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Additive Manufacturing and Experimental Biomechanical Validation of Low-Cost Body-Powered Upper-Limb Prostheses for Pediatric Users: A Systematic Review of Evidence for PETG-Based Hybrid Flexible–Rigid Designs in Uganda

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Abstract

Children with congenital upper-limb differences or limb absence may experience difficulties with bimanual activities, object handling, participation, and independence. These challenges can be greater in settings where prosthetic services, fabrication facilities, technical expertise, and maintenance resources are limited. This systematic review examines evidence relevant to developing and experimentally evaluating an affordable, body-powered upper-limb prosthesis for pediatric users in Uganda. Emphasis is placed on fused filament fabrication (FFF), polyethylene terephthalate glycol-modified (PETG), flexible–rigid structures, cable actuation, growth accommodation, mechanical performance, durability, and functional assessment. Evidence from biomedical engineering, prosthetics, rehabilitation, additive manufacturing, and assistive-technology studies was synthesized thematically. The reviewed studies show that additive manufacturing supports customized designs, rapid modification, and accessible prototype production, while body-powered systems can reduce dependence on batteries and electronic components. However, existing studies commonly involve small samples, limited long-term testing, inconsistent reporting of printing conditions, and varied assessment methods. PETG is suitable for several printed components, but its performance depends on build orientation, raster arrangement, layer bonding, and processing conditions. The evidence supports an integrated development approach combining local requirements, anthropometry, material-process control, mechanical testing, durability assessment, functional evaluation, maintenance, and cost analysis. This approach provides a basis for developing and validating a locally adaptable pediatric prosthetic prototype for Uganda.

Keywords: *Upper-limb prosthesis; pediatric prosthetics; additive manufacturing; 3D printing; fused filament fabrication; PETG; body-powered prosthesis; biomechanics; hybrid flexible–rigid structures; Uganda; low-resource settings.*

Figure 1. Evidence-to-design framework for translating systematic-review findings into a locally appropriate pediatric prosthesis.

1. Introduction

Effective upper-limb prosthetic care depends on several factors beyond the availability of the device itself. Cost, appropriate fitting, follow-up services, repair facilities, trained personnel, financing, and continuity of care all influence whether a prosthesis remains useful over time [1–4]. These issues are especially important for children because physical growth, changes in body dimensions, increasing activity levels, and developmental needs can require periodic adjustment, replacement, or modification of prosthetic components.

In Uganda, the suitability of a prosthetic device is closely linked to affordability, local fabrication capability, mechanical reliability, and the availability of appropriate methods for performance verification [5–9]. Additive manufacturing provides an opportunity to address some of these requirements because digital designs can be adjusted, reproduced, and manufactured without the molds and specialized tooling required by many conventional fabrication methods. The Cyborg Beast demonstrated the feasibility of producing an inexpensive body-powered prosthetic hand for children, while later investigations examined its functional use, user experiences, and rehabilitation outcomes [10–14]. Despite these developments, existing reviews indicate that the clinical evidence remains variable, with limited information on long-term use, durability, and sustained effectiveness [15–18].

The mechanical behavior of an additively manufactured prosthesis is also determined by the conditions under which it is produced. Factors such as build orientation, infill level, raster arrangement, nozzle temperature, layer height, printing speed, and bonding between successive layers can affect the strength, stiffness, and failure characteristics of printed parts [19–28]. PETG should therefore be evaluated according to its actual manufacturing conditions rather than solely on its bulk material properties. This is particularly relevant for prosthetic components exposed to repeated cable forces, bending loads, contact forces, and occasional impacts.

This systematic review brings together evidence relevant to the development of a low-cost, body-powered, PETG-based pediatric upper-limb prosthesis incorporating flexible and rigid components for use in Uganda. The review considers clinical and service requirements, body-powered and additive-manufactured prosthetic technologies, pediatric design considerations, relationships between FFF parameters and PETG properties, flexible–rigid integration, mechanical transmission and articulated mechanisms, mechanical and functional validation, and issues of implementation, maintenance, and affordability in low-resource environments.

