Review

ANNALS OF MEDICINE & SURGERY

OPEN

Surgical decision-making in the digital age: the role of telemedicine – a narrative review

Shehla Parveen, MBBS[a], Maryam Amjad, MBBS[a], Sameer Abdul Rauf, MBBS[a], Shahdil Arbab, MBBS[a], Syed Abdan Jamalvi, MBBS[a], Shah Emaad-Ur-Rehman Saleem, MBBS[a], Syed Khizar Ali, MBBS[a], Jaiwanti Bai, MBBS[a], Maria Mustansir, MBBS[a], Fnu Danish, MBBS[b], Muhammad Asif Khalil, MBBS[c], Md Ariful Haque, MBBS, MD, MPH[d,e,f,*]

Abstract

This narrative review delves into the transformative role of telemedicine in the realm of surgical decision-making. Telemedicine, a significant innovation in healthcare services, leverages electronic information and communication technologies to provide healthcare services when distance separates the participants. It addresses the challenges of increased healthcare demands, an aging population, and budget constraints. Telemedicine technologies are employed for pre- and postoperative consultations, monitoring, and international surgical teleconferencing and education. They enhance healthcare access, particularly in remote areas, and facilitate knowledge sharing among healthcare professionals. The review also provides a historical context and discusses the technological advancements in telemedicine, including the rise of digital health technologies and the integration of artificial intelligence and machine learning in healthcare. It delves into the details of telemedicine technologies such as telesurgery, telerobotics, telepathology, teleimaging, remote patient monitoring, and virtual and augmented reality. Despite the numerous benefits, the implementation of telemedicine is often hindered by various complex and diverse ethical and legal concerns, including privacy and data security. The review highlights the need for further evidence on health outcomes and cost savings, bridging the digital divide, and enacting policies to support telemedicine reimbursement. It also emphasizes the need for incorporating telemedicine modules in medical education. It recommends that policy-making bodies consider utilizing telemedicine to address healthcare coverage gaps, particularly in rural areas.

Keywords: artificial intelligence, intraoperative guidance, preoperative planning, surgical decision-making, telemedicine

Introduction

Clinical decision-making (CDM) is a fundamental skill in the surgical profession. It includes two mental processes best viewed as extremes of a continuum, from analytical to intuitive. Depending on the intricacies of the case and the clinician's experience and competence, individual judgments are often made by combining all of them. The intuitive type of decision-making is based on pattern recognition; with more expertise and the capacity to recognize common patterns, this strategy becomes more efficient, requiring fewer mental resources. On the other hand, the analytical type tends to be slower, so an unexpected finding or response would trigger the surgeon to pause and reconsider their strategy[1]. Another strategy surgeons may use is Rule-based, which involves identifying the situation and referring to a manual for the appropriate procedure, and Creative, which entails developing a new approach to an unexpected problem that is infrequently used in a high-pressure situation[2]. Three contexts from a surgeon's day-to-day clinical practice are presented to highlight the complexity of CDM.

- Context 1: Diagnosing and treating a patient: The surgeon deals with several pieces of information, and a provisional diagnosis or several diagnoses are made in the initial contact with the patient. Simultaneously, we will weigh in on each of these characteristics and observe patterns that have been observed before with their range of likely diagnoses, management plans, and risks.
- Context 2: Preparing for a surgery: Preoperative briefing by the supervising surgeon helps prepare the team, enhances the procedure's safety, and is essential for anticipating any potential challenges, thereby reducing the risk of complications.
- Context 3: Monitoring the progress of an operation: During a procedure, expert surgeons continuously review all relevant information to monitor the outcomes of their decisions. This process involves maintaining situational awareness, which is the ability to dynamically stay aware of the situation, including their progress, the patient's condition, team activities, timing, and equipment[1].

[a]Liaquat National Medical College, Karachi, Pakistan, [b]Jinnah Sindh Medical University, Karachi, Pakistan, [c]Karachi Medical and Dental College, Karachi, Pakistan, [d]Department of Public Health, Atish Dipankar University of Science and Technology, Dhaka, Bangladesh, [e]Voice of Doctors Research School, Dhaka, Bangladesh and [f]Department of Orthopaedic Surgery, Yan'an Hospital Affiliated to Kunming Medical University, Kunming, Yunnan, China

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

*Corresponding author. Address: Department of Public Health, Atish Dipankar University of Science and Technology, Voice of Doctors Research School, Dhaka, Bangladesh. E-mail: arifulhaque58@gmail.com (M.A. Haque).

Annals of Medicine & Surgery (2025) 87:242–249

Received 24 August 2024; Accepted 7 December 2024

Published online 9 January 2025

http://dx.doi.org/10.1097/MS9.0000000000002874

Telemedicine is regarded as one of the most significant innovations in healthcare services[3]. It utilizes electronic information and communication technologies to deliver and support healthcare when participants are separated by distance[4]. It complements, rather than replaces, necessary face-to-face consultations. It removes the need for in-person visits to obtain medical advice or treatment[5]. It addresses the challenges of the 21st century, such as increased healthcare demands, an aging population, the need to manage large volumes of information, and budget constraints[3]. It's valuable for treating chronic diseases like diabetes, high cholesterol, and high blood pressure[5]. Other uses include mental health and nutrition counseling, medication prescriptions, physical therapy exercises, and tele-intensive care[6]. It also enhances access to information for health professionals with electronic search engines like MEDLARS and PUBMED, providing up-to-date information instantly via the Internet. This facilitates ongoing education for health professionals, helping them maintain and expand their skills[7]. A systematic review of fourteen studies found that tele-triage can reduce unnecessary emergency room visits by 1.2%–22.2% and decrease clinician workload[8].

