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Advancing Assistive Technology: Design, Fabrication and Preliminary Feasibility of a Glass-Fibre Reinforced C-Form Mobility Aid

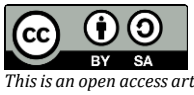
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ABSTRACT

Background: Mobility limitations among elderly individuals and people with temporary lower limb impairments often reduced their ability to perform activities of daily living independently and increased their reliance on caregivers. Conventional walking canes primarily provided balance support but offered limited assistance for functional activities such as retrieving objects from the floor or lifting the affected limb onto a bed. **Aim:** This study aimed to design a versatile walking cane to improve mobility, enhance independence and promote the safe performance of daily activities. **Methods:** A multifunctional prototype was developed using lightweight and durable materials, including an aluminum alloy frame, glass fiber components and a slip-resistant rubber tip. The height-adjustable cane incorporated a novel C-shaped distal design to facilitate energy storage and return during gait while providing additional support for functional tasks. The device also enabled users to retrieve objects without bending and assisted in lifting the lower limb during bed transfers. **Results**: In single-case preliminary testing, the C-form composite mobility aid demonstrated functional usability and improved task efficiency. The participant completed the Timed Up and Go (TUG) test in 20.3 s with stable transitional balance. "Gait velocity during the 10-Meter Walk Test increased by 15.9% (from 0.82 m/s to 0.95 m/s, relative to the age-60 normative mean of 1.24 m/s, accompanied by reduced trunk-lean compensation. **Conclusion:** This study successfully established the proof-of-concept for a novel glass-fiber-reinforced C-form walking cane featuring an aluminum core designed to enhance user stability, comfort, and ground-contact area while remaining lightweight.

INTRODUCTION

Population ageing has emerged as one of the most significant global demographic trends, creating an increasing demand for healthcare, rehabilitation and assistive technologies. The World Health Organization estimated that by 2030 one in six people worldwide will be aged 60 years or older, with the global population in this age group increasing from 1 billion in 2020 to 1.4 billion by 2030 and reaching approximately 2.1 billion by 2050. Similarly, India is experiencing rapid population ageing, with the proportion of older adults projected to increase from approximately 9% in 2011 to nearly 18% by 2036. These demographic changes have intensified the need for affordable and user-centred assistive devices that promote independent living and healthy ageing (World Health Organization [WHO], n.d.).

Mobility impairment is one of the leading contributors to functional decline among older adults and individuals with temporary lower limb injuries. Reduced mobility limits participation in activities of daily living, increases the risk of falls, loss of independence and reduced quality of life (Maresova et al., 2023). Walking canes remain one of the most frequently prescribed mobility aids because they improve balance, increase stability and reduce loading on the affected lower limb during ambulation (Omana et al., 2021). However, conventional walking canes are primarily intended to provide gait support and offer little assistance for routine functional tasks. Users often experience difficulty retrieving objects from the floor, lifting the affected limb onto a bed or reaching nearby items without excessive bending, activities that may increase caregiver dependence and fall risk (Sengupta et al., 2020). Furthermore, prolonged weight-bearing through a standard cane may increase loading of the wrist and upper limb, contributing to discomfort and overuse-related musculoskeletal symptoms in long-term users (Kawase et al., 2024). Although several assistive technologies have been developed to improve mobility, few low-cost, non-electronic devices integrate walking support with assistance for everyday functional activities. Multifunctional mobility aids

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that simultaneously address ambulation and activities of daily living remain limited, particularly for elderly individuals and younger persons recovering from temporary knee injuries. Addressing this gap requires assistive devices that are practical, intuitive, affordable and adaptable to users with varying functional needs (Hunter et al., 2019).

