Epidemiology & Health Data Insights
(eISSN 3080-8111)

Review Article

Telemedicine and Remote Proctoring in Surgery: Current Trends, Evidence, and Future Directions

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Received: Dec 30, 2025
Accepted: Jan 13, 2026

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Abstract:
Telemedicine has become a vital element of modern surgical practice, facilitating virtual consultations, intraoperative collaboration, and postoperative monitoring. One of its most innovative applications is remote proctoring, or teleproctoring—the real-time supervision and assistance of surgical procedures across distances. The COVID-19 epidemic has accelerated the impact of these technologies on surgical education, credentialing, and global access to specialized expertise. This narrative review synthesizes literature from 2005 to 2025 obtained from PubMed, ResearchGate, Web of Science, and Google Scholar. The emphasis includes telemedicine and remote proctoring in surgical care, education, and quality assurance. Chosen materials comprise original investigations, systematic reviews, and policy documents that pertain to technical platforms, clinical outcomes, educational applications, implementation issues, and regulatory considerations. Modern teleproctoring technologies include secure, low-latency, high-definition video broadcasts enhanced by augmented reality features and telestration capabilities. The available evidence, primarily from observational studies, confirms the approach's viability, cost-effectiveness, improved training efficiency, and high user acceptance across disciplines such as minimally invasive, robotic, and endoscopic surgery. However, inconsistencies in outcome measurements, a lack of randomized controlled trials, and varying legal frameworks restrict wider applicability. The safety profiles appear promising, yet data deficiencies remain. Telemedicine and remote proctoring are developing into integral components of surgical care. Essential future directions include the implementation of artificial intelligence solutions, the development of standardized outcome metrics, the execution of comparative research, the enhancement of cybersecurity measures, and the promotion of fair access in resource-constrained settings. When integrated within strong regulatory and ethical frameworks, remote proctoring has the potential to function as a fundamental pillar of efficient and interconnected global surgical practice.

Keywords: Telemedicine, Remote Proctoring, Augmented Reality (AR), Artificial Intelligence (AI), Telestration

Introduction

In the past two decades, telemedicine has transitioned from a revolutionary innovation to a fundamental component of contemporary healthcare delivery [1,2]. This transformation is particularly evident in surgery, which has introduced both unprecedented opportunities and formidable challenges for remote technologies most notably by underscoring the necessity for well-structured training, timely specialist input, and efficient perioperative care [3, 4-7]. The COVID-19 pandemic significantly expedited the adoption of these technologies, showcasing the feasibility of virtual consultations, cross-border surgical collaboration, and remote supervision; these trends continue to dramatically impact surgical practice today [4, 8-10].

Telemedicine in surgical practice includes a range of applications, such as preoperative consultations, intraoperative support, and postoperative follow-up [10, 11]. Remote proctoring involves the real-time oversight of a surgeon's performance by a more experienced peer, primarily to ensure quality assurance and fulfill credentialing standards. Tele-mentoring, closely associated with remote proctoring, entails active and interactive instruction during processes to facilitate skill transfer [12]. These methods differ significantly from telesurgery, which involves the remote execution of surgical procedures with robotic systems—a field that remains predominantly experimental. This review primarily focuses on telemedicine and remote proctoring in surgery, specifically examining their roles in education, training, and quality assurance and enhancement.

The capacity of these technologies to improve access to experts, expedite surgical training, and maintain consistent standards of care across institutions highlights their growing importance. Remote proctoring eliminates the necessity for qualified surgeons to travel, so enabling the secure adoption of innovative techniques and equipment, which conserves both financial resources and time. Furthermore, these tools can address significant deficiencies in surgical knowledge in remote or resource-limited environments. Simultaneously, they express significant apprehensions over quality assurance, the maintenance of professional norms, and medico-legal accountability [7, 13, 14].

This review aims to analyze the changing role of remote proctoring and telemedicine in surgery, focusing on the technology that facilitate these modalities, their uses in clinical and educational settings, and the outcomes recorded thus far. Besides clarifying prospects for enhanced worldwide integration into surgical practice, it tackles significant implementation obstacles, encompassing technical, legal, and ethical factors. Ultimately, it outlines research goals and prospective directions, providing essential information for institutions, physicians, and politicians.

Methodology

This narrative review synthesizes the current evidence on telemedicine and remote proctoring in surgery, focusing particularly on technological platforms, clinical implementation, educational value, quality assurance, and emerging patient-level outcomes.

A comprehensive literature search was conducted across PubMed, ResearchGate, Web of Science, and Google Scholar, using combinations of the following keywords: telemedicine, remote proctoring, surgical telementoring, digital surgery, intraoperative telemedicine, virtual surgical training, and future directions in telehealth.

