Archives of ISPRM 2026;1(2):114-127

Review

OPEN ACCESS

Three-dimensional printing in rehabilitation medicine: Clinical applications, implementation challenges, and future directions from a low-resource setting

Md. Israt Hasan[1], Shamim Ahmed Deowan[2], Taufiq Morshed[3], Fatema Newaz[4], Syed Mozaffar Ahmed[5]

[1]Department of Physical Medicine and Rehabilitation, Sher-e-Bangla Medical College, Barishal, Bangladesh
[2]Department of Robotics and Mechatronics Engineering, University of Dhaka, Dhaka, Bangladesh
[3]Department of Orthopedic Surgery, National Institute of Traumatology and Orthopedic Rehabilitation, Dhaka, Bangladesh
[4]Department of Physical Medicine and Rehabilitation, Kumudini Women's Medical College, Tangail, Bangladesh
[5]Department of Physical Medicine and Rehabilitation, Bangladesh Medical University, Dhaka, Bangladesh

Abstract

Three-dimensional (3D) printing has emerged as a transformative technology in rehabilitation medicine, enabling personalized orthoses, rapid prototyping, and point-of-care device fabrication. While high-income settings report growing clinical adoption, evidence from low- and middle-income countries (LMICs) remains limited, particularly with respect to real-world implementation, interdisciplinary collaboration, and system-level barriers. Existing evidence suggests that 3D-printed orthoses are usually comparable to conventional devices in biomechanical performance, with limited high-quality evidence demonstrating clear superiority. In this narrative review, we discuss clinical applications and implementation challenges of 3D printing in rehabilitation medicine, with particular emphasis on institutional pilot experience from Bangladesh. A structured literature search (2010-2025) was performed in PubMed and Scopus using predefined inclusion criteria focused on rehabilitation-oriented additive manufacturing. Bangladesh-specific pilot cohorts were incorporated to contextualize real-world feasibility. In a prospective descriptive cohort of patients with De Quervain's tenosynovitis (n = 17 receiving 3D-printed orthoses), no device-related structural failures or adverse skin reactions were observed during six-week follow-up. The average fabrication turnaround time was 7 to 10 days compared with 1 to 2 days for conventional splints, highlighting workflow trade-offs in resource-constrained environments. Clinical literature indicates potential advantages of additive manufacturing in anatomical conformity, weight reduction, and user satisfaction; however, implementation in tropical LMIC settings introduces material durability concerns, particularly when using polylactic acid (PLA), which may be susceptible to thermal deformation and moisture-related degradation. Successful integration, therefore, depends not only on customization capability but also on climate-appropriate material selection, interdisciplinary collaboration, and structured end-user engagement. In conclusion, current evidence suggests potential for improved usability and satisfaction with 3D-printed orthoses, while biomechanical outcomes appear largely equivalent to conventional devices in most applications. Sustainable adoption in low-resource rehabilitation systems requires embedded engineering capacity, regulatory clarity, workforce development, and user-centered co-design frameworks.

Keywords: Assistive technology, low-resource settings, orthoses, rehabilitation medicine, 3D printing.

Submitted: February 03, 2026
Accepted: April 12, 2026
Published: June 10, 2026

Correspondence: Md. Israt Hasan, MD. Department of Physical Medicine and Rehabilitation, Sher-e-Bangla Medical College, Barishal, Bangladesh.

E-mail: isratpmr@gmail.com

Doi: https://doi.org/10.5606/archisprm.2026.28

Citation:
Hasan Md. I, Deowan SA, Morshed T, Newaz F, Ahmed SM. Three-dimensional printing in rehabilitation medicine: Clinical applications, implementation challenges, and future directions from a low-resource setting. Arch ISPRM 2026;1(2):114-127. https://doi.org/10.5606/archisprm.2026.28.

Three-dimensional (3D) printing, or additive manufacturing (AM), has increasingly entered rehabilitation medicine as a method for producing customized orthoses and assistive devices.[1-3] By enabling layer-by-layer fabrication from digital models, AM allows geometric complexity and personalization that are difficult to achieve through conventional thermoplastic molding or prefabricated systems.[3] In rehabilitation contexts, where devices must accommodate anatomical variability and evolving functional goals, customization represents a significant clinical consideration.

Beyond personalization, AM offers mechanical design flexibility that permits modulation of internal lattice structures, wall thickness, and material distribution, enabling theoretical manipulation of stiffness-to-weight ratios.[3-7] While these engineering advantages are attractive, current clinical evidence suggests that 3D-printed orthoses are usually comparable rather than consistently superior to conventional devices in terms of biomechanical function and clinical outcomes.[5,6] Systematic reviews in surgical and medical applications further emphasize that AM presents both advantages and limitations, with clinical benefit highly context-dependent.[1]

Most published evidence supporting AM in healthcare originates from high-income settings, where integrated engineering infrastructure, reliable power supply, and established regulatory pathways facilitate translation from design to clinical use.[2,8,9] In contrast, low- and middle-income countries (LMICs) operate within markedly different structural realities. While conventional fabrication methods may limit accessibility due to centralized workshops and material dependency, AM introduces new barriers, including the need for computer-aided design (CAD) expertise, hardware maintenance, environmental control during printing, and consistent filament supply chains.[2,9] Thus, implementation in LMIC rehabilitation systems represents a trade-off between customization potential and infrastructural demands.

Bangladesh provides a relevant context in which to examine these trade-offs. Rehabilitation services in Bangladesh face workforce constraints and limited assistive technology infrastructure. Institutional initiatives have begun exploring the feasibility of customized 3D-printed orthoses, including a published case report demonstrating the use of 3D printing technology in the management of carpal tunnel syndrome.[10] While such experiences illustrate technical feasibility, they also underscore the need to evaluate broader system-level determinants of sustainability and scalability in resource-constrained environments.

A meaningful involvement of the end-user is often underemphasized in technology-centered discussions. Evidence from orthotic and assistive technology literature demonstrates that device utilization and functional benefit depend not only on mechanical performance but also on comfort, usability, and adherence.[4,6] Objective monitoring studies and systematic reviews highlight variability in real-world orthosis usage, emphasizing that adoption is influenced by user-centered factors beyond structural rigidity alone.[4] In low-resource settings, poorly designed or underutilized devices represent inefficient allocation of scarce healthcare resources. Therefore, embedding user feedback and satisfaction assessment into AM workflows is essential for responsible implementation.

Despite growing global interest in 3D printing applications across medical fields,[8,9] literature specifically examining implementation realities in low-resource rehabilitation environments remains limited. Existing reviews frequently emphasize technological capabilities and case-based successes,[1-3,5,9] but provide less attention to biomechanical trade-offs, workflow feasibility, environmental durability, and system-level sustainability within tropical LMIC contexts.