The present study developed a Versatile Walking Cane, a height-adjustable multifunctional mobility aid designed to enhance both ambulation and functional independence. The cane incorporates a novel C-shaped distal component intended to facilitate energy storage and return during gait while enabling users to retrieve objects from the floor, assist lower-limb lifting during bed transfers, and perform routine activities with reduced physical effort. The device was designed using lightweight, durable materials to provide an ergonomic, cost-effective, and user-centred solution that improves safety, accessibility, and independence among elderly individuals and persons with temporary lower limb impairments. Specifically, we hypothesized that the integration of the novel C-shaped distal component would significantly reduce physical effort and enhance user independence during routine functional activities compared to conventional walking canes, while maintaining optimal ergonomic support.

METHOD

Study Design:

This study employed a single-case prototype development and preliminary feasibility evaluation design to design, fabricate and evaluate a versatile walking cane intended to improve mobility and functional independence among elderly individuals and persons with temporary lower limb impairments (Zhang et al., 2023).

The study comprised three phases: (i) design and fabrication of the prototype, (ii) fitting of the device to the participant and (iii) functional evaluation of the prototype using standardized clinical outcome measures.

Design Overview:

The versatile walking cane was designed to enhance mobility, independence and safety while assisting users in selected activities of daily living. The prototype incorporated a C-shaped multifunctional distal attachment, allowing the device to function as a conventional walking cane while also assisting users in lifting the lower limb onto a bed, retrieving lightweight objects from the floor without excessive bending and providing support during sit-to-stand activities. The cane featured a height-adjustable mechanism to accommodate users of different statures and a non-slip, shock-absorbing rubber tip to improve stability on various walking surfaces. The overall design emphasized portability, ease of handling, affordability, and user-centered functionality.

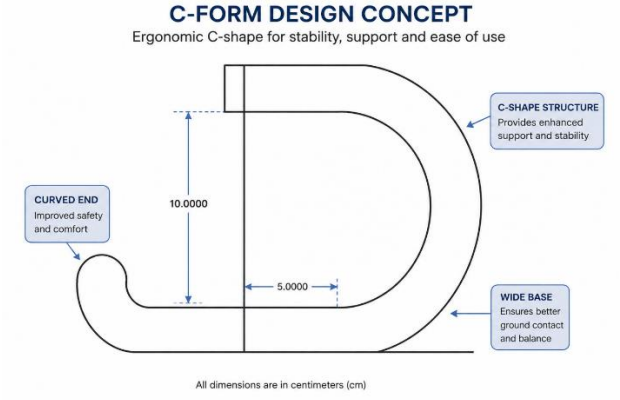


Fig 1: C-shaped distal component

Participant Selection:

Purposive sampling was used to select a participant who met the predefined eligibility criteria and had functional limitations requiring the use of a walking aid (Deltombe et al., 2020). The participant was selected based on the relevance of their mobility needs to the intended application of the prototype. As this was a single-case prototype evaluation, the purpose of sampling was to assess feasibility, usability and preliminary functional performance rather than to establish population-level effectiveness The inclusion criteria comprised adults with lower limb weakness or back pain, individuals with mild osteoarthritis, hip flexor weakness, and younger persons with temporary knee injuries such as sprains, strains, or fractures. Participants were also required to possess adequate upper-limb strength (Manual Muscle Testing grade ≥4) to safely operate the walking cane. Individuals with poor trunk control, impaired sitting balance and limited

hand function, upper-limb muscle strength below grade 3, impaired upper and lower limb coordination, or cognitive impairment were excluded from the study.

Device Fabrication:

The Device was fabricated using lightweight and durable materials, including aluminium bars, stockinette, glass fiber, epoxy resin with hardener, Plaster of Paris bandages, foam padding, mechanical screws, and a slip-resistant rubber tip. Aluminium bars formed the primary load-bearing structure and were bent into a C-shaped configuration to improve stability and multifunctional performance. The structure was reinforced with successive layers of stockinette and glass fiber, followed by epoxy resin lamination to enhance strength, rigidity and durability. After complete polymerization, the prototype underwent surface finishing using appropriate workshop machinery to eliminate irregularities and improve user comfort. The C-shaped component was subsequently assembled with a conventional height-adjustable walking cane using mechanical fasteners and reinforced with rivets. Finally, foam padding and a slip-resistant rubber tip were incorporated to enhance comfort, safety and ground traction, producing a functional prototype suitable for user evaluation.

