ORIGINAL ARTICLE

Recent Advances in Cardiothoracic Anaesthesia: A Scoping Review of Innovations, Outcomes, and Future Directions

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ABSTRACT **Background**: Cardiothoracic anaesthesia has rapidly evolved owing to advances in monitoring, pharmacology, and perioperative care. Increasingly complex surgical techniques have positioned anaesthetists as key contributors to optimising outcomes, minimising complications, and supporting enhanced recovery. Despite these developments, the evidence base remains fragmented, emphasising the need for a comprehensive synthesis of recent progress.

Objectives: This scoping review summarises recent innovations in cardiothoracic anaesthesia, assesses their effects on perioperative and long-term outcomes, and highlights priorities for future research and practice.

Methods: The review followed Arksey and O'Malley's framework and PRISMA-ScR guidelines. Major databases (PubMed, Embase, Scopus, Web of Science, and Cochrane Library) were searched for articles published from 2010 to 2025. Eligible studies reported empirical research on innovations in monitoring, pharmacology, intraoperative techniques, or perioperative care in cardiothoracic anaesthesia. Data were thematically organised under innovations, outcomes, and future directions.

Results: Key innovations included advanced transesophageal echocardiography, near-infrared spectroscopy, AI-assisted monitoring, short-acting pharmacological agents, multimodal analgesia, and fast-track anaesthesia protocols. These advances were associated with improved patient outcomes, such as reduced morbidity, earlier extubation, shorter ICU stays, and enhanced recovery. Healthcare systems benefited from decreased costs and resource utilisation. Future directions focus on precision medicine, AI-driven decision support, tele-anaesthesia, and global implementation of scalable innovations.

Conclusion: Cardiothoracic anaesthesia is entering a transformative era characterised by precision, digital integration, and inclusivity. Although perioperative care and outcomes have improved, gaps remain in long-term evidence, paediatric populations, and global applicability.

Keywords: Cardiothoracic Anaesthesia, Perioperative Outcomes, Fast-track Anaesthesia, Artificial Intelligence, Precision Medicine.

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INTRODUCTION

Cardiothoracic anaesthesia has undergone remarkable evolution in recent decades, driven by advances in surgical techniques, perioperative monitoring, pharmacological innovations, and critical care integration.[1] As cardiac and thoracic procedures become increasingly complex, the role of anaesthetists has expanded beyond intraoperative care to encompass perioperative optimisation, risk stratification, and long-term outcome improvement.[2] The traditional emphasis on maintaining haemodynamic stability has now been complemented by innovations aimed at myocardial protection, neurological preservation, enhanced recovery, and reduced hospital stays. These changes reflect

broader global trends towards patient-centred care and value-based healthcare delivery.[3]

Despite the growing body of research, the literature on cardiothoracic anaesthesia remains fragmented, with studies often focused on narrow aspects such as drug efficacy, monitoring technologies, or single-centre experiences.[4] A comprehensive mapping of recent advances is therefore needed to identify not only what has been achieved but also the persisting gaps that limit translation into routine practice.[5] Scoping reviews are particularly suited for this purpose, as they allow for systematic exploration of heterogeneous evidence without the restrictions of meta-analysis.

This review aims to synthesise current knowledge on innovations in cardiothoracic anaesthesia, evaluate their impact on perioperative and long-term outcomes, and highlight emerging trends that are shaping the future of practice. Specifically, the review addresses three guiding questions: (1) What are the most significant recent innovations in cardiothoracic anaesthesia? (2) How have these innovations influenced patient outcomes and clinical practice? (3) What directions should future research and practice take to strengthen the field? By adopting this approach, the review seeks to provide clinicians, researchers, and policymakers with a structured understanding of the evolving landscape of cardiothoracic anaesthesia and its implications for patient care.

METHODOLOGY

This scoping review adopted the methodological framework proposed by Arksey and O'Malley and further refined by the Joanna Briggs Institute (JBI) for scoping reviews.[6] The review process was conducted in line with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines to ensure transparency and reproducibility.[7]

A systematic search was performed across major biomedical databases, including PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library. The search strategy combined key terms such as "cardiothoracic anaesthesia," "cardiac anaesthesia," "thoracic anaesthesia," "advances," "innovations," and "outcomes." Reference lists of included studies and relevant review articles were also hand-searched to capture additional literature. The search was limited to publications from the past 15 years (2010–2025) to reflect recent advances and emerging practices. Only peer-reviewed articles published in English were included.