Accordingly, this narrative review adopts a Bangladesh-centered implementation perspective. Rather than presenting a broad technical overview alone, it examines four interrelated domains shaping AM in rehabilitation medicine within a low-resource setting:

(1) clinical applications and biomechanical considerations;
(2) end-user integration and usability;
(3) system-level implementation barriers including infrastructure and workflow constraints; and

(4) material durability and sustainability considerations relevant to tropical environments.

By synthesizing local clinical experience with international literature, in this review, we critically evaluate the role of 3D printing in rehabilitation medicine, identifying both its practical potential and contextual limitations in resource-constrained health systems.

Literature search and Review Approach

This narrative review was informed by a structured but non-systematic search of the English-language literature on 3D printing applications in rehabilitation medicine. Electronic databases including PubMed and Scopus were searched for articles published between January 2010 and December 2025. Google Scholar was additionally screened to identify relevant implementation reports and supplementary literature. Search terms included combinations of the following keywords: "3D printing" OR "additive manufacturing" AND "rehabilitation" OR "physical medicine" OR "orthoses" OR "assistive devices." The complete search strings for PubMed and Scopus are provided in Supplementary Appendix 1 to enhance transparency and reproducibility.

Eligibility Criteria

Studies were included if they (1) reported clinical, biomechanical, or implementation-related applications of 3D printing in rehabilitation contexts; (2) focused on externally applied orthoses, splints, prosthetic components, or assistive devices; and (3) included clinical outcomes, biomechanical validation, usability data, or implementation insights. Studies were excluded if they (1) focused exclusively on dental, maxillofacial, or surgical implant applications without rehabilitation relevance; (2) were purely technical engineering studies without clinical or functional application; and (3) lacked sufficient methodological description.

Study Selection and Synthesis

Identified records were screened based on title and abstract, followed by full-text review where appropriate. Given the heterogeneity of study designs, device types, and outcome measures, quantitative meta-analysis was not feasible. Instead, findings were synthesized narratively, with emphasis on clinical applicability and implementation relevance in low-resource settings.

To enhance clarity and facilitate structured comparison, key clinical and biomechanical studies were summarized in Table 1, detailing study design, sample size, intervention characteristics, reported outcomes, and principal findings.

In addition to published literature, institutional pilot data from Bangladesh were incorporated to contextualize implementation feasibility and workflow challenges. These data are presented as feasibility observations rather than comparative efficacy evidence. Given the narrative design and heterogeneity of included studies, a formal quality appraisal tool (e.g., Downs and Black checklist) was not applied; instead, study design and methodological limitations are summarized descriptively in Table 1.

Overview of Additive Manufacturing in Rehabilitation

A focused technical overview is necessary to contextualize the feasibility of AM within rehabilitation practice. Unlike implant-based surgical applications, rehabilitation-oriented 3D printing primarily targets externally worn orthoses, prosthetic components, and assistive devices that must be practical, durable, and reproducible in clinical environments. Recent scoping and systematic reviews highlight growing interest in rehabilitation-center-based fabrication models while emphasizing variability in workflow maturity and clinical validation.[11]

Additive Manufacturing Techniques

Among available AM methods, fused deposition modeling (FDM) remains the predominant technology in rehabilitation settings due to its affordability, accessibility, and compatibility with commonly available thermoplastic filaments.[11-13] Reviews examining workflow implementation in clinical practice indicate that FDM systems are most frequently integrated into rehabilitation departments because they require comparatively lower capital investment and technical infrastructure.[13]

Alternative technologies such as selective laser sintering (SLS) and stereolithography (SLA)

Table 1. Summary of key clinical and implementation studies on 3D-printed orthoses in rehabilitation medicine, including Bangladesh-based pilot experience

Author (year)	Country	Study design	N	Device type	Comparator	Outcomes	Key findings	Limitations
Jin et al.[3] (2015)	USA	Review	-	Orthoses & prostheses	Conventional	Design feasibility	Customization flexibility	Limited outcome data
Baronio et al.[7] (2016)	Italy	Technical study	Experimental	Hand orthosis	Traditional fabrication	Mechanical feasibility	Feasible reverse engineering	No clinical follow-up
Chae et al.[5] (2020)	Korea	Case series	3	Upper limb orthosis	None	Functional scores	Improved comfort & usability	No control group
Schwartz and Schofield[6] (2023)	USA	Systematic review	Variable	Upper limb orthoses	Conventional	Functional outcomes	Generally equivalent performance	Small heterogeneous studies
Devanand and Kedgley[4] (2023)	UK	Systematic review	Variable	Extremity orthoses	Mixed	Usage monitoring	Variable adherence	Monitoring heterogeneity
Hasan et al.[10] (2024)	Bangladesh	Case report	1	CTS orthosis	Conventional	Symptom improvement	Feasible in LMIC	Single case
Institutional Pilot (2021-2023)	Bangladesh	Prospective cohort	17	Wrist-thumb orthosis	Conventional splint	VAS, QuickDASH, QUEST	No failures; 7-10-day turnaround	Non-randomized

VAS, Visual Analog Scale; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand; QUEST, Quebec User Evaluation of Satisfaction with Assistive Technology; CTS, Carpal tunnel syndrome.

offer improved surface resolution and material uniformity; however, they typically require controlled laboratory environments and higher-cost equipment.[14,15] While such methods have demonstrated feasibility in hospital-based point-of-care laboratories, their routine use in low-resource rehabilitation departments remains limited. Consequently, FDM-based workflows represent the most scalable pathway for AM integration within resource-constrained settings.

Digital Workflow and Design Process

A defining feature of 3D printing in rehabilitation is its digital design-to-fabrication workflow. Anatomical data acquisition may involve manual measurement, optical surface scanning, or low-cost 3D scanning technologies.[16-18] Advances in scanning systems have facilitated more precise contour capture, enhancing customization accuracy for orthotic and prosthetic devices.

Following acquisition, digital models are refined using CAD software to optimize alignment, joint positioning, ventilation, and load distribution. Reviews of prosthetic and orthotic design emphasize that digital workflows allow iterative modification without repeated casting, potentially improving efficiency and reproducibility. However, implementation studies indicate that successful deployment depends heavily on clinician-engineer collaboration and digital literacy within rehabilitation teams.

Materials and Environmental Stability

Material selection is a critical determinant of mechanical performance, patient comfort, and long-term durability. Commonly used thermoplastics in rehabilitation-oriented 3D printing include polylactic acid (PLA), thermoplastic polyurethane (TPU), and other engineering polymers.[11,13]

The PLA is frequently utilized due to its low cost, ease of printing, and dimensional stability. Systematic reviews of 3D-printed orthoses report that PLA-based devices can achieve functional outcomes comparable to conventional orthoses in many upper-limb applications.[14] However, PLA has a relatively low glass transition temperature (55 to 60°C), which may predispose it to deformation under prolonged heat exposure. In tropical climates characterized by high ambient

temperatures and humidity, these properties raise concerns regarding long-term structural integrity.

