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Review Paper

Telemedicine and remote monitoring in burn care: A review of current applications

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ABSTRACT

Burn injury is one of the most destructive types of trauma, with considerable physical, psychological, and financial costs to individuals as well as to healthcare systems. Specialized care for burns remains scarce in most areas, particularly in remote or resource-limited regions. Telemedicine and remote monitoring have become valuable tools for bridging these care gaps. This review provides an overview of existing applications, benefits, and challenges of telemedicine and remote monitoring for burns, as well as future directions for their wider application. An in-depth review of contemporary literature was conducted to evaluate telemedicine-based methodologies in various areas of burn treatment, including teleconsultation, remote patient follow-up, wound assessment, and rehabilitation. The use of advanced tools, such as artificial intelligence and wearable sensors, in augmenting remote care was also investigated. Telemedicine facilitates prompt specialist consultations, reduces unnecessary transfers, and supports early recognition in underserved groups. Remote monitoring devices have enhanced wound management, optimized rehabilitation processes, and facilitated greater patient satisfaction. Technical limitations, data privacy, security, and unstandardized clinical guidelines constitute challenges that still need answers from research and policy. Telemedicine, combined with remote monitoring, holds promising capabilities for significantly improving the provision of care for burns by expanding access, enhancing patient outcomes, and optimizing healthcare resource management. Overcoming the challenges on offer will require interdisciplinary collaboration and advancements in technology to unlock all these benefits fully.

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1. Introduction

Burn injuries constitute a global health priority that requires specialized, often costly care [1,2]. Acute management of burns is characterized by the immediate care of fluid resuscitation, wound care, and infection control, typically involving admission to specialized burn facilities [3]. Geographical distance and unequal resources, particularly in remote locations and Low- and Middle-Income Countries (LMICs), significantly undermine the availability of adequate and prompt care [4,2]. Telemedicine and remote monitoring hold promise for overcoming barriers by enhancing the availability of specialized care and improving outcomes [5,6]. This study examines the use of telemedicine and remote monitoring, investigating its existing applications, benefits, limitations, and potential future directions in the care of burns.

2. Telemedicine in Burn Care

Telemedicine, the remote administration of healthcare through the use of information and communication technology [7], has demonstrated considerable promise in many areas of medicine, including the care of burns [8]. It benefits through cost reduction, enhancement of care quality, and expanded availability of specialists, especially important within the care of burns, where specialized resources and talent are most likely to reside within regional burn facilities [8,9]. Figure 1 illustrates how telemedicine can streamline burn care by bridging geographical gaps, enabling real-time expert consultations, and facilitating remote follow-up. As shown, these innovations not only reduce the burden of travel and associated costs but also promote the early detection of complications and continuity of care, especially in resource-limited areas and during public health emergencies, such as pandemics.

2.1 Remote Patient Follow-up

Remote patient follow-up, a crucial feature of telemedicine in burn care, utilizes technology to monitor patients' progress after receiving care [8]. It can significantly reduce the frequency of clinic visits, saving patients money and time, while facilitating early intervention in the event of complications. A review of one program, telemedicine, that linked a rehabilitation center with a burn care center found that virtual visits reduced the need for ambulance transports, resulting in significant cost savings. Patients were delighted, with most satisfaction stemming from reduced travel times and increased compliance with rehabilitation care [9].

The success of remote follow-up, nonetheless, relies on the availability of reliable technology among patients and on appropriate self-monitoring [10].

2.2 Teleconsultation

Teleconsultation facilitates immediate consultation with burn patient experts, avoiding the need for extended travel to specialized facilities [8]. It is most useful in remote locations where there is poor availability of burn specialists [11,12]. The use of easily accessible, user-friendly media, such as WhatsApp, has been effective in facilitating consultations where resources are scarce. WhatsApp consultations have been shown to result in a significant reduction in unnecessary outpatient attendance and admissions, leading to substantial cost savings for the institution [11]. The success of teleconsultation, nonetheless, depends on the quality of the technology employed and how well the clinician is able to evaluate the remote patient [10].