Articles published between 2005 and 2025 were deemed eligible, with particular emphasis on studies from the last decade to capture advancements in contemporary surgical practice and technological development. Eligible sources included original clinical studies, observational cohorts, feasibility studies, randomized controlled trials (where available), systematic and narrative reviews, consensus statements, and relevant policy or regulatory documents. Gray literature from professional surgical organizations and regulatory bodies was also examined to incorporate perspectives on governance and implementation.

Given the narrative design of this review, no formal risk-of-bias assessment or meta-analysis was performed. Nonetheless, the strength and quality of the available evidence are discussed explicitly throughout, especially with regard to patient safety and clinical outcomes. Studies were organized thematically into five categories: (1) foundational and current technological infrastructure; (2) clinical, educational and credentialing applications; (3) epidemiological and patient-level outcomes; (4) implementation barriers; and (5) future directions and priorities for future research. Findings were synthesized descriptively, with careful attention to heterogeneity in outcome reporting and the inherent limitations of the existing evidence base.

Historical Evolution and Context

In the last fifty years, surgical telemedicine has evolved with significant progress in medical technology, communications, and computing. NASA innovated telemetry monitoring of astronauts' vital signs during space flights in the 1960s, thus establishing the foundational concepts of remote healthcare delivery. Presently, the foundation for remote surgical assistance has been formed as hospitals commenced trials using closed-circuit television systems to enable consultations across diverse locations.

The foundations of surgical telementoring were created in the 1980s and 1990s, when advancements in video transmission allowed surgeons to offer real-time instruction to their peers. These nascent applications were particularly beneficial in military and rural healthcare settings, where access to specialists remained severely constrained. A significant milestone was achieved in 2001 with the "Lindbergh Operation"—the inaugural entirely transatlantic laparoscopic cholecystectomy, performed remotely from New York on a patient in France. Despite its high cost and technological demands, this landmark procedure showcased the viability of telesurgery and stimulated further study into remote surgical interventions [15,16].

As robotic-assisted and less invasive surgical procedures emerged in the 2000s, academic and clinical focus transitioned to credentialing, monitoring, and training regimens. Remote proctoring has emerged as a practical solution, enabling expert surgeons to observe live procedures, provide instant feedback, and ensure operational safety—all without being physically present in the operating theater [15, 17].

The incorporation of remote supervision into surgical education intensified in the 2010s, propelled by innovations in digital platforms, secure streaming technology, and high-speed internet infrastructure. The COVID-19 epidemic further strengthened these advancements, transforming remote proctoring and telemedicine from experimental methods into essential components of contemporary surgical training and patient care [10, 15].

Technology and Platforms

The technological environment supporting telemedicine and remote proctoring in surgery includes a variety of platform types. This encompasses synchronous video conferencing systems that provide real-time, high-definition feeds from the operating room; specialized proctoring platforms featuring telestration and integrated audio channels; heads-up displays and augmented reality overlays to improve visualization; robotic platforms that incorporate telementoring functionalities within their consoles; asynchronous review systems facilitating postoperative analysis of recorded procedures; and wearable devices or remote monitoring tools. These categories collectively illustrate the progression from basic video connectivity to advanced multimodal systems that provide thorough observation, training, and ongoing patient care [18,19-23]. Table 1 delineates several platform kinds, their applications, along with their benefits and drawbacks.

Table 1: Platform taxonomy showing their uses, advantages, and limitations

Platform Category	Core Features	Advantages	Limitations	Typical Use-Case	Estimated cost tier
Synchronous Video Conferencing (e.g., Zoom for Healthcare)	HD (High Definition) OR (Operating Room) feed, two-way audio, multi-party support	Widely available, relatively low cost, scalable	Limited surgical annotation tools, potential latency issues	Remote case discussions, basic supervision[20]	Low
Dedicated Remote Proctoring Platforms (e.g., Proximie, Avail)	Telestration, multi-camera integration, AR overlays, secure compliance	Optimized for surgery, real-time interactive tools	Higher cost, requires stable bandwidth	Credentialing, intraoperative proctoring[29]	High
AR (Augmented Reality)/Heads-Up Display Systems	Live overlays, anatomy labeling, heads-up visualization	Enhances precision, immersive	Requires specialized hardware, training	Advanced surgical mentoring[20]	High

Robotic Platforms with Telementoring (e.g., da Vinci with tele-observation modules)	Console sharing, remote camera control, high-definition feeds	Full procedural view, built into robotic workflow	Expensive, limited to robotic cases	Robotic surgery training, advanced mentoring[29]	High
Asynchronous Tele-Review Systems	Recording with time-stamped annotations, cloud storage	Flexible review, useful for QA (Quality Assurance) and training	No real-time feedback	Postoperative debrief, performance assessment[50]	Medium
Remote Monitoring/Wearables	Biometric tracking, app-based reporting	Extends follow-up beyond OR, patient engagement	Limited intraoperative utility	Postoperative recovery, complication monitoring[23]	Medium

