# ORIGINAL RESEARCH ARTICLES

# Features of Telerehabilitation and Considerations for Resource-Limited Settings: A Scoping Review

Emily Kelly[1], Jamie L. Tingey[2] C Jessica Ott,[3], Helena Hahn[4,5], Jacob A. Bentley[6], Stephen T. Wegener[4,7], Zehra Zaidi[4], Nukhba Zia[4] Abdulgafoor M. Bachani[4]*

1 Department of Clinical Psychology, Seattle Pacific University, Seattle, WA
2 Department of Psychiatry and Behavioral Sciences, Division of Sleep Medicine, Stanford University, CA, USA
3 AAAS Science & Technology Policy Fellow
4 Department of International Health, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD
5 Department of Electrical and Computer Engineering, Whiting School of Engineering, Johns Hopkins University, Baltimore, MD
6 Department of Rehabilitation Medicine, University of Washington School of Medicine, Seattle, WA, USA
7 Department of Physical Medicine and Rehabilitation, Johns Hopkins School of Medicine, Baltimore, MD

## *ABSTRACT*

***Aim**: The global need for rehabilitation is extensive yet remains significantly unmet. Health systems, especially in low- and middle-income countries (LMICs), lack structures and resources to address the rapidly growing need for rehabilitation services. Telerehabilitation offers an innovative approach to narrow health systems gaps and facilitate rehabilitation services. Few studies have investigated features and functionalities used in telerehabilitation, especially regarding implications for resource-limited settings and LMICs. This scoping review aims to identify technological features and functionalities used to deliver telerehabilitation, map them onto clinical care processes, and outline gaps and directions for future research, especially regarding considerations for resource-limited settings.*

***Methods**: This study utilized the PRISMA- checklist. Six databases were searched (PubMed, Embase, Scopus, CINAHL, Compendex, NARIC) to identify articles that described the remote delivery of rehabilitation services. Three reviewers screened and selected relevant publications. Descriptive statistics and qualitative content analysis were used to analyze full-text articles. **Results**: 135 articles were included in the full-text review. The publication year ranged from 1997 to 2021. The most frequently identified telerehabilitation feature was*

* **Corresponding Author:** A M Bachani, Johns Hopkins International Injury Research Unit, Health Systems Program, Department of International Health, Johns Hopkins Bloomberg School of Public Health, 615 N. Wolfe Street, Suite E-8146, Baltimore, MD 21205, USA. E-mail: abachani@jhu.edu

*"data collection," followed by "videoconferencing," and "messaging." Features mapped onto six clinical categories, with "implementation" accounting for 41% of all features, Only 18% of articles focused on LMICs. Few papers included a comprehensive platform of features, discussed integration into health systems, or included financial analyses.*

***Conclusions**: Diverse technological tools exist for the remote delivery of rehabilitation services, but few cohesive platforms offer features across multiple clinical categories. Additionally, high income countries are overwhelmingly represented in the literature. Future directions for research include expanded focus on resource-limited settings and LMICS, discussion about financial considerations, and attention to health systems integration. **Limitations**: The generalizability of our findings are limited given the rapid growth of literature on telerehabilitation and continued development of apps and platforms since the time of review.*

***Keywords:** Rehabilitation, low-and middle-income countries (LMICs), telehealth, disability, health systems integration*

## INTRODUCTION

As the world's population ages and prevalence of chronic health conditions grows, there has been a rapid increase in the number of people experiencing disability or functional changes who need rehabilitation services. Extending beyond curative care, rehabilitation encompasses interventions to optimize functioning and reduce the experience of disability in individuals with health conditions in their interactions with their environment (World Health Organization [WHO], 2023). Rehabilitation is broad in its scope and presents as a uniquely relevant service for diverse health conditions, impairments, and ages across the lifespan (Cieza, 2019). Though identified as a global public health goal (Heinemann et al., 2020), the need for rehabilitation greatly surpasses its availability, with global estimates of 2.4 billion people who would benefit from rehabilitation services (Institute for Health Metrics and Evaluation, n.d.).

Health systems lack structures and resources to address this growing need, particularly in resource-limited settings and low- and middle-income countries (LMICs). Populations in LMICs are disproportionately affected by unmet rehabilitation needs. Seventy-seven percent of global physical rehabilitation needs are in LMICs (Jesus et al., 2019) but only 3% of people in LMICs receive

needed rehabilitation services (Khan et al., 2018). Clinical leaders, health planners, and patients in LMICs have been found to have a poor understanding of the nature of rehabilitation (Khan et al., 2018). With limited awareness of its potential for far-reaching health, social, and economic benefits to both individuals and systems, service planning for rehabilitation delivery is undervalued and often deprioritized by governments (Bernhardt et al., 2020). Where rehabilitation does exist, services are often delayed, fragmented, poor in quality, insufficiently covered, and separated from mainstream healthcare delivery (Naicker et al., 2019). Moreover, a lack of trained rehabilitation providers across care levels (e.g., primary and community) renders rehabilitation inaccessible to many individuals who would otherwise benefit from services (Iemmi et al., 2015) .

Telerehabilitation has been defined as "the provision of rehabilitation services at a distance using telecommunications technology as the delivery medium" (Russell, 2007). The number of publications referencing telerehabilitation has increased exponentially in recent years (Zheng et al., 2022), corresponding with advances in telecommunications technology. As a field, telerehabilitation is still emerging, having been broadly introduced in 1997 within a set of proposed priorities for new Rehabilitation Engineering Research Centers outlined by the National Institute on Disability and Rehabilitation Research in the U.S. Department of Education (1998). The funding priority for telerehabilitation was driven in part by shorter hospital stays and a subsequent need for innovative ways to continue rehabilitative care outside of acute care facilities, especially for those living in rural or remote settings. Winters (2002) outlined a conceptual framework for telerehabilitation service delivery that was extended by Parmanto and Saptono (2009) and which includes four models of teleconsultation, telemonitoring, telehomecare, and teletherapy that can be mapped along four quadrants defined by axes of service delivery intensity (i.e., volume of information exchanged) and duration. Consideration for intensity of information exchange and duration of clinical care can inform selection of optimal technological approaches for telerehabilitation service delivery. Recent technological advances and the COVID-19 pandemic have led to an upsurge in telerehabilitation adoption and innovation (Matsumoto et al., 2021), representing an unprecedented opportunity for growth within the field.