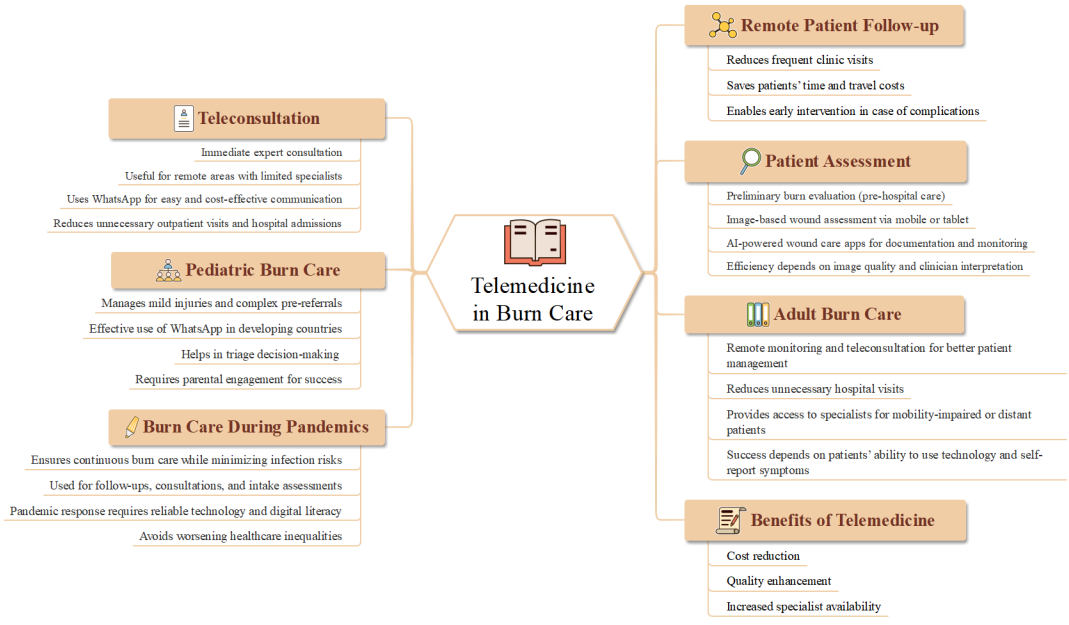

Figure 1. Telemedicine in Burn Care

2.3 Patient Assessment

Telemedicine can also be helpful in the preliminary evaluation of burn injuries, particularly in pre-hospital care [8]. Remote devices, such as image-based wound evaluation using mobile or tablet devices and advanced imaging [13], can also aid in pre-hospital patient triage and the determination of referral to a burn care center. It can make processes in burn care services efficient and ensure that care is provided to patients on time [14]. Artificial Intelligence (AI)-integrated wound care apps have also been shown to enhance wound documentation and management processes, including remote patient monitoring [15]. The reliability of a remote patient assessment, nonetheless, is very much dependent on the quality of the images and the clinician's interpretation skills [13].

2.4 Pediatric Burn Care

Telemedicine plays a crucial role in pediatric burn care, particularly in managing mild injuries and facilitating the pre-referral evaluation of complex conditions. The use of readily accessible media, such as WhatsApp, has been particularly effective in developing countries, where facilities and resources are generally limited. A pre-hospital consultation, improved decision-making in triage and referral, and a reduction in unnecessary referrals and outpatient visits were achieved using WhatsApp in one study [11]. Care planning tailored to the child's stage of life, ensuring a suitable guardian or parental engagement, is crucial to the successful implementation of telemedicine within pediatric burn care [10].

2.5 Adult Burn Care

Telemedicine is also effective in managing adult burns, particularly through remote patient monitoring and teleconsultation [8,9]. Remote monitoring of patient progress is an effective way to reduce unnecessary hospital visits and enhance treatment compliance. Teleconsultation is effective in providing patients with access to specialist consultations without requiring extended journeys, especially for individuals with mobility impairments or those residing in remote areas [9]. The success of telemedicine in managing adult burns depends on how well the patient can utilize technology and accurately describe their condition [10].

