided techniques.[4,5]

EMERGING DRUGS AND TECHNOLOGIES

Cardiothoracic anaesthesia and critical care are technology intensive disciplines that have made measurable improvements in patient care and safety over the last decade, more so with the advent of newer drugs and technologies that are pushing the envelope to better diagnose, investigate and treat cardiac disease. One of the foremost new technologies

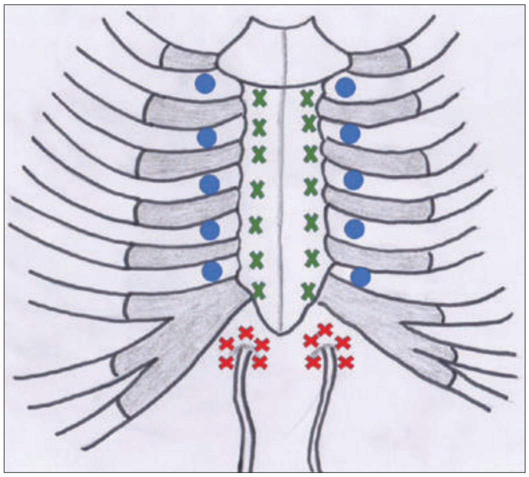

Figure 2: Points of injection. (Adapted from the primary author's previous publication[1])

Table 1: Various blocks used for cardiac surgery

Name of the block	Target nerve	Target plane	Area covered
Pectoral nerve block (PECS) 1 and 2 (modified PECS 1)	PECS 1-lateral and medial pectoral nerves PECS 2 -Intercostal nerves (T2-T-6) long thoracic nerve of bell, and thoracodorsal nerve.	Between pectoralis major and minor Between pectoralis minor and serratus anterior	Anterior chest wall Anterior and lateral part of chest and axilla
Erector spinae block (ESB)	Dorsal and ventral rami	Deep to erector spinae muscle at the level of T6 transverse process	Anterior and posterior chest wall, axilla and medial aspect of upper arm.
Pecto-intercostal-fascial plane block (PIFB)	Anterior cutaneous branches of intercostal nerve	Between pectoralis major and external intercostal muscle, on lateral side of sternal margin	Medial part of chest wall
Transverse thoracic muscle plane (TTP) block	Multiple anterior cutaneous branches of thoracic 2-6 segments	Between transverse thoracic muscle and intercostal muscle	Medial part of chest wall including internal mammary area

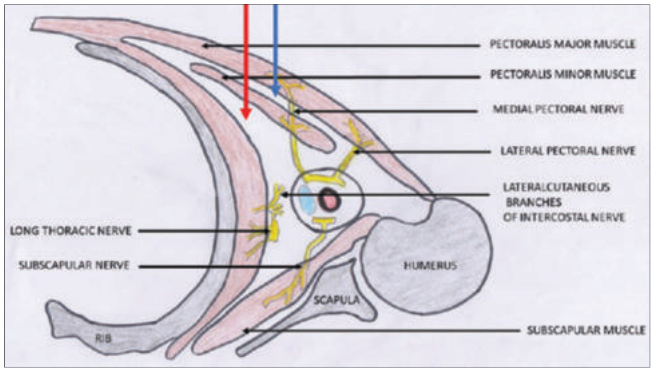

Figure 3: Showing plane for injection in Pecs 1 and Pecs 2 block. (Adapted from the primary author's previous publication[1])

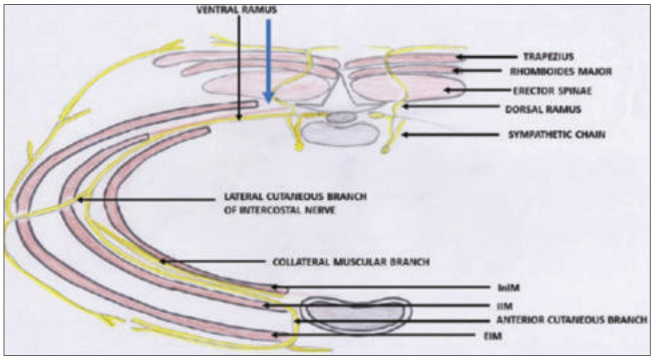

Figure 4: Blue arrow—plane for injection in erector spinae block. EIM = external intercostal muscle, IIM = internal intercostal muscle, InIM = innermost intercostal muscle. (Adapted from the primary author's previous publication[1])