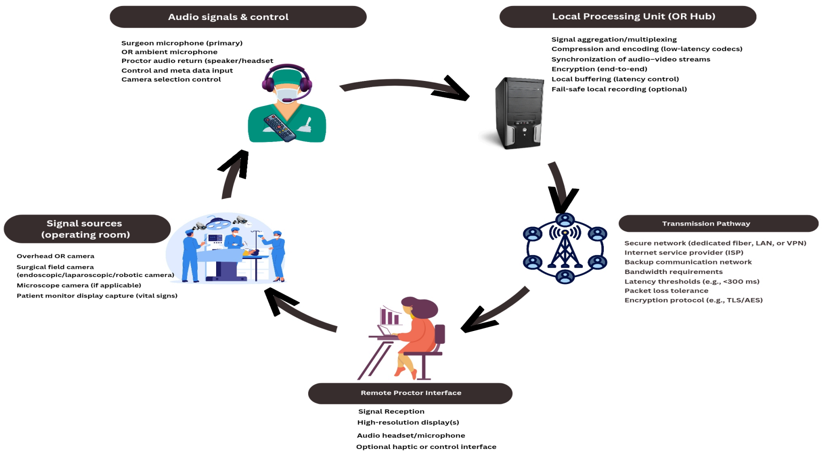
Core Technical Requirements

Latency and bandwidth are fundamental components of efficient telemedicine solutions. Ultra-low latency (<200 ms) is essential for intraoperative guidance, since it reduces communication delays that could jeopardize surgical coordination and decision-making. Likewise, sufficient bandwidth guarantees the dependable transmission of uncompressed or minimally compressed surgical video feeds [24].

Frame rate and video resolution hold similar significance in telemedicine platforms. Frame speeds between 30 and 60 frames per second facilitate seamless observation of swift instrument motions, while high-definition (1080p) or 4K video feeds allow proctors to perceive intricate anatomical details. Multi-camera solutions provide an extensive viewpoint, integrating wide-angle operating room visuals, concentrated operative field imagery, and recordings of robotic or laparoscopic console displays. Furthermore, dependable bidirectional audio channels are essential for uninterrupted communication [19, 24-26].

Effortless integration with hospital information technology systems—such as Picture Archiving and Communication Systems (PACS) and Electronic Health Records (EHRs)—promotes the exchange of imaging and patient records within the proctoring environment, hence improving workflow efficiency [1,27]. To preserve patient privacy and reduce institutional liability, end-to-end encryption, strong authentication, and secure storage protocols are essential for compliance with HIPAA, GDPR, and other data protection legislation [14, 28].

Figure 1 showing signal flow in a remote proctoring system



Key Functional Features

Besides technological requirements, platforms must integrate many functional characteristics to guarantee the efficacy of remote proctoring. A crucial component is real-time telestration, which allows proctors to annotate live video broadcasts by drawing right on the surgical channel. This can be linked with remote control of camera angles in robotic or endoscopic systems, so ensuring that the remote expert retains an appropriate perspective [20,29].

Augmented reality annotations allow labels or drawings to remain "anchored" to anatomical features as the operation field changes, so providing dynamic guidance. Furthermore, additional collaboration tools such as shared whiteboards, document sharing, and multiparty conferencing—enable concurrent participation by academics, trainees, and device vendors [20, 21, 29, 30]. It can also activate re-logging and recording tools that document time-stamped annotations, operational decisions, and procedural milestones. This data underpins credentialing, quality enhancement initiatives, and the creation of training repositories for surgical education [16, 18, 31, 32].

Advancing Technologies

Multisensory feedback systems, robots, and artificial intelligence (AI) are driving the forthcoming era of telemedicine advancement. An AI-assisted decision support system analyzes live video streams to emphasize anatomical structures, automatically identify instruments, and detect violations from established procedural protocols. Simultaneously, AI-driven metric extraction produces objective performance measures for training and credentialing, encompassing instrument motion monitoring and quantification of operating durations [25, 33-35].

To cultivate a more immersive environment for instruction and oversight, experimental platforms are investigating multimodal integration, including haptic feedback, which would enable distant mentors or proctors to perceive resistance faced throughout operations. Ultimately, distant robotic telesurgery—a theoretically viable but logistically and regulatory hard field in which surgeons operate robotic equipment from thousands of kilometers away—continues to be under development [36-38]. These developments suggest that telemedicine may progress from passive oversight to active surgical participation, notwithstanding problems associated with cybersecurity, licensure, and medical accountability [14, 28].

Clinical Applications and Evidence-Based

The three primary stages of care in the clinical implementation of telemedicine and remote proctoring in surgery—preoperative consultation and assessment, intraoperative remote proctoring and telementoring, and postoperative follow-up and monitoring—form a cohesive framework for the integration of digital tools into surgical practice. Despite the varying robustness of supporting data, each phase utilizes digital connectivity to improve continuity of treatment, boost surgical training, and broaden patient access [18, 35].