2.6 Burn Care During Pandemics

The Coronavirus disease 2019 (COVID-19) pandemic underscored the vital role of telemedicine in ensuring continuous access to essential burn care while minimizing the risk of infection. The majority of burn units had to adapt their practices to involve follow-up of patients, consultations, and intake assessments through telemedicine [16,17]. It allowed them to maintain good care without risking the transmission of infection to patients or healthcare workers [16]. A pediatric burn unit demonstrated that adding an outpatient pre-hospital clinic, along with telemedicine, sustained treatment quality during pandemic periods [17]. The extensive use of telemedicine during pandemics, however, relies on technological availability, digital literacy, and the avoidance of exacerbating health inequities [16,12].

3. Remote Monitoring in Burn Care

Burn injuries constitute a global health burden that imposes considerable emotional, financial, and physical distress on individuals and healthcare systems [18,19]. The economic burden is also tremendous for both healthcare providers and patients [19]. Traditional care for burns is often accessed through extended travel by patients to specialized facilities, which can increase distress, particularly for individuals residing in remote or underserved areas [19,20]. Remote monitoring devices hold promise for overcoming this by increasing specialized care coverage for burns and enhancing patient access [18,20].

3.1 Acute Burn Management: Triage, Transfer, and Initial Assessment

Telehealth platforms have also played a crucial role in ensuring the effective triage, transfer, and referral of patients [18]. The platforms provide the prompt determination of burn severity, facilitating early interventions and the efficient use of resources. It is reported that through telehealth, there is a greater awareness of triage, a closer approximation of the body surface area involved, and more guidance on measures of acute burn resuscitation [19]. Computer vision integrated with AI enhances this process by providing avenues for the effective classification of burn severity through imaging. This technology can also distinguish between superficial partial-thickness and deep partial-thickness burns, thereby advising subsequent treatment decisions [21].

3.2 Post-Acute Care and Rehabilitation

Telehealth plays an integral part in the rehabilitation and post-acute care of burned individuals by facilitating ongoing monitoring and care [18]. It is characterized by remote follow-up appointments, avoiding frequent visits to specialized facilities [18,20]. The integration of telehealth into rehabilitative care has demonstrated cost-saving improvements in care transitions and care quality, resulting in considerable savings on transportation and physicians' time. It also enables remote monitoring, facilitating compliance with rehabilitation care plans and resulting in better throughput of patients in rehabilitation facilities [9].

3.3 Wound Assessment and Management

Remote wound monitoring is also crucial in burn care, enabling real-time monitoring of wound healing without the need for face-to-face consultations [21,22].

Computer vision-based AI apps can evaluate high-quality images to monitor wound parameters, such as size, color changes, or signs of eschar, granulation tissue, or scabbing [2]. It enables objective wound monitoring, facilitating early interventions to treat complications. A wound monitoring AI-based app demonstrated good wound documentation outcomes and showed a positive effect on wound healing in a study. The app also facilitated remote patient monitoring and reduced patient travel [22].

3.4 Patient Education and Support

Telehealth platforms can also give educational content and follow-up care to patients and caregivers [18]. The content can range from wound care and pain management to infection control and psychosocial care. A study of mobile phone features used for self-management showed that informal caregivers were most likely to use mobile apps [23]. Smartphone apps specifically designed to care for burns, such as Telemedicine Optimized Burn Intervention (TOBI), can facilitate safe communication between practitioners and patients through messaging and the transmission of wound images [24].

3.5 Remote Monitoring of Physiological Parameters

The incorporation of remote monitoring devices and wearable sensors enables uninterrupted evaluation of physiological parameters and vital signs [25,26]. It is possible to relay this information to healthcare professionals, allowing the early identification of complications and prompt interventions. The technology is emerging, but its promise of reforming pre-hospital and remote management of burns is tremendous. The process can also be enhanced using machine learning programs, which provide automated interpretation of body signals, making decision-making easier [25].

