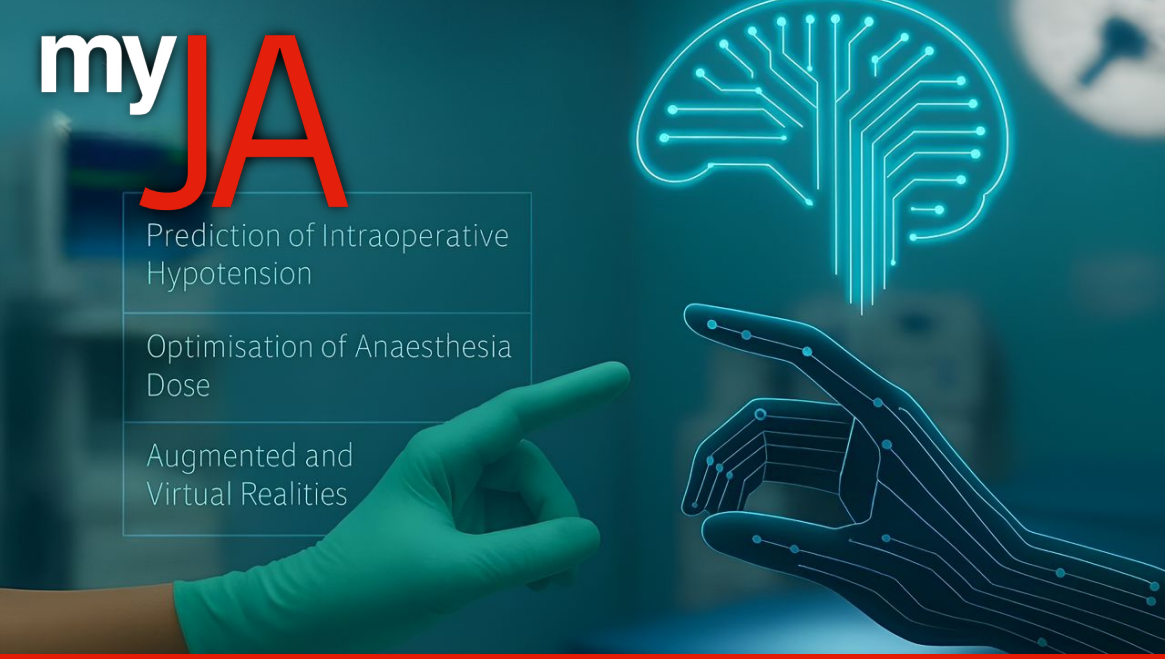

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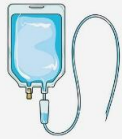

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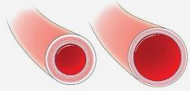

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Artificial intelligence in anaesthesiology, intensive care, and pain medicine: opportunities for a digital future

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Artificial intelligence (AI) is a rapidly advancing field of computer science that enables machines to perform tasks traditionally requiring human cognitive abilities such as learning and problem solving.[1] It is commonly defined as a system's ability to accurately interpret external data, learn from such data, and apply that knowledge to achieve specific goals and tasks through adaptatve decision-making.[2] AI is increasingly embedded in daily life, shaping how people work, learn, and interact. In transportation, AI helps manage traffic flow, power navigation systems, and support the development of safer, more efficient vehicles. In finance, it improves security through fraud detection, streamlines transactions, and enables personalised financial services. Even in daily routines, smart devices and virtual assistants help manage schedules, control home environments, and provide instant access to information.

In healthcare, the potential of AI is vast, though widespread clinical adoption remains at an early stage. AI can enable healthcare systems to advance towards AI augmented care, encompassing precision diagnostics, precision therapeutics, and ultimately precision medicine.[1] It incorporates machine learning that includes deep learning and natural language processing to enhance data interpretation and decision-making.[3] Research in AI application continues to expand rapidly, demonstrating potential in drug discovery, virtual clinical consultation, disease diagnosis, prognosis, medication management, and health monitoring.[1,3] In the near future, AI tools may enable earlier detection of diseases and guide timely, targeted interven-

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tions. They could also support healthcare systems by improving workflow efficiency, resource allocation, and decision-making. Ultimately, AI offers promising opportunities to make healthcare delivery more proactive, precise, and patient-centred.

AI is also transforming the landscape of anaesthesiology and intensive care, which are uniquely positioned to benefit due to its data-rich, real-time environments. Predictive analytics, anaesthesia delivery systems, patient monitoring, image analysis, decision support systems, personalised anaesthesia, simulation-based education, and risk assessment tools present opportunities to refine how anaesthesiologists learn, make decisions, and deliver care.[4,5] In anaesthesia, AI can assist in predicting difficult airways, optimising anaesthetic dosing, enhancing intraoperative monitoring through continuous data interpretation, and predicting intraoperative hypotension and postoperative complications.[4,5] Moreover, AI-assisted devices have been shown to improve ultrasound image acquisition and interpretation for regional anaesthesia, potentially broadening access to this technology by enabling use even among non-experts.[3] Beyond direct clinical applications, AI can also enhance hospital logistics by accurately predicting surgery durations and potential cancellations, improving operating theatre efficiency, reducing waiting times, and lowering costs.[3]

In intensive care, AI systems may help identify patients at risk of sepsis, acute kidney injury, or mortality, while assisting with ventilator management, haemodynamic optimisation, and nutritional planning.[6] In pain medicine, AI holds the potential to personalise therapy by analysing individual characteristics and biosignals, such as electroencephalograms, electromyography, and facial recognition to quantify pain objectively and guide personalised analgesic titration and opioid stewardship.[7] Within medical education, AI-driven simulation, virtual patients, and adaptive learning platforms can revolutionise how trainees acquire and refine clinical skills. Although many of these innovations are still in developmental stages, growing evidence highlights AI's capacity to improve precision, safety, and efficiency across these domains.

Globally, AI has advanced rapidly, powering models that predict intraoperative and postoperative hypotension, hypoxaemia, and depth of anaesthesia.[4,6] Deep-learning algorithms can now analyse physiological waveforms and optimise ventilator settings, while explainable AI systems identify key biomarkers and guide early interventions in critical illness.[8] However, most of these innovations are built from datasets in high-income countries, limiting their direct applicability in our regional context.[6] For Malaysia and Southeast Asia, the next critical step is to generate robust local data, validate predictive models, and ensure that AI-driven solutions reflect our patient demographics, healthcare resources, and clinical priorities. Strengthening digital infrastructure as well as fostering collaboration

between clinicians and data scientists will be essential to ensure safe, meaningful, and context-appropriate AI integration.

This issue of Malaysian Journal of Anaesthesiology highlights the potential adaptation of AI within our specialty. The e-learning survey by Chua *et al.* explores anaesthesiology trainees' engagement with online learning platforms, illustrating how AI could potentially enable adaptive learning systems that can personalise content, monitor learner progress, and support competency-based training. The simulation study by Abdul Wahab *et al.* evaluates the BIOBASE biological isolation chamber in containing aerosolised particles during patient transport, an area that could benefit from AI-based environmental sensors and real-time data modelling to strengthen infection control and safety. The predictive study by Md Ralib *et al.* compares intensive care prognostic and renal scores in predicting hospital mortality, reflecting the potential of machine-learning algorithms to refine existing scoring systems for more accurate, context-specific predictions relevant to Malaysian intensive care unit populations. Together, these studies mark a collective shift toward data-informed, technology-enabled, and safety-focused practice, key elements in advancing the digital transformation of anaesthesiology.

Beyond these featured works, several emerging themes illustrate the growing convergence of AI, simulation, and sustainability. The Green Anaesthesia Policy, for instance, could utilise AI-supported environmental monitoring and predictive analytics to optimise anaesthetic gas use, reduce the carbon footprint, and enhance operating theatre efficiency. Case reports on submental intubation techniques and complications from subclavian line injury highlight how AI-integrated augmented and virtual reality technologies may enhance procedural accuracy and airway safety. Collectively, these developments reinforce how AI and immersive technologies can be used to advance both patient safety and environmental stewardship in anaesthetic practice.

As Malaysia progresses toward comprehensive digital healthcare integration, the field of anaesthesiology must continue to lead this transformation. Embedding AI into clinical care, education, and research will ensure that innovation remains ethical, explainable, and locally relevant.[9] The future depends on strong collaboration among clinicians, educators, engineers, and data scientists to ensure that technology amplifies rather than replaces human expertise. Through sustained research and cross-disciplinary partnerships, Malaysian anaesthesiologists can evolve from adopting global innovations to driving regional breakthroughs, setting new standards for safe, intelligent, and compassionate care.

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Beyond the diagnosis: what I learned from a case

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God gives life, doctors save lives. For as long as I can remember, I have grown up hearing doctors compared to God, the middlemen of fate, pulling people back to the realm of the living, when they should have been long gone. I hear the reverence for doctors in the voice of my grandfather when he talks about how his doctor at the hospital skillfully diagnosed the root cause of his prolonged leg issues. I grew up seeing doctors as people who save their patients, long before I learned exactly how they do it. Throughout my short posting in anaesthesia and specifically the Intensive Care Unit (ICU), I learnt that doctors do more than save lives and despite our biggest hopes, doctors are humans at the end of the day. They can't create miracles, but they will always give everything they have to help**.**

When I walked into the ICU on my first day, there was a flurry of activity; nurses, MOs, specialists, all walking around the ward reviewing patients, administering medications, and talking to their families. When we joined the rounds, I started to get a clearer picture of the exact role of an anaesthetist in the ICU. In my other postings, if a patient has other comorbidities, the topic of discussion would still mainly revolve around the specific specialty. But in the ICU, the anaesthesiologists discussed the patients' comorbidities in detail. They were the conductors deciding what to do next, what approach to take, and leading the management of the patient. It was here I met a patient whose case left an indelible mark on me.

The patient was a middle-aged woman connected to several machines. Despite the growing noise of the doctors and nurses in the ICU, she did not stir; the only constant was the rising and falling of her chest. The anaesthesiologist began explaining that this patient was brought in for a routine gynaecological procedure when she suffered a blood clot to the brain. After that it was complication after complication and despite the valiant efforts of the operating team, she was pronounced brain-dead. Everyone knows the term; we understand the implications of being

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brain-dead but the difference between knowing in theory and seeing it for yourself is truly jarring. You know the patient is dead, but you see the rising of her chest, the colour in her cheeks: it looks like she's just taking a nap, ready to wake up anytime. If I, as a stranger found it hard to believe that she was truly gone, how could her family face this reality? Families often find it difficult to understand that their relatives could be brain-dead since they simply look asleep.[1] After our rounds, we had a discussion with the specialist. She said a brain-dead patient is medically considered dead. According to a study, brain death is defined as the irreversible loss of all functions of the brain, including the brainstem.[2]

In situations like this, the doctor would explain the patient's condition to the family and ask if they could discontinue the patient from the ventilator and pronounce the time of death when the patient stops breathing. I asked my doctor, "What if the family does not want to discontinue the ventilator? What if they cannot accept that the patient is gone?" She explained that they would respect the family's wishes and give them time to accept the reality. Compassionate communication during end-of-life care is essential for helping families navigate grief and uncertainty.[3] "Wouldn't it just be a waste of resources?" asked my course mate. "We do not just treat the patient; we also treat the patient's family. We help them understand what has happened to their loved ones with compassion, we make decisions which are not just for the patient's or the hospital's benefit but for their families as well. The patient is gone but their family is still here praying for hope, and we must help them through this loss the best way we can" she said. A brain-dead patient will eventually pass despite ventilator support. Over time, the patient will suffer from multi-organ failure and most brain-dead patients pass within hours to days. I heard from the doctor that the patient's family was unable to accept that their loved one was brain-dead. After all, she was just supposed to go for a routine procedure. The following day, as I walked past the ICU, I saw the patient's husband crying on the lap of the gynaecologist who was comforting him. The patient had passed.

This case taught me empathy, compassion, communication, qualities that cannot be found in the textbook but in the ICU. As students, we learn to focus on the chief complaint and elicit just enough history to reach a diagnosis. In the ICU I learned that we need to look at the bigger picture, treat the patient as well as their family, communicate with compassion, and use words they understand instead of spitting out the medical terminology that we've memorized. Empathy and effective communication have been shown to improve both patient satisfaction and clinical outcomes.[4] In anaesthesiology, doctors do more than put preoperative patients to sleep, they safeguard their comfort, monitor their comorbidities, and coordinate critical care.[5] Even when there is nothing they can do to save the patient, they support them through the grief.

This posting has truly been a turning point in my life, giving me a new perspective, showing me that being a good doctor goes beyond clinical knowledge and technical skills. It requires empathy and clear communication with both patients and their loved ones. I hope this article reminds trainees that medicine is not just about managing diseases and performing procedures. Guiding families through difficult realities, showing compassion in moments of loss, and communicating with clarity and kindness is an integral part of the job. My time in the ICU showed me that anaesthesia is more than physiology and machines, it is the art of combining knowledge with compassion.

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The CoA-MSA Consensus Statement on Green Anaesthesia: a starter toolkit for sustainable practice in Malaysia

Syarifah Noor Nazihah **Sayed Masri**[1], Samuel **Tsan** Ern Hung[2], Mohd Fitry **Zainal Abidin**[3], Huwaida **Abdul Halim**[4], Jennifer **Ong** An Chi[5], Shahridan **Mohd Fathil**[6], Mohd Zulfakar **Mazlan**[7], Sobha **KK Gopala Kurup**[4], **Lee** Kwan Tuck[8], Ina Ismiarti **Shariffuddin**[3]

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Abstract

The healthcare sector contributes approximately 4%–5% of global greenhouse gas emissions, with anaesthetic practice identified as a notable source. Recognising the urgent need for environmentally sustainable approaches, the Malaysian Society of Anaesthesiologists (MSA) and College of Anaesthesiologists (CoA) have developed a national consensus statement to guide green and sustainable anaesthesia practice in Malaysia.

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This consensus statement was formulated through a literature review, aligned with the principles of the World Federation of Societies of Anaesthesiologists (WFSA), and expert deliberation within the CoA-MSA Green Anaesthesia Working Group. It proposes practical strategies across the 3 carbon emission scopes: direct emissions (Scope 1), indirect energy-related emissions (Scope 2), and indirect supply chain-related emissions (Scope 3), while integrating workforce well-being as a core dimension of sustainability.

The statement recommends low-flow anaesthesia, restricted use of nitrous oxide, and preference for volatile agents with lower GWP. It promotes total intravenous and regional anaesthesia where clinically appropriate and encourages monitoring of anaesthetic depth to reduce unnecessary consumption of volatile agents. Scope 2 interventions include optimising energy use in operating theatres, deactivating systems outside operational hours, and transitioning towards renewable energy. Scope 3 focuses on reducing single-use items, implementing recycling, conducting life-cycle assessments, and strengthening sustainable procurement. Importantly, the consensus statement acknowledges the physiological and psychological challenges climate change imposes on anaesthesia providers, advocating institutional measures that safeguard staff health, hydration, and mental resilience.

This CoA-MSA statement represents Malaysia's first national initiative to integrate sustainability into anaesthetic practice. By balancing environmental responsibility with patient safety and provider well-being, it calls on every anaesthesiologist to make the operating theatre a place that heals both patients and the planet. The document provides a roadmap for climate-resilient, resource-efficient, and compassionate anaesthetic care in Malaysia.

Keywords: climate resilience/change, environmental sustainability, green anaesthesia, healthcare emissions, perioperative care,

Introduction

The term "global warming" refers to an increase in the Earth's temperature as a result of greenhouse gases. It has emerged as the most pressing challenge of the twenty-first century, with far-reaching consequences, including health concerns, economic instability, and environmental degradation. Extreme weather events, such as droughts, floods, heatwaves, and wildfires, have become more frequent in recent years, and these events are directly related to global warming. This event affects not only the economy but also biodiversity, food security, energy systems,

and public health.[1] The degradation of ecosystems, the declining capacity of oceans to sequester carbon, and an almost 1°C rise in mean global temperature over the past century underscore the pressing need for collective action to reduce carbon footprints and transition to sustainable practices.[2]

Carbon dioxide, methane, and nitrous oxide are the primary contributors to greenhouse gases, with a significant portion originating from human activities, including transportation, manufacturing, construction, agriculture, and the oil and gas industries. The health sector has been shown to contribute to 4%–5% of global greenhouse gas emissions worldwide.[3] The National Health Service (NHS) of England calculated that its carbon footprint was 25 megatonnes of CO_2 in 2019: 62% from the supply chain, 24% from the direct delivery of care, and 10% from workers, patients, and visitors travelling to and from work. This value includes approximately 5% from anaesthetic gases and metered-dose inhalers.[4] These findings highlight the need to reframe sustainability initiatives in healthcare by moving beyond a narrow focus on anaesthetic gases and clinical practice alone. Instead, the entire perioperative and healthcare ecosystem must be addressed. Positioning anaesthesia within this broader ecological footprint is critical to the development of targeted, sustainable strategies that can reduce the sector's overall carbon footprint.

Several key concepts are central to understanding the role of anaesthesia in climate change. Global warming potential (GWP) is a standardised measure that compares the climate impact of greenhouse gases over a defined time horizon, usually 100 years, with carbon dioxide serving as the reference gas, which has a GWP of 1.[5] The carbon footprint refers to the total direct and indirect greenhouse gas emissions associated with an individual, organisation, product, or activity, and it is typically expressed in kilograms or tonnes of carbon dioxide equivalents. Radiative forcing describes the imbalance between incoming solar radiation absorbed by the Earth and outgoing energy released into space, measured in watts per square metre.[5] Together, these concepts provide the framework for quantifying and comparing the environmental impact of anaesthetic practice.

Equally important is an understanding of the 3 scopes of healthcare-related emissions. Scope 1 encompasses direct emissions from controlled sources, such as anaesthetic gases. Scope 2 refers to indirect emissions from energy use, which are particularly significant in energy-intensive operating theatres. Scope 3 includes indirect emissions across the supply chain, from the manufacture and transport of medicines and medical devices to the use of single-use consumables and waste disposal. Addressing all 3 scopes is essential if meaningful and sustainable reductions in perioperative and healthcare-related emissions are to be achieved.

Education in sustainability equips anaesthetists with the knowledge and skills to practise environmentally responsible anaesthesia without compromising patient safety. This paper presents the consensus statement on green anaesthesia developed by the Malaysian Society of Anaesthesiologists (MSA) and the College of Anaesthesiologists (CoA). In alignment with the World Federation of Societies of Anaesthesiologists (WFSA), the *CoA-MSA Consensus Statement on Green Anaesthesia* (see full document at the end of the article) provides evidence-based and practical strategies tailored to the Malaysian context. Its aim is to provide anaesthetists in Malaysia with a structured framework for practising green anaesthesia that balances environmental sustainability with patient safety and clinical efficiency.[6]

Scope 1: Reducing direct emissions

All anaesthetic gases are greenhouse gases, with nitrous oxide and isoflurane exhibiting ozone-depleting properties. It has long been postulated that anaesthetic gases contribute significantly to GWP. Andersen *et al.* estimated the emission of inhalational gases to be equivalent to that of 1 million cars.[7] The WFSA recommends the use of inhalational agents with the lowest GWP, such as sevoflurane over desflurane.[6] Desflurane should be employed in limited circumstances, including elderly patients, long surgeries, morbid obesity, and specific neurosurgical cases, where it has been demonstrated to enhance patient safety and outcomes.[8-11] However, according to the latest Intergovernmental Panel on Climate Change (IPCC) consensus, using the GWP metric to measure the impact of anaesthetic gases may not accurately reflect their true contribution to climate change. The GWP metric does not account for the short atmospheric lifespan of these gases. The IPCC defines short-lived climate forcer pollutants with lifetimes of less than 20 years, and all anaesthetic gases fall into this category, including desflurane.[12] Besides that, the small value of radiative forcing of all anaesthetic gases (< 0.0003) made the value small and will be lost within the natural variability of the climate system.[13]

On the other hand, nitrous oxide contributes significantly to climate change, with an atmospheric lifetime of approximately 123 years and a radiative forcing value of 0.21. It is also an ozone-depleting agent.[13] Most of the nitrous oxide production originates from agricultural activities and the combustion of fossil fuels. Although the amount of nitrous oxide used in hospitals is small, only 5% is metabolised, and the rest is exhaled and released to the environment.[14] The impact of nitrous oxide is the most pronounced in comparison to other volatile anaesthetic agents. Consequently, we suggest that the use of nitrous oxide be restricted to parturients in labour because it is still a viable option for analgesia, particularly in remote hospitals.

Low-flow anaesthesia was introduced more than 10 years ago and is defined as a fresh gas flow of 1 l/min. Virtue *et al.* describe a fresh gas flow usage of 0.5 l/min and call it minimal gas flow.[15,16] The fear regarding the use of low flow was derived from concerns about the accumulation of Compound A and carbon monoxide, which are specifically produced in CO_2 absorbents that contain potassium hydroxide.[17] Such absorbents are no longer available in the market at this point in time. The prerequisite for low-flow anaesthesia is a closed-circuit system with a leak-free connection and calibrated flow meters, capable of measuring flow rates as low as 50 ml/min. However, the anaesthetist must not neglect patient safety when using low-flow anaesthesia. Continuous monitoring of inspired oxygen is essential for a vigilant anaesthetist. Low-flow anaesthesia not only reduces emissions but also provides economic advantages.[18]

The use of total intravenous anaesthesia (TIVA) and regional anaesthetic technique has a minimal impact on direct emissions. Hence, this technique is deemed most environmentally friendly.[19] However, TIVA requires disposable plastic syringes, intravenous (IV) tubing, and often target-controlled infusion pumps, which consume a small amount of electricity. These disposables and process EEG monitoring add modest cost as well as environmental burden in the form of plastic waste. According to an audit from a Dutch hospital, waste and related costs associated with the use of TIVA are high, at 43 kg per week, of which 14 litres are medication. The costs exceed €350,000 per year.[20] It is important to note that propofol disposal must be done appropriately, as it is known to be toxic to aquatic populations. Improper disposal can lead to harmful effects on the environment.[21]

Finally, using either volatile or TIVA, monitoring the depth of anaesthesia (DoA) plays an important role in reducing emissions and minimising the impact on the environment. Accurate assessment of DoA should be tailored to individuals and, at the same time, prevent awareness and overdose of anaesthetic agents.[22] In a review assessing the cost-effectiveness of using DoA, it has been shown that DoA is associated with reduced anaesthetic requirements, shorter anaesthetic recovery time, and lower costs.[23] We recommend monitoring the DoA to reduce volatile consumption.

Scope 2: Indirect emissions from the energy used

A systematic deactivation of operational systems outside designated working hours can help reduce energy use. This is especially important for heating, ventilation, and air conditioning (HVAC) equipment, anaesthetic gas scavenging mechanisms, and anaesthetic delivery machines.[24] Drinhaus *et al.* demonstrated

that anaesthesia workstations utilise high consumption of energy during standby mode. Switching off anaesthesia workstations overnight has a potential cost reduction of between €5,000 and €11,600 per year.[24] Other than that, using energy-saving technologies such as LED lighting, motion-activated lighting systems, and cordless medical instruments will make surgical areas much less polluting and leave less of an impact on the environment overall.[25] Concurrently, the provision of comprehensive training to personnel regarding energy conservation protocols is anticipated to foster enhanced sustainability initiatives across healthcare institutions. A strategic transition towards renewable energy sources, exemplified by photovoltaic (solar panel) systems, holds the potential to significantly diminish carbon emissions and lessen dependence on fossil fuels.[26] Moreover, proactive measures to prevent energy dissipation, such as the insulation of windows to preclude heat loss and the strategic incorporation of large windows to maximise natural illumination, are imperative. Implementing wider windows with appropriate glazing and a daylight-linked dimming lighting control strategy in an Italian hospital led to a 17% reduction in primary energy demand.[27]

Scope 3: Indirect emissions from the supply chain

Indirect emissions from the supply chain, often categorised as Scope 3 emissions, arise from activities that are not directly controlled by a healthcare organisation but are essential to its operations—such as the production, transportation, and disposal of products.[28] It is essential to note that medical waste accounts for 4% of total plastic waste, and prior to the COVID-19 pandemic, plastics comprised 23% of the total waste in the NHS.[29] Reducing the number of items used can minimise unnecessary consumption of resources and energy throughout the supply chain. This can be achieved by limiting the use of single-use items, preparing medications only when required, and ensuring that medication ampoules are used in their entirety whenever possible.[30] The usage of single-use items in operating rooms and intensive care units (ICUs) is sometimes necessary to ensure safety and hygiene. However, many single-use items have now been replaced with reusable equivalents to reduce waste generation.

Evidence supports the environmental benefits of this approach: for example, an Australian study found that single-use disposable plastic laryngoscope handles generate 16–18 times more life cycle CO_2 emissions compared to reusable steel handles.[31] This significant difference highlights the potential of reusables to reduce environmental impact in healthcare settings, provided that infection control and patient safety are not compromised.

