

What is the current state of precision rehabilitation? A mixed methods scoping review

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Abstract

Background

Precision health approaches aim to predict, deliver and optimize the right intervention, at the right time, for the right person. While precision medicine is well-established, its application in rehabilitation remains nascent. This study aimed to **1)** Map the state of knowledge on precision rehabilitation by describing the extent, scope and nature of the literature, identifying similarities and differences with precision medicine, and describing the role of technologies and artificial intelligence (AI); **2)** Describe knowledge users' perspectives on precision rehabilitation; and **3)** Integrate quantitative and qualitative results to develop a working definition of precision rehabilitation.

Methods

A convergent mixed-methods design was used to conduct a scoping review with a qualitative consultation phase. The scoping review followed Johanna Briggs Institute methodological recommendations and PRISMA-ScR reporting guidelines. Five databases were searched for adjacent keywords 'precision' AND 'rehabilitation'. Data were extracted and analyzed descriptively and thematically. In parallel, individual interviews were conducted with knowledge users at three North American rehabilitation centers. Transcripts were analyzed using deductive content analysis. Mixed method integration synthesized and contrasted literature-derived and knowledge users-derived insights.

Results

Forty-nine articles met inclusion criteria; 26 (53%) were primary research studies, while 23 (47%) were non-empirical publications. Amongst research studies, 14 (54%) involved technology use, while 5 (19%) used AI. Seven (14%) articles included a definition of precision medicine, while 22 (45%) included a definition of precision rehabilitation. Interviews with 16 knowledge users highlighted that personalization is uniquely expressed in precision rehabilitation as compared to medicine and identified rehabilitation-specific facilitators and barriers to precision approaches. Data integration confirmed that a focus on function differentiates precision approaches in rehabilitation from medicine, clarified rehabilitation-specific logistical barriers to technology-enabled data collection in precision approaches, and attributed limited AI use to concerns about predictions based solely on data that excludes psychosocial factors and population heterogeneity.

Conclusions

Results indicate greater similarities than differences between precision approaches in rehabilitation and medicine, while highlighting rehabilitation's emphasis on personalization, function and participation.

Findings identify key barriers and facilitators and support a proposed definition of precision rehabilitation for further refinement through peer consensus to accompany advances in research and clinical practice.

Background

Precision health tailors diagnosis, treatment and prevention strategies based on individual patients' biological, psychological, behavioral and environmental characteristics [1–3]. Precision applications in specific medical fields such as cancer genomics, cardiovascular disease, and rare genetic disorders are well-described [1]. Newer domains such as precision mental health and precision psychiatry are emerging in which both biological (e.g., genetic variants, brain imaging patterns) and digital biomarkers (e.g., wearables, digital interactions) can identify optimal medications or monitor for signs of relapse [2, 4, 5].

The term 'precision rehabilitation' emerged in the literature in the year following a National Institutes of Health (NIH) Medical Rehabilitation Research Resource Network (MR3) conference on Precision Rehabilitation in 2021 [6]. Two main research teams proposed foundational concepts and outlined similarities and differences with precision medicine [6, 7]. Both teams agreed that precision rehabilitation must align with the field's emphasis on multifactorial influences on lifetime functioning and called for larger sample sizes and more patient heterogeneity in rehabilitation studies. The two teams also emphasized the opportunities for genomics in predicting optimal rehabilitation intervention and recognized the need to identify biomarkers linked to meaningful measures of function. Finally, they agreed that to benefit from low-cost measurement technologies (such as wearable devices enabling continual real world data collection), rehabilitation research must standardize its data collection procedures to facilitate data sharing and create the large databases necessary for artificial intelligence (AI) based prediction and classification analyses. The most recent contribution by the Cotton et al. team is a causal framework that can process heterogeneous rehabilitation data across different levels of function and time to suggest individualized treatment plans [8]. This contribution is the first step towards actionable clinical tools to operationalize precision rehabilitation.

To accompany these advances, a synthesis of the emerging literature base is required to understand its current state and identify gaps in knowledge. To the authors' knowledge, no such synthesis exists. Because precision approaches may immediately impact health care delivery through their impact on institutional policies and funding decisions, it is equally important to explore how knowledge users experience precision concepts and their perspectives on future directions. A scoping review is the ideal knowledge synthesis methodology because of its focus on mapping the breadth and depth of available evidence, identifying knowledge gaps and clarifying key concepts from a diverse range of methodological sources [9, 10]. Scoping review methodology can include an optional qualitative consultation phase that adds value by incorporating real-world experiences and perspectives from knowledge users [11]. Methodologically rigorous consultation phases in scoping reviews can help bridge the gap between evidence and practical implementation challenges [11].

This scoping review used a convergent mixed methods design to map the current state of knowledge regarding precision rehabilitation by describing the extent, scope, and nature of the literature base, identifying similarities and differences with precision medicine, and describing the role of technologies and AI in precision rehabilitation approaches. A consultation phase describes knowledge users' perspectives regarding the implementation of precision rehabilitation and its similarities and differences with precision medicine. Mixed-methods integration compares insights from the literature and knowledge users to inform a suggested definition of precision rehabilitation for consensus and iterative improvement.