Eligibility criteria were defined using the Population Concept Context (PCC) framework.[8] Eligible studies included patients undergoing cardiothoracic surgery (Population), innovations in anaesthetic practice, pharmacology, monitoring, or perioperative care (Concept), and any clinical or experimental setting globally (Context). Both quantitative and qualitative studies, as well as grey literature from professional bodies, were considered. Exclusion criteria were case reports, opinion pieces without empirical basis, and studies unrelated to anaesthetic practice.

Data charting involved the extraction of study characteristics (author, year, country, design, sample size), type of innovation, outcomes assessed, and key findings. To ensure rigour, two independent reviewers conducted screening and data extraction, with discrepancies resolved through consensus. Findings were synthesised thematically, allowing classification under three domains: innovations, outcomes, and future directions.

Innovations in Cardiothoracic Anaesthesia

Recent years have witnessed significant innovations in cardiothoracic anaesthesia, spanning monitoring technologies, pharmacological strategies, intraoperative techniques, and digital integration. These advances are redefining the standard of care by promoting precision, enhancing safety, and supporting faster recovery.[9]

One major area of innovation is perioperative monitoring. The introduction of advanced transesophageal echocardiography (TEE) has enabled real-time assessment of ventricular function, valvular pathology, and fluid responsiveness, thereby guiding individualised haemodynamic management.[10] Near-infrared spectroscopy (NIRS) now provides non-invasive monitoring of cerebral and somatic tissue oxygenation, reducing the risk of neurological injury. More recently, artificial intelligence (AI)–assisted platforms and machine learning algorithms are being integrated into anaesthetic monitoring to predict adverse events and support clinical decision-making.[11]

Pharmacological developments have also reshaped cardiothoracic anaesthesia. The adoption of short-acting agents such as remifentanil and dexmedetomidine has facilitated early extubation and reduced intensive care unit (ICU) stay.[12] Multimodal analgesia, incorporating regional techniques such as paravertebral and erector spinae plane blocks, is increasingly replacing opioid-heavy regimens, thereby improving recovery profiles and minimising opioid-related complications.[13] Cardioprotective drugs, including selective β-blockers and newer inotropes, are also being studied for enhanced myocardial preservation.[14]

Regional anaesthesia has re-emerged as an important component of multimodal analgesia in contemporary cardiothoracic anaesthesia, complementing general anaesthesia and supporting enhanced recovery protocols. Techniques including thoracic epidural anaesthesia (TEA), paravertebral block (PVB), erector spinae plane block (ESPB), pectoralis (PECS) blocks, and serratus anterior plane (SAP) blocks have demonstrated potential to improve perioperative outcomes. TEA and PVB are associated with superior analgesia, decreased opioid requirements, improved pulmonary function, and reduced stress response following cardiac surgery, particularly in off-pump and minimally invasive procedures. More recently, ultrasound-guided fascial

plane blocks such as ESPB and PECS have attracted interest due to their relative technical simplicity and lower risk of hemodynamic instability or epidural haematoma, which is advantageous for patients receiving perioperative anticoagulation or antiplatelet therapy.[15]

Intraoperative innovations include fast-track anaesthesia protocols that allow early tracheal extubation, even in high-risk cardiac procedures, without compromising safety.[16] Anaesthetic approaches tailored for minimally invasive cardiac and thoracic surgeries, such as video-assisted thoracoscopic surgery (VATS) and robotic-assisted cardiac interventions, demand specialised techniques for one-lung ventilation and precise haemodynamic control.[17]

Furthermore, the digitisation of perioperative care through electronic anaesthesia records and tele-anaesthesia platforms has improved documentation, continuity of care, and multidisciplinary collaboration.[18] Simulation-based training has also emerged as a critical innovation for skill acquisition in advanced cardiothoracic anaesthesia.[19] Collectively, these innovations signify a paradigm shift from a purely intraoperative focus to a holistic, patient-centred, and technologically supported model of care, laying the foundation for future precision anaesthesia for cardiothoracic surgery.