Emerging design optimization studies, including pediatric ankle-foot orthosis (AFO) development, demonstrate that material selection and internal geometry significantly influence stiffness and fatigue behavior.[19] Materials such as polyethylene terephthalate glycol-modified (PETG) and Nylon provide greater thermal resistance and improved fatigue performance compared with PLA, though they require more controlled printing conditions and technical expertise. These trade-offs are particularly relevant for lower-limb orthoses exposed to repetitive dynamic loading.

Therefore, material choice in rehabilitation settings should be guided not only by printability and cost, but also by climatic conditions, expected mechanical demands, hygiene considerations, and available technical capacity.

Clinical Relevance to Rehabilitation Practice

The technological characteristics of AM align closely with core principles of rehabilitation medicine, particularly personalization, functional optimization, and iterative modification. Digital modeling enables individualized device geometry tailored to patient anatomy and biomechanical requirements. Moreover, digital storage of design files allows reproducibility and modification without repeated physical casting, potentially improving workflow efficiency and long-term service delivery.[20,21]

However, technological capability alone does not ensure clinical benefit. The effectiveness of 3D-printed devices depends on appropriate patient selection, sound biomechanical design, structured clinical oversight, and integration within comprehensive rehabilitation programs. These considerations reinforce the need for physiatrist-led implementation frameworks that balance innovation with functional safety and system-level feasibility.

Clinical Applications of 3D Printing in Rehabilitation Medicine

The principal clinical applications of 3D printing in rehabilitation involve customized, externally applied orthoses and assistive devices designed to support, immobilize, or facilitate movement. Unlike surgical implants, rehabilitation devices must tolerate prolonged wear, repetitive functional demands, and evolving patient conditions. Recent reviews highlight expanding use across musculoskeletal and neurological rehabilitation domains, while emphasizing variability in study quality and outcome reporting.[22,23]

Upper-Limb Orthoses and Splints

Upper-limb conditions represent the most extensively reported applications of 3D printing in rehabilitation. Individually tailored wrist, hand, and thumb orthoses have been developed for traumatic injuries, chronic hand conditions, de Quervain's tenosynovitis, and other musculoskeletal disorders.[24,25] Randomized and preliminary controlled studies suggest that personalized 3D-printed wrist orthoses can achieve outcomes usually comparable to conventional thermoplastic devices in terms of pain reduction and functional improvement.[26,27]

Customization improves anatomical conformity and may enhance patient comfort and aesthetic acceptance, factors known to influence adherence and satisfaction.[28] Open-lattice or ventilated designs can improve breathability compared with traditional solid thermoplastic splints. However, increased porosity may reduce structural rigidity if not biomechanically optimized, requiring careful balancing between ventilation and load-bearing stability.

Current evidence suggests that 3D-printed upper-limb orthoses demonstrate functional performance comparable to conventional devices, with potential advantages in personalization and patient-reported comfort, rather than consistent biomechanical superiority.[24,27]

Lower-Limb Orthoses and Gait-Related Devices

Lower-limb rehabilitation applications include AFOs, foot orthotics, and components of gait-assistive devices. Customization is particularly important in lower-limb orthoses, where small variations in alignment or stiffness can significantly influence gait biomechanics and energy expenditure. A recent systematic

review examining 3D-printed AFOs reported promising effects on gait parameters, though heterogeneity in design and testing methods remains substantial.[29]

Earlier prosthetic fabrication studies and rapid prototyping approaches demonstrate technical feasibility of AM in load-bearing lower-limb applications.[30] More recent optimization studies in pediatric cerebral palsy populations have shown that internal geometry and material selection critically influence mechanical stiffness and device performance.[19]

More importantly, lower-limb orthoses are subjected to repetitive cyclic loading during gait, imposing substantially greater mechanical demands than static upper-limb splints. While static stiffness may approximate conventional devices, fatigue life and long-term durability vary depending on material choice, print orientation, and infill structure. Therefore, cautious interpretation of mechanical equivalence is warranted, particularly in dynamic gait applications.

In addition to orthotic devices, modular and customized 3D-printed assistive components have been developed to support gait training and mobility tasks, demonstrating feasibility and user-centered adaptability in rehabilitation contexts.[31]

Neurological and Pediatric Rehabilitation

In neurological rehabilitation, 3D printing has been applied to fabricate customized splints and assistive devices for individuals with stroke, spinal cord injury, and cerebral palsy. Pilot studies have shown that personalized assistive devices may improve task-specific function and daily activity performance, particularly when integrated into structured rehabilitation programs.[32]

Pediatric rehabilitation represents a particularly promising domain, as children frequently outgrow conventional orthoses, necessitating repeated refabrication. Digital storage of design files may facilitate efficient reproduction and modification of devices.[33] However, it is of utmost importance to recognize that geometric scaling of a digital model does not automatically preserve biomechanical stiffness. Structural revalidation is necessary to ensure appropriate load-bearing capacity as device dimensions increase, particularly in lower-limb orthoses subjected to dynamic forces.

Moreover, the ability to incorporate lightweight structures and child-friendly design features may enhance acceptance and adherence among pediatric populations, provided that mechanical safety is rigorously maintained.

Assistive Devices and Adaptive Equipment

Beyond orthoses, 3D printing has been used to create a wide range of assistive devices and adaptive tools, including customized grips, utensil holders, writing aids, and environmental control interfaces. These devices are often highly individualized and poorly suited to mass production, making them ideal candidates for AM.[34]

In rehabilitation settings, such devices can play a critical role in promoting independence and participation, particularly for individuals with upper-limb impairment or limited dexterity. The low material cost and rapid prototyping capacity of 3D printing allow clinicians to trial multiple designs and refine devices based on user feedback, fostering a more participatory and patient-centered rehabilitation process.[35]

Clinical Limitations and Evidence Gaps

Despite growing enthusiasm, the clinical evidence supporting 3D-printed rehabilitation devices remains heterogeneous. Many studies are limited by small sample sizes, short follow-up periods, and variability in outcome measures. Furthermore, few investigations address long-term durability, cost-effectiveness, or comparative effectiveness across diverse healthcare settings.[36] These limitations highlight the need for cautious interpretation of existing evidence, stressing the importance of contextual factors such as infrastructure, workforce, and regulatory oversight in determining real-world clinical impact.

Implementation Experience from a Low-Resource Setting

Implementation of 3D printing technology in rehabilitation medicine within low-resource settings is shaped primarily by system-level

factors rather than technological capability alone. Drawing on experience from government-funded pilot initiatives in Bangladesh (n = 17 patients receiving customized wrist-thumb orthoses), the proposed rehabilitation-led framework (Figure 1) provides a structured lens to understand how clinical priorities, interdisciplinary collaboration, infrastructure capacity, and iterative evaluation interact under real-world constraints typical of LMICs.