Methods

The protocol for this scoping review is accessible online [12]. The scoping review was developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis, Extension of Scoping Review (PRISMA-SCR) guidelines [13] and follows the six methodological stages outlined by Arksey and O'Malley, updated by Levac et al., and Peters et al. [9, 10, 14]. The consultation phase procedures were informed by Buus et al.'s recommendations [11]. The scoping review used a convergent mixed-methods design, in which quantitative and qualitative data were collected in parallel, separately analyzed, and subsequently merged to highlight similarities and differences between the current literature and knowledge users' perspectives [15].

Stage 1: Identifying the research question

The population of interest is individuals receiving or eligible for physical rehabilitation services (any condition, age group, or setting). The concept is precision rehabilitation, and the context is all study designs and publication types in any healthcare setting or geographical location. The primary research question was: What is the extent, range, and nature of the literature on precision rehabilitation? Secondary research questions were: 1) How does precision rehabilitation differ from precision medicine? 2) What roles do technologies and AI play in precision rehabilitation? and 3) How do actors in the field describe precision rehabilitation, its implementation in clinical practice, and its facilitators and barriers?

Stage 2: Identifying relevant sources

Searches were undertaken in five electronic bibliographic databases including CINAHL, Medline, Embase, PsycINFO and Web of Science in June 2023. Preliminary searches informed the decision to exclude search terms involving precision synonyms such as "personalised", "predictive" or "customised", as a high number of irrelevant studies emerged from initial searches that included these terms. The final search terms included the word 'precision' adjacent ('adj2') to the word 'rehabilitation' in study titles, abstracts and keyword lists. For example, articles including a sentence such as '*personalized (precision) neurorehabilitation care and management*' met the inclusion criteria [16].

Stage 3: Study selection

Eligible articles included those published between January 2010 and June 2023. Articles were included if they described original research or the protocol of original research, involved human participants or samples including historical datasets, and collected health-related data. Reviews, editorial articles, conference abstracts or posters were included. Articles not published in English, not in a rehabilitation context, involving animal populations, and those where the full-text article could not be retrieved were excluded. No limitations were placed on the study population, context or setting. The PRISMA flowchart can be found in the protocol paper [12].

All stages of the screening process were conducted in Covidence (Veritas Health Innovation). Duplicates were removed by Covidence, with the research team manually checking for missed duplicates. Title, abstract and full-text screening against inclusion and exclusion criteria were performed by APL and ED. Discrepancies at each screening stage were discussed with DL until consensus was reached.

Stage 4: Charting the data

Following independent data extraction on 10 articles by APL and ED, the authors met to resolve discrepancies and modify the data extraction framework. Extraction was then realized independently on the remaining articles by APL and ED, with DL consulted to resolve uncertainties. The data extraction framework can be found in the protocol paper [12].

Stage 5: Collating, summarizing and reporting the results

Descriptive and numerical analyses used counts and frequencies to map the extent and range of precision rehabilitation literature (e.g. article characteristics, study populations, outcome measures, use of technologies and/or AI). Two authors (APL and DL) independently categorized the extracted study aims or objectives and met to iterate and confirm categories. Concepts present in definitions of either precision medicine or precision rehabilitation (or both) were identified through a thematic analysis [17].

Stage 6: Consultation phase

As recommended by Buus et al. [11] and Arksey & O'Malley [14], the consultation exercise was conducted within a convergent mixed methods study design. The CHU Sainte-Justine Research Ethics Board provided ethical approval (# 2024-6324). The consultation phase was conducted in tandem with quantitative procedures; neither the interview guide nor the qualitative analysis was informed by scoping review results or analyses. Pouliot-Laforte et al., (2026) provides full details about consultation phase data collection and analysis procedures [18]. Using purposeful and convenience sampling methods, knowledge users (i.e. clinicians, managers and researchers) were recruited in three large hospital or rehabilitation centres in North America. Purposeful sampling was informed by Arksey and O'Malley's suggestion to seek consultants who may challenge established views and understandings [14]. As such,

practicing clinicians and rehabilitation managers in addition to researchers were purposefully recruited. Semi-structured interviews were conducted in person or online via a secured virtual platform (Microsoft Teams; Microsoft Corporation, Redmond, VA, USA). Interviews were audio recorded and transcribed. A two-step hybrid deductive-inductive thematic approach [19] was structured around four predetermined themes from the interview questions: 1) Key concepts of precision rehabilitation and how they compare to precision medicine; 2) Current situation regarding precision rehabilitation in their context; 3) Barriers and facilitators to precision rehabilitation; and 4) Future directions for precision rehabilitation. Following the first transcript reading, a list of codes was collaboratively developed by APL and DL. Both researchers then independently coded the transcript and met to refine the list of codes. This list was subsequently used by the 2 researchers to independently code the remaining transcripts. Following coding, an inductive approach was used to identify sub-themes within each of the predetermined themes.

Mixed methods analyses

An expansive convergent approach was used to compare the two datasets, identify common concepts, and determine areas of convergence, divergence and/or expansion [20]. On this basis, a proposed definition of precision rehabilitation was developed that incorporates the convergent elements.