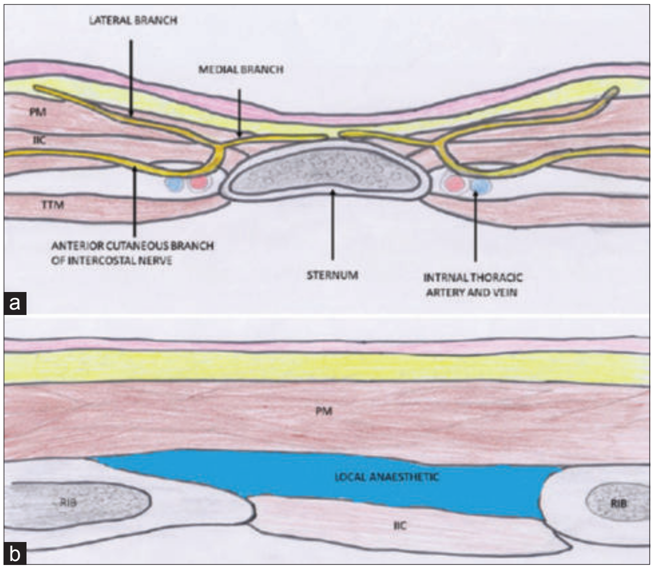

Figure 5: (a) Intercostal nerve anatomy in the parasternal region (b) Drug deposition for pecto-intercostal fascial block. PM = pectoralis major; IIC = internal intercostal muscle; TTM = transverse thoracic muscle. (Adapted from the primary author's previous publication[1]

on this front is the development of Aveir leadless pacemaker (LP).[6] Aveir LP was developed to prevent the complications of traditional transvenous pacing systems, namely cardiac perforation, tricuspid valve injuries, infective endocarditis, lead fractures, central venous thrombosis, etc. It is indicated in patients with symptomatic bradycardia and is currently available in VVI, VOO, OVO and pacing off mode (firmware upgrade needed for dual chamber pacing). Aveir LP senses right ventricular blood temperature for its rate-responsive mode and therefore perioperative hypo/hyperthermia as well as rewarming after hypothermic cardiopulmonary bypass may lead to pacing at rates higher than the programmed.[6] If the patient is pacing dependent, either a magnet is used or the Aveir LP is reprogrammed to VOO mode perioperatively. Continuous electromagnetic interference may lead to automatic entry into VOO mode with the possibility of R on T phenomenon. Monopolar electrocautery should be kept as far as possible and bipolar cautery should be used if needed. Aveir LP is magnetic resonance imaging conditional at 1.5 and 3T. Even though battery drain is the main drawback, emerging innovations like using the heartbeat's kinetic energy to pace the heart or wireless charging may soon find a solution to these problems.

Medical therapies such as dilators and diuretics have definitely reduced mortalities and exacerbations of heart failure. Empagliflozin is a novel sodium glucose cotransporter 2 (SGLT2) inhibitor which has been shown to decrease both mortality and hospitalisations in heart failure both in diabetics and non-diabetics.[7] In patients with obstructive hypertrophic cardiomyopathy with symptoms despite maximal therapy, mavacamten significantly decreased the number of patients meeting guideline criteria for septal reduction therapy after 16 weeks.[8] Progression of heart failure despite optimal drug therapies has led to the development of device-based therapies for the critically ill. A pioneer amongst these emerging technologies is the splanchnic nerve block in the treatment of acute heart failure which prevents the acute shift of blood from the splanchnic reservoir to the thoracic compartment, thus decreasing intracardiac filling pressure and increasing cardiac output.[9] The cardiac pulmonary nerve stimulator (Cardionomic, Inc) is an investigational catheter-based device designed to stimulate the cardiac autonomic nerves surrounding the right pulmonary artery electrically. The system has the potential to improve both inotropy and lusitropy, increase systemic perfusion and enhance decongestion in heart failure with preserved ejection fraction (EF) using a temporary percutaneous device.[10]

ARTIFICIAL INTELLIGENCE IN CARDIAC ANAESTHESIOLOGY

AI is the capability of computers or computer-controlled machines to imitate human behaviour. Most AI functions are based on two subfields: machine learning and deep learning. Machine learning is the process through which computers utilise algorithms to learn from data and perform tasks without explicit programming. Deep learning is a subset of machine learning, but there are a lot more layers of algorithms and multi-layered artificial neural networks to process data. Data derived from the AI is very useful for the cardiac anaesthesiologist for diagnostic augmentation, preoperative counselling, optimisation, event prediction (hypoxia and hypotension), resource allocation, developing an anaesthesia plan and personalised perioperative interventions.[11]

AI plays a major role particularly in the real-time analysis of imaging studies like echocardiography. Perioperative echocardiography including 3D imaging and TEE has now supplanted the once-gold standard "pulmonary artery catheters" for monitoring perioperative cardiac function. Automation of strain measurements, valvular assessment, EF, cardiac output assessment, chamber quantification, and other AI applications related to imaging could help anaesthesiologists obtain data more quickly, efficiently and precisely with a lower risk of human errors. AI-assisted diagnostic augmentation creates more time for anaesthesiologists to focus on the therapeutic strategies and diagnostic conundrums in perioperative emergencies.