Technology enhances service quality, reduces costs, and boosts patient satisfaction[3]. These technologies are applicable in various areas such as administration, warehouse and drug management, and specific diagnostic and treatment procedures[9]. For instance, barcode technology helps prevent errors in drug dispensing in clinical and hospital settings. Studies at a 735-bed tertiary care center showed that requiring staff to scan all medication doses during dispensing led to a 93%–96% reduction in dispensing errors. Research indicates that wearable sensors such as Fitbit's data on steps, heart rate, energy expenditure, and sleep can identify adults at high risk of depression with about 80% accuracy. Tag-based real-time locating systems (RTLS), employed for contact tracing in hospital settings during the COVID-19 epidemic, are another application for wearable technology. Digital health technologies can also facilitate clinical trials. For example, a trial involving the Apple Watch found that 34% of participants who received irregular pulse notifications had atrial fibrillation confirmed by subsequent ECGs, with 84% of notifications aligning with atrial fibrillation, demonstrating the app's utility for early detection[10].

Methodology

This narrative review explores the role of telemedicine in enhancing surgical decision-making in contemporary healthcare. A comprehensive literature search was conducted using PubMed/MEDLINE and Google Scholar databases, encompassing studies published up to 2024. Search terms included "telemedicine," "surgical decision-making," "digital health," "remote consultation," "telesurgery," "telemonitoring," and "patient outcomes." Articles focusing on integrating telemedicine technologies in surgical contexts, including their impact on preoperative planning, intraoperative guidance, and postoperative care, were included. Only English-language articles that discussed telemedicine's application in surgical decision-making were considered for this review.

The article selection process was based on established methodologies for narrative reviews, as outlined by Rezapour *et al*, to ensure comprehensive and relevant inclusion criteria[11]. Screening of titles and abstracts was performed to select articles that met the inclusion criteria, encompassing clinical trials and observational studies. Articles exploring telemedicine's effectiveness in improving surgical outcomes, managing complex cases remotely, and enhancing patient access to specialized care were prioritized. Additionally, references and citations within selected articles were cross-referenced to ensure comprehensive coverage of relevant literature. This review aims to provide insights into how telemedicine reshapes surgical practices, fostering a more connected and efficient healthcare environment.

Telemedicine: historical context and technological advancements

The rise of digital technology in healthcare is both exciting and ethically challenging. Improved efficiency and reliability come with the potential loss of personal connection between patients and doctors. Balancing the use of technology while maintaining a human touch is essential. Privacy is a critical concern with digital health solutions, raising issues about data security and who controls patient information. Additionally, integrating artificial intelligence (AI) and machine learning in healthcare enhances capabilities but raises questions about fairness and transparency[12].

In the 1800s, significant medical innovations transformed healthcare. René Laennec's invention of the stethoscope in 1816 allowed doctors to listen to internal body sounds, significantly improving diagnostic accuracy. The mid-century development of anesthesia revolutionized surgery by enabling pain-free procedures, making more complex operations possible. Wilhelm Conrad Roentgen's discovery of X-rays in 1895 provided a way to non-invasively visualize internal structures, aiding in detecting fractures, tumors, and other conditions without surgery. Advances in microscopy during this period also deepened the understanding of diseases[13].

Telemedicine transforms healthcare using digital health technologies to address challenges in nephrology. These innovations aim to improve patient outcomes by optimizing toxin removal and empowering patients. Home dialysis and teledialysis are examples of how patients can manage their health more independently[14]. For heart failure patients, telemedicine offers non-invasive methods like phone consultations, virtual visits, and remote monitoring of vital signs. More invasive procedures, such as using specialized catheters like the pulmonary artery catheter, further extend telemedicine's capabilities in patient management[15]. Table 1 provides an overview of the progression of telemedicine, showcasing significant advancements across various eras.

Role of telemedicine in surgical decision-making

Telesurgery and telerobotics integrate pre- and postoperative video communication and provide surgical care to patients in remote locations. These technologies also facilitate knowledge sharing with consultants to enhance patient care and train upcoming surgeons[18].

In surgical care, telemedicine technologies are employed for pre- and postoperative consultations, monitoring, and international surgical teleconferencing and education[19]. Effective telemedicine improves healthcare access, especially in remote areas. Laferriere *et al* describe a "hub and spoke" model, where a central

Table 1

Outlines the evolution of telemedicine, highlighting key developments across different periods

Time period	Key developments in telemedicine
1950s	First use of telemedicine involved transmitting radiologic images over telephone lines for diagnostic purposes. Laid the groundwork for remote medical consultations using emerging communication technologies[16].
Late 20th century	The surge in telemedicine adoption is driven by: • Growing popularity of the internet. • Advancements in video conferencing. • Mobile health apps. • Wearable devices. • Enabled healthcare providers can interact with and monitor patients remotely[16].
Early 21st century	Telemedicine rapidly gained traction as a practical solution for improving healthcare accessibility, especially in underserved areas. Remote patient monitoring and wearable technology integration expanded virtual care delivery capabilities[16].
COVID-19 pandemic	We have significantly accelerated the mainstream adoption of telemedicine. Healthcare systems sought to provide care safely while limiting in-person contact. The surge in telemedicine usage has continued[17].
Present day	Telemedicine is widely accepted as a mainstream method of care delivery. Telehealth services are becoming increasingly integrated into the healthcare system. Ongoing policy changes and technological advancements continue to shape the future of telemedicine. Virtual care is becoming more accessible, specialized, and globally connected[17].

specialist hospital (the hub) is connected to regional medical centers (the spokes) via telemedicine services[20].

A skilled laparoscopic surgeon can perform complex procedures with remote guidance using a tele-operative system. In six laparoscopic cases, the laparoscopic telepresence system enabled successful telesurgical consultations. These complex cases, usually requiring a specialist's presence, were managed entirely by a skilled laparoscopic surgeon with remote guidance from a pediatric or reconstructive urological surgeon[21]. According to Bullard *et al*, mobile phone images of CT scans allowed neurosurgeons to make patient decisions, reducing patient transfers from referring hospitals by 30%–50%[22]. A new orthopedic project has created a video conferencing link between the university hospital and a district medical center 155 miles away, where outpatients and postoperative patients are examined by a district orthopedic nurse supervised by an orthopedic consultant at the university hospital[23].