Results

Article screening

The search resulted in 188 articles of which 103 were duplicates; 85 articles were screened. Following title and abstract screening, 28 articles were excluded. Eight articles were excluded following full paper screening. Pouliot-Laforte et al. (2025) provides the PRISMA flowchart with reasons for article exclusion [12]. A total of 49 articles published between 2017-2023 were included in the scoping review.

Characteristics of the included studies

Table 1 presents a summary of study characteristics; Appendix 1 provides further information.

Insert Table 1. here

Study aims/objectives

Three overarching categories of study aims/objectives were identified: 1) Classifying, identifying, or measuring function to inform precision rehabilitation (n=19); 2) Implementing precision medicine concepts in rehabilitation (n=11); and 3) Discussing, developing or testing precision rehabilitation (n=19). Table 2 provides examples of study aims/objectives within each category.

Insert Table 2. here

Outcome measures

Amongst the 24 primary research articles, over half (14; 58%) measured outcomes at the International Classification of Functioning, Disability and Health (ICF) body structure and function level only [21]. Three studies (13%) included outcome measures associated with activities as defined by the ICF such as daily physical activity or mobility. Another three studies (13%) included measures related to environmental factors; for example, sociodemographic data or characteristics of the physical environment such as noise, lighting, or room temperature. Five studies (21%) examined variables linked to personal factors, including quality of life. Finally, two studies (8%) measured variables related to participation as described by the ICF framework; for example, qualitative interviews exploring the patient’s experiences of returning to work and activity participation after injury.

Technology and/or AI use

Non-research articles were excluded from this part of the analysis, as perspective or editorial papers were not expected to use technology or AI, yielding a total of 26 studies. Most (n=21, 81%) did not use AI. The five studies that used AI all employed a machine learning methods to predict (n=4) or classify (n=1). In each of these studies, the AI models were developed using data obtained through technology-based data collection. More than half of the included articles used some form of technology (n=14; 54%): wearables were most frequent (n=6), followed by instrumented devices (n=3), robot-assisted therapy (n=1), electronic health records (n=1), virtual reality (n=2, one used VR in a telerehabilitation context), and genome sequencing (n=1). Technologies were used for data collection (n=9) (e.g., movement tracking), for intervention (n=3) (e.g., delivering the intervention, monitoring performance during the intervention, or providing feedback), or for both data collection and intervention (n=2).

Insert figure 1 here

Description of precision rehabilitation and/or precision medicine by the authors

Of the 49 studies included in the scoping review, 29 (59%) defined or described precision medicine (7) or precision rehabilitation (22), either by describing the concept in their own words, or through referencing or quoting a definition proposed in another publication. No article proposed a new definition of precision rehabilitation. Table 3 presents the frequency with which concepts identified in scoping review thematic analyses appeared in descriptions of precision rehabilitation as compared to precision medicine. Specific to descriptions of precision rehabilitation, Figure 2 presents a word cloud visualizing the frequency of appearance of individual words.

Insert table 3 here

Insert figure 2 here

Appearance of the term ‘precision rehabilitation’ in the included articles

Forty three of the 49 studies (87%) included in the scoping review used the term ‘precision rehabilitation’ in either the keywords, title, abstract, or article body. The term was used between 1 and 41 times per article (mean 4.5 uses, standard deviation 6.4 uses). Twenty-six articles (49% of the total number of articles in review; 60% of the articles using the term) used the term in the title (16), keywords (6) or abstract (26) while 21 articles (43% of total articles; 49% of those using the term) included the term in the body of the text: 14 in the introduction, 6 in methods, 3 in the results, and 7 in the discussion or conclusion.

Findings from the consultation phase

Pouliot-Laforte et al., (2026) provides full results of the consultation phase [18]. To facilitate understanding of the mixed methods integration, qualitative results are summarized in Table 4.

Insert Table 4. here

Mixed methods integration

1. Dataset comparison

Quantitative and qualitative data were compared to identify concepts common to both datasets. For these concepts, convergence, divergence and/or expansion [20] are discussed below. Table 5 synthesizes the mixed methods results in a joint display.

Insert Table 5. here

a. The role of personalization in precision rehabilitation

Findings from the two datasets diverged for this concept, with the qualitative results expanding on the quantitative results. In the quantitative findings, personalization (or individualization) was evident in nearly all descriptions of both precision medicine (86%) and precision rehabilitation (90%). These findings indicate that the research community does not view personalization as unique to rehabilitation. However, in the qualitative findings, knowledge users emphasized that personalization is foundational to rehabilitation care delivery, independent of any precision approach, and suggested ways in which precision approaches could enhance and extend this inherent personalization.