Rehabilitation-Led Clinical Need as the Entry Point

In contrast to technology-driven adoption models, implementation in this setting was initiated by clearly defined rehabilitation needs. High-prevalence musculoskeletal conditions such as carpal tunnel syndrome and de Quervain's tenosynovitis frequently require prolonged orthotic use, yet conventional prefabricated devices often fail to accommodate anatomical variability, occupational demands, and patient comfort. Biomechanical optimization and ergonomic splint design have been shown to significantly influence pressure distribution and symptom control in these conditions.[37,38] Poor fit and discomfort are well-recognized contributors to reduced adherence and suboptimal functional outcomes in rehabilitation practice.[37,38]

These unmet clinical needs provided the primary justification for exploring patient-specific,

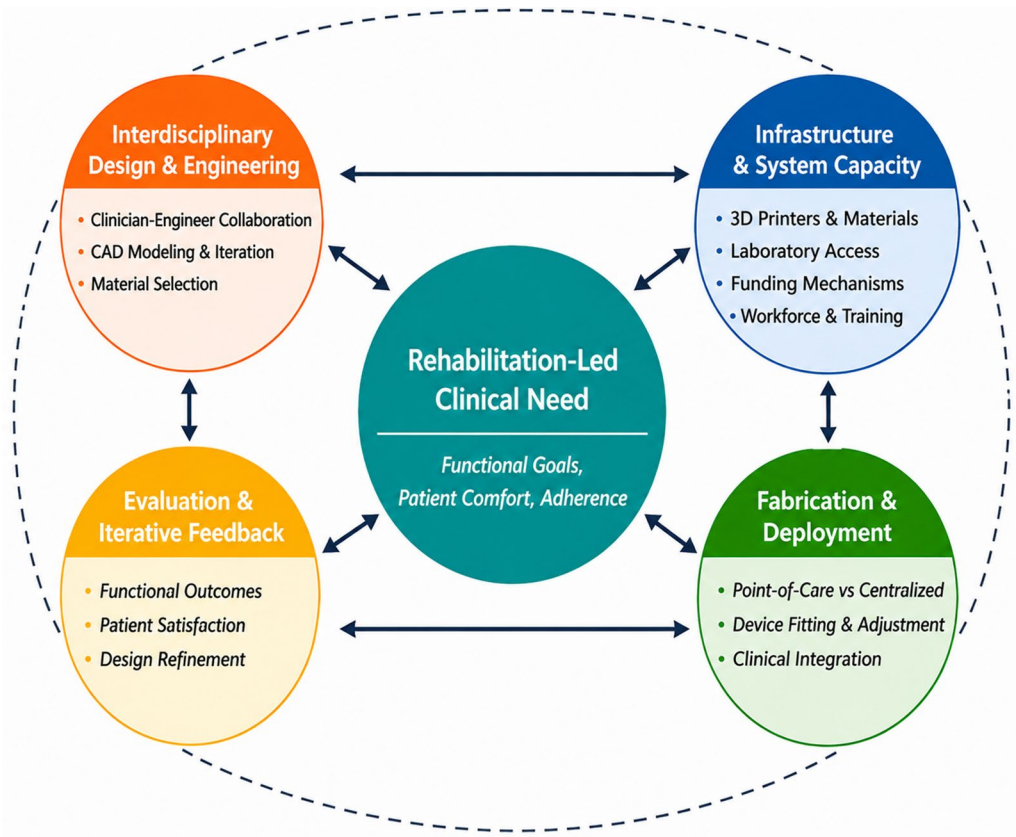

Figure 1. A rehabilitation-led framework for implementing 3D printing technology in low-resource settings.

The framework positions rehabilitation-driven clinical need at the core, supported by four interdependent domains: interdisciplinary design and engineering, infrastructure and system capacity, fabrication and deployment, and evaluation with iterative feedback. System-level constraints common in LMICs such as funding limitations, regulatory gaps, and workforce constraints surround and influence all domains. Effective and sustainable implementation requires continuous physiatrist-led coordination across the system rather than isolated technological adoption.

3D, three-dimensional; LMICs, low- and middle-income countries.

3D-printed orthoses rather than adopting the technology for novelty or research interest alone.

Interdisciplinary Design and Engineering Collaboration

Consistent with the framework, interdisciplinary collaboration emerged as a central enabling factor. Rehabilitation physicians and orthopedic surgeons worked closely with engineers from an academic robotics and mechatronics department to translate clinical requirements into digital designs. Similar clinician-engineer partnerships and co-design approaches have been identified as critical facilitators of successful AM integration in healthcare and assistive technology development.[39,40]

However, reliance on external engineering laboratories introduced structural dependency. Limited availability of engineering personnel, competing academic priorities, and restricted access to printing facilities extended design iteration cycles and delayed device deployment. Broader analyses of assistive technology access in LMICs similarly emphasize coordination and system barriers as major determinants of adoption feasibility.[41]

Infrastructure and System Capacity Constraints

Infrastructure limitations represent a substantial obstacle to sustainable implementation in this context. Dedicated rehabilitation-based 3D printing facilities were not available, necessitating centralized fabrication in external laboratories. Broader reviews of AM technologies highlight that equipment cost, maintenance demands, and environmental control requirements remain limiting factors in many healthcare systems.[42]

Material procurement further constrained consistency, with limited local availability of suitable filaments and fluctuating costs affecting reproducibility. Although pilot funding from academic and governmental sources enabled feasibility testing, finite grant duration and fixed budgets restricted sample size and long-term follow-up. Experiences from other LMIC initiatives demonstrate that short-term project-based funding rarely supports sustained integration of 3D printing into routine prosthetic or rehabilitation services without institutional investment and capacity building.[43]

Fabrication, Deployment, and Clinical Integration

Fabrication and deployment followed a centralized model rather than point-of-care manufacturing. Anatomical data were obtained through clinical measurement and manual contouring rather than on-site 3D scanning, and digital files were transferred to external engineering collaborators for design refinement and printing. This workflow resulted in an average fabrication turnaround time of 7 to 10 days, compared with approximately 1 to 2 days for conventional thermoplastic splints within the same institution. This extended timeline limited rapid iteration and reduced opportunities for same-day fitting and modification, an advantage frequently associated with point-of-care 3D printing in high-resource settings.[21] Device fitting required additional patient visits, increasing indirect costs and logistical burden. These observations underscore that the oft-cited immediacy of AM is highly context-dependent and not inherently achievable in resource-constrained environments. Notably, during short-term follow-up, no structural device failures or adverse skin reactions were observed in the pilot cohort. However, longer-term durability and cost-effectiveness analyses were beyond the scope of this feasibility phase.