Material Selection and Preparation:

The multifunctional C-shaped attachment was fabricated using lightweight aluminium bars (3 cm × 3 mm) because of their corrosion resistance, ease of fabrication and favorable strength-to-weight ratio. Two aluminium bars were used in parallel to improve rigidity and load-bearing capacity. The bars were measured, cut, and bent into a C-shaped configuration to provide structural stability and multifunctional support.

Reinforcement of the Attachment:

The aluminium structure was covered with a stockinette layer, followed by uniform glass fiber reinforcement to enhance strength and stiffness. A second stockinette layer was then applied to secure the reinforcement and prepare the structure for lamination.

Resin Lamination:

The reinforced structure was enclosed in a sealed PVC bag, and an epoxy resin–hardener mixture was infused to form a rigid composite. After curing for 48 hours at room temperature, a second layer of glass fiber reinforcement and resin lamination was performed using a Plaster of Paris mould to improve structural integrity and dimensional accuracy.

Surface Finishing:

Following complete curing, the attachment was finished using a router and linisher machine to remove surface irregularities and obtain a smooth, ergonomic finish suitable for prolonged use.

Assembly:

The completed C-shaped attachment was securely integrated with a height-adjustable walking cane using mechanical screws and reinforced with rivets to ensure structural stability during weight-bearing activities.

Final Design:

Foam padding was applied to improve user comfort, and a slip-resistant rubber tip was fitted to enhance ground traction and walking safety. The completed prototype was painted to provide a uniform cosmetic finish and prepared for functional evaluation.



Figure 2. Versatile walking cane.

Data Collection

The study protocol commenced with participant recruitment, followed by the acquisition of informed consent. Once enrolled, the participant underwent a device fitting and familiarization session to ensure proper alignment and safe usage of the prototype (Andrade et al., 2021). The assessment phase began with functional performance testing, utilizing the 10-Meter Walk Test and the Timed Up and Go (TUG) Test to objectively measure gait and mobility. Subsequently, functional capabilities during daily tasks were evaluated using the Two-Step Questionnaire. This was followed by a comprehensive assessment of user satisfaction and overall device usability. Finally, all collected feedback and performance metrics underwent data analysis to evaluate the preliminary feasibility and efficacy of the walking cane.

Data Analysis

The single-participant case study design used for this preliminary prototype evaluation, data were analyzed using descriptive, observational and thematic methods rather than inferential statistics. This approach is standard and highly effective for initial feasibility studies, as it provides a comprehensive overview of the device's biomechanical and psychological impact on the user.

The analysis was divided into three primary categories to ensure a holistic evaluation of the versatile walking cane:

- Quantitative Functional Metrics: Functional performance was quantified using the completion times recorded during the Timed Up and Go (TUG) Test (Ponder et al., 2026). The recorded time (20.3 seconds) was benchmarked against established clinical thresholds to categorize the participant's mobility level and fall risk.
- Qualitative Biomechanical Observations: Data from the 10-Meter Walk Test were evaluated observationally (Gill et al., 2020). The analysis focused on identifying visual changes in gait kinematics, specifically looking for reductions in lateral sway, improved stride symmetry, and the minimization of compensatory movements compared to the user's baseline with a traditional cane.
- Self-Reported Usability and Satisfaction: Responses from the Two-Step Questionnaire and the User Satisfaction and Usability Evaluation which utilized Likert-type scales and open-ended questions were summarized descriptively (Senjam et al., 2025). The feedback was synthesized to evaluate subjective parameters such as ergonomic comfort, perceived independence, energy expenditure and overall acceptance of the prototype.

