Anesthesiology and Digital Health in Surgery and Perioperative Care: A Survey

www.surveyx.cn

Abstract

The integration of anesthesiology, anesthesia, digital health, surgery, telemedicine, perioperative care, and health informatics represents a transformative shift in healthcare delivery, enhancing patient outcomes and surgical precision. This survey explores advancements across these interconnected domains, emphasizing their collective role in optimizing perioperative management and fostering patient-centered care. Key innovations include closed-loop anesthesia delivery systems and augmented reality applications, which have improved precision and safety in surgical settings. The role of artificial intelligence in personalizing anesthetic regimens and predictive analytics is also highlighted, alongside the potential of digital health technologies to enhance proactive healthcare through personalized therapies. Telemedicine has emerged as a crucial component of perioperative care, offering remote monitoring and decision support that enhance patient management. However, challenges persist, including privacy concerns and regulatory compliance, particularly with emerging technologies like the Metaverse and blockchain. Future research should focus on validating AI models in clinical settings, addressing ethical concerns, and exploring interdisciplinary collaborations to enhance AI deployment in anesthesia. Additionally, efforts should be directed towards developing cost-effective augmented reality solutions and exploring new applications in healthcare. The survey concludes that integrating these fields offers promising avenues for advancing healthcare delivery, with future research directions including refining analytical approaches and developing robust control techniques for anesthesia delivery systems, enhancing robotic autonomy, and exploring innovative educational frameworks for training healthcare professionals.

1 Introduction

1.1 Scope and Significance

The integration of anesthesiology, anesthesia, digital health, surgery, telemedicine, perioperative care, and health informatics signifies a transformative shift in modern healthcare, enhancing patient outcomes and service efficiency. This survey investigates the interplay among recent advancements in anesthesiology technology, artificial intelligence in surgical practice, and optimized perioperative management, emphasizing their combined contribution to surgical precision and patient-centered care. Innovations such as telemedicine, machine learning, and computer vision are examined to illustrate their potential to revolutionize surgical procedures and improve healthcare outcomes [1, 2, 3, 4, 5]. Notably, advancements in anesthesiology techniques and monitoring systems have significantly reduced surgical risks and complications, while insights into the neural circuits of anesthesia offer parallels with natural sleep, which are crucial for both clinical practice and neuroscience.

Digital health interventions, including mobile computing and diverse data integration, are vital for promoting personalized and proactive healthcare. These technologies enable continuous patient monitoring and tailored therapies, overcoming the limitations of traditional clinical datasets by

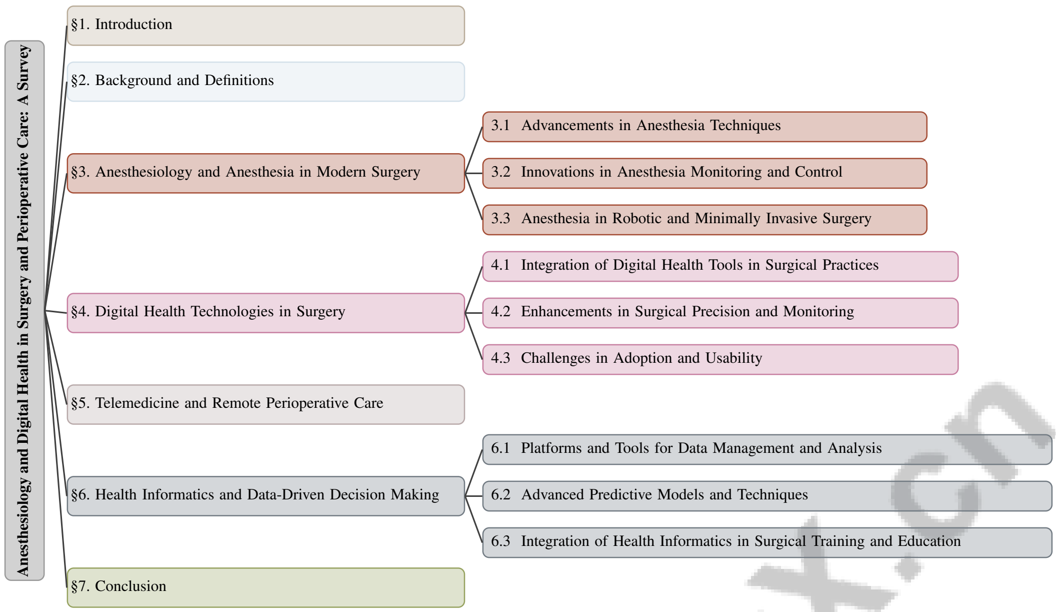


Figure 1: chapter structure

incorporating a broader spectrum of patient data [6]. The Human Digital Twin (HDT) concept emphasizes systematic digital representations of human pathophysiology, enhancing clinical decision-making and data management. Furthermore, augmented reality (AR) applications, such as wearable access and remote surgery, demonstrate the transformative potential of digital technologies in medical practices [7].

Advanced data analytics platforms are essential for real-time assessment of postoperative complications, which pose significant challenges in healthcare, including increased costs, extended hospital stays, and, in rare cases, patient mortality [8]. With approximately 230 million surgeries performed globally each year, healthcare providers must predict complications and implement preventive measures to enhance patient outcomes and reduce costs [8]. The survey also reviews reinforcement learning (RL) methods and their applications in precision and digital health, reflecting growing interest in AI technologies for healthcare [9].

Additionally, the gut microbiome's role in anesthetic effects, postoperative pain, and perioperative outcomes underscores its significance in pain medicine [10]. The evolution of preoperative evaluations for pediatric patients highlights their importance in ensuring safe anesthetic care, impacting patient safety and resource utilization [11]. This survey analyzes research trends in digital health-related articles, addressing the concentration, scope, and characteristics of research across various academic disciplines [4].

The collective impact of integrating these fields is substantial, offering new paradigms for patient care and aligning with broader goals of equitable and effective healthcare interventions. By addressing these multifaceted challenges and opportunities, this survey lays the groundwork for future innovations in healthcare, enhancing the quality and efficiency of service delivery across diverse clinical settings [12].

1.2 Structure of the Survey

This survey is structured into several key sections, each addressing critical aspects of the integration of anesthesiology, anesthesia, digital health, surgery, telemedicine, perioperative care, and health informatics. The introduction outlines the significance and scope of these fields in transforming modern healthcare. Following this, the background and definitions section provides an in-depth overview of essential concepts and terminologies, tracing the historical development and current state of these domains.

The survey then explores the role of anesthesiology and anesthesia in modern surgery, focusing on advancements in techniques, innovations in monitoring and control, and the application of anesthesia

AI-generated, for reference only.

in robotic and minimally invasive surgeries. A subsequent section analyzes the role of digital health technologies in surgical practices, emphasizing the integration of digital tools such as health digital twins and artificial intelligence, which enhance surgical precision, real-time monitoring, and clinical decision support. It also addresses challenges related to technology adoption and usability, including data privacy, regulatory compliance, and the necessity for collaboration among healthcare stakeholders to facilitate successful implementation [13, 3, 14, 4, 15].

The analysis then shifts to telemedicine and remote perioperative care, discussing telemedicine's role in supporting perioperative processes, its benefits and limitations in preoperative and postoperative settings, and technological innovations enhancing its capabilities. Successful applications are illustrated through real-world case studies, including the use of Retrieval Augmented Generation (RAG) models in preoperative tasks, the potential of the Metaverse in healthcare delivery, and innovative AR solutions for ventriculoperitoneal shunt operations, highlighting their efficiency, accuracy, and scalability in medical practice [16, 7, 17, 18].

The penultimate section explores health informatics and data-driven decision-making, emphasizing platforms and tools for data management and analysis, advanced predictive models, and the integration of health informatics in surgical training and education. The conclusion synthesizes key findings, reflecting on the collective impact of these integrated fields on healthcare and suggesting future research directions. Ethical considerations, particularly those adapted from military applications to address challenges in healthcare AI, are acknowledged throughout the survey to ensure responsible and effective implementation of these technologies [19].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Historical Development of Anesthesiology and Anesthesia

The progression of anesthesiology and anesthesia has been transformative, with pivotal milestones such as Horace Wells' nitrous oxide demonstration and William T. G. Morton's use of diethyl ether in the mid-19th century revolutionizing surgical procedures by enabling pain-free operations. These innovations, supported by figures like John Collins Warren, have laid a foundation for technological advancements that enhance safety and monitoring in modern medicine [20, 2, 21, 22, 23]. Morton's 1846 public demonstration of ether anesthesia was instrumental in global anesthetic adoption, soon followed by chloroform and nitrous oxide, expanding clinicians' options.

Professional societies and specialized training programs have significantly shaped anesthesiology as a distinct specialty. The American Dental Society of Anesthesiology (ADSA), established in 1953, advanced dental anesthesiology, leading to its recognition as a specialty by the American Dental Association (ADA) in 2019 despite challenges from other dental fields [22].