Telemedicine Prior to Surgery

Telemedicine has been thoroughly included into preoperative care, especially for patient evaluation, triage, and preparation. Surgeons can remotely assess imaging studies, acquire patient histories, and determine the suitability of surgical intervention during teleconsultations. Multiple studies demonstrate that patient satisfaction with telemedicine is equivalent to that of in-person consultations, highlighting benefits such as diminished travel time, decreased expenses, and enhanced accessibility for patients in underserved or rural areas. Moreover, virtual preoperative counseling enhances shared decision-making by reinforcing informed consent procedures and allowing family members to engage in consultations. Nonetheless, constraints remain. The inability to do thorough physical evaluations remotely is a significant obstacle for difficult surgical candidates. Adoption is further hindered by medico-legal ambiguities around accountability and cross-jurisdictional practice. Notwithstanding these obstacles, preoperative telemedicine has proven its ability to improve accessibility and efficiency, thus becoming a common element of surgical practice in well-resourced healthcare systems [5, 14, 35, 39].

Intraoperative Remote Supervision and Telementoring

The intraoperative applications of telemedicine, especially remote proctoring and telementoring, signify significant innovations in surgical practice. A multitude of models has been created to enhance these methodologies. In the unidirectional broadcast paradigm, surgical teams relay live operating video to a remote proctor, who passively monitors to provide guidance or guarantee quality control. Advanced systems facilitate interactive proctoring, allowing remote specialists to deliver real-time verbal and visual advice, frequently reinforced by augmented reality (AR) overlays or telestration [20, 29, 40-42].

Vendor-supported proctoring represents an evolving concept wherein device specialists remotely assist surgical teams during the introduction of novel implants or technologies. Furthermore, remote proctoring is increasingly favored for credentialing and credential renewal, providing economical supervision to institutions while eliminating the necessity for in-person travel [31, 43, 44].

Despite the inconsistent findings about intraoperative teleproctoring, it is nevertheless promising. Pilot investigations and feasibility reports from several surgical specialties consistently indicate that these devices are technically feasible, exhibiting acceptable latency and image quality [7, 9, 18, 20, 45, 46]. Case series in laparoscopic and robotically-assisted surgery indicate advantages including diminished conversion rates, abbreviated learning curves, and enhanced surgeon confidence [3, 7, 13, 22, 47, 48]. For instance, initial applications in minimally invasive operations such as colectomy and laparoscopic cholecystectomy shown that telementored trainees attained expertise more swiftly [32]. Urology has evolved as a leader in this field, particularly through the utilization of robotic platforms for integrated proctoring in treatments such as robotic prostatectomy and partial nephrectomy [44,49]. Remote proctoring has been utilized in orthopedics and gynecology for navigation-assisted and minimally invasive procedures, while remote guidance has facilitated catheter-based interventions in interventional cardiology and radiology [50-52].

Project ECHO and regional telementoring networks exemplify systematic initiatives that demonstrate how remote assistance can disperse expertise globally by linking surgeons in low-resource or community settings with high-volume academic facilities. [53] Observational evidence indicates that intraoperative teleproctoring improves procedural success and training efficiency, although insufficient randomized controlled trials. Nonetheless, additional research is needed to validate its influence on patient safety and long-term outcomes [2, 20, 32, 45].

Post-Surgical Care and Remote Monitoring

The incorporation of digital monitoring tools and telemedicine in postoperative treatment has significantly increased. Virtual follow-up consultations, typically conducted through secure video platforms or mobile applications, enable wound evaluations, medication assessments, and the early identification of problems. Research demonstrates that remote wound evaluation produces patient satisfaction and diagnosis accuracy equivalent to in-person consultations [6,54]. Wearable devices that monitor vital signs, activity levels, and sleep patterns are being tested to identify early indicators of infection, thromboembolism, or decompensation [23,55]. While outcomes are influenced by infrastructure and patient compliance, early discharge initiatives that include virtual monitoring have shown promise in reducing hospital durations and minimizing unplanned readmissions. A growing body of research supports telemonitoring as a beneficial complement to conventional follow-up, especially in improving patient convenience and treatment continuity; yet, data remains inconsistent concerning enhancements in critical outcomes such as death [56].

Remote Proctoring for Surgical Education, Credentialing, and Competency Assessment

The secure and consistent use of breakthrough surgical procedures and equipment is primarily dependent on proctoring. Historically, it has been both expensive and logistically challenging for expert surgeons to travel and mentor colleagues during live procedures. Remote proctoring provides a scalable, economical, and efficient solution, facilitating real-time oversight, feedback, and credentialing without necessitating physical presence. This improves worldwide access to professional guidance [13, 42-44, 57].

