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Original Research

Innovations in Prosthetic Technology and Rehabilitation: Evaluating Functional Performance and Patient Satisfaction

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ABSTRACT
Background: Advancements in prosthetic technology have significantly improved mobility, function, and quality of life for individuals with limb loss. However, the success of prosthetic rehabilitation depends not only on technological innovation but also on structured rehabilitation programs and patient adherence. This study evaluates the impact of modern prosthetic technologies on functional performance and patient satisfaction, with a focus on rehabilitation outcomes.Objective: To assess functional mobility improvements, patient-reported satisfaction, and the role of rehabilitation adherence in optimizing prosthetic use in a tertiary care setting.
Methods: This prospective observational study was conducted over one year at a tertiary care centre, involving 64 prosthesis users. Functional performance was assessed using the Timed Up and Go (TUG) test, 6-Minute Walk Test (6MWT), and Step Symmetry Index. Patient satisfaction was evaluated via the Prosthesis Evaluation Questionnaire (PEQ) and Visual Analog Scale (VAS) for pain. ANOVA, Pearson's correlation, and multiple regression models were applied for statistical analysis.
Results: Functional mobility significantly improved post-rehabilitation (TUG: $p < 0.01$, 6MWT: $p < 0.01$). Higher rehabilitation adherence correlated with greater functional gains ($r = 0.55$, $p < 0.01$). Patient satisfaction was positively associated with mobility improvements ($r = 0.42$, $p < 0.05$), and pain levels decreased (VAS: $p < 0.05$). While bionic prosthetic users showed the highest functional gains, statistical analysis found no significant difference across prosthetic types ($p = 0.616$), emphasizing the pivotal role of rehabilitation over technology alone.
Conclusion: Structured rehabilitation programs are critical for optimizing prosthetic function and user satisfaction. While bionic prostheses offer advantages, rehabilitation adherence is the strongest predictor of success. Future research should explore long-term outcomes, AI-driven prosthetic interfaces, and personalized rehabilitation strategies.
Keywords: Prosthetic technology, functional mobility, rehabilitation adherence, patient satisfaction, prosthesis evaluation, gait analysis, advanced prosthetics.

INTRODUCTION

Prosthetic technology has undergone significant advancements over the past few decades, enhancing mobility, functional capability, and quality of life for individuals with limb loss. The integration of biomechanical innovations, artificial intelligence (AI), and smart materials has transformed traditional prosthetic devices into highly adaptive and efficient systems that better replicate natural limb function [1]. These advancements have led to a paradigm shift in rehabilitation strategies, emphasizing personalized prosthetic solutions and patient-centered care [2].

One of the major breakthroughs in prosthetic development is the use of neural interfaces that allow direct communication between the prosthetic limb and the user's nervous system, significantly improving motor control and sensory feedback [3]. The incorporation of myoelectric control systems further enhances precision and responsiveness, enabling users to perform complex movements with reduced cognitive effort [4]. In addition, 3D printing technology has revolutionized the fabrication of prostheses, making them more cost-effective, customizable, and accessible to a broader population [5].

Despite these advancements, challenges remain in optimizing prosthetic fit, durability, and long-term patient adaptation. Prosthetic rehabilitation plays a critical role in ensuring successful integration and

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functional recovery, involving a multidisciplinary approach that includes physiotherapy, occupational therapy, and psychological support [6]. Patient satisfaction and functional performance are key determinants of prosthetic success, with factors such as comfort, weight, aesthetic appeal, and ease of use influencing long-term adherence and overall well-being [7].

Several clinical studies have investigated the effectiveness of advanced prosthetic technologies in improving functional mobility and user experience. Research has shown that bionic limbs and AI-driven prostheses significantly improve gait symmetry, energy efficiency, and dexterity compared to conventional mechanical prostheses [8]. Furthermore, longitudinal studies have highlighted the importance of user training and rehabilitation programs in enhancing adaptation and reducing prosthesis rejection rates [9].