Technological progress has been crucial in anesthesiology's evolution, with innovations in real-time data acquisition and digital-to-analog conversion enhancing anesthetic precision and patient monitoring [24]. However, current monitoring methods often fail to account for individual patient variability in anesthetic response, highlighting the need for personalized approaches [25]. The COVID-19 pandemic underscored anesthesiology's vital role in managing healthcare resources amid elective surgery backlogs, affecting outcomes and resource allocation [26]. It also disrupted traditional training, prompting a shift to virtual education [27].

The mental health of anesthesiology staff, especially in high-stress ICU environments, has gained attention due to significant PTSD rates and other mental health issues [28]. Addressing these challenges is crucial for the well-being and effectiveness of anesthesiology personnel. Furthermore, AI integration in anesthetic practice offers workflow enhancements but presents challenges requiring careful consideration [21]. Understanding neural circuits involved in general anesthesia, such as consciousness and amnesia, remains incomplete, necessitating further research [29].

Anesthesiology's historical development reflects a dynamic interplay of scientific innovation, professional advocacy, and clinical advancements, enhancing patient care and surgical outcomes across diverse contexts. Ongoing challenges include comprehensive preoperative evaluations, managing patient anxiety related to testing, and balancing interventions with resource constraints [11].

AI-generated, for reference only.

2.2 Fundamentals of Digital Health and Its Evolution

Digital health represents a transformative shift in healthcare, driven by technological advancements aimed at enhancing patient care, optimizing outcomes, and streamlining operations. This multifaceted approach includes mobile health (mHealth), health IT, wearable devices, telehealth, and personalized medicine, facilitating real-time monitoring and data-driven decision-making [6]. The integration of mobile technologies and real-world data collection addresses traditional healthcare datasets' limitations, which often fail to capture the multidimensional nature of patient experiences and outcomes.

Recent advancements have introduced technologies like augmented reality (AR) and virtual reality (VR) for surgical training and remote mentoring in robotic surgery, enhancing educational landscapes and contributing to broader Metaverse applications in healthcare. However, challenges related to AR implementation and security persist [7].

Digital health progression is further characterized by decentralized computing architectures, such as fog computing, enabling efficient data processing and management, particularly for large language models (LLMs) [30]. The integration of IoT devices into healthcare systems is driving significant changes, although challenges related to data collection, organization, accessibility, and regulatory compliance remain [31].

Machine learning (ML) and artificial intelligence (AI) are crucial in digital health, offering novel solutions for surgical practices and decision-making processes. These technologies facilitate advanced methods, such as 2D/3D registration, improving surgical precision and outcomes [32]. However, effective AI integration in clinical settings requires careful consideration, particularly given the scarcity of publicly available large-scale labeled surgical datasets [33].

The concept of Human Digital Twins (HDTs), inspired by industrial digital twins, represents a significant advancement in digital health, modeling human pathophysiology for testing and optimization to enhance personalized healthcare services. However, digital twins' adoption in healthcare faces obstacles, including a lack of advanced predictive models, insufficient representative data for validation, unclear regulatory pathways, and scalability issues [13].

Despite these challenges, digital health holds the potential to revolutionize healthcare by providing more personalized, efficient, and accessible care. Addressing these barriers and harnessing technological innovations is essential for improving healthcare delivery worldwide. Quantum machine learning (QML) emerges as a promising approach for processing digital health data, offering potential advantages over classical machine learning methods [34].

In recent years, the field of anesthesiology has undergone significant advancements that have transformed surgical practices. This evolution is not only characterized by the development of new techniques but also by improvements in monitoring and control mechanisms that enhance patient safety and outcomes. Figure 2 illustrates the hierarchical structure of these advancements in anesthesiology and anesthesia in modern surgery, categorizing key innovations into three main areas: anesthesia techniques, monitoring and control, and their application in robotic and minimally invasive surgery. Each category within the figure highlights significant technological innovations, enhancements in surgical environments, educational aspects, and challenges associated with these advancements. This comprehensive overview emphasizes the transformative impact that these developments have had on surgical practices, paving the way for more effective and efficient patient care.

3 Anesthesiology and Anesthesia in Modern Surgery

3.1 Advancements in Anesthesia Techniques

Recent innovations in anesthesia have significantly enhanced precision, safety, and adaptability, leading to improved patient outcomes. Closed-loop anesthesia delivery (CLAD) systems exemplify these advancements by automating anesthesia adjustments based on real-time patient data [35]. These systems are complemented by model-based automatic control, integrating pharmacokinetic/pharmacodynamic (PK/PD) models with real-time monitoring to optimize drug infusion rates [36]. Artificial intelligence (AI) further augments these techniques, with deep reinforcement learning for anesthetic dosing (DRL-AD) optimizing propofol infusion and AI models predicting postoperative complications, such as nausea and vomiting [37, 38].

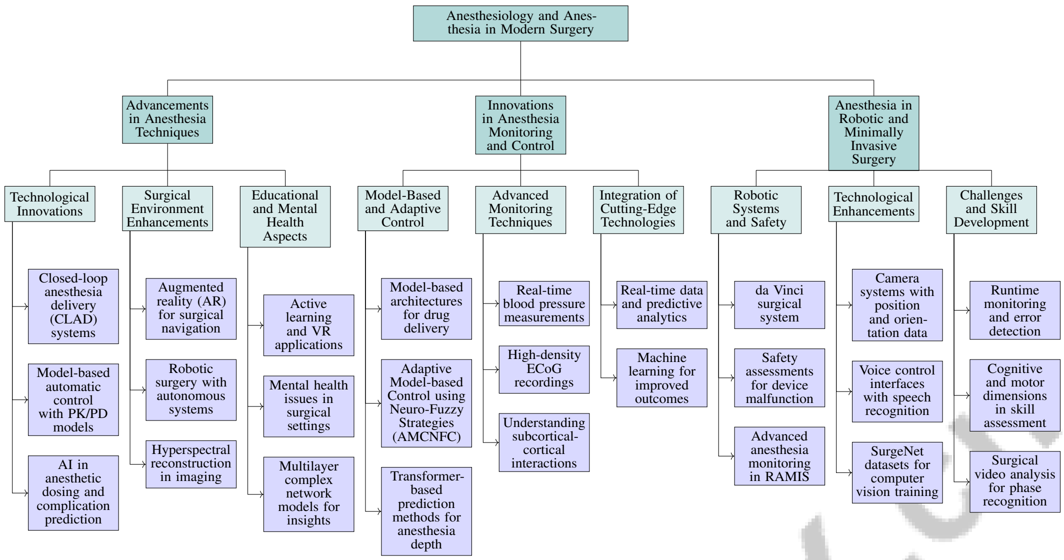


Figure 2: This figure illustrates the hierarchical structure of advancements in anesthesiology and anesthesia in modern surgery, categorizing key innovations in anesthesia techniques, monitoring and control, and their application in robotic and minimally invasive surgery. Each category highlights significant technological innovations, enhancements in surgical environments, educational aspects, and challenges, emphasizing the transformative impact on surgical practices.

As illustrated in Figure 3, recent advancements in anesthesia techniques can be categorized into key areas: automated anesthesia systems, augmented surgical environments, and mental health and educational improvements. Each category encompasses specific innovations and methodologies that contribute to enhanced precision, safety, and adaptability in anesthesia practices. Augmented reality (AR) technologies enhance surgical environments by projecting holograms of patient anatomy, improving surgical navigation and outcomes [39]. In robotic surgery, autonomous systems perform surgical tasks with enhanced safety and adaptability, further augmented by advanced imaging techniques like hyperspectral reconstruction [40, 41]. Educational advancements, including active learning techniques and VR applications like SurgTwinVR, improve knowledge retention and skills application in anesthesiology [23, 42].

Despite these advancements, the high-stress nature of surgical settings contributes to mental health issues among practitioners, highlighting the need for supportive measures [28]. Innovations such as multilayer complex network models offer new insights into anesthesia techniques, paving the way for further advancements [43].

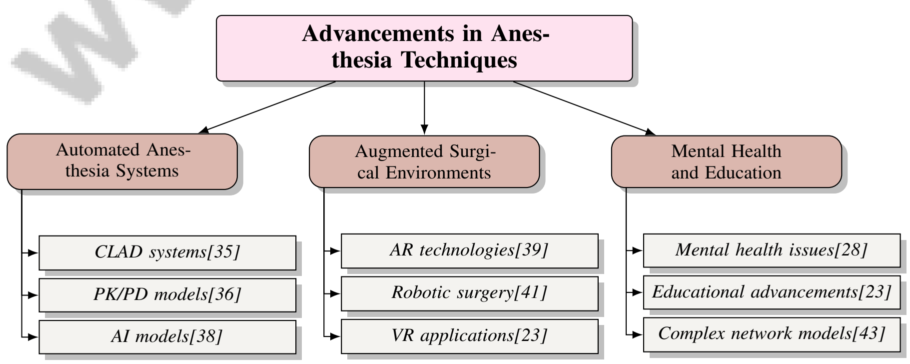


Figure 3: This figure illustrates recent advancements in anesthesia techniques, highlighting key areas such as automated anesthesia systems, augmented surgical environments, and mental health and educational improvements. Each category encompasses specific innovations and methodologies that contribute to enhanced precision, safety, and adaptability in anesthesia practices.