2. Methods

The review was conducted as a systematic thematic evidence synthesis rather than a quantitative meta-analysis. A pooled statistical analysis was not considered appropriate because the available studies differ in participant characteristics, level of limb absence or deficiency, prosthetic design, manufacturing method, material, duration of intervention, and outcome measures. The reporting approach was guided by the PRISMA 2020 framework, particularly its emphasis on clearly defined review questions, eligibility considerations, evidence domains, and transparent synthesis [29][30].

The review framework was based on the research problem and the associated engineering and clinical objectives. Literature was considered from biomedical engineering, prosthetics, rehabilitation, additive manufacturing, and assistive-technology fields. Greater emphasis was placed on peer-reviewed systematic reviews, clinical studies, engineering investigations that described their methods, relevant technical standards, and guidance from recognized institutions. Earlier studies were also retained where they provided important information on established prosthetic devices, mechanical mechanisms, or assessment methods. Sources consisting mainly of unsupported commercial claims or lacking adequate methodological information were not treated as primary evidence. The available source material did not contain a complete database-specific search record, detailed search strings, a defined search date, or a protocol-registration number. These details have therefore not been introduced retrospectively. Instead, the review retains the documented thematic search and eligibility approach and identifies the associated reporting limitation.

2.1 Review Questions

The review was guided by six questions. First, what requirements are supported by the literature for low-cost pediatric upper-limb prostheses? Second, what evidence is available for body-powered and additively manufactured prosthetic designs? Third, how do FFF and PETG processing parameters affect structural performance? Fourth, how can rigid and flexible functions be appropriately distributed within a hybrid prosthetic structure? Fifth, which mechanical, biomechanical, and functional measures are suitable for evaluating such a device? Finally, which design, maintenance, and service considerations are particularly relevant to Uganda and other low-resource settings?

2.2 Evidence domains and eligibility framework

The evidence was organized into six domains. The framework retained the original concepts and the types of evidence sought in each domain.

Table 1: Thematic Domains, Core Concepts, and Primary Evidence Sought in the Literature Review

Domain	Core concepts	Primary evidence sought
Clinical/prosthetic	Upper limb; child; congenital difference; amputation	Function, acceptance, fitting, outcome measures
Design/actuation	Body-powered; cable; tendon; articulated hand	Mechanical advantage, force, excursion, control
Manufacturing	3D printing; FFF/FDM; additive manufacturing	Customization, process reporting, dimensional accuracy
Materials	PETG; polymers; flexible materials; anisotropy	Tensile/flexural behavior, fatigue, interfaces
Context	Uganda; LMICs; prosthetic services; assistive technology	Access, repair, workforce, sustainability
Validation	Grasp; pinch; ROM; SHAP; Box and Block; durability	Measurement reliability and clinical relevance

Evidence was synthesized thematically rather than by pooled effect size. This approach allowed findings from clinical studies, engineering experiments, standards and service-delivery literature to be compared without assuming that their outcomes were directly interchangeable.

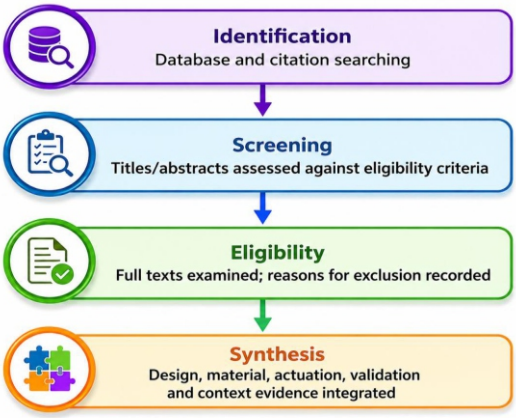

Figure 2. Transparent review and evidence-synthesis workflow retained from the source document.

3. Results: Thematic Synthesis of the Evidence

3.1 Assistive Technology and Prosthetic Service Delivery

WHO and UNICEF identify access to assistive technology as a broader health and service-delivery issue involving suitable products, trained personnel, service provision, financing, and supporting policies [1][2]. Similarly, WHO guidance on prosthetic and orthotic services emphasizes the need for technologies that respond to individual requirements while remaining practical and sustainable within the setting where they are delivered [3][4]. In Uganda, therefore, the usefulness of a technically advanced prosthesis depends not only on its design but also on whether users can obtain appropriate fitting, replacement components, repairs, and follow-up services.