Telehealth offers a novel approach to managing patients, particularly those with chronic conditions, through remote consultations, education, and follow-ups. This approach aims to improve access, empower patients, and encourage positive lifestyle changes, thereby preventing and reducing hypertension-related complications[24]. Telemanagement of heart failure patients is a promising approach. Advanced technological platforms for e-health management at patients' homes include telecare, home monitoring of cardiovascular implantable electronic devices, remote monitoring of hemodynamic devices, and telerehabilitation, ensuring optimal long-term management for heart failure patients[25]. In adult patients with OSAS, telemedicine is beneficial for consultations and diagnosis, achieved through remote recordings of oxygen saturation and other parameters via telemonitored respiratory polygraphy or polysomnography. Additionally, remote monitoring can track patient progress and ensure adherence to daily treatments such as continuous positive airway pressure (CPAP)[26].

Telemedicine methods include (1) video conferencing for real-time or synchronous communication between a doctor and patient in different locations and (2) email for asynchronous or store-and-forward consultations, allowing the doctor to review patient information at a convenient time without the patient being present[27]. Telemonitoring involves remotely tracking vital signs reported by patients, data from wearable devices, cardiac implantable electronic devices, and invasive remote hemodynamic monitoring[28]. Prominent AI technologies, such as machine learning (ML) and deep learning, have significantly influenced diagnostics, patient monitoring, drug discovery, and telemedicine. Progress in disease detection and early intervention has been made through AI-generated algorithms in clinical decision support systems and disease prediction models. AI-supported telemedicine has set a standard for delivering healthcare remotely and managing patient follow-ups.

Furthermore, AI-driven applications and wearable devices enable continuous monitoring of vital signs in ambulatory settings[29]. Telemedicine investigations have incorporated various medical instruments known as telemedicine peripherals, such as electronic stethoscopes, teleophthalmoscopes, and video-otoscopes[30]. Telemedicine offers the advantage of remote patient care and quick access to expert opinions and education through the exchange of stored data and images (store-and-forward method) or in real-time[31]. Technologies accessible to patients and providers include wearable devices and mobile health applications for screening fevers and encephalopathy, workflows based on electronic patient-reported outcome assessments for symptom management, machine learning algorithms for predicting emerging CRS in real time, clinical decision support systems for toxicity management, and digital coaching for overall wellness efforts[32,33]. Telemedicine has shown valuable insights into distance-based care, especially during the COVID-19 pandemic, by supporting continuity of care for nursing home residents. Remote specialists perceived it to enhance timely onsite management, improving care quality. Care providers in multidisciplinary areas offered residents a wide range of telemedicine services and promoted interprofessional collaboration between acute and long-term care[34].

The growing number of older adults needing care, the increased demand for care services, and the shortage of healthcare workers are significant societal challenges. In these situations, telemedicine appears promising, especially for rapid support in acute medical cases. However, in addition to the medical and technical potential, the acceptability and usability of telemedical consultations are crucial for sustainable implementation and acceptance, as they facilitate collaboration among healthcare workers[35]. Tele-cardiology collaborative services can avoid many evacuations and treat cases locally with remote technical support. This international telemedicine service has enabled more efficient evacuations, reduced travel and housing expenses, and improved the health system[36].

Telemedicine is rapidly growing in healthcare service delivery. It facilitates communication between patients and providers for measuring, recording, and tracking blood pressure and educating and training patients on managing it[37]. Hospital services for patients with decompensated heart failure are expensive, complex to plan, and not consistently effective. Telemedicine programs for heart failure may improve the quality of care. Educational home telemonitoring of heart failure patients following hospitalization provides long-term clinical benefits in terms of rehospitalization and death in real-world settings, depending on the patient's level of program use. These benefits are expected to impact the disease burden[38] significantly. A study by Bilgrami *et al* assessed changes in patient activation and general self-efficacy through telemedicine for IBD. Remote monitoring did not improve self-efficacy or patient activation compared to routine care[39].

Telemedicine technologies

Health systems innovated worldwide during the COVID-19 pandemic while reducing visits to secondary and tertiary care facilities. They successfully utilized innovations like Accurx, AlldayDr, Attend Anywhere, Doctify, LIVI Connect, NYE Health, Q Health, Refero, and Visiba Care for video and audio calling and messaging between patients and providers in remote consultations[40]. This method is limited to developed countries and extends to developing countries like Bangladesh, which are adopting remote consultations. For instance, the "On Cloud Healthcare Clinic" enables healthcare delivery in rural and remote areas[41].

Telepathology allows a remote pathologist to view images of tissue samples. First, the tissue samples are transformed into high-resolution images and then sent to the pathologist. Specialized software is used for analysis and diagnosis, facilitating collaborative evaluations and consultations. Furthermore, telepathology contributes to education and training by enabling remote teaching and interactive learning sessions[42]. Teleimaging enables transplant teams to view images of donor organs. Radiological images are uploaded to a server, allowing transplant teams early access to these images aiding in their decision-making. The "Cristal Images" initiative by the French Ministry of Health employs teleimaging to enhance the effectiveness and efficiency of organ transplants[43]. Teleradiology is also part of teleimaging, where the digital transfer of radiographic images is used for distant interpretation. It's a faster and more reliable method in emergency conditions, consultations, and radiological treatments in rural or isolated places. This technology significantly improves the quality and accessibility of radiology services, following standards like Picture Archiving and Communication Systems (PACS) and Digital Imaging and Communications in Medicine (DICOM)[44].