3.2 Innovations in Anesthesia Monitoring and Control

Innovations in anesthesia monitoring and control have significantly enhanced precision and safety, utilizing advanced technologies to optimize patient outcomes. Model-based architectures integrate patient monitoring with automated drug delivery systems, maintaining optimal anesthesia depth through continuous real-time adjustments [44]. The Adaptive Model-based Control using Neuro-Fuzzy Strategies (AMCNFC) exemplifies this by dynamically adjusting drug infusion rates based on real-time feedback [45].

Transformer-based prediction methods enhance anesthesia depth prediction accuracy by integrating temporal drug effects and patient physiological data [46]. Hybrid architectures like hiNet improve intraoperative monitoring by predicting hypoxemia, allowing timely interventions [47]. The application of deep neural networks within reinforcement learning frameworks optimizes continuous dosing policies, enhancing anesthesia control [37].

Innovations such as real-time blood pressure measurements for patient model validation and high-density ECoG recordings for analyzing dynamic community structure changes during anesthesia induction represent significant advancements in monitoring [48, 49]. Understanding interactions between subcortical and cortical areas during induction is crucial for improving anesthesia monitoring and control [29].

These advancements underscore the importance of integrating cutting-edge technologies to enhance anesthetic precision and safety. Leveraging real-time data, predictive analytics, and machine learning, recent innovations in anesthesiology are poised to improve patient outcomes significantly [2, 21, 3, 8, 50].

3.3 Anesthesia in Robotic and Minimally Invasive Surgery

The application of anesthesia in robotic and minimally invasive surgery (MIS) represents a substantial evolution in surgical methodologies, enhancing precision, safety, and patient outcomes. Robotic systems like the da Vinci surgical system integrate advanced technologies, providing enhanced precision and control during intricate procedures [51]. However, the complexity of these systems necessitates robust safety assessments to mitigate device malfunction risks [51].

In robotic-assisted minimally invasive surgery (RAMIS), advanced anesthesia monitoring techniques are critical due to the precision required. The choice of anesthetic techniques, such as volatile anesthesia versus total intravenous anesthesia (TIVA), significantly impacts neural activity levels during surgery [52]. Autonomous systems enhancing surgical precision, such as camera systems integrating position and orientation data, aid in visualizing critical anatomical structures [53]. Voice control interfaces with advanced speech recognition technology further improve surgical efficiency and precision [54].

Innovative datasets like SurgeNet enhance the training of computer vision techniques applied to minimally invasive surgeries, improving the accuracy and reliability of automated systems [39]. Despite these advancements, challenges persist in ensuring the safety and efficacy of robotic surgeries. Enhanced methods for runtime monitoring and error detection are essential to address executional errors in RMIS [55]. Incorporating cognitive and motor dimensions in skill assessment highlights the importance of skill development in robotic surgery [56].

The evolution of anesthesia techniques to meet the demands of advanced surgical practices underscores the transformative impact of anesthesia in modern surgical practices, paving the way for further advancements in the field [40]. Recent studies on surgical video analysis for phase recognition emphasize the necessity for improved methods to analyze and enhance surgical procedures [57].

4 Digital Health Technologies in Surgery

4.1 Integration of Digital Health Tools in Surgical Practices

Incorporating digital health tools into surgical practices marks a significant advancement, enhancing efficiency, precision, and patient safety. This transformation is driven by artificial intelligence (AI) and real-time imaging technologies that augment surgical robots and improve procedural outcomes [40]. AI applications, such as context-aware detection systems, enhance safety by identifying unsafe events during procedures [58]. Augmented reality (AR) technologies offer immersive visualizations for better preoperative planning and intraoperative guidance, with optical see-through head-mounted displays (OST-HMD) enabling real-time 3D holographic visualizations of patient anatomy, thus enhancing spatial awareness and reducing repetitive imaging [59]. This complements the Integrated Data Processing Method (IDPM), which fuses multiple data sources to enhance surgical effectiveness [12].

To illustrate the breadth of these advancements, Figure 4 depicts the integration of digital health tools in surgical practices, highlighting key areas such as AI and imaging, VR and education, and deep learning methods. Each category emphasizes specific advancements and applications that contribute to enhanced surgical outcomes and training.

Virtual reality (VR) also plays a pivotal role in surgical education, with platforms like SurgTwinVR immersing users in digital twins of real surgical scenarios, thereby improving skills [42]. Frameworks such as IMHOTEP utilize VR to facilitate interaction with multimodal patient data, aiding in understanding complex surgical scenarios [60].

Deep learning methods have significantly advanced surgical procedures by improving tool localization, segmentation, tracking, and depth estimation [61]. RGB to hyperspectral reconstruction enhances imaging efficiency [41], while federated learning frameworks enable privacy-preserving data sharing, fostering robust predictive models across various surgical contexts [4]. Quantum machine learning (QML) further enhances processing of complex surgical data [34].

The integration of digital health tools offers opportunities for improved surgical outcomes and patient care. As technologies advance, their integration is set to fundamentally transform surgical practices, empowering surgeons to utilize big data analytics, refine intraoperative decision-making, and visualize complex anatomical structures, ultimately leading to safer and more effective surgical outcomes [62, 5, 3].

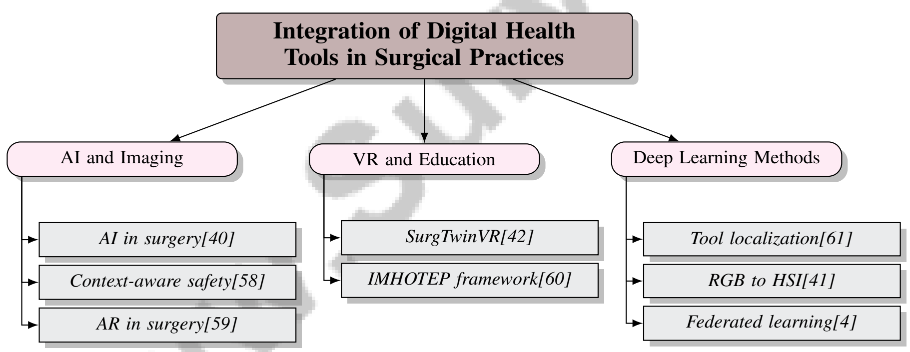


Figure 4: This figure illustrates the integration of digital health tools in surgical practices, highlighting key areas such as AI and imaging, VR and education, and deep learning methods. Each category emphasizes specific advancements and applications that contribute to enhanced surgical outcomes and training.

4.2 Enhancements in Surgical Precision and Monitoring

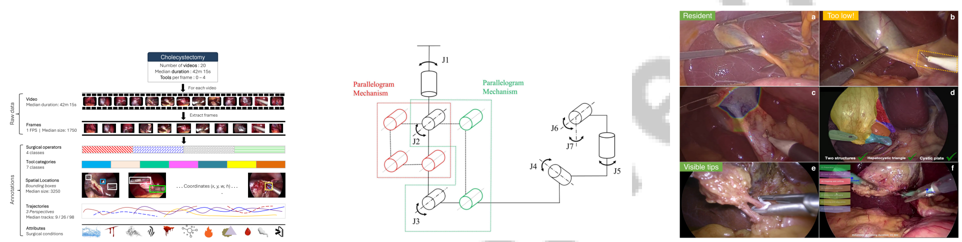
Digital technologies have substantially enhanced surgical precision and patient monitoring, offering innovative solutions that improve the efficacy and safety of surgical interventions. Hyperspectral camera technology, for instance, enhances precision in image-guided surgeries by simulating light transport in tissue, facilitating informed decisions [63]. AI is instrumental in this transformation, with platforms like HealthGuardian utilizing multimodal data integration to enhance AI model development for clinical studies, improving decision-making and patient outcomes [64]. Convolutional neural networks automate tissue perfusion classification, enhancing precision in surgeries such as colorectal procedures [65].

Digital health technologies enable personalized, continuous, and real-time patient monitoring, crucial for early detection of complications and timely interventions, thereby improving surgical outcomes [66]. In robotic surgery, velocity scaling techniques optimize robotic manipulator movements, enhancing surgical precision [67]. Advancements in surgical tool detection and tracking through deep learning have further contributed to procedural safety and efficiency [61].

The HoloNav method exemplifies the use of intuitive 3D visualization to enhance surgical workflows, allowing for accurate navigation and alignment [68]. The Imhotep framework aids in understanding complex anatomical relationships by rendering patient-specific data in 3D [60]. Automated surgical systems benefit from AI advancements, with models like the modified YOLOv5 achieving high accuracy in detecting instruments [69]. Time series data methods capture nuances in surgical motions, enabling accurate task classification [70]. The ThinkStep method integrates contextual and temporal cues in surgical video analysis, enhancing understanding of surgical actions and potential errors [71]. Innovations in mapping surgeons' hand and finger motions through deep neural networks have improved the accuracy of estimating surgical tool poses [72].