Evidence from Uganda points to challenges related to personnel, equipment, availability of materials, and access to prosthetic services. Local studies also indicate the importance of involving users and relevant stakeholders in the design process and of providing devices that can be adjusted to individual needs [5–9]. Studies conducted in other resource-constrained settings suggest that additive manufacturing may help address some production-related difficulties. However, the benefits of 3D printing depend on access to trained personnel, digital design skills, suitable materials, reliable equipment, and appropriate quality-control procedures [31–34]. Local or distributed manufacturing should consequently be viewed as one possible means of improving production capacity rather than as a replacement for professional fitting, testing, and quality assurance.

3.2 Upper-Limb Prosthesis Technologies and Rationale for Body-Powered Designs

Upper-limb prostheses are generally grouped into passive, body-powered, and externally powered systems.

Passive devices are mainly intended to provide positioning, support, or stabilization. Body-powered prostheses transfer movement from the user through a mechanical linkage or cable system, whereas externally powered devices rely on electrical sensing and powered actuators [35–40]. The choice among these approaches should be based on the intended function, user's preferences and abilities, anatomical level, training requirements, and the resources available for continued support.

Body-powered and myoelectric prostheses offer different functional characteristics and practical requirements [37]. Myoelectric systems can provide control options that are not available in simple mechanical systems, but they depend on electronic components, power sources, and appropriate technical support. Body-powered systems, in contrast, can provide mechanical feedback through the transmission system and are generally less dependent on batteries and electronic components [37]. Their mechanical construction may also be advantageous where access to charging facilities, electronic repairs, or specialized maintenance services is limited [10][11] [37–41]. These considerations support the investigation of a low-cost body-powered design for pediatric users in settings where long-term technical and maintenance support may be constrained.

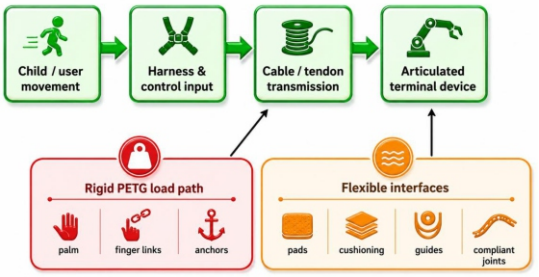

Figure 3. Proposed hybrid architecture for a pediatric body-powered prosthesis.

Mechanical transmission should be evaluated as a complete system. The force mechanical advantage can be expressed as MA = Fg/Fa, where Fg is output grasp force and Fa is input actuation force. Increasing force amplification may, however, require greater cable excursion or reduce opening range. Friction, cable routing, joint resistance and structural compliance can further reduce efficiency. Accordingly, grasp force alone is insufficient; actuation force, displacement, range, repeatability and post-cycling performance should be reported together [41–46].

3.3 Pediatric-Specific Design Requirements

Pediatric prosthetic users have needs that differ substantially from those of adults, and therefore children should not be considered simply as smaller versions of adult users. Changes in body size associated with growth can affect socket dimensions and interface fit, while developmental differences influence strength, coordination, and the ability to control the prosthesis.

In addition, activities such as playing, attending school, and participating in sports may expose the device to frequent, variable, and sometimes unpredictable loads [12–14] [47–52]. Based on the reviewed literature, pediatric upper-limb prostheses should therefore emphasize low distal weight, adjustable dimensions, replaceable components in areas subject to frequent wear, and designs that can accommodate changes in body size without requiring complete replacement or redesign of the device.

Studies of transitional 3D-printed prostheses have reported improvements in selected measures of dexterity; however, these results should not be interpreted as evidence of overall clinical effectiveness across pediatric populations [11][13][15]. Evidence concerning user experience also demonstrates that factors such as comfort, aesthetic appearance, reliability, and social acceptance can strongly influence whether a child consistently uses a prosthesis [14][49]. Furthermore, recent evaluations of outcome measures for children with upper-limb deficiency suggest that no single assessment tool adequately represents all relevant dimensions of prosthetic use. A combination of performance-based assessments and reports from users or caregivers is therefore more appropriate for evaluating pediatric prosthetic outcomes [53].