4. Advantages and Challenges of Telemedicine and Remote Monitoring in Burn Care

Burn injuries are a global health burden that calls for specialized care and resources [27]. The severity of burns is wide-ranging, ranging from trivial superficial burns that require little or no care to full-thickness burns that demand extended hospital stays and advanced reconstructive surgical treatments [28]. Traditional care for burns is primarily face-to-face-based but is highly challenging, especially in remote or underserved areas with limited access to specialized burn facilities [29]. Telemedicine and remote monitoring devices have tremendous potential to enhance burn care delivery, improve care outcomes, and address health inequities [30]. Figure 2 illustrates the principal challenges associated with implementing telemedicine and remote monitoring in burn care. As shown, these hurdles include limitations in accurately assessing wounds remotely, the need for proper training and education of healthcare providers, and the absence of standardized protocols that could guide consistent, high-quality care. Cultural and linguistic barriers, data security and privacy concerns, and infrastructural limitations further complicate widespread adoption. Recognizing and addressing these issues are key steps toward making telemedicine an effective and equitable solution for managing burn injuries.

4.1 Advantages of Telemedicine and Remote Monitoring in Burn Care

4.1.1 Enhanced Accessibility and Reduced Geographic Barriers

Telemedicine significantly improves the availability of specialized care for burns, particularly among remote or underserved populations [29]. The virtual consultation, remote patient monitoring, and immediate advisory function preclude the need for extended travel, thereby lightening the burden on patients' families [31]. It is particularly valuable for individuals with severe burns, which can make travel impossible [32]. Telemedicine also enables practical cooperation and improved communication among caregivers who are far apart, ensuring that the complex care of burns is coordinated [33].

4.1.2 Improved Patient Monitoring and Early Intervention

Remote monitoring enables continuous observation of vital signs, wound healing, and potential complications [34]. Proactive monitoring can identify early complications, enabling early management and potentially avoiding poor outcomes [35]. For instance, remote monitoring can identify signs of infection, dehydration, or hyperthermia, enabling early management and avoiding hospital readmission [36]. Continual monitoring also allows the gathering of valuable information on how well or poorly the patient is responding to therapy, enabling care plans to be adapted accordingly [37].

4.1.3 Cost-Effectiveness and Resource Optimization

Telemedicine can also save money through reduced hospital readmissions, reduced hospital stays, and lower need for costly transportation [30]. By allowing remote follow-up visits, telemedicine reduces the need for face-to-face visits to burn centers, freeing up valuable resources to treat other individuals [38]. Such efficient use of resources can pay off exceptionally well in resource-tight situations [39]. Furthermore, remote monitoring can reduce the frequency of hospital visits, resulting in lower overall healthcare expenses for individuals [35].