The complex higher-order SVD (complex-HOSVD) method enhances analysis of physiological data, further improving surgical precision and monitoring [73]. Current research indicates that OST-HMDs can improve surgical outcomes by providing real-time guidance without distracting surgeons from the surgical site [59].

These advancements underscore the transformative role of digital tools in enhancing surgical precision and monitoring. Leveraging AI, AR, and computer vision, healthcare providers can significantly improve surgical outcomes, reduce errors, and enhance patient care, leading to a more effective healthcare system [5, 7, 2, 3].



(a) Cholecystectomy: A Dataset for Surgical Operations and Trajectory Analysis[74]

(b) Parallel Mechanism with Multiple Cylinders[75]

(c) Improving Surgical Skills through Interactive Training[5]

Figure 5: Examples of Enhancements in Surgical Precision and Monitoring

As illustrated in Figure 5, digital health technologies are revolutionizing surgical procedures, enhancing both precision and monitoring capabilities. The "Cholecystectomy: A Dataset for Surgical Operations and Trajectory Analysis" provides a comprehensive dataset of 20 recorded videos detailing surgical dynamics and tool trajectories, offering insights for improving accuracy. The "Parallel Mechanism with Multiple Cylinders" showcases a mechanical setup designed to optimize movement and control for enhanced precision. Lastly, the "Improving Surgical Skills through Interactive Training" emphasizes the role of interactive training in refining surgical techniques, highlighting the significance of posture and instrument handling. Collectively, these examples underscore the pivotal role of digital health technologies in advancing surgical practices by providing tools that enhance precision, monitoring, and educational training [74, 75, 5].

4.3 Challenges in Adoption and Usability

The adoption of digital health technologies in surgical environments faces several challenges that hinder effective implementation. A primary obstacle is the complexity of automating surgical tasks, which requires a unified framework to ensure motion safety across procedures, exacerbated by the need for precise coordination to prevent errors [76]. Using computer vision in automation can lead to false positives due to visual similarities between instruments and other objects, necessitating improved tracking accuracy [77].

Another significant challenge is the lack of real-time kinesthetic and tactile feedback in robotic surgery, limiting surgeons' ability to perceive forces acting on tools and posing safety risks [78]. Existing methods, including deep reinforcement learning, struggle to adapt to unforeseen circumstances, potentially compromising safety [79].

Data security concerns and high costs associated with developing digital health technologies further impede adoption. The reliance on extensive annotated data for training computer vision models presents a barrier, as obtaining accurate annotations often requires expert knowledge [80]. Additionally, inflexible data integration solutions restrict options for on-premises or cloud integration, limiting scalability [31].

Challenges in distinguishing medical instruments from surrounding tissue, particularly in ultrasound-guided procedures, complicate alignment and detection methods [81]. Disparities in access to safe anesthesia practices in low-resource settings further complicate the integration of digital health technologies, as high maternal complication rates persist [82].

Participant retention in remote digital health studies poses another challenge, with difficulties in maintaining engagement over time impacting the reliability of outcomes [83]. Moreover, the tendency of large language models (LLMs) to hallucinate facts jeopardizes patient safety, necessitating robust validation mechanisms [84].

To overcome these barriers, a comprehensive strategy addressing technological, behavioral, and systemic challenges is essential, as highlighted by recent research trends in digital health [85, 4, 13, 15]. Addressing these challenges will enable healthcare providers to leverage digital innovations to enhance surgical outcomes and improve patient care.

5 Telemedicine and Remote Perioperative Care

5.1 Role of Telemedicine in Perioperative Care

Telemedicine is pivotal in perioperative care, enhancing patient management and surgical outcomes through technological advancements. Innovations such as augmented reality (AR) systems facilitate remote monitoring, decision support, and surgical training by providing real-time guidance, ultimately improving workflow and outcomes [39]. These AR tools enable remote surgeons to interact with complex surgical tasks more effectively.

Telemedicine's efficacy is further augmented by deep learning models that analyze video recordings to monitor anesthesiologists' visual attention, thereby ensuring optimal focus and enhancing patient safety [50]. Comprehensive preoperative evaluations are crucial for improving patient safety, satisfaction, and resource utilization [11]. Insights from microbiome research offer personalized perioperative management strategies, improving surgical outcomes [10].

Despite these advancements, challenges persist, particularly in terms of technical issues related to registration accuracy and usability [59]. Addressing these challenges is essential for effective adoption in perioperative processes. Haptic devices can expedite surgical training by providing directional cues, enhancing residents' proficiency [78]. As telemedicine evolves, further research is needed to overcome these challenges and explore broader applications across surgical disciplines.

5.2 Benefits and Limitations in Preoperative and Postoperative Settings

Benchmark	Size	Domain	Task Format	Metric
LLM-PRP[86]	90,844	Anesthesia	Classification	F1 Score, MAE
DRHS[83]	3,484,786	Digital Health	User Engagement Analysis	Retention Duration, User Activity Streak
Hypnos[87]	6,506	Anesthesiology	Question Answering	BLEU, ROUGE
dVRK[67]	2	Surgical Robotics	Surgical Resection	Total Time, Total Distance
HeiCo[88]	10,040	Surgery	Instrument Detection And Segmentation	DSC, HD
MIS-Bench[69]	3,405	Surgical Instrument Detection	Object Detection	mAP, F1-score
CholecTrack20[74]	35,000	Laparoscopic Surgery	Multi-Class Multi-Object Tracking	Jaccard Index, Cohen's Kappa
AVOS[89]	1997	Surgery	Action Recognition	mean average precision, mean recall

Table 1: This table presents a comprehensive overview of various benchmarks used in perioperative care, detailing their size, domain, task format, and evaluation metrics. The benchmarks span diverse applications, including anesthesia, digital health, and surgical robotics, highlighting the versatility and scope of large language models and other computational techniques in enhancing surgical workflows.

Telemedicine integration in preoperative and postoperative settings offers significant advantages, particularly in diagnostics and decision-making. Hyperspectral imaging (HSI) cameras enhance diagnostic accuracy through systematic camera selection methods [63], critical for precise preoperative assessments.

Predictive analytics, especially through large language models (LLMs), provide powerful tools for stratifying perioperative risks and guiding decision-making processes. Establishing benchmarks for evaluating LLMs' predictive performance showcases their potential to transform perioperative care by offering data-driven insights [86]. Table 1 provides a detailed summary of key benchmarks relevant to the integration of telemedicine and predictive analytics in perioperative care settings.

However, limitations persist, such as the lack of depth perception in mobile-based simulators for robotic surgery, impacting performance and training outcomes [90]. This underscores the need for advanced simulation technologies that accurately replicate robotic-assisted minimally invasive surgery (RAMIS) [91]. Additionally, the stochastic nature of surgery complicates scheduling and resource allocation, necessitating advanced stochastic programming techniques to optimize perioperative processes [92, 93]. Limitations in existing studies, such as small sample sizes and lack of controlled trials, further complicate the assessment of telemedicine's clinical efficacy [59]. Comprehensive research is necessary to establish telemedicine's clinical advantages and guide its integration into surgical workflows.

5.3 Technological Innovations Enhancing Telemedicine

Recent technological innovations have significantly advanced telemedicine, improving healthcare delivery. Natural language processing (NLP) technologies enhance telemedicine platforms by allowing intuitive interactions [84]. The Metaverse's integration into healthcare creates immersive environments, enhancing patient engagement and remote consultations, though challenges remain regarding data privacy and security [18]. Blockchain technology offers solutions for secure data management, yet regulatory compliance and scalability issues hinder widespread adoption [15].

As illustrated in Figure 6, these key technological innovations can be categorized into several areas: NLP and Metaverse integration, robotic surgery training, and advancements in data and error detection. Each category highlights specific technologies and approaches that contribute to improving telemedicine's effectiveness and application in healthcare. Affordable mobile-based simulators for robotic surgery training demonstrate cost-effective telemedicine solutions, enabling skill practice across various settings [90]. The BEDS (Bench to Bedside) framework integrates seamlessly into workflows, preserving surgeon autonomy [94]. Advancements in surgical navigation systems, like HoloNav, enhance telemedicine by reducing radiation exposure and improving workflow integration [68].

Datasets like Cholectrack 2.0 highlight the importance of expanding research to encompass diverse surgical procedures, improving tracking algorithms [74]. The ThinkStep approach enhances real-time processing capabilities and error detection accuracy by leveraging spatial and temporal information [71].

Despite these advancements, challenges such as the polynomial time complexity of methods like Dynamic Time Warping (DTW) may impede real-time application efficiency, necessitating ongoing research [70]. Ensuring real-time data processing while maintaining privacy and security remains a significant challenge.

Mechanical constraints of existing teleoperation systems limit movement and control, posing challenges to telemedicine effectiveness [95]. Addressing these challenges and leveraging new technologies can further enhance telemedicine's role in healthcare delivery.