3.4 Additive Manufacturing for Upper-Limb Prostheses

Fused filament fabrication (FFF) offers several advantages for the development of upper-limb prostheses because digitally designed components can be manufactured directly, allowing designs to be modified and reproduced relatively quickly. Previous reviews have identified a wide range of 3D-printed upper-limb prosthetic devices and have reported the potential for reducing material and manufacturing costs. Nevertheless, these studies have also identified gaps in evidence concerning long-term acceptance, functional performance, and mechanical durability [16–18]. More recent systematic reviews have reported promising results in selected measures of function and user satisfaction, although the available evidence remains constrained by small participant groups and differences in the outcome measures used across studies [17][54].

The value of additive manufacturing extends beyond the possibility of reducing production costs. Its capacity for digital customization, parametric design, and repeatable fabrication makes it particularly suitable for pediatric prostheses that require controlled resizing and modular replacement as the child grows [12][47][55]. However, reliable clinical application requires appropriate manufacturing controls. These include recording and controlling printing parameters, maintaining consistency between material batches, inspecting critical dimensions, and mechanically validating manufactured components before use [19–28][56].

3.5 PETG and Process-Dependent Mechanical Behavior

Polyethylene terephthalate glycol (PETG) represents a practical candidate for structural prosthetic components because it offers a combination of printability, toughness, and resistance to environmental effects. Nevertheless, the FFF manufacturing process produces a layered structure composed of deposited material roads, which means that the mechanical properties of the final component can vary according to the direction of loading and the conditions used during printing [19–28]. Previous investigations consistently demonstrate that parameters such as print orientation, extrusion temperature, infill percentage, layer height, and raster configuration can significantly influence tensile strength and other mechanical properties [19–24]. More recent optimization studies have additionally demonstrated that the interaction between infill architecture and raster angle can produce substantial changes in component stiffness and strength [25][26].

Consequently, tensile testing of standardized specimens alone is insufficient for establishing the suitability of PETG for pediatric prosthetic components. Individual elements such as finger links, cable attachment points, palm structures, and joints are subjected to different combinations of stresses, stress concentrations, and loading directions. A more appropriate validation approach is therefore a two-stage process. The first stage should involve characterization of selected PETG printing configurations using standardized test specimens. The second stage should evaluate representative prosthetic components and the completed device under realistic static and cyclic loading conditions [19–28] [56–60].

Table 2: Influence of Additive Manufacturing Process Parameters on Mechanical Performance and Process Control

Process variable	Likely engineering consequence	Recommended control
Build orientation	Changes alignment of roads/layers with load	Orient critical tensile paths favorably
Layer height	Affects interfaces, resolution and build time	Report and hold constant during comparisons
Nozzle temperature	Influences interlayer diffusion/bonding	Calibrate within filament specification
Infill and wall count	Changes stiffness, mass and local collapse resistance	Optimize by component function, not globally
Raster angle/pattern	Changes directional stiffness and failure path	Align with dominant stresses where possible
Speed/cooling	Can alter fusion and void structure	Use validated machine-specific settings

3.6 Hybrid Flexible–Rigid Architectures

A prosthetic terminal device must perform two functions simultaneously: it must transmit forces effectively while also adapting sufficiently to the shape and surface characteristics of objects being grasped. A fully rigid construction can maintain its geometry and transfer loads efficiently, but it may provide limited conformity during contact. Conversely, excessive flexibility may compromise positional stability and result in energy losses during operation. Hybrid architectures provide a practical solution by separating structural and contact functions. In such designs, rigid PETG components can be used for primary load-beasring structures, while flexible materials are incorporated into areas such as contact pads, compliant joints, cable guides,

and regions that directly interact with the user or grasped objects [7][57] [61–66].

