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# Design and Development of A 3d-Printed External Prosthetic Elbow Joint with Adjustable Locking Mechanism

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***Abstract***

***Background:*** Restoration of elbow function in individuals with trans-humeral amputation and elbow disarticulation remains challenging due to limitations in prosthetic suspension, restricted space for joint mechanisms, and unreliable locking systems in existing prosthetic elbow joints. A functional, cost-effective, and mechanically simple elbow joint with reliable locking is essential to improve performance of activities of daily living.

***Objective:*** This study aimed to design and develop an external prosthetic elbow joint capable of providing controlled elbow flexion and extension with a reliable adjustable locking mechanism suitable for body-powered prosthetic systems.

***Methods:*** A conceptual prototype development study was conducted. The prosthetic elbow joint was designed using computer-aided design software and fabricated using fused deposition modelling with poly-lactic acid, supplemented by steel components at critical load-bearing regions. The joint incorporated a push-lock latching mechanism actuated through a Bowden cable, enabling elbow flexion and extension in 40° increments up to a maximum range of approximately 160°. Prototype-level evaluation focused on functional feasibility, range of motion, locking reliability, and structural stability.

***Results:*** The fabricated prototype demonstrated smooth and controlled elbow flexion and extension with consistent locking at predefined angular positions. The locking mechanism showed reliable engagement without unintended disengagement during repeated manual testing. The joint maintained structural integrity and alignment under simulated loading conditions. Additive manufacturing enabled accurate fabrication with minimal post-processing. However, the prototype was relatively bulky and did not incorporate forearm pronation–supination.

***Conclusion:*** The developed 3D-printed external prosthetic elbow joint successfully achieved controlled flexion–extension with secure adjustable locking, offering a cost-effective and mechanically simple solution for body-powered upper-limb prostheses. Further design refinement and clinical evaluation are required to improve compactness, expand functionality, and validate long-term clinical applicability.

## I. INTRODUCTION

Major upper-extremity limb loss represents a relatively small proportion (8%) of the total limb-loss population, estimated at 1.5 million individuals.[1] Functional interaction with the environment is positively correlated with preservation of limb length.

Proximal amputations, such as shoulder disarticulation or forequarter amputation, necessitate bulky prosthetic systems and are associated with substantially increased energy expenditure. Therefore, whenever feasible, preservation of the elbow and shoulder joints is prioritized in clinical practice to optimize post-amputation function. In contrast, very short residual segments following high trans-radial or high trans-humeral amputations may compromise the functional contribution of the adjacent proximal joint. For effective prosthetic suspension and preservation of joint function, a minimum residual bone length of approximately 5 cm distal to the joint is required. Although distal third forearm amputations maintain the anatomical origin and insertion of the pronator teres and supinator muscles, functional forearm rotation of the residual limb is rarely observed in clinical practice.[1,2]

Conversely, joint disarticulations offer distinct advantages and disadvantages. While the resulting long residual limbs may be incompatible with many modern prosthetic systems and often necessitate soft tissue augmentation, including myodesis or myoplasty, to protect bony prominences and ensure prosthetic comfort, preservation of distal condyles and intact muscle units provides superior prosthetic suspension and rotational stability. Furthermore, diaphyseal humeral shortening combined with elbow disarticulation can enhance prosthetic fit and rotational control while maintaining adequate space for prosthetic integration.[1-4]

Rehabilitation of individuals with trans-humeral amputation remains clinically challenging, with prosthetic suspension being a major limiting factor. Although elbow disarticulation allows improved suspension due to the presence of humeral condyles, the limited available space restricts the integration of elbow joint mechanisms-particularly electronic systems-thereby necessitating the use of externally mounted hinge joints.[5]

The prosthetic elbow joint plays a critical role in restoring upper-limb function. It enables controlled elbow flexion and extension, which are essential for performing activities of daily living such as feeding, grooming, reaching, and object manipulation. An effective prosthetic elbow joint also improves functional reach, enhances task efficiency, and supports proper upper-limb biomechanics.

Additionally, the availability of a stable locking mechanism at desired angles contributes to improved safety, load-bearing capacity, and user confidence during functional activities. Overall, a well-designed prosthetic elbow joint significantly enhances independence, functional performance, and quality of life in trans-humeral amputees & Elbow Disarticulation.[6-9]

Based on an extensive review of the literature and currently available commercial prosthetic elbow joints, there remains a lack of a functional elbow joint capable of providing controlled elbow flexion and extension along with reliable locking at desired positions to facilitate the performance of functional tasks.