Many devices and technologies are used in real-time remote patient monitoring (RPM) to monitor patients' health. IoT (Internet of Things) technology is critical, continuously monitoring vital signs like blood pressure, temperature, and other crucial health data. This continuous monitoring notifies caregivers of any problems, which is especially useful for postoperative and elderly care[45]. Wearable and implanted devices that monitor physiological signals are also crucial in RPM technologies. Examples include the "V-patch system" and "Toumaz SensiumTM." Another significant advancement is the "Body Area Network" (BAN), a wireless network collecting vital signs from sensors implanted on or within the body and sending information to healthcare providers[46]. Implantable cardioverter-defibrillators (ICDs) and pacemakers are examples of BAN devices treating potentially fatal arrhythmias and retaining diagnostic data on cardiac health[47]. During the COVID-19 pandemic, the "Cosinuss ear sensor" tracked patients in home quarantine, using photoplethysmography (PPG) to monitor temperature, oxygen saturation, heart rate, and breathing rate[48]. Innovative mobile applications have transformed smartphones into essential tools for RPM. These applications are part of "Medical Cyber-Physical Systems" (MCPS), integrating physical processes with communication and technology for patient care. For example, Bluetooth-enabled pillboxes help manage medication schedules effectively. The "TeleCARE system," featuring a mobile application for Android OS and wearable devices using "Android Wear," integrates Google Now technology into a smartwatch. This system supports body sensors like heart rate monitors, commonly found in Android-based watches. The "TeleCARE" mobile application also utilizes the phone's built-in sensors for measuring various health-related parameters such as heart rate and pedometer functions[49].

The medical field has embraced virtual and augmented reality (VR/AR) for training and simulating complex procedures like Point-Of-Care Ultrasound (POCUS). Mixed Reality Capture (MRC) on the Microsoft HoloLens allows trainees to see their mentors' natural hand movements during virtual medical training[50]. Commercial-mounted Mounted Devices (HMDs) project AR into the trainee's field of vision, accessible to both local and remote users via devices like smartphones, tablets, or monitors. These technologies extend to tele-ultrasound, enabling remote consultants to examine live ultrasound images and provide real-time instructions. Gadgets like Google Glass allow physicians to see what paramedics see, and surgeons can virtually oversee a patient's wound, providing instructions[51]. Aside from AR, VR is essential for training medical personnel in intensive care units (ICUs), where they practice skills such as CPR, tracheostomy care, bronchoscopy, and extracorporeal membrane oxygenation (ECMO). AR technology empowers surgeons with heads-up displays of critical information, aids in pre-procedure planning, and overlays visuals and data for execution, offering real-time data and imaging to boost provider confidence in ICU procedures. VR also benefits patients by providing distraction, relaxation experiences, comfort during procedures, pain and stress management, and aiding sleep. VR gaming enhances cognitive and motor skills[52]. Telerehabilitation uses Mixed Reality (MR) platforms for remote post-clinical care, rehabilitation, and recovery (e.g., stroke, Parkinsonism, multiple sclerosis), increasing patient motivation and enabling home-based care. VR and AR technologies facilitate teleconsultation, remote assessment, clinical rounds, and surgical care, enhancing convenience and reducing staff exposure while promoting shared decision-making in scenarios like acute stroke assessment, COVID-19 ward rounds, trauma, pre-surgical planning, and intraoperative navigation[53].

Telehealth is evolving with AI and ML, offering enhanced quality and performance. AI systems rapidly detect and identify issues, improving efficiency. They also aid in patient history and diagnosis, helping physicians catch critical details. AI simulates disease progression and assesses cancer risk, facilitating non-intrusive human-to-human interactions through health checks, question answering, alerts, and reminders. AI-driven data analysis in telehealth aids remote patient monitoring by flagging pre-emptive symptoms of conditions like COPD exacerbation[54]. In Emergency Triage (E-triage) systems, ML makes accurate decisions under resource-constrained conditions[55]. AI and ML impact anesthesia by enhancing perioperative care precision and moving toward personalized medicine. These technologies support remote patient monitoring, making future healthcare more accessible at lower costs and improving efficiency across perioperative care stages from presurgical planning to postoperative management[56]. Machine Learning utilizes patient data such as genetic information, clinical history, or lifestyle for personalized treatment strategies, predictive analytics to forecast treatment responses, and ML-guided biomarker discovery for precision decision-making[57]. In emergencies and for diseases requiring quick, precise diagnosis, AI processes extensive medical data, identifies patterns, and detects anomalies overlooked by traditional methods[58].

Benefits of telemedicine in surgical decision-making

It is a common trend worldwide that specialized care is limited to centralized areas, reducing its reach for those living outside the said areas. Telemedicine breaks down geographical barriers, enabling patients in remote or underserved areas to access specialized medical care that would otherwise be unavailable, promoting integrated care. In fields such as surgical oncology, with the help of telemedicine, surgical oncologists can remotely consult with healthcare providers and interact with patients at local sites that lack these areas of expertise. It allows patients to continue visiting their local medical facility while receiving consultation from a distant specialist[59].

Telemedicine allows specialists to interact with patients and healthcare providers in remote or underserved areas without specialized care. Factors such as convenience, lack of travel, scheduling ease, and time saved and cost reduction secondary to lack of travel and parking expenses[60]. Surgery teleconsultations primarily involve sending radiology images, videos, or clinical pictures to minimize unnecessary patient transfers or travel, reduce related costs, and facilitate rapid decision-making in some cases[61].

It was demonstrated that patients saved around 79.6 to 367.2 miles when they opted for teleconsultations instead of in-person visits, which equaled around 77.5 to 317 minutes. This added up to monetary savings of around $176. Additionally, telemedicine prevented patients and their families from having to take time off work or other responsibilities. It eliminated the need for patients to spend one or more nights in a hotel[62].

In patients with increasing long-term conditions, primary and secondary care collaboration is essential for managing surgical patients with multimorbidity and reducing medical errors. Primary care providers need easy access to surgical expertise, while surgeons require comprehensive patient information from primary care[63]. Through telecommunication, healthcare providers can easily share patient information, medical records, and diagnostic results, leading to more coordinated and comprehensive care.