Computer-assisted needle navigation vascular access, regional blocks, event (hypoxia or hypotension) prediction, and clinical decision support systems have a potential role in the management of complex cardiac surgeries.

Cardiac surgery is one of the high-risk factors for accidental awareness under general anaesthesia (AAGA). Limited cardiac reserve, emergency surgery, high-dose opioid technique and use of cardiopulmonary bypass (CPB) have been attributed to the increased incidence of AAGA. Balanced anaesthesia techniques and autonomous closed-loop systems using bispectral index (BIS)-guided hypnosis may reduce the incidence of AAGA. Goal-directed perfusion management techniques have been shown to improve organ preservation during CPB.[12] Recent studies have shown that perfusionists may benefit from AI-derived perfusion management algorithms that integrate with various metabolic parameters, including haemoglobin content, oxygen levels, haemodynamic variables, near-infrared spectroscopy and BIS values.[13]

Big data analytics and AI will be crucial in the future of cardiac surgery for prognostic communication, tailored treatment options and research. Numerous studies have demonstrated the superiority of AI mortality prediction models over more conventional methods like logistic regression analysis and anaesthesiologists' prediction.[14,15] Chang Junior *et al*.[16] evaluated the ability of various AI predictive models on the large data pools for predicting individual patient mortality after congenital heart surgery. They suggested the random forest model for predicting individual mortality after cardiac surgery. Wang *et al*.[17] developed a machine learning algorithm that can reliably predict the need for red blood cell transfusions during cardiac surgery. The predictive capabilities of these AI algorithms can assist anaesthesiologists in accurately assessing haemorrhagic risk and transfusion requirements for a planned cardiac intervention. Other significant uses of AI in cardiac surgery include reviewing team or individual performance, anticipating operating time, continuous cardiac output monitoring, analysis of heart rate variability, delaying sternal closure during congenital cardiac surgeries, predicting weaning from mechanical ventilation, delirium occurrence, etc.

There are several issues to consider before relying on AI for interpretation. AI interpretation related to rare clinical circumstances, like intraoperative awareness, is not reliable. In these scenarios, big data approaches could be leveraged to overcome issues of data scarcity.[18]

Even with a perfect AI algorithm, interpretation will be subpar if the input data is of poor quality. As there is a scope for errors, clinicians must always be vigilant to identify machine-made faults. Despite its drawbacks, AI applications must be widely incorporated into routine perioperative management to improve personalised patient care and outcomes.

ADVANCES IN IMAGING

Periprocedural imaging is a vital procedural adjunct and is integral to the success of surgery or intervention. The main role would be to assess procedural suitability, for procedural guidance, confirm success, and to exclude procedure-related complications. Echocardiography has evolved from M-mode imaging to two-dimensional (2DE) imaging, TEE and three-dimensional echocardiography (3DE).

Suboptimal image quality in 2DE occurs in approximately 20% of all patients and leads to misdiagnosis. Adaptive contrast enhancement software strengthens image pixels from real structures while suppressing noise or artefacts to produce high-contrast, high-resolution images.[19]

Despite being available for years, 3DE is only used in routine clinical settings for volumetric chamber analysis and 3D evaluation of valvular pathology. Automated endocardial border detection software drastically cuts the time needed for 3D quantitative analysis (148 seconds to 17 seconds, an 82% reduction in analysis time), and it also produces more accurate data with higher reproducibility.[19]

AI provides support to novice echocardiographers by helping them in the interpretation of images, automation of cardiac measurements and comparing their images with prestored data thereby guiding them to obtain high-quality cardiac images.[20] Acoustic radiation force impulse imaging, shear wave elasticity imaging and supersonic shear imaging are elastography techniques using cardiac ultrasound to measure myocardial stiffness which is an important component in the pathophysiology of diastolic dysfunction and in heart failure with preserved ejection fraction (HFpEF).[21]

Epicardial echocardiogram is used intraoperatively to assess residual surgical defects due to the non-availability of suitable probes for neonates and infants. A miniaturised microTEE probe (5.6 mm 32-element phased array transducer) is presently available for perioperative use for neonates.[22] Intracardiac echo (ICE) intravascular ultrasound transducer, an 8-Fr, 2.5-mm, 64-element crystal array is also available for use. The ICE probe must be advanced into the right atrium using an extra venous femoral approach (8 or 10 F), and cardiac images from inside the heart are imaged. Both microTEE in adults and ICE are usually done under local anaesthesia, thus avoiding intubation and the associated possible risk of oesophageal trauma. It also reduces the procedural timing and thereby the fluoroscopy exposure. The main disadvantage of ICE is the cost of the single-use catheter.[23] Intraoperative TEE offers the best solution for imaging, at least in the structural heart arena, and should be the standard of care to improve procedural success and outcomes. Just as sophisticated cardiac imaging that is available today would have been unthinkable a decade back, future advancements are anticipated to build on current capabilities to provide greater insight into the human heart.