Pedagogical Frameworks and Curricula

Remote proctoring has progressed from simple live-streamed observation to comprehensive educational frameworks that incorporate competency-based assessment, asynchronous video analysis, and real-time telementoring. In these models, trainees advance through established skill milestones, receiving real-time coaching from the proctor via augmented reality overlays, auditory instructions, or telestration. Asynchronous methods facilitate objective feedback and longitudinal progress tracking by permitting the annotation and delayed examination of recorded surgical footage [20, 21, 30].

To improve psychomotor abilities prior to actual surgery, simulation-based training programs increasingly include remote coaching sessions with virtual or physical simulators. Structured curricula, including endoscopic training networks and robotic surgery credentialing programs, have effectively incorporated remote proctoring into formal certification pathways, thus guaranteeing consistent global standards and thorough documentation of competency advancement [43,44].

Evaluation and Measurements

In teleproctoring settings, objective assessment is crucial for credentialing and competency preservation. Frequently utilized metrics encompass task-specific error counts, instrument motion monitoring (e.g., path length and motion efficiency), procedural duration, and validated assessments such as the Objective Structured Assessment of Technical Skills (OSATS). Remote platforms can capture high-definition video feeds for subsequent blinded evaluation, thus facilitating consistent and reproducible assessments [43, 44, 58].

Moreover, performance data from motion analysis systems or robotic consoles can be automatically recorded and measured. To guarantee a thorough evaluation, checklists that analyze teamwork, communication, and procedural processes are utilized in conjunction with technical data. Recorded films offer a permanent, reviewable documentation of technical proficiency, so facilitating continuous professional growth and re-credentialing while enhancing accountability and transparency [20, 43, 44].

Effectiveness and Learner Engagement

Recent evidence indicates that remote proctoring expedites learning curves, boosts confidence, and aids in skill acquisition, especially in robotic and minimally invasive techniques [22, 32, 41]. Current study indicates significant satisfaction among both mentors and trainees, who attribute considerable value to this instructional methodology [21,50]. However, the efficacy of supervision and feedback is significantly affected by system dependability, camera placement, and the clarity of communication [59].

Outcomes are influenced by psychosocial factors; attaining the ideal equilibrium between supervision and autonomy is crucial. Excessive oversight may undermine confidence, while inadequate feedback can impede learning. The effectiveness of instruction mostly depends on the relationship between the proctor and trainee, the promptness of feedback, and organized debriefings. Cumulative evidence supports remote practice as a legitimate and scalable instructional technique in contemporary surgical training, however the majority of existing data originates from feasibility studies and a limited number of randomized controlled trials [18, 31, 50, 60].

Box 1. Checklist for Conducting a Remote Proctoring Session

1. **Conduct a pre-briefing** to align expectations, goals, and team roles.
2. **Verify camera positioning** to ensure full visualization of the operative field, instruments, and monitor.
3. **Use standardized communication protocols** with clear, unambiguous terminology.
4. **Perform simulation-based practice** to confirm technical readiness before live procedures.
5. **Confirm patient consent and data security compliance** (privacy, encryption, platform authorization).
6. **Complete structured post-procedure documentation and debriefing.**

Epidemiological and Patient-Level Outcomes of Teleproctoring in Surgery

Although much of the literature on telemedicine and remote proctoring in surgery has emphasized feasibility, technical aspects, and educational benefits, a growing body of evidence now explores patient-level and epidemiological outcomes. These metrics are essential for assessing the broader clinical impact of teleproctoring, extending beyond procedural efficiency and trainee development.

Morbidity and Mortality

Observational studies and case series indicate that teleproctored procedures yield morbidity and mortality rates comparable to those of conventionally supervised surgeries. In minimally invasive, robotic, and endovascular operations, no consistent elevation in intraoperative complications or perioperative mortality has emerged with remote proctoring. That said, most evidence stems from non-randomized cohorts and early adoption periods, warranting cautious interpretation [56].

Surgical Site Infections and Readmissions

Data on surgical site infection (SSI) rates and hospital readmissions after teleproctored surgery are sparse. Available reports show no meaningful differences in SSI incidence or 30-day readmission rates compared with historical or matched institutional controls [50]. Telemedicine-enabled postoperative follow-up may offer indirect advantages, such as earlier detection of wound issues and better care continuity, potentially lowering readmission risks—though firm causal links remain unproven.

Conversion Rates as a Surrogate Outcome

Conversion from minimally invasive to open surgery serves as a key process metric tied to patient morbidity, hospital stay, and recovery. Several observational studies describe stable or reduced conversion rates in teleproctored cases, especially during the learning curve for advanced laparoscopic and robotic procedures [61,62]. This pattern implies that real-time expert input can promote safer decisions and technical precision, possibly improving patient outcomes. However, variations in case complexity and surgeon experience hinder direct cross-study comparisons.