5.4 Case Studies and Practical Implementations

Telemedicine's integration into perioperative care and surgical education is exemplified by real-world implementations enhancing surgical training and efficiency. A notable case study involves deep multimodal fusion techniques in robot-assisted surgeries, where a dataset of 3912 feedback instances was collected during live procedures, demonstrating telemedicine's effectiveness in real-time surgical environments [96].

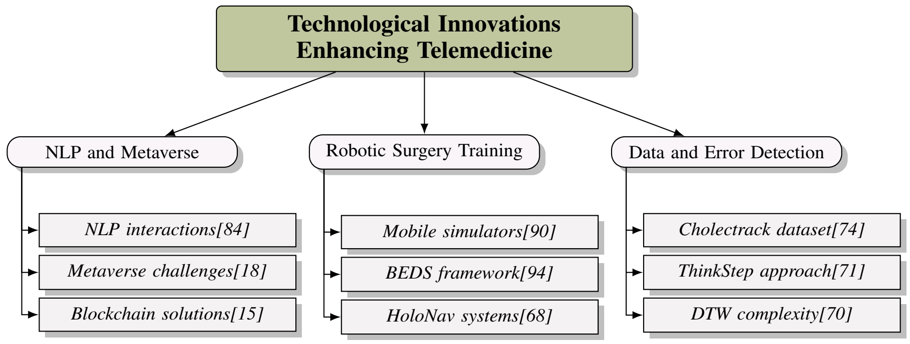


Figure 6: This figure illustrates the key technological innovations enhancing telemedicine, categorized into NLP and Metaverse integration, robotic surgery training, and data and error detection advancements. Each category highlights specific technologies and approaches that contribute to improving telemedicine's effectiveness and application in healthcare.

Another significant implementation is the IMU-based teleoperation system, achieving comparable efficiency to traditional robotic systems with adequate training, enhancing operator mobility in remote or resource-limited settings [95].

These case studies illustrate telemedicine's transformative impact on surgical education and practice. Leveraging advanced technologies and methodologies, telemedicine offers new opportunities for improving surgical outcomes and expanding access to quality healthcare services. As telemedicine evolves, comprehensive research and practical implementations are essential to fully harness its potential, especially with emerging frameworks like the Virtual Human Twin, which aims to integrate diverse resources for enhanced clinical decision support and personalized health forecasting [4, 13].

6 Health Informatics and Data-Driven Decision Making

6.1 Platforms and Tools for Data Management and Analysis

Health informatics has rapidly advanced, fostering platforms and tools crucial for managing healthcare data to enhance decision-making and patient outcomes. Microservice-based architectures, which separate analytic services from cloud infrastructure, enable flexible AI model integration, optimizing data utilization across clinical settings [11]. In surgical applications, the Integrated Data Processing Method (IDPM) systematically aggregates data to enhance processing and analysis, improving surgical outcomes and minimizing harm [12]. Augmented reality (AR) systems further refine surgical precision by enhancing spatial awareness and visualization [39].

Machine learning (ML) and deep learning techniques have transformed healthcare data management by automating diagnostics and improving decision-making through identifying complex data relationships. For instance, pharmacology-informed neural stochastic differential equation models leverage longitudinal data to elucidate pharmacokinetics and pharmacodynamics [25]. In robotic-assisted surgery, systems like the Context-aware Safety Monitoring System (CASMS) enhance safety by analyzing real-time kinematic data [78]. The Integrated Planning and Control Framework (IPCF) aligns feedback with data management, dynamically adjusting robotic movements.

Frameworks like HAPI-FHIR enhance interoperability by implementing patient-centric data management approaches, addressing technical, semantic, and process-related challenges [6, 97, 98, 84, 4]. The integration of heterogeneous records into uniform formats, as exemplified by MIMIC-IV datasets, underscores the importance of data standardization for effective analysis. Surveys of deep learning frameworks tailored for electronic health record (EHR) data highlight the need for specialized methodologies due to EHR data heterogeneity, identifying techniques for tasks like information extraction and outcome prediction [99, 100, 101].

Advancements in platforms like Health Guardian are essential for improving healthcare delivery. These tools facilitate diverse data collection and analysis, enabling AI-driven models that optimize decision-making. By incorporating traditional clinical data, patient-reported outcomes, and social determinants, these innovations address biases and ensure generalizability, leading to a more effective healthcare system [4, 64, 102, 6]. Leveraging these innovations enhances decision-making, resource utilization, and patient outcomes across clinical environments.

6.2 Advanced Predictive Models and Techniques

Advanced predictive models and techniques are pivotal in enhancing healthcare decision-making, significantly improving patient outcomes and operational efficiencies. Integrating machine learning (ML) and artificial intelligence (AI) into healthcare systems revolutionizes pattern extraction from complex datasets, facilitating timely risk assessments. The Intelligent Perioperative System (IPS) processes electronic health record (EHR) data to identify high-risk patients, optimizing perioperative care [12].

Pharmacokinetic/pharmacodynamic (PK/PD) models advance anesthesia management by modeling complex drug responses, informed by advanced sensors that improve clinical decisions. The IDPM principle emphasizes diverse dataset integration for richer insights, crucial for developing predictive models [12]. In robotic surgery, multi-modal large language models (LLMs) enhance reasoning, improving decision-making under complex conditions [40]. Metrics like RMSE and PSNR evaluate hyperspectral image accuracy, essential for assessing predictive models in surgical applications [41].

Despite advancements, challenges remain before clinical implementation, including data quality assurance, bias mitigation, and robust validation processes to confirm innovations' effectiveness and safety [4, 9, 6, 16]. Augmented reality (AR) in healthcare faces security concerns and protocol standardization needs. Quantum machine learning (QML) in healthcare, particularly regarding scalability and noise handling, requires further exploration.

Future research will focus on integrating real-time sensor data and expanding case bases to improve predictive models' adaptability and accuracy. Metrics like mean average precision (mAP) and R^2 are crucial for evaluating models predicting complications, contributing significantly to enhanced patient safety and optimized decision-making [103, 16, 1, 8]. Understanding community structures in functional brain networks during different consciousness states enriches predictive modeling.

Integrating advanced predictive models, particularly those leveraging AI and ML, transforms clinical decision-making by delivering accurate, timely, and personalized insights. This evolution is underscored by developing patient-centered data science frameworks combining traditional data with patient-reported outcomes and social determinants, enabling comprehensive patient understanding. Reinforcement learning methods address dynamic treatment challenges, enhancing patient outcomes and digital health innovations' real-world application [6, 9]. Future research should focus on addressing limitations like data standardization and stakeholder involvement to fully realize these models' potential in healthcare.

6.3 Integration of Health Informatics in Surgical Training and Education

Integrating health informatics into surgical training and education represents a significant evolution, leveraging advanced technologies like AI, computer vision, and evidence-based methodologies. These innovations enhance surgical trainees' learning experiences and facilitate clinical decision support systems and real-time feedback mechanisms, improving skills and optimizing patient care [78, 3, 23, 5, 96]. Technologies like continuum robotics, exemplified by the ENDO robot, provide hands-on experience with state-of-the-art systems, aligning with educational frameworks emphasizing knowledge acquisition and skill development.

Simulation-based education is a cornerstone, providing frameworks for evaluating control strategies like closed-loop anesthesia delivery (CLAD) systems. These frameworks offer benchmarks for advancements in surgical training, ensuring trainees encounter diverse scenarios enhancing adaptability and decision-making [35]. Collaboration between researchers and clinicians aligns detection algorithms with clinical requirements, enhancing health informatics tools' applicability in training [81].

Future research should refine patient-centered data science frameworks, address AI model biases, and explore additional data types to augment training programs [6]. Integrating ensemble multi-task approaches in predictive models, like the Intelligent Perioperative System (IPS), improves predictive accuracy and insights into surgical complications [92]. Developing larger datasets and enhancing model robustness are crucial for integrating health informatics into training and education [61].

The adaptation of virtual training methods during the COVID-19 pandemic underscores evaluating these methods' effectiveness and exploring trainees' emotional well-being [27]. Developing national standards for anesthesiology training post-pandemic ensures training programs remain relevant. Multisite clinical federated learning informs health informatics integration by assessing tasks and dataset sizes' effects on model performance [101].

Safety assessments in robotic telesurgical systems, demonstrated by fault injection studies, ensure safety mechanisms' robustness and hazard identification [51]. Incorporating these assessments into training prepares professionals to manage risks in robotic surgeries. Future research should focus on developing standardized protocols for video recording, improving data quality, and fostering interdisciplinary collaboration to enhance computer vision applications [5].

Additionally, research should address technical challenges, enhance user experience through ergonomic design, and conduct larger clinical trials to validate optical see-through head-mounted displays (OST-HMDs) in surgery [59]. Refining preoperative assessment protocols, exploring innovative evaluation methods, and addressing high-risk pediatric populations' needs are also essential [11]. Research will focus on improving device ergonomics and integrating human factors into platforms like RAVEN II for enhanced training [78].