Recycling ensures that materials are reprocessed rather than discarded. Recycling should be promoted by ensuring the segregation of waste streams in operating theatres and ICUs. Collaboration between hospital administration and local authorities can strengthen recycling infrastructure and maintain regulatory compliance. This process requires ongoing commitment. As demonstrated by Evliya *et al.*, targeted training initially increased the amount of recyclable waste per surgery from 1.30 kg to 1.80 kg ($p = 0.01$) in the first month. While there was a decrease in medical waste per surgery from 4.92 kg to 4.14 kg, this change was not statistically significant ($p = 0.09$). Importantly, by the second month post-training, waste levels began to revert to baseline (recyclable: 1.79 kg; medical: 5.07 kg per surgery), indicating that the positive effects of a single training session may diminish without continued reinforcement. [32]

Promoting sustainability in anaesthesiology settings requires rethinking procurement strategies to prioritise suppliers with strong environmental commitments and redesigning supply kits to eliminate non-essential items, reducing waste at the source. Additionally, establishing robust internal protocols for the timely maintenance and repair of equipment can extend the lifespan of valuable assets and minimise the need for premature replacement. Ensuring that supplier agreements include comprehensive post-sale support and guaranteed availability of spare parts further supports the efficient repair and ongoing functionality of equipment, fostering a more resource-efficient and environmentally responsible approach to healthcare operations. [33]

To carry out the research programme, anaesthetic departments should undertake local waste and resource audits, as well as life cycle assessments of items and practices, to identify environmental hotspots. These findings should then be published and disseminated throughout the department, hospital, and community to inform sustainable practice changes, such as implementing the 6Rs of sustainability (Reduce, Recycle, Reuse, Refuse, Rethink, and Research), purchasing more eco-friendly products, and advocating for policy changes to reduce the environmental footprint of healthcare. [30]

Integrating sustainability into anaesthesia training and ongoing education is crucial to foster lasting change in clinical practice. Increasing staff awareness about the environmental impact of their clinical choices empowers them to advocate for and adopt greener practices. However, without ongoing reinforcement, the positive effects of a single training session may fade over time. This is evidenced by Elviya *et al.*, who found that 40% of doctors lacked sufficient knowledge prior to training, and those most supportive of further education were often the least informed ($p = 0.02$), illustrating significant gaps in previous education. [32] In Malaysia, the proportion of anaesthesiologists with adequate knowledge of sustainability is high, but most of

the respondents did not receive adequate education and training on this subject, indicating substantial room for improvement. Addressing these educational gaps through comprehensive and continuous training is vital to ensure the widespread adoption of sustainable practices among Malaysian anaesthesiologists.

Wellbeing and self-care of anaesthesia care providers

Climate change poses increasing risks not only to patients but also to the healthcare workforce. It disproportionately affects individuals whose work is physically or cognitively demanding and undertaken in constrained environments. Anaesthesia providers, operating in thermally variable hospital settings and often in prolonged use of personal protective equipment (PPE), face increased vulnerability. Beyond environmental hazards, the climate-related psychological stressors place anaesthesia providers at increased risk of fatigue, dehydration, mental distress, and reduced clinical performance. Our toolkit focused on the health impacts of climate change relevant to anaesthesia providers from physiological, psychological, and occupational perspectives. The toolkit also outlined personal and institutional strategies to mitigate health and psychological risks, thus creating climate-resilient healthcare systems that protect the well-being of both providers and patients.

From the physiological perspective, exposure to elevated temperatures compromises human thermoregulation, leading to heat stress and, in severe cases, heat-related disorders such as exhaustion, heat syncope, and stroke. Anaesthesia providers are particularly susceptible due to prolonged periods in PPE and indoor environments with poor ventilation or limited cooling infrastructure. During prolonged shifts, especially in warm operating theatres or high-humidity regions, anaesthesia providers may experience significant fluid loss due to sweating, compounded by reduced opportunities to hydrate during procedures. Dehydration impairs cognitive function, concentration, and decision-making, which are critical components in anaesthetic care. In addition, prolonged dehydration may lead to diseases such as chronic kidney disease. The widespread use of PPE, particularly since the COVID-19 pandemic, has exacerbated heat burden among providers. Insulating gowns limit sweat evaporation, increasing thermal discomfort and cardiovascular strain. Climate-related wildfires, haze events, and increased urban heat contribute to poor air quality, raising the burden of respiratory illness. Anaesthesia providers with pre-existing respiratory conditions are particularly vulnerable. Moreover, indoor air pollution from outdated ventilation systems in some facilities may exacerbate symptoms such as wheezing and fatigue. Finally, vector-borne diseases such as dengue, malaria, and zoonoses are expanding geographically due to climate warming. Anaesthesia providers may be increasingly involved in

managing perioperative and critical care for patients with complex febrile illnesses, raising occupational exposure risks.[34]

From the psychological and occupational perspectives, climate change has multiple negative implications for anaesthesia providers. Heat exposure may lead to increased mental fatigue, irritability, and reduced job satisfaction. Climate-induced disasters, such as floods and pandemics, may lead to higher rates of anxiety, burnout, and post-traumatic stress disorder among anaesthesia providers. There is also evidence that increasing heat and humidity have profound adverse effects on worker productivity.[34] Lastly, eco-anxiety, defined as the psychological distress associated with awareness of climate change, has been shown to have significant implications for overall well-being and health among the general population. A meta-analysis conducted by Gago *et al.* revealed a moderate negative correlation between the level of climate anxiety and psychological well-being.[35] Eco-anxiety has also been linked with feelings of apathy or paralysis.[36]

Strengthening workforce resilience is therefore a key component of sustainable healthcare. This can be achieved by integrating climate-related health risks education into staff wellness programmes, closely monitoring and identifying high-heat areas within the hospital—such as wards, on-call rooms, and older facilities with limited climate control—and promoting regular hydration and adequate rest. Staff should be encouraged to consume 150–250 ml of fluids every 20–30 minutes in hot or humid conditions, while peer support systems, such as "buddy checks", can help detect early signs of heat strain, especially among junior and auxiliary staff. Additionally, ensuring equitable access to designated cooling zones, such as air-conditioned rooms or shaded areas, further supports the health and safety of all staff members.

It is also important to implement measures to improve mental health and psychological well-being in achieving heat resilience. Knowledge on climate-related stressors such as heat fatigue, post-traumatic stress disorder, and eco-anxiety should be imparted through wellbeing initiatives. In addition, anaesthesia providers serving in the frontline of climate-related events such as floods and heat emergencies should be provided with psychological first aid, peer support, and structured debriefing.

Finally, healthcare institutions should take responsibility for heat protection and staff well-being. Strategies that can be taken include implementation of indoor climate control standards for operating theatres, routine staff health alerts for high-heat and poor air quality days, creation of "green rest rooms" with cooling, hydration and rest facilities, and incorporation of heat and air quality surveillance into occupational health protocols. Healthcare infrastructure should integrate

passive cooling (*e.g.*, reflective roof materials, tree shading) and renewable energy-powered air conditioning. Building design should prioritise natural ventilation and insulation to reduce heat gain. These changes align with both occupational health objectives and broader emissions reductions.

In conclusion, sustainable anaesthetic practice is fundamental to the future of safe and effective healthcare. The *CoA-MSA Consensus Statement on Green Anaesthesia* provides practical guidance to reduce emissions across the perioperative process while maintaining patient safety and clinical standards. Meaningful progress requires education, leadership, and shared commitment from clinicians and institutions. By integrating environmental responsibility into everyday practice, anaesthesiologists can contribute to a low carbon and climate resilient healthcare system that protects both patients and the planet.

Declarations

Competing interests
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College of Anaesthesiologists, AMM

Malaysian Society of Anaesthesiologists

CoA-MSA CONSENSUS STATEMENT ON GREEN ANAESTHESIA

– A STARTER TOOLKIT

For the College of Anaesthesiologists (CoA) and Malaysian Society of Anaesthesiologists (MSA)
Climate-Conscious, Evidence-Based, Health-Centred Anaesthetic Practice

INTRODUCTION

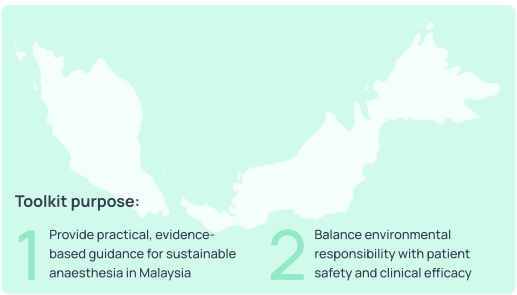
Climate change is the greatest global health threat of the 21st century, and healthcare significantly contributes to environmental degradation.

Anaesthesia has a disproportionately high environmental impact due to:


Energy-intensive operating theatres


Volatile anaesthetic agents with high global warming potentials (GWPs)


Single-use consumables



Toolkit purpose:

1. Provide practical, evidence-based guidance for sustainable anaesthesia in Malaysia
2. Balance environmental responsibility with patient safety and clinical efficacy

ROLE OF ANAESTHESIOLOGIST

Anaesthesiologists are central figures in perioperative care and uniquely placed to champion sustainability.

Can influence **Scope 1** (direct emissions), **Scope 2** (energy-related emissions), **Scope 3** (supply chain emissions), and **improve wellbeing and self-care of anaesthesia providers** through daily clinical decisions.

The World Federation of Societies of Anaesthesiologists has underscored this responsibility through **three core directives:**

1. Ensuring patient safety while implementing green practices
2. Fostering global unity across income settings
3. Advocating for healthcare-wide mandates to curb contributions to global warming.

OBJECTIVES OF THE TOOLKIT

Awareness:
Highlight anaesthesia's environmental impact in Malaysia.

Actionable Guidance:
Offer practical, locally relevant carbon-reduction strategies.

Support Initiatives:
Help departments align with national climate goals.

Foster Collaboration:
Promote teamwork among anaesthesiologists, surgeons, nurses, and administrators.

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KEY RECOMMENDATIONS & STRATEGIES

Scope 1: Direct Emission

Practice Low-flow anaesthesia
(≤1 L/min)

Lower flow reduces volatile agent consumption, costs, and emissions.[1,2] It is safe with modern CO_2 absorbers and reduces unnecessary environmental release.

1

Limit use of Desflurane
(specific cases only)

Global Warming Potential (GWP) data: Desflurane (2540), long atmospheric lifetime. We recommend the use of Desflurane only for specific indications. Examples include but not limited to the patients with morbid obesity, elderly patients, patients undergoing long surgeries and neuro-surgeries.[3-6]

2

Limit use of Nitrous Oxide(N_2O)
(labour analgesia only)

N_2O: Ozone depleter [7,8], small volume but high impact

3

Total Intravenous Anaesthesia (TIVA) / Regional Anaesthesia preferred

TIVA/Propofol: Life cycle assessment shows lower footprint, —even accounting for the manufacturing and disposal of syringes and IV sets.[9-11]

4

Use Depth of Anaesthesia (DoA) monitoring

DoA monitoring reduces agent use, and may lead to reduction of Green House Gas (GHG) emissions. [11]

5

Use leak-free closed-circuit with scavenging

Leak prevention essential for occupational safety. A leak-free anaesthesia machine is essential for the effective practice of low-flow anaesthesia.[12-14]

6

Scope 2: Indirect Emission From The Energy Used

Minimise energy consumption

Power off out of hours

Heat, Ventilation and Air-Conditioning (HVAC) Systems:
Ensure systems are powered down when not in use.

Anaesthetic Gas Scavenging System (AGSS):
Switch off when theatres are not in use or volatile anaesthetics are not being utilized.

Anaesthesia Machines:
Power down post-procedure, which can save approximately 50 kWh per day per machine.

Ventilators/ ICU Monitors:
Activate eco-mode during standby, which reduces energy consumption by 30%.

Utilise centralised monitoring to minimise the need for redundant devices:
- Introduce 'shutdown' and 'power on' checklists.
- Install occupancy sensors and automate 'set-back' modes HVAC systems.

Use cordless electrical equipment with rechargeable batteries

Implement energy-saving measures

Examples included but not limited to:
- Use of LED lightbulbs
- Install motion-activated lights.

Optimise temperature and humidity

- Maintain operating theatre (OT) temperature: 18-22°C with hypothermia prevention; Burns Unit: 24-30°C.
- Keep OT doors closed to reduce temperature loss. Maintain OT relative humidity between 30% and 60% for patient comfort and infection control.

1

Transition towards sustainable energy generation

Shifting to renewables significantly decreases life-cycle emissions of all hospital operations.

- Encourage solar, rooftop systems
- Sustainability planning with engineers

2

Prevention of energy loss

- Encourage window/ natural light sources to reduce electrical lighting.
- Optimisation of insulation/heat transfer for new facilities/major renovations of hospital facilities.

3

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Malaysian Society of Anaesthesiologists

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Climate-Conscious, Evidence-Based, Health-Centred Anaesthetic Practice

KEY RECOMMENDATIONS & STRATEGIES

Scope 3: Indirect Emission from the Supply Chain

Application of 6R, EM concepts[13–16,17]

Reduce

- Minimise non-essential single-use items.
- Prepare medications only when needed to reduce waste.
- Use medication ampoules fully whenever possible.
- Shorten ICU and hospital stays to lessen resource use and environmental impact.

Reuse

Where appropriate, substitute single-use items with reusable alternatives, provided they meet all relevant safety and hygiene standards.

Recycle

- Segregate waste streams in operating theatres and ICUs.
- Collaborate with hospital administration and local authorities to improve recycling infrastructure and ensure compliance.

Rethink

- Prioritise procurement from suppliers with strong environmental commitments.
- Redesign supply kits to eliminate non-essential.

Repair

- Implement internal protocols for timely equipment maintenance and repair.
- Ensure supplier agreements include full post-sale support and guaranteed spare parts.

Research

- Conduct and support local audits and life cycle assessments of anaesthesia-related products and practices.
- Publish and share findings.

Education[16] & Culture Change

- Integrate sustainability into anaesthesia training and continuing education programs.
- Raise awareness among staff about the environmental impact of clinical choices and empower them to advocate for greener practices.
- Celebrate and share successes (e.g., Green Anaesthesia Day) to foster a culture of environmental responsibility.

Monitor and Audit

- Regularly track supply use, waste generation, and recycling rates in the OT and ICU.
- Benchmark against national and international standards and set measurable sustainability targets.
- Use audit data to drive continuous improvement and inform procurement and clinical practice changes.

Encourage sustainable waste management[18-21]

Optimise use of waste containers[22]

- Segregate waste into designated, color-coded waste collection containers.
- Dedicated rubbish containers.

Reduce leftover and unutilised disposable medical items

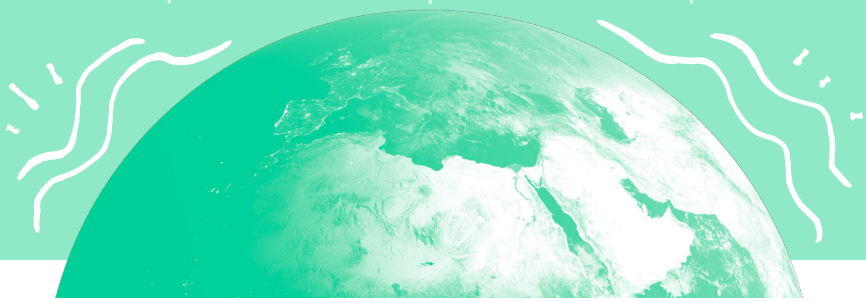
- Minimise partially used disposables.
- Limit unnecessary openings of single-use items.
- Optimise consumable supply usage.
- Prevent wastage of unopened medical disposables.

Ensure safe pharmaceutical waste disposal[23-26]

- Dedicated pharmaceutical disposal.
- Medication residue management.
- Safe handling of unused medication.

Promote paperless practices

- Minimize paper usage.
- Implement paperless documentation.
- Promote digital record-keeping.
- Decrease reliance on printed materials.



College of Anaesthesiologists, AMM

Malaysian Society of Anaesthesiologists

CoA-MSA CONSENSUS STATEMENT ON GREEN ANAESTHESIA

– A STARTER TOOLKIT

For the College of Anaesthesiologists (CoA) and Malaysian Society of Anaesthesiologists (MSA)
Climate-Conscious, Evidence-Based, Health-Centred Anaesthetic Practice

KEY RECOMMENDATIONS & STRATEGIES

Wellbeing & Self-care of Anaesthesia Care Provider

Create awareness of physical health risks due to heat

Anaesthesia providers are vulnerable to extreme weather, heat, air pollution, and resource strain.[27,28] Strengthening workforce resilience is essential to sustainable healthcare. This can be done by:

Integrate climate-related health risks into staff wellness programmes.

Monitor and identify high-heat areas in the hospital. Examples include but not limited to wards, on-call rooms, and older facilities with limited climate control.

Promote hydration and rest

- Encourage regular hydration. Aim for 150–250 mL fluid intake every 20–30 minutes in hot or humid environments.
- Implement peer support systems ('buddy checks') to identify early signs of heat strain, particularly among junior and auxiliary staff.
- Use designated cooling zones (e.g. air-conditioned rooms, shaded areas) equitably across all staff groups.

Empower mental health and heat resilience[27,28]

- Address climate-related stressors such as heat fatigue, haze, and disaster response within staff wellbeing programmes.
- Provide basic psychological first aid training for frontline staff and team leaders following climate-related events (e.g. floods, heat emergencies).
- Enable peer support and debriefing to help staff cope with climate-induced stress, including resource strain and community displacement.

Address occupational & systemic challenges[28]

- Advocate for system-level upgrades to create safer, greener, and more resilient workplaces.
- Encourage cardiovascular fitness and regular aerobic exercise to enhance physiological heat tolerance.

College of Anaesthesiologists, AMM

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– A STARTER TOOLKIT

For the College of Anaesthesiologists (CoA) and Malaysian Society of Anaesthesiologists (MSA)
Climate-Conscious, Evidence-Based, Health-Centred Anaesthetic Practice

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Survey among anaesthesiology trainees on usage and needs in comparison with YouTube analytics-based analysis of an educational anaesthesiology YouTube channel

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Abstract

Background: Research on anaesthesiology trainees' e-learning usage and needs are limited. This study explores e-learning preferences among University of Malaya anaesthesiology trainees, global engagement of an anaesthesiology YouTube channel, and comparisons between local and global trends.

Methods: A cross-sectional survey was conducted among University of Malaya anaesthesiology trainees in mid-2024 using a modified Matava questionnaire. YouTube analytics from 319 educational videos on @ForeverLearningAnaes (FLA) were analysed. Statistical analysis was performed using IBM SPSS version 29.

Results: The survey demonstrated satisfactory validity (ICC: 0.678–0.994; Cronbach's α: 0.689–0.994), with a 90.3% response rate (n = 75). Preferred e-learning formats included e-books, videos, slide-based courses, and quizzes. Trainees spent significantly more time on e-learning than traditional learning, with first-year trainees dedicating the most study hours. Smartphones, tablets, and laptops were the primary devices used. Key motivations for e-learning included

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exam preparation, case management, and acquiring new knowledge. The most valued features were flexibility in time, place, and pace of learning. NYSORA Education was the highest-rated YouTube channel. Preferred video duration was 5–15 minutes. The 3 most desired e-learning content types were procedural skills, practice exam questions and answers, and journal article summaries. FLA videos reached 97 countries, primarily lower-middle-income nations, with mobile phones as the dominant viewing device. Clinical/procedural videos had higher engagement than basic sciences videos. The average view duration per video for FLA viewers was approximately 3 minutes.

Conclusion: These findings can inform educators in developing digital learning resources to support self-paced, lifelong learning for anaesthesiology trainees globally.

Keywords: anaesthesiology, critical care, E-learning, YouTube

Introduction

E-learning is increasingly utilized in education,[1] yet research on anaesthesiology trainees' usage patterns, format preferences, and content needs remains scarce. Additionally, no published studies have analysed channel analytics from an anaesthesiology-themed educational YouTube (YT) channel, limiting insights into its impact on digital learning. Understanding these factors can help optimise e-learning content for anaesthesiology and critical care education.

This study explores the e-learning usage patterns and preferences of anaesthesiology trainees at the University of Malaya Medical Centre (UMMC) through a survey and compares the findings with analytics from the @ForeverLearningAnaes (FLA) YT channel. The survey questionnaire was adapted from Matava *et al.*'s 2013 study on Canadian anaesthesiology trainees' e-learning experiences.[2] FLA analytics were extracted to assess global engagement trends, offering a comparative perspective on local and international usage.

Our study aimed to enhance the quality of e-learning by identifying key metrics from YT channel analytics that could improve anaesthesiology education through video streaming platforms. Additionally, insights gained may contribute to the future development of artificial intelligence-driven educational tools in anaesthesiology. This study sought to answer 3 key questions:

1. What are the usage patterns, format preferences, and content needs of UMMC anaesthesiology trainees regarding e-learning?
2. What are the global reach, adoption, and engagement patterns of a YT channel dedicated to anaesthesiology education?
3. How do the YT usage patterns of UMMC trainees compare with global trends?

By addressing these questions, this study aimed to provide valuable guidance for e-learning content creators and educators.[3]

Methods

Our study design was analytical, observational, non-interventional, and cross-sectional. The study was conducted in 2024 at UMMC. Approval from the University of Malaya Medical Centre-Medical Research Ethics Committee (UMMC-MREC), Research Unit of Anesthesiology and Intensive Care Department, and Head of the UMMC Anesthesiology and Intensive Care Department was obtained. The collected data was anonymous, ensuring subject confidentiality.

The first study population comprised in-campus UMMC anesthesiology trainees older than 18 years, who consented to partake in the study (N = 83). The second study population comprised viewers of FLA YT videos.

Sampling and data collection method

Total population sampling was used for the survey on usage patterns, format preferences, and content needs of anaesthesia residents among in-campus UMMC anaesthesiology trainees.

Channel analytics from https://www.youtube.com/@ForeverLearningAnaes were collected from studio.youtube.com channel analytics reports, including data of 319 educational videos on the FLA YT channel[4] published between 9/9/2019 to 8/6/2024. These YT videos were created by the primary investigator of this study regarding core topics in anesthesiology and critical care. FLA's videos consist of narrated mind maps designed using mind mapping software, edited based on reputable texts and articles, and recorded using the screen record function of a laptop. Data from all these anesthesiology and critical care videos were collected and included in data analysis. Various outcome variables as detailed below were collected. YT uses proprietary algorithms to ensure the accuracy of channel analytic reports.

Survey questionnaire on e-learning usage and needs: development and validation procedure

The questionnaire was developed in accordance with published guidelines for the creation of surveys,[5] with reference to the questionnaire used in a published study.[2] The study by Matava[2] was distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/2.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The questionnaire consisted of 2 parts. The first part included questions aimed at collecting information on the subjects' sociodemographic data. The second part was a 10-item questionnaire aimed at gathering information on the subjects' e-learning usage pattern and needs. The language used in the questionnaire was English, and the study population is proficient in English (https://study.um.edu.my/entry-requirements). The questionnaire's validity and reliability were assessed according to recommendations for questionnaire validation.[6] The operational definitions of variables and selected YT channel analytics metrics are found in the Appendix.

Data analysis

Statistical analysis was carried out with the IBM SPSS Statistical package version 29. After data checking and reduction, descriptive and associational analysis was conducted under the guidance of statisticians from Research Unit of Anesthesiology and Intensive Care Department, UM.

Results

Survey results

Our survey questionnaire demonstrated satisfactory face validity and reliability (ICC: 0.678–0.994; Cronbach's α: 0.689–0.994).[8-10] A total of 75 subjects consented to participate in the study, resulting in a response rate of 90.3%. Demographic data for the respondents (n = 75) are presented in Table 1.

Regarding preference ratings for e-learning content formats among in-campus UMMC anaesthesiology trainees, the mean ranks for e-book/articles, videos, slide-based courses, quizzes, Lecturio, podcasts and other formats were 5.19, 4.74, 4.51, 4.07, 3.65, 3.54 and 2.29, respectively ($\chi^2 = 125.30$, $p < 0.001$).

Table 1. Demographic data of in-campus UMMC anaesthesiology trainees vs @ForeverLearningAnaes YouTube (FLA YT) channel viewers

UMMC anaesthesiology trainees*	FLA YT channel viewers**
Age group (%)	
30-35 years (78.7%)	18–24 years: 28.6%
36-41 years 21.3%	25–34 years: 53.1%
	35–44 years: 16.4%
	45–54 years: 1.8%
	>55 years: 0.08%
Gender (%)	
Male: 53.3%	Male: 55.1%
Female: 46.7%	Female: 44.9%

*From survey data on May 2024, $n = 75$
**Time frame: 9/9/2019 to 8/6/2024

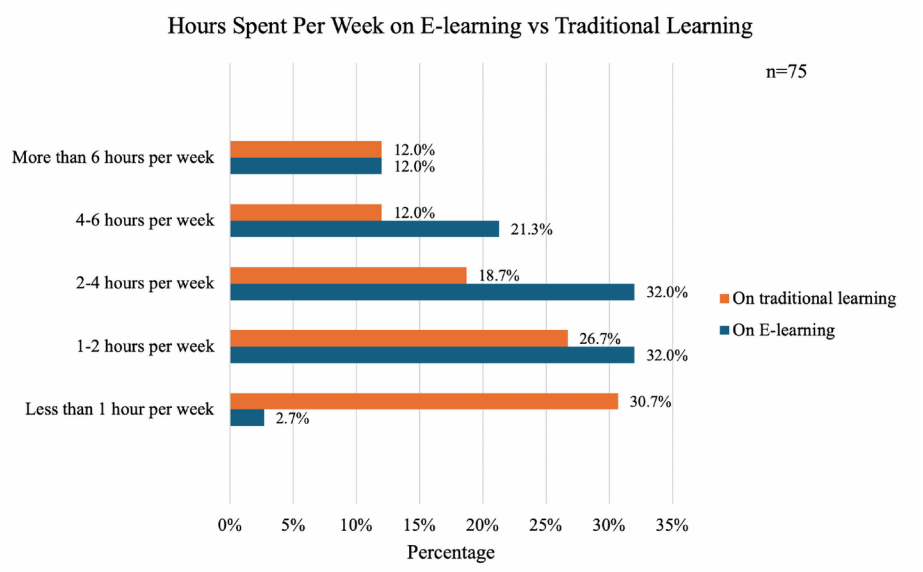

Fig. 1. Hours spent on e-learning per week vs hours spent on traditional learning per week by in-campus UMMC anaesthesiology trainees.