Summary of Epidemiological Evidence

In summary, existing evidence suggests that teleproctoring does not compromise patient safety and may even support better procedural results, particularly in resource-limited settings lacking on-site expertise. Nonetheless, the absence of large-scale prospective trials and uniform outcome measures poses a major limitation. Future studies should focus on rigorous epidemiological endpoints to clarify the population-wide effects of teleproctoring in surgery.

Outcomes, Quality Metrics, and Safety

Standardized outcome indicators are crucial for effectively assessing telemedicine and remote practices in surgery. Research in this field presents a varied spectrum of endpoints categorized into four primary domains: patient-centered outcomes (e.g., complications, mortality, readmissions), process outcomes (e.g., operative durations, conversion rates, workflow efficiency), educational outcomes (e.g., technical skill assessments, learning curve advancement), and system outcomes (e.g., cost-effectiveness, time savings, accessibility). Uniform reporting across these categories would enhance meta-analyses and benchmarking of telesurgical performance [3, 13, 22, 32, 48, 56, 57].

Safety Considerations

Remote surgical supervision necessitates that safety remains the highest priority. Potential dangers encompass video slowness, communication delays, or connectivity loss during critical surgical periods [59, 63]. Furthermore, a visual-only interface poses a danger of misinterpretation of structures or instructions, so jeopardizing patient results [63]. Structured escalation processes are essential, incorporating predefined thresholds for ceasing remote guidance or transitioning to autonomous decision-making. Data from feasibility studies and initial clinical series suggest that remote proctoring is as safe as in-person mentorship, with no rise in intraoperative complications or conversion rates [7,46]. Nevertheless, published data remains limited, contradictory, and primarily observational. Systematic safety reporting is unreliable, especially in the documentation of near-miss incidents and device-related failures. Rigorous multicenter prospective trials are essential to develop definitive safety profiles and operational standards for teleproctored surgery.

Quality Assurance and Metrics

To maintain stringent standards, remote proctoring must be included within current institutional quality assurance (QA) frameworks. Continuous improvement can be attained through routine session recordings, systematic debriefings, and root cause investigations of any bad or poor outcomes. A standardized minimal dataset for teleproctoring studies should encompass: (1) case type and complexity; (2) latency and bandwidth data; (3) proctor-trainer communication metrics; (4) complication and conversion rates; (5) validated skill assessment scores; and (6) cost and time outcomes.

Integrating these markers into surgical registries and hospital quality assurance (QA) systems would promote accountability, reproducibility, and sustained safety monitoring. Professional associations and certifying bodies can utilize structured reporting to establish competency thresholds for remote surgical guiding.

Legal, Ethical, Privacy, and Regulatory Considerations

The establishment of consistent legal and regulatory frameworks has not kept pace with the swift global proliferation of tele-monitoring and remote proctoring. Principal challenges encompass the sufficiency of informed consent for live-streamed or recorded procedures, potential malpractice liability, and cross-jurisdictional licensure issues. As the distinctions between clinical supervision and educational observation become increasingly ambiguous in tele-surgical environments, institutions must implement explicit rules to safeguard patient rights, ensure accountability, and preserve data privacy [14, 28].

Licensure and Credentialing

Teleproctoring presents intricate licensing and credentialing problems, as it frequently involves mentors and learners located in disparate jurisdictions or nations. Remote proctors encounter possible legal liabilities, as numerous governments limit medical practice to professionals licensed within their own borders. In accordance with institutional telehealth regulations, hospitals may necessitate that remote participants get temporary privileges [2,64].

To guarantee adherence to safety, data security, and interoperability standards, credentialing must extend beyond individual surgeons to include platform vendors and device manufacturers. At the institutional level, formulating policies that delineate explicit roles, qualifications, and legal protections reduces culpability in instances of negative outcomes from teleproctored procedures and ensures operational clarity [2,64].

Data Protection, Consent, and Documentation

Regulations like HIPAA in the United States and GDPR in the European Union establish rigorous privacy duties for the use of live video, audio, and surgical recordings. To attain compliance, robust data encryption, stringent access controls, and explicitly defined retention durations are needed. Consent forms must clearly indicate the possibility of real-time remote supervision, data transmission, and video recording during surgical procedures. Whenever possible, anonymised or pseudonymized patient data should be utilized, especially in recordings intended for credentialing or educational purposes. Institutions must restrict data utilization to sanctioned therapeutic or educational purposes and implement stringent procedures for retention and deletion [14, 28].

Ethical Considerations

In addition to privacy considerations, teleproctoring presents more ethical dilemmas. Inequities in digital infrastructure that limit access to high-quality remote supervision aggravate the worldwide surgical skills gap, hence intensifying issues over equality. Patients must comprehend the function and influence of the remote expert in their surgical procedure to guarantee autonomy and transparency [32, 63].
Disclosure and oversight are crucial to mitigate possible conflicts of interest, particularly those that emerge when industry-hired proctors participate in device rollouts. To preserve patient trust and professional integrity, it is essential to keep clear differences among therapeutic, commercial, and educational aims [65].