Therefore, this study aims to design and develop a prosthetic elbow joint capable of providing complete elbow flexion and extension, along with a reliable locking mechanism at desired positions, to facilitate the performance of the aforementioned functional tasks.

## II. Methodology

### *2.1. Study Design*

A conceptual and functional prototype development study was conducted to design and fabricate an external prosthetic elbow joint with an adjustable locking mechanism. The objective was to achieve controlled elbow flexion and extension with reduced energy expenditure using a body-powered control system.

### *2.2. Design Framework*

The prosthetic elbow joint was designed to allow sagittal plane motion through flexion and extension while enabling secure locking at predetermined angular positions. Emphasis was placed on mechanical simplicity, safety, structural stability, and cost-effectiveness, ensuring suitability for individuals with elbow disarticulation and trans-humeral amputations.

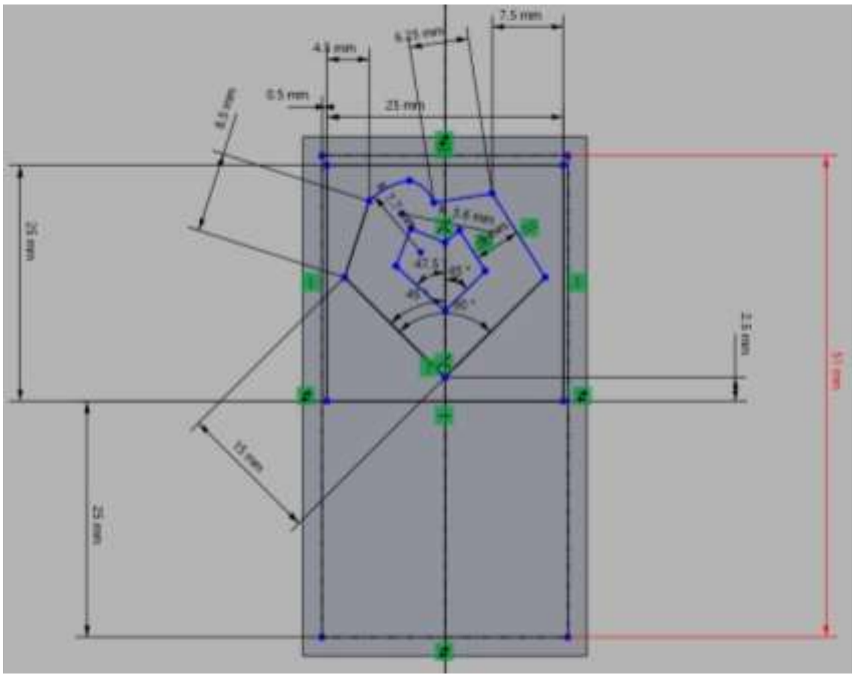

**Figure 1: 2D drawing in Auto cad Software**

### *2.3. Materials and Components*

The prototype was fabricated using poly-lactic acid (PLA) through fused deposition modelling (FDM) technology, selected for its adequate tensile strength, moderate flexibility, low cost, and ease of fabrication. Steel components were incorporated at critical load-bearing and locking regions to enhance durability. The elbow joint assembly comprised a base body, gear arm, locking pin, spring, pulley system, Bowden cable, fastening screws, and an external covering shell.

### *2.4. Computer-Aided Design and Modelling*

Initial dimensions were developed using AutoCAD 2D (Figure1) drawn sketches  based on anatomical and functional requirements. These sketches were translated into three-dimensional computer-aided design (CAD) models using Geomagic Design X software(Figure 2). Individual components were designed and assembled virtually to verify alignment, range of motion, and spatial accommodation of the internal locking mechanism. The finalized models were exported in STL format for additive manufacturing.