The number of hours spent on e-learning per week was significantly greater than that spent on traditional learning ($p = 0.001$), as shown in Figure. 1. First-year trainees spent significantly more time studying compared to trainees in more senior years ($p < 0.01$).

Table 2. Device types used for e-learning by in-campus UMMC anaesthesiology trainees vs device types used to view videos of @ForeverLearningAnaes YouTube channel from 9/9/2019 to 8/6/2024

Device type	UMMC AT (% who answered 'yes'), *n* = 75	Total views by FLA viewers (%)	Total watch time by FLA viewers (%)
Mobile phone	77.3	60.9	55.0
Computer	74.7 (laptop)	28.1	29.9
Tablet	76	8.5	10.5
TV	1.3	2.4	4.3

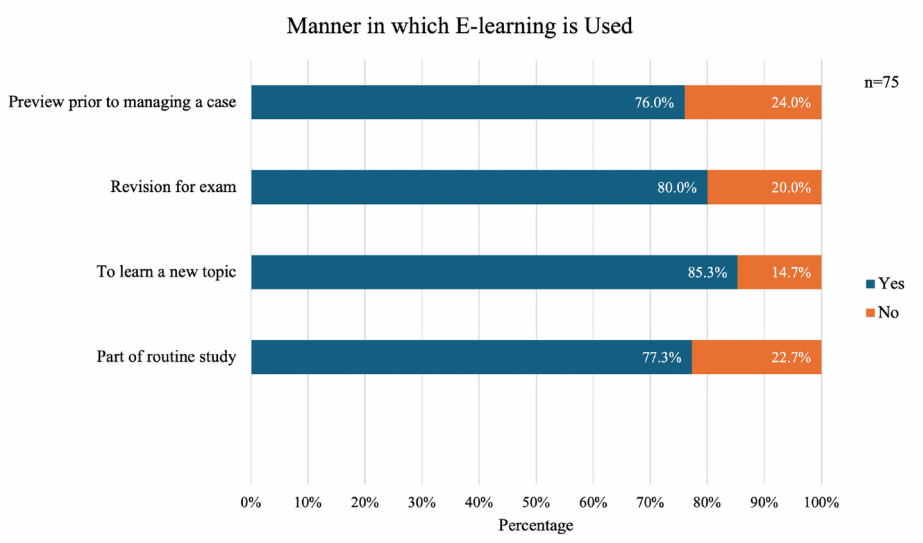

Fig. 2. Manner in which e-learning is used by in-campus UMMC anaesthesiology trainees.

The 3 most used devices for e-learning were smartphones (77.3%), tablet computers (76.0%), and laptops (74.7%) (Table 2). Most trainees used e-learning to revise for an exam (80.0%), manage a case (76.0%), and acquire new knowledge (85.3%) (Fig. 2). The top 3 most valued features of e-learning were the ability to review materials whenever (94.7%), wherever (88.0%), and at one's own pace (84.0%) (Fig. 3).

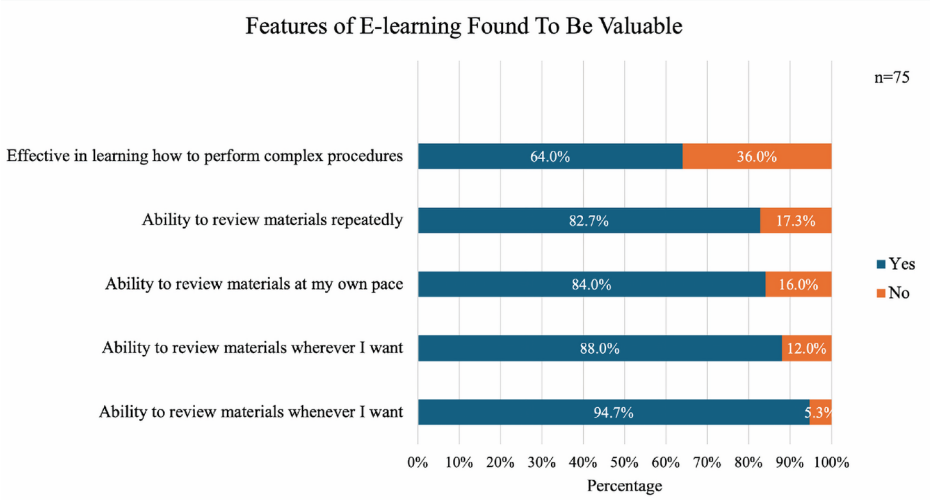

Fig. 3. Features of e-learning found to be valuable by in-campus UMMC anaesthesiology trainees.

Table 3. Preferred e-learning content topics by in-campus UMMC anaesthesiology trainees

Preferred e-learning content topics	Frequency	Percentage
Basic sciences + Procedural topics + Clinical topics	40	53.3%
Procedural topics + Clinical topics	15	20.0%
Basic sciences + Procedural topics	8	10.7%
Procedural topics only	6	8.0%
Basic sciences only	1	1.3%

The highest-rated YT channel in terms of usefulness was NYSORA Education, compared to American Society of Anesthesiologists, Royal College of Anaesthetists, ForeverLearning, Anesthesia Patient Safety Foundation, International Society for Anesthetic Pharmacology, and other YT channels, with mean ranks of 6.03, 4.31, 4.25, 3.88, 3.34, 3.23, and 2.95, respectively ($\chi^2 = 160.967$, $p < 0.001$).

Most trainees preferred 5–15-minute educational YT videos (54.7%) over other durations: < 5 minutes (4.0%), 15–30 minutes (29.3%), 30–45 minutes (6.7%), and > 45 minutes (5.3%).

The most preferred e-learning content topics among anaesthesiology trainees were basic sciences, clinical topics, and procedural topics (Table 3). The most preferred e-learning content types, in descending order, were procedural skills,

practice exam questions-and-answers, journal article summaries, case presentations, didactic lectures, and discussions or debates, with mean ranks of 4.85, 3.69, 3.63, 3.28, 3.05, and 2.51, respectively ($\chi^2 = 96.781$, $p < 0.001$).

FLA channel analytics results

Videos on FLA were viewed by audiences from 97 countries (Fig. 4), with the majority of views coming from lower-middle-income countries (Fig. 5).[11] Most FLA video viewers were between 18 and 34 years old (Table 1), with mobile phones and computers being the most commonly used devices for viewing (Table 2). The activity patterns of FLA viewers on YT are depicted in Figure 6.

The top 3 traffic sources contributing to FLA's views were YT search (56.0%), suggested videos (10.8%), and external sources (10.1%). Between September 9, 2019, and June 8, 2024, a total of 10,216 subscribers joined the FLA YT channel. Returning and new viewers contributed nearly equally to the total percentage of views (51.1% and 48.9%, respectively). The 2 most common types of comments[12] were positive (60.5%) and interrogative (33.7%).

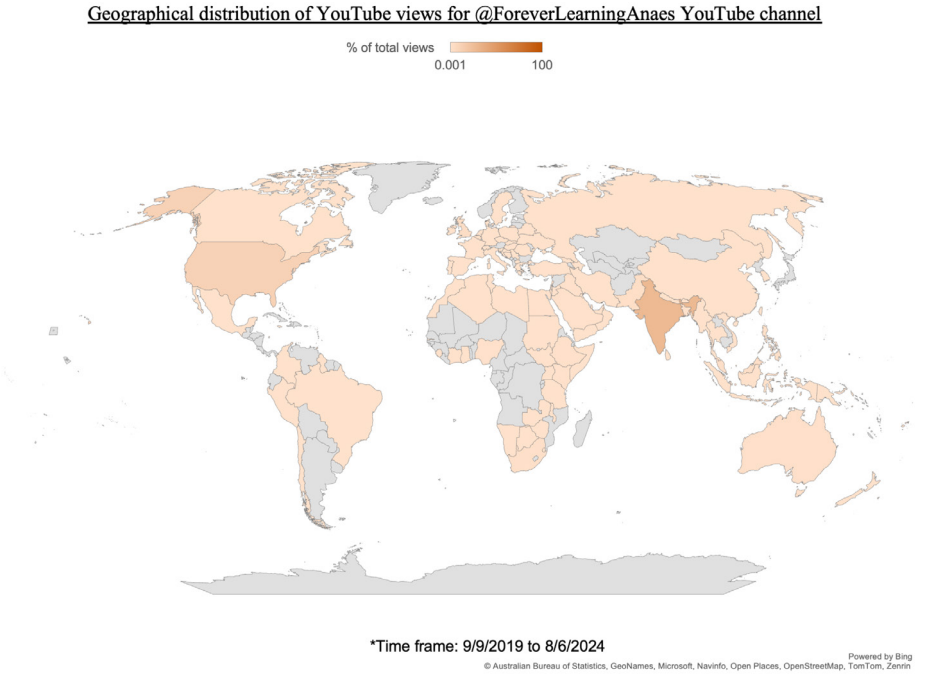

Fig. 4. Geographical distribution of YouTube views of the @ForeverLearningAnaes YouTube channel.

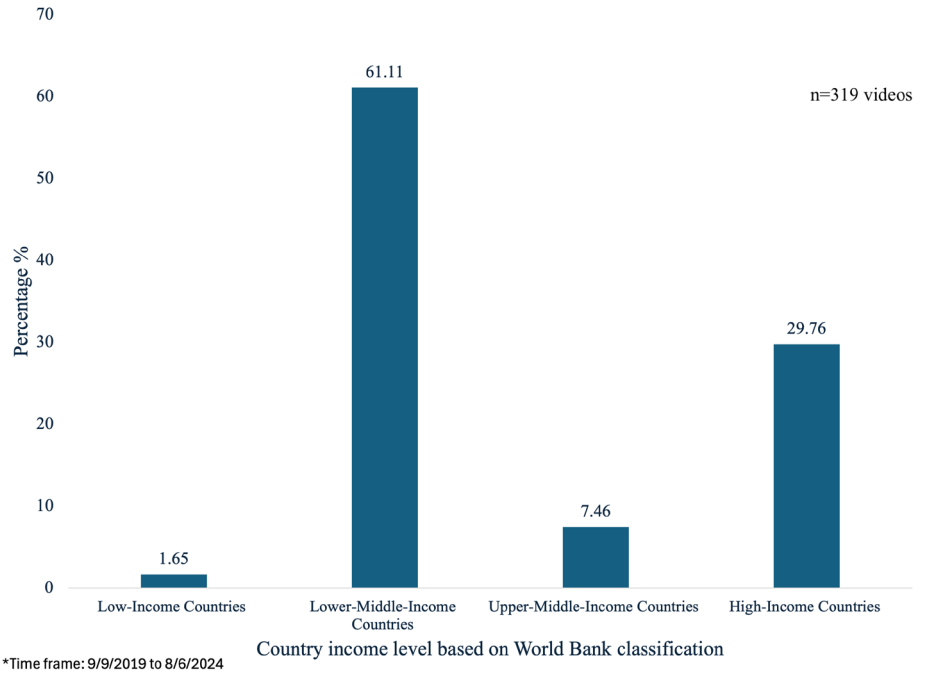

Fig. 5. Geographical distribution of YouTube views of the @ForeverLearningAnaes YouTube channel according to country income level.

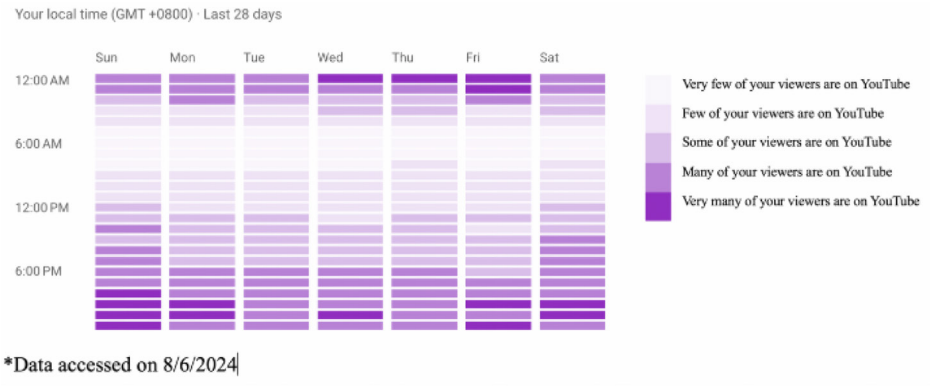

Fig. 6. The times when viewers of the @ForeverLearningAnaes YouTube channel are on YouTube.

When comparing basic sciences videos to clinical/procedural videos on FLA, clinical/procedural videos showed higher viewer engagement. This was evidenced by higher median average percentage viewed, median average view duration, and median views per playlist start, despite basic sciences videos being available on YT for a longer duration (Table 4). The average view duration per FLA video was 3 minutes and 15 seconds.

Table 4. Engagement metrics of 319 educational videos on @ForeverLearningAnaes YouTube channel published between 9/9/2019 to 8/6/2024 according to video type

Metric	Video type		*P*-value	Statistic
	Basic sciences	Clinical/ Procedural		
Number of videos	178	141		
Median years since published (range)	4.0 (3.5)	1.5 (4.7)	< 0.001	U = 4790.5
Median views[a] (range)	808 (43041)	249 (18713)	< 0.001	U = 6950.0
Median watch time[a] in hours (range)	34.6 (3512.0)	16.4 (943.5)	< 0.001	U = 8191.0
Median average percentage viewed[a] (range)	20.4 (54.0)	27.2 (81.5)	< 0.001	U = 15404.0
Mean average view duration[a, b] (SD)	2.8 min (1.0 min)	3.4 min (1.3 min)	< 0.001	t = -3.889
Median views from playlist[a] (range)	119 (4206)	47 (593)	< 0.001	U = 3907.5
Median views per playlist start[a] (range)	2.5 (11.5)	2.8 (13.5)	< 0.001	U = 14598.0
Median playlist watch time in hours[a] (range)	8.7 (136.2)	3.7 (30.6)	0.009	U = 5464.0
Median likes vs dislikes %[a] (range)	100.0 (75.0)	100 (33.3)	< 0.001	U = 13314.5
Median impressions[a] (range)	19483 (476082)	8358 (228401)	0.019	U = 6373.5
Median impressions click through rate[a] (range)	2.8% (13.7%)	1.9% (7.5%)	< 0.001	U = 9024.0
Mean card clicks[a] (SD)	.01% (.07%)	.04% (.50%)	< 0.001	t = -0.962
Median subscribers[a] (range)	6 (548)	2 (377)	0.337	U = 8197.0

[a]per video
[b]Mean difference (95% CI) = -0.5 (-0.8 to -0.3)

Discussion

Our study developed and validated a concise survey questionnaire to assess anaesthesiology trainees' e-learning usage and needs, yielding a high response rate[13] of 90.3%. This tool may be useful for future research on digital learning preferences among medical trainees. The survey findings provided valuable insights into anaesthesiology trainees' e-learning habits. The most preferred formats were e-books/articles, videos, slide-based courses, and quizzes. Trainees spent significantly more time on e-learning than traditional learning, with first-year students dedicating the most hours, likely due to their intensive primary examination preparation. The most commonly used devices were smartphones, tablets, and laptops. Key motivations for e-learning included exam preparation, case management, and acquiring new knowledge. The most valued features were flexibility in access, self-paced learning, and convenience. Trainees rated NYSORA Education as the most useful YT channel and preferred video durations of 5–15 minutes. The most desired content types were procedural skills, journal article summaries, and practice exam questions-and answers.

These findings align with prior studies emphasising the importance of digital learning for self-directed, lifelong education.[14] Past research highlighted the role of social technologies in creating flexible learning environments, allowing trainees to tailor their education to individual needs.[15] The COVID-19 pandemic accelerated digital learning adoption, with 98.7% of trainees expressing interest in learning anaesthesiology and critical care via YT. YT's accessibility facilitates on-demand education,[16] particularly benefiting trainees in resource-limited settings.[17]

We examined global engagement patterns using analytics from FLA, a dedicated anaesthesiology YT channel. Videos reached audiences in 97 countries, with most views from lower-middle-income countries.[11] This suggests that YT enhances global access to medical education, contributing to professional development and knowledge dissemination.[18] Viewer demographics were consistent with our survey, with most users aged 18–34 years and accessing content via mobile phones and computers. The primary traffic sources were YT search, suggested videos, and external sources. New and returning viewers were roughly equal in their contribution to the total percentage of views on FLA, with comments largely positive or inquisitive.[12]

Comparing content types, clinical and procedural videos received higher engagement than basic sciences videos, as evidenced by longer watch times and increased interaction. This finding aligns with the results of our survey among UMMC anaesthesiology trainees regarding their preferred content topics. These findings mirror previous research demonstrating the effectiveness of video-based learning

for procedural skills training.[19] The average view duration per video was about 3 minutes, slightly lower than the 5–15 minutes preferred by trainees, indicating potential areas for engagement improvement.

Taken together, these findings highlight a clear difference between trainees' stated preferences and actual engagement patterns on the FLA channel. While trainees reported an optimal video length of 5–15 minutes, real-world analytics demonstrated an average viewing duration of only 3 minutes, suggesting that attention spans and competing demands may limit sustained engagement. This discrepancy underscores the need for educators to design content that balances pedagogical depth with brevity and accessibility. Furthermore, the higher engagement with procedural content compared to basic sciences reflects a pragmatic, exam- and practice-driven learning culture, which may risk underemphasizing foundational knowledge unless curricula deliberately integrate both. The global reach of the FLA channel, particularly in lower-middle-income countries, also raises important equity implications: YT may serve as a low-cost bridge for disseminating specialised medical education internationally, but reliance on a single platform highlights vulnerabilities in access, quality assurance, and sustainability.

Strategies to enhance viewer engagement

To optimise e-learning via YT, we propose several strategies based on previous research:[1,15,18]

1. Aligning content with core textbook topics and board exam materials.
2. Addressing gaps in local curricula.
3. Using high-quality production with subtitles, clear audio, and engaging visuals.
4. Keeping videos between 6–9 minutes to balance information density and engagement.
5. Employing an informal, tutorial-style approach with voiceover animations.
6. Organising videos into structured playlists.
7. Actively responding to viewer feedback and prompting continued engagement.

By implementing these strategies, YT-based anaesthesiology education can better cater to trainees' preferences and improve retention.

Study limitations

Our study had several limitations. While the survey had a high response rate (90.3%), the 9.7% who did not participate could have introduced bias. The study was conducted at a single centre, limiting generalizability. Additionally, FLA videos were produced by a single creator, affecting content diversity. YT's proprietary algorithm affects real-time data accuracy and precludes validation. Viewing a video does not necessarily indicate knowledge retention, which was beyond the study's scope.

Trainees without a subscription to YT Premium may have been distracted by advertisements, affecting engagement. The lack of a validated rating system was another limitation, as no standardised framework exists to evaluate the quality of medical education videos on YT.

True analytical comparison between the survey dataset and YT analytics could not be performed. YT analytics only provides aggregated descriptive summary data rather than subject-level information, restricting the analysis to a side-by-side descriptive comparison rather than statistical testing using software such as SPSS.

Although the FLA YouTube channel was not ranked by trainees as the most popular or useful among anaesthesiology channels, it was selected for analysis for pragmatic reasons. As the channel owner, the author of this study had unrestricted access to its analytics data, enabling detailed examination without the need for external permissions. Importantly, the channel demonstrates global reach, with viewership spanning 97 countries, supporting its relevance as a proxy for international usage patterns. Given time and resource constraints, analysis was restricted to a single channel to limit complexity. Future research could strengthen generalizability by requesting access to analytics from higherranked channels identified in the trainee survey, allowing comparison of similarities and differences in international usage patterns across various anaesthesiology and critical care channels.

Future research directions

Further studies should explore the impact of e-learning on academic performance and skill acquisition, comparative effectiveness of video-based versus traditional learning methods, and optimisation of artificial intelligence-driven learning tools for anaesthesiology education.[1]

By addressing these areas, educators can refine digital learning strategies, ensuring that e-learning platforms remain effective, engaging, and accessible for anaesthesiology trainees worldwide.

Conclusion

This study highlights the need for effective online educational content and the role of professional educators in enhancing its quality.[20] Despite challenges, multimedia learning theories[21] provide guidelines for content design. Our study findings aim to support educators in developing digital learning content that promote self-paced, on-demand, and lifelong learning.

Declarations

Ethics approval and consent to participate

The study titled 'Survey among anaesthesiologist trainees on e-learning usage and needs in comparison with big data analysis of an educational anaesthesiology YouTube channel' was performed in accordance with the Declaration of Helsinki, had informed and explicit consent from study subjects, and had approval by an appropriate ethics committee/institutional review board (Medical Research Ethics Committee, Universiti Malaya Medical Centre; MREC ID NO: 2024226-13465).

Competing interests

None to declare.

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Appendix

SURVEY QUESTIONNAIRE: E-LEARNING USAGE AND NEEDS

Interviewee code number (for researcher's usage):
Instructions: Please tick ✓ at the appropriate box/boxes and fill up (in words) in the appropriate box, thank you.

Demographics			
1. Age (years)	_____	2. Gender	☐Male ☐Female
3. Ethnicity	☐Malay ☐Chinese ☐Indian ☐Others: _____	4. Academic year	
5. Marital status	☐Married ☐Unmarried	6. Number of children	_____
7. Usual mode of **transport** to UMMC	☐Public transport ☐Private transport: Car ☐Private transport: Motorcycle ☐Walking ☐Others: _____	8. Estimated **duration of time to travel** between UMMC and place of stay	a) During rush hour traffic: _____ (hour/min) b) During light traffic: _____ (hour/min)

E-LEARNING (LEARNING VIA ELECTRONIC MEDIA) USAGE AND NEEDS		
1. Rate the **importance** of the following **E-learning content types or tools** to you in learning anaesthesiology and critical care topics: **E-books/articles**: ☐unimportant ☐slightly important ☐moderately important ☐very important ☐extremely important **Podcasts**: ☐unimportant ☐slightly important ☐moderately important ☐very important ☐extremely important **Videos**: ☐unimportant ☐slightly important ☐moderately important ☐very important ☐extremely important **Slide-based courses (includes weekly department CMEs)**: ☐unimportant ☐slightly important ☐moderately important ☐very important ☐extremely important **Quizzes**: ☐unimportant ☐slightly important ☐moderately important ☐very important ☐extremely important **Lecturio**: ☐unimportant ☐slightly important ☐moderately important ☐very important ☐extremely important **Others**: _____ ☐unimportant ☐slightly important ☐moderately important ☐very important ☐extremely important		
2. How many **hours per week** do you spend on **E-learning** (including online CMEs)?	☐ None ☐ Less than 1 hour per week ☐ 1-2 hours per week	☐ 2-4 hours per week ☐ 4-6 hours per week ☐ More than 6 hours per week
3. How many **hours per week** do you spend on learning using **hardcopy** materials?	☐ None ☐ Less than 1 hour per week ☐ 1-2 hours per week	☐ 2-4 hours per week ☐ 4-6 hours per week ☐ More than 6 hours per week
4. What **type of device** do you use for E-learning? *(select all that apply)*	☐ Mobile phone ☐ Laptop computer ☐ Tablet computer	☐ Desktop computer ☐ Smart TV ☐ Others: _____
5. Which of the following describe **how you use E-learning**? *(select all that apply)*	☐ Part of routine study ☐ To learn a new topic ☐ Revision for exam	☐ Preview prior to managing a case in the operation theatre/Clinic/ICU ☐ Others: _____

E-LEARNING (LEARNING VIA ELECTRONIC MEDIA) USAGE AND NEEDS		
6. Which of the following features of E-learning do you find most **valuable**? *(select all that apply)*	☐ Ability to review materials whenever I want ☐ Ability to review materials wherever I want ☐ Effective in learning how to perform complex procedures	☐ Ability to review materials at my own pace ☐ Ability to review materials repeatedly ☐ Others: _____
7. a) Have you watched these **YouTube (YT) channels?** b) If watched, are the contents of the said YT channel **helpful** in learning anaesthesiology and critical care topics?	**1) NYSORA education** ☐Never watched ☐Unhelpful ☐Slightly helpful ☐Moderately helpful ☐Very helpful ☐Extremely helpful **2) American Society of Anesthesiologists** ☐Never watched ☐Unhelpful ☐Slightly helpful ☐Moderately helpful ☐Very helpful ☐Extremely helpful **3) Anesthesia Patient Safety Foundation** ☐Never watched ☐Unhelpful ☐Slightly helpful ☐Moderately helpful ☐Very helpful ☐Extremely helpful **4) International Society for Anesthetic Pharmacology** ☐Never watched ☐Unhelpful ☐Slightly helpful ☐Moderately helpful ☐Very helpful ☐Extremely helpful **5) Royal College of Anaesthetists** ☐Never watched ☐Unhelpful ☐Slightly helpful ☐Moderately helpful ☐Very helpful ☐Extremely helpful **6) ForeverLearning** ☐Never watched ☐Unhelpful ☐Slightly helpful ☐Moderately helpful ☐Very helpful ☐Extremely helpful **7) Others** *(please state):* ☐Never watched ☐Unhelpful ☐Slightly helpful ☐Moderately helpful ☐Very helpful ☐Extremely helpful	
8. What is your **preferred duration of a YT video** to learn anaesthesiology and critical care topics?	☐ <5min ☐ 5-15min ☐ 15-30min	☐ 30-45min ☐ >45min
9. What are your **preferred content topics** when learning anaesthesiology and critical care topics on YT? *(select all that apply)*	☐ Basic sciences ☐ Procedural topics ☐ Clinical topics	☐ Others: _____

E-LEARNING (LEARNING VIA ELECTRONIC MEDIA) USAGE AND NEEDS	
10. Are you likely to **watch the following content types** when learning anaesthesiology and critical care topics on YT?	**1) Recorded didactic lecture** ☐Very unlikely ☐Unlikely ☐Neutral ☐Likely ☐Very likely **2) Discussions or debates** ☐Very unlikely ☐Unlikely ☐Neutral ☐Likely ☐Very likely **3) Journal article summaries** ☐Very unlikely ☐Unlikely ☐Neutral ☐Likely ☐Very likely **4) Procedural skills** ☐Very unlikely ☐Unlikely ☐Neutral ☐Likely ☐Very likely **5) Case presentations** ☐Very unlikely ☐Unlikely ☐Neutral ☐Likely ☐Very likely **6) Practice exam Q&A** ☐Very unlikely ☐Unlikely ☐Neutral ☐Likely ☐Very likely
Would you like to learn more about anaesthesia & critical care education on YT?	☐ Yes ☐ No

Operational definitions of variables and selected YT channel analytics metrics

Survey on usage patterns, format preferences and content needs of anaesthesia residents outcome variables:

1. Preferred e-learning content format: Preferred e-learning content format chosen by the respondent. Options include ‘E-books’, ’podcasts’, ’videos’, ‘slide based courses’, ‘quizzes’, ‘others’.
2. Hours spent on e-learning per week: Hours spent on e-learning per week by the respondent.
3. Hours spent on traditional learning per week: Hours spent on learning using hardcopy materials per week by the respondent.
4. Device type used for e-learning: Type of device used by the respondent for e-learning. Options include ‘mobile phone’, ‘computer’, ‘tablet’, ‘smart TV’ and ‘others’.
5. Manner in which e-learning is used: Manner in which e-learning is used in learning anesthesiology and critical care topics. Options include ‘part of routine study’, ‘to learn a new topic’, ‘revision for exam’, ‘preview prior to managing a case in the OR/Clinic/ICU’ and ‘others’.