Recommendations for Policy

Multidisciplinary oversight committees, vendor certification requirements, uniform consent forms, and harmonized regional rules are critical components of an effective governance system. In the swiftly advancing domain of surgical telemedicine, these safeguards maintain ethical standards, guarantee legal responsibility, and protect patient safety.

Implementation Enablers and Barriers

While evidence supports telemedicine and remote proctoring in surgery, their general usage is still inconsistent. Obstacles stem from various causes, such as workflow integration concerns, human and cultural factors, financial and reimbursement issues, and technical and infrastructure limits. Global scalability of remote surgical education and teleurgical support requires understanding hurdles and identifying effective enablers [14,63,64].

Technical and Infrastructure Obstacles

Low- and middle-income countries have network instability, leading to latency and poor video quality, making high-speed internet connectivity difficult. Operating rooms sometimes lack standardized HD camera systems and portable audiovisual setups for remote monitoring [59,66,67]. Interoperability issues hinder seamless integration with hospital IT systems, such as PACS and EHRs [27]. Cybersecurity issues and data security concerns further complicate matters. Implementing teleproctoring systems is hindered by expensive hardware costs, ongoing maintenance, and limited technical staff in resource-constrained hospitals [67].

Human Capital Management and Organizational Culture

Cultural and human considerations can overshadow technical constraints. Some surgeons are still hesitant to use teleproctoring due to worries about surveillance, performance evaluations, and medical-legal implications. Some individuals worry about distractions and communication difficulties during live surgical procedures [14,59,66,67].

Operating room teams may need training in camera placement, audiovisual troubleshooting, and situational awareness during remote observation. Psychological resistance may arise from privacy, data recording, and monitoring concerns [14,24,59,63,66]. To foster acceptance, openness, trust, and incorporating teleproctoring within a culture of safety and continual learning are crucial.

Financial and Reimbursement Issues

Teleproctoring's economy is unpredictable. While remote mentorship reduces travel costs, significant upfront investments in hardware, software licensing, and IT support are generally required. Institutional incentives for tele-surgical operations are limited by unclear or absent reimbursement policies [2,68].

To ensure long-term cost savings and improved access, thorough cost-benefit and value analyses are crucial. The financial viability of teleproctoring programs in public and commercial healthcare sectors can be improved by implementing uniform billing codes, public-private collaborations, and outcome-based funding methods.

Enablers

For successful implementation, institutional leadership, infrastructure finance, user-centered platform design, pilot programs led by local champions, and solid cost-effectiveness and safety statistics are essential for continued investment and growth [69,70].

Equity and Global Perspectives

Teleproctoring and remote surgical mentorship can significantly narrow worldwide surgical access and expertise gaps. A dearth of trained surgeons and restricted training opportunities hinders equitable healthcare delivery in many low- and middle-income countries (LMICs). Teleproctoring saves travel costs and promotes capacity building by eliminating the requirement for physical presence and providing real-time expert supervision. Innovative initiatives like global laparoscopic telementoring collaborations in Latin America and sub-Saharan Africa demonstrate how digital connectivity may empower local teams, enhance procedures, and promote long-term skill development. The models demonstrate how teleproctoring can provide specialist treatment in remote areas and democratize surgical education [7,15,33,34].

However, without investing in training and infrastructure, these advances may worsen existing imbalances. Many LMICs face challenges such as incompatible digital systems, unpredictable power supply, and limited bandwidth, hindering effective implementation. Additionally, relying on external experts or proprietary platforms may compromise local autonomy and sustainability. Scalable low-bandwidth technologies, culturally responsive training programs, and local ownership are crucial for achieving equitable outcomes. Global relationships should promote long-term mentorship, technology transfer, and institutional capacity building above short-term donor projects. Sustainable teleproctoring initiatives should prioritize ethical collaboration, affordability, and local empowerment to promote surgical self-reliance [59,66,69,70].

Future Directions and Research Priorities

Despite breakthroughs in surgical teleproctoring and telemedicine, significant evidence and regulatory gaps remain. Current research are mostly descriptive or small-scale pilots, with limited randomized or comparative data. Consistent heterogeneity in outcome measures limits efficacy consensus and meta-analyses. Limited research exists on cost-effectiveness, long-term evaluations of workflow implications, safety, and knowledge retention. In conclusion, mature regulatory and reimbursement structures hinder widespread adoption and uniformity [2,14,68].

Priorities for Technical Research and Development

Research should focus on technologies that improve safety, interactivity, and real-time reliability. Improved adaptive compression algorithms and low-latency global streaming are crucial for maintaining communication in diverse network conditions. For operating room environments, AR interfaces should be designed to withstand lighting variations, camera motions, and sterilization protocols [18,20].