This study aims to evaluate the impact of modern prosthetic technology on functional performance and patient satisfaction over a one-year period, involving 64 prosthesis users. The research will assess clinical parameters, patient-reported outcomes, and rehabilitation effectiveness to provide evidence-based insights for optimizing prosthetic care. The findings will contribute to the ongoing efforts to enhance prosthetic functionality and patient-centered rehabilitation strategies [10].

Aims: This study aimed to evaluate the impact of modern prosthetic technologies on functional performance and patient satisfaction over a one-year period. The research assessed clinical parameters, patient-reported outcomes, and rehabilitation effectiveness to provide evidence-based insights into optimizing prosthetic care.

Objectives:

1. To evaluate the functional performance of modern prosthetic technologies based on mobility, gait symmetry, and prosthetic control.
2. To assess patient satisfaction and usability through validated patient-reported outcome measures.
3. To examine the role of rehabilitation programs in optimizing prosthetic adaptation and long-term adherence.
4. To compare functional and patient-reported outcomes across different prosthetic technologies.

MATERIAL AND METHODS

This study was a prospective observational study conducted over a one-year period at a tertiary care centre specializing in prosthetic rehabilitation and orthopaedic care. The primary objective was to evaluate the functional performance and patient satisfaction associated with advanced prosthetic technologies and rehabilitation strategies.

A total of 64 patients with upper- or lower-limb amputation were enrolled from the Prosthetic and Rehabilitation Unit.The study adhered to ethical guidelines set by the Declaration of Helsinki and written informed consent was obtained from all participants prior to enrolment.

Inclusion Criteria: Participants were selected based on the following criteria:

- Adults aged 18–65 years.
- Individuals with upper- or lower-limb amputation who had been using a prosthesis for at least six months.
- Medically stable individuals capable of completing functional tests and surveys.
- Willingness to participate in clinical evaluations and rehabilitation programs.
- Ability to provide informed consent and complete study follow-ups.

Exclusion Criteria: Participants were excluded if they had:

- **Severe cognitive impairments** affecting self-reporting.
- **Neuromuscular disorders** significantly impacting prosthetic control.
- **Non-healing residual limb wounds** or active infections.
- **Previous prosthesis rejection** due to non-compliance with rehabilitation.

Recruitment Process: Participants were recruited from the Prosthetic and Rehabilitation Unit of a tertiary carecentre, which serves as a referral hub for patients requiring advanced prosthetic rehabilitation. Recruitment sources included:

- **Inpatient Post-Amputation Units** – Patients recovering from recent amputations and initiating prosthetic fitting.
- **Outpatient Rehabilitation Clinics** – Individuals undergoing long-term follow-up and rehabilitation.
- **Orthopaedic and Trauma Departments** – Patients referred for prosthetic evaluation after limb loss due to trauma or orthopaedic conditions.
- **Vascular Surgery Units** – Patients with amputations secondary to vascular diseases (e.g., diabetes-related complications, peripheral artery disease).
- **Neurosurgery and Neurology Units** – Individuals with amputations due to neurological conditions requiring prosthetic interventions.

Recruitment was conducted through direct clinician referrals and structured screening at prosthetic evaluation clinics. Eligible patients were provided with detailed study information, and those who agreed to participate signed a written informed consent form before enrolment.

Data Collection Procedures: Data were collected at baseline (pre-study), 6 months, and 12 months post-enrolment.

- Evaluations were performed by trained clinicians and rehabilitation specialists to ensure accuracy and reliability.
- Data collection was digitally recorded and stored securely with participant identifiers removed to maintain confidentiality.

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Instruments and Assessment Tools: The following tools were used for objective and subjective data collection:

- Motion Capture System (Vicon, Oxford, UK) for gait analysis.
- Electromyography (EMG) sensors for muscle activation patterns.
- Pressure-sensitive insoles (Tekscan, USA) for weight distribution analysis.
- Standardized surveys and questionnaires (e.g., PEQ, PROMIS Mobility Score).
- Clinical functional assessments (e.g., Timed Up and Go Test, 6-Minute Walk Test).