6. Features of e-learning found to be valuable by respondents: Options include 'ability to review materials whenever I want', 'ability to review materials wherever I want', 'effective in learning how to perform complex procedures', 'ability to review materials at my own pace', 'ability to review materials repeatedly' and 'others'.
7. Usefulness of select anesthesiology YT channels: Rating (Likert scale) of the usefulness of select anesthesiology YT channels by the respondent.
8. Preferred duration of YT video: Preferred duration of YT videos by the respondent for learning anesthesiology and critical care topics.
9. Preferred content topics: Preferred content topics by the respondent for learning anesthesiology and critical care topics. Options include 'basic science topics', 'procedural topics', 'clinical topics', and 'others'.
10. Preferred content type: Preferred content type by the respondent for learning anesthesiology and critical care topics. Options include 'recorded didactic lectures', 'discussions or debates', 'journal article summaries', 'procedural skills', 'case presentations', and 'practice exam Q&As'.

Selected YT channel analytics metrics[7]
Audience metrics

1. Viewer demographics: Statistics of viewers who watched the videos of a YT channel stratified according to age, gender and geography.
2. When viewers are on YT: Frequency distribution of times viewers were on YT
3. Traffic sources: Traffic sources report shows how viewers found the content creator's videos and which sources garnered the most views and watch time.
4. Subscriber growth: The change in total subscribers which is found by subtracting subscribers lost from subscribers gained for the selected date range and region.

Engagement metrics

1. Unique viewers: Estimated number of people who watched one's contents within a selected date range.
2. Returning viewers: Viewers who have previously watched your channel and returned to watch within the selected time period.
3. Average views per viewer: The average number of times a viewer watched any video on a channel (in channel analytics) or a particular video (in video analytics).
4. Watch time: Total amount of time viewers have watched videos of a YT channel.
5. Average percentage viewed: Average percentage of a video that the audience watches per view.

6. Average view duration: Estimated average minutes watched per view for the selected video and date range.
7. Likes (vs dislikes): The percentage of likes a video received (out of the total number of likes and dislikes).
8. Comments: Comments from viewers on a YT video.
9. Impressions click through rate: Views per impressions shown, whereby impressions are the number of times video thumbnails were shown to viewers on YT.
10. Card clicks: Number of times a card has been clicked.
11. Top videos: Most-watched videos in a specified time period.
12. Views from playlist: Number of views a video receives when watched as part of a playlist.
13. Playlist watch time: Duration of time people watch a video when watched as part of a playlist.
14. Views per playlist start: Average number of video views after a playlist is initiated.

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Submental intubation in maxillofacial fracture surgery: single-centre experience

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Abstract

Introduction: Submental intubation provides a valuable alternative in maxillofacial fracture surgery when oral and nasal routes are contraindicated. A key advantage is that it allows for dental occlusion, which is necessary for proper alignment of fractured bone fragments. Despite its benefits, this technique remains underutilised in Malaysia due to limited research, training, and exposure among anaesthesiologists. Therefore, this study aimed to explore the types of maxillofacial fractures as well as the indications and complications of submental intubation.

Methods: This was a retrospective study using the census sampling technique. A total of 11 patients who underwent submental intubation via a paramedian approach with double haemostats at Hospital Teluk Intan between January 2022 and March 2025 were reviewed. Immunocompromised patients were excluded. A descriptive analysis was performed on the types of maxillofacial fractures, indications for submental intubation and postoperative complications.

Results: Data from 11 patients were analysed (median age: 24 years; interquartile range: 17–42 years; 9 males and 2 females; 8 Malays, 1 Chinese and 2 Indians). Seven patients (63.6%) sustained combined midface and mandibular fractures, 3 patients (27.3%) had midface fractures, and 1 patient (9.1%) had mandibular

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fracture. Additionally, 7 patients (63.6%) presented with nasal bone and/or septum fractures, 2 patients (18.2%) had skull base fracture, and 2 patients (18.2%) had combined fractures of nasal bone, septum, and skull base. One patient developed a postoperative infection and hypertrophic scar, while the remaining 10 recovered uneventfully. The observed complication rate was 9.1% (95% CI: 0.2%–40.3%).

Conclusion: Submental intubation appears to be a safe and feasible alternative with minimal complications. Larger studies are needed to validate these preliminary findings.

Keywords: airway management, alternative airway techniques, complications, maxillofacial trauma, submental intubation

Introduction

Airway management in patients with complex maxillofacial fractures remains a significant challenge for anaesthesiologists. In Malaysia, submental intubation is not commonly used outside the field of oral and maxillofacial surgery despite its advantages. Nasal intubation is typically the method of choice in maxillofacial surgery because it allows intraoperative maxillomandibular fixation to achieve optimal dental occlusion and proper alignment of fractured facial bone fragments.[1-3] However, in cases with fractures of the naso-orbital ethmoid complex, skull base, or anterior and middle cranial fossae,[4,5] nasal intubation is rendered unsafe and is contraindicated. In such scenarios, submental intubation offers a safe, effective, and practical alternative in intraoperative airway management without compromising surgical access or occlusion.

Submental intubation was first introduced by Altemir in 1986 to allow the passage of an endotracheal tube through the anterior floor of the oral cavity.[1,4] The original procedure begins with oral intubation followed by conversion to the submental route.[1,4] This is achieved by making a 2-cm transverse incision in the submental region, followed by blunt dissection through muscles of the floor of the mouth until the oral mucosa is reached.[4] The pilot balloon and the endotracheal tube are then exteriorised through the soft tissue tunnel using a haemostat.[1,4] After the surgery, the endotracheal tube is reversed to its original oral position.[1] Since its introduction, various modifications have been made to the technique to improve safety and efficiency.

With the development of submental intubation, tracheostomy, which is traditionally the alternative to nasal and oral intubation, can be avoided in cases

not requiring prolonged postoperative ventilation.[1] Tracheostomy is generally undesired and is typically reserved as a last resort due to its specialised postoperative care and the higher risk of both immediate and late complications,[1,2,4,5] including pneumothorax, pneumonia, surgical emphysema, tracheal stenosis, tracheomalacia, recurrent laryngeal nerve palsy, and injury to other structures of the cervical neck.[1,4,5]

In contrast, submental intubation is relatively safe, minimally invasive, simple and time-efficient.[1,4] The literature reports a 100% success rate with the average duration of the procedure being approximately 10 minutes.[6,7] The complication rate is low, ranging from 7% to 9%.[1,7] The most common complication is skin infection, followed by hypertrophic scarring and orocutaneous fistula formation.[1,5,7] Rare complications include injury to adjacent vital structures, such as lingual neurovascular bundle, marginal mandibular branch of facial nerve, sublingual gland, duct of the submandibular gland and formation of mucocele.[1-4] In addition, other rare complications associated with the endotracheal tube include tube dislodgement or kinking, accidental extubation, tube migration into the bronchus, pilot balloon damage, and desaturation.[2]

To date, research on submental intubation within the local context remains limited, particularly in relation to its local incidence, complications, and feasibility. While submental intubation has been studied in other regions, the technique remains underutilised in Malaysia, largely due to a lack of widespread training and exposure among anaesthesiologists. Consequently, many are unfamiliar with the procedure, leading to hesitation in its application.[2] This highlights the need to assess the current practice of submental intubation in Malaysia and evaluate its feasibility, associated complications, and potential for broader implementation. Accordingly, this study aimed to investigate the types of maxillofacial fractures, indications, and complications of using submental intubation in the Department of Oral and Maxillofacial Surgery of Hospital Teluk Intan.

Methods

This was a retrospective study using the census sampling technique. This study was approved by National Medical Research Register (RSCH ID-25-03214-SG7). A total of 11 patients who underwent submental intubation for intraoperative airway management at Hospital Teluk Intan between January 2022 and March 2025 were identified from the operation theatre list. All patients with maxillofacial fractures in which nasal and oral intubation were not feasible were included in this study. Immunocompromised patients with impaired postoperative healing and those

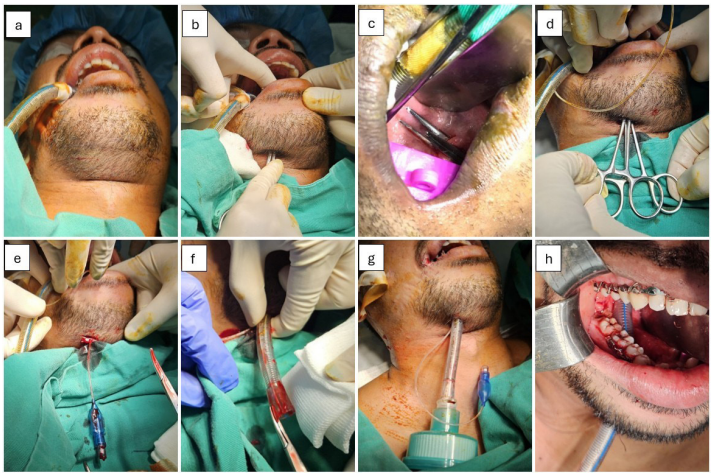

Fig. 1. Submental intubation technique. *(a)* With oral intubation in place, 1.5-cm paramedian incision made at the submental region. *(b)* Blunt dissection made from the incision site through the floor of the mouth. *(c)* Intraoral view showing blunt dissection to the oral mucosa. *(d)* Insertion of double haemostats. *(e)* Exteriorisation of the pilot balloon through the soft tissue tunnel using a haemostat. *(f)* Exteriorisation of the endotracheal tube using another haemostat. *(g)* Extraoral view showing completed submental intubation after conversion from the oral to submental route. *(h)* Intraoral view showing completed submental intubation.

who were not compliant with postoperative instructions were excluded from the study. Sample size calculation was not applicable, as all eligible patients were included in the study.

The same technique of submental intubation was employed for all patients by 2 oral and maxillofacial surgeons. This technique was in accordance with the general principles of the original Altemir technique using a flexometallic endotracheal tube with a modification consisting of a 1.5-cm paramedian incision and exteriorisation of the endotracheal tube and pilot balloon using double haemostats as illustrated in Figure 1.

As routine antibiotic prophylaxis, 1.5 g of intravenous cefuroxime was given 1 hour preoperatively, and the oral dose of 250 mg was continued twice daily postoperatively for 1 week. Oral hygiene was maintained postoperatively using 0.12% chlorhexidine mouthwash 2 to 3 times daily for 1 week. Patients were reviewed postoperatively on day 1, then at 1 week and 1 month to assess any postoperative complications. Surgical site infection was defined as infection that occurred after surgery at the site of submental intubation with purulent drainage, pain, swelling, redness, or heat. A hypertrophic scar was defined as an abnormally thick, raised

and red or dark scar that formed at the site of submental intubation. Inter-rater agreement was not performed as the measurement outcomes were primarily objective.

The clinical record, computed tomography report, and operation note of patients were reviewed and analysed. Data collection form was used to collect the study data on the types of maxillofacial fractures, indications, and complications of submental intubation. Statistical analysis was performed using SPSS 24.0 (IBM Corporation, USA). Descriptive data was presented as number and percentage of patients in respective categories.

Results

Between January 2022 and March 2025, 99 patients in the Department of Oral and Maxillofacial Surgery in Hospital Teluk Intan underwent maxillofacial fracture surgery under general anaesthesia using various intubation techniques. Among these, submental intubation was used in 11 patients (11.1%) as the means of intra-operative airway management. The demographics of patients who underwent submental intubation are presented in Table 1; most patients were male (81.8%) and Malay (72.7%) with the median age of 24 years. The clinical profile of patients who underwent submental intubation are shown in Table 2.

Figure 2 shows the types of maxillofacial fractures that required submental intubation. Combined midface and mandibular fractures were the most common (63.6%), followed by isolated midface (27.3%) and isolated mandibular (9.1%) fractures. Figure 3 highlights the indications for submental intubation: 7 patients (63.6%) underwent submental intubation due to nasal bone and/or septum fractures, 2 (18.2%) due to base of skull fracture, and 2 (18.2%) due to combined fractures of nasal bone, septum, and skull base.

Only 1 patient developed complications, including skin abscess on postoperative day 3 and hypertrophic scar at 2 weeks postoperatively, both of which were managed successfully. The remaining 10 patients had uneventful recoveries (Fig. 4). The observed complication rate was 9.1% (95% CI: 0.2%–40.3%).

Table 2. Clinical profile of patients who underwent submental intubation at Hospital Teluk Intan between January 2022 and March 2025

Case	Gender	Age	Ethnicity	Types of maxillofacial fracture surgery	Indications	Complications
1	Male	42	Chinese	Combined midface and mandible fractures (left zygomaticomaxillary complex, Le Fort 1, bilateral subcondyles and symphysis of mandible)	Nasal bone and septum fractures	None
2	Male	25	Indian	Combined midface and mandible fractures (left zygomaticomaxillary complex, Le Fort 1, bilateral parasymphysis of fracture)	Nasal bone and septum fractures	None
3	Male	36	Malay	Isolated midface fracture (Le Fort 2)	Nasal bone and septum fractures	Skin abscess, hypertrophic scarring
4	Male	17	Malay	Combined midface and mandible fractures (left zygomaticomaxillary complex, left coronoid process of mandible)	Base of skull fracture	None
5	Male	41	Malay	Combined midface and mandible fractures (Le Fort 2, left zygomaticomaxillary complex, right parasymphysis, left ramus of mandible)	Base of skull, nasal bone and septum fractures	None

Case	Gender	Age	Ethnicity	Types of maxillofacial fracture surgery	Indications	Complications
6	Male	24	Indian	Isolated midface fracture (right zygomaticomaxillary complex, Le Fort 2)	Base of skull, nasal bone and septum fractures	None
7	Male	33	Malay	Isolated midface fracture (Le Fort 1, left zygomaticomaxillary complex)	Nasal bone and septum fractures	None
8	Male	22	Malay	Combined midface and mandible fractures (left zygomaticomaxillary complex, left angle of mandible)	Nasal septum fracture	None
9	Male	20	Malay	Combined midface and mandible fractures (Le Fort 1, left zygomaticomaxillary complex, right orbital floor, left parasymphysis, left body of mandible)	Nasal bone fracture	None
10	Female	19	Malay	Combined midface and mandible fractures (right zygomaticomaxillary complex, symphysis of mandible)	Nasal bone fracture	None
11	Female	22	Malay	Isolated mandible fracture (left parasymphysis, right angle of mandible)	Base of skull fracture	None

Table 1. Demographics of patients who underwent submental intubation at Hospital Teluk Intan between January 2022 and March 2025

Demographics	Number of patients (%)
Gender	
Male	9 (81.8)
Female	2 (18.2)
Age	
≤ 18	1 (9.1)
>18 and <60	10 (90.9)
Ethnicity	
Malay	8 (72.7)
Chinese	1 (9.1)
Indian	2 (18.2)

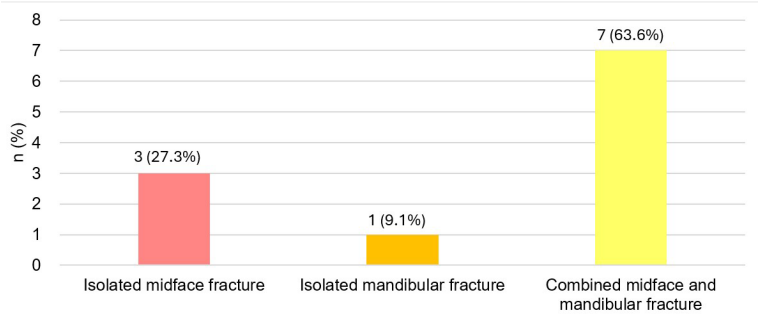

Fig. 2. Types of maxillofacial fractures that underwent submental intubation at Hospital Teluk Intan between January 2022 and March 2025.

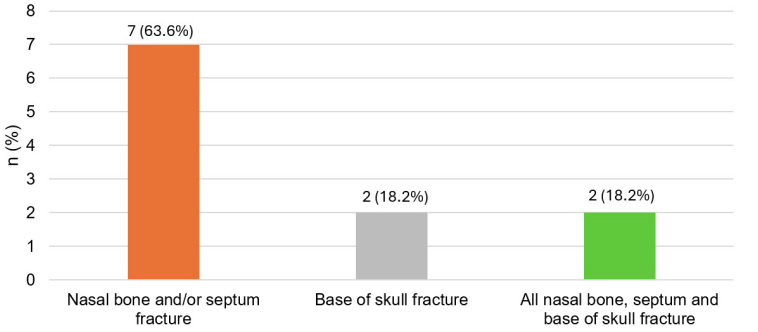

Fig. 3. Indications for submental intubation at Hospital Teluk Intan between January 2022 and March 2025.

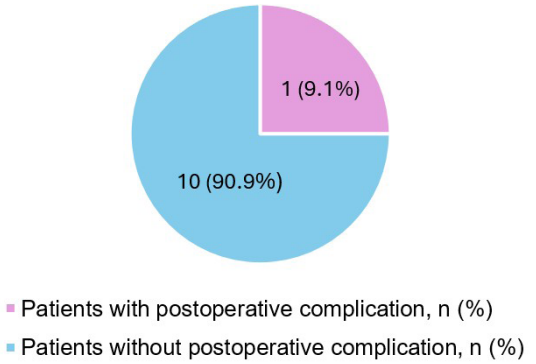

Fig. 4. Complications of submental Intubation at Hospital Teluk Intan between January 2022 and March 2025.

Discussion

Patient profile

Nasal intubation is routinely the first-line route of intubation in oral and maxillofacial surgery to ensure unobstructed access to the surgical field of the oral cavity. In this study, more than half the cases presented with fractures of the nasal bone and/or septum, approximately one-fifth with fractures of the base of skull, and another one-fifth sustained combined fractures of the nasal bone, septum, and base of the skull. Nasal intubation is contraindicated in these cases because it poses a risk of intracranial penetration, cerebrospinal fluid leakage, and meningitis.[4,5] Hence, submental intubation is the preferred and most reliable alternative, as it allows the surgeon to maintain dental occlusion throughout the intraoperative fixation of fractured bones.

Submental intubation is commonly performed in maxillofacial fracture surgery followed by orthognathic surgery.[1,7] In this study, the majority of the cases involved combined midface and mandibular fractures, with 3 patients presenting isolated midface fractures and only 1 with an isolated mandibular fracture. While nasal intubation is contraindicated in certain cases, oral intubation is also impractical because the endotracheal tube obstructs the surgical field and prevents the achievement of dental occlusion, which is essential for proper fracture fixation.

Technical modification

The same technique of submental intubation was performed by 2 oral and maxillofacial surgeons for all patients. In Altemir's original method, the suggested length of skin incision is 2 cm parallel to the mandibular lower border and about one fin-

ger-width below it.[1,2] In this study, a slightly smaller, paramedian incision of 1.5 cm was made on the submandibular region to minimise scarring. This incision length is sufficient to pass a flexometallic tube up to 7.5 mm size with minimal trauma and stress to the skin during exteriorisation.[1]

As the dissection closely follows the medial aspect of the mandible, a paramedian approach was used for all patients in this study with the rationale to avoid injury to the surrounding vital structures.[8] When this technique was originally introduced by Altemir in 1986, the median approach through the submental triangle was standard. However, in 2003, Altemir recommended the paramedian approach in the submandibular triangle to avoid damaging vital structures such as the anterior belly of the digastric muscle, the geniohyoid muscle insertion, and the submandibular gland duct.[2] Therefore, the paramedian approach is believed to be anatomically safer and associated with fewer postoperative complications.

While some surgeons prefer to use a single haemostat to exteriorise the endotracheal tube and pilot balloon, this technique risks creating a separate pathway for the tube after exteriorising the pilot balloon.[1] Various modifications and devices have been introduced to maintain the patency of the submental tunnel, including nasal speculums, dilators, pharyngeal loop, 2-0 silk suture, laparoscopic trocars, sterile disposable camera cable drapes, Nelaton catheters, dental needle cap fixations, percutaneous dilatational tracheostomy kits, and ultrasound-guided techniques.[1,2] In this study, double haemostats were used to exteriorise the endotracheal tube and pilot balloon sequentially. After creating the submental tunnel, the second haemostat was inserted guided by the first haemostat.[1] The haemostats then grasped and exteriorised the endotracheal tube and pilot balloon, respectively, one after another, maintaining a single continuous passage. Compared to device-assisted methods, using double haemostats is a cost-effective and straightforward technique in performing submental intubation.

The technique employed in this study was simple and time efficient, requiring only basic surgical instruments. The average duration of the procedure was under 10 minutes, comparable to previous reports.[6,7] Given its relative simplicity and speed, submental intubation remains a favourable airway route in maxillofacial surgery when nasal intubation is not feasible.

Complications

The complication rate of submental intubation in our study was low (9.1%), consistent with previous reports of 7% to 9%.[1,7] Only 1 out of 11 patients developed postoperative complications, a skin abscess and hypertrophic scar. This aligns with an earlier study identifying skin infection (3.5%) as the most common complication, followed by hypertrophic scar (1.2%), and orocutaneous fistula formation (1.1%).[1,5,7]

Compared to tracheostomy which is another alternative when nasal intubation is contraindicated, submental intubation is associated with fewer long-term complications and requires minimal postoperative care, making it a safer and less invasive airway route.[5]

The only complicated case involved the patient who developed a skin abscess on postoperative day 3. Although infection can result from improper aseptic technique,[9] all submental intubations adhered to the standard aseptic protocol, including preoperative skin disinfection and sterile draping. Routine antibiotic prophylaxis, 1.5 g of intravenous cefuroxime was given 1 hour preoperatively followed by postoperative doses for 1 week. Oral hygiene was maintained using 0.12% chlorhexidine 2 to 3 times a day postoperatively for 1 week.

The abscess formation most likely resulted from other factors such as saliva trickling from the intraoral wound, suboptimal wound closure, and contamination during the reversal from submental to oral intubation.[9] To minimise the risk of infection, Das *et al.* recommend avoiding overly tight skin sutures to allow drainage and leaving the mucosal wound to heal by secondary intention.[5] Accordingly, this study emphasises procedural sterility, controlled intraoral contamination, meticulous wound closure, postoperative wound care, broad-spectrum antibiotics, and oral hygiene maintenance.[5]

The same patient also developed a hypertrophic scar 2 weeks postoperatively, likely due to infection-induced inflammation impairing wound healing. The hypertrophic scarring may also be related to individual susceptibility to abnormal wound healing in response to skin inflammation.[10] Overactive fibroblasts producing excess collagen and growth factors contribute to hypertrophic scarring.[10] No treatment was provided as it was aesthetically acceptable to the patient and was well concealed below the lower border of the mandible.

Limitations

A key limitation of this study is its small sample size, as submental intubation is not the first-line route for airway management in maxillofacial fracture surgery and is therefore not routinely performed at this single-centre site. With only 1 patient experiencing postoperative complications, the 95% confidence interval was wide (0.2%–40.3%) limiting the precision of the estimate. Additionally, the retrospective design of this study introduces the risk of missing data and potential single-centre bias.

Future recommendations

The accuracy and generalisability of the study can be enhanced through larger prospective cohort studies or by pooling data from multiple centres. This study

demonstrated a high success rate for submental intubation with minimal postoperative complications when performed by trained clinicians. These findings reinforce the feasibility of submental intubation as a safe and effective alternative to tracheostomy in maxillofacial surgery when nasal intubation is contraindicated. Current anaesthesia training programmes in Malaysia offer limited exposure to submental intubation, highlighting a clear gap in curriculum design. The results of this study support the integration of structured submental intubation training into postgraduate curriculum and continuous professional development initiatives. Furthermore, interdisciplinary collaboration between anaesthesiologists and oral maxillofacial surgeons should be actively promoted to broaden the adoption of this technique.