Outcomes of Recent Advances

The implementation of recent innovations in cardiothoracic anaesthesia has translated into meaningful improvements in perioperative and long-term outcomes for patients undergoing cardiac and thoracic procedures.[20] These outcomes can be broadly categorised into patient-centred benefits, perioperative safety enhancements, and healthcare system efficiencies.

From a patient perspective, innovations such as multimodal analgesia and enhanced recovery protocols have reduced postoperative pain, improved respiratory mechanics, and facilitated faster mobilisation.[21] Early extubation strategies, supported by the use of short-acting anaesthetic agents, have significantly shortened intensive care unit (ICU) and overall hospital stays, thereby improving patient satisfaction and quality of recovery.[22] Enhanced monitoring modalities, including advanced echocardiography and near-infrared spectroscopy, have been associated with reductions in postoperative neurological complications and improved myocardial preservation.[23]

In terms of perioperative safety, the integration of AI-driven predictive tools and goal-directed haemodynamic management has reduced the incidence of adverse events, including low cardiac output syndrome, acute kidney injury, and major arrhythmias.[24] Moreover, the use of regional anaesthetic techniques in thoracic surgery has been shown to decrease pulmonary complications, particularly in patients with underlying respiratory disease, by reducing the need for prolonged opioid administration and mechanical ventilation.[25]

Healthcare systems have also benefited from these advances. Fast-track anaesthesia protocols and minimally invasive surgical techniques supported by tailored anaesthetic approaches have reduced ICU bed utilisation, hospital length of stay, and readmission rates, thereby lowering overall costs of care.[26] These gains are especially important in places with limited resources, where better perioperative outcomes are key for fair access to care. While most evidence for these methods comes from high-income countries, enhanced recovery protocols are starting to be used in Nigeria. For instance, the Nigerian Chapter of the ERAS Society now promotes evidence-based perioperative care. An audit at Mary Immaculate Specialist Hospital (Benin) found that following ERAS-type protocols rose from about 48% to 87%, and the number of elective abdominal surgery patients discharged within 48 hours went from one-third to over 70%. This shows that even in resource-limited settings, structured perioperative care, including fast-track anaesthesia, can shorten hospital stays.[27] Paediatric cardiac anaesthesia at Obafemi Awolowo University Teaching Hospital also uses fast-track practices, and other small studies have found earlier ambulation, early feeding, and shorter hospital stays with these protocols.[28] However, there is still little published data on ICU bed use, readmission rates, or cost savings in Nigeria. So, while these approaches are promising, their adoption is still new, and more local research is needed to measure their impact on ICU use, hospital costs, and fair access to care.

Importantly, these outcomes extend beyond the immediate postoperative period. Studies increasingly highlight that innovations in anaesthetic management contribute to better long-term survival, reduced incidence of chronic pain, and improved functional capacity.[29] However, variations in outcomes across institutions underscore the need for standardisation and broader multi-centre validation of these practices.

Future Directions in Cardiothoracic Anaesthesia

The trajectory of cardiothoracic anaesthesia points towards an era of personalisation, digital integration, and global applicability. Future developments are likely to be shaped by precision medicine, artificial intelligence, and an increasing emphasis on equity of access across diverse healthcare systems.[30]

Personalised anaesthesia, guided by genomics and pharmacogenomics, is expected to refine drug selection, dosing, and risk stratification. Genetic profiling of enzymes involved in anaesthetic metabolism, for instance, could minimise variability in drug responses, optimise haemodynamic stability, and reduce adverse outcomes.[31] Integration of big data and predictive analytics into perioperative care will further enable real-time risk assessment and individualised decision-making, potentially transforming anaesthetists into "perioperative data scientists."[32]

Artificial intelligence and machine learning applications are projected to expand from predictive monitoring to

fully integrated clinical support systems. Future anaesthetic workstations may autonomously adjust ventilation, fluid therapy, and drug delivery based on continuous multimodal monitoring, enhancing precision while reducing cognitive workload on clinicians.[33] Advances in tele-anaesthesia and remote perioperative monitoring also hold promise, particularly for extending specialist expertise to underserved regions.[34]

Training and skill development will remain central to sustaining these innovations. Simulation-based learning, virtual reality platforms, and AI-enhanced decision-training modules will become essential tools for preparing anaesthetists to manage complex cardiothoracic cases.[35] Equally important will be cross-disciplinary collaboration with cardiologists, surgeons, engineers, and data scientists to foster innovation.