Research on printable joints and bio-inspired mechanisms has demonstrated the increasing feasibility of manufacturing compliant mechanisms and, in some cases, integrating multiple functions within a single printed structure [61][62]. However, interfaces between flexible and rigid materials require separate mechanical assessment because failure can occur through mechanisms such as interfacial peeling, localized stress concentration, material wear, or differences in deformation between the two materials. Material selection should therefore be guided primarily by the expected load paths and functional requirements rather than by appearance. Rigid materials are most appropriately assigned to anchors, structural members, and other load-bearing links, whereas compliant materials should be introduced only where their flexibility provides a demonstrable improvement in grip conformity, comfort, shock absorption, or controlled movement.

3.7 Articulated and Bio-Inspired Hand Mechanisms

Bio-inspired prosthetic design does not necessarily require exact reproduction of the anatomical structure or movement of the human hand. Instead, selected biological principles can be adapted to create mechanisms that are simpler to manufacture while retaining useful functional characteristics. Evidence from articulated 3D-printed prosthetic hands shows that features such as interconnected finger segments, tendon-like force transmission, and simplified thumb–finger opposition can be incorporated into practical mechanical designs [41][61] [67–71]. The work of Cuellar and colleagues is particularly relevant because it investigated articulated, bio-inspired fingers incorporated into a body-powered 3D-printed hand [41].

The major design challenge involves achieving an appropriate balance between functional capability and mechanical simplicity. Increasing the number of degrees of freedom may allow the prosthesis to conform more effectively to different objects and perform a wider range of grasping actions. However, greater mechanical complexity can also increase friction, device mass, assembly requirements, maintenance demands, and the number of potential failure points. For an affordable pediatric prosthesis, the available evidence therefore supports identifying a limited set of functionally important grasp patterns and optimizing the device for reliable and repeatable performance rather than attempting to reproduce the full range of movements available in the human hand [41][61] [67–71].

3.8 Mechanical, Biomechanical and Durability Validation

Variation in evaluation methods remains an important limitation within the existing literature on upper-limb prosthetic devices. Recent critical assessments have emphasized the need for more consistent and standardized testing approaches, while comparative investigations of commercially available and 3D-printed prosthetic hands have demonstrated the usefulness of structured, protocol-based performance evaluation [72][73]. The available evidence therefore supports a hierarchical validation framework in which testing progresses from the basic material level to the complete service level. This framework should include material characterization, component-level mechanical testing, transmission assessment, kinematic evaluation, durability and cyclic-loading tests, manufacturing quality assessment, functional performance testing, and, ultimately, service-level evaluation under realistic conditions of use. Such an integrated approach can provide a more reliable basis for determining whether a pediatric prosthesis is mechanically safe, functionally effective, manufacturable, and sufficiently durable for repeated everyday use.

Table 3: Multi-Level Validation Framework for Assessing the Performance, Functionality, Durability, and Serviceability of the Proposed Prosthetic Device

Validation layer	Recommended measures	Why it matters
Material	UTS, modulus, strain, flexural response	Establish process-specific PETG behavior
Component	Bending, tensile anchors, joint wear	Capture geometry-specific failure
Transmission	Fa, cable excursion, Fg, efficiency	Quantify user effort and output
Kinematics	ROM, aperture, repeatability	Establish usable motion
Durability	Cycles to failure, force retention, wear	Identify degradation, not only catastrophic failure
Manufacturing	Mass, dimensional error, print time	Assess reproducibility and pediatric suitability
Functional	Box and Block, task battery, SHAP-derived tasks where appropriate	Connect mechanics to meaningful activity
User/service	Comfort, satisfaction, repair time, replaceability, cost	Assess real-world appropriateness

Cyclic testing is particularly important. A device may pass a single static test while progressively losing grasp force through cable wear, joint loosening or cracking. Test reports should therefore document baseline performance, inspection intervals, cycle count, failure mode and retained performance after cycling [15–18] [72–76]. Relevant mechanical test standards include ASTM D638, ASTM D790, ISO 527 and ISO 178, while prosthetic-device evaluation should also consider applicable upper-extremity prosthesis guidance [69–73].