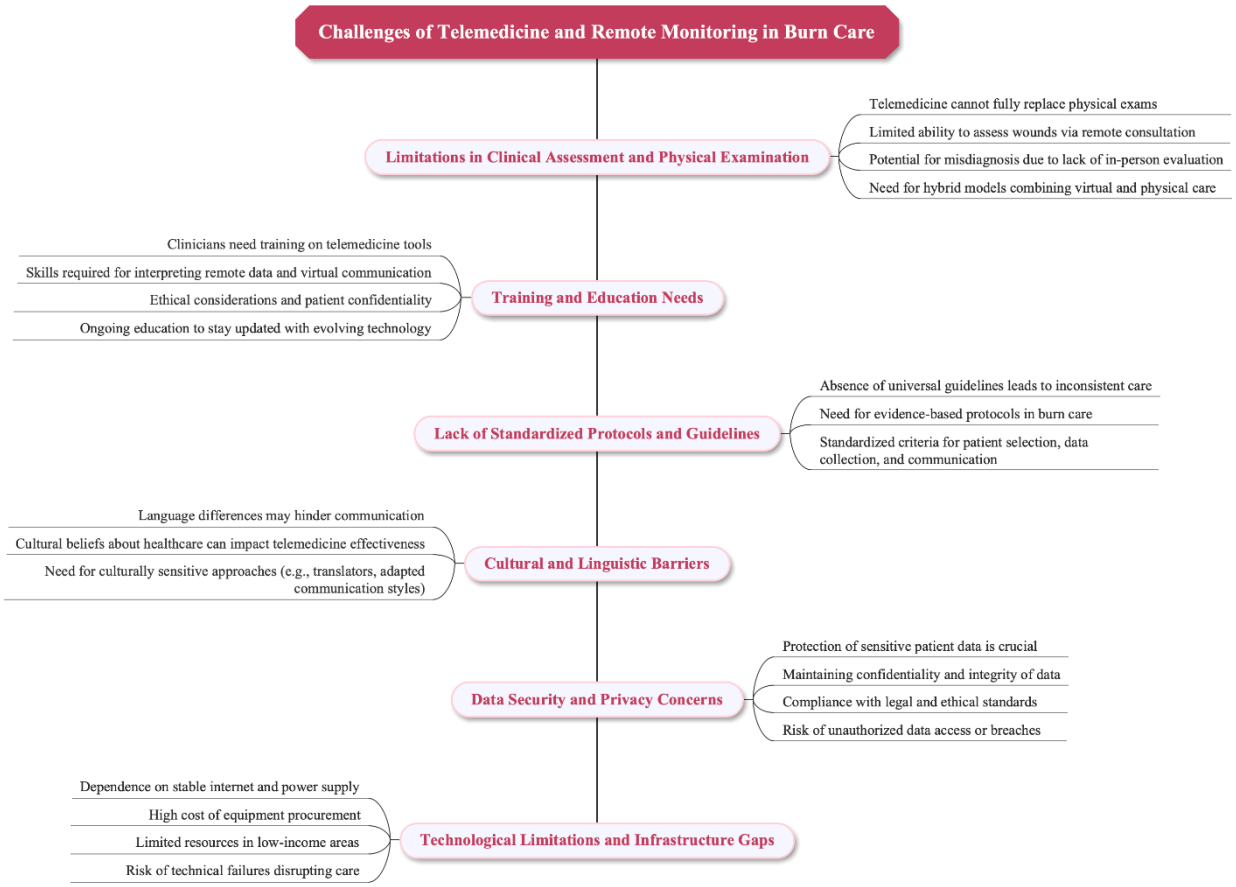

Figure 2. Key Challenges in Telemedicine and Remote Monitoring for Burn Care

4.1.4 Enhanced Patient Engagement and Empowerment

Telemedicine can also improve patient engagement and satisfaction by providing easy access to health professionals [30]. Convenient virtual consultations facilitate effective communication, enabling patients to freely discuss their concerns and receive prompt care [40]. Effective communication can ensure compliance with care plans and lead to better outcomes [35]. Remote monitoring also empowers people by providing greater control of recovery processes [41].

4.2 Challenges of Telemedicine and Remote Monitoring in Burn Care

4.2.1 Technological Limitations and Infrastructure Gaps

The successful operation of remote monitoring and telemedicine also relies on promising technology and suitable infrastructure [29]. The operation of these technologies is problematic in areas with poor internet coverage or unstable power [39]. The cost of procuring suitable equipment is also likely to serve as a limiting factor where there is inadequate resource availability [31]. Technical breakdown is also expected to disrupt service delivery, compromising the safety of care [35].

4.2.2 Data Security and Privacy Concerns

The collection of sensitive patient data through telemedicine interfaces raises issues of data protection and confidentiality [42]. The privacy and integrity of patient data are critical to maintaining patient trust and compliance with applicable laws [43]. The use of adequate protection measures and compliance with protection guidelines are essential in order to minimize risks [41]. The vulnerability of loss of or unauthorized use of data necessitates that caution is taken on protection measures [43].

4.2.3 Limitations in Clinical Assessment and Physical Examination

Telemedicine and remote monitoring can't altogether substitute for face-to-face clinical assessments and physical examinations. While remote monitoring is helpful, it can't convey wound evaluation details, which are best assessed through palpation and visual observation [44]. The inability to have a complete physical exam can undermine the reliability of diagnosis and care planning. The necessity is evidenced by this

flaw to employ a blended mode that combines telemedicine with face-to-face consultation where appropriate [35].