Surgeons not practicing at large academic medical centers with greater access to other surgeons may benefit from telemedicine in the form of collaborative advisory for difficult cases that can improve patient care and management[64].

In surgical neuro-oncology, the conversion rates to surgery or radiosurgery are comparable between telemedicine and in-person cohorts. Telemedicine has proven to be an effective tool in surgical neuro-oncology practice. It facilitates initial patient consultations, diagnostic discussions, imaging reviews, obtaining informed consent, and scheduling procedures when necessary[65].

Postoperative care in telemedicine can be successfully conducted by (SMS) text messaging, smartphone applications, automated calls, and wearable devices. Telemedicine in postoperative care can be used for scheduled follow-ups, routine monitoring, and managing issues. It can aid in the routine monitoring of clinical data such as ileostomy output, blood pressure and medication adherence, surgical drain output, and home spirometry results[66].

Telemedicine minimizes the need for physical infrastructure, reduces travel expenses, and decreases the likelihood of unnecessary hospital admissions and readmissions, leading to cost-effectiveness and resource efficiency in the form of decreased carbon footprint[60,62].

Challenges and limitations

Telemedicine, which combines medical practice with information and communications technology, has proven highly effective for remote healthcare, particularly in areas with limited access to healthcare facilities. However, the implementation of telemedicine is often hindered by various complex and diverse ethical and legal concerns[67].

Privacy and data security are critical considerations in telemedicine, requiring robust encryption and anonymization techniques to protect patient data. Responsible data handling practices, such as decentralized data sharing, are essential to ensure patient privacy[68].

Telehealth was initially developed to provide primary care to underserved patients in rural areas. The emphasis on patient satisfaction, efficient and quality care, and cost reduction has led to increased adoption of telehealth. However, regulatory, legal, and reimbursement barriers have impeded the widespread implementation of telehealth services.[69].

The widespread adoption of telemedicine has been hindered by numerous barriers, including lack of awareness, implementation costs, inefficiencies, difficulty performing physical examinations, limited perceived benefits, negative financial implications, concerns about medicolegal liability, and regulatory restrictions[70].

The COVID-19 pandemic has significantly impacted various aspects of human interaction, including financial, healthcare, and social environments. Social distancing measures have proven effective in controlling the spread of the virus, leading to hospital closures and reduced non-COVID clinical visits. As a result, telemedicine and video medicine visits have been incentivized and adopted to provide distance-based care[71].

Although telemedicine physical examinations have limitations, most components of a standard physical examination can be conducted remotely with a systematic approach. Modifications and considerations for maximizing the examination remotely can benefit healthcare providers incorporating telemedicine into their practice[72].

Success factors for telemedicine programs include financial sustainability, ease of use, and utilization of existing resources. Challenges faced by these programs include limited technological infrastructure, funding limitations, and conflicting health system priorities.[73,74].

The COVID-19 pandemic has rapidly accelerated the adoption of telemedicine due to social restrictions. While telemedicine improves access to healthcare for many, there remain barriers and challenges for individuals with disabilities. Infrastructure and access barriers, operational challenges, regulatory barriers, communication barriers, and legislative barriers need to be systematically addressed to ensure equitable healthcare access for this vulnerable population[75].

Social determinants of health contribute to disparities in access to care and inferior outcomes in pediatric populations. Telemedicine has been shown to bridge the gap between healthcare providers and underserved populations, particularly in rural areas. However, the COVID-19 pandemic has further highlighted the need for solutions to address obstacles such as lack of broadband access, digital literacy, language barriers, and systemic issues within the healthcare system to ensure equitable telemedicine access and prevent worsening healthcare disparities[76].

Future directions

In 2019, the World Health Organization (WHO) developed a framework for incorporating digital innovations and technology into healthcare. The WHO's recommendations on digital interventions in healthcare emphasize the evaluation of benefits, harms, acceptability, feasibility, resource utilization, and equity considerations[77]. Telemedicine, which allows clinicians to assess patients remotely, has shown potential in addressing healthcare resource distribution challenges by enabling care delivery to remote areas with limited access to doctors and specialists. It also reduces travel requirements carbon footprints, and facilitates specialized care for patients with rare diseases. During the COVID-19 pandemic, telemedicine, particularly in neuro-oncology, has expanded significantly and gained acceptance among patients and providers[78].

Lifestyle interventions with personalized self-management programs have demonstrated positive outcomes for patients with type 2 diabetes mellitus (T2DM). Tele-assisted interventions have resulted in more significant reductions in HbA1c levels compared to standard care and improvements in diabetes self-management and body mass index[79].

Telemedicine has proven effective for initial evaluations of spine surgical patients, even without an in-person physical examination. It has also shown benefits in dermatology, allowing preoperative consultations, intraoperative consultations with dermatopathologists, care coordination, and post-procedural monitoring[80,81].

Despite its significance, telemedicine has not been integrated into medical school curricula. Incorporating telemedicine modules in medical education can enhance students' confidence in practical telemedicine skills and alleviate uncertainties regarding its use[82,83].

Medical school curricula can include telemedicine-specific educational goals to equip students with core telemedicine and clinical skills. These goals can focus on access to care, cost, cost-effectiveness, patient experience, and clinician experience[84].

While telemedicine has improved access to care and demonstrated positive health outcomes in various clinical conditions, further evidence is needed on health outcomes and cost savings. Bridging the digital divide and enacting policies to support telemedicine reimbursement are crucial steps for realizing its full potential[85,86].

We recommend that the policy-making bodies consider utilizing telemedicine to address healthcare coverage gaps, particularly in rural areas. Access to high-speed bandwidth is essential for bridging geographical gaps in medical access. However, accepting new technology among older age groups may require time and should be considered.