Evaluation, Iterative Feedback, and Sustainability

Despite these constraints, iterative feedback between clinicians, engineers, and patients was achievable on a limited scale. Patient-reported comfort, satisfaction, and functional perception were assessed using structured evaluation approaches informed by assistive technology satisfaction frameworks such as the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST).[44] Feedback guided incremental design refinements and reinforced the importance of user-centered evaluation in rehabilitation technology adoption.

However, absence of standardized regulatory pathways, formal quality assurance mechanisms,

and reimbursement models constrained transition from pilot implementation to sustained clinical service. Global digital health governance frameworks emphasize the necessity of regulatory clarity, workforce training, and institutional accountability for scaling technological innovation responsibly within health systems.[45] Without alignment across these domains, AM risks remaining an episodic innovation rather than an integrated rehabilitation service.

Cross-Cutting Lessons from the Low-Resource Context

Collectively, this experience highlights that effective implementation of 3D printing in rehabilitation medicine requires coordinated action across clinical prioritization, interdisciplinary collaboration, infrastructure development, regulatory governance, and sustainable financing. Technological feasibility alone is insufficient. Physiatrist-led clinical oversight, embedded engineering capacity, stable material supply chains, and institutional commitment are essential to prevent 3D printing from remaining confined to short-term pilot projects. Addressing these system-level determinants is critical for equitable and scalable integration of AM into rehabilitation services in LMICs.

Ethical, Regulatory, and Workforce Considerations

The integration of 3D printing technology into rehabilitation medicine raises important ethical, regulatory, and workforce considerations that extend beyond technical feasibility. In low-resource settings, these dimensions play a decisive role in determining whether AM evolves into a sustainable clinical service or remains confined to isolated pilot initiatives.

Ethical Considerations in Personalized Device Fabrication

Personalization is a defining advantage of 3D printing in rehabilitation; however, it introduces ethical responsibilities related to patient safety, informed consent, and data governance. Customized devices are frequently fabricated outside traditional commercial manufacturing pathways, raising questions about quality assurance, material biocompatibility, and accountability in the event of device failure. Recent scoping reviews in orthopedics emphasize that regulatory uncertainty and unclear liability structures remain central ethical concerns in AM applications.[46] Ethical practice therefore requires transparent communication with patients regarding the pilot or non-commercial nature of such devices, particularly when long-term durability and comparative effectiveness data are limited.

Digital workflows used in 3D printing often utilize anatomical data acquired through medical imaging and scanning technologies. Consequently, robust measures for patient data protection, secure storage and management of digital design files, and clear delineation of data ownership are critical. These considerations are particularly important in multicenter academic collaborations, where the exchange of digital datasets across institutions may raise additional ethical, legal, and regulatory challenges. Legal analyses highlight underexplored data protection and intellectual property issues in medical 3D printing, particularly in jurisdictions with evolving digital governance frameworks.[47] These concerns are amplified in LMIC contexts, where formal data protection systems may be underdeveloped. Rehabilitation-led oversight is therefore critical to ensure that innovation does not compromise patient rights or safety.

Regulatory and Quality Assurance Challenges

Regulatory oversight of 3D-printed medical devices remains an evolving area globally. Guidance from regulatory bodies such as the U.S. Food and Drug Administration (FDA) has begun to outline technical considerations for additively manufactured medical devices, primarily focusing on design control, material characterization, and process validation.[48] However, these frameworks often emphasize implants and surgical guides rather than externally applied rehabilitation devices.

In many LMICs, including Bangladesh, specific regulatory guidance for 3D-printed orthoses and assistive devices is limited or absent, creating uncertainty regarding device classification,

approval processes, and post-market surveillance. Scholarship on medical 3D printing regulation underscores the need for proportionate, risk-based approaches tailored to device function and clinical context rather than wholesale adoption of high-risk implant standards.[49] Rehabilitation professionals should therefore engage constructively with regulators to develop pragmatic oversight mechanisms that balance safety with innovation and access.

Workforce Capacity and Interdisciplinary Training Needs

Workforce limitations represent a major bottleneck in sustainable implementation. Effective integration of AM requires not only access to engineers and designers but also digital literacy among rehabilitation professionals. A recent nationwide survey among occupational therapists demonstrated increasing engagement with 3D printing technologies, while simultaneously highlighting variability in training and confidence levels.[50] Physiatrists, therapists, and orthotists must understand fundamental principles of digital design, material properties, and iterative prototyping to communicate clinical requirements effectively and evaluate device performance.

In low-resource settings, biomedical engineering expertise is often concentrated within academic institutions rather than embedded in healthcare facilities, reinforcing dependency on external collaborators and limiting responsiveness to clinical demand. Calls for expanded rehabilitation workforce capacity emphasize the integration of digital competencies into professional training and health system planning.[51,52] Strengthening interdisciplinary education and institutional collaboration is therefore essential to prevent technological innovation from outpacing clinical capacity.

Governance, Equity, and Professional Leadership

Beyond individual competencies and regulatory frameworks, governance structures determine whether 3D printing advances equity-oriented rehabilitation goals or exacerbates disparities. Analyses of global assistive device ecosystems caution that fabrication technologies may remain concentrated in urban academic hubs unless deliberate strategies promote decentralized and community-based access.[53]

Embedding AM within public rehabilitation services, guided by national policy and professional leadership, is therefore essential to promote equitable distribution. Physiatrists are uniquely positioned to assume leadership roles in this process, bridging clinical, ethical, and system-level perspectives. By anchoring technological innovation in functional outcomes, patient-centered care, and health system priorities, rehabilitation professionals can help ensure that 3D printing contributes meaningfully to universal health coverage and disability-inclusive development agendas.

Future Directions and Research Priorities

The future integration of 3D printing technology into rehabilitation medicine depends on shifting from isolated pilot initiatives toward coordinated, system-level implementation. For low-resource settings, this transition necessitates strategic alignment of clinical priorities, research agendas, and policy frameworks to ensure that AM contributes meaningfully to equitable rehabilitation care rather than remaining a niche innovation.

Moving from Pilot Projects to Routine Clinical Services

Most current applications of 3D printing in rehabilitation are limited to feasibility studies, case reports, and small-scale pilot projects. Although these initiatives have demonstrated considerable technical feasibility and clinical potential, broader implementation requires the development of structured frameworks for integration into routine rehabilitation practice. Such efforts should focus on establishing dedicated point-of-care or institutionally embedded fabrication facilities, supported by standardized protocols for device design, manufacturing, fitting, quality assurance, and long-term follow-up. The adoption of these frameworks may facilitate scalability, improve consistency of care, and promote the sustainable incorporation of 3D printing technologies into rehabilitation services.