4.2.4 *Lack of Standardized Protocols and Guidelines*

The widespread use of remote monitoring and telemedicine in burn care requires evidence-based protocols and guidelines. Without guidelines, variations in practice are likely to occur, which could compromise safety and care. Evidence-based protocols must be developed to guide the effective use of these technologies in various burn contexts, ensuring their implementation is successful and without adverse consequences. The guidelines must address issues such as patient selection, data collection methods, and communication strategies [45,46].

4.2.5 *Training and Education Needs*

The effective use of remote monitoring and telemedicine also depends on the provision of suitable training and education for health professionals. Clinicians need to have the competency to use technology, interpret data generated by remote monitoring systems, and communicate effectively with patients through virtual interfaces [36]. The programs also need to address issues of best practices and ethics on maintaining confidentiality of data and safety [47]. It is also essential to have access to ongoing professional development to stay current with technological innovations and evolving best practices [40].

4.2.6 *Cultural and Linguistic Barriers*

The effective practice of telemedicine also requires overcoming potential cultural and linguistic barriers. For multicultural populations, differences in language, communication, and health-related beliefs can hinder virtual consultations and remote monitoring. Culturally sensitive measures, such as employing translators or adapting communication methods, are crucial to ensure equitable access to care. Awareness of multicultural perspectives is essential, along with respecting them, to ensure effective practice [48].

5. Current Evidence and Studies on Telemedicine and Remote Monitoring in Burn Care

Studies on telemedicine and remote monitoring in burn care have been on the rise over the last decade. Various observational studies, pilot trials, and systematic reviews indicate both the applicability and benefits of telemedicine and remote monitoring. However, inconsistencies in study design, patient populations, and platforms have raised some limitations in drawing conclusions that can be applied to all [18,19,30].

5.1 *Systematic Reviews and Meta-Analyses*

Several systematic reviews have demonstrated that telemedicine and remote monitoring platforms are cost-reducing, enhance care continuity, and enable early identification of complications [6,8,19]. Teleconsultations and mobile health-based apps have been found to have high patient satisfaction rates on most occasions, associated with reduced travel time and healthcare expenses [11,18].

Rehabilitation interventions that utilize video-based follow-ups combined with AI-based wound assessment have also been found to have high patient compliance and convenience [9,22].

5.2 *Clinical Outcomes and Cost Savings*

Clinical endpoint research on various endpoints, including inpatient wound healing times, infection rates, and hospital readmission rates, has shown that telemedicine facilitates more timely detection of complications (e.g., infections or prolonged wound healing) [35,36].

Early intervention initiated by telemonitoring is correlated with reduced rates of unplanned hospital revisits and potentially reduced rates of morbidity [9,19]. Cost-effectiveness studies, although limited, indicate considerable savings for patients as well as healthcare organizations through reduced in-person follow-ups and lower transport costs [4,8].

5.3 *User Satisfaction and Acceptance*

Patient satisfaction and that of providers remain important markers for telehealth success in burn care. Some studies indicate that patients value telemedicine for its convenience, enhanced access to specialists in minutes, and constant communication [10,30].

Clinician satisfaction, on the other hand, can depend on the easy incorporation of remote patient data into existing processes, system platform reliability, as well as medicolegal concerns [10,38]. To sustain high levels of acceptance, strong clinician training courses and access to user-friendly telehealth tools will be necessary [40,47].

5.4 *Evidence Gaps and Limitations*

Despite encouraging results, crucial gaps remain. Some studies are based on small sample sizes, short follow-up periods, or the absence of control groups, which limits their validity for comparative purposes. Standardized outcome measures are also lacking, with discrepancies in descriptions of wound healing, pain management, and recovery to function [8,18]. Further, research is infrequently designed to address cultural flexibility, data privacy, and security across regions [12,41]. These limitations underscore the need for further high-volume, high-grade research to confirm evidence-based practice.