Telerehabilitation offers an innovative approach to narrow health systems gaps by relying on information and communications technologies to provide rehabilitation services across the care continuum. Telerehabilitation has the

potential to enhance access to rehabilitation services and increase the quality of care by reducing geographic and mobility barriers, decreasing the cost of care via increased time efficiencies and centralization of client data, and customizing services via intervention in the client's home environment. Effective integration of telerehabilitation requires an understanding of technological requirements and user needs and preferences. As remote and technology-based delivery of health services has become more common (Giacalone et al., 2022; Uscher-Pines et al., 2020), there have been corresponding increases in research on implementation and outcomes. Relatively few studies, however, have investigated emerging information and communication technologies in the specific context of telerehabilitation. Moreover, to the best of our knowledge, no studies have synthesized evidence on this topic with respect to implications for resource-limited settings and LMICs.

## Objective

The purpose of this scoping review is to systematically document telerehabilitation features and functionalities (e.g., software design architecture, user interface, delivery modalities) that have been tested or used to deliver rehabilitation through some form of technology, with particular attention to features that are appropriate for implementation in resource-limited settings and LMICs. We also aim to summarize key telerehabilitation features, categorize them in relation to clinical care processes, and describe gaps and deficiencies in existing features.

# METHODS

A scoping review of the literature on telerehabilitation features and functionalities was conducted using the methodological framework outlined by Arksey and O'Malley (2005) and in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR; Tricco et al., 2018). The breadth of our purpose and aims are suitable for analysis via a scoping review.

### Stage 1: Identify the Research Question

The primary research question of interest was: *what features and functionalities have been developed and/or tested for the delivery of telerehabilitation services?* Within the context of this review, we use the phrase "features and functionalities" (hereafter referred to simply as "features") to refer to the range of tasks and services

enabled via the use of information and communications technologies. The results of the scoping review will additionally inform the creation of a telerehabilitation application specifically designed for use within LMICs, which is currently in development. Given our overarching focus of this research, we were interested in the following sub-questions:

1. What features have been tested and implemented in LMICs?
2. How do the existing telerehabilitation features integrate with and map onto healthcare delivery processes and services?
3. What is known about the economic costs of implementation and long-term sustainability of telerehabilitation service delivery technologies?

**Stage 2: Identify the Relevant Studies**

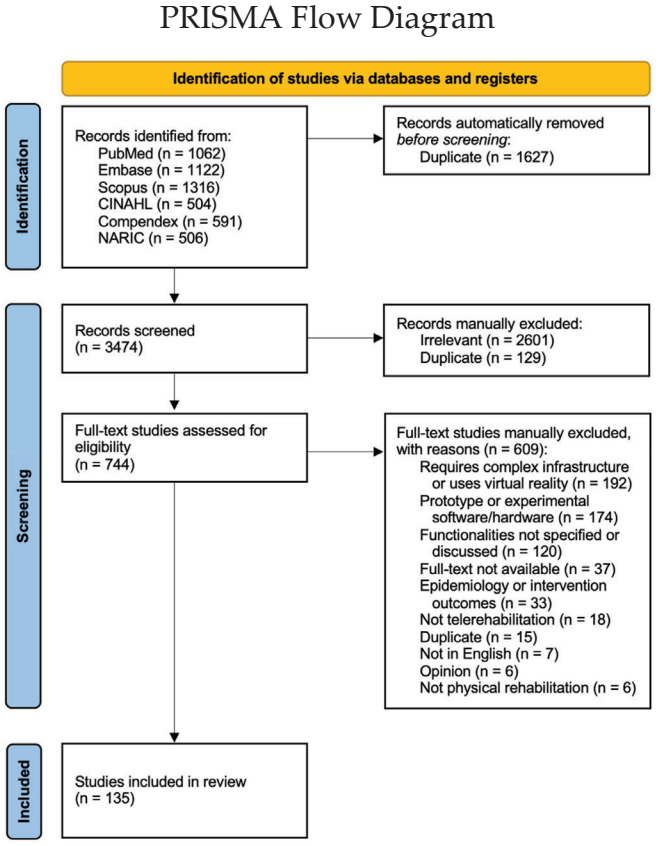
Our review included full-text articles in peer-reviewed and gray literature published any time up until the literature search was concluded in October of 2021. We included articles that described the provision of rehabilitation through telehealth or telemedicine services, as part of an overall telehealth or standalone telerehabilitation service. All types of rehabilitation services (physical, sensory, mental health) were included across all conditions, age groups, and genders. To capture the full breadth of features, any study design was included without any geographic restrictions. Articles were excluded if there was no full-text available in English, if the focus was on intervention outcomes without description of features, or if the service provision was exclusively in-person. With the assistance of a librarian, we searched for articles in the PubMed, Embase, Scopus, CINAHL, Compendex, and NARIC databases. For example, search terms used to search the PubMed database were: ("Telerehabilitation"[Mesh] OR telerehabilitat*[tiab] OR tele-rehabilitat*[tiab] OR "e-rehabilitat*"[tiab] OR "remote rehabilitat*"[tiab] OR "virtual rehabilitat*"[tiab]) AND ("Technology"[Mesh] OR "Software"[Mesh] OR technolog*[tiab] OR application*[tiab] OR platform*[tiab] OR feature*[tiab] OR functionalit*[tiab] OR "virtual reality"[tiab] OR software*[tiab]).

**Stage 3: Literature Selection**

With the assistance of a librarian, all publications were imported into Covidence, a web-based collaboration software platform that streamlines the production of systematic and other literature reviews. Initial screening for exact duplicates excluded 129 articles. The remaining abstracts were independently reviewed by

three of the authors (EK, JT, and HH). These three authors met regularly with another author (NZ) during the screening process to ensure standardization of approach; group discussion and consensus were used when it was unclear if a publication met inclusion or exclusion criteria. At the full-text review phase, a consensus decision was made to exclude articles that exclusively described features requiring difficult to access (e.g., limited production of proprietary movement sensors) or virtual reality technologies; articles were included if they incorporated additional features. This decision was made to better manage the full-text review process, while minimizing data loss. Review of abstracts excluded 2,601 publications that did not meet inclusion criteria. Full-text review was completed by the same three authors, after which an additional 609 studies were excluded, leaving 135 publications that met criteria for data extraction. Figure 1 depicts the PRISMA flow diagram for this review.