Implementation research emphasizes that embedding innovation within existing service delivery structures rather than treating it as a parallel experimental pathway is critical for sustainability, particularly in resource-constrained health systems.[54] Without deliberate integration into organizational processes, AM risks remaining episodic and grant-dependent.

Research Priorities: Clinical Effectiveness and Cost-Utility

Robust clinical research is essential to guide rational adoption of 3D printing in rehabilitation medicine. Future studies should move beyond proof-of-concept designs toward comparative effectiveness trials evaluating 3D-printed devices against conventional orthoses using standardized functional outcomes, patient-reported measures, adherence metrics, and durability assessments.

Given fiscal constraints in LMICs, economic evaluation is particularly important. Established frameworks for economic evaluation of healthcare programs provide structured approaches for assessing cost-utility and cost-effectiveness in relation to health outcomes.[55] Longitudinal studies examining durability, maintenance requirements, and long-term functional impact are also needed to determine whether initial investments in digital fabrication yield sustained benefits over the lifespan of rehabilitation devices.

Workforce Development and Capacity Building

Sustainable implementation requires targeted investment in workforce development. Incorporation of basic digital fabrication concepts into physiatry, orthotics, and rehabilitation therapy curricula represents an important step forward. Evidence suggests that even short educational interventions can positively influence healthcare professionals' attitudes toward 3D printing and improve technology acceptance.[56]

Strengthening interdisciplinary training through joint clinician-engineer workshops, certification programs, and institutional innovation hubs can reduce reliance on external collaborators and enhance responsiveness to patient needs. Broader calls to expand and strengthen the global rehabilitation workforce reinforce the importance of aligning technological advancement with workforce capacity building.[51,52]

Policy, Regulation, and Governance Frameworks

Policy development represents a critical future priority. National rehabilitation and assistive technology strategies should explicitly recognize 3D printing as a potential modality for personalized device provision. As materials and fabrication technologies evolve including integration of smart materials and adaptive design approaches, regulatory systems must adapt accordingly.[57]

Risk-proportionate frameworks tailored to externally applied rehabilitation devices are necessary to ensure safety without unnecessarily restricting innovation. International commitments under the Convention on the Rights of Persons with Disabilities (CRPD) underscore national and global responsibilities to improve access to assistive technologies.[58] Engagement of rehabilitation professionals in policy formulation is therefore essential to align regulatory standards with clinical realities and rights-based access principles.

Equity-Oriented Innovation and Global Collaboration

Future research and implementation efforts must remain grounded in equity considerations. Without deliberate planning, access to digital fabrication technologies may remain concentrated in urban academic centers, potentially widening geographic and socioeconomic disparities. Global estimates of rehabilitation need highlight the scale of unmet demand worldwide, particularly in LMICs.[59] Decentralized fabrication models, shared innovation hubs, and collaborative design libraries offer promising avenues to extend access to underserved populations. International partnerships and multicenter research networks can accelerate adaptation of validated device models and support context-sensitive innovation.

The Role of Rehabilitation Leadership

The future of 3D printing in rehabilitation medicine will depend not only on continued technological advancement but also on effective professional leadership and successful integration into healthcare systems. Physiatrists, with their comprehensive understanding of function, participation, disability, and healthcare delivery, are uniquely positioned to promote the ethical, patient-centered, and sustainable implementation of 3D printing technologies. Through leadership in interdisciplinary collaboration and active engagement in research, policy development, and implementation strategies, rehabilitation professionals can help ensure that 3D printing evolves from a promising technological innovation into an integral component of rehabilitation care. Such an approach will enable these technologies to strengthen healthcare systems, improve patient outcomes, and support the delivery of personalized rehabilitation interventions.

In conclusion, 3D printing offers meaningful potential to advance personalized rehabilitation care, particularly through customized orthoses and assistive devices. While existing evidence suggests improvements in fit, comfort, and patient satisfaction, experience from low-resource settings indicates that clinical impact depends primarily on system-level factors rather than technology alone. Sustainable integration requires a rehabilitation-led approach that aligns clinical needs with interdisciplinary collaboration, infrastructure capacity, regulatory oversight, and workforce development. Without such alignment, 3D printing is likely to remain limited to pilot initiatives. The conceptual framework proposed in this review provides a pragmatic guide for implementation and scale-up. Physiatrists play a central role in leading ethical, patient-centered adoption of AM, ensuring that technological innovation translates into equitable and sustainable rehabilitation services.

Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contributions

M.I.H., S.M.A.: Idea/concept; M.I.H., S.A.D., S.M.A.: Design; S.M.A., S.A.D.: Control/supervision; M.I.H., S.A.D.: Data collection and/or processing; M.I.H., S.A.D., T.M.: Analysis and/or interpretation; M.I.H., F.N.: Literature review, references and fundings; M.I.H.: Writing the article; S.M.A., T.M., F.N.: Critical review; S.A.D., T.M.: Materials.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

AI Disclosure

The authors declare that artificial intelligence (AI) tools were not used, or were used solely for language editing, and had no role in data analysis, interpretation, or the formulation of conclusions. All scientific content, data interpretation, and conclusions are the sole responsibility of the authors. The authors further confirm that AI tools were not used to generate, fabricate, or 'hallucinate' references, and that all references have been carefully verified for accuracy.

REFERENCES

1. Martelli N, Serrano C, van den Brink H, Pineau J, Prognon P, Borget I, et al. Advantages and disadvantages of 3-dimensional printing in surgery: A systematic review. Surgery 2016;5159:1485-500. doi: 10.1016/j.surg.2015.12.017.
2. Javaid M, Haleem A. Additive manufacturing applications in medical cases: A literature based review. Alex J Med 2018;54:411-22. doi: 10.1016/j.ajme.2017.09.003.
3. Jin YA, Plott J, Chen R, Wensman J, Shih A. Additive manufacturing of custom orthoses and prostheses–a review. Procedia Cirp 2015;36:199-204. doi: 10.1016/j.procir.2015.02.125.
4. Devanand DB, Kedgley AE. Objective methods of monitoring usage of orthotic devices for the extremities: A systematic review. Sensors (Basel) 2023;23:7420. doi: 10.3390/s23177420.
5. Chae DS, Kim DH, Kang KY, Kim DY, Park SW, Park SJ, et al. The functional effect of 3D-printing individualized orthosis for patients with peripheral nerve injuries: Three case reports. Medicine (Baltimore) 2020;99:e19791. doi: 10.1097/MD.0000000000019791.
6. Schwartz DA, Schofield KA. Utilization of 3D printed orthoses for musculoskeletal conditions of the upper extremity: A systematic review. J Hand Ther 2023;36:166-78. doi: 10.1016/j.jht.2021.10.005.
7. Baronio G, Harran S, Signoroni A. A critical analysis of a hand orthosis reverse engineering and 3D printing process. Appl Bionics Biomech 2016;2016:8347478. doi: 10.1155/2016/8347478.