MINIMALLY INVASIVE CARDIAC SURGERIES AND ANAESTHESIA

MICS is quickly gaining acceptance because of possible advantages and higher patient satisfaction. These pose lots of challenges and require meticulous planning, preoperative assessment and efficient intraoperative communication because they involve interdisciplinary teamwork. MICS are cardiac surgeries through several small thoracic or sternal incisions or through percutaneous approaches.[24]

Types of MICS

Cardiac surgery on beating heart

Transcatheter approaches: Transcatheter aortic valve insertion (TAVI), etc.

Minimally invasive direct coronary artery bypass (MIDCAB)

Cardiac surgery via Port access with video assistance and percutaneous CPB

Total endoscopic coronary artery bypass (TECAB)

Robotic-assisted cardiac surgery (RACS)

Minimally invasive thoracic approaches to mitral and aortic valves and atrium[24,25]

Anaesthetic approaches

The technique depends on the nature of the surgery, surgical approach, incision site and perfusion techniques with the aims like haemodynamic stability, organ protection, etc.

Preoperative care

Preoperative clinical evaluation, haematological and radiological investigations of the heart and vessels for any anatomical abnormalities and for vascular access are mandatory along with echocardiography. Prolonged lung isolation requires pulmonary function and blood gases in selected cases. Patients with resting arterial partial pressure of carbon dioxide (PaCO$_2$) >50 mm Hg and arterial partial pressure of oxygen (PaO$_2$) <65 mm Hg are unlikely to tolerate MICS. Risk factors like peripheral vascular disease, chronic obstructive pulmonary disease, irradiation of the chest, oesophageal disease and musculoskeletal abnormality, etc., should be identified. All patients need to be counselled for all perioperative events and the possibility of full sternotomy (2–15%).[26]

Intraoperative care

TEE is mandatory along with standard monitoring to confirm the diagnosis, in the placement of various cannula, de-airing and confirmation of repair. External defibrillator pads are essential as internal paddles cannot be used. The patient position has to be confirmed preoperatively, pressure points need to be adequately padded, and intravenous lines have to be secured depending on the surgical site and cannulation technique. It has to be kept in mind that meticulous planning and communication is necessary as access to the patient is limited due to MICS instrumentation.[25] If intrathoracic insufflation is planned for surgical access, pressures have to be limited to below 10 mm Hg to avoid decrease in venous return and cardiac output. End-tidal carbon dioxide, peak and plateau airway pressure monitoring is a must to avoid hypoxia, hypercarbia and barotrauma.[25]

Postoperative care

Care is similar to conventional cardiac surgery, with an emphasis on early recovery. A key component of ERACS is pain control. As part of multimodal analgesia, ultrasound-guided local anaesthesia has been found to decrease opioid usage, length of hospital stay and patient discomfort.[27]

Procedures in the catheterisation laboratory

Endovascular procedures like valve replacements (aortic, mitral, pulmonary, tricuspid), device placements for congenital heart problems, left atrial occlusion in case of clots, complex percutaneous interventions, devices for rhythm management (implantable cardioverter-defibrillators, permanent pacemaker implantations, etc.) and heart failure are done, and this area is expanding including hybrid labs with entire operation theatre setups for complex procedures. Anaesthesiologists' concerns while selecting an anaesthesia plan include remote location anaesthesia, radiation exposure, adequate sedation, immobilisation and faster recovery. Arrhythmias and hypotension are common and need to be tackled. MICS is a rapidly growing field having very promising outcomes and gives us an opportunity to acquire new skills.

SUMMARY

Rapid advances in interventional cardiology and poor outcomes associated with cardiac surgeries have reduced the number of open-heart surgeries performed. However, incorporating cutting-edge technological developments into surgical approaches and perioperative care, using AI in decision-making and conducting research to bridge knowledge gaps and compassionate attitudes will improve perioperative outcomes and restore the glory of this speciality.

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Conflicts of interest

There are no conflicts of interest.

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