Global Conference on Medical and Health Sciences
Hosted Online from Madrid, Spain
Date: 14th April, 2026
Website: https://econferencia.com

ARTIFICIAL INTELLIGENCE–BASED PRECISION ANESTHESIA: ADAPTIVE DOSING MODELS FOR PATIENT-SPECIFIC MANAGEMENT

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Abstract

The administration of anesthesia requires precise dosing to balance patient safety and procedural efficacy. Traditional methods often rely on standardized protocols and clinician experience, which may not account for inter-individual variability in pharmacokinetics and pharmacodynamics. Artificial Intelligence (AI) offers a transformative approach by integrating patient-specific data—such as age, weight, comorbidities, genetic profiles, and real-time physiological parameters—to optimize anesthesia dosing. AI-assisted systems utilize machine learning models and predictive algorithms to recommend individualized doses, reduce adverse events, and enhance recovery outcomes. This thesis explores the application of AI in anesthesia dosage selection, discussing computational frameworks, clinical utility, benefits, limitations, and future directions.

Keywords: Artificial Intelligence, Anesthesia, Individualized Dosing, Machine Learning, Pharmacokinetics, Predictive Analytics, Personalized Medicine.

Introduction

Anesthesia management is a critical component of surgical care, demanding precise dosing to achieve adequate sedation, analgesia, and muscle relaxation while minimizing complications. Inter-patient variability in drug response poses a challenge to standardized dosing, contributing to risks such as hypotension, respiratory depression, delayed recovery, or intraoperative awareness (Smith et al., 2018). AI-assisted individualized anesthesia dosing systems aim to mitigate these risks by leveraging computational models that incorporate patient-specific variables and real-time monitoring data. Machine learning models can analyze historical datasets, patient demographics, genetic markers, comorbidities, and physiological measurements to generate personalized dosage recommendations. This thesis examines the technological, clinical, and ethical aspects of AI-assisted anesthesia dosing, emphasizing the potential for improved patient safety, efficiency, and postoperative outcomes.

Main Body

AI-assisted anesthesia dosage systems combine data acquisition, predictive modeling, and decision support to optimize perioperative care. Patient-specific data, including weight, age, gender, genetic variants affecting drug metabolism, comorbidities, and current medications, are input into AI algorithms to estimate optimal induction and maintenance doses. Intraoperative physiological monitoring—including heart rate, blood pressure, oxygen saturation, and EEG-based depth-of-anesthesia indices—provides dynamic feedback, enabling real-time dose adjustment. Machine learning models, such as random forests, support vector machines, gradient boosting, and deep neural networks, are trained on large datasets comprising patient characteristics, anesthetic regimens, and clinical outcomes to predict individualized dosing requirements (Mason et al., 2020). Reinforcement learning algorithms have been explored to continuously optimize anesthesia delivery during surgery. By modeling the patient's physiological response to varying drug levels, reinforcement learning systems adapt dosing strategies in real time, maximizing safety and efficacy (Zhou et al., 2021). Natural language processing (NLP) is also employed to extract relevant clinical insights from electronic health records (EHRs) and perioperative notes, improving the algorithm's understanding of patient-specific risks and responses. Clinical applications of AI-assisted individualized dosing span diverse anesthetic agents, including intravenous induction drugs, volatile anesthetics, opioids, and muscle relaxants. In cardiovascular-compromised patients, AI models can recommend lower induction doses to prevent hypotension while maintaining adequate sedation. For patients with hepatic or renal impairment, pharmacokinetic modeling within AI systems adjusts drug metabolism predictions to prevent toxicity. Pediatric and geriatric populations, often vulnerable to dosing errors due to physiological variability, benefit from AI-driven precision dosing (Smith et al., 2018). The benefits of AI-assisted anesthesia dosing are significant. By providing individualized recommendations, these systems reduce the likelihood of under- or over-dosing, minimizing intraoperative complications such as hypotension, hypoxia, or awareness under anesthesia. Optimized dosing shortens recovery times, enhances postoperative outcomes, and improves resource efficiency in the operating room. AI support also reduces cognitive burden on anesthesiologists, allowing focus on complex decision-making and patient monitoring. Furthermore, aggregated AI predictions contribute to evidence-based practice, enabling continuous learning and refinement of dosing protocols (Mason et al., 2020). Challenges in implementing AI-assisted anesthesia dosing include data quality, model validation, and clinician trust. AI algorithms require large, high-quality datasets encompassing diverse patient populations to ensure accurate predictions. Integration with real-time monitoring devices and EHRs must address interoperability and cybersecurity concerns, as sensitive patient information is processed and transmitted. Algorithm transparency and explainability are critical for clinician acceptance, as black-box models may be resisted without clear reasoning behind dose recommendations (Topol, 2019). Ethical considerations include liability in cases of AI-driven dosing errors and the need for regulatory approval to ensure safety and efficacy. Future directions in AI-assisted anesthesia dosing involve multi-modal data integration, combining genomics, metabolomics, wearable sensor outputs, and intraoperative monitoring for even greater personalization. Reinforcement learning and adaptive control systems will refine dynamic dosing strategies, improving patient outcomes while reducing anesthetic waste. Collaborative AI networks across institutions may leverage federated learning to improve model generalizability without compromising patient privacy. The development of explainable AI models will enhance clinician confidence and facilitate regulatory approval, enabling widespread adoption of personalized anesthesia dosing.

Conclusion

AI-assisted individualized anesthesia dosage selection represents a paradigm shift in perioperative care, addressing inter-patient variability and improving patient safety, efficacy, and recovery. By leveraging machine learning, predictive analytics, and real-time physiological monitoring, AI systems provide precise, personalized dosing recommendations that reduce intraoperative complications and enhance postoperative outcomes. Benefits include improved patient safety, efficiency, and resource utilization, while challenges remain in data quality, integration, transparency, and ethical considerations. Ongoing advancements in AI modeling, multi-modal data integration, and explainable algorithms promise to further optimize anesthesia management, establishing personalized AI-assisted dosing as a standard of care in modern surgical practice.

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