8. Ventola CL. Medical applications for 3D printing: Current and projected uses. P T 2014;39:704-11.
9. Peters J, Bleakney A, Sornson A, Hsiao-Wecksler E, McDonagh D. User-driven product development: Designed by, not designed for. Des J (Aldershot) 2024;27:133-52. doi: 10.1080/14606925.2023.2275868.
10. Hasan MI, Tasnim M, Ahmed SM, Morshed T, Deowan SA. 3D printing technology in the management of carpal tunnel syndrome: A case report. Bangabandhu Sheikh Mujib Medical University Journal. 2024;30;:e71690-. doi: 10.3329/bsmmuj.v17i1.71690.
11. Pereira JS, Xavier ASMS, Monteiro RDS, Cruz VV, Pereira MFS, Tholl AD, et al. 3D-printed orthoses and prostheses for people with physical disability in rehabilitation centers: A scoping review. BMC Musculoskelet Disord 2024;25:783. doi: 10.1186/s12891-024-07875-3.
12. Borthakur PP. The role and future directions of 3D printing in custom prosthetic Design. Engineering Proceedings. 2025;81:10. doi: 10.3390/engproc2024081010.
13. Alrasheedi NH, Tlija M, Elloumi N, Louhichi B. A critical review of 3D printed orthoses towards workflow implementation in the clinical practice. J Eng Res 2025;13:1038-51. doi: 10.1016/j.jer.2024.01.024.
14. Atallah H, Qufabz T, Bakhsh HR, Ferriero G. The current state of 3D-printed orthoses clinical outcomes: A systematic review. BMC Musculoskelet Disord 2025;26:822. doi: 10.1186/s12891-025-09070-4.
15. Tel A, Kornfellner E, Molnár E, Johannes S, Moscato F, Robiony M. Selective laser sintering at the Point-of-Care 3D printing laboratory in hospitals for cranio-maxillo-facial surgery: A further step into industrial additive manufacturing made available to clinicians. Ann 3D Print Med 2024;16:100175. doi: 10.1016/j.stlm.2024.100175.
16. Ten Kate J, Smit G, Breedveld P. 3D-printed upper limb prostheses: A review. Disabil Rehabil Assist Technol 2017;12:300-14. doi: 10.1080/17483107.2016.1253117.
17. Silva R, Silva B, Fernandes C, Morouço P, Alves N, Veloso A. A review on 3D scanners studies for producing customized orthoses. Sensors (Basel) 2024;24:1373. doi: 10.3390/s24051373.
18. Dombroski CE, Balsdon ME, Froats A. The use of a low cost 3D scanning and printing tool in the manufacture of custom-made foot orthoses: A preliminary study. BMC Res Notes 2014;7:443. doi: 10.1186/1756-0500-7-443.
19. Pangestu PA, Harito C, Sitepu E, Herawan SG, Abrori SA, Tobing CC. 3D-printed ankle foot orthosis (AFO) with optimized material and design for children with cerebral palsy. Designs 2025;10:1. doi: 10.3390/designs10010001.
20. Manero A, Smith P, Sparkman J, Dombrowski M, Courbin D, Kester A, et al. Implementation of 3D printing technology in the field of prosthetics: Past, present, and future. Int J Environ Res Public Health 2019;16:1641. doi: 10.3390/ijerph16091641.
21. Mitsouras D, Liacouras P, Imanzadeh A, Giannopoulos AA, Cai T, Kumamaru KK, et al. Medical 3D printing for the radiologist. Radiographics 2015;35:1965-88. doi: 10.1148/rg.2015140320.
22. Bełżek A, Żerebiec M, Saj N, Rupeć Z, Kamiński P, Kaczmarski M, et al. Advances in 3D printed orthotics for rehabilitation. Wiad Lek 2025;78:539-43. doi: 10.36740/WLek/202602.
23. Vennam S, Vijayasankar KN, Pati F. 3D printed personalized assistive devices: a material, technique, and medical condition perspective. Appl Mater Today 2024;40:102403. doi: 10.1016/j.apmt.2024.102403.
24. Oud TAM, Lazzari E, Gijsbers HJH, Gobbo M, Nollet F, Brehm MA. Effectiveness of 3D-printed orthoses for traumatic and chronic hand conditions: A scoping review. PLoS One 2021;16:e0260271. doi: 10.1371/journal.pone.0260271.
25. Franco S, Ramos M, Cordova R, Ochoa E, Ccama G, Molina A. Design, manufacturing and mechanical evaluation of a 3D printed customized wrist-hand orthosis for the treatment of de quervain tenosynovitis. Engineering Proceedings 2025;83:2. doi: 10.3390/engproc2025083002.
26. Kim SJ, Kim SJ, Cha YH, Lee KH, Kwon JY. Effect of personalized wrist orthosis for wrist pain with three-dimensional scanning and printing technique: A preliminary, randomized, controlled, open-label study. Prosthet Orthot Int 2018;42:636-43. doi: 10.1177/0309364618785725.
27. Graham J, Wang M, Frizzell K, Watkins C, Beredjiklian P, Rivlin M. Conventional vs 3-dimensional printed cast wear comfort. Hand (N Y) 2020;15:388-92. doi: 10.1177/1558944718795291.
28. Kittani R, Watson A, Silverman S, Kanakaraju K, Chen J, Beltran J, et al. Evaluation of patient preference in 3D printed cast and associated cost compared to current standard of care. Ann 3D Print Med 2025:100223. doi: 10.1016/j.stlm.2025.100223.
29. Pollen TN, Jor A, Munim F, He Y, Daryabor A, Gao F, et al. Effects of 3D-printed ankle-foot orthoses on gait: A systematic review. Assist Technol 2025;37:287-303. doi: 10.1080/10400435.2024.2411563.
30. Hsu LH, Huang GF, Lu CT, Hong DY, Liu SH. The development of a rapid prototyping prosthetic socket coated with a resin layer for transtibial amputees. Prosthet Orthot Int 2010;34:37-45. doi: 10.3109/03093640902911820.
31. Lee CH. Design and development of a customized 3D-printed assistive device using modular 3D blocks. Disabil Rehabil Assist Technol 2025;20:1861-73. doi: 10.1080/17483107.2025.2462170.
32. Kuo FL, Wu YS, Kuo TY, Lee YS, Huang SW, Lee HC. Effects of 3D-printed assistive device on daily life function in patients with neurological impairment: A pilot study. Disabil Rehabil Assist Technol 2024;19:1648-56. doi: 10.1080/17483107.2023.2227222.
33. dos Santos Tavares G, Junior PA. Uso de Impressão 3D na Confecção de Órteses para Correção de Deformidades no Pé Plano Infantil. Journal of the Foot & Ankle 2025;19:6-. doi: 10.30795/jfootankle.2025.v19.1932.
34. Domingos Dias W, Soares JH, Corrêa Guimarães L, Espinosa Martínez N, Ramos Luz T, da Costa Soares Sousa Lima Y, et al. Exploring additive manufacturing in assistive technologies to transform the educational experience: empowering inclusion. J Complex Health Sci 2024;7:81-94. doi: 10.21595/chs.2024.24119.