Conclusion

This single-centre experience suggests that submental intubation is a feasible and safe alternative in maxillofacial surgery when oral and nasal intubation are not viable. With only 1 minor complication reported, it demonstrates the technique's low-risk profile when performed under aseptic conditions with proper postoperative care. Further research through larger prospective studies is needed to confirm these findings. Submental intubation remains an underutilised yet effective option for managing difficult airways—a clean, controlled and practical technique deserving of a place in the contemporary anaesthetist's repertoire.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the Declaration of Helsinki and approved by the National Medical Research Register (RSCH ID-25-03214-SG7). Informed consent was obtained from patients for photography and publication purposes.

Competing interests
None.

Funding
None.

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Effectiveness of a biological isolation chamber in containing and evacuating aerosolised particles during simulated patient transport

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Abstract

Introduction: The BIOBASE biological isolation chamber (BBIC) was used to limit the spread of SARS-CoV-2 transmission during transport of COVID-19 patients. We aim to study the effectiveness of BBIC in limiting the spread of aerosol during static transport amongst healthcare workers.

Methods: Nebulised saline 0.9% was generated to saturate aerosolised particles within the BBIC placed within a constructed outer enclosure. Negative pressure was activated and particulate matter (PM), PM_{10} and $PM_{2.5}$ concentrations were measured over 60 minutes using AS-LUNG sensors placed inside (C_{in}) and outside (C_{out}) the BBIC. Control, closed ports, and open port models were developed to assess the effectiveness of the BBIC in containing and evacuating aerosolised particles. The ratio of measured C_{in} to the measured $C_{out,}$ designated as F_{iso}, ($F_{iso} = C_{in}/ C_{out}$) was derived.

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Results: The differences in F_{iso} value of PM_{10} compared to $PM_{2.5}$ in the closed ports test were significant at minute 15 and 25 ($p < 0.001$ respectively). The differences in F_{iso} value of PM_{10} compared to $PM_{2.5}$ in the open ports test was significant at minute 15 ($p < 0.001$), which suggests that both the closed and open ports tests effectively contained the PM_{10} as compared to $PM_{2.5}$ aerosolised particles. The F_{iso} negatively correlated with time for the open ports ($r = -0.79$, $p = 0.035$) and closed ports tests ($r = -0.79$, $p = 0.035$) for PM_{10}.

Conclusions: The closed and open BBIC ports effectively contain and evacuate PM_{10} aerosolised particles during simulation of static transport of COVID-19 patients. The BBIC contains and evacuates PM_{10} more effectively than $PM_{2.5}$ aerosolised particles.

Keywords: aerosolised particles, COVID-19, infectious disease transmission, transportation of patients

Introduction

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) virus was identified in the respiratory tract of patients with pneumonia in Wuhan, Hubei China in December 2019. The World Health Organization declared the infection a pandemic on March 11 2020.[1] Many measures have been taken to limit spread of SARS-CoV-2 infection. The emergence of more virulent strains of SARS-CoV-2 potentially increases the risk of transmission amongst the public and the healthcare workers.[2-5]

The SARS-CoV2 virus has the capacity to transmit from one host to another via direct or indirect droplet contact or inhalation of suspended nuclei droplets within the atmosphere.[6-10] These droplets are generated from the respiratory tract and have variable particle sizes ranging from 0.25 to 42 µm, depending on the respiratory activity (coughing, sneezing, talking, singing, etc).[11-13] Coughing, heavy breathing, and sneezing generate large amounts of aerosolised particles ranging from 0.35–10 µm.[14-17]

Direct droplet spread refers to droplets generated from the respiratory tract that land on another host's mucosal surface. Indirect droplet spread is when there is a direct physical interaction with the infected host or surfaces in which the infected host has come into contact.[18-19] Airborne transmission occurs when there is inhalation of droplet nuclei or aerosolised particles into the lower airway. The term nuclei droplets are smaller sized droplets, 5 to 10 µm, that may remain

airborne for longer periods of time (from minutes to hours).[20-22] The distance a particle can travel is rather complex and dependent upon many factors including particle size, flow velocity, density, air turbulence, humidity, and particle composition and humidity.[19-24]

Several measures to limit droplet spread in preventing SARS-CoV-2 transmission have been applied. Physical barrier models, including personal protective equipment recommendations, plastic draping segments within intensive care units, barrier chambers, and transport isolation pods (isopods), have been utilized.[25-27] Isopods are physical barrier chamber class I medical devices designed to limit the transmission of highly infectious disease during transport of infected patients.[28-34] The BIOBASE biological isolation chamber (BBIC; BIOBASE model BFG VI; Shandong, China) was used in many major hospitals in Malaysia during the COVID-19 pandemic.[35] However, there are issues with barrier chambers: increased intubation time, longer exposure risk, secondary aerosolization, increased duration of patient transport, disinfection issues, and high cost are among many problems reported.[28-34]

To date, the quantitative data on the effectiveness of the transport barrier chambers to limit aerosol spread during transport of COVID-19 patients is still limited. We aim to study the effectiveness of BBIC in limiting spread of aerosol during simulation of static transport of COVID-19 patient amongst healthcare workers.

Materials and methods

This simulation study was conducted within a 2-week duration in August 2022 following the approval from institutional Secretariat of Research and Innovation as well institutional Research and Ethics Committee.

The BBIC model BFG VI with dimensions of 1900 x 680 x 500 mm and a built-in negative pressure capacity running at a pressure magnitude of 19 Pascals was used in all the simulation tests. There were 3 HEPA filters that filtered particle sizes of 0.3 µm. The chamber was equipped with an all-around zipper system for easy operation. The chamber had 10 integrated glove portals to allow for easy access to the patient and 2 utility portals used for infusions and other medical equipment and were zipped and sealed during transport of COVID-19 patients. Should medical interventions be required, these access ports would be zipped open to conduct necessary procedures (Fig. 1a).

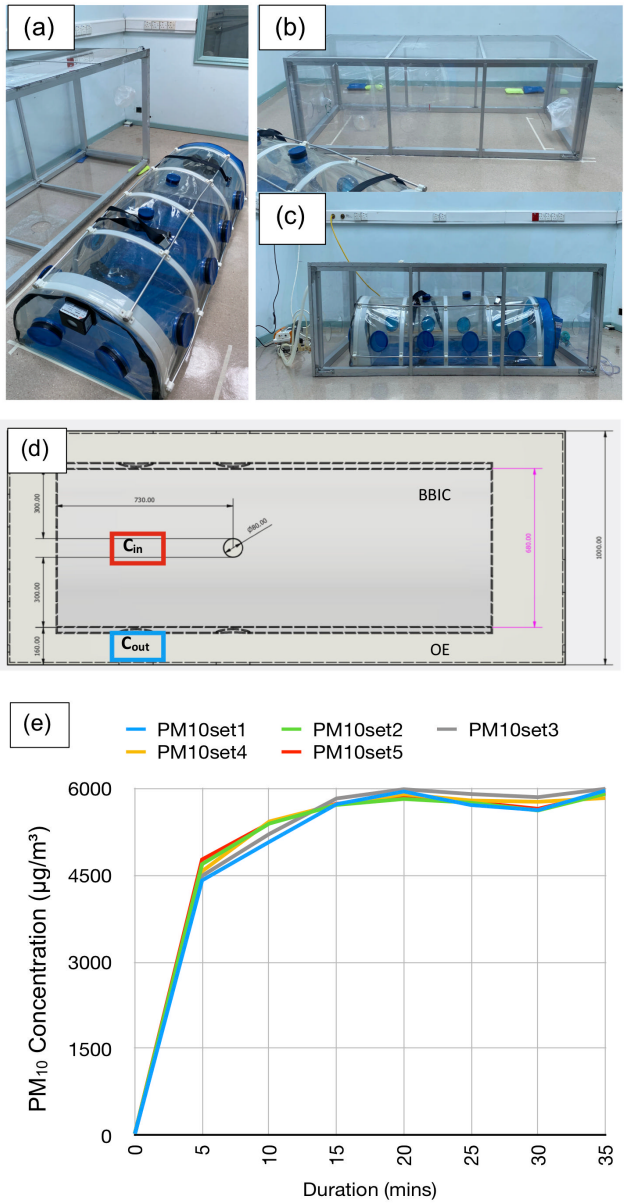

Fig. 1. (a) BBIC. *(b)* Outer enclosure (OE). *(c)* OE encapsulating BBIC. *(d)* Longitudinal view of the OE encapsulating the BBIC. Red square: location of AS-LUNG device measuring C_{in} within BBIC. Blue square: location of AS-LUNG device measuring C_{out}. *(e)* Measured concentration of PM_{10}.

A constructed outer enclosure (OE) was placed encapsulating the BBIC (Fig. 1b and 1c). The OE was to maintain the standard external BBIC environment (room air temperature average 26.2°C, relative humidity average 59.7%, room air pressure of 1 atm), and to provide a standard compartment for generated aerosol particle concentration measurement. The OE was constructed to fix a volume of 2300 x 1000 x 650 mm cuboidal body using polycarbonate material reenforced with an outer-skeletal aluminium structure to contain aerosol particles generated from within and prevent significant air leak to obtain accurate measurement. Several circular access and ventilatory ports were carved out from the polycarbonate body.

A nebulizer with its reservoir filled with 10 cc of normal saline 0.9% was used to deliver nebulized saline 0.9% connected to a flowmeter attached to the wall oxygen source outlet running at a flow rate of 10 l/min, with capacity to generate aerosolised particles with diameter of 3–5 µm. An Electrolux Vacuum Cleaner Fustar 1600-R-140 Model Z1231 was set to run at a suction power of 320 W for purging both the BBIC and OE for a duration of 10 minutes before the start of every experiment set to obtain a standard baseline room air particle concentration.

The particle concentration of the generated aerosols was measured with a device known as the AS-LUNG portable optical particle sensor (Acadamia Sinica, Taipei, Taiwan). A pair of these sensors were used simultaneously, one was placed within the BBIC and the other was placed outside of the BBIC, within the OE compartment (Fig. 1d). This device was able to sense and measure concentration of particulate matter (PM), $PM_{2.5}$ and $PM_{10,}$ in µg/m³. Measured concentrations of $PM_{2.5}$ and PM_{10} collected within the BBIC were designated as C_{in} and concentrations of $PM_{2.5}$ and PM_{10} collected outside the BBIC were designated as C_{out}.

The PM_{10} particle size range was chosen to be measured and analysed for this study to simulate coughing, heavy breathing, or sneezing and would generate aerosolised particles ranging from 0.35–10 µm within BBIC chamber during transport of COVID-19 infected patients. These droplets were assumed to be carrying SARS-CoV-2 virus. Larger droplets above 10 µm remained suspended longer in air and might accumulate within the BBIC chamber over time hence increasing the risk of secondary aerosolization. With the same rationale, $PM_{2.5}$ particles were also measured and analysed to assess the effectiveness of BBIC containment and evacuation function. Within the context of this simulation study, we designated the term F_{iso} as a ratio of measured particle concentration within the BBIC (C_{in}) to the measured particle concentration outside of the BBIC (C_{out}), mathematically expressed as: $F_{iso} = C_{in} / C_{out}$.

We designated containment as a state in which an increase in F_{iso} value caused by an increase in C_{in} concentration on a background of relatively low C_{out} concentration

at time 15 minutes, in which the average peak steady state particle concentration was achieved. Evacuation, a state in which a decline in F_{iso} caused by a decrease in both C_{in} and C_{out} concentration during application of negative pressure of from minute 15 to minute 75 (60-minute duration).

The control test, closer ports test,and open ports test were each repeated 3 times. The average data for measured concentration C_{in} and C_{out} was calculated. The F_{iso} for PM_{10} and $PM_{2.5}$ were derived and graphically analysed for each respective test.

OE particle concentration reproducibility test

A qualitative assessment of the OE was carried out using the Vosentech thermal microfogger (Vosentech, Philadephia, PA, USA), a device that generated artificial fog to assess aerosol leak from the OE to the room air. The OE was placed in a fixed designated area without BBIC placed within the enclosure. Each ventilation and access port and the surrounding edges of the OE that were in contact with the floor were sealed and secured to ensure no leak was detected upon initiation of the microfogger machine. Video was recorded with a camera at every side of the OE for a duration of 5 minutes to detect any visible fog leaking from surrounding edges.

After ensuring no fog leak was detected, the AS-LUNG device placed within the OE was switched on, nebulized saline 0.9% was generated within the OE for a duration of 15 minutes and was stopped after 15 minutes, as peak steady state particle concentration was achieved. The AS-LUNG device was left switched on for the next 35 minutes. The concentration of PM_{10} from AS-LUNG data was then collected and graphically analysed. This process was repeated 5 times as a standard measure to obtain the average peak steady state concentration. A graph illustrating a wash-in curve of PM_{10} concentration against time was then plotted (Fig. 1e). Average peak steady state concentration was maintained for 20 minutes.

Control test

In the control test, no BBIC was used within the OE (Fig. 2). The steps outlined in the reproducibility test above were repeated after ensuring all access ports with peripheral edges on all sides of the OE were well sealed. Both AS-LUNG measurement devices were switched on for 60 minutes and the concentration of PM_{10} and $PM_{2.5}$ data were collected.

Closed ports aerosol particle containment and evacuation test

In this test, the BBIC was placed in a designated area within the OE. The steps in the control test were repeated after all the BBIC access ports were tightly zipped (Fig. 2).

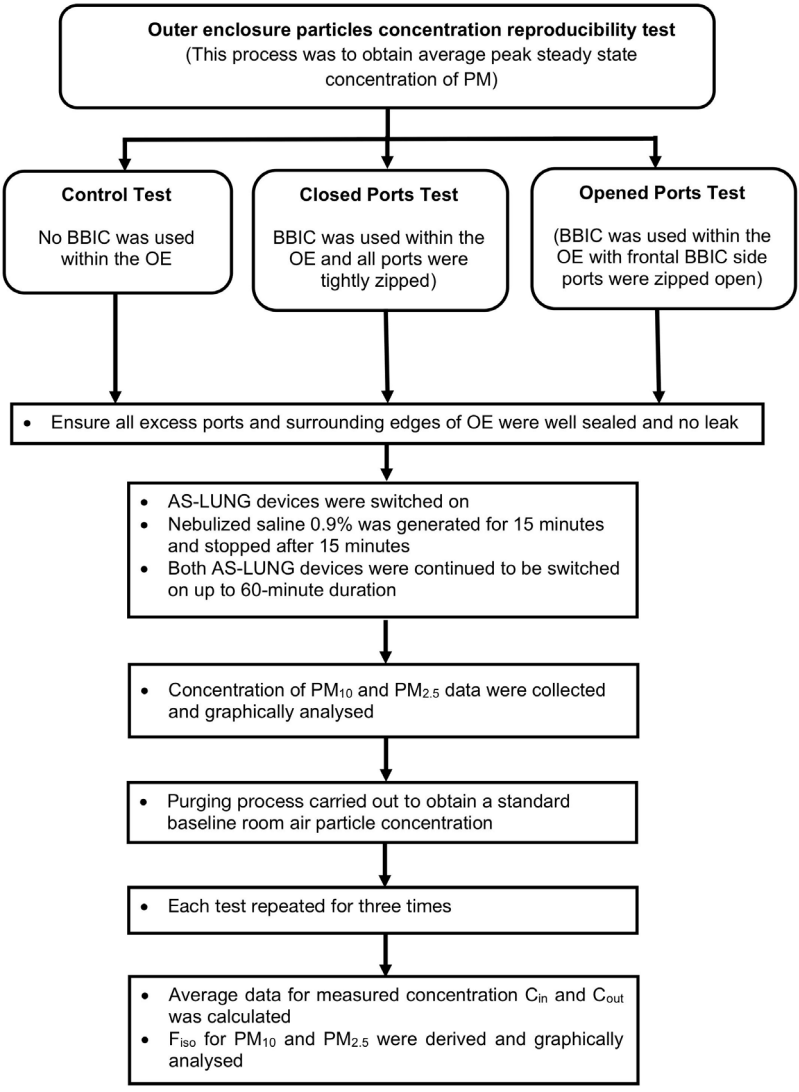

Fig. 2. Flow diagram of the setup for the control test, closed ports test, and open ports test.

Open ports aerosol particle containment and evacuation test

The 4 frontal BBIC side ports were zipped open to simulate the working environment when the healthcare personnel would require access to the patient during transportation. The same steps were repeated (Fig. 2).

Statistical analysis

The PM_{10} and $PM_{2.5}$ concentrations were measured and F_{iso} was calculated and analysed using Apple Numbers version 12.2.1 (7035.0.161) and IBM SPSS statistics version 28.0.0.0 (190). Descriptive statistics were reported. Pearson's correlation coefficient assessed the relationship between PM_{10} and $PM_{2.5}$ F_{iso} over time from minute 15 to minute 75. Repeated measurement ANOVA was used in all 3 tests (control, closed ports, and open ports) to assess significant F_{iso} difference at every time point. Statistical significance was determined to be $p < 0.05$.

Results

Control aerosol particle containment and evacuation test

The control test for both $PM_{2.5}$ and PM_{10} concentrations exhibited relatively constant F_{iso} at each time point from minute 15 to minute 75, respectively (Fig. 3a and 3b). However, F_{iso} was not correlated with time for either PM_{10} readings ($r = 0.47$, $p = 0.282$) nor $PM_{2.5}$ readings ($r = 0.16$, $p = 0.72$). There was a significant difference in F_{iso} between the PM_{10} control test and $PM_{2.5}$ control test at minute 25, 35, 45, 55, and 65, $p < 0.001$, respectively (Fig. 3c). In contrast, differences in concentration of C_{in} and C_{out} for $PM_{2.5}$ were relatively smaller than for PM_{10} which resulted in lower F_{iso} for the $PM_{2.5}$ control test. These findings mean that the position of healthcare workers within the vicinity of the BBIC during static transport would have different exposure rates depending on the dispersion pattern of the generated aerosol.

Aerosol particle containment and evacuation test for PM_{10}

Compared to the control test, F_{iso} PM_{10} in the closed ports test was higher at minute 15 and 25 and declined over time while F_{iso} in the control test remained constant (Fig. 4a). There was a significant difference in F_{iso} between the PM_{10} closed ports test and control test at minute 15 to 75 ($p < 0.05$ respectively). This suggests that the closed ports test contained and evacuated PM_{10} aerosolised particles more effectively than the control test and provided a good physical barrier within the BBIC chamber**.** The F_{iso} of closed ports test was also negatively and strongly correlated with time ($r = -0.79$, $p = 0.035$), which implied effective evacuation of PM_{10} aerosolised particles. As the negative pressure of the BBIC applied from minute 15 for a duration of 60 minutes, C_{in} concentrations within the BBIC decreased over time, hence reduced the F_{iso}.

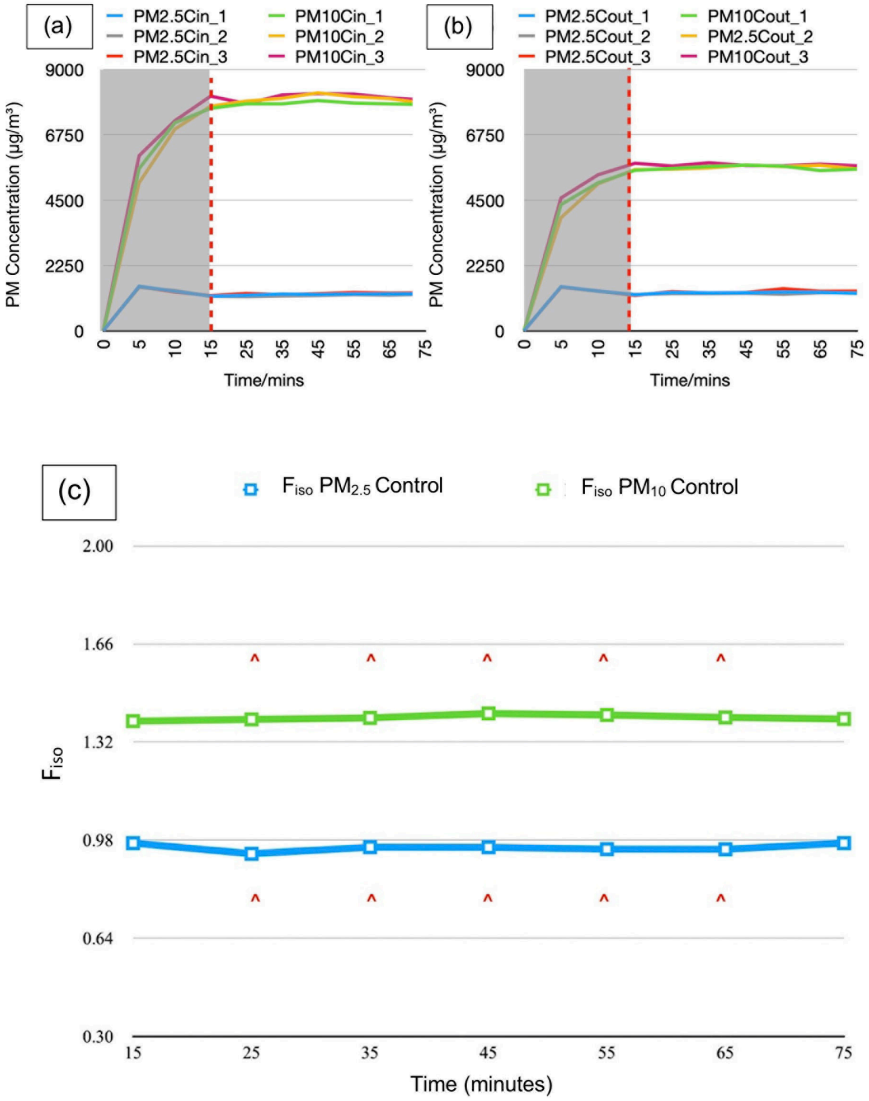

Fig. 3. (a) Concentration (C_{in}) of PM_{10} and $PM_{2.5}$ in control test. *(b)* Concentration (C_{out}) of PM_{10} and $PM_{2.5}$ in control test. *(c)* The F_{iso} of PM_{10} and $PM_{2.5}$ in control test for 60 minutes. Shaded area: duration for generation of nebulized saline within the outer enclosure. (^: $P < 0.05$).

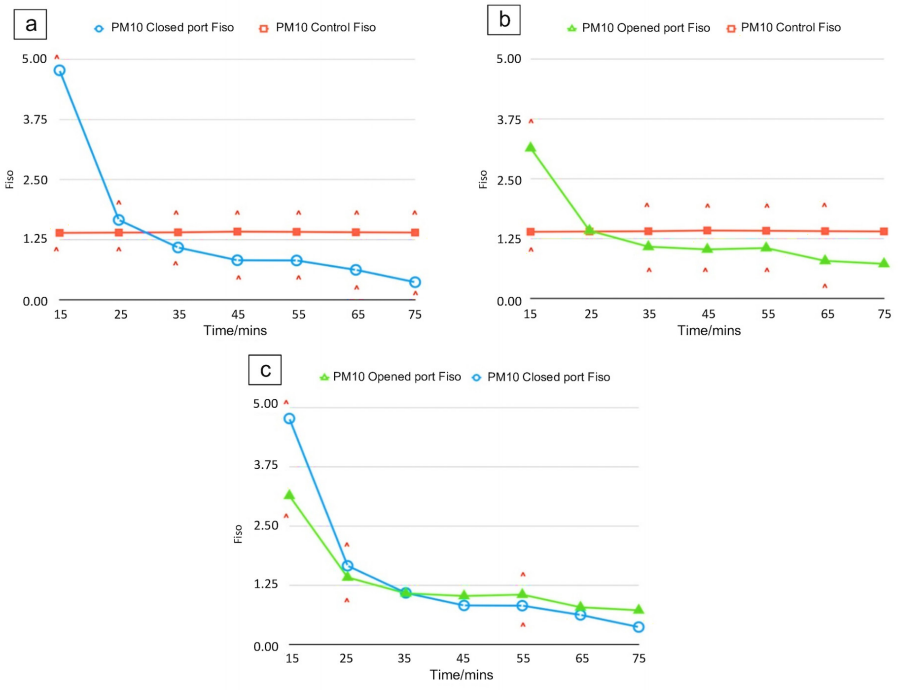

Fig. 4. Comparison of F_{iso} PM_{10}. *(a)* Closed ports test and control test. *(b)* Open ports test and control test. *(c)* Open ports test and closed ports test. (^: $P < 0.05$).

The F_{iso} PM_{10} in the open ports test was higher at minute 15 and then declined overtime while the F_{iso} in the control test remained constant (Fig. 4b). The difference in F_{iso} between PM_{10} in the open ports and control tests was significant at minute 15, 35, 45, 55, and 65 ($p < 0.05$, respectively). The F_{iso} was negatively and strongly correlated with time ($r = -0.79$, $p = 0.035$). These findings suggest that both containment and evacuation of PM_{10} aerosolised particles was more effective in the open ports test compared to the control test. Despite the BBIC's open ports, a barrier was still present to contain generated aerosols.