**Figure 1**



### Stage 4: Charting the Data

A literature extraction tool was created using Microsoft Excel. Extracted data included title, author(s), publication/journal, year of publication, study design, research objective, hardware and software requirements, features, condition (i.e., rehabilitation treatment target), age (i.e., age for intervention target), geographic location (grouped into WHO regions), and income level of geographic context. Reviewers also provided a subjective relevance rating to identify publications that included rich details about multiple features, especially those that included more than simply audio- or videoconferencing capabilities, or which described comprehensive telerehabilitation platforms. One reviewer (EK) read 10-15 articles and created a preliminary list of features. All reviewers then met to review the list and agree on common terminology. The features list was iteratively refined throughout the full-text review and all reviewers met regularly to ensure common understanding of feature definitions. Since one of our aims was to map features onto healthcare delivery processes and services, the features were grouped into categories (listed in Table 1) by steps of the nursing process (American Nurses Association, 2021) and one extra "administrative" category. This categorization system was selected based on its succinct grouping of healthcare delivery processes, which were deemed broad enough to apply across the various healthcare disciplines involved in telerehabilitation.

### Stage 5: Collating, Summarizing, and Reporting the Results

Following review of all full-text articles, the collected data was summarized by frequency of occurrence. One article could describe multiple features, which were coded separately, therefore one article could contribute to frequencies across multiple features. Frequencies were analyzed to identify emerging trends and overall themes.

**Table 1**

Telerehabilitation Features Organized by Case Management Category

| Category | % | Feature | Includes | All | | LMICs | |
|---|---|---|---|---|---|---|---|
| | | | | *n* | % | *n* | % |
| Assessment | 25 | Data collection | Remote collection and storage of electronically collected patient information (ROM, pulse rate, time and date of intervention, etc.), electronic storage and transmission of patient progress on treatment (captured via technology) | 72 | 11 | 9 | 7 |
| | | Motion tracking | Gesture recognition, wearable sensors, gait/limb tracking | 20 | 3 | 4 | 3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | ePRO or ePROM (electronic patient reported outcomes/measures) | Self-reported patient data (e.g., completion of exercises, subjective rating of pain/fatigue/ strength) without clinical interpretation | 38 | 6 | 8 | 7 |
| | | Environment Modeling* | 3D modeling of home environment for adaptation assessment; home assessments via videoconferencing (e.g., for safety evaluations) | 4 | 1 | 1 | 1 |
| | | Video recording | Patient recording exercise performance | 9 | 1 | 1 | 1 |
| | | Video transmission | Electronic transmission of recorded videos (e.g., store and forward) | 22 | 3 | 4 | 3 |
| Diagnosis | 8 | Report/statistics generation | Treatment algorithms based on patient data, automatic reports of patient progress | 26 | 4 | 4 | 3 |
| | | Rehab database | Library of preset therapeutic regimens for specified conditions, evidence-based treatment guidelines | 17 | 3 | 6 | 5 |
| | | Video review* | Provider review of patient-uploaded videos | 5 | 1 | 0 | 0 |
| Plan | 18 | Plan of care management | Provider orders, rehabilitation care plan, treatment planning, patient demographic data | 53 | 8 | 9 | 7 |
| | | Patient instructions | Specific treatment, exercise, or rehabilitation instructions (written/ video recorded) | 41 | 6 | 7 | 6 |
| | | Decision Support | Software algorithms offering insight to providers based on evidence and/or client data; consultation with other providers for treatment decisions (e.g., specialty providers) | 9 | 1 | 2 | 2 |
| | | Scheduling | Appointment, meeting, or task scheduling | 21 | 3 | 5 | 4 |
| Implement | 40 | Audioconferencing | Analog telephone/mobile phone calls | 27 | 4 | 7 | 6 |
| | | Videoconferencing | Synchronous video calling with audio (e.g., Skype, Facetime, Facebook calling) | 63 | 9 | 9 | 7 |
| | | Patient education | General health education, written/video resources, synchronous classes/sessions | 41 | 6 | 4 | 3 |
| | | Synchronous TR (telerehabilitation) | Real-time videoconferencing with provider and patient doing rehab exercises/therapy | 36 | 5 | 7 | 6 |
| | | Support group(s) | | 14 | 2 | 2 | 2 |
| | | Referral mechanisms* | Provider-to-provider referrals | 1 | 0 | 0 | 0 |
| | | Serious games | Therapeutic exercises in a gaming framework | 22 | 3 | 4 | 3 |
| | | Remote operation | Remote operation of assistive technologies | 3 | 0 | 0 | 0 |
| | | Self-management | Software or hardware specifically designed to assist patients with unsupervised self-management, or tracking tools that can be used to share information with providers | 11 | 2 | 0 | 0 |
| | | Messaging | a/synchronous chatting, emails, provider-patient, provider-provider | 58 | 9 | 13 | 11 |
| Evaluation | 3 | Note recording | Provider documentation | 6 | 1 | 2 | 2 |
| | | Real-time (RT) feedback | Real-time feedback to the patient regarding technique or progress during exercise or activity (via automated visual, auditory, or haptic modalities) | 11 | 2 | 1 | 1 |
| Administrative Tools | 6 | Search tool | | 8 | 1 | 4 | 3 |
| | | User management | Administrative management of personas/ permissions, password/code management | 21 | 3 | 6 | 5 |
| | | Confidentiality/security | | 14 | 2 | 2 | 2 |
| | | Payment for services* | | 1 | 0 | 0 | 0 |
| Total | 100 | | | 674 | 100 | 121 | 100 |

*Note.* * = feature not mentioned in any highly relevant publication

## RESULTS

The initial search yielded 3,474 records of which 135 publications underwent full-text review. Selected characteristics of the included publications are listed in Table 2. The year of publication spanned from 1997 to 2021 with the majority (52%) published in 2018 or later (shown in Figure 2). There was wide variation in publication type (including conference proceedings, open-access peer-reviewed publications, and traditional peer-reviewed publications) owing in large part to the inclusion of technical papers describing the on-going development of hardware and software platforms. The largest percentage of articles were published in conferences and journals through the Institute of Electrical and Electronics Engineers (IEEE) ($n$ = 25, 19%), followed by JMIR journals ($n$ = 10; 7%), the International Journal of Telerehabilitation ($n$ = 8; 6%), and Telemedicine and e-Health ($n$ = 8; 6%). Commonly reported hardware and software components are listed in Table 3. All full-text publications included in the review are listed in the supplementary material. The remaining results will be reviewed in order of our research questions.