Conclusion

In conclusion, telemedicine has transformed surgical decision-making, enhancing healthcare by leveraging electronic communication technologies. It addresses challenges such as rising healthcare demands, an aging population, and budget constraints while improving preoperative planning, intraoperative guidance, and postoperative care. Despite challenges like privacy concerns, this review highlights telemedicine's advancements in telesurgery, telerobotics, and remote consultations. The potential of telemedicine remains significant, with further research needed on health outcomes and cost savings. Supportive policies will be crucial in integrating telemedicine into mainstream healthcare, ensuring its continued impact on surgical decision-making.

Ethical approval

Not applicable.

Consent

Not applicable.

Sources of funding

All the authors declare to have received no financial support or sponsorship for this study.

Author's contribution

S.P., M.A., S.A.R.: conceptualization, writing – original draft, final approval, and agreeing to the accuracy of the work; S.A., S. A.J., S.E.R.S., S.K.A., J.B., M.M., F.D., M.A.K.: writing – original draft, final approval, and agreeing to the accuracy of the work; M.A.H.: writing – editing, final approval, and agreeing to the accuracy of the work.

Conflicts of interest disclosure

All the authors declare to have no conflicts of interest relevant to this study.

Research registration unique identifying number (UIN)

Not applicable.

Guarantor

Sameer Abdul Rauf.

Data availability statement

Data will be available on reasonable request.

Provenance and peer review

Not commissioned, externally peer-reviewed.

References

[1] Crebbin W, Beasley SW, Watters DAK. Clinical decision making: how surgeons do it. ANZ J Surg 2013;83:422–28.
[2] Flin R, Youngson G, Yule S. How do surgeons make intraoperative decisions? Qual Saf Health Care 2007;16:235–39.
[3] Stoumpos AI, Kitsios F, Talias MA. Digital transformation in healthcare: technology acceptance and its applications. Int J Environ Res Public Health 2023;20:3407.
[4] Field MJ. Telemedicine: A Guide to Assessing Telecommunications in Health Care. National Academies Press (US); 1996. https://www.ncbi.nlm.nih.gov/books/NBK45440
[5] Thomas L. What is telemedicine? News-Medical Net. Published January 2023;18.
[6] Tee-Melegrito RA Telemedicine: definition, uses, benefits, and more. Published September 30, 2022. https://www.medicalnewstoday.com/articles/telemedicine
[7] Hjelm NM. Benefits and drawbacks of telemedicine. J Telemed Telecare 2005;11:60–70.
[8] Kidholm K, Jensen LK, Johansson M, *et al*. Telemedicine and the assessment of clinician time: a scoping review. Int J Technol Assess Health Care 2024;40:e3.
[9] Pakulska T, Religioni U. Implementation of technology in healthcare entities – barriers and success factors. J Med Econ 2023;26:821–23.
[10] Wai A, Torkamani A, Butte AJ, *et al*. The promise of digital healthcare technologies. Front Public Health 2023;11:1196596.
[11] Rezapour M, Yazdinejad M, Rajabi Kouchi F, *et al*. Text mining of hypertension researches in the west Asia region: a 12-year trend analysis. Ren Fail 2024;46:2337285.
[12] Rampton V, Böhmer M, Winkler A. Medical technologies past and present: how history helps to understand the digital era. J Med Human 2022;43:343–64.
[13] Roguin A. Rene theophile hyacinthe laennec (1781-1826): the man behind the stethoscope. Clin Med Res 2006;4:230–35.
[14] Canaud B, Davenport A, Leray-Moragues H, *et al*. Digital health support: current status and future development for enhancing dialysis patient care and empowering patients. Toxins (Basel) 2024;16:211.
[15] Accorsi TAD, Santos GGRD, Nemoto RP, *et al*. Telemedicine and Patients with Heart Failure: Evidence and Unresolved Issues. Einstein (Sao Paulo).2024;22 eRW0393
[16] Institute of Medicine (US) Committee on evaluating clinical applications of telemedicine; Field MJ, editor. Telemedicine: A Guide to Assessing Telecommunications in Health Care. Washington (DC): National Academies Press (US). 2; 1996. Evolution and Current Applications of Telemedicine. Available from: https://www.ncbi.nlm.nih.gov/books/NBK45445/
[17] Kichloo A, Albosta M, Dettloff K, *et al*. Telemedicine, the current COVID-19 pandemic and the future: a narrative review and perspectives moving forward in the USA. Family Med Commun Health 2020;8:e000530.