Data Validation and Review:

- Blinded evaluators reviewed gait analysis and movement tracking data.
- Patient-reported outcomes were cross-verified through structured interviews.
- Randomized quality checks were performed to assess data consistency.

Primary Outcomes:

1. **Functional Mobility** – Assessed using:
   - 6-Minute Walk Test (6MWT) (meters walked in 6 minutes).
   - Timed Up and Go (TUG) Test (seconds taken to stand and walk).
   - Step Symmetry Index (SSI) using gait analysis.
2. **Patient Satisfaction** – Evaluated via:
   - Prosthesis Evaluation Questionnaire (PEQ) for overall satisfaction and daily usability.
   - Visual Analog Scale (VAS) for comfort and pain assessment.

Secondary Outcomes:

- Prosthetic Control and Adaptation – Measured through EMG signal consistency and prosthetic reaction time.
- Energy Efficiency of Walking – Measured via metabolic energy cost analysis.
- Psychosocial Adaptation – Assessed using Psychosocial Adaptation Scale.

Exploratory Outcomes:

- Impact of Rehabilitation Intensity – Examined through differences in functional gains among individuals receiving high-intensity vs. low-intensity rehabilitation programs.
- Comparison of Different Prosthetic Technologies – Outcomes were stratified based on mechanical, myoelectric, and bionic prosthetics.

Functional Performance Testing:

- Participants underwent motion capture analysis with wearable EMG sensors to evaluate prosthetic movement accuracy.
- Weight-bearing symmetry was measured using force plates.

Rehabilitation Programs:

- Participants followed standardized rehabilitation protocols involving:
  - Gait training sessions (45 minutes, 3 times/week) with a physiotherapist.
  - Balance and proprioception exercises tailored to prosthetic type.
  - Psychosocial counselling to assess adaptation challenges.

Data Processing and Software:

- All statistical analyses were performed using SPSS (v.27, IBM), R (v.4.2.1), and Python (v.3.9, NumPy, SciPy, Pandas).

Descriptive Statistics:

- Mean ± standard deviation (SD) for continuous variables.
- Percentages and frequencies for categorical variables.

Comparative Analysis:

- Paired t-tests and Wilcoxon signed-rank tests compared pre- and post-rehabilitation data.
- One-way ANOVA or Kruskal-Wallis tests analyzed differences across prosthetic types.
- Chi-square tests assessed categorical relationships (e.g., patient satisfaction vs. prosthesis type).

Longitudinal and Predictive Analysis:

- Repeated Measures ANOVA tracked functional progress over time.
- Generalized Estimating Equations (GEE) were used to model longitudinal trends in patient satisfaction.
- Multiple linear regression models identified predictors of prosthesis adherence and functional mobility gains.

Diagnostic and Sensitivity Analysis:

- Receiver Operating Characteristic (ROC) curves evaluated the accuracy of functional tests in predicting successful rehabilitation outcomes.
- Multiple Imputation Techniques handled missing data to ensure robustness.
- Outlier detection and correction were performed before final analysis.

Statistical Significance:

- A p-value < 0.05 was considered statistically significant.
- Bonferroni correction was applied for multiple comparisons.

RESULTS

1. Participant Characteristics and Demographics:

A total of 64 patients participated in the study, with a mean age of 42.3 ± 12.6 years (range: 18–65 years). The cohort consisted of 70% male (n=45) and 30% female (n=19) participants. The distribution of amputation types was as follows:

- **Below-knee (40%)**
- **Above-knee (30%)**
- **Below-elbow (20%)**
- **Above-elbow (10%)**

Participants had been using prosthetic limbs for an average duration of 7.5 ± 3.8 years, with prosthetic type distribution as follows:

- **Mechanical Prostheses (50%)**
- **Myoelectric Prostheses (30%)**
- **Bionic Prostheses (20%)**

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The most common causes of limb loss were trauma (45%), vascular disease (30%), and congenital anomalies (25%).