Qualitative findings revealed a fundamental tension between precision's emphasis on data-driven standardization and rehabilitation's tradition of clinician-specific personalization. For knowledge users, personalization processes vary according to individual clinician expertise, creating inconsistency in care delivery across providers and institutions, even though each clinician engages in personalized care. Qualitative results further diverge from quantitative findings by suggesting that precision rehabilitation could offer decision-making frameworks that preserve individualization while reducing variability in care quality, and that precision approaches could enhance personalization by integrating data-informed evidence with client factors. Taken together, these findings suggest that precision rehabilitation may

complement, rather than replace, existing personalization by adding evidence-based guidance to clinician expertise and patient preferences.

b. The concept of 'function' is more important to precision rehabilitation as compared to precision medicine

Datasets converge on this concept, with qualitative findings expanding on quantitative results. Function was an important finding in this scoping review; 1) Nineteen articles had the objective of 'Classifying, Identifying, measuring function towards precision rehabilitation'; and 2) the concept of 'function' was never included in any description of precision medicine, while it was included in 18% of the studies that described precision rehabilitation. For example: *'Precision rehabilitation—that is, applying the optimal type and dose of therapy at the ideal time to maximize return of function for individual patients.'* [22] A second example: *'because the goal of precision rehabilitation is to identify the right treatment(s), the right dosage(s), and right time(s) to maximize function and quality of life, patients must be recognized as essential knowledge users.'*[6] In the qualitative findings, Theme 3 « The future of precision rehabilitation will focus on function » develops the importance of function to precision rehabilitation through 3 subthemes: « 3.1 Precision rehabilitation will inform decisions and optimize rehabilitation trajectories »; « 3.2 Precision rehabilitation will share data between multiple sites to deal with patient heterogeneity and achieve the larger sample sizes required for predictive modeling »; « 3.3 Precision rehabilitation will focus on improving or maintaining long-term functional independence » (see Table 4).

Function is defined in the International Classification of Functioning, Disability and Health (ICF) framework as: " (...) a multi-dimensional concept encompassing a person's body functions (physiological and psychological), body structures (anatomical parts), activities (execution of a task), and participation (involvement in life situations)". [21]. The datasets converge in that both provide examples of function across the 3 ICF levels (body structures and functions, activities, and participation). Quantitative studies addressed impairment-level function (movement patterns, strength deficits) and activity-level function (walking, reaching). The participation level received less emphasis, as only two studies assessed a participation-level outcome.

Knowledge users, however, prioritized activity and participation outcomes in their descriptions of precision rehabilitation. While they discussed impairment-level biomarkers, they emphasized that functional trajectories must extend to well-being and participation. At the activity level, qualitative results focused on the importance of measuring functional performance in real-world contexts rather than solely in clinical settings. Technologies such as wearables and smartphone tracking were identified as facilitators for capturing activity-level function, including community mobility and everyday task performance. Knowledge users emphasized that interventions targeting impairments should ultimately enhance community engagement. In addition, knowledge users emphasized the longitudinal and dynamic nature of function in precision rehabilitation, expanding the focus on cross-sectional measurement approaches predominant in articles included in the scoping review. Secondly, qualitative

results highlighted the need to include the psychosocial dimensions of function that are infrequently measured in quantitative studies.

c. Rehabilitation-specific barriers and facilitators explain the limited technology and AI use in the precision rehabilitation literature.

The quantitative review captured frequency of technology and AI use in the included studies, but not their implementation challenges. Qualitative findings address this gap by identifying barriers and facilitators from the perspective of knowledge users. Qualitative findings revealed technology-specific barriers. Despite promises of reduced burden, automated data collection still requires clinicians to monitor and troubleshoot systems. Additionally, technologies must be both personalized *and* generalized, in that they must be useful to multiple patients to justify the time investment and learning curve required for clinicians.

While knowledge users acknowledged AI as essential for precision rehabilitation's predictive goals, they identified implementation challenges. Population heterogeneity characteristic of rehabilitation populations (such as stroke) complicates prediction accuracy and raises ethical concerns. Knowledge users emphasized the importance of psychosocial and contextual factors in rehabilitation outcomes, noting these are challenging to measure and model. These concerns extend to measurement issues related to psychosocial factors that were seen as essential to rehabilitation decision-making. As with precision medicine, prediction in precision rehabilitation may therefore require robust integration of biological, physiological, environmental, and social data to adequately capture the complexity of functional recovery.

2. A proposed definition of precision rehabilitation

Dataset comparison informed a definition of precision rehabilitation encompassing areas of convergence and expansion in quantitative and qualitative results:

"Precision rehabilitation parallels precision medicine in its focus on determining the right intervention for the right individual at the right time, using similar data-driven methods. However, precision rehabilitation distinguishes itself through its primary focus on functional wellbeing and participation across the lifespan. This requires accounting for individuals' changing environments, social contexts, and life circumstances—factors that introduce variability beyond biological mechanisms. Consequently, predictive models in precision rehabilitation must accommodate smaller, more heterogeneous datasets and account for the complex, dynamic interactions between person, environment, and function in real-world settings."

Discussion

This convergent mixed method scoping review integrates quantitative evidence and qualitative knowledge user perspectives to map precision rehabilitation concepts and their implementation in clinical practice and research. In 2022, French et al. argued for the active implementation of precision

approaches by the rehabilitation community [7]. This is the first study to directly engage the knowledge users who will implement and benefit from precision rehabilitation regarding its conceptualization and implementation challenges. This study identifies where knowledge user perspectives converge with or diverge from published evidence, revealing gaps between research and practice realities. When applicable, Cotton et al.'s causal framework for precision rehabilitation [8] provides important context for interpreting our findings, which we discuss below.