Globally, there is an urgent need to adapt these advances to low- and middle-income countries (LMICs). Simplified monitoring technologies, cost-effective pharmacological strategies, and scalable training models could bridge gaps in resource-constrained settings, ensuring that innovations benefit patients universally rather than being confined to high-income contexts.[36] Taken together, these future directions signal a paradigm shift towards precision, automation, and inclusivity in cardiothoracic anaesthesia, with the potential to redefine perioperative care for the next generation.

GAPS IN CURRENT LITERATURE

While recent advances in cardiothoracic anaesthesia have produced measurable benefits, several gaps in the literature limit their translation into universal practice. One of the most notable deficiencies is the scarcity of large-scale, multi-centre randomised controlled trials (RCTs) evaluating the comparative effectiveness of new pharmacological agents, monitoring technologies, and fast-track protocols.[37] Much of the available evidence remains confined to single-centre studies with heterogeneous methodologies, limiting external validity and generalisability.

Another critical gap lies in the underrepresentation of long-term outcomes. Most studies focus on perioperative morbidity and short-term mortality, with little attention to functional recovery, quality of life, neurocognitive function, and long-term survival. This omission is particularly relevant as cardiac and thoracic surgical populations are ageing, with many patients living for decades after surgery.[38] Understanding the extended impact of anaesthetic strategies on their overall health trajectory is essential.

Paediatric and congenital cardiothoracic anaesthesia also remains relatively underexplored. Innovations in monitoring and pharmacology have largely been validated in adult populations, leaving gaps in their applicability to neonates, infants, and children who have unique physiological challenges.[39] Similarly, thoracic anaesthesia literature is less developed than its cardiac counterpart, especially in the context of minimally invasive procedures and novel regional techniques.

From a global health perspective, disparities in access to advanced anaesthetic technologies and training further highlight gaps in applicability. The majority of published studies emerge from high-income countries, while data from low- and middle-income countries (LMICs) remain scarce.[40] This creates uncertainty about the feasibility and impact of implementing these innovations in resource-constrained settings.

Finally, the integration of artificial intelligence and big data analytics into cardiothoracic anaesthesia is still in its infancy. Although promising, evidence on its clinical utility, ethical considerations, and cost-effectiveness is insufficient. Addressing these gaps through collaborative, interdisciplinary, and globally inclusive research will be key to shaping the next phase of cardiothoracic anaesthesia practice.[41]

CONCLUSION

Cardiothoracic anaesthesia has evolved into a dynamic speciality characterised by technological innovation, refined pharmacological strategies, and enhanced perioperative care models. This scoping review has mapped recent advances across three domains: innovations, outcomes, and future directions, demonstrating how the field has progressed from a primarily intraoperative focus to a holistic, patient-centred, and precision-driven discipline.

The innovations identified, including advanced monitoring techniques, multimodal analgesia, fast-track anaesthesia, and digital integration, have collectively transformed perioperative management. These practices have been shown to improve short-term outcomes such as reduced morbidity, earlier extubation, shorter hospital stay, and greater patient satisfaction, while also signalling potential long-term benefits for survival and functional recovery. Furthermore, advances in minimally invasive and robotic-assisted surgery have reshaped anaesthetic approaches, requiring anaesthetists to adapt to increasingly complex surgical environments.

Looking ahead, the field is poised to embrace personalised anaesthesia informed by genomics, big data, and artificial intelligence. These tools promise to revolutionise risk stratification, drug selection, and perioperative decision-making. At the same time, simulation-based training, tele-anaesthesia, and collaborative research are expected to prepare the next generation of anaesthetists for the challenges of highly specialised cardiothoracic care. Importantly, global adaptation of these advances will be essential to ensure equity, especially for patients in low- and middle-income countries where resource constraints limit access to cutting-edge technologies.

Nevertheless, gaps persist in the evidence base, particularly regarding long-term outcomes, paediatric and thoracic subpopulations, and the generalisability of innovations beyond high-income contexts. Addressing these limitations through multi-centre trials, global collaborations, and inclusive research agendas will be critical. In conclusion, cardiothoracic anaesthesia stands

at the threshold of a transformative era. By integrating innovations with patient-centred outcomes and global applicability, the speciality is well-positioned to redefine standards of care and improve the lives of patients undergoing cardiac and thoracic surgery worldwide.

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