Integrating health informatics into surgical training enhances professionals' capabilities by leveraging AI, computer vision, and educational methodologies. These technologies improve patient outcomes by providing data-driven insights and decision support systems while addressing healthcare education challenges, such as updated teaching practices and procedural skills assessment. By collaborating with data scientists and utilizing innovative strategies, surgical training can be transformed to optimize learning and clinical effectiveness, leading to higher quality care and expanded surgical services access [5, 3, 23]. Leveraging technologies and developing robust frameworks promises a dynamic, responsive, and effective future for surgical training. Future improvements could focus on enhancing data protection measures and exploring blockchain for secure data sharing.

7 Conclusion

The integration of anesthesiology, digital health, surgery, telemedicine, perioperative care, and health informatics has led to significant advancements in healthcare, enhancing patient outcomes and surgical precision. This survey underscores the impact of Enhanced Recovery After Surgery (ERAS) protocols in reducing recovery times and complications, and it highlights the recognition of dental anesthesiology as a specialty, emphasizing its role in public safety and professional standards. Innovations such as closed-loop anesthesia delivery systems and augmented reality (AR) in surgical settings have improved precision and safety, with artificial intelligence facilitating personalized anesthetic regimens and predictive analytics. The potential for automated classification of fluorescence angiography promises to standardize techniques in colorectal surgery, offering new research directions. Exploring neural pathways and molecular mechanisms differentiating anesthetic effects remains crucial, impacting clinical practice.

Digital health technologies, including anticipatory mobile health solutions, have advanced proactive healthcare by tailoring therapies through user data and machine learning. However, privacy and regulatory challenges persist, particularly with innovations like the Metaverse and blockchain. Future research should refine the Virtual Health Twin (VHT) concept, address ethical and legal issues, and develop sustainable business models for these infrastructures.

Telemedicine has become vital in perioperative care, offering remote monitoring and decision support that enhance patient management. The pandemic has underscored the need for cohesive strategies to address surgical delays and ensure equitable care access, highlighting long-term impacts on healthcare training and finances. Interventions aimed at improving the Sense of Coherence (SOC) among ICU and anesthesiology staff could mitigate psychopathological symptoms, enhancing overall healthcare delivery.

Future research should validate AI models in clinical settings, address ethical concerns, and promote interdisciplinary collaborations to advance AI applications in anesthesia. Efforts should focus on developing cost-effective AR solutions, enhancing security measures, and exploring new AR applications in healthcare. Integrating emotional intelligence (EI) training into anesthesiology education may improve patient outcomes and reduce burnout. Furthermore, implementing evidence-based educational practices can enhance learning outcomes for anesthesiology residents, ultimately improving patient care.

AI-generated, for reference only.

References

[1] Katharina Kohler and Ari Ercole. Characterising complex healthcare systems using network science: The small world of emergency surgery, 2019.

[2] Christian Seger and Maxime Cannesson. Recent advances in the technology of anesthesia. *F1000Research*, 9:F1000–Faculty, 2020.

[3] Daniel A Hashimoto, Guy Rosman, Daniela Rus, and Ozanan R Meireles. Artificial intelligence in surgery: promises and perils. *Annals of surgery*, 268(1):70–76, 2018.

[4] Junhyoun Sung and Hyungsook Kim. Digital health discussion through articles published until the year 2021: A digital topic modeling approach, 2023.

[5] Pietro Mascagni, Deepak Alapatt, Luca Sestini, Maria S Altieri, Amin Madani, Yusuke Watanabe, Adnan Alseidi, Jay A Redan, Sergio Alfieri, Guido Costamagna, et al. Computer vision in surgery: from potential to clinical value. *npj Digital Medicine*, 5(1):163, 2022.

[6] Mohsen Amoei and Dan Poenaru. Patient-centered data science: an integrative framework for evaluating and predicting clinical outcomes in the digital health era, 2024.

[7] Jinat Ara, Hanif Bhuiyan, Yeasin Arafat Bhuiyan, Salma Begum Bhyan, and Muhammad Ismail Bhuiyan. Ar-based modern healthcare: A review, 2021.

[8] Reza Shirkavand, Fei Zhang, and Heng Huang. Prediction of post-operative renal and pulmonary complications using transformers, 2023.

[9] Nina Deliu and Bibhas Chakraborty. Artificial intelligence-based decision support systems for precision and digital health, 2024.

[10] Amir Minerbi and Shiqian Shen. Gut microbiome in anesthesiology and pain medicine: a narrative review. *Anesthesiology*, 137(1):93, 2022.

[11] Joseph D Tobias. Preoperative anesthesia evaluation. In *Seminars in Pediatric Surgery*, volume 27, pages 67–74. Elsevier, 2018.

[12] Fabien Robineau, Frédéric Boy, Jean-Pierre Orliaguet, Jacques Demongeot, and Yohan Payan. Guiding the surgical gesture using an electro-tactile stimulus array on the tongue: A feasibility study, 2007.

[13] Marco Viceconti, Maarten De Vos, Sabato Mellone, and Liesbet Geris. From the digital twins in healthcare to the virtual human twin: a moon-shot project for digital health research, 2023.

[14] A perspective on the use of health digital twins in computational pathology.

[15] Andrew M. Nguyen. Challenges of blockchain applications in digital health: A systematic review, 2023.

[16] Yu He Ke, Liyuan Jin, Kabilan Elangovan, Hairil Rizal Abdullah, Nan Liu, Alex Tiong Heng Sia, Chai Rick Soh, Joshua Yi Min Tung, Jasmine Chiat Ling Ong, Chang-Fu Kuo, Shao-Chun Wu, Vesela P. Kovacheva, and Daniel Shu Wei Ting. oretrieval augmented generation for 10 large language models and its generalizability in assessing medical fitness, 2024.

[17] Tandin Dorji, Pakinee Aimmanee, and Vich Yindeedej. A plausibility study of using augmented reality in the ventriculoperitoneal shunt operations, 2024.

[18] Fatemeh Ebrahimzadeh and Ramin Safa. Unlocking the potential of metaverse in innovative and immersive digital health, 2024.

[19] David Oniani, Jordan Hilsman, Yifan Peng, COL, Ronald K. Poropatich, COL Jeremy C. Pamplin, LTC Gary L. Legault, and Yanshan Wang. From military to healthcare: Adopting and expanding ethical principles for generative artificial intelligence, 2023.

[20] Markus M Luedi, Dietrich Doll, Steven D Boggs, and Frank Stueber. Successful personalities in anesthesiology and acute care medicine: are we selecting, training, and supporting the best? *Anesthesia & Analgesia*, 124(1):359–361, 2017.

[21] Valentina Bellini, Emanuele Rafano Carnà, Michele Russo, Fabiola Di Vincenzo, Matteo Berghenti, Marco Baciarello, and Elena Bignami. Artificial intelligence and anesthesia: a narrative review. *Annals of translational medicine*, 10(9):528, 2022.

[22] Joel M Weaver. The history of the specialty of dental anesthesiology. *Anesthesia Progress*, 66(2):61, 2019.

[23] Susan M Martinelli, Robert S Isaak, Randall M Schell, John D Mitchell, Matthew D McEvoy, and Fei Chen. Learners and luddites in the twenty-first century: bringing evidence-based education to anesthesiology. 2019.

[24] Charles K. Chui, Yu-Ting Lin, and Hau tieng Wu. Real-time dynamics acquisition from irregular samples – with application to anesthesia evaluation, 2014.

[25] John H. Abel, Marcus A. Badgeley, Taylor E. Baum, Sourish Chakravarty, Patrick L. Purdon, and Emery N. Brown. Constructing a control-ready model of eeg signal during general anesthesia in humans, 2019.

[26] Sue J Fu, Elizabeth L George, Paul M Maggio, Mary Hawn, and Rahim Nazerali. The consequences of delaying elective surgery: surgical perspective. *Annals of surgery*, 272(2):e79–e80, 2020.

[27] Anjum Anwar, Christian Seger, Ashley Tollefson, Carol Ann B Diachun, Pedro Tanaka, and Soban Umar. Medical education in the covid-19 era: Impact on anesthesiology trainees. *Journal of Clinical Anesthesia*, 66:109949, 2020.

[28] Sarah K Schäfer, Johanna Lass-Hennemann, Heinrich Groesdonk, Thomas Volk, Hagen Bomberg, Marlene Staginnus, Alexandra H Brückner, Elena Holz, and Tanja Michael. Mental health in anesthesiology and icu staff: sense of coherence matters. *Frontiers in psychiatry*, 9:440, 2018.

[29] Olivia A Moody, Edlyn R Zhang, Kathleen F Vincent, Risako Kato, Eric D Melonakos, Christa J Nehs, and Ken Solt. The neural circuits underlying general anesthesia and sleep. *Anesthesia & Analgesia*, 132(5):1254–1264, 2021.

[30] Philipp Zagar, Vishnu Ravi, Lauren Aalami, Stephan Krusche, Oliver Aalami, and Paul Schmiedmayer. Dynamic fog computing for enhanced llm execution in medical applications, 2024.

[31] Italo Buleje, Vince S. Siu, Kuan Yu Hsieh, Nigel Hinds, Bing Dang, Erhan Bilal, Thanhnha Nguyen, Ellen E. Lee, Colin A. Depp, and Jeffrey L. Rogers. A versatile data fabric for advanced iot-based remote health monitoring, 2023.