Artificial intelligence shows particular promise for advancing teleproctoring. It could enable automated error detection, real-time anatomical and gesture recognition, performance analytics, and outcome prediction. Such AI-assisted systems may enhance clinical decision-making, provide objective competency assessments, and lessen the cognitive burden on remote mentors ultimately enhancing both patient safety and the effectiveness of surgical training [71]. While developing haptic feedback systems for remote robots, tactile sensation can be restored, improving procedural precision and operator confidence [36,37,38]. Technical standards for interoperability between devices, video codecs, and hospital IT systems are crucial for multi-vendor compatibility, cybersecurity, and easy data exchange among institutions [27].

In low-resource and low-bandwidth environments, future efforts should prioritize developing scalable, cost-effective platforms that operate reliably under limited infrastructure. Approaches such as simplified audiovisual tools, mobile-friendly interfaces, and locally hosted data storage could promote greater equity and long-term sustainability.

Priorities in Clinical and Educational Research

Multicenter trials with statistical power are needed for strong clinical evidence. Real-world variability can be accounted for in cluster-randomized and stepped-wedgetrial designs to assess the influence of remote monitoring on surgical outcomes and procedural learning curves [22,32]. By establishing institutional registries and standardized outcome databases, patient safety, competency retention, and procedural efficacy may be monitored longitudinally. Comparative research of remote and in-person proctoring methods should evaluate surgeon confidence, patient satisfaction, and system-level outcomes beyond technical success [39]. Coordinated reporting and meta-analysis might benefit from a core set of teleproctoring outcomes. Ultimately, educational research should focus on feedback models, cognitive load control, and skill durability through lengthy follow-up.

Implementation and Policy

Evidence-based policy frameworks are crucial for integrating teleproctoring into surgical ecosystems. Research should focus on simplifying remote expert credentialing, clarifying shared accountability, and developing reimbursement options for cross-border teleconsultations [14,44,64,69]. Cost-sharing systems and public-private partnerships require implementation studies, especially in low- and middle-income contexts. Innovative regulations, like "sandboxes" for controlled testing of developing technology, can promote safe adoption while maintaining patient protection [72].

Collaboration among surgeons, engineers, ethicists, regulators, patient advocates, and industry stakeholders is crucial for teleproctoring to advance. To transform teleproctoring into a robust, egalitarian, and internationally scalable surgical collaboration, interdisciplinary teams must establish unified standards, interoperable infrastructures, and evidence-based protocols.

Practical Advice for Clinicians and Institutions

To safely integrate teleproctoring into surgical practice, clinicians and institutions should follow these evidence-based strategies:

• Create teleproctoring policies for institutions: Define processes for informed consent, data privacy, recording, and storage. Align with national and international data protection regulations, including HIPAA and GDPR.

Start pilots and simulations: Evaluate camera location, audio quality, and network reliability before live procedures. Perform simulation-based dry runs to prepare teams and address connectivity issues.

• Utilize structured communication and workflow tools: Use standardized checklists, pre-procedure briefings, and post-case debriefs to enhance coordination and educational advantages.

•Include QA monitoring: Collect data on teleproctored procedures, such as length, complications, conversion rates, and training outcomes, to identify patterns.

• Conduct focused team training to instruct OR personnel in camera operation, audio optimization, and professional communication during remote engagements.

• Consult legal, IT, and credentialing teams early to ensure secure connections, authorized access, and liability protections for remote proctors.

• Promote equitable access: Implement low-bandwidth choices, mobile-friendly interfaces, and resource-building programs for the participation of partners in low- and middle-income countries.

Adopting these standards promotes safety, uniformity, and longevity in teleproctoring, while promoting global equity and quality improvement.

Conclusion

Telemedicine and remote proctoring have evolved from experimental inventions to essential technologies that shape modern surgery, education, and international collaboration. Evidence suggests significant benefits in improving access, training efficacy, and processes, but there is a lack of high-quality comparative analyses and long-term outcome studies. Continuous improvement requires rigorous reviews, consistent measures, and collaborative research to close gaps. Additionally, investments in digital infrastructure, cybersecurity, and uniform regulatory frameworks are crucial for maintaining safe and ethical standards.

In the upcoming future, fairness and sustainability are crucial as technology, policy, and education intersect.

With proper implementation, remote proctoring can enhance surgical excellence and global health capacity in the digital age.

Acknowledgments

Author Contributions: Conceptualization, P. J.; methodology, P. J., O. A. and A. C.; validation, P. J., O. A. and A. C.; formal analysis, P. J., O. A. and A. C.; investigation, P. J., O. A. and A. C. ; resources, P. J., O. A. and A. C.; data curation, P. J., O. A. and A. C.; writing – original draft preparation, P. J., O. A. and A. C.; writing – review and editing, P. J., O. A. and A. C.; visualization, P. J., O. A. and A. C.; supervision, P. J., O. A. and A. C.; project administration, P. J., O. A. and A. C.

Disclosures: No conflict of interest.

Funding: No funding was received.

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