**Table 2**

Selected Characteristics of Full-Text Publications Included in the Scoping Review

| | *n* | % |
|---|---|---|
| Study Design | | |
| Randomized Controlled Trial (RCT) | 2 | 1.5% |
| Proposed Design | 9 | 6.7% |
| Case Study | 10 | 7.4% |
| Other | 14 | 10.4% |
| Review | 30 | 22.2% |
| Pilot | 31 | 23.0% |
| Descriptive Overview | 39 | 28.9% |
| Condition Category | | |
| Mental disorders | 3 | 2% |
| Chronic respiratory diseases | 3 | 2% |
| Sensory impairments | 4 | 3% |
| Neoplasms | 5 | 4% |
| Cardiovascular diseases | 8 | 6% |
| Musculoskeletal disorders | 20 | 15% |
| Neurological disorders | 46 | 34% |
| Rehabilitation in general | 46 | 34% |

*Note*. Total $n$ = 135

**Figure 2**

Year of Publication of Articles Included in the Scoping Review

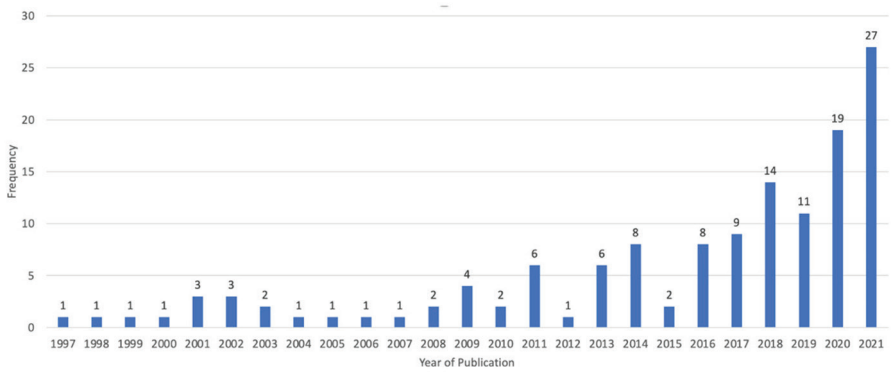



**Table 3**

Commonly Reported Telerehabilitation Hardware and Software Components

| | Hardware | Software |
|---|---|---|
| Components | ▪ Computer or laptop<br>▪ Smartphones (iOS and Android)<br>▪ Mobile devices (e.g., tablets)<br>▪ Wearable sensors (e.g., Fitbit, Apple Watch, heart rate monitoring device)<br>▪ Motion tracking devices (e.g., Microsoft Kinect, Nintendo Wii)<br>▪ Camera or webcam<br>▪ Microphone<br>▪ Speaker or headphones<br>▪ Internet access equipment (e.g., router)<br>▪ Plug-in accessory devices (e.g., joystick, mouse, keyboard)<br>▪ Database server<br>▪ Inertial sensors (in a smartphone and in a standalone device)<br>▪ Telephone<br>▪ Videoconferencing systems<br>▪ Video projector<br>▪ Biometric sensors | ▪ Audio- and videoconferencing (e.g., Skype, WhatsApp, Zoom, TeamViewer, GoToMeeting, Viber, Greenlight)<br>▪ Email and messaging applications (e.g., WhatsApp)<br>▪ Internet and data sharing applications (e.g., 4G, LTE, Bluetooth)<br>▪ Social media applications<br>▪ Computer sharing (e.g., remote desktop control)<br>▪ Cloud computing and database management<br>▪ Website/software/application creation and management tools (e.g., Apache, Java, Microsoft Visual Studio, .NET)<br>▪ Digital telehealth platforms (e.g., Doxy.me, thera-LINK, TheraNest, Zoom, SimplePractice, Vsee, GoToMeeting, UpDox, eVisit, VA Video Connect)<br>▪ Comprehensive computer and web-based telerehabilitation programs (e.g., VISYTER [Versatile and Integrated System for Telerehabilitation])<br>▪ Motion tracking software (e.g., Leap Motion) |

## Features

Our primary research question aimed to generate a list of features that have been developed and/or tested for the delivery of telerehabilitation services. A total of 29 separate features were identified and categorized, as listed in Table 1. Across all years, the most frequently mentioned feature was data collection, followed by videoconferencing, messaging, plan of care management, and patient education. When considering only publications from the past five years (2017-2022; $n$ = 80), the same five features had the highest frequencies with only slight changes in rank order and with data collection remaining the most frequently mentioned feature. On the other hand, when examining studies across the first ten years of data collection (1997-2006; n = 50) videoconferencing and audioconferencing were the two most frequently mentioned features and accounted for 36% of all feature mentions. Similarly, 12 of the features (including report/statistics generation, decision support, and confidentiality/security), weren't mentioned at all until after 2006. As noted in the methods, reviewers provided subjective relevance ratings based on alignment with study objectives. Highly relevant articles provided rich and substantive descriptions of features and had to include at least three features. Studies that were subjectively rated as highly relevant ($n$ = 26) spanned the years 2009-2021 and 69% of them were published after 2015. Highly relevant publications that were not a review paper ($n$ = 21) mentioned an average of 7 features (ranging from 4-12), and across all 26 publications only 4 of the 29 total features were not mentioned. Features and selected characteristics of highly relevant publications are listed in Table 4.