[18] Huang EY, Knight S, Guetter CR, *et al*. Telemedicine and telementoring in the surgical specialties: a narrative review. Am J Surg 2019;218:760–66.
[19] Aziz SR, Ziccardi VB. Telemedicine using smartphones for oral and maxillofacial surgery consultation, communication, and treatment planning. J Oral Maxillofac Surg 2009;67:2505–09.
[20] McMaster T, Wright T, Mori K, *et al*. Current and future use of telemedicine in surgical clinics during and beyond COVID-19: a narrative review. Ann Med Surg (Lond) 2021;66:102378.
[21] Cheriff AD, Schulam PG, Docimo SG, *et al*. Telesurgical consultation [published correction appears in in 1997 Oct;158(4):1530]. J Urol 1996;156:1391–93.
[22] Bullard TB, Rosenberg MS, Ladde J, *et al*. Digital images taken with a mobile phone can assist in the triage of neurosurgical patients to a level 1 trauma centre. J Telemed Telecare 2013;19:80–83.
[23] Augestad KM, Lindsetmo RO. Overcoming distance: video-conferencing as a clinical and educational tool among surgeons. World J Surg 2009;33:1356–65.
[24] Piskorz D, Alcocer L, López Santi R, *et al*. Blood pressure telemonitoring and telemedicine, a Latin America perspective. Blood Press 2023;32:2251586.
[25] Piotrowicz E. The management of patients with chronic heart failure: the growing role of e-health. Expert Rev Med Devices 2017;14:271–77.
[26] Rizzo L, Barbetta E, Ruberti F, *et al*. The role of telemedicine in children with obstructive sleep apnea syndrome (OSAS): a review of the literature. J Clin Med 2024. 13:2108.
[27] Patterson VT. Teleneurology. J Telemed Telecare 2005;11:55–59.
[28] Alvarez P, Sianis A, Brown J, *et al*. Chronic disease management in heart failure: focus on telemedicine and remote monitoring. Rev Cardiovasc Med 2021;22:403–13.
[29] Iqbal J, Cortés Jaimes DC, Makineni P, *et al*. Reimagining healthcare: unleashing the power of artificial intelligence in medicine. Cureus 2023. 15:e44658.
[30] Sud E, Anjankar A. Applications of telemedicine in dermatology. Cureus 2022;14:e27740.
[31] Wurm EMT, Hofmann-Wellenhof R, Wurm R, *et al*. Telemedicine and teledermatology: past, present and future. J Dtsch Dermatol Ges 2008;6:106–12.
[32] Banerjee R, Shah N, Dicker AP. Next-generation implementation of chimeric antigen receptor t-cell therapy using digital health. JCO Clin Cancer Inform 2021;5:668–78.
[33] Rezapour M, Ansari NN. Designing and producing a telerehabilitation mobile application and a web-based smart dashboard for online monitoring of patients at risk of stroke during Covid-19 pandemic and post-pandemic era. Int J Basic Sci Med 2021;6:127–31.
[34] Tan AJ, Rusli KD, McKenna L, *et al*. Telemedicine experiences and perspectives of healthcare providers in long-term care: a scoping review. J Telemed Telecare 2024;30:230–49.
[35] Offermann J, Ziefle M, Sira N, *et al*. Telemedicine in nursing homes: insights on the social acceptance and ethical acceptability of telemedical consultations. Digit Health 2023;9:20552076231213444.
[36] Lapão LV, Correia A. Improving access to pediatric cardiology in Cape Verde via a collaborative international telemedicine service. Stud Health Technol Inform 2015;209:51–57.
[37] Khanijahani A, Akinci N, Quitiquit E. A systematic review of the role of telemedicine in blood pressure control: focus on patient engagement. Curr Hypertens Rep 2022;24:247–58.
[38] Sabatier R, Legallois D, Jodar M, *et al*. Impact of patient engagement in a French telemonitoring programme for heart failure on hospitalization and mortality. ESC Heart Fail 2022;9:2886–98.
[39] Bilgrami Z, Abutaleb A, Chudy-Onwugaje K, *et al*. Effect of TELEmedicine for inflammatory bowel disease on patient activation and self-efficacy [published correction appears in Dig Dis Sci. 2019 Dec 2]. Dig Dis Sci 2020;65:96–103.
[40] Shah N, Thakrar A, Visvanathan S, *et al*. Virtual online consultation platforms for secondary care: a review of the options. BMJ Innov 2021;7:135–40.
[41] Miah SJ, Hasan J, Gammack JG. On-cloud healthcare clinic: an e-health consultancy approach for remote communities in a developing country. Telematics Inf 2017;34:311–22.
[42] Petersen JM, Jhala D. Telepathology: a transforming practice for the efficient, safe, and best patient care at the regional veteran affairs medical center. Am J Clin Pathol 2022;158:S97–S98.
[43] Zarca K, Dupont J-CK, Jacoud L, *et al*. Effectiveness and efficiency of teleimaging in the transplantation process: a mixed method protocol. BMC Health Serv Res 2019;19:1–5.