Both F_{iso} PM_{10} for open ports and closed ports tests declined over minutes 15 to 75. The F_{iso} in the closed ports test was higher at minute 15 and 25 and steadily declined lower than the F_{iso} in the open ports test (Fig. 4c). The difference in F_{iso} between PM_{10} in the open ports and closed ports tests was significant at minute 15, 25, and 55 ($p < 0.001$, 0.036, and 0.029, respectively). These findings imply that the closed ports BBIC was more effective in containing PM_{10} aerosolised particles compared to the open ports BBIC, and that both effectively evacuated PM_{10} aerosolised particles over time. This was due to the closed ports BBIC being

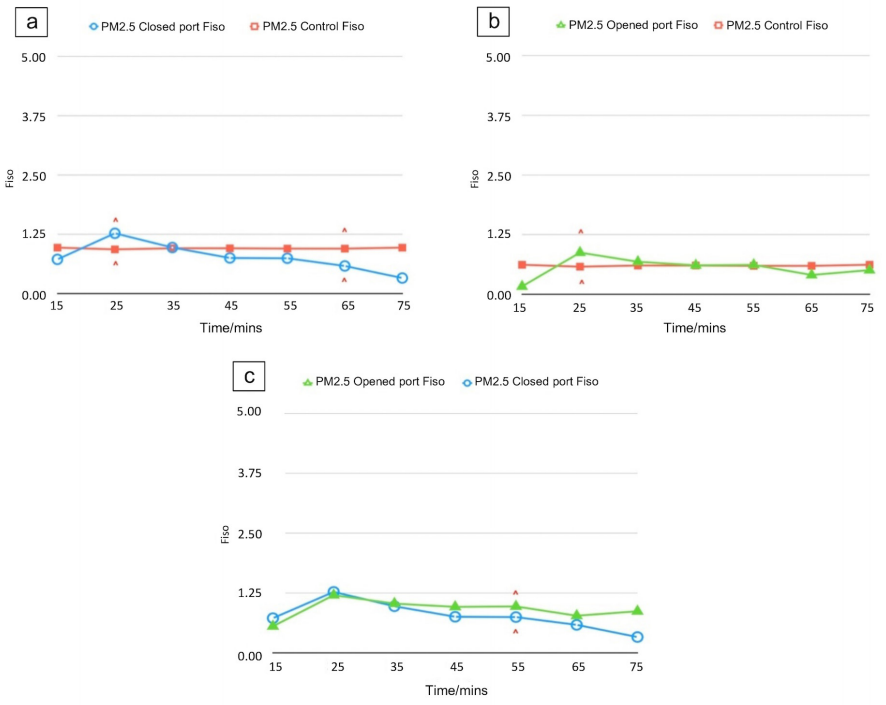

Fig. 5. Comparison of F_{iso} $PM_{2.5}$. *(a)* Closed ports test and control test. *(b)* Open ports test and control test. *(c)* Open ports test and closed ports test. (^: $P < 0.05$).

well sealed, resulting in the BBIC's internal and external environment being well isolated. In the open ports test, the internal chamber of the BBIC communicates with the outer environment of the BBIC within the OE.

Aerosol particle containment and evacuation test for $PM_{2.5}$

Compared to the $PM_{2.5}$ control test, the F_{iso} in the $PM_{2.5}$ closed ports test was higher at minute 25 and then declined over time, while the F_{iso} in the control test remained constant (Fig. 5a). The correlation between F_{iso} in the $PM_{2.5}$ closed ports test with time was not significant (r = -0.72, p = 0.066). The difference in F_{iso} between the closed ports test and control test was significant at minute 25 and 65 (p = 0.003 and 0.003, respectively). From this data we deduce that there was insufficient evidence to suggest that the closed ports and control tests would effectively contain and evacuate $PM_{2.5}$ aerosolised particles.

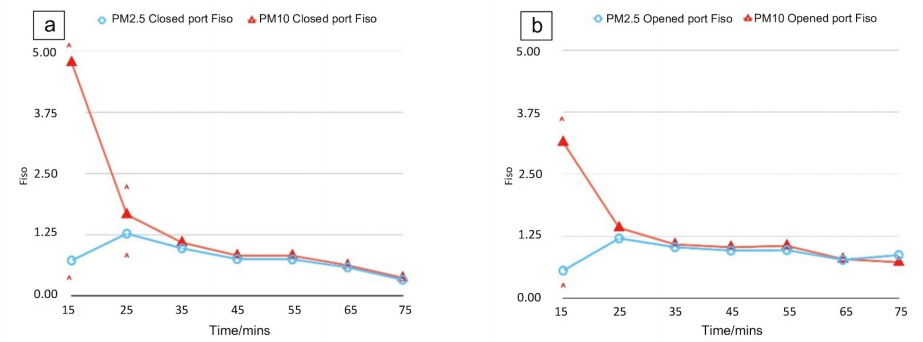

Fig. 6. (a) Comparison of F_{iso} (PM_{10}) and F_{iso} ($PM_{2.5}$) in closed ports test. *(b)* Comparison of F_{iso} (PM_{10}) and F_{iso} ($PM_{2.5}$) in open ports test. (^: $P < 0.05$).

Compared to the $PM_{2.5}$ control test, the F_{iso} in the open ports test was lower at minute 15, and then again at minute 65 to 75 (Fig. 5b) while the F_{iso} in the control test remained constant. The correlation between the F_{iso} for $PM_{2.5}$ in the open ports test and time was poor ($r = 0.015$, $p = 0.975$). The difference in F_{iso} was significant at minute 25 ($p = 0.017$). In general, these findings imply that both the control test and open ports test did not effectively contain and evacuate $PM_{2.5}$ aerosolised particles.

The F_{iso} for $PM_{2.5}$ in the closed ports test increased at minute 25 and decreased at minute 35 to 75 (Fig. 5c). The F_{iso} difference was significant at minute 55 ($p = 0.036$). The F_{iso} for $PM_{2.5}$ in both the closed and open ports tests were poorly correlated with time ($r = -0.72$, $p = 0.066$ and $r = 0.015$, $p = 0.975$, respectively). From this data, we deduce that there was insufficient evidence to suggest that the closed ports test and open ports test were more effective in containing and evacuating $PM_{2.5}$ aerosolised particles.

Comparison between aerosol particle containment and evacuation test for PM_{10} and $PM_{2.5}$

The F_{iso} for both PM_{10} and $PM_{2.5}$ in the closed ports tests decreased from minute 15 to 75. However, the F_{iso} for PM_{10} in the closed ports test was higher at minute 15 and 25 (Fig. 6a). The difference in F_{iso} for PM_{10} compared to that of $PM_{2.5}$ readings was significant at minute 15 and 25 ($p < 0.001$, respectively). This suggests that closed ports BBIC was more effective in containing PM_{10} compared to $PM_{2.5}$ aerosolised particles.

Compared to $PM_{2.5}$ open ports, the F_{iso} for PM_{10} open ports decreased over time from minute 15 to 75 while F_{iso} for $PM_{2.5}$ in the open ports test increased from

minute 15 to 25, followed by a minimal decline from minute 25 to 75 (Fig. 6b). The F_{iso} for PM_{10} in the open ports test was higher than that of the $PM_{2.5}$ open ports test at minute 15 and 25. The difference in F_{iso} of PM_{10} compared to that of $PM_{2.5}$ was significant at minute15 ($p < 0.001$). This suggests that the open ports BBIC was more effective in containing PM_{10} compared to $PM_{2.5}$ aerosolised particles.

Discussion

This simulation study was designed to test the effectiveness of BBIC in containing and evacuating aerosolised particles. Using F_{iso} as a ratio of aerosolised particle concentration within the BBIC (C_{in}) to the aerosolised particle concentration outside the BBIC (C_{out}), we were able to estimate trends that signify effective containment and evacuation function of the BBIC during static transport of COVID-19 patients.

Aerosol exposure is clinically relevant because both aerosol and droplets constitute an exposure risk for COVID-19. [34,35] Our simulations demonstrated, in general, that a well-utilized, functioning BBIC with closed ports and application of negative pressure was able to effectively contain and evacuate PM_{10} aerosolised particles. In real clinical scenarios, the utility of BBIC with all the ports closed would reduce PM_{10} aerosol concentration carrying SARS-CoV-2 in the surrounding environment and therefore reduce the risk of aerosol exposure to healthcare workers in the vicinity of the BBIC. The BBIC contains the spread and evacuates the infective aerosols via application of negative pressure, which directs the generated aerosols towards the HEPA filters. This can be beneficial for different situations as the utility of isolation chambers has been shown to reduce medical cessation in emergency departments and reduce delays attributed to disinfection of computed tomography machines in radiology departments.[25]

Conversely, the control group represents healthcare workers transporting COVID-19 patients without using a BBIC. As a result, C_{out} concentrations in this scenario would be higher than that of clinical scenarios where the BBIC is utilized. Higher C_{out} levels mean that the generated aerosol concentration in environment is increased, therefore increasing the risk of exposure of aerosol carrying SARS-CoV-2 to healthcare workers in the vicinity of the BBIC.

In contrast, opening the access ports during static transport of COVID-19 patients would cause an increase in PM_{10} particle concentration in the environment, hence increasing the risk of droplet exposure to healthcare workers in the vicinity of the BBIC. Nonetheless, the utility of the BBIC itself, irrespec-

tive of access ports being open or closed, results in less PM_{10} particle concentrations in the environment air and therefore reduces the risk of droplet exposure to healthcare workers during transport. The effect of applying negative pressure is analysed in other quantitative studies involving isolation hood and intubation box models, which have shown reductions in generated particulate count during application of negative pressure, while isolation without negative pressure shows retention of particulate count within the chamber.[22,29] The importance of applying negative pressure during BBIC usage should be emphasized because retention of aerosolised particles may contribute to secondary aerosolization.[28,31]

Interestingly, when comparing the $PM_{2.5}$ simulations in our study, there was insufficient evidence to suggest that control, closed ports, and open ports tests were more effective in containing and evacuating $PM_{2.5}$ aerosolised particles. This could be attributed to the possibility of BBIC equipment leak to smaller diameter aerosolised particles or the intrinsic characteristics of $PM_{2.5}$ aerosolised particles, such as size, composition, and density, playing a role in aerosol movement direction.[20-22] Small droplets have been shown to freely travel in the air and carry their viral content meters and tens of meters from where they originated.[36] In real clinical scenarios, this would mean that the environment air would have higher $PM_{2.5}$ particle concentration carrying SARS-CoV2, which increases the risk of droplet exposure to healthcare workers in the vicinity of the BBIC during static transport, irrespective of whether the access ports are opened or closed.

Furthermore, we noted F_{iso} differences between PM_{10} and $PM_{2.5}$ when measuring generated aerosolised particles in separate positions of AS-LUNG sensors. In real clinical scenarios, these findings suggest that the position of healthcare workers within the vicinity of the BBIC during static transport of COVID-19 patients entails different exposure rates depending on the dispersion pattern of generated aerosols.[28,37] These differences would also require further mathematical computational fluid dynamics simulations to predict the pattern of dispersion of generated aerosol and as such, should be the subject of future discussion not relevant to this current study.

This simulation study was carried out to quantitatively assess the effectiveness of containing and evacuating aerosolised particles in an isolation chamber of a specific brand. Comparisons of isolation chambers of various designs are required. The simulation was designed to assess quantitative data during static transport and not dynamic transport of patients. We did not consider simulations involving variable patient conditions including coughing, sneezing, or heavily breathing. The nature of this study is simulation-only, where patient-derived aerosols may differ in behaviour from nebulized saline.

We recommend proper usage of the BBIC, ensuring the equipment is well charged before transport, regular maintenance of the negative pressure function and the HEPA filters, regular disinfection of the internal chambers, as well as proper education and training of healthcare workers to ensure safety during BBIC usage. We suggest computational fluid dynamics simulation software to be considered in future studies to assess the variability of aerosol movement and dispersion.

Conclusion

The closed and open BBIC ports effectively contained and evacuated PM_{10} aerosolised particles during simulation of static transport of COVID-19 patients. The BBIC contained and evacuated PM_{10} more effectively than $PM_{2.5}$ aerosolised particles.

Declarations

Ethics approval and informed consent
This simulation study was conducted within the two-week duration in August 2022 at the Department of Anaesthesiology and Intensive Care, Hospital Canselor Tuanku Muhriz following the approval from Secretariat of Research and Innovation, Faculty of Medicine, Universiti Kebangsaan Malaysia and institutional Research and Ethics Committee (Code: JEP-2022-212).

Competing interests
Dr. Azarinah Izaham and Dr. Rufinah Teo serve in Malaysian Journal of Anaesthesiology's Editorial Board. Neither were involved in the publication process prior to acceptance. Malaysian Journal of Anaesthesiology employs a double-blind review system. The remaining authors have no competing interests to disclose.

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None to declare.

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Comparative analysis of intensive care unit prognostication scores and their renal components in predicting hospital mortality among critically ill patients

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Abstract

Introduction: Prognostication is essential for risk stratification in the intensive care unit (ICU). The SOFA, APACHE II, and SAPS II scores are widely used severity scoring systems, although their renal components differ. Given the association of acute kidney injury (AKI) with higher morbidity and mortality, this study aimed to evaluate these scoring systems and identify which renal component best predicts ICU outcomes. Such an insight can enhance the precision of risk assessment in critically ill patients.

Methods: A retrospective observational cohort study was conducted involving all patients admitted to the ICU of Sultan Ahmad Shah Medical Centre (SASMEC@ICU). SOFA, APACHE II, and SAPS II scores, along with their individual components, were calculated within the first 24 hours of ICU admission.

Results: Of the 1,513 patients analysed, 360 (23.8%) died in hospital. The SOFA score had the highest predictive accuracy for hospital mortality with an AUC of

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0.78, followed by SAPS II (0.77) and APACHE II (0.72). Optimal cut-off points were identified for practical application. The renal components of the SOFA and SAPS II had similar AUCs of 0.64, while APACHE II's renal component was lower (0.62). Findings were consistent in the AKI subgroup.

Conclusions: The SOFA score outperformed APACHE II and SAPS II in predicting hospital mortality in critically ill patients. The renal components of the SOFA and SAPS II scores were more predictive than the that of APACHE, likely due to the inclusion of urine output criteria. Future multicentre studies using raw patient-level data are needed to develop a robust prognostic model tailored to our local ICU population.

Keywords: APACHE II score, intensive care unit, prognostication, SAPS II Score, SOFA Score

Introduction

Accurate prediction of outcomes in critically ill patients is essential for clinical decision-making, prognostication, and resource allocation in the intensive care unit (ICU).[1] Commonly used severity scoring systems include the Acute Physiology Chronic and Health Evaluation score (APACHE),[2] Simplified Acute Physiology Score (SAPS),[3] and the Sequential Organ Failure Assessment (SOFA).[4] These tools incorporate various physiological variables to estimate the severity of illness and risk of mortality.

These prognostic tools are frequently utilised to assist clinicians in estimating the probability of survival or the need for interventions. Both APACHE II and SAPS II scores include a range of physiological variables, and the SOFA score is designed to assess the severity of organ failure, including renal dysfunction. Despite their widespread use, there is ongoing debate about the accuracy of these scoring systems for predicting outcomes, particularly regarding mortality.

Acute kidney injury (AKI) is a common complication in ICU patients and is strongly associated with increased morbidity and mortality.[5] Consequently, renal function plays a central role in severity scoring. Each scoring system incorporates renal parameters differently: SAPS II uses blood urea nitrogen and urine output, APACHE II includes serum creatinine, while SOFA integrates both serum creatinine and urine output. The variations may influence the predictive performance of each score. This study aims to compare the predictive accuracy of the 3 commonly used scoring systems and to determine the best renal scores for predicting hospital

mortality in the ICU. The findings will offer insights into which renal score is most useful for clinical prognostication and decision-making.

Methods

This retrospective cohort observational study was conducted in the intensive care unit (ICU) of Sultan Ahmad Shah Medical Centre (SASMEC @IIUM). Ethical approval was obtained from the International Islamic University Malaysia Research Ethics (IREC 2021-304). All patients admitted to the ICU during the study period were screened for inclusion and exclusion criteria. Inclusion criteria included age above 18 years and ICU stay longer than 24 hours. Exclusion criteria included missing data. AKI was defined according to the Kidney Disease-Improving Global Outcomes (KDIGO) creatinine definition.

Data for ICU scoring systems (SOFA, APACHE II, and SAPS II), including their individual component scores, were routinely recorded and extracted from existing ICU records. Details of how the individual components were scored in APACHE II, SOFA, and SAPS are detailed in Appendix 1, with renal component scoring outlined specifically in Appendix 2.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± standard deviation (SD) for normally distributed data or median (interquartile range) for non-normally distributed data. Group comparisons were conducted using the independent t-test for normally distributed variables or the Mann-Whitney U test for non-parametric data. Categorical variables were compared using the chi-square test. A p-value < 0.05 was considered statistically significant.

The predictive performances of the scoring systems were evaluated using the area under the curve (AUC) of the receiver operating characteristic (ROC) curve of sensitivity versus 1-specificity. AUC values were interpreted as follows: 0.7–0.8 (acceptable), 0.8–0.9 (excellent), and > 0.9 (outstanding). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for each score. The optimal cut-off values were determined using Youden's index**,** which identifies the point on the ROC curve that maximizes the difference between true positive and false positive rates.

A predefined subgroup analysis was conducted for patients diagnosed with AKI according to KDIGO creatinine criteria. The performance of the total and renal scores

in this subgroup was separately evaluated using ROC curve analysis to determine if predictive accuracy differed in this high-risk population.

The sample size for this study was not determined a priori but was based on available data from ICU admissions over the 6-year period from 2017 to 2021. Historical data indicate approximately 400 admissions per year, resulting in a total pool of 1,600 patients. This sample size was sufficient to detect a good discriminatory performance of AUC of more than 0.80 with 80% power at a 5% significance level.

Results

A total of 1,691 ICU admissions were recorded between 2017 to 2021; after excluding missing data, 1,513 admissions were analysed (Fig. 1). Among these, 360 patients (23.8%) died during hospitalisation, while 1,153 (76.2%) survived. Within the cohort, 741 patients (49.0%) had AKI within 7 days of ICU admission, of which 219 (14.5 %) were Stage 1, 47 (3.1%) Stage 2, and 475 (31.4%) Stage 3.

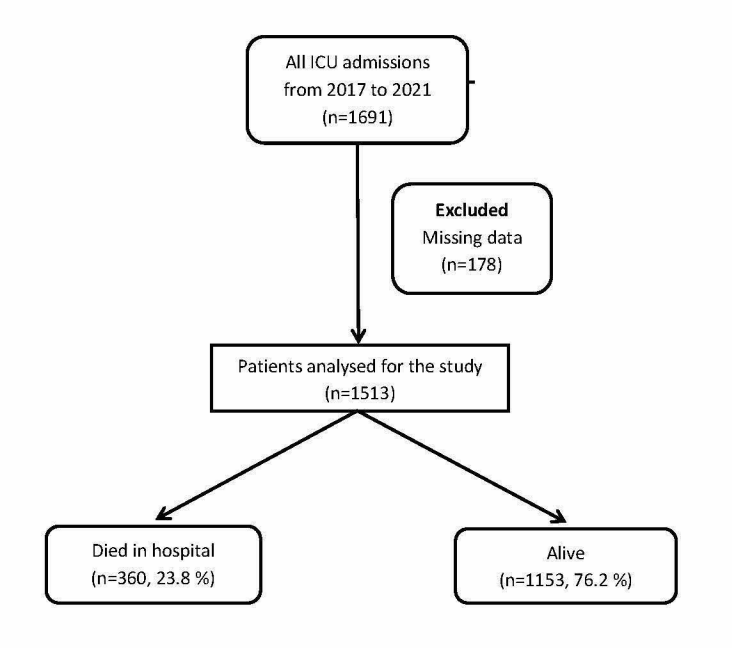

Fig. 1. Patient flow diagram.

Demographic and clinical characteristics

Table 1 shows the demographic and clinical characteristics of patients who died versus those who survived. Patients who died during hospitalisation were significantly older than those who survived (62.3 vs. 56.8 years, $p < 0.0001$). A greater proportion of deaths occurred among patients admitted under the medical category compared to the surgical group ($p < 0.0001$). The incidence of AKI was similar between those who died and those who survived (48.5% vs. 49.2%, $p = 0.82$), and there were no significant differences in AKI staging between the groups. However, patients who died had significantly higher peak serum creatinine levels within 7 days (304 vs. 194 µmol/L, $p < 0.0001$), indicating more severe renal dysfunction. Additionally, a significantly higher proportion of patients who died required mechanical ventilation (85.8% vs. 56.3%, $p < 0.0001$), reflecting greater severity of illness.

Table 1. Comparison of demographic and clinical profiles between survivors and non-survivors

Variables	All patients (*n* = 1513)	Died in hospital (*n* = 360)	Alive (*n* = 1153)	*p*-value
Age (years)	58.1 ± 15.2	62.3 ± 12.7	56.8 ± 15.7	< 0.0001
Gender (male)	836 (55.3)	199 (55.3)	637 (55.2	0.99
Category **Medical** **Surgical**	 797 (52.7) 715 (47.3)	 226 (62.8) 134 (37.2)	 571 (49.5) 581 (50.4)	< 0.0001
AKI by KDIGO creatinine criteria	741 (49.0%)	174 (48.5%)	567 (49.2%)	0.82
AKI Stages **Stage I** **Stage II** **Stage III**	 219 (14.5%) 47 (3.1%) 475 (31.4)	 48 (13.4%) 10 (2.8%) 359 (31.1)	 171 (14.8%) 37 (3.2%) 116 (32.3)	0.87
Baseline creatinine (µmol/l)	140 ± 161	175 ± 278	150 ± 182	0.55
Maximum creatinine within 7 days (µmol/l)	220 ± 241	304 ± 233	194 ± 238	< 0.0001
Mechanical ventilation, n (%)	958 (63.3)	309 (85.8%)	649 (56.3%)	< 0.0001

Data expressed as mean ± SD, n (%), or median (lower quartile – upper quartile). AKI: Acute Kidney Injury; KDIGO: Kidney Disease-Improving Global Outcomes; APACHE II: Acute Physiology and Chronic Health Evaluation II Score; SOFA: Sequential Organ Failure Assessment

The total scores of APACHE II, SAPS II and SOFA scores were higher in those who died compared to those who survived (Table 2). Among the components of APACHE II score, patients who died had significantly worse values in cardiovascular parameters (mean arterial pressure and heart rate), biochemical markers (pH, sodium, potassium, creatinine, haematocrit, white cell count, and bicarbonate), as well as higher scores for age and chronic health status ($p < 0.0001$ for all). Similarly, all 6 organ-specific components of the SOFA score, respiratory, haematology, hepatic, cardiovascular, central nervous system, and renal, were markedly elevated in those who died compared to survivors ($p < 0.0001$). In the SAPS II score, all components showed significantly higher values among non-survivors, except for temperature and chronic disease, which did not differ significantly between groups ($p = 0.11$ and $p = 0.73$, respectively). These findings reflect a consistent pattern of more severe physiological derangements and organ dysfunction among patients who did not survive.

Table 2. Comparison of APACHE II, SOFA, and SAPS II Scores and Their Individual Components Subscores by Hospital Survival Outcome

Variables	**All patients (*n* = 1513)**	**Died in hospital (*n* = 360)**	**Alive (*n* = 1153)**	***p*-value**
APACHE II Score	14.89 ± 7.30	18.89 ± 6.72	13.48 ± 6.99	< 0.0001
Temperature	0.08 ± 0.36	0.08 ± 0.30	0.08 ± 0.38	0.92
Mean arterial pressure	0.38 ± 0.86	0.60 ± 1.04	0.32 ± 0.78	< 0.0001
Heart rate	0.65 ± 1.00	0.84 ± 1.08	0.59 ± 0.97	< 0.0001
Respiratory rate	0.27 ± 0.66	0.32 ± 0.73	0.26 ± 0.63	0.14
Oxygenation	0.90 ± 1.28	1.03 ± 1.33	0.86 ± 1.27	0.02
ph	0.95 ± 1.33	1.43 ± 1.50	0.79 ± 1.23	< 0.0001
Sodium	0.29 ± 0.75	0.43 ± 0.85	0.25 ± 0.71	< 0.0001
Potassium	0.29 ± 0.71	0.42 ± 0.90	0.25 ± 0.63	< 0.0001
Creatinine	1.46 ± 1.64	2.03 ± 1.69	1.28 ± 1.58	< 0.0001
Haematocrit	0.79 ± 1.14	1.07 ± 1.31	0.71 ± 1.07	< 0.0001
White cell count	0.66 ± 0.94	0.88 ± 1.06	0.59 ± 0.89	< 0.0001
Bicarbonate	1.59 ± 1.55	2.15 ± 1.63	1.42 ± 1.48	< 0.0001
Glasgow Coma Scale	3.07 ± 4.86	4.26 ± 4.96	2.72 ± 4.78	0.03

Variables	All patients (*n* = 1513)	Died in hospital (*n* = 360)	Alive (*n* = 1153)	*p*-value
Age	3.18 ± 2.00	3.68 ± 1.84	3.02 ± 2.02	< 0.0001
Chronic health	3.18 ± 2.23	3.65 ± 2.17	3.02 ± 2.24	< 0.0001
SOFA Score	4.83 ± 3.67	7.76 ± 3.87	3.92 ± 3.09	< 0.0001
Respiratory	1.18 ± 1.21	1.49 ± 1.27	1.08 ± 1.17	< 0.0001
Haematology	0.37 ± 0.82	0.61 ± 0.98	0.29 ± 0.76	< 0.0001
Hepatic	0.51 ± 0.92	0.85 ± 1.15	0.41 ± 0.80	< 0.0001
Cardiovascular	1.07 ± 1.61	1.98 ± 1.82	0.78 ± 1.42	< 0.0001
Central nervous system	0.55 ± 1.21	1.12 ± 1.61	0.38 ± 1.00	< 0.0001
Renal	1.11 ± 1.45	1.64 ± 1.51	0.94 ± 1.38	< 0.0001
SAPS II Score	32.1 ± 16.5	34.2 ± 16.9	31.2 ± 16.2	< 0.0001
Age	9.45 ± 5.35	10.94 ± 4.59	8.98 ± 5.48	< 0.0001
Heart rate	0.78 ± 1.55	1.17 ± 1.84	0.65 ± 1.43	< 0.0001
Systolic blood pressure	0.53 ± 1.79	1.03 ± 2.47	0.37 ± 1.48	< 0.0001
Temperature	0.06 ± 0.47	0.09 ± 0.59	0.05 ± 0.43	0.11
PF ratio	6.33 ± 1.85	6.63 ± 1.87	6.22 ± 1.82	0.002
Urine output	3.09 ± 4.18	5.00 ± 4.78	2.49 ± 3.78	< 0.0001
Urea	2.66 ± 3.43	4.11 ± 3.55	2.20 ± 3.26	< 0.0001
White cell count	0.67 ± 1.51	0.95 ± 1.78	0.58 ± 1.40	< 0.0001
Potassium	0.45 ± 1.08	0.67 ± 1.26	0.39 ± 1.01	< 0.0001
Sodium	0.25 ± 1.01	0.47 ± 1.35	0.19 ± 0.87	< 0.0001
Bicarbonate	1.69 ± 2.16	2.56 ± 2.39	1.42 ± 1.99	< 0.0001
Bilirubin	0.41 ± 1.84	0.95 ± 2.83	0.24 ± 1.34	< 0.0001
Glasgow Coma Scale	2.25 ± 6.45	4.58 ± 8.99	1.53 ± 5.23	< 0.0001
Chronic disease	7.73 ± 4.50	7.86 ± 4.26	6.01 ± 1.73	0.73
Type of admission	5.29 ± 2.60	6.01 ± 1.73	5.06 ± 2.78	< 0.0001

Predictive performance of APACHE II, SOFA and SAPS II for hospital mortality

The predictive performance of APACHE II, SOFA, and SAPS II scores for hospital mortality is shown in Table 3 and Figure 2A. Among the 3, the SOFA score demonstrated the highest discriminatory ability (AUC = 0.78), followed closely by the SAPS II score (AUC = 0.77), and the APACHE II score, which had the lowest AUC at 0.72. Using Youden's index, the optimal cut-off points for predicting hospital mortality were 14.5 for APACHE II, 5.5 for SOFA, and 33.5 for SAPS II. These cut-off values reflect the best trade-off between sensitivity and specificity and may serve as practical thresholds for identifying critically ill patients at higher risk of in-hospital death.