**Table 4**

Selected Characteristics of Highly Relevant Articles Included in the Scoping Review

| Authors | Year | Features | Condition | WHO Region | Income level |
|---|---|---|---|---|---|
| Anton et al. | 2018 | Plan of care management, Report/statistics generation, Scheduling, Patient instructions, Videoconferencing, Motion tracking, ePROMS | Musculoskeletal disorders | Multiple Regions | High Income Countries |
| Bacungan et al. | 2021 | User management, Plan of care management, Note recording, Messaging, Patient instructions, Confidentiality/security, Scheduling | Cardiovascular diseases | Western Pacific Region | LMIC |
| Caggianese et al. | 2019 | Motion tracking, Plan of care management, Report/statistics generation, Serious games | Neurological disorders | European Region | High Income Country |
| Chamorro-R et al. | 2018 | User management, Search tool, Messaging, Plan of care Management, Report/statistics generation, Synchronous TR | Musculoskeletal disorders | Region of the Americas | LMIC |
| Chiensriwimol et al. | 2017 | User management, Search tool, Plan of care management, Serious games, Data collection, Report/statistics management | Musculoskeletal disorders | Not specified | Not specified/ applicable |
| Finkelstein et al. | 2011 | Data collection, ePRO, Plan of care management, Patient instructions, Report/statistics generation, Patient education, Video transmission | Neurological disorders | Region of the Americas | High Income Country |
| Hosseiniravandi et al. | 2020 | Synchronous TR, messaging, Plan of care management, Scheduling, Videoconferencing, Report/statistics generation | Rehabilitation in general | Not specified | Not specified/ applicable |
| Houlihan et al. | 2011 | Data collection, patient instructions, Scheduling, Report/statistics generation, Audioconferencing | Neurological disorders | Region of the Americas | High Income Country |
| Jameie et al. | 2019 | Data collection, ePRO, Report/statistics generation, Plan of care management, Patient education, Messaging, | Cardiovascular diseases | Not specified | Not specified/ applicable |
| Kim et al. | 2012 | Fata collection, ePRO, Report/statistics generation, Search tool, Videoconferencing | Rehabilitation in general | Region of the Americas | High Income Country |
| Korostelev et al. | 2014 | User management, Confidentiality/security, Data collection, Messaging, Plan of care management | Neoplasms | Region of the Americas | High Income Country |
| Kringle et al. | 2020 | Data collection, Plan of care management, Patient instructions, Patient education, Messaging | Neurological disorders | Region of the Americas | High Income Country |
| Ku et al. | 2021 | Data collection, Video transmission, Plan of care management, Patient instructions, Scheduling, User management | Rehabilitation in general | Western Pacific Region | High Income Country |
| Landers & Ellis | 2020 | Data collection, ePROM, Report/statistics generation, Video transmission, Patient instructions, Motion tracking | Neurological disorders | Region of the Americas | High Income Country |

| | | | | | |
|---|---|---|---|---|---|
| MacKo et al. | 2016 | Rehab database, Patient education, Video recording, Video transmission, Plan of care management | Neurological disorders | Region of the Americas | LMIC |
| Marziniak et al. | 2018 | Plan of care management, Scheduling, Videoconferencing, Patient education, Data collection, ePRO, Report/statistics generation, Decision support, Delf-management, Motion tracking, Patient instruction, Derious games, Synchronous TR, Support group | Neurological disorders | Multiple Regions | Not specified/ applicable |
| Moral-Munoz et al. | 2021 | Data collection, Serious games, Report/statistics generation, Patient instructions, Patient education, Messaging, Self-management, RT feedback | Rehabilitation in general | Not specified | Not specified/ applicable |
| Parmanto & Saptono | 2009 | Videoconferencing, Decision support, Synchronous TR, RT feedback, Environment modeling, Support groups, Patient education, Data collection, Messaging, Serious games, Video recording, Video transmission, Self-management, Confidentiality/ security, | Rehabilitation in general | Not specified | Not specified/ applicable |
| Parmanto et al. | 2010 | Data collection, Videoconferencing, RT feedback, Synchronous TR, Scheduling, Plan of care, Decision support, Motion tracking, Audioconferencing, ePRO, Messaging, Confidentiality/security, User management | Rehabilitation in general | Region of the Americas | High & Low Income |
| Perez-Medina et al. | 2019 | Self-management, Patient instructions, ePRO, Data collection, RT feedback, Serious games, Messaging, Plan of care management | Musculoskeletal disorders | Not specified | Not specified/ applicable |
| Rawstorn et al. | 2016 | Synchronous TR, Patient education, Patient instructions, RT feedback, ePRO, Data collection, Messaging, Plan of care management, Self-management, Report/statistics generation, Support groups, Confidentiality/security | Cardiovascular diseases | Western Pacific Region | High Income Country |
| Rosso et al. | 2018 | Plan of care management, Videoconferencing, User management, Search tool, Messaging, Data collection, Rehab database, Decision support | Neurological disorders | European Region | High Income Country |
| Solana et al. | 2015 | Decision support, Plan of care management, Patient instructions, Data collection, Report/statistics generation, Confidentiality/ security, Note recording, Videoconferencing, Messaging, Support groups, Scheduling | Neurological disorders | European Region | High Income Country |
| Tsavourelou et al. | 2016 | Synchronous TR, Data collection, Patient instructions, Patient education, RT feedback, Motion tracking, Remote operation, Videoconferencing, Audioconferencing, User management, Confidentiality/security | Rehabilitation in general | European Region | High Income Country |
| Yue et al. | 2013 | User management, Plan of care management, Search tool, Report/ statistics generation, ePRO, Patient instructions, Messaging, Scheduling, Rehab database | Neurological disorders | Western Pacific Region | LMIC |
| Zyliski et al. | 2020 | Videoconferencing, Scheduling, Plan of care management, Motion tracking, ePRO, Data collection | Neurological disorders | European Region | High Income Country |

## Geographic Distribution

The first of our research sub-questions aimed to generate a list of features that have been used in LMICs. Geographic location and income level were extracted from full-text publications and are illustrated in Figures 3 and 4. High income countries are overwhelmingly represented in the literature, as is research focused on the Region of the Americas and the European Region. Overall, LMICs were only represented in 24 (18%) of the publications. Given the high concentration of LMICs in the African and South-East Asia Regions, it is noteworthy that only 3% of all publications referenced these regions specifically. Moreover, 17% and 22% of publications, respectively, did not include any reference to geographic location or income level. Features included in articles representing LMICs are listed in Table 1. The most frequently mentioned feature was messaging ($n$ = 13), followed by data collection ($n$ = 9), plan of care management ($n$ = 9), and videoconferencing ($n$ = 9). Of all 29 features, only five were not mentioned in articles representing LMICs.