3.9 Functional Assessment and Outcome Measurement

Functional evaluation should be selected according to the characteristics of the intended users and the specific tasks that the prosthesis is expected to perform. The Box and Block Test has been applied in studies involving pediatric 3D-printed prostheses to assess gross manual dexterity [11][77]. The Southampton Hand Assessment Procedure provides a structured method for evaluating prehension and manipulation of objects. At the same time, recent research highlights the continuing need for outcome measures that are appropriately validated for children with upper-limb deficiency [53] [78–81].

For the proposed prototype, a practical assessment battery should incorporate several complementary measures rather than relying on a single performance indicator. These should include objective measurements of grasp and pinch force, joint range of motion and opening aperture, timed object-transfer activities, age-appropriate dexterity assessments, task completion rates, and the frequency of object slippage. User- or caregiver-reported functional performance should also be considered alongside comfort, maintenance requirements, and ease of repair. Combining these measures provides a more comprehensive assessment and reduces the possibility of judging a prosthesis as successful simply because it is capable of producing sufficient mechanical force in controlled laboratory testing.

3.10 Evidence Relevant to Uganda and Other Low-Resource Settings

Evidence from Uganda and other low- and middle-income countries indicates that adaptation to the local context should be considered an essential engineering requirement rather than an additional implementation consideration. Factors such as user and clinician involvement in design, locally relevant daily activities, available maintenance services, and reliable access to materials can substantially influence whether a prosthetic technology can be implemented successfully [5–9] [31–34]. Studies of adjustable prosthetic devices used within Ugandan clinical services further suggest that clinical feasibility alone does not guarantee long-term usability. Practical issues, including cleaning, exposure to heat, component repair, and continued technical support, must also be addressed [8][9]. A prototype intended for local use should therefore incorporate modularity as part of its service and maintenance strategy. Components that are expected to experience regular wear, including cables, pads, fasteners, and similar parts, should be designed for straightforward replacement. Parametric CAD models should permit controlled adjustment of dimensions as the child grows, while manufacturing documentation should enable the device to be reproduced using comparable equipment and materials. Cost analysis should also provide a transparent breakdown of consumable materials, purchased components, machine operating time, energy consumption, assembly requirements, and expected replacement components [31–34] [82–85].

4. Discussion

The overall evidence suggests that additive manufacturing has reached a level of technical development that supports continued investigation of customized pediatric upper-limb prostheses. However, the strength of the available clinical evidence remains below the level of confidence suggested by the growing interest in 3D-printing technologies [15–18][54].

The literature does not demonstrate that 3D printing is automatically superior to conventional manufacturing methods. Its principal advantage instead appears to arise from the combination of design flexibility, rapid modification, digital resizing, and the possibility of decentralized or distributed production. Body-powered mechanisms continue to be relevant where durability, limited dependence on specialized infrastructure, and ease of maintenance are important considerations [37–41]. Their practical advantages, however, do not remove the need to quantify the mechanical losses associated with actuation. Mechanical advantage, cable travel, output force, range of motion, and repeatability are interdependent parameters, and improvements in one characteristic may adversely affect another [41–46]. These relationships should therefore be evaluated together when developing and optimizing the actuation system.

PETG should likewise be assessed according to its behavior as an additively manufactured material rather than assumed to possess the same properties as conventionally manufactured bulk PETG. Printing parameters can affect anisotropy, interlayer bonding, stiffness, and failure characteristics [19–28]. The proposed research should consequently establish a direct relationship between material characterization using standardized specimens and the mechanical performance of individual components and the complete assembled prosthesis. This approach is more likely to identify failure mechanisms relevant to actual prosthetic use than material testing alone. The use of hybrid flexible–rigid architectures is promising because it permits structural load-bearing and object-contact functions to be assigned to materials with different mechanical characteristics [61–66]. Nevertheless, evidence specifically addressing flexible–rigid interfaces in pediatric prosthetic applications remains limited. The key engineering concern is therefore not simply whether different materials can be incorporated into a single printed device, but whether their interfaces can maintain adequate performance under repeated loading, environmental exposure, cleaning, wear, and the varied activities associated with childhood.

