Genomics and artificial intelligence: Re-engineering the anaesthesia paradigm for the 21st century

Dear Editor,

Personalised medicine is not a new concept. Anaesthesiologists have traditionally tailored care based on patient characteristics such as age, weight, comorbidities, and physiological responses, guided primarily by clinical experience and population-based evidence. However, routine clinical practice consistently demonstrates substantial inter-individual variability in drug responses and physiological tolerance, with identical anaesthetic techniques often producing markedly different haemodynamic and clinical effects. This variability is increasingly attributed to genetic diversity, ethnic differences, and comorbid conditions such as hepatic and renal dysfunction, cardiovascular disease, obesity, and endocrine disorders, all of which significantly influence pharmacokinetics and pharmacodynamics.

The true paradigm shift, however, is the emergence of artificial intelligence (AI), which is transforming personalised medicine from an experience-based practice into a precise, predictive, and data-driven science. By integrating large clinical datasets, genomic information, and real-time physiological monitoring, AI offers the potential to move personalised anaesthesia from theoretical promise to clinical reality and overcome the limitations of traditional protocol-driven approaches.

Advances in pharmacogenomics have illuminated the mechanisms behind variable responses to anaesthetic drugs. For example, cytochrome P450 2B6 (CYP2B6) gene polymorphisms alter propofol metabolism,[1] butyrylcholinesterase (BCHE) gene variants influence recovery from succinylcholine,[2] and mutations in ryanodine receptor (RYR1) and calcium voltage-gated channel subunit alpha1 S (CACNA1S) genes predispose to malignant hyperthermia.[3] Similarly, opioid receptor gene (OPRM1) variants modify analgesic requirements.[4] Understanding these associations allow anaesthesiologists to anticipate responses and adverse effects, improving both efficacy and safety. However, genomics alone cannot operationalise personalised anaesthesia without tools capable of integrating and interpreting complex multidimensional data in real time.

Genomics lays the biological groundwork for personalised anaesthesia, but data science and AI now enable real-time individualisation. AI enables the practical implementation of personalised anaesthesia by integrating genomic information, continuous physiological monitoring, and perioperative big data into clinically actionable insights. Machine learning algorithms can analyse complex datasets to predict intra-operative hypotension, post-operative delirium, and analgesic requirements more accurately than traditional risk scores. Closed-loop anaesthesia delivery systems that automatically titrate hypnotics and analgesics based on EEG and haemodynamic inputs represent early examples of AI-enabled precision care.[5] In regional anaesthesia, AI is improving ultrasound image interpretation, needle trajectory prediction, and block success rates.[6] Thus, while personalised medicine provides the conceptual foundation, AI provides the technological capability to make precision anaesthesia achievable in routine practice. Together, predictive analytics and bedside practice are fostering a learning anaesthesia ecosystem that continually refines personalised care.[7]

Beyond genomics and AI-driven analytics lies phenotypic personalisation, which involves tailoring anaesthetic care based on measurable physiological characteristics. Examples include individualised blood pressure targets guided by cerebral autoregulation monitoring in neuroanaesthesia, fluid optimisation using dynamic preload indices such as stroke volume variation and pulse pressure variation, and EEG-guided titration of anaesthetic depth to prevent both awareness and excessive anaesthetic exposure. These approaches demonstrate how technology is progressively enabling objective individualisation of anaesthetic management.

Pharmacogenomic testing in anaesthesia is constrained by limited high-quality prospective evidence, lack of standardised clinical guidelines, and uncertainty in translating genotype–phenotype associations into actionable dosing decisions. In addition, high costs, limited availability, long turnaround times, and ethical concerns related to data privacy and equity restrict its routine perioperative application.

The ultimate goal of personalised anaesthesia is to move from reactive to predictive and preventive care. Imagine a pre-operative assessment where genomic profiling identifies a patient at risk for delayed emergence, opioid hypersensitivity, or postoperative nausea. Contemporary anaesthesia practice already considers patient-specific factors; however, the integration of genomic parameters would further individualise anaesthetic planning, optimise drug selection and dosing, minimise complications, and enhance recovery strategies beyond conventional approaches. Such a transformation would not only improve patient outcomes but also enhance satisfaction, cost-effectiveness, and safety across the perioperative continuum. The future of anaesthesia is not merely to deliver sleep, amnesia, and analgesia but to deliver them precisely to the right patient, with the right drug, at the right dose, at the right time.

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Author contributions

A K: Concept and design of study or acquisition of data or analysis and interpretation. A K, HMR K: Drafting the article and revising it critically for important intellectual content. A K, HMR K: Final approval of the version to be published. A K, HMR K: Agreement to be accountable for all aspects of the work.

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