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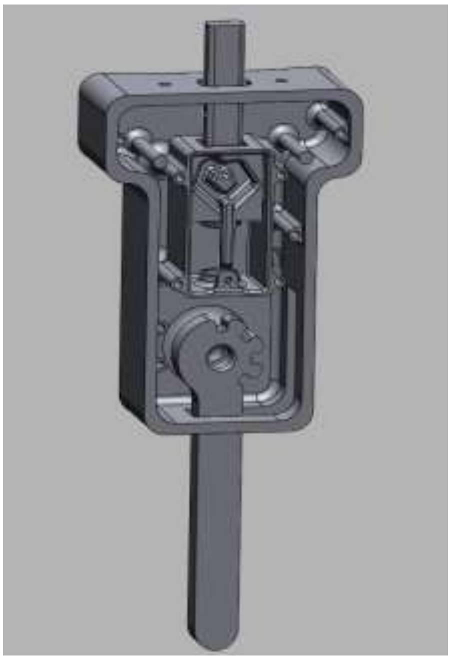
*2.5. Fabrication Procedure*

Additive manufacturing was performed using an Ender-3 Pro fused deposition modelling printer. The CAD models were processed through slicing software to generate printer-compatible toolpaths.

Printed components underwent post-processing and were mechanically assembled to form the functional elbow joint prototype, followed by integration of the locking and cable-actuated control mechanisms.



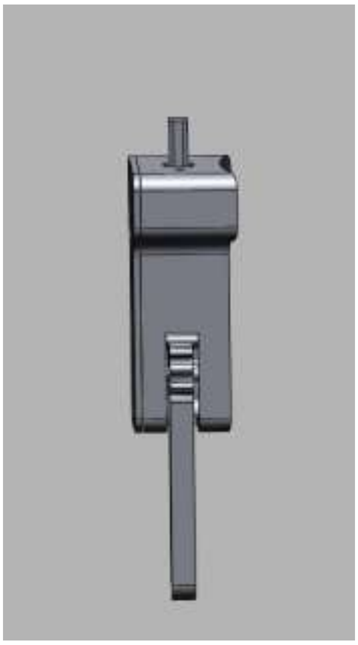


**Figure 2: 3D modelling functional elbow joint**

*2.6. Working Principle*

The prosthetic elbow joint operates through a push-lock latching mechanism actuated by a Bowden cable. Activation of the push-lock bar enables incremental elbow flexion or extension in 40° intervals, allowing a maximum range of motion of approximately 160°. Once the desired position is attained, the locking mechanism automatically engages to stabilize the joint. Re-activation of the push-lock bar permits repositioning of the elbow as required for functional tasks(Figure 3).

*2.7. Outcome Assessment*

Prototype-level evaluation focused on functional feasibility, including range of motion, reliability of the locking mechanism, smoothness of joint operation, and structural stability under simulated use conditions. Clinical evaluation involving amputee participants is proposed for future validation.

## III. Result

The designed external prosthetic elbow joint was successfully fabricated using 3D printing technology and mechanically assembled into a functional prototype. The prototype demonstrated effective elbow flexion and extension with an integrated locking and unlocking mechanism, fulfilling the primary design objectives of the study.

The prosthetic elbow joint achieved a maximum range of motion of approximately 160°, with movement occurring in discrete 40° incremental positions. The locking mechanism reliably engaged at each predefined position, allowing the elbow to be securely maintained during simulated functional tasks. Releasing and repositioning of the joint was smooth and could be performed without excessive effort through the body-powered control system.

The push-lock latching system provided consistent and stable locking across all available positions. No unintended disengagement or slippage was observed during manual testing, indicating adequate mechanical stability of the locking assembly. The mechanism allowed repeated locking and unlocking without noticeable wear or functional degradation during prototype-level evaluation.

The combined use of PLA for structural components and steel for load-bearing elements resulted in a stable assembly capable of supporting the prosthetic forearm segment under simulated loading conditions.

The joint maintained alignment throughout flexion and extension movements, and no structural failure was observed during repeated operational cycles.

**Figure 3: Final design of functional Prosthetic Elbow joint**

The use of computer-aided design and fused deposition modelling enabled accurate fabrication of the joint components with acceptable dimensional precision. Minor post-processing was sufficient to achieve proper assembly and functional movement, demonstrating the feasibility of using low-cost additive manufacturing techniques for prosthetic elbow joint development.

Although the prototype achieved the intended flexion–extension and locking functions, the overall structure was relatively bulky, and forearm pronation–supination was not incorporated in the current design. These limitations were identified as areas for further refinement in future iterations.