**Figure 3**

Distribution of Geographic Location of Full-Text publications by WHO Region

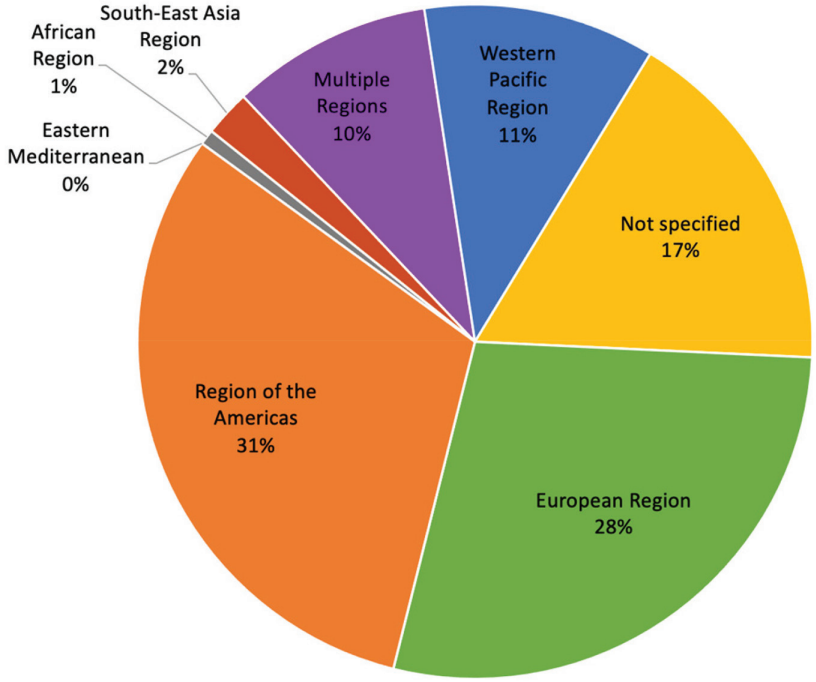
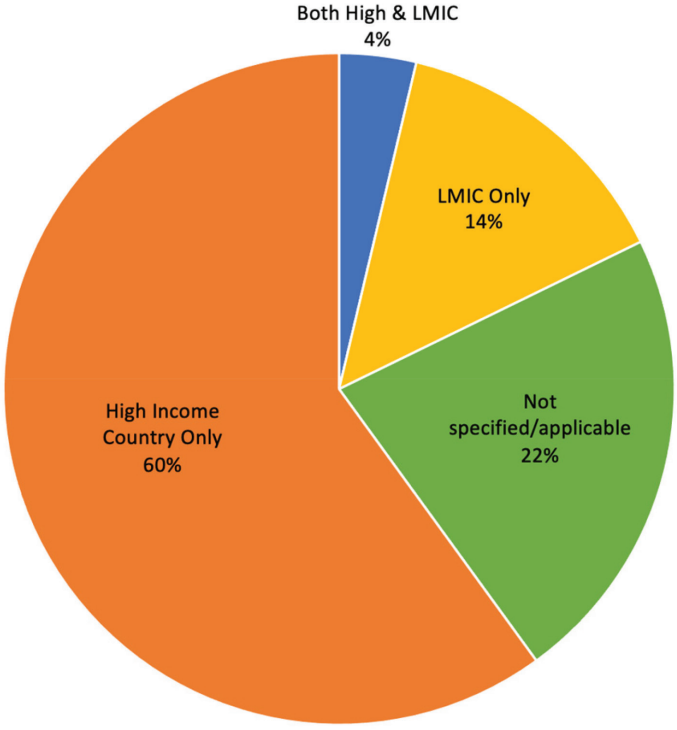


**Figure 4**

Distribution of Income Level Based on Geographic Location of Full-Text Publications




## Features by Case Management Category

Our second research sub-question aimed to map telerehabilitation features onto healthcare delivery processes and services. We similarly noted publications that described features integration into healthcare systems. All identified features were grouped into case management categories, as described previously, and outlined in Table 1. The most frequently mentioned features overall were those within the "Implementation" category, followed by the "Assessment" category. Few papers introduced a single telerehabilitation platform or application with features spanning multiple clinical categories, though there were several notable exceptions. Only 34 (25%) publications described six or more features as part of one system or platform (e.g., Anton et al., 2018; Parmanto et al., 2010; Rawstorn et al., 2016; Ruiz-Ruano et al., 2013). Anton and coauthors (2018) described the development of a comprehensive platform (Kinect-based Telerehabilitation System [KiReS]) designed to provide telerehabilitation services to people with

musculoskeletal disorders, which was tested in both Spain and Australia. The KiReS platform included more than 10 features across four clinical categories. Similarly, Rawstorn et al. (2016) described creation of a comprehensive platform (REMOTE-CR) to deliver remote cardiac rehabilitation exercise programs in New Zealand, which included more than 10 features across all clinical and administrative categories. Features commonly associated with integration into healthcare systems (e.g., decision support, scheduling, referral mechanisms, user management, and payment for services) were infrequently noted and altogether accounted for only 8% of all feature mentions.

### Economics and Sustainability

Our final research sub-question aimed to identify the scope of the available telerehabilitation literature that included discussion of economic costs of implementation and factors pertaining to long-term sustainability. Across the literature, there was sparse discussion of actual economic costs or long-term sustainability. Lakhani et al. (2021) described the use of freely available mobile applications within their program of care, specifically to ensure access within their low-income context of India. Two publications included an explicit discussion of cost-benefit analysis (Solana et al., 2015; Tsavourelou et al., 2016) and both concluded that the investment was worth the cost. A separate search however did not yield any follow-up publications discussing the actual return-on-investment (ROI) of the projects. The vast majority of publications included in this review described technological innovation without explicit discussion of economic cost to the consumer, long-term financial viability, or ROI. Similarly, there was no discussion of long-term sustainability of telerehabilitation features.