35. Bañuls-Lapuerta FA, Marti-Miralles V, Gónzalez-García RJ, Martínez-Rico G. Effectiveness of 3D printed custom assistive devices in the school environment. Sci Rep 2025;15:39520. doi: 10.1038/s41598-025-23325-z.
36. Li J, Chen S, Shang X, Li N, Aiyiti W, Gao F. Research progress of rehabilitation orthoses based on 3D printing technology. Advances in Materials Science and Engineering 2022;2022:5321570. doi: 10.1155/2022/5321570.
37. Tam WS, Yip J, Fang C, Yick KL, Ng SP. An optimal de Quervain's tenosynovitis splint with ergonomic thumb support and evenly distributed pressure. Heliyon 2024;10:e26330. doi: 10.1016/j.heliyon.2024.e26330.
38. Buonamici F, Furferi R, Governi L, Lazzeri S, McGreevy KS, Servi M, et al. A practical methodology for computer-aided design of custom 3D printable casts for wrist fractures. Vis Comput 202036:375-90. doi: 10.1007/s00371-018-01624-z.
39. Quaresma C, Oliveira A, Quintão C, Soares B. (2025). The 3D Printing Center for Health: Advancing Personalized Healthcare Solutions Through Additive Manufacturing. In Proceedings of the 18th International Joint Conference on Biomedical Engineering Systems and Technologies-BIODEVICES. SciTePress; 2025. p. 197-204. doi: 10.5220/0013262000003911
40. Thorsen R, Bortot F, Caracciolo A. From patient to maker - a case study of co-designing an assistive device using 3D printing. Assist Technol 2021;33:306-12. doi: 10.1080/10400435.2019.1634660.
41. Tangcharoensathien V, Witthayapipopsakul W, Viriyathorn S, Patcharanarumol W. Improving access to assistive technologies: challenges and solutions in low- and middle-income countries. WHO South East Asia J Public Health 2018;7:84-9. doi: 10.4103/2224-3151.239419.
42. Iftekar SF, Aabid A, Amir A, Baig M. Advancements and limitations in 3D printing materials and technologies: A critical review. Polymers (Basel) 2023;15:2519. doi: 10.3390/polym15112519.
43. Hussaini A, Kyberd P, Mulindwa B, Ssekitoleko R, Keeble W, Kenney L, et al. 3D printing in LMICs: functional design for upper limb prosthetics in Uganda. Prosthesis 2023;5:130-47. doi: 10.3390/prosthesis5010011.
44. Demers L, Weiss-Lambrou R, Ska B. Development of the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST). Assist Technol 1996;8:3-13. doi: 10.1080/10400435.1996.10132268.
45. World Health Organization. Global Strategy on Digital Health 2020-2025. Geneva: World Health Organization [Internet]. 2021 [cited 15.01.2026]. Available from: https://www.who.int/publications/i/item/9789240020924.
46. Akpa-Inyang F, Rocher A, O'Connor M, Marais L. Ethical and regulatory issues in the application of 3D printing in orthopaedics: A scoping review. J Orthop Rep 2025;26:100610. doi: 10.1016/j.jorep.2025.100610.
47. Pettersson ABV, Ballardini RM, Mimler M, Li P, Salmi M, Minssen T, et al. Legal issues and underexplored data protection in medical 3D printing: A scoping review. Front Bioeng Biotechnol 2023;11:1102780. doi: 10.3389/fbioe.2023.1102780.
48. U.S. Food and Drug Administration. Technical Considerations for Additive Manufactured Medical Devices. FDA [Internet]. 2017 [cited 15.01.2026]. Available from: https://www.fda.gov/regulatory-information/search-fda-guidance-documents/technical-considerations-additive-manufactured-medical-devices.
49. Daly A. Medical 3D printing, intellectual property, and regulation. In: 3D Printing in Medicine. Amsterdam: Woodhead Publishing; 2nd ed. 2023. p. 385-98.
50. Harada Y, Sawada Y, Momma H, Takeshima R, Suzurikawa J. A nationwide survey on 3D printer utilization among occupational therapists in Japan. Disabil Rehabil Assist Technol 2025;20:3162-76. doi: 10.1080/17483107.2025.2538669.
51. Sivan M, Negrini S. An expanded workforce is needed to strengthen rehabilitation in health systems. BMJ 2024;384:q60. doi: 10.1136/bmj.q60.
52. World Health Organization. Rehabilitation 2030: A Call for Action. Geneva: World Health Organization [Internet]. 2017 [cited 15.01.2026]. Available from: https://www.who.int/initiatives/rehabilitation-2030.
53. Savage S, Flores-Saviaga C, Rodney R, Savage L, Schull J, Mankoff J. The global care ecosystems of 3D printed assistive devices. ACM Trans Access Comput 2022;15:1-29. doi: 10.1145/3537676.
54. Tack P, Victor J, Gemmel P, Annemans L. 3D-printing techniques in a medical setting: A systematic literature review. Biomed Eng Online 2016;15:115. doi: 10.1186/s12938-016-0236-4.
55. Drummond MF. Methods for the economic evaluation of health care programmes. Available from: http://thuvienso.thanglong.edu.vn//handle/TLU/6779
56. Cronin UM, Lyons E, O'Sullivan A, Cummins NM, O'Sullivan L. Healthcare professionals' initial attitudes towards 3D printing and effects of a short educational briefing: A pre-post pilot study utilising the technology acceptance model: Attitudes towards 3D Printing in healthcare. Ann 3D Print Med 2025;19:100205. doi: 10.1016/j.stlm.2025.100205.
57. Sarwar MA, Stampone N, Usman M. From static to adaptive: a systematic review of smart materials and 3D/4D printing in the evolution of assistive devices. Actuators 2025;14:483. doi: 10.3390/act14100483.
58. Borg J, Lindström A, Larsson S. Assistive technology in developing countries: National and international responsibilities to implement the Convention on the Rights of Persons with Disabilities. Lancet 2009;374:1863-5. doi: 10.1016/S0140-6736(09)61872-9.
59. Cieza A, Causey K, Kamenov K, Hanson SW, Chatterji S, Vos T. Global estimates of the need for rehabilitation based on the Global Burden of Disease study 2019: A systematic analysis for the Global Burden of Disease Study 2019. Lancet 2021;396:2006-17. doi: 10.1016/S0140-6736(20)32340-0.