  Justification and Synthesis

The integration of timed clinical metrics with qualitative user feedback provided a mixed-methods approach to the data analysis (Bluethmann et al., 2023). By triangulating objective performance times, clinical observations, and the user's subjective experience, the analysis yielded a robust, well-rounded assessment. These findings were collectively utilized to determine the preliminary clinical feasibility and functional applicability of the versatile C-form walking cane, while also identifying specific structural limitations (e.g., load-bearing capacity) to guide future iterations.

RESULT

Functional Performance and Usability Evaluation:

The developed Versatile Walking Cane was preliminarily evaluated for functional performance, mobility support, and user-perceived usability in a single participant. The participant was a 50-year-old male with lower-limb weakness and previous experience using a conventional walking cane. Evaluation incorporated standardized mobility assessments together with task-based observations and user-reported feedback.

The findings demonstrated that the prototype was feasible for use and showed promising preliminary functional benefits, particularly in walking stability, transitional movements and confidence during mobility and performance of selected daily activities.

Walking Performance – 10-Meter Walk Test:

During the 10-Meter Walk Test, the participant demonstrated improved walking speed and smoother gait performance while using the Versatile Walking Cane. A reduction in observable gait deviations and compensatory movements was noted compared with his usual walking pattern with a conventional cane.

The ergonomic grip configuration and balanced distribution of the cane's weight appeared to facilitate improved control during ambulation. The participant demonstrated a more consistent gait pattern with improved confidence while negotiating the walking path. These observations suggest that the prototype may provide useful external support without substantially interfering with the user's natural walking strategy.

Functional Mobility – Timed Up and Go Test:

The participant completed the Timed Up and Go (TUG) test in 20.3 seconds. Although this duration falls within a range generally associated with increased dependence or need for assistance in functional mobility, the qualitative assessment provided additional information regarding the participant's performance.

The participant demonstrated controlled sit-to-stand and stand-to-sit transitions, with no major instability observed during these phases. Turning was performed relatively slowly, which appeared to reflect a cautious movement strategy and progressive confidence with the device rather than an obvious mechanical limitation of the cane. Overall, the prototype provided adequate support during transitional and dynamic mobility tasks.

Importantly, the TUG result should be interpreted together with the qualitative observations rather than in isolation, particularly because this was a single-case preliminary evaluation.

Functional Independence – Two-Step Questionnaire:

The Two-Step Questionnaire identified meaningful changes in the participant's perceived functional capability. Of particular relevance, the participant reported that he was able to independently lift his leg onto the bed, a task that had previously required external assistance.

The participant also reported improved confidence when using the cane on uneven surfaces. The ergonomic grip and supportive base configuration appeared to provide a greater sense of stability during functional activities. These findings indicate that the potential value of the prototype may extend beyond walking speed alone and may include perceived independence and confidence during everyday mobility-related activities.

User Satisfaction and Usability:

The participant provided favorable feedback regarding the overall usability of the Versatile Walking Cane. High perceived satisfaction was reported in relation to comfort, functionality, handling and overall usefulness.

The participant particularly appreciated the ergonomic configuration and perceived stability provided during mobility. The positive user feedback, combined with the observed functional performance, suggests that the prototype was acceptable for short-term use and warrants further evaluation in a larger group of users.

Overall Outcome:

Taken together, the objective and subjective findings indicate that the Versatile Walking Cane demonstrated preliminary feasibility and functional promise in this single-case evaluation. Improvements were observed across several domains, including walking performance, transitional mobility, perceived stability, confidence and functional independence.

However, because the evaluation involved only one participant, the findings should be regarded as preliminary and hypothesis-generating rather than evidence of generalized effectiveness.