[32] Mathias Unberath, Cong Gao, Yicheng Hu, Max Judish, Russell H Taylor, Mehran Armand, and Robert Grupp. The impact of machine learning on 2d/3d registration for image-guided interventions: A systematic review and perspective, 2021.

[33] Aneeq Zia, Kiran Bhattacharyya, Xi Liu, Ziheng Wang, Satoshi Kondo, Emanuele Colleoni, Beatrice van Amsterdam, Razeen Hussain, Raabid Hussain, Lena Maier-Hein, Danail Stoyanov, Stefanie Speidel, and Anthony Jarc. Surgical visual domain adaptation: Results from the miccai 2020 surgvisdom challenge, 2021.

[34] Riddhi S. Gupta, Carolyn E. Wood, Teyl Engstrom, Jason D. Pole, and Sally Shrapnel. Quantum machine learning for digital health? a systematic review, 2025.

[35] Sourish Chakravarty, Ayan S. Waite, John H. Abel, and Emery N. Brown. A simulation-based comparative analysis of pid and lqg control for closed-loop anesthesia delivery, 2020.

[36] Mohamed Abdelaziz Zaitri, Hanaa Zitane, and Delfim F. M. Torres. Pharmacokinetic/pharmacodynamic anesthesia model incorporating psi-caputo fractional derivatives, 2023.

[37] Gabe Schamberg, Marcus Badgeley, and Emery N. Brown. Controlling level of unconsciousness by titrating propofol with deep reinforcement learning, 2020.

[38] Maxim Glebov, Teddy Lazebnik, Boris Orkin, Haim Berkenstadt, and Svetlana Bunimovich-Mendrazitsky. Predicting postoperative nausea and vomiting using machine learning: A model development and validation study, 2023.

[39] Sebastian Andress, Alex Johnson, Mathias Unberath, Alexander Winkler, Kevin Yu, Javad Fotouhi, Simon Weidert, Greg Osgood, and Nassir Navab. On-the-fly augmented reality for orthopaedic surgery using a multi-modal fiducial, 2018.

[40] Michael Yip and Nikhil Das. Robot autonomy for surgery. In *The Encyclopedia of MEDICAL ROBOTICS: Volume 1 Minimally Invasive Surgical Robotics*, pages 281–313. World Scientific, 2019.

[41] Tobias Czempiel, Alfie Roddan, Maria Leiloglou, Zepeng Hu, Kevin O'Neill, Giulio Anichini, Danail Stoyanov, and Daniel Elson. Rgb to hyperspectral: Spectral reconstruction for enhanced surgical imaging, 2024.

[42] Jonas Hein, Jan Grunder, Lilian Calvet, Frédéric Giraud, Nicola Alessandro Cavalcanti, Fabio Carrillo, and Philipp Fürnstahl. Virtual reality for immersive education in orthopedic surgery digital twins, 2024.

[43] Chun-Wang Su, Liang Zheng, You-Jun Li, Hai-Jun Zhou, Jue Wang, Zi-Gang Huang, and Ying-Cheng Lai. Hysteresis in anesthesia and recovery: Experimental observation and dynamical mechanism, 2020.

[44] Dayang Liu. A model-based architecture for automatic anesthesia infusion, 2021.

[45] Mohammad Javad Khodaei, Mohammad Hadi Balaghi Inaloo, Amin Mehrvarz, and Nader Jalili. An adaptive neuro-fuzzy strategy in closed-loop control of anesthesia, 2019.

[46] Yongkang He, Siyuan Peng, Mingjin Chen, Zhijing Yang, and Yuanhui Chen. A transformer-based prediction method for depth of anesthesia during target-controlled infusion of propofol and remifentanil, 2023.

[47] Hanyang Liu, Michael C. Montana, Dingwen Li, Chase Renfroe, Thomas Kannampallil, and Chenyang Lu. Predicting intraoperative hypoxemia with hybrid inference sequence autoencoder networks, 2022.

[48] Mahdi Yousefi, Klaske van Heusden, Ian M. Mitchell, J. Mark Ansermino, and Guy A. Dumont. Reducing conservatism in model-invariant safety-preserving control of propofol anesthesia using falsification, 2018.

[49] Eduardo C. Padovani. Characterization of the community structure of large-scale functional brain networks during ketamine-medetomidine anesthetic induction, 2023.

[50] Sapir Gershov, Fadi Mahameed, Aeyal Raz, and Shlomi Laufer. More than meets the eye: Analyzing anesthesiologists' visual attention in the operating room using deep learning models, 2023.

[51] Homa Alemzadeh, Daniel Chen, Andrew Lewis, Zbigniew Kalbarczyk, Jaishankar Raman, Nancy Leveson, and Ravishankar K. Iyer. Systems-theoretic safety assessment of robotic telesurgical systems, 2015.

[52] Amitai Bickel, Alexey Gavrilov, Shimon Ivry, Neta B Maimon, Lior Molcho, and Nathan Intrator. Reduced neural activity during volatile anesthesia compared to tiva: evidence from a novel eeg signal processing analysis, 2022.

[53] Alaa Eldin Abdelaal, Nancy Hong, Apeksha Avinash, Divya Budihal, Maram Sakr, Gregory D. Hager, and Septimiu E. Salcudean. Orientation matters: 6-dof autonomous camera movement for minimally invasive surgery, 2020.

[54] Ana Davila, Jacinto Colan, and Yasuhisa Hasegawa. Voice control interface for surgical robot assistants, 2024.

[55] Zongyu Li, Kay Hutchinson, and Homa Alemzadeh. Runtime detection of executional errors in robot-assisted surgery, 2022.

[56] Erim Yanik, Xavier Intes, and Suvranu De. Cognitive-motor integration in assessing bimanual motor skills, 2024.

[57] Syed Abdul Mateen, Niharika Malvia, Syed Abdul Khader, Danny Wang, Deepti Srinivasan, Chi-Fu Jeffrey Yang, Lana Schumacher, and Sandeep Manjanna. Thoracic surgery video analysis for surgical phase recognition, 2024.

[58] Mohammad Samin Yasar and Homa Alemzadeh. Real-time context-aware detection of unsafe events in robot-assisted surgery, 2020.

[59] Manuel Birlo, P. J. "Eddie" Edwards, Matthew Clarkson, and Danail Stoyanov. Utility of optical see-through head mounted displays in augmented reality-assisted surgery: A systematic review, 2022.

[60] Micha Pfeiffer, Hannes Kenngott, Anas Preukschas, Matthias Huber, Lisa Bettscheider, Beat Müller-Stich, and Stefanie Speidel. Imhotep - virtual reality framework for surgical applications, 2018.

[61] Mansoor Ali, Rafael Martinez Garcia Pena, Gilberto Ochoa Ruiz, and Sharib Ali. A comprehensive survey on recent deep learning-based methods applied to surgical data, 2023.

[62] Vladimir Ivanov, Anton Krivtsov, Sergey Strelkov, Dmitry Gulyaev, Denis Godanyuk, Nikolay Kalakutsky, Artyom Pavlov, Marina Petropavloskaya, Alexander Smirnov, and Andrew Yaremenko. Surgical navigation systems based on augmented reality technologies, 2021.

[63] Anant S. Vemuri, Sebastian Wirkert, and Lena Maier-Hein. Hyperspectral camera selection for interventional health-care, 2019.

[64] Vince S. Siu, Kuan Yu Hsieh, Italo Buleje, Takashi Itoh, Tian Hao, Ben Civjan, Nigel Hinds, Bing Dang, Jeffrey L. Rogers, and Bo Wen. Health guardian: Using multi-modal data to understand individual health, 2023.

[65] Fluorescence angiography classification in colorectal surgery – a preliminary report.

[66] Samira Pakravan, Nikolaos Evangelou, Maxime Usdin, Logan Brooks, and James Lu. From noise to signal: Unveiling treatment effects from digital health data through pharmacology-informed neural-sde, 2024.

[67] Florian Richter, Emily K. Funk, Won Seo Park, Ryan K. Orosco, and Michael C. Yip. From bench to bedside: The first live robotic surgery on the dvrk to enable remote telesurgery with motion scaling, 2021.

[68] Florentin Liebmann, Simon Roner, Marco von Atzigen, Florian Wanivenhaus, Caroline Neuhaus, José Spirig, Davide Scaramuzza, Reto Sutter, Jess Snedeker, Mazda Farshad, and Philipp Fürnstahl. Registration made easy – standalone orthopedic navigation with hololens, 2020.

[69] Tochukwu Onyeogulu, Salman Khan, Izzeddin Teeti, Amirul Islam, Kaizhe Jin, Adrian Rubio-Solis, Ravi Naik, George Mylonas, and Fabio Cuzzolin. Situation awareness for automated surgical check-listing in ai-assisted operating room, 2022.

[70] Mehrdad J. Bani and Shoele Jamali. A new classification approach for robotic surgical tasks recognition, 2017.