## DISCUSSION

Telerehabilitation offers an innovative approach to advance global health care initiatives by reducing access barriers and gaps in service delivery. Literature examining the current telerehabilitation landscape with consideration for resource-limited settings and LMICs is scarce. In this paper, we extracted and analyzed information on telerehabilitation features from 135 publications. Our broad goal was to identify and map telerehabilitation features noted in the literature to-date. We specifically sought to identify features that have been or could be implemented in LMICs, note how these features map onto healthcare delivery processes and into healthcare systems, and describe what is known

about the economic costs of service delivery technologies. A total of 29 features were identified, with the three most common features being data collection, videoconferencing, and messaging. When mapping features onto clinical care categories, we found that most features contributed to implementation of rehabilitation services and clinical assessment. Gaps that were revealed in the literature included few comprehensive platforms with features across multiple phases of clinical care, limited research representation in LMICs and in certain geographic regions (e.g., the Eastern Mediterranean, African, and South-East Asian Regions), and virtually no discussion of financial costs or long-term sustainability.

**Lack of Comprehensive and Integrated Platforms**

Our findings highlight the need for more comprehensive telerehabilitation platforms that offer features spanning the range of clinical and administrative categories that can be easily integrated into healthcare systems. With limited exceptions, few papers in this scoping review introduced a single telerehabilitation platform with features spanning multiple clinical categories. Similarly, our review revealed that most telerehabilitation features mapped onto the clinical assessment (24%) and implementation (41%) domains. Even fewer features appear to be available to aid in the clinical aspects of diagnosis (8%) or evaluation (3%) when working with rehabilitation patients. While these particular interventions can be quite complex in standard clinical practice and pose challenges for successful translation to telerehabilitation, diagnostic and evaluation tools are crucial for identifying and resolving problems early in implementation (Finch et al., 2012). Given prominent concerns about data privacy and security in the literature (Mamdouh et al., 2020; Saptono et al., 2009), the scarcity of confidentiality and security features is also notable, particularly in relation to the frequent mention of data collection features. One meaningful feature that appeared to be lacking in the literature was that of decisional support. Decisional support features can equip frontline workers, particularly those less familiar with rehabilitation medicine, with a tool to aid in treatment decisions and consulting with specialty rehabilitation providers. In LMICs, this stands out as one of the most important functionalities for narrowing gaps in service delivery where human resources are scarce (Finch et al., 2012).

Effective implementation of telerehabilitation into health care systems likely requires a range of features and functionalities to match the diverse clinical

demands inherent in rehabilitation across the care continuum. Results from a recent qualitative analysis that focused on telerehabilitation implementation emphasized the value of various support mechanisms for all individuals involved in the rehabilitation process (e.g., patient, provider, non-clinical staff; Anil et al., 2021). Other studies have similarly found a need for diverse features that can assist in various clinical categories involved in rehabilitation (Rothgangel et al., 2017). Of note, the importance of comprehensive telerehabilitation platforms can be assumed by the inherent qualities of the International Classification of Functioning, Disability and Health (ICF; World Health Organization, 2001). The ICF is a biopsychosocial model that is key in the conceptual understanding of a person's functioning, disability, and health. It provides a clear framework that highlights the necessity that services should address diverse factors, as well as dynamic relationships between an individual and their environment. To this end, telerehabilitation systems that are limited in scope (e.g., delivery of an exercise program in the absence of ongoing evaluation) or lack interactive features (e.g., message systems to facilitate patient-provider communications) are falling short of rehabilitation's overarching goal to improve functioning by attending to various factors that affect activity and participation. Solana et al. (2015) described development of a comprehensive cognitive telerehabilitation platform called the Guttman Neuropersonal Trainer (GNPT) that was built on ICF standards and taxonomy. The GNPT platform included 12 different features across all clinical categories. It was explicitly designed with interoperability in mind such that it could easily operate within and across healthcare systems and electronic health records and was tested with 887 patients across 27 different organizations and 83 patient homes. The scope of the services offered across multiple organizations is an example of what can be achieved with a thoughtfully designed comprehensive telerehabilitation platform.

**Skewed Global Distribution of Telerehabilitation Research and Development**

Despite intentional efforts to conduct a review that discussed features and functionalities appropriate for implementation in resource-limited settings and LMICs, very few papers were in the setting of or published by authors in LMICs (14%), which limits our knowledge about how contextual factors shape the implementation of telerehabilitation in LMICs. More than half of the papers included in the full-text review were conducted in the Regions of the Americas (31%) and European Region (28%), with an extremely scarce number of publications conducted in the Eastern Mediterranean (0%), African (1%), and

South-East Asia Regions (2%). This undoubtedly relates to an adjacent finding of ours that the vast majority of papers were published in high-income countries (60%). This aligns with a recent study that found the top five countries in number of publications relating to telerehabilitation were all high-income countries (Zheng et al., 2022). The one publication from the African Region (Teriö et al., 2019) described research evaluating a mobile phone-supported (primarily using short message service [SMS]) intervention for post-stroke rehabilitation in urban Uganda. The services included few features, but the authors did include rich information regarding barriers and facilitators unique to that cultural context. There were three publications from the South-East Asia Region (Lakhani et al., 2021; Sahu et al., 2021; Tyagi et al., 2019), which were all situated in India. These three studies again described a limited number of features but included descriptions and discussion regarding the best choice of features to ensure accessibility and feasibility for their intended populations. Overall, a significant portion of the reviewed publications (22%) did not specify or include details regarding intended or relevant geographic regions. This skewed and equivocal global distribution of telerehabilitation research raises concern for effective integration in LMICs. Literature that has examined facilitators and barriers to implementing telerehabilitation, particularly in LMICs, has consistently emphasized the need to better understand the local context and culture of a given geographic region (Binkley et al., 2020; Finch et al., 2012; Rabanifar & Abdi, 2021).