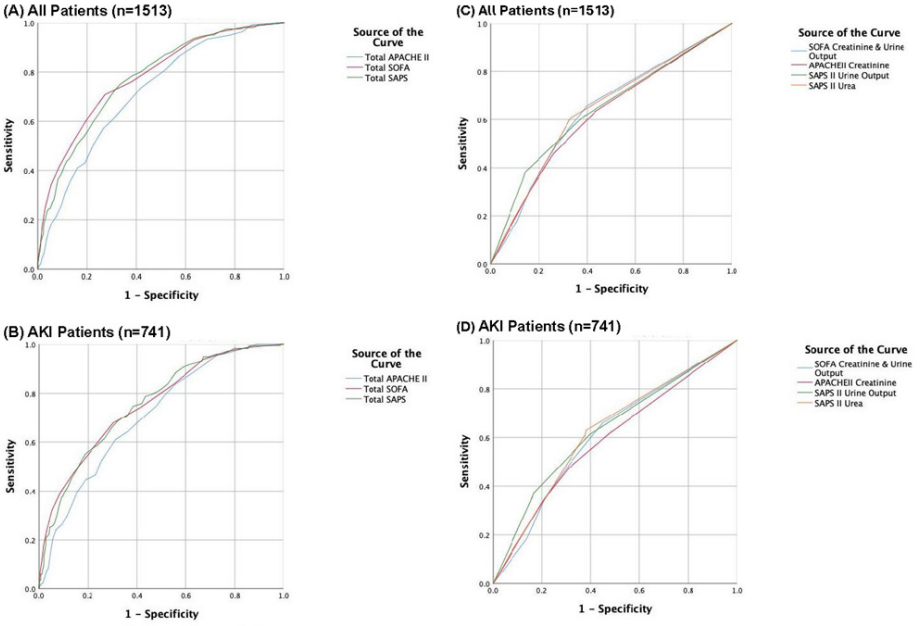

Fig. 2. Receiver operating characteristic (ROC) curves showing the predictive performance of the total scores of APACHE II, SOFA, and SAPS II in all ICU patients *(A)* and in patients with AKI *(B)*. *(C)* and *(D)* illustrate the performance of the renal components of the scoring systems, APACHE II creatinine, SOFA creatinine and urine output, SAPS II urea, and SAPS II urine output—for all patients and AKI patients, respectively.

Table 3. Predictive accuracy of APACHE II, SOFA, and SAPS II scores for hospital mortality

Scoring systems	AUC (95% CI)	*p*	Optimal cut-off point	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
APACHE II	0.72 (0.69–0.75)	< 0.0001	14.5	73.3 (68.8–77.9)	58.4 (55.5 - 61.2)	35.5 (32.0–38.9)	87.5 (85.2 -89.9)
SOFA	0.78 (0.75–0.81)	< 0.0001	5.5	70.8 (66.1–75.5)	72.8 (70.2–75.3)	44.8 (40.7–48.9)	88.9 (86.9% to 90.9)
SAPS II	0.77 (0.75–0.80)	< 0.0001	33.5	69.7 (64.9–74.5)	70.8 (68.2–73.5)	42.8 (38.8–46.8)	88.2 (86.1 - 90.3)

AUC: area under the curve; PPV: positive predictive values; NPV: negative predictive value

Table 4. Predictive accuracy of renal components from APACHE II, SOFA, and SAPS II scores for hospital mortality

Renal components	AUC (95% CI)	*p*	Optimal cut-off point	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
APACHE II renal score	0.62 (0.59–0.65)	< 0.0001	0.5	63.3 (58.4–68.3)	56.7 (53.8–59.6)	31.4 (28.0–34.7)	83.2 (80.6–85.8)
SOFA renal score	0.64 (0.61–0.67)	< 0.0001	0.5	65.6 (60.7–70.5)	60.2 (57.4–63.1)	34.0 (30.5–37.5)	84.8 (82.4–87.3)
SAPS II urea	0.64 (0.61–0.67)	< 0.0001	1.5	60.8 (55.8–65.9)	66.8 (64.1–69.6)	36.6 (32.7–40.4)	84.5 (82.1–86.8)
SAPS II urine output	0.64 (0.61–0.67)	< 0.0001	5	38.3 (33.2–43.3)	85.7 (83.7–87.7)	45.5 (39.9–51.1)	81.7 (79.5–83.8)

AUC: area under the curve; PPV: positive predictive values; NPV: negative predictive value

Predictive performance of the renal components of APACHE II, SOFA and SAPS II for hospital mortality

Table 4 and Figure 2C compare the predictive performance of renal components derived from APACHE II, SOFA, and SAPS II scores. Among them, the SOFA renal score demonstrated the highest discriminatory power (AUC = 0.64)**,** followed closely by the SAPS II urea score and urine output score (both AUC = 0.64), and the APACHE II renal component (AUC = 0.62). Although all showed statistically significant association with mortality ($p < 0.0001$), their predictive performances were modest.

The optimal cut-off points for the renal components are interpreted as follows: an APACHE II renal score of 0.5 corresponds to creatinine levels between 140 and 150 µmol/L; a SOFA renal score of 0.5 corresponds to creatinine levels between 110 and 170 µmol/L. For SAPS II, a renal score of 1.5 reflects urea levels between 10 and 29.6 mmol/L, while a score of 0.5 corresponds to urine output between 500 and 1000 mL per day.

Subset analysis in patients with AKI

A subset analysis among patients with AKI (n = 741) showed consistent findings. The SOFA score demonstrated the highest predictive accuracy for hospital mortality with an AUC of 0.75, followed closely by the SAPS II score, also with an AUC of 0.75, and the APACHE II score with an AUC of 0.71.

Similarly, the renal components of each scoring system showed modest predictive performance in this subgroup. The SOFA renal score had an AUC of 0.64, the SAPS II urea and urine output components both had AUCs of 0.64, and the APACHE II renal score had an AUC of 0.62. These results reinforce the consistency of the main findings in patients with AKI (Figs. 2B and 2C).

Discussion

The study evaluated the predictive accuracy of renal components in 3 widely used ICU severity scoring systems, SOFA, APACHE II, and SAPS II, for hospital mortality in critically ill patients. Among them, the SOFA score demonstrated the highest overall predictive performance (AUC 0.78), followed by SAPS II (AUC 0.77) and APACHE II (AUC 0.72). The renal components of SOFA and SAPS II scores showed better discrimination (AUC of 0.64 for both) compared to the renal component of APACHE II (AUC of 0.62).

The SOFA score is widely used for assessment of organ dysfunction and failure,[6,7] yet its utility in predicting mortality compared to the existing outcome scores has not been as extensively documented.[8–10] This study demonstrated that the SOFA scores outperformed both APACHE II and SAPS II in predicting hospital mortality. This is consistent with other studies that showed the predictive utility of SOFA score for mortality in general ICU patients,[11] patients with sepsis,[12] severe acute pancreatitis,[13] cardiovascular disease[14] and haematological malignancies.[15] The SOFA score has been shown to be associated with the prediction of 1-year mortality in 120 general ICU patients in our local setting.[8] In patients with AKI, the SOFA score has been shown to predict mortality, outperforming other severity scores. In a study of 836 patients with AKI on renal replacement therapy, SOFA demonstrated superior

predictive performance compared to APACHE II.[16] Similarly, in 189 AKI patients, the SOFA score achieved an AUC 0.908 (95% CI 0.866 to 0.950) for in-hospital mortality, the highest among the four scoring systems evaluated.[17]

The renal components of the SOFA, SAPS II, and APACHE II differ in their criteria. The renal SOFA score incorporates both serum creatinine and urine output, while renal SAPS II uses blood urea nitrogen and urine output, and renal APACHE II relies solely on serum creatinine (Appendix 2). The KDIGO guideline[18] recommends the use of both creatinine and urine output for AKI diagnosis. However, urine output is often difficult to measure, leading many studies to rely solely on creatinine criteria. Additionally, the urine output-based definition of AKI may be overly sensitive, potentially leading to overestimation of AKI cases.[19] Nevertheless, our results indicate that the renal components of the SOFA and SAPS II scores were more predictive of hospital mortality than the renal component of the APACHE II score. Both renal scores of SOFA and SAPS II incorporate urine output as the criteria. This finding is consistent with previous studies suggesting that incorporating multiple renal parameters, such as urine output and serum creatinine, may improve the predictive accuracy of these scoring systems.[20]

The identification of optimal cut-off points for APACHE II (14.5), SOFA (5.5), and SAPS II (33.5) enhances their clinical utility in ICU mortality prediction. These thresholds differ from those reported in a study of patients with acute respiratory distress syndrome in Vietnam, which showed SOFA > 9.5 and APACHE II > 19.5 as predictive of higher mortality.[21] This highlights the importance of local data due to variations in demographics, disease severity, and disease class. Defining setting-specific thresholds allows for more tailored risk stratification to the local population. Similarly, identifying renal component cut-offs offers additional prognostic value, though precise thresholds require future studies with raw patient-level data.

While this study primarily focused on the renal domain, other organ-specific components, such as cardiovascular, respiratory, hepatic, coagulation, and neurological functions, may also influence mortality prediction. Though not analysed individually in this study, future research could explore the relative prognostic contribution of each organ domain within these scoring systems.

Limitations of the study

Our study has several limitations. First, it was conducted in a single centre, which may limit the generalizability of the findings to different patient populations and clinical practices. Second, the retrospective design may introduce biases related to data completeness and patient selection, potentially affecting the reliability of the results. Third, we were unable to compare AKI defined by the KDIGO criteria with the renal components of the 3 scoring systems, as hourly urine output was not routinely

captured in our ICU. Future studies should address this gap to better validate the renal components of these scoring systems. Fourth, given the dynamic clinical status of ICU patients, reliance on a single time-point assessments may be suboptimal. Future studies should explore the prognostic value of serial scoring over time. Finally, we were only able to perform discrimination analysis using AUC, as access was limited to the total and domain-level scores of APACHE II, SOFA, and SAPS II. The lack of raw data restricted our ability to evaluate model calibration, a limitation that should be addressed in future research.

Conclusion

This study demonstrated the superior predictive performance of the SOFA score for hospital mortality in critically ill patients, outperforming both APACHE II and SAPS II. The renal components of SOFA and SAPS II were more predictive than that of APACHE II, likely due to their incorporation of urine output criteria in addition to biochemical parameters. Future multicentre studies using raw patient-level data should develop robust, locally tailored prognostic models by integrating demographic, biochemical, and physiological trends through machine learning

Declarations

Ethics approval and consent to participate and publish
Ethical approval was obtained from the International Islamic University Malaysia Research Ethics (IREC 2021-304). As the data obtained were from database, waiver of consent has been sought and approved by the ethics committee. Consent for publication was approved by SASMEC@IIUM.

Competing interests
Dr. Md Ralib and Dr. Mat Nor serve as editorial board members of Malaysian Journal of Anaesthesiology. Neither were involved in any part of the editorial process prior to publication.

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Appendix 1. APACHE II, SAPS II, and SOFA Scores

Acute physiologic assessment and chronic health evaluation (APACHE) II score

Reproduced from Wong and Knaus.[2]

A. Physiologic variables points

PHYSIOLOGIC VARIABLE	HIGH ABNORMAL RANGE					LOW ABNORMAL RANGE				PT SCORE
	4	3	2	1	0	1	2	3	4	
Temperature - rectal (°C)	> 41	39-40.9		38.5-38.9	36-38.4	34-35.9	32-33.9	30-31.9	< 29.9	
MAP (mmHg)	> 160	130-159	110-129		70-109		50-69		< 49	
Heart Rate	> 180	140-179	110-139		70-109		55-69	40-54	< 39	
Respiratory Rate (non-ventilated or ventilated)	> 50	35-49		25-34	12-24	10-11	6-9		< 5	
Oxygenation: [A-aDO$_2$ = (FiO$_2$ x 710) – (PCO$_2$ x 1.25) – PO$_2$]					FiO$_2$ = PCO$_2$ = PO$_2$ =					
a. FiO$_2$ > 0.5 record A-aDO$_2$	> 500	350-499	200-349		< 200					
b. FiO$_2$ < 0.5 record only PaO$_2$					PO$_2$ > 70	PO$_2$ 61-70		PO$_2$ 55-60	PO$_2$ < 55	
Arterial pH	> 7.7	7.6-7.69		7.5-7.59	7.33-7.49		7.25-7.32	7.15-7.24	< 7.15	
Serum Na (mmol/L)	> 180	160-179	155-159	150-154	130-149		120-129	111-119	< 110	
Serum K (mmol/L)	> 7	6-6.9		5.5-5.9	3.5-5.4	3-3.4	2.5-2.9		< 2.5	
Serum Creatinine (umol/L)	> 305	170-304	130-169		53-129		<53			
Hematocrit (%)	> 60		50-59.9	46-49.9	30-45.9		20-29.9		< 20	
WBC (total/mm^3)	> 40		20-39.9	15-19.9	3-14.9		1-2.9		< 1	
Glasgow Coma Score (GCS)	Score = 15 minus actual GCS (see below)									
Serum HCO$_3$ (venous mmol/L) - not preferred, use if no ABG's	> 52	41-51.9		32-40.9	22-31.9		18-21.9	15-17.0	< 15	
									ACUTE PHYSIOLOGY SCORE (APS): Sum of the 12 individual variable points =	

B. Age Points - Assign points to age as follows:

AGE (yrs)	POINTS
<44	0
45-54	2
55-64	3
65-74	5
>75	6
AGE SCORE=	

C. Chronic Health Points - If the patient has a history of severe organ system insufficiency (see below) or is immunocompromised assign points as follows:

a. For nonoperative or emergency postoperative pt -- 5 points
b. For elective postoperative pt -- 2 points

CHRONIC HEALTH SCORE =

D. APACHE II SCORE - Sum of A + B + C

CHRONIC HEALTH DEFINITIONS

Organ insufficiency or immuno-compromised state evident prior to this hospital admission and are consistent with the following criteria:

A. APS points	
B. Age points	
C. Chronic Health points	
APACHE II SCORE =	

LIVER: Biospy-proven cirrhosis and documented portal hypertension; prior episodes of upper GI bleeding attributed to portal hypertension; or prior episodes of hepatic failure/encephalopathy/coma

CARDIOVASCULAR: New York Heart Association Class IV

RESPIRATORY: Chronic restrictive, obstructive, or vascular disease resulting in severe exercise restriction (*i.e.*, unable to climb stairs or perform activities of daily living or household duties; or documented chronic hypoxia, hypercapnia, secondary polycythemia, severe pulmonary hypertension (>40 mmHg), or ventilator dependency

RENAL: Receiving chronic dialysis

IMMUNO-COMPROMISED: The patient has received therapy that suppresses resistance to infection (*i.e.*, immuno- suppressive treatment, chemotherapy, radiation, long term or recent high dose steroids, or has a disease that is sufficiently advanced to suppress resistance to infection (*i.e.*, leukemia, lymphoma, AIDS)

GLASCOW COMA SCALE		
Parameter	**Response**	**Points Assigned (please circle)**
Eyes Open	Spontaneously	4
	On spoken command	3
	On pain	2
	No response	1
Best Motor Response	To spoken command	6
	To painful stimulus:	
	Localized pain	5
	Flexion withdrawal	4
	Flexion abnormal	3
	Extension	2
	No response	1
Best Verbal Response	(Not on ventilator)	
	Oriented & converses	5
	Disoriented & converses	4
	Inappropriate words	3
	Incomprehensible sounds	2
	No response	1
	(On ventilator)	
	Appears oriented	5
	Questionably oriented	3
	Generally unresponsive	1
	Total GCS =	

Simplified acute physiology (SAPS) II score

Reproduced from Le Gall.[3]

Points variable	26	13	12	11	9	7	6	5	4	3	2	0	1	2	3	4	6	7	8	9	10	12	15	16	17	18
Age In years												<40						40-59				60-69	70-74	75-79		≥80
Heart rate Beats per minute				<40							40-69	70-119				120-159		≥160								
Systolic BP mmHg		<70						70-99				100-199		≥200												
Body temperature												<39			≥39											
Only if ventilated or Continuous Positive Airway Preassure PaO_2/FiO_2				<100	100-199		≥200																			
Urinary output Litre per day				<0.5					0.5-0.999			≥1.0														
Serum urea mmol/l												<10.0					10-29.9				≥30.0					
WBC $10^3/mm^3$			<1.0									1.0-19.9			≥20											
Serum potassium mmol/l										<3.0		3.0-4.9			≥5.0											
Serum sodium mmol/l								<125				125-144	≥145													
Serum bicarbonate mmol/l							<15			15-19		≥20														
Bilirubin umol/l												<68.4				68.4-102.5				≥102.6						
Glasgow Coma Scale	<6	6-8				9-10		11-13				14-15														
Chronic disease																				Met. cancer	Haema malign				AIDS	
Type of admission												Elective surgery					Medical		Emergency surgery							
Sum of points																										

Total SAPS II score: _____ Points_____ Risk of Hospital Death %

Sequential organ failure assessment (SOFA) score

Reproduced from Vincent *et al.*[4]

SOFA Score	0	1	2	3	4
Respiration PaO_2/FiO_2	>400	<400	<300	101–200 with respiratory support	0 –100 with respiratory support
Haematological Platelets$x10^3$ per mm^3	>150	101 - 150	51 - 100	21 - 50	0 - 20
Hepatic Bilirubin umol/l	0 - 19	20 - 32	33 - 101	102 - 204	>204
Cardiovascular Hypotension *Inotrope/ vasopressor ≥ 1 hour	MAP > 70 mmHg	MAP <70mmHg	Dopamine 1-5µg/kg/min or Dobutamine any dose	Dopamine 6-15 µg/kg/min or Adrenaline ≤0.1 µg/kg/min or Noradrenaline ≤0.1 µg/kg/min	Dopamine >15 µg/kg/min or Adrenaline >0.1 µg/kg/min or Noradrenaline >0.1 µg/kg/min
Central Nervous System Glasgow Coma Score	15	13 - 14	10 - 12	6 - 9	3 - 5
Renal Creatinine umol/l or Urine output ml/ day	0 - 110-	110 - 170-	171 - 299-	300 - 440 or 200 - 499	>440 or < 200
TOTAL					

*Adrenergic agents administered for at least 1 hour

TOTAL SOFA SCORE:

Appendix 2

Table 1. Renal components of APACHE II, SAPS II and SOFA scores

Scoring system	Variables	Components	Score
Renal SOFA	Creatinine and urine output	Creatinine ≥ 440 µmol/l or urine output < 200 ml/day	+4
		Creatinine 300– 400 µmol/l or urine output < 500 ml/day	+3
		Creatinine 171–299 µmol/l	+4
		Creatinine 110–170 µmol/l	+1
		Creatinine < 110 µmol/l	0
Renal SAPS II	Urine output	Urine output < 500 ml/day	+11
		Urine output 500 to 999 ml/day	+4
		Urine output ≥ 1000 ml/day	0
Renal SAPS II	Urea	Urea ≥ 30 mmol/l	+10
		Urea 10–29.6 mmol/l	+6
		Urea < 10 mmol/l	0
Renal APACHE II	Creatinine	Creatinine ≥ 350 µmol/l	+4
		Creatinine 200–340 µmol/l	+3
		Creatinine 150– 90 µmol/l	+2
		Creatinine 60–140 µmol/l	0
		Creatinine < 60 µmol/l	+2

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Massive haemothorax from inadvertent subclavian vein injury during tunnelled dialysis catheter insertion requiring surgical repair

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Abstract

Massive haemothorax is a rare but life-threatening complication of internal jugular vein catheterisation. We report a 55-year-old male with end-stage renal failure and limited intravascular access who required a tunnelled dialysis catheter after fistula failure and missed haemodialysis. Multiple ultrasound-guided insertion attempts resulted in an inadvertent massive left haemothorax. The patient developed immediate postprocedural respiratory distress, requiring intensive care unit (ICU) admission, mechanical ventilation, and vasopressor support. Computed tomography of the thorax confirmed left sided haemothorax, and an ultrasound-guided chest tube was inserted. It drained 700 mL of blood. He received transfusion of 4 units each of packed red blood cells, fresh frozen plasma, cryoprecipitate, and platelets. After stabilisation, he was transferred urgently to a tertiary hospital for cardiothoracic surgery. Thoracotomy revealed subclavian vein injury, which was repaired with an estimated intraoperative blood loss of 1.8 L. Postoperatively, he was successfully weaned from mechanical ventilation over 4 days in ICU. Early recognition of this rare complication and timely definitive intervention is essential to improving outcomes and ensuring patient safety.

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Keywords: central venous catheter, inadvertent vascular injury, massive haemothorax

Introduction

Central venous catheter (CVC) placement is essential for anaesthetists in operating theatres and intensive care units (ICU) for various purposes such as venous access, medication delivery, renal replacement therapy, and monitoring. Understanding and mitigating the risks of complications, particularly mechanical ones, is crucial. These complications can occur during or after placement. This case report presents a potentially fatal complication of CVC placement and discusses vascular injury to the central venous anatomy as a mechanical complication following CVC insertion as well as its management.

Case presentation

An average built 55-year-old man with a history of end-stage renal failure and exhausted intravascular access was admitted to the hospital due to complications from failed fistulas and missed haemodialysis sessions. The patient's regular medications did not include any anticoagulants or antiplatelets. The nephrology team had attempted to place a tunnelled dialysis catheter in the left internal jugular vein (IJV) as his right IJV was thrombosed. The procedure required multiple attempts despite ultrasound guidance. During the final attempt, the catheter was advanced over a guidewire, but there was no inflow or outflow from both lumens of the catheter. When the proceduralist removed the catheter, the patient suddenly reported left chest pain and shortness of breath. Immediate vital signs revealed hypotension, with blood pressure 70/40 mmHg and S_pO_2 88%. Saturation improved to 100% after the patient was placed on a high-flow mask. Blood pressure improved to 108/76 mmHg with administration of 500 mL crystalloid.

Physical examination showed reduced movement of the left chest and dullness on percussion. A bedside ultrasound revealed left pleural effusion, and a portable chest X-ray was urgently performed (Fig. 1). The chest X-ray post procedure showed complete opacification of the left chest consistent with haemothorax. The patient was immediately transferred to the intensive care unit (ICU) and intubated due to impending respiratory arrest. Large-bore intravenous (IV) branulas and femoral CVC were inserted for resuscitation. The haemodynamic was supported with 0.08–0.1 mcg/kg/min norepinephrine to maintain a mean arterial pressure of 65 mmHg for

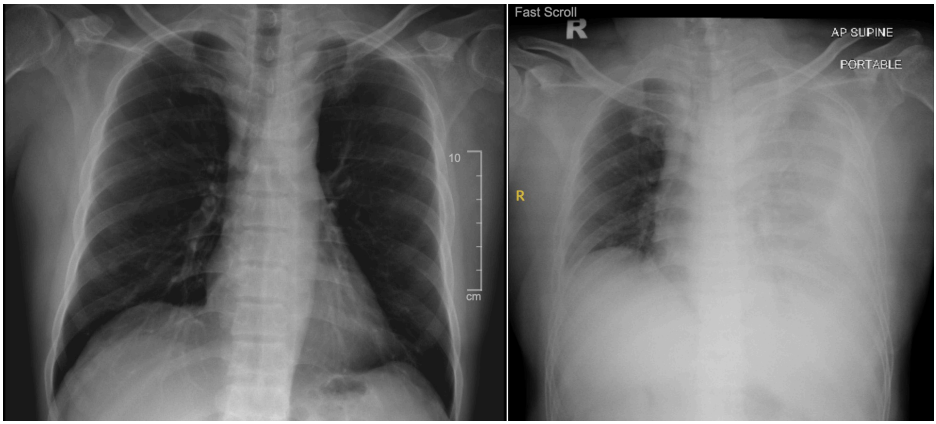

Fig. 1. (Left) Pre-procedure and *(right)* post-procedure chest X-ray.