1. Shared foundations, distinct features: precision rehabilitation and precision medicine

1.1 The role of personalization

Personalization is understood differently in published literature than in clinical practice. The included articles describe personalization in a way that is similar to its conceptualization in precision medicine. However, participants in the consultation study described personalization as an inherent component of rehabilitation practice, rather than a novel precision contribution. As noted previously, tailoring treatments is a fundamental aspect of clinical practice, since clinicians must base their decision on each patient's unique characteristics [23]. Knowledge users identified an added value proposition for the future of precision rehabilitation: the potential to create a framework to systematize how personalization decisions are made in clinical practice [18]. By integrating data and enabling AI-powered pattern recognition, such framework could standardize the personalization process while maintaining individualized care. The causal framework proposed by Cotton et al. (2024) provides one potential structure for achieving this balance by modeling how interventions influence outcomes across multiple pathways, potentially allowing clinicians to weigh algorithmic predictions against individual patient contexts and values [8].

1.2 Function as a central focus of precision rehabilitation

Both quantitative and qualitative findings identified function as central to precision rehabilitation and as a key distinction from precision medicine. In rehabilitation, an emphasis on function across the ICF domains differs from medicine's focus on disease-specific biomarkers and pathophysiology [21]. Precision rehabilitation must address the challenge of measuring and incorporating psychosocial factors into predictive models, as these factors influence outcomes [6,7].

Qualitative findings expand the literature's cross-sectional measurement focus by emphasizing the need for longitudinal measurement over time. Knowledge users described the potential for precision approaches to track functional trajectories, identify critical intervention windows, and predict long-term participation outcomes. This requires biomarkers, outcomes measures, and predictive models that span from an impairment to a participation focus across time [22]. This temporal dimension aligns with Cotton et al.'s (2024) emphasis on Optimal Dynamic Treatment Regimens that make sequential decisions to maximize long-term function, rather than optimizing single intervention episodes [8].

2. Addressing technology and AI implementation challenges

The quantitative results showed limited representation of technologies and AI in the literature; knowledge users viewed technology and AI use as essential to the future of precision rehabilitation. Barriers and facilitators synthesized from knowledge user perspectives can inform how technologies are developed and marketed in a precision approach. For example, rather than building fixed-feature technologies, developers might create modular platforms with core functionalities that can be extended through add-ons that are tailored to specific populations or goals. AI-driven systems could automate personalization, adjusting parameters based on real-time patient performance without requiring clinician configuration, reducing time burden [24]. The causal framework proposed by Cotton et al. (2024) could inform such adaptive systems by modeling how different intervention parameters influence outcomes for patients with specific characteristics, enabling automated personalization decisions [8]. Findings regarding barriers to technology use for data collection provide additional suggestions for framework implementation. Causal models offer limited value if data collection technologies are overly burdensome or if personalization-generalizability tensions hinder adoption. Framework implementation should therefore include the development of practical measurement technologies and intervention technologies that balance personalization with efficiency. Framework development and validation should engage knowledge users, including researchers, clinicians, patients, payers, and policy makers. Qualitative findings demonstrate that knowledge user perspectives reveal implementation considerations not apparent in research literature alone. Knowledge user consultation can inform framework refinement to address real-world needs and constraints.

Ethical concerns expressed by knowledge users about the risks of AI-based prediction in heterogeneous populations reflect broader challenges in developing appropriate predictive models for rehabilitation contexts [25,26]. Addressing these concerns will require several parallel efforts. First, rehabilitation research must develop and validate measures of psychosocial factors for inclusion in predictive models. Second, the field needs ethical frameworks governing AI use in rehabilitation decision-making, including guidelines on when algorithmic predictions should inform versus determine treatment decisions [8]. Third, knowledge users including patients, clinicians, payers, and ethicists should collaboratively develop policies ensuring equitable access to rehabilitation interventions regardless of algorithmic predictions. Cotton et al.'s (2024) causal framework acknowledges these challenges by emphasizing the importance of modeling across ICF domains and incorporating contextual factors that influence outcomes [8,22].

3. Moving toward consensus: advancing the definition of precision rehabilitation

This study contributes a working definition of precision rehabilitation that integrates quantitative and qualitative findings to capture both shared precision medicine principles and rehabilitation-specific features. The proposed definition is intended to stimulate discussion and refinement within the rehabilitation community rather than serve as a final formulation. The rehabilitation community is invited to provide feedback on the definition, viewing it as a springboard for discussion rather than a definitive statement. Feedback will be facilitated through a formal consensus process using Delphi methods or a nominal group technique, involving diverse knowledge users such as researchers across rehabilitation disciplines, clinicians from various practice settings, patients and family members, payers, and

policymakers [27]. The aim of proposing this definition is not to prematurely close debate or constrain further field development, but to establish sufficient shared understanding to enable coherent research programs, meaningful knowledge synthesis, and coordinated implementation efforts.