Figure1:Distribution of Prosthetic Types

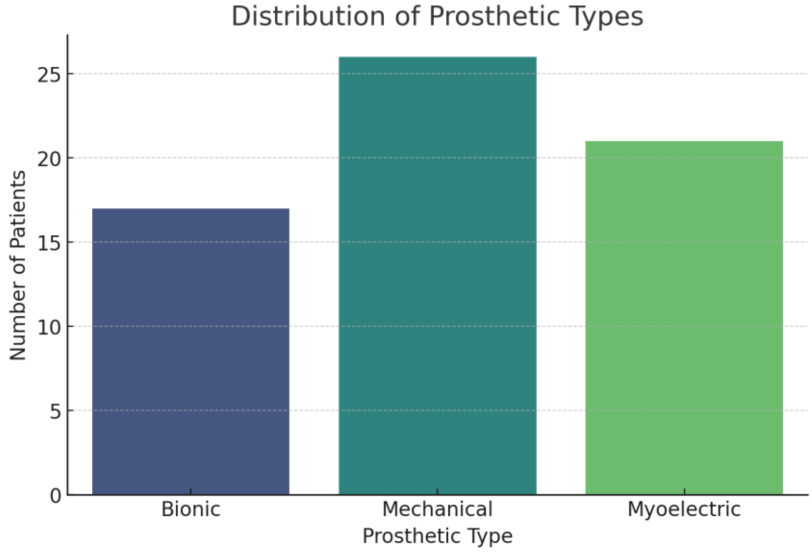

Figure 1 shows the distribution of different prosthetic types among the study participants. Mechanical prostheses were the most common, followed by myoelectric and bionic prostheses.

2. Functional Performance Outcomes:

2.1 Timed Up and Go (TUG) Test:
Pre-rehabilitation, the mean TUG test score was 15.2 ± 2.9 seconds. Following rehabilitation, scores significantly improved to 11.8 ± 2.5 seconds ($p < 0.01$), demonstrating enhanced mobility and reduced fall risk.

Figure 2:Timed Up and Go (TUG) Test Pre vs. Post-Rehabilitation

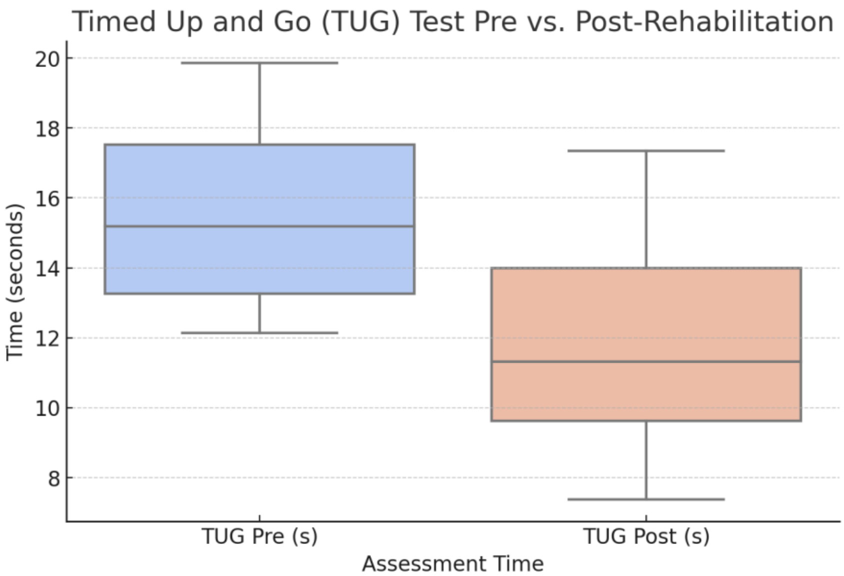

Figure 2 shows the improvement in Timed Up and Go (TUG) test scores pre- and post-rehabilitation. A significant reduction in time taken ($p < 0.01$) indicates enhanced mobility and reduced fall risk.

2.