[71] Zhimin Shao, Jialang Xu, Danail Stoyanov, Evangelos B. Mazomenos, and Yueming Jin. Think step by step: Chain-of-gesture prompting for error detection in robotic surgical videos, 2024.

[72] Mohammad Fattahi Sani, Raimondo Ascione, and Sanja Dogramadzi. Mapping surgeon's hand/finger motion during conventional microsurgery to enhance intuitive surgical robot teleoperation, 2021.

[73] Raheleh Baharloo, Jose C. Principe, Parisa Rashidi, and Patrick J. Tighe. Analysis of intra-operative physiological responses through complex higher-order svd for long-term post-operative pain prediction, 2021.

[74] Chinedu Innocent Nwoye, Kareem Elgohary, Anvita Srinivas, Fauzan Zaid, Joël L. Lavanchy, and Nicolas Padoy. Cholectrack20: A dataset for multi-class multiple tool tracking in laparoscopic surgery, 2023.

[75] Bharath Rajiv Nair, Aravinthkumar T., and B. Vinod. Advancing robotic surgery: Affordable kinesthetic and tactile feedback solutions for endotrainers, 2024.

[76] Fangxun Zhong and Yun-Hui Liu. Integrated planning and control of robotic surgical instruments for tasks autonomy, 2023.

[77] Michael Zhang, Xiaotian Cheng, Daniel Copeland, Arjun Desai, Melody Y. Guan, Gabriel A. Brat, and Serena Yeung. Using computer vision to automate hand detection and tracking of surgeon movements in videos of open surgery, 2020.

[78] Gustavo D. Gil, Julie M. Walker, Nabil Zemiti, Allison M. Okamura, and Philippe Poignet. How to enhance learning of robotic surgery gestures? a tactile cue saliency investigation for 3d hand guidance, 2019.

[79] Sadra Zargarzadeh, Maryam Mirzaei, Yafei Ou, and Mahdi Tavakoli. From decision to action in surgical autonomy: Multi-modal large language models for robot-assisted blood suction, 2025.

[80] Sebastian Bodenstedt, Martin Wagner, Darko Katić, Patrick Mietkowski, Benjamin Mayer, Hannes Kenngott, Beat Müller-Stich, Rüdiger Dillmann, and Stefanie Speidel. Unsupervised temporal context learning using convolutional neural networks for laparoscopic workflow analysis, 2017.

[81] Hongxu Yang, Caifeng Shan, Alexander F. Kolen, and Peter H. N. de With. Medical instrument detection in ultrasound-guided interventions: A review, 2021.

[82] Laurence Ring, Ruth Landau, and Carlos Delgado. The current role of general anesthesia for cesarean delivery. *Current anesthesiology reports*, 11:18–27, 2021.

[83] Abhishek Pratap, Elias Chaibub Neto, Phil Snyder, Carl Stepnowsky, Noémie Elhadad, Daniel Grant, Matthew H. Mohebbi, Sean Mooney, Christine Suver, John Wilbanks, Lara Mangravite, Patrick Heagerty, Pat Arean, and Larsson Omberg. Indicators of retention in remote digital health studies: A cross-study evaluation of 100,000 participants, 2019.

[84] Fergus Imrie, Paulius Rauba, and Mihaela van der Schaar. Redefining digital health interfaces with large language models, 2024.

[85] Yunlong Wang, Ahmed Fadhil, Jan-Philipp Lange, and Harald Reiterer. Integrating taxonomies into theory-based digital health interventions for behavior change: A holistic framework, 2018.

[86] Philip Chung, Christine T Fong, Andrew M Walters, Nima Aghaeepour, Meliha Yetisgen, and Vikas N O'Reilly-Shah. Large language model capabilities in perioperative risk prediction and prognostication, 2024.

[87] Zhonghai Wang, Jie Jiang, Yibing Zhan, Bohao Zhou, Yanhong Li, Chong Zhang, Liang Ding, Hua Jin, Jun Peng, Xu Lin, and Weifeng Liu. Towards training a chinese large language model for anesthesiology, 2024.

[88] Lena Maier-Hein, Martin Wagner, Tobias Ross, Annika Reinke, Sebastian Bodenstedt, Peter M. Full, Hellena Hempe, Diana Mindroc-Filimon, Patrick Scholz, Thuy Nuong Tran, Pierangela Bruno, Anna Kisilenko, Benjamin Müller, Tornike Davitashvili, Manuela Capek, Minu Tizabi, Matthias Eisenmann, Tim J. Adler, Janek Gröhl, Melanie Schellenberg, Silvia Seidlitz, T. Y. Emmy Lai, Bünyamin Pekdemir, Veith Roethlingshoefer, Fabian Both, Sebastian Bittel, Marc Mengler, Lars Mündermann, Martin Apitz, Annette Kopp-Schneider, Stefanie Speidel, Hannes G. Kenngott, and Beat P. Müller-Stich. Heidelberg colorectal data set for surgical data science in the sensor operating room, 2021.

[89] Emmett D. Goodman, Krishna K. Patel, Yilun Zhang, William Locke, Chris J. Kennedy, Rohan Mehrotra, Stephen Ren, Melody Y. Guan, Maren Downing, Hao Wei Chen, Jevin Z. Clark, Gabriel A. Brat, and Serena Yeung. A real-time spatiotemporal ai model analyzes skill in open surgical videos, 2021.

[90] Piyamate Wisanuvej, Petros Giataganas, Paul Riordan, Jean Nehme, and Danail Stoyanov. Affordable mobile-based simulator for robotic surgery, 2018.

[91] Yarden Sharon, Daniel Naftalovich, Lidor Bahar, Yael Refaely, and Ilana Nisky. Combining time-dependent force perturbations in robot-assisted surgery training, 2021.

[92] Zheng Feng, Rajendra Rana Bhat, Xiaoyong Yuan, Daniel Freeman, Tezcan Baslanti, Azra Bihorac, and Xiaolin Li. Intelligent perioperative system: Towards real-time big data analytics in surgery risk assessment, 2017.

[93] Batuhan Celik, Serhat Gul, and Melih Celik. A stochastic programming approach to surgery scheduling under parallel processing principle, 2021.

[94] Jin Xie, Teng Zhang, Jose Blanchet, Peter Glynn, Matthew Randolph, and David Scheinker. The design and implementation of a broadly applicable algorithm for optimizing intra-day surgical scheduling, 2022.

[95] Guanhao Fu, Ehsan Azimi, and Peter Kazanzides. Mobile teleoperation: Feasibility of wireless wearable sensing of the operator's arm motion, 2022.

[96] Rafal Kocielnik, Elyssa Y. Wong, Timothy N. Chu, Lydia Lin, De-An Huang, Jiayun Wang, Anima Anandkumar, and Andrew J. Hung. Deep multimodal fusion for surgical feedback classification, 2023.

[97] Prabath Jayathissa and Roshan Hewapathirana. Hapi-fhir server implementation to enhancing interoperability among primary care health information systems in sri lanka: Review of the technical use case, 2024.

[98] Wenhao Li, Niranjan Bidargaddi, and John Fouyaxis. Dhlink: A microservice platform supporting rapid application development and secure real-time data sharing in digital health, 2021.

[99] Nicola Rieke, Jonny Hancox, Wenqi Li, Fausto Milletari, Holger Roth, Shadi Albarqouni, Spyridon Bakas, Mathieu N. Galtier, Bennett Landman, Klaus Maier-Hein, Sebastien Ourselin, Micah Sheller, Ronald M. Summers, Andrew Trask, Daguang Xu, Maximilian Baust, and M. Jorge Cardoso. The future of digital health with federated learning, 2021.

[100] Benjamin Shickel, Patrick James Tighe, Azra Bihorac, and Parisa Rashidi. Deep ehr: a survey of recent advances in deep learning techniques for electronic health record (ehr) analysis. *IEEE journal of biomedical and health informatics*, 22(5):1589–1604, 2017.

[101] Won Joon Yun, Samuel Kim, and Joongheon Kim. Multi-site clinical federated learning using recursive and attentive models and nvflare, 2023.

[102] Bo Wen, Vince S. Siu, Italo Buleje, Kuan Yu Hsieh, Takashi Itoh, Lukas Zimmerli, Nigel Hinds, Elif Eyigoz, Bing Dang, Stefan von Cavallar, and Jeffrey L. Rogers. Health guardian platform: A technology stack to accelerate discovery in digital health research, 2022.

[103] Asli Okur, Ralf Stauder, Hubertus Feussner, and Nassir Navab. Quantitative characterization of components of computer assisted interventions, 2017.

AI-generated, for reference only.

Disclaimer:

SurveyX is an AI-powered system designed to automate the generation of surveys. While it aims to produce high-quality, coherent, and comprehensive surveys with accurate citations, the final output is derived from the AI's synthesis of pre-processed materials, which may contain limitations or inaccuracies. As such, the generated content should not be used for academic publication or formal submissions and must be independently reviewed and verified. The developers of SurveyX do not assume responsibility for any errors or consequences arising from the use of the generated surveys.