Scoping study limitations

First, the literature search ended in 2023, meaning recent publications, including important theoretical contributions, are not represented. Given the rapid pace of development in this emerging field, findings may not fully capture the current state of knowledge. Second, search terms were limited to "precision" and excluded adjacent terms such as "personalized" or "individualized". This decision was necessary to maintain feasibility, as broader searches yielded overwhelming numbers of unrelated results. However, this approach may have excluded relevant work using alternative terminology, potentially underestimating the breadth of related research. Third, the qualitative consultation phase included only three rehabilitation sites selected through convenience sampling. All were large, research-intensive academic medical centers in North America, limiting the diversity of perspectives. Smaller community rehabilitation programs, non-academic settings, international perspectives, and patient and family viewpoints are underrepresented. Including perspectives from these groups might have revealed additional implementation considerations or different priorities than those articulated by the primarily researcher and clinician participants in this study. Fourth, information about barriers and facilitators to technology or AI use was not extracted from the included articles. While qualitative findings expand substantially on the limited technology discussion observed in the literature, it cannot be confirmed that these barriers are absent from published research, only that they were not prominent in study objectives, aims, or descriptions of precision rehabilitation concepts. A more targeted review specifically examining barriers and facilitators across the included studies might reveal additional convergence between published literature and knowledge user perspectives. Finally, the scoping review methodology, while appropriate for mapping an emerging field, has inherent limitations in terms of quality assessment and synthesis. As is typical for scoping reviews, risk of bias assessment was not performed, and studies were not excluded based on quality criteria; therefore, contributions are not weighed based on methodological rigour.

Conclusion

This scoping study provides the first mixed methods synthesis of precision rehabilitation, identifying directions for development and gaps in current evidence and practice. Quantitative findings demonstrate that precision rehabilitation shares key principles with precision medicine, while qualitative findings introduce distinct rehabilitation features not apparent in the published literature. Function emerges as a central organizing principle distinguishing precision rehabilitation from precision medicine, with knowledge users emphasizing the need for approaches that include participation outcomes. While technologies and AI are essential enablers of precision rehabilitation's data-driven approach, it will be important to balance automated personalization with clinical efficiency and to establish ethical frameworks ensuring algorithmic predictions augment rather than replace clinical expertise. This study's

proposed working definition can serve as a foundation for consensus-building processes that engage diverse knowledge users to establish shared understanding of precision rehabilitation's core components and distinctive features. Precision rehabilitation promises improved functional outcomes through targeted interventions but faces practical and ethical implementation challenges. This study provides a foundation for future research and implementation efforts by synthesizing current knowledge and identifying considerations essential for translating research into practice.

Declarations

Ethics approval and consent to participate: Ethical approval for this study was obtained from the CHU Sainte-Justine Research Ethics Board (protocol # 2024-6324). Written informed consent was obtained from all participants prior to their enrolment in the study.

Consent for publication: Not applicable

Availability of data and materials: The datasets used and/or analysed are available from the corresponding author upon reasonable request.

Competing interests: none

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Authors' contributions: Conceptualization (APL, DK, DL), Methodology (APL, ED, DL), Formal Analysis (APL, ED, DL), Writing – Original Draft Preparation (APL, DL), Writing – Review and Editing (APL, ED, DK, DL).

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Tables

Table 1. Summary of study characteristics

Study characteristics	Counts	Specific characteristics
Type of paper	26	Research article
	11	Conference abstract
	12	Editorial
Country of corresponding author	22	USA
	5	UK
	5	Italy
	4	China
	3	Canada
	1	Australia, Austria, Belgium, Czech Republic, Japan, Malaysia, Netherlands, Singapore, Spain, Switzerland, Taiwan
	3	Not stated
Study design	12	Editorial
	2	Case control study
	7	Cross-sectional study
	3	Framework
	4	Narrative review
	2	Prospective study
	1	Case report, Cohort analysis, Conceptual analysis, Descriptive paper, Interpretive paper, Longitudinal study, Meta-analysis, Pilot study, Prognostic study, Retrospective study, Proof of concept, Simulation, Systematic review, Systematic mapping study
	1	Not stated
Population	4	Healthy individuals
	11	Post-stroke
	2	Traumatic brain injury
	2	Acquired brain injury
	2	Lumbar spinal fusion surgery

	1	Autism spectrum disorder, Aphasia, Neurological disorder, Musculoskeletal trauma, Parkinson, Low-back pain, Developmental disorders, Complex condition
	23	No participants
Age	2	Children
	2	Adults
	1	Elderly
	5	Not stated
	27	Not applicable