There is a dire need for telerehabilitation research and development in LMICs. Despite the overall growth in evidence and advancements of telerehabilitation, skewed representation of this work in high-income countries further disadvantages LMICs, where the impact of disability and unmet rehabilitation needs are already disproportionately greater. Gaps in rehabilitation care tend to be the widest and most prevalent in LMICs due to poor healthcare infrastructure, scarce resources, and limited transit (Neill et al., 2023). Integrating telerehabilitation in these resource-limited settings may prove most advantageous in narrowing gaps, yet the dearth of development and research in these settings may lead to even more fragile infrastructures. It is crucial that more research be conducted and tested in these contexts to obtain a comprehensive understanding of the successes and challenges of telerehabilitation integration.

Our review further highlights this necessity, as many telerehabilitation features, even those deemed relatively basic and not technically advanced (e.g., audioconferencing, electronically collected patient information), were proposed

without consideration for rules, policies, and/or infrastructure of given geographic regions (e.g., privacy and security, data exchange standards, power lines, internet access). For example, one systematic review evaluated studies using SMS and mobile application-based interventions (i.e., m-health) in surgical settings and found them to be efficient and accurate in evaluating postsurgical symptoms (Lu et al., 2018). Moreover, these relatively simple m-health interventions were associated with increased patient adherence, improved clinic attendance, lower readmission rates, and high satisfaction among patients and physicians. While these interventions show potential for improving precision and personalization in healthcare, authors later identified privacy as a notable barrier for successful implementation (e.g., regular SMS cannot be encrypted) given current standards regarding protection of patient health information. To this end, specific contextual considerations are critical for practical application of telerehabilitation and, unfortunately, inadequately addressed in the literature.

One pilot study that emerged in our review was exemplary in providing a comprehensive description of a web-based tool that delivers prescribed exercise plans and education to individuals following stroke (MacKo et al., 2016). Major strengths of this study were that initial field testing of the tool was conducted in the country in which it was intended to be used (i.e., Jamaica) and tested with individuals for which the tool was designed (i.e., adults with recent history of stroke and hemiparetic gait deficits). Equally noteworthy was that the project was led by an institution that conducts research with an international perspective that considers translation in other LMICs (University of the West Indies Solutions for Developing Countries). This context-driven lens allowed for astute considerations in the initial development and pertinent recommendations for continued advancements (e.g., cost-effective model, systems level solutions to enable early referrals). Additionally, testing the tool with users who comprise the targeted rehabilitation population yielded clinically meaningful observations. For example, a subset of users (15%) experienced leg discomfort with selected exercises. This finding helped in refining the assessment process of who may be most appropriate for this telerehabilitation (e.g., functional capacity *and* pain tolerability) and emphasized the importance of regular monitoring and customization among patients. Without first identifying what and where current health systems gaps exist in LMICs and considering patient-specific characteristics, telerehabilitation is unlikely to aid in mitigating those gaps. Our findings urge the need for more context-derived telerehabilitation systems.

### Lack of Financial and Sustainability Considerations

Our scoping review revealed very little inclusion of cost-benefit analysis, financial considerations, or long-term sustainability efforts. Matsumoto et al. (2021) noted that reimbursement for telerehabilitation services has traditionally been a barrier to adoption, a sentiment similarly reflected in a survey of Swiss physiotherapists regarding their use of telerehabilitation during the COVID-19 pandemic (Rausch et al., 2021). Saptono et al. (2009) described five required characteristics of a telerehabilitation infrastructure that included openness, extensibility, scalability, cost-effectiveness, and security. Only two articles, however, included explicit discussion of cost-benefit analyses. There were no articles that included prospective discussion of long-term sustainability.

### Future Directions

Our review exposed several gaps and deficiencies in the literature on telerehabilitation that precluded clear recommendations for adoption of technology or implementation of existing platforms or systems. However, these findings offer some general directions. First, irrespective of geographical region, little to no papers gave mention to the very real financial constraints that intersect with developing telerehabilitation functionalities. An unstructured, post-hoc review further indicated that very few authors or developers went on to conduct a follow-up analysis of the telerehabilitation feature being implemented in local settings. The lack of meaningful discussion regarding economic costs and how telerehabilitation features might fit into existing health systems suggests that future work should consider return on investment and long-term viability at the outset of developing or presenting telerehabilitation technologies. Second, there is limited empirical evidence on telerehabilitation features and functionalities. Higher quality systematic reviews and clinical trials that focus on the integration of telerehabilitation features into existing health systems are imperative to begin bridging gaps in rehabilitation care, particularly in LMICs. In addition, well-designed mixed-method research could provide insight into how and why certain features provide value and enhance the overall quality of care.

## Limitations

This scoping review has several limitations that warrant caution when interpreting findings. First, given the rapidly growing body of literature in this area, the review findings will quickly become dated. Second, our criteria specifically

required provision of rehabilitation through telehealth or telemedicine services, and likely excluded features that may be relevant for telerehabilitation if they were introduced within broader domains. Third, telerehabilitation apps and platforms are continuously being updated and some features have likely changed or evolved since our literature search was concluded. Additionally, some papers included in the review were outdated and features may also be outdated and/or impractical in the current landscape. Fourth, the review excluded non-English publications, which may have excluded relevant articles published in other languages, especially those from LMICs. Finally, due to the limited availability of peer-reviewed literature focused on telerehabilitation, article quality was not formally evaluated.

## Conclusion

This scoping review provides an overview of telerehabilitation features and functionalities that assist in the delivery of rehabilitation at a distance through telecommunications technology, with a specific interest in technology appropriate in resource-limited settings. Our results indicate that limited empirical evidence exists in this area of research, with the majority of papers existing in the grey literature. An important finding is the limited discussion of comprehensive platforms integrating multiple features and functionalities. Furthermore, despite our efforts to review features and functionalities that can be used in resource-limited settings, few papers conducted their research or development in LMICs. These findings can be used to inform the future development of telerehabilitation systems in LMICs to better meet the needs of the local context. Ideally, future work will focus on developing comprehensive telerehabilitation platforms designed with the context in mind, offering wide-ranging features that adequately map onto the clinical needs involved in successful rehabilitation delivery.

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Corresponding Author: Johns Hopkins International Injury Research Unit, Health Systems Program, Department of International Health, Johns Hopkins Bloomberg School of Public Health, 615 N. Wolfe Street, Suite E-8146, Baltimore, MD 21205, USA. E-mail address: abachani@jhu.edu (A.M. Bachani).

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