Overall, the evidence points toward a need to move beyond basic proof-of-concept demonstrations toward systematic and traceable validation. A comprehensive prototype investigation should document the materials used, printing and processing parameters, manufacturing repeatability, actuation requirements, static and cyclic mechanical performance, functional outcomes, ease of servicing, and overall cost. Integrating these engineering and user-oriented measures would provide a stronger basis for determining whether the resulting prosthesis is not only technically functional but also practical and sustainable for pediatric prosthetic care in Uganda.

4.1 Key research gaps and implications

Table 4: Summary of Key Research Gaps and Proposed Contributions of the Present Study

Research gap	Evidence status	Recommended contribution
Pediatric mechanical evidence	Sparse and heterogeneous	Report force, ROM, mass and cyclic durability
PETG in complete prostheses	Mostly coupon-based studies	Link process parameters to component and device behavior
Flexible–rigid integration	Limited prosthetic-specific validation	Test interfaces and contact-function benefits
Actuation efficiency	Often underreported	Measure Fa, excursion, Fg and losses
Outcome standardization	No single ideal pediatric measure	Use a multi-domain, transparent battery
Ugandan implementation	Emerging but limited	Include repair, local supply and service considerations
Growth accommodation	Important but incompletely quantified	Develop parameterized modular geometry
Affordability	Often reduced to material price	Report total fabrication and replacement costs

4.2 Proposed evidence-to-design pathway

Based on the synthesis, the experimental research should proceed through: (i) requirements elicitation with clinicians, prosthetic personnel and users or caregivers; (ii) parameterized anthropometric CAD; (iii) concept selection against measurable criteria; (iv) PETG process screening; (v) component-level mechanical testing; (vi) prototype manufacture and dimensional inspection; (vii) actuation and kinematic testing; (viii) cyclic durability testing; (ix) functional task evaluation; (x) cost, repair and maintainability analysis; and (xi) iterative redesign. Human testing should follow, rather than replace, laboratory safety and mechanical validation.

5. Limitations of the Evidence and of the Review

The evidence base is limited by the predominance of case reports, case series and prototype demonstrations, which restrict causal inference [15] [17,18]. Engineering studies frequently use standard coupons rather than complete prosthetic devices, limiting direct transferability to real structures [19–28]. Outcome measures also vary substantially, and pediatric psychometric evidence remains incomplete [53]. In addition, findings from high-resource laboratories cannot automatically be transferred to Uganda because material supply, printer reliability, technical expertise and clinical follow-up may differ [31–34].

The present review has a further reporting limitation: the source document describes a structured thematic search framework but does not provide a complete database search log, reproducible search strings, screening counts or formal protocol-registration information. Accordingly, the review should be interpreted as a systematic thematic synthesis of the documented evidence rather than as a fully reproducible quantitative systematic review. Future work should strengthen reproducibility by reporting databases, complete search strings, search dates, duplicate removal, screening numbers, reasons for exclusion and, where appropriate, a formal risk-of-bias assessment.

6. Conclusion

The available evidence provides a strong rationale for developing a low-cost, body-powered, additively manufactured pediatric upper-limb prosthesis for Uganda, but it does not yet provide a complete validated blueprint. The central research opportunity is an integrated design-and-validation pathway that connects local requirements and anthropometry with PETG process control, hybrid flexible–rigid material allocation, mechanical transmission, cyclic durability and functional assessment.

Such a study can move beyond proof-of-concept printing by producing traceable evidence on what the prototype can do, how much user effort it requires, how performance changes with repeated use, how accurately it can be reproduced, and whether it remains practical to repair, resize and maintain in the Ugandan context.

Appendix A. Recommended Reporting Checklist for the Prototype

Item	Minimum reporting requirement
User/design target	Age range, deficiency/amputation level, anthropometric basis
CAD	Version, parameterization, revision identifier
Printer	Model, nozzle diameter, calibration method
Material	Manufacturer, grade, color, batch where available
Print parameters	Orientation, temperature, layer height, infill, walls, speed
Mechanical testing	Fixture, loading rate, sample number, failure definition
Actuation	Input force, cable excursion, routing, output force
Durability	Cycle profile, inspections, retained performance, failure mode
Function	Task protocol, familiarization, repetitions, scoring
Economics	Material, energy, purchased components, labor/handling, replacements
Reproducibility	CAD/STL version and complete build/test records

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