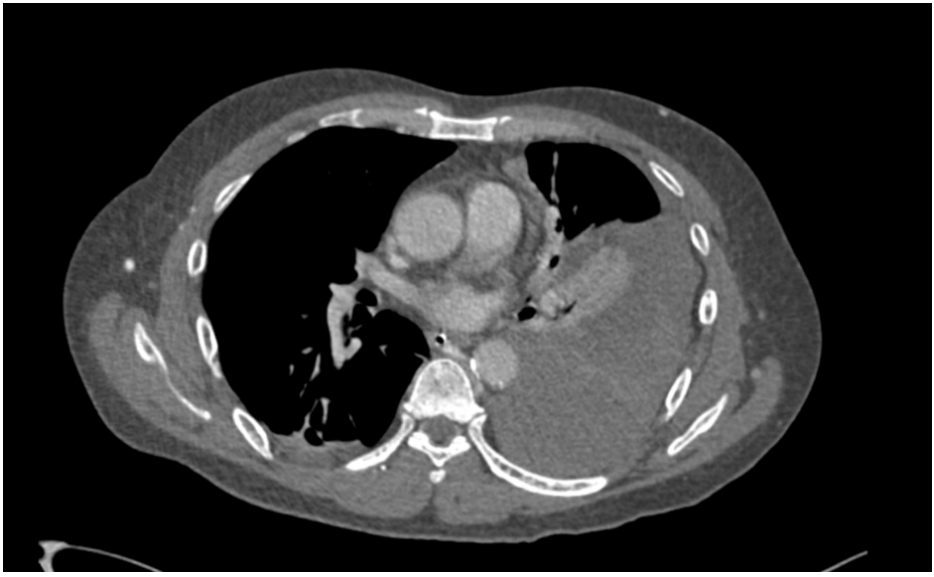

Fig. 2. Computed tomography of the thorax showing left pleural effusion, likely haemothorax.

adequate organ perfusion.

An urgent computed tomography of the thorax, as shown in Figure 2, reaffirmed left sided haemothorax. A pigtail size 12F was placed under ultrasound guidance by the radiologist, which drained 700 mL of frank blood. The patient's haemoglobin dropped from 8.9 g/dL to 5 g/dL in the span of 3 hours. Continuous resuscitation with blood products included transfusion of 4 units of packed red blood cells

followed by 4 units of fresh frozen plasma, cryoprecipitates, and platelets, respectively. Concurrent with resuscitation efforts, he was referred to the surgical team. The decision was made to clamp the chest tube and to transfer the patient to a tertiary hospital with cardiothoracic services. During the emergency thoracotomy, the surgeon detected a direct puncture wound inferior to the left subclavian vein at the left innominate junction with active bleeding. Total estimated blood loss during the surgery was recorded at 1.8 L. Following surgery, the patient was weaned from mechanical ventilation in the ICU over 4 days and later transferred to the general ward.

Discussion

The IJV is a major vein responsible for draining blood from the brain, face, and neck. It originates at the jugular foramen, receiving blood from the sigmoid sinus and inferior petrosal sinus, and descends in the neck alongside the common carotid artery. Medially, it is related to the carotid arteries and the vagus nerve, while laterally it is bordered by the sternocleidomastoid muscle. The IJV collects blood from several tributaries including the facial, lingual, pharyngeal, and thyroid veins and terminates by merging with the subclavian vein to form the brachiocephalic vein. The right and left brachiocephalic veins form the superior vena cava.[1]

In patients with end-stage renal failure, repeated vascular access procedures such as CVC insertions and arteriovenous fistulas can distort normal vascular anatomy through scarring, thrombosis, or stenosis of central veins. These anatomical changes increase the technical difficulty of subsequent catheter placements, even when performed under ultrasound guidance. In this case, multiple prior CVC insertions likely contributed to the challenging cannulation, with limited options after the right IJV thrombosed. Possible causes for right IJV thrombosis include repeated catheter-related endothelial trauma, venous stasis, and a prothrombotic state associated with uraemia.[2] Despite real-time ultrasound, complications can still occur when vessels are small, scarred, or anatomically distorted, leading to misdirection of dilators or guidewires into adjacent structures.[3] Mechanical complications of CVC placement often occur during the Seldinger or modified Seldinger technique, which involves needle cannulation of the central vein, guidewire insertion, dilatation of the skin at the vessel entry site, and catheter advancement over the guidewire.[4] Most complications are detected immediately or soon after insertion. While the types of complications for larger CVCs are similar, they may be more severe due to the catheter size. Direct vascular injury, *e.g.*, laceration, through-and-through injury, or dissection can occur following insertion of CVC. Risk factors include malposition of the needle or

guidewire within the central lumen of vessel, difficult dilator advancement over the guidewire, and larger calibre catheter.

The presentation of vascular injury can vary significantly, ranging from asymptomatic cases to immediate or delayed complications such as haematomas, pleural or pericardial effusion, and cardiovascular collapse. It is essential to maintain a high level of suspicion for unexpected bloody pleural or pericardial effusion as well as an unanticipated drop in haematocrit or episode of hypotension. In this case, the patient developed acute chest pain, dyspnoea, hypoxia, and hypotension almost immediately after CVC placement. The rapid onset of respiratory compromise, coupled with unilateral decreased chest movement and ultrasound evidence of pleural effusion, raised a high suspicion of vascular injury.

The management of haemothorax requires a systematic approach to ensure rapid stabilisation and effective treatment. The first step is recognition and assessment, which involves quickly identifying signs of respiratory distress and hemodynamic instability through vital signs and physical examination. Haemodynamic stabilisation follows, with intravenous access established for fluid resuscitation and blood transfusion as needed while maintaining a mean arterial pressure of 60–65 mmHg to ensure organ perfusion without exacerbating bleeding.

It is very important to be vigilant in CVC insertion, especially in patients with limited vascular access. Symptoms such as chest pain, dyspnoea, or hypoxia should prompt immediate imaging to rule out iatrogenic injuries like haemothorax. Several factors likely increased the chance of mechanical complications in this patient: difficult anatomy from previous cannulations, thrombosis of the right IJV, and multiple attempts at cannulation on the left side despite ultrasound guidance. Each repeated attempt increases the risk of inadvertent vessel injury. Immediate management in our hospital included rapid recognition of haemothorax, securing the airway through endotracheal intubation, insertion of femoral venous access for resuscitation, initiation of vasopressor support, and placement of an ultrasound-guided chest drain that evacuated 700 mL of blood.

According to Advanced Trauma Life Support guidelines, massive haemothorax is defined by the need for thoracotomy and the indications are blood loss > 1,500 mL or one-third of blood volume or blood loss > 200 ml/h (3 ml/kg/h) over 2–4 hours, or continued need for blood transfusion. In this case, the immediate drainage of 700 ml of blood raised concern for the development of massive haemothorax.

Massive haemothorax compresses the lung and mediastinum, reducing venous return and impairing cardiac output. Blood loss leads to hypovolemia, decreasing preload and systemic perfusion. Combined, these effects cause hypotension,

tachycardia, and shock. Respiratory compromise further worsens oxygen delivery, exacerbating tissue hypoxia and haemodynamic instability.[4] In this case, the patient's abrupt onset of hypotension, hypoxia, and respiratory distress following catheter insertion together with immediate drainage of 700 mL of blood, fulfilled the clinical criteria of a massive haemothorax. From a safety perspective, doctors must maintain a high index of suspicion for complications when patients deteriorate after CVC placement.

A chest tube should be inserted to drain the haemothorax, relieve lung compression, and restore respiratory function.[5] Ultrasound guidance is advised for precise chest tube placement.[6] In unstable patients requiring thoracotomy, a chest tube of 24–28 French is recommended,[7,8] although smaller tubes may be effective in selected cases.[9] If there is rapid blood accumulation (>20 ml/kg), surgery may be necessary.[10] Urgent imaging (chest X-ray or computed tomography of the thorax) is necessary to confirm the diagnosis and identify the source of bleeding.[10] Finally, in cases of severe injury, referral and transfer to a specialised surgical team or tertiary care centre should be arranged for optimal management. The urgency of referral to a tertiary centre in this case was underscored by the ongoing haemodynamic instability and significant blood loss despite initial drainage and resuscitation. Massive haemothorax with evidence of central vascular injury exceeds the capacity of a general hospital and mandates transfer for cardiothoracic surgical repair.

The learning points from this case in terms of the perspective of CVC placement are strict adherence to ultrasound-guided technique during CVC insertion and avoiding multiple attempts at cannulation, particularly in anatomically challenging patients. It is also important to use appropriately sized catheters to ensure smooth passage of dilators and thereby reduce vessel trauma.[11] As a reminder, when resistance is met, advancement must not be forced and guidewire position must be reassessed.[12,13]

This case raises several learning points regarding detection and management of complication of CVC placement. Frequent clinical assessments should be performed post-procedure, including measurements of heart rate, blood pressure, and oxygenation as well as physical examination (*e.g.*, percussion, auscultation). Early chest imaging (ultrasound or X-ray) post-CVC insertion in high-risk or symptomatic cases should be performed.[14,15] Serial haematocrit levels may help to detect occult bleeding.[16] Coordination and multidisciplinary team management between anaesthesiology, ICU, and surgical teams should not be delayed when clinical deterioration is observed, especially when patients require transportation to a different hospital for escalation of management.[17]

Conclusion

This case highlights the importance of prompt recognition of a rare complication of CVC placements. Appropriate and timely intervention, and well-coordinated multidisciplinary management of rare complications can significantly improve patient outcome.

Declarations

Informed consent for publication
The patient provided written informed consent for the publication of the medical data and images contained in this article

Competing interests
None to declare.

Funding
None to declare.

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Dexmedetomidine-facilitated anaesthesia in paediatric single ventricle physiology undergoing dental rehabilitation: two case reports

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Abstract

We describe 2 successful cases of children with single ventricle physiology (SVP) who underwent dental rehabilitation under general anaesthesia, a scenario that carries significant challenges. Both patients received intranasal dexmedetomidine as premedication, which provided effective anxiolysis, facilitated intravenous access, and contributed to perioperative haemodynamic stability. One patient was maintained on sevoflurane, while the other received total intravenous anaesthesia with propofol and remifentanil. In both cases, deep extubation was performed safely, aided by dexmedetomidine's sedative and sympatholytic properties and careful titration of anaesthetic depth. These cases highlight important anaesthetic considerations in SVP, including the role of dexmedetomidine as premedication, careful titration of anaesthetic agents to achieve haemodynamic goals, particularly in reducing pulmonary vascular resistance, the potential to omit muscle relaxants, goal-directed fluid therapy, and the importance of smooth extubation.

Keywords: deep extubation, dexmedetomidine, sevoflurane, single ventricle physiology, total intravenous anaesthesia

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Introduction

Single ventricle defects are a group of complex congenital heart diseases (CHD) characterized by the presence of a single functional ventricular chamber.[1-3] These include conditions such as hypoplastic left heart syndrome, tricuspid atresia, and double-inlet left ventricle. Some anomalies with 2 ventricles, such as unbalanced atrioventricular septal defects, are also functionally single ventricle due to structural limitations that prevent biventricular circulation.[3] Complete mixing of systemic and pulmonary venous return occurs at the atrial or ventricular level, and outflow tract obstruction is commonly present.[3] Standard surgical management involves staged palliative procedures including the bidirectional Glenn shunt and Fontan operation, aimed at optimizing the balance between pulmonary and systemic blood flow.[2-3]

Perioperative risk assessment is essential in this group. The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) classifies children with CHD into minor, major, and severe risk categories. Patients with single ventricle physiology (SVP) fall into the severe category, requiring anaesthesia management in tertiary centres with cardiac expertise and intensive care backup.[2]

These patients pose significant anaesthetic challenges due to limited cardiovascular reserve and dependence on passive pulmonary circulation.[1,2] Despite their complex cardiovascular physiology, these cases contribute uniquely by describing anaesthetic approaches for dental procedures in SVP, with a focus on intraoperative haemodynamic trends and perioperative management considerations.

Case presentation

Case 1

The first patient was a 5-year-old boy with tricuspid atresia, a small ventricular septal defect, and pulmonary stenosis. As part of staged palliation, he had undergone a balloon atrial septostomy in 2019, followed by a right bidirectional Glenn shunt, repeat atrial septostomy and pulmonary artery augmentation in 2021. His baseline oxygen saturation at home ranged from 75% to 80%. An echocardiogram performed in March 2024 confirmed a patent Glenn shunt.

He had recently been hospitalised for pneumonia requiring high-flow nasal cannula oxygen therapy with a 4-day stay. He was not on any anticoagulant or anti-failure medications. Preoperative haemoglobin was 17 g/dl and haematocrit 51%. The patient was kept nil by mouth for 6 hours for solids and allowed clear fluids up to 2 hours preoperatively. EMLA cream was applied to both hands in the ward

prior to transfer. Upon arrival at the operating theatre, intranasal dexmedetomidine 3 mcg/kg was administered as premedication and an intravenous cannula was successfully inserted 20 minutes later.

Standard American Society of Anesthesiologists (ASA) monitoring was applied, including dual pulse oximetry. Induction consisted of intravenous (IV) midazolam 0.1 mg/kg, IV ketamine 1.5 mg/kg, and IV fentanyl 2 mcg/kg, followed by rocuronium 1 mg/kg to facilitate nasal intubation. A 4.5-mm cuffed nasal RAE endotracheal tube was secured 16 cm at the nares. Antibiotic prophylaxis for infective endocarditis was administered preoperatively.

Anaesthesia was maintained with sevoflurane at 1.9% (minimum alveolar concentration [MAC] 0.7). Controlled ventilation was applied (tidal volume 6 ml/kg, PEEP 5 cmH_2O, Fio_2 0.35, $EtCO_2$ 35 mmHg). Intraoperative SpO_2 ranged 85%–88%.

Multimodal analgesia included IV morphine 0.1 mg/kg, IV paracetamol 15 mg/kg, rectal diclofenac 12.5 mg, and local infiltration by the dentist with mepivacaine 2% with adrenaline. IV dexamethasone 0.15 mg/kg was administered as an antiemetic.

Baseline vital signs were blood pressure (BP) 99/57 mmHg (mean arterial pressure [MAP] 71 mmHg), heart rate (HR) 96 bpm, and SpO_2 83%. Post-induction, BP transiently increased to 123/85 mmHg and HR to 114 bpm. Intraoperative vitals remained stable, with BP ranging 86–93/48–57 mmHg (MAP 61–69 mmHg), HR 88–95 bpm, SpO_2 86%–88%, and temperature 36°C. This represented a mild reduction in MAP of approximately 10 mmHg below baseline, which was well tolerated without desaturation or signs of poor perfusion. Fluid management consisted of no maintenance infusion, and a total of 10 ml/kg Hartmann's solution given as replacement boluses. Total procedure time was approximately 1.5 hours.

Toward the end of the procedure, IV sugammadex 2 mg/kg was given to reverse neuromuscular blockade. Sevoflurane was discontinued while the patient was maintained on FiO_2 0.5 with ultra-low-flow anaesthesia to facilitate slow washout. At MAC 0.7, spontaneous respiration with adequate minute ventilation was observed. Anaesthesia was then transitioned to intermittent IV propofol boluses (0.5–1 mg/kg) to maintain depth for emergence. Deep extubation was done smoothly to a face mask at 5 l/min. He remained stable in the recovery area and was discharged to the ward on room air after 15 minutes. The perioperative course was uneventful.

Case 2

The second patient was a 9-year-old boy with autism spectrum disorder and pulmonary atresia with an intact ventricular septum and a unipartite right ventricle. He previously underwent balloon atrial septostomy and patent ductus arteriosus

stenting in 2015 and a bilateral Glenn shunt with pulmonary artery augmentation in 2019. An echocardiography in July 2024 confirmed a patent Glenn shunt.

He was not on any anticoagulant or heart failure medications. Preoperative haemoglobin was 15 g/dl, and haematocrit 44%. He was kept nil by mouth for 6 hours for solid food and allowed clear fluids up to 2 hours before the procedure. EMLA cream was applied to both hands before transfer to the operating theatre.

Upon arrival in the preoperative bay, the patient received intranasal dexmedetomidine 3 mcg/kg as premedication. After 20 minutes, IV cannulation was attempted but unsuccessful; therefore, inhalational induction with sevoflurane was commenced using incremental concentrations of 2% and 4% with standard ASA monitors applied.

Once IV access was secured, boluses of IV ketamine 2 mg/kg and IV remifentanil 1 mcg/kg were given. Smooth intubation was performed without muscle relaxants, facilitated by remifentanil. Target-controlled infusion propofol (Peadfusor model) was commenced at 5 mcg/mL, and remifentanil infusion at 0.2 mcg/kg/min. Nasal intubation was performed using a 5.5-mm cuffed RAE tube, secured 18 cm at the nares. Antibiotic prophylaxis for endocarditis was administered.

Remifentanil infusion was maintained at 0.1 mcg/kg/min intraoperatively, while target-controlled infusion propofol was titrated to 3.5 mcg/ml. Multimodal analgesia included IV morphine 0.1 mg/kg, IV paracetamol 15 mg/kg, and local anaesthesia mepivacaine 2% with adrenaline by the dental team. IV dexamethasone 0.15 mg/kg was given as an antiemetic.

Baseline vital signs were BP 98/61 mmHg (MAP 73 mmHg), HR 78 bpm, and SpO_2 84%. Post-induction, the patient's BP dropped by 20% to 68/38 mmHg (MAP 48 mmHg) and was managed with 2 boluses of IV phenylephrine (10 mcg each). Intraoperatively, vital signs remained stable: BP 70–80/44–46 mmHg (MAP 53–57 mmHg), HR 73–76 bpm, SpO_2 86%–89%, and temperature 36.3°C. Fluid management consisted of 10 ml/kg Hartmann's solution, administered as boluses.

Ventilation was maintained using pressure support ventilation with a tidal volume of 6 ml/kg, PEEP 5 cmH_2O, rate 18 bpm, FiO_2 0.35, and $EtCO_2$ target of 35–40 mmHg. The procedure lasted 1.5 hours. Propofol was discontinued approximately 20 minutes before the end of surgery, and remifentanil was discontinued at the completion of the procedure. This facilitated a smooth deep extubation and the patient was transitioned to a face mask at 5 l/min. He remained stable in the recovery area and was discharged to the general ward on room air. The perioperative course was uneventful.

Discussion

Children with SVP are categorised as severe risk within the ACS NSQIP framework.[2] Nonetheless, this risk is heterogeneous; those with well-compensated Glenn or Fontan physiology may be considered major risk for selected outpatient procedures, provided that thorough preoperative assessment and multidisciplinary planning are undertaken.[2]

Both cases presented practical challenges, including preoperative anxiety, behavioural difficulties, *e.g.*, autism, and lack of IV access. A tailored induction plan, such as the use of intranasal dexmedetomidine, provides the dual advantage of preoperative anxiolysis and reduced anaesthetic maintenance requirements.[4-6] It has an onset of 20–30 minutes and a duration of action up to 135 minutes. In both cases, its use as premedication decreased the doses of sevoflurane and total intravenous anaesthesia (TIVA) agents required, while its sympatholytic profile supported smoother induction and emergence without respiratory compromise.[1] Its growing utility in children with CHD is increasingly recognised in current literature.[1,2,5]

Induction strategies using ketamine remain a reliable induction agent for children with SVP, as it preserves heart rate, systemic vascular resistance, and cardiac output.[1,3] In contrast, propofol can cause vasodilation and hypotension, as seen in Case 2 with a 20% transient drop in MAP requiring vasopressor support (IV phenylephrine 1 mcg/kg) after induction. However, this drop in BP could also have been caused by initial sevoflurane induction for IV access placement. Nevertheless, with a carefully titrated TIVA regimen, propofol combined with remifentanil offers advantages of smoother emergence, haemodynamic predictability, and the possibility of avoiding muscle relaxants.[7]

In the TIVA case, smooth tracheal intubation was achieved without muscle relaxants by administering boluses of ketamine and remifentanil.[1,7] An IV remifentanil bolus of 2–4 mcg/kg following induction has been shown to provide optimal intubating conditions comparable to relaxant use. Intubation performed either after a reduction in heart rate or approximately 30 seconds post-administration of IV remifentanil.[8,9] No significant bradycardia or muscle rigidity was observed in our patient. Avoiding muscle relaxants preserved spontaneous ventilation, which is advantageous in Glenn physiology where passive pulmonary blood flow can be impeded by high intrathoracic pressures.

Maintenance of anaesthesia with sevoflurane, as in Case 1, is commonly employed in paediatric practice because of its familiarity, non-irritating profile, and controllable depth of anaesthesia.[3] However, sevoflurane produces dose-dependent vasodilation and reductions in systemic vascular resistance, which may

be poorly tolerated in SVP if not titrated carefully.[1,3] The use of a muscle relaxant can help limit sevoflurane requirements, thereby reducing the risk of significant systemic vascular resistance depression. At the same time, controlled ventilation with muscle relaxation may increase intrathoracic pressure and impede passive pulmonary blood flow through the Glenn shunt. Ventilation strategies such as applying an optimal PEEP of 4–5 cmH_2O, tidal volumes of 6–8 mL/kg, and targeting an end-tidal CO_2 of 35–45 mmHg is recommended.[1,2]

At our centre, children with SVP and Glenn shunt undergoing short dental procedures (< 2 hours) typically receive a single intraoperative crystalloid bolus of 10 ml/kg. Further fluid administration is restricted to this limit and guided by continuous haemodynamic monitoring. Euvolemia is essential in Glenn circulation, where pulmonary blood flow depends on passive venous return.[1,2] While IV maintenance fluids were traditionally started preoperatively to prevent dehydration, current practice favours allowing clear oral fluids until transfer to the operating theatre.[2,10] This strategy is particularly practical in neurodivergent children who may resist IV cannulation. Perioperative fluid management should be individualised: patients unable to maintain oral intake should receive IV fluids, whereas intraoperative management should prioritise goal-directed therapy.[1,2] Excessive fluid administration risks pulmonary congestion and impaired haemodynamics, underscoring the importance of tailored fluid strategies in this population.

Prophylaxis antibiotics should be given consistent with 2008 American Heart Association (AHA)/American College of Cardiology (ACC) guidelines, which recommend endocarditis prevention in patients with unrepaired cyanotic CHD or palliative shunt undergoing dental procedures involving gingival manipulation.[11]

Both awake and deep extubation techniques are recognised approaches in paediatric anaesthesia, each with distinct advantages and limitations. Deep extubation is often preferred in our practice, as it provides smoother emergence and greater haemodynamic stability, particularly in children with CHD.[12,13] This technique, however, requires experience and vigilance due to the potential risk of airway obstruction compared with awake extubation. [12,13]

TIVA offers advantages over volatile anaesthetics for deep extubation by allowing more precise titration of depth and smoother transitions.[7] In contrast, maintaining adequate spontaneous ventilation at a deep plane of anaesthesia with sevoflurane can be challenging.[3] Traditionally, a MAC above 1.0 is the target, along with established spontaneous ventilation, before proceeding with deep extubation.[12] In our cases, we adapted this recognised approach by discontinuing sevoflurane earlier and maintaining anaesthetic depth with intermittent propofol boluses (0.5–1 mg/kg). This adjustment promoted more reliable spontaneous ventilation

and facilitated a smoother extubation profile. Our experience aligns with emerging evidence that adjuncts such as dexmedetomidine or propofol can enhance the safety of deep extubation in paediatric patients with CHD.[13,14]

This case series illustrates that both volatile and TIVA-based anaesthetic techniques can be applied safely in children with SVP undergoing dental rehabilitation. The consistent factor across both cases was the use of intranasal dexmedetomidine, which provided effective anxiolysis, facilitated IV access, and contributed to perioperative haemodynamic stability. Its sedative and sympatholytic properties also supported smooth deep extubation, minimising the risk of haemodynamic surges and airway complications. These reports demonstrate dexmedetomidine's role as a versatile adjunct in this high-risk population, particularly in supporting anxiolysis and stable deep extubation, areas that remain underrepresented in the existing literature. Larger prospective studies are warranted to further evaluate its safety and efficacy in children with SVP undergoing non-cardiac procedures.

This report is limited by its small sample size (2 cases), which precludes generalisation of findings. Invasive haemodynamic monitoring (*e.g.*, arterial line, central venous pressure) was not used, restricting detailed physiological assessment. Long-term postoperative outcomes were not captured, and only immediate perioperative results are available. Additionally, as both cases were relatively short dental procedures, the applicability of these strategies to longer or more complex non-cardiac surgeries remains uncertain.

Conclusion

Children with SVP require proper perioperative planning with strategies to maintain preload, reduce pulmonary vascular resistance, and ensure smooth recovery for safe outcomes in this high-risk population. Both sevoflurane and TIVA can be used safely for short non-cardiac procedures. Intranasal dexmedetomidine shows promise as an anxiolytic, reducing anaesthetic requirements and facilitating smoother deep extubation.

Declarations

Informed consent for publication

Informed consent was obtained from the patients' legal guardians for the publication of the clinical data contained in this case report.

Competing interests
None to declare.

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