[44] Bashshur RL, Krupinski EA, Thrall JH, *et al*. The empirical foundations of teleradiology and related applications: a review of the evidence. Telemedicine and e-Health 2016;22:868–98.
[45] Akram PS, Ramesha M, Valiveti SAS, *et al* (2021, March). IoT based remote patient health monitoring system. In 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS) (Vol. 1, pp. 1519–24). IEEE.
[46] Oleshchuk V, Fensli R. Remote patient monitoring within a future 5G infrastructure. Wireless Personal Commun 2011;57:431–39.
[47] Movsowitz C, Mittal S. Remote patient management using implantable devices. J Interv Cardiac Electrophy 2011;31:81–90.
[48] Müller A, Haneke H, Kirchberger V, *et al*. Integration of mobile sensors in a telemedicine hospital system: remote-monitoring in COVID-19 patients. J Public Health 2022;30:93–7.
[49] Szydło T, Konieczny M. Mobile and wearable devices in an open and universal system for remote patient monitoring. Microproc Microsyst 2016;46:44–54.
[50] Wang S, Parsons M, Stone-mclean J, *et al*. Augmented reality as a telemedicine platform for remote procedural training. Sensors 2017;17:2294.
[51] Dinh A, Yin AL, Estrin D, *et al*. Augmented reality in real-time telemedicine and telementoring: scoping review. JMIR Mhealth Uhealth 2023;11:e45464.
[52] Kanschik D, Bruno RR, Wolff G, *et al*. Virtual and augmented reality in intensive care medicine: a systematic review. Ann Intensive Care 2023;13:81.
[53] Worlikar H, Coleman S, Kelly J, *et al*. Mixed reality platforms in telehealth delivery: scoping review. JMIR Biomed Eng 2023;8:e42709.
[54] Kuziemsky C, Maeder AJ, John O, *et al*. Role of artificial intelligence within the telehealth domain. Yearb Med Inform 2019;28: 035–040.
[55] Salman OH, Taha Z, Alsabah MQ, *et al*. A review on utilizing machine learning technology in the fields of electronic emergency triage and patient priority systems in telemedicine: coherent taxonomy, motivations, open research challenges and recommendations for intelligent future work. Comput Methods Programs Biomed 2021;209:106357.
[56] Bellini V, Valente M, Gaddi AV, *et al*. Artificial intelligence and telemedicine in anesthesia: potential and problems. Minerva Anestesiol 2022;88:729–34.
[57] Verma P, Mishra N, Srivastava V. Machine learning for personalized medicine: tailoring treatment strategies through data analysis. The Pharma Innovation 2019;8:11–14.
[58] Channapatna R. Role of AI (artificial intelligence) and machine learning in transforming operations in healthcare industry: an empirical study. Int J 2023;10:2069–76.
[59] Jue JS, Spector SA, Spector SA. Telemedicine broadening access to care for complex cases. J Surgical Res 2017;220:164–70.
[60] Ahmad F, Wysocki RW, Fernandez JJ, *et al*. Patient perspectives on telemedicine during the COVID-19 pandemic. Hand (N Y) 2023;18:522–26.
[61] Deldar K, Bahaadinbeigy K, Tara A. Teleconsultation and clinical decision making: a systematic review. Acta Inform Med 2016;24:286–92.
[62] Gunter RL, Chouinard S, Fernandes-Taylor S, *et al*. Current use of telemedicine for post-discharge surgical care: a systematic review. J Am Coll Surg 2016;222:915–27.
[63] Janssen M, Sagasser MH, Fluit CRMG, *et al*. Competencies to promote collaboration between primary and secondary care doctors: an integrative review. BMC Fam Pract 2020;21:1-13.
[64] Elbuluk AM, Ast MP, Stimac JD, *et al*. Peer-to-peer collaboration adds value for surgical colleagues HSS Journal®: The Musculoskeletal. J Hospital for Spec Surg 2018;14:294–98.
[65] Smit RD, Mouchtouris N, Reyes M, *et al*. The use of telemedicine in pre-surgical evaluation: a retrospective cohort study of a neurosurgical oncology practice. J Neurooncol 2022;159:621–26.
[66] Ellimoottil C, Skolarus T, Gettman M, *et al*. Telemedicine in urology: state of the art. Urology 2016;94:10–16.
[67] Solimini R, Busardò FP, Gibelli F, *et al*. Ethical and legal challenges of telemedicine in the era of the COVID-19 pandemic. Medicina (Kaunas) 2021;57:1314. doi: 10.3390/medicina57121314.
[68] Elendu C, Amaechi DC, Elendu TC, *et al*. Ethical implications of AI and robotics in healthcare: a review. Medicine (Baltimore) 2023;102:e36671.
[69] Gajarawala SN, Pelkowski JN. Telehealth benefits and barriers. J Nurse Pract 2021;17:218–21.
[70] Makhni MC, Riew GJ, Sumathipala MG. Telemedicine in orthopaedic surgery: challenges and opportunities. J Bone Joint Surg Am 2020;102:1109–15.
[71] Wahezi SE, Duarte RA, Yerra S, *et al*. Telemedicine during COVID-19 and beyond: a practical guide and best practices multidisciplinary approach for the orthopedic and neurologic pain physical examination [published correction appears in Pain Physician. 2020 Nov;23(6):647]. Pain Physician 2020;23:S205–S238.
[72] Van Nest DS, Ilyas AM, Rivlin M. Telemedicine evaluation and techniques in hand surgery. J Hand Surgery Global Online 2020;2:240–45.
[73] Jha AK, Sawka E, Tiwari B, *et al*. Telemedicine and community health projects in Asia. Dermatol Clin 2021;39:23–32.
[74] Samizadeh R, Zadeh MK, Jadidi M, *et al*. Discovery of dangerous self-medication methods with patients, by using social network mining. Int J Bus Intell and Data Min 2023;23:277–87.
[75] Annaswamy TM, Verduzco-Gutierrez M, Frieden L. Telemedicine barriers and challenges for persons with disabilities: COVID-19 and beyond. Disabil Health J 2020;13:100973.
[76] Romain CV, Trinidad S, Kotagal M. The effect of social determinants of health on telemedicine access during the COVID-19 pandemic. Pediatr Ann 2022;51:e311–e315.
[77] Li JO, Liu H, Ting DSJ, *et al*. Digital technology, tele-medicine and artificial intelligence in ophthalmology: a global perspective. Prog Retin Eye Res 2021;82:100900.
[78] Wasilewski A, Mohile N. Tele-neuro-oncology: current practices and future directions. Curr Oncol Rep 2022;24:99–103.
[79] von Storch K, Graaf E, Wunderlich M, *et al*. telemedicine-assisted self-management program for type 2 diabetes patients. Diabetes Technol Ther 2019;21:514–21.
[80] Melnick K, Porche K, Sriram S, *et al*. Evaluation of patients referred to the spine clinic via telemedicine and the impact on diagnosis and surgical decision-making. J Neurol Neurosurg Spine 2023;39:600–06.
[81] Sohn GK, Wong DJ, Yu SS. A review of the use of telemedicine in dermatologic surgery. Dermatologic Surgery: Official Pub Am Soc Dermatologic Surgery 2020;46:501–07.
[82] Vogt L, Schmidt M, Follmann A, *et al*. Telemedicine in medical education: an example of a digital preparatory course for the clinical traineeship - a pre-post comparison. GMS J Med Educ 2022;39:Doc46.
[83] Rezapour M, Khavanin Zadeh M, Sepehri MM. Implementation of predictive data mining techniques for identifying risk factors of early AVF failure in hemodialysis patients. Comput Math Methods Med 2013;2013:830745.
[84] Jumreornvong O, Yang E, Race J, *et al*. Telemedicine and medical education in the age of COVID-19. Acad Med 2020;95:1838–43.
[85] Barbosa W, Zhou K, Waddell E, *et al*. Improving access to care: telemedicine across medical domains. Annu Rev Public Health 2021;42:463–81.
[86] Scott Kruse C, Karem P, Shifflett K, *et al*. Evaluating barriers to adopting telemedicine worldwide: a systematic review. J Telemed Telecare 2018;24:4–12.