Table 2. Categorization of the aims and objectives of the studies

Scoping review categories	N	Original article aims	Example
Classifying, identifying, measuring function to inform precision rehabilitation	19	a) Describe a technology to measure function or enhance rehabilitation effectiveness; b) Identifying predictive variables to optimize a rehabilitation intervention; c) Present a technology-based method to classify function.	« Demonstrate the safety, sense of presence, system usability, and face validity of the Virtual Reality Comprehensive Balance Assessment and Training (VR-ComBAT) in healthy individuals » (Moon et al, 2021); « Using machine learning to build predictive models to predict postintervention outcomes and identify the most important predictors for these outcome measures in stroke rehabilitation » (Chen et al., 2023)
Implementing precision medicine concepts in rehabilitation	11	a) Develop a datacentric rehabilitation approach; b) Describe the relevance of 'omics' for rehabilitation; c) Evaluate the potential rehabilitation biomarker; d) Describe the relevance of epigenetics for rehabilitation.	« Summarizing how “-omics” technologies can inform rehabilitation-relevant outcomes for a range of populations with neurologically related disability by including outcome metrics linked to the World Health Organization’s International Classification of Functioning, Disability, and Health (WHO-ICF) domains of impairments in body function, activity limitations, and participation restrictions » (Wagner et al, 2017); « design and development of new generation datacentric approach (including biofeedback and physiological parameters- based methods) to treatment of balance disorders through exergames offering many levels of difficulties that can be adjusted through choice of parameters » (Brezany et al, 2018)
Discussing, developing or testing precision rehabilitation	19	a) Test precision rehabilitation; b) Mentions how the work could contribute to future precision rehabilitation efforts; c) Discuss concepts or approaches related to	« Reporting the successful use of precision rehabilitation medicine in a patient with two MYH2 missense mutations » (Chen et al, 2018); « capture a weekly record of life as lived in the first 4 weeks following lumbar spinal fusion surgery from the patient’s own perspective » (Masson et al, 2019)

precision
rehabilitation;

d) Argue for
expanding the
factors
considered as
important in a
rehabilitation
intervention;

e) Comment on or
introduce a
precision
rehabilitation
publication.

Table 3. Thematic analysis-derived concepts and their frequencies in medicine versus rehabilitation definitions

Concepts	Precision Medicine [n=7]	Precision Rehabilitation [n=22]
Optimizing interventions or outcomes	3 (43%)	10 (45%)
Individualized or personalized	6 (86%)	20 (90%)
Genetics and personal biology	5 (71%)	3 (14%)
Environmental or lifestyle factor	3 (43%)	6 (27%)
Data and outcomes	2 (29%)	6 (27%)
Function	0 (0%)	4 (18%)

Table 4. Summary of findings from the consultation phase

Theme	Subtheme	Description
1. Key concepts of precision rehabilitation parallel those of precision medicine but have their own unique features.	n/a	Precision rehabilitation shares core principles with precision medicine, such as delivering optimal interventions at the appropriate time to specific individuals. Precision rehabilitation differs by emphasizing elements such as functional biomarkers, inherent personalization in care delivery, and a focus on maintaining long-term functional independence across physical, cognitive, and psychosocial domains.
2. There are rehabilitation-specific facilitators and barriers to a precision approach	2.1 To facilitate precision rehabilitation, we need to innovate <i>what and how</i> we measure, as well as <i>who</i> measures and <i>when</i> .	Advancing precision rehabilitation requires comprehensive measurement of psychosocial factors alongside biological and functional data, strategic timing of assessments aligned with critical decision points rather than rigid schedules, and leveraging technologies for unobtrusive real-world data collection to reduce clinician burden while increasing measurement frequency and relevance.
	2.2 Technologies can both facilitate and obstruct the personalization required for precision rehabilitation.	While technologies enable detailed continuous data capture in real-world contexts, they also present challenges. These include the time burden of customizing intervention parameters and the difficulty of balancing individual tailoring with the generalizability needed for clinical efficiency and commercial viability.
	2.3 The heterogeneity of rehabilitation populations and interventions complicates decisions based primarily on evidence.	The substantial variability within rehabilitation populations and the lack of standardized intervention descriptions create challenges for applying predictive AI models trained on heterogeneous data to individual patients. They also raise concerns about balancing algorithmic predictions with clinical expertise and client-centered goals.
3. The future of precision rehabilitation will focus on function	3.1 Precision rehabilitation will inform decisions and optimize rehabilitation trajectories.	Precision rehabilitation should provide data-driven guidance for determining optimal intervention timing and targeting, enabling more efficient resource allocation by identifying critical windows for intervention and eliminating unnecessary clinical visits while ensuring timely access to appropriate services.
	3.2 Precision rehabilitation will share data between multiple sites to deal with patient heterogeneity and achieve the larger samples	Developing effective predictive models requires collaborative multi-site networks that standardize data collection using common measures and timepoints, creating sufficiently large datasets to train AI models

sizes required for predictive modeling.

capable of identifying meaningful patterns across heterogeneous rehabilitation populations.

3.3 Precision rehabilitation will focus on improving or maintaining long-term functional independence.

The goal of precision rehabilitation will be to enhance functional outcomes by linking impairment-level measurements to participation and quality of life outcomes across the International Classification of Functioning framework and using technology-enabled assessments to predict and optimize real-world function over time.

Table 5. The joint display of quantitative and qualitative findings.