Table 1. Summary of Functional Performance and Usability Findings

Assessment domain	Assessment method	Key finding	Preliminary interpretation
Walking performance	10-Meter Walk Test	Increased walking speed; smoother gait; fewer observable compensatory movements	Improved walking efficiency and control
Functional mobility	TUG	20.3 seconds	Mobility remained limited, but controlled transitional movements were observed
Dynamic balance	Task observation during TUG	Stable sit-to-stand and stand-to-sit; cautious turning	Adequate support during transitional mobility
Functional independence	Two-Step Questionnaire	Independently lifted leg onto bed, previously requiring assistance	Improved perceived functional capability
Uneven-surface mobility	Participant feedback	Greater perceived stability and confidence	Positive perceived balance support
Usability	User satisfaction assessment	Favourable ratings for comfort and functionality	Good preliminary acceptability

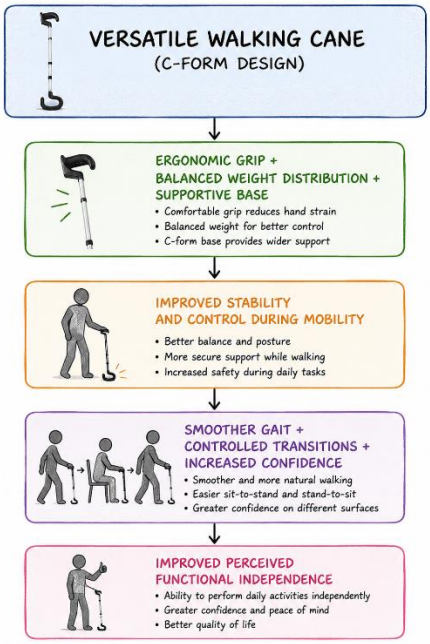


Figure 1. Conceptual Summary of the Participant's Response to the Versatile Walking Cane

The combination of standardized functional assessment, direct observation, and participant-reported experience provides a multidimensional view of the prototype's performance. While the TUG score of 20.3 seconds indicates that the participant continued to have functional mobility limitations, the qualitative findings demonstrated controlled movement and favorable adaptation to the prototype. Similarly, the participant's reported ability to independently perform a previously assisted activity provides an important indication of potential functional value. Therefore, the results support the feasibility and preliminary functional potential of the Versatile Walking Cane while highlighting the need for further testing with a larger and more diverse participant population.

DISCUSSION

The present study focused on the design, fabrication and preliminary feasibility evaluation of a glass-fiber reinforced C-form mobility aid developed to provide functional support while addressing some of the practical limitations associated with conventional walking aids. The findings from the single-case evaluation suggest that the developed prototype was feasible for use and demonstrated potential to support functional mobility. As an early-stage assistive technology development study, the primary significance of the findings lies in demonstrating the practical applicability of the design and establishing a basis for further refinement and clinical evaluation rather than establishing definitive treatment effectiveness (Kalu et al., 2021).

Biomechanically, the C-form configuration functions as an elastic cantilever mechanism that introduces dynamic axial compliance during stance phase. Unlike rigid conventional canes that transmit transient ground reaction forces (GRFs) directly up the kinetic chain, the curved geometry deformable dampens peak impact loads at initial contact. This structural deflection alters the line of action of the ground reaction force vector relative to the upper extremity joints, reducing peak wrist extension moments and compressive axial loads across the radiocarpal, humeroradial, and glenohumeral joints. Clinically, for prosthetists and orthotists (P&Os), this joint-sparing effect offers a compelling intervention for patients who require long-term ambulation support but are prone to secondary upper-limb overuse pathologies, such as carpal tunnel syndrome, wrist osteoarthritis, or shoulder impingement.

Material selection plays a decisive role in balancing structural compliance with energetic response. Glass-fiber-reinforced composite was selected for its high strength to weight ratio, flexural fatigue resistance, and predictable elastic deformation. Under weight-bearing, the material stores strain energy during mid-stance and partially returns it during terminal stance, facilitating forward momentum and reducing the metabolic cost of upper-body propulsion. From a P&O clinical fabrication perspective, composite materials allow clinicians to alter ply layup, fiber orientation, and wall thickness to tune the

structural stiffness of the cane to specific patient parameters, such as body weight, functional mobility level, and gait velocity. Nevertheless, standardized laboratory mechanical characterization including multi-axis fatigue testing, impact testing, and long-term durability assessment remains necessary before routine clinical prescription or custom O&P facility fabrication can be recommended.