6. Future Perspectives and Research Directions

Telemedicine and remote monitoring have enormous potential to improve burn care; however, there are still areas that require growth and refinement. Overcoming obstacles in technology, evidence-based practices, and regulation will be key to maximizing their effectiveness and ensuring everyone has equal access.

6.1 *Integration of Advanced Technologies*

Emergent new developments in artificial intelligence (AI), machine learning (ML), and computer vision are reframing clinicians' guidelines for wound assessment. These techniques can now better recognize early warning signs of infection, in addition to forecasting complications [21,25]. Conversely, developments in wearables, biosensors, and real-time analytics are opening doors to new paths for more individualized, anticipatory care for burns. No less valuable are innovations in uniform imaging protocols and seamless telehealth systems, which offer tools to enhance communication and coordination among care teams across disciplines [13,18].

6.2 *Development of Robust Telemedicine Protocols*

The advancement of consensus-driven, evidence-based guidelines is crucial for facilitating the broader implementation of telemedicine in burn care. These protocols should outline the selection criteria for telemedicine suitability, recommended follow-up intervals, and standardized methods for data collection and wound assessment [45,46]. Clear frameworks for privacy and data security, as well as legal liability, are equally crucial for earning the trust of both patients and providers [42,43].

6.3 *Health Policy and Funding*

Support from institutions and governments, in the form of targeted funds and policy reforms, can drive the expansion of telemedicine, particularly in low-resource settings. Subsidizing telehealth care, investing in high-speed connectivity, and incentivizing adoption by health providers can bridge location gaps for more equitable delivery of care [29,39]. Policies must also foster cross-border partnerships to transfer telemedicine advancements and best practices globally [2,4].

6.4 *Ongoing Education and Training*

Extensive training for clinicians, specialists in burns care, and allied professionals will maximize the use of remote monitoring technologies. Ongoing professional learning, telemedicine certifications, and modular curriculum units can standardize knowledge and competencies in the digital healthcare field [36,47]. Training for patient and caregiver education in the safe use of telehealth systems is also crucial for ongoing use and compliance [23,41].

6.5 *Expanded Research and Validation*

Large-scale, prospective trials with standardized measures of burn severity, wound healing progression, and patient satisfaction should receive high priority in future studies. Comparative trials involving telemedicine-based care compared to usual in-person care could further improve evidence for cost-effectiveness and outcome benefits [5,18]. Qualitative studies that address the cultural, ethical, and psychosocial aspects of telehealth can inform patient-centered intervention design [35,48].

7. Conclusion

Bridging geographic divides, optimizing resource allocation, and patient-centered care, telemedicine, and remote monitoring can potentially revolutionize burn care delivery. Evidence presented to date highlights vast advantages from cost reduction to better outcomes, but still points to areas for development, including data security, technology infrastructure, and uniform standards. In the future, greater collaboration among clinicians, researchers, and policymakers will play a crucial role in scaling such innovations for broader reach, especially in underserved communities. Through high-capacity telehealth platforms, AI-based wound examination, and continued professional development, advancements in the specialty can lead to high-quality, accessible burns care for all. Ultimately, the success of telemedicine in treating burns will depend on a delicate balance between medical expertise, patient engagement, technology, and supportive regulatory systems.

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Authors' contributions

S YK: Conceptualization of the review, primary drafting of the manuscript, and coordination of revisions. S KM: Contributed to the design and structure of the review, critical revision of content, and interpretation of data from literature sources. M S and P BT: Assisted with literature search, data collection, and initial drafting of sections related to biomaterials and their applications. F M: Provided input on the technical aspects of wound dressings, assisted in analyzing data, and contributed to manuscript editing. M M and P A: Involved in drafting and revising the manuscript, with a focus on the biomedical engineering aspects, and provided critical feedback on the review's final version. All authors read and approved the final version of the manuscript.

Conflict of interest

No potential conflict of interest was reported by the authors.

Ethical declarations

Not applicable.

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