Common concept across both datasets	Quantitative findings	Qualitative findings	Mixed methods Comparison/integration
The role of personalization in precision rehabilitation	Personalization appeared in nearly all descriptions of both precision medicine (86%) and precision rehabilitation (90%), with no distinction between the two fields.	Knowledge users described personalization as already foundational to rehabilitation practice, suggesting precision approaches could systematize existing personalization through structured decision-making frameworks.	<i>Diverge and expand.</i> While quantitative findings positioned personalization as a shared precision principle, qualitative findings revealed how knowledge users view precision rehabilitation's contribution as expanding existing personalized practice through evidence-based frameworks that structure how clinicians make individualization decisions.
The concept of 'function' is more important in precision rehabilitation as compared to precision medicine	Function was not included in descriptions of precision medicine but appeared in 18% of precision rehabilitation descriptions. While studies addressed outcomes at all ICF levels, they concentrated on impairment and activity outcomes.	Knowledge users prioritized activity and participation outcomes, emphasizing longitudinal tracking of functional trajectories in real-world contexts and the need to measure psychosocial dimensions of function.	<i>Converge and expand.</i> Datasets converged on function as central to precision rehabilitation and distinct from precision medicine; qualitative findings expanded by prioritizing participation-level outcomes and emphasizing longitudinal, real-world measurement of functional trajectories including psychosocial dimensions
Rehabilitation-specific barriers and facilitators explain the limited technology and AI representation in the precision rehabilitation literature	Technology and AI were used in 54% and 19% of included studies, respectively. Applications primarily focused on measurement (9 studies) and intervention delivery (3 studies).	Knowledge users identified key barriers including ongoing clinician burden from monitoring automated systems, tension between personalization and generalizability of technologies, population heterogeneity complicating AI prediction, and challenges measuring psychosocial factors essential to rehabilitation outcomes.	<i>Expand.</i> Qualitative findings expand on limited mention of AI and technology in precision rehabilitation literature by revealing barriers.

Figures

Relations between the aims, the use of technologies, AI and definition

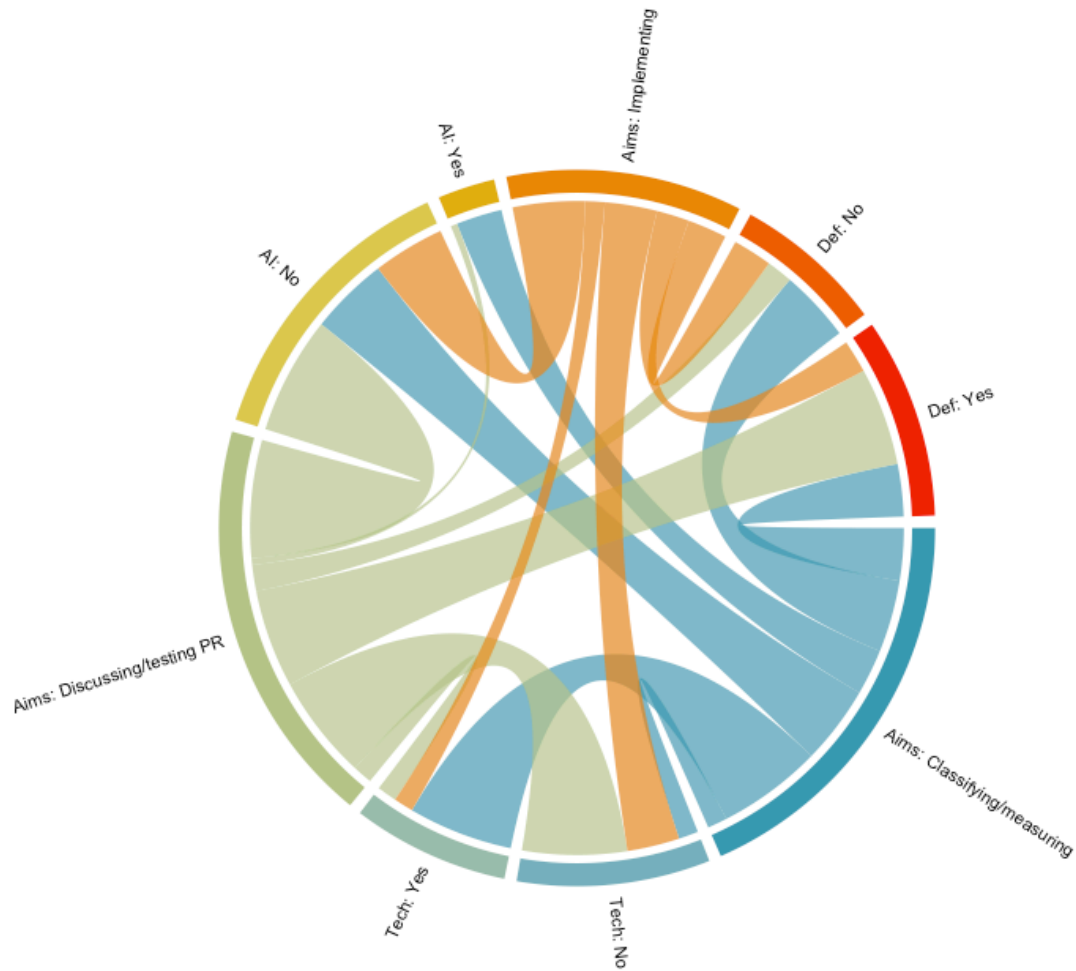


Figure 1

Relationship between study objectives and technology and/or AI use in the 49 included articles. Each segment on the circumference represents one category: study aims: classifying/measuring precision rehabilitation (blue), discussing/testing precision rehabilitation (green), implementing precision rehabilitation (orange); technology use: yes/no (blue green); AI use: yes/no (yellow). Ribbons connect categories that co-occur within the same articles, and the width of each ribbon is proportional to the number of articles contributing to that connection.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Appendix1.Allarticlesincluded.pdf](#)