## IV. DISCUSSION

The present study aimed to design and develop an external prosthetic elbow joint capable of providing controlled flexion and extension with a reliable locking mechanism to support functional task performance in individuals with elbow disarticulation and trans-humeral amputation. The results demonstrate that the developed prototype successfully achieved its primary functional objectives.

The prosthetic elbow joint provided a functional range of motion of approximately 160°, which is sufficient to perform most activities of daily living, such as reaching, feeding, and grooming. The incorporation of a push-lock latching mechanism enabled stable positioning of the elbow at predetermined angular intervals, thereby addressing a key limitation identified in existing commercially available prosthetic elbow joints—namely, inadequate or unreliable locking at functional positions.

The use of a body-powered control mechanism offers advantages in terms of simplicity, reliability, and reduced cost when compared to myoelectric or electronically controlled elbow units. This is particularly relevant in low-resource settings, where access to advanced prosthetic technologies may be limited. The application of 3D printing technology facilitated rapid prototyping, design customization, and cost reduction, supporting its feasibility for prosthetic component development.

However, certain limitations were observed in the current prototype. The overall bulkiness of the joint may affect cosmetic acceptance and user comfort. Additionally, the absence of forearm pronation–supination restricts the functional envelope of the prosthesis and may necessitate compensatory movements during complex tasks. These findings are consistent with reports in the literature that highlight trade-offs between mechanical simplicity and functional versatility in external elbow joint designs.

Future iterations should focus on reducing the overall profile of the joint, incorporating rotational capabilities, and conducting systematic mechanical testing and clinical trials to evaluate long-term durability, user satisfaction, and functional outcomes.

## V. CONCLUSION

The study successfully designed and developed a 3D-printed external prosthetic elbow joint with an adjustable locking mechanism. The functional prototype demonstrated effective elbow flexion and extension with secure locking at desired positions, thereby enabling the performance of essential functional tasks.

The proposed design offers a cost-effective and mechanically simple alternative to existing prosthetic elbow joints, particularly suited for body-powered prosthetic systems.

Although the prototype met its primary design objectives, further refinement is required to reduce bulk, enhance functionality, and improve cosmetic appeal. Future work should include clinical evaluation, material testing, and integration of additional degrees of freedom to validate the applicability of the design for routine prosthetic use. Overall, the developed prosthetic elbow joint shows promise as a functional and economical solution for upper-limb amputees.

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## REFERENCES

[1] Pierrie SN, Gaston RG, Loeffler BJ. Current concepts in upper-extremity amputation. J Hand Surg Am [Internet]. 2018;43(7):657–67. Available from: http://dx.doi.org/10.1016/j.jhsa.2018.03.053

[2] Baccarani A, Follmar KE, De Santis G, et al. Free vascularized tissue transfer to preserve upper extremity amputation levels. Plast Reconstr Surg. 2007;120(4):971e981.

[3] Beltran MJ, Kirk KL, Hsu JR. Minimally invasive shortening humeral osteotomy to salvage a through-elbow amputation. Mil Med. 2010;175(9):693e696.

[4] Kusnezov N, Dunn JC, Stewart J, Mitchell JS, Pirela-Cruz M. Acute limb shortening for major near and complete upper extremity amputations with associated neurovascular injury: a review of the literature. Orthop Surg. 2015;7(4):306e316.

[5] de Luccia N, Marino HL. Fitting of electronic elbow on an elbow disarticulated patient by means of a new surgical technique. Prosthet Orthot Int [Internet]. 2000;24(3):247–51. Available from: http://dx.doi.org/10.1080/03093640008726556

[6] Radcliffe CW. *Prosthetic rehabilitation of the upper limb amputee.* Prosthet Orthot Int. 2011;35(3):293–305.

[7] Merad M, de Montalivet E, Touillet A, Martinet N, Roby-Brami A, Jarrassé N. Can We Achieve Intuitive Prosthetic Elbow Control Based on Healthy Upper Limb Motor Strategies? *Front Neurorobot.* 2018;12:1.

[8] Abd Razak NA, Abu Osman NA, Gholizadeh H, et al. Biomechanics principle of elbow joint for transhumeral prostheses: comparison of normal hand, body-powered, myoelectric & air splint prostheses. *BioMed Eng OnLine.* 2014;13:134.

[9] Upper limb prosthetic prescription. *J Rehabil Med.* 2007;39(2):103–110.

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