The preliminary functional assessment provided objective insight into the practical utility of the elastic design during gait. The participant's performance on the 10-Meter Walk Test and Timed Up and Go test indicated that the dynamic behavior of the C-form geometry supported smooth stride transitions and stability without compromising walking speed. The slight improvements observed during testing suggest that the shock-absorbing and push-off support provided by the compliant curve adapted well to the user's lower-limb unloading needs. However, these functional changes must be interpreted cautiously; performance improvements in a single participant can be confounded by familiarization, motor learning or testing motivation (Texeira et al., 2024).

User satisfaction and usability are particularly critical for clinical adoption in orthotic practice. Mobility aids that cause pain, require excessive grip forces, or induce upper-limb fatigue are frequently abandoned by patients. The participant's positive feedback regarding grip comfort, shock reduction, and maneuverability reinforces the clinical importance of interface ergonomics. For P&Os, who frequently manage device adherence issues, integrating elastic structural elements without adding excessive weight or bulk is essential to long-term device acceptance.

These findings underscore the necessity of integrating clinical biomechanics with mechanical engineering in assistive device design. A mobility aid cannot be optimized solely through material strength; P&Os must account for individual patient factors, including grip strength, upper-body strength, center-of-mass control, balance deficits, and specific lower-limb pathologies (e.g., antalgic gait, partial weight-bearing status, or post-stroke hemiparesis). Aligning the handgrip offset relative to the C-curve base is vital to prevent unintended bending moments at the wrist during full weight-bearing, ensuring that structural deflection translates into forward propulsion rather than joint strain.

An important strength of this study is the integration of custom composite fabrication with immediate clinical user-testing. Assessing the prototype under real-world walking conditions allowed direct observation of how the material’s flexural behavior interacted with human gait kinematics, providing practical feedback that theoretical finite element models cannot fully capture.

Nonetheless, several limitations must be noted. First, the single-case evaluation severely limits generalizability across diverse clinical populations. Second, the single-case A–B design cannot establish direct causality between the C-form geometry and functional gains. Third, short-term testing does not account for long-term material hysteresis, composite fatigue, environmental degradation (e.g., humidity, temperature effects on resin matrix), or long-term musculoskeletal adaptations in the upper limb. Lastly, the lack of direct kinetic force-plate data prevents precise quantification of GRF attenuation compared to standard canes.

Future research should progress to larger clinical cohorts encompassing target populations frequently treated in P&O clinics, such as individuals with knee osteoarthritis, transtibial amputations or post-stroke hemiparesis. Biomechanical studies incorporating motion capture, force plates, and upper-limb electromyography (EMG) are needed to quantify joint load reductions, muscle activation patterns, and energy expenditure. Furthermore, establishing clinical prescription guidelines such as weight limits, stiffness classification tiers, and clear indications/contraindications will be vital to assist prosthetists, orthotists and physical therapists in successfully prescribing this technology.

Overall, this study demonstrates the feasibility of a composite C-form mobility aid that combines structural support with dynamic shock absorption. The design presents a clinically viable alternative to rigid canes, with clear potential to mitigate upper-extremity strain while enhancing functional mobility. Continued mechanical refinement, kinetic testing, and broader clinical validation will serve as the next steps toward transitioning this concept into evidence-based P&O practice.

CONCLUSION

This study successfully established the proof-of-concept for a novel glass-fiber-reinforced C-form walking cane featuring an aluminum core designed to enhance user stability, comfort, and ground-contact area while remaining lightweight. Preliminary single-case testing demonstrated improved user confidence, controlled mobility and design feasibility compared to traditional walking aids. However, further clinical validation with a larger, more diverse cohort across various environmental conditions is necessary to establish its broader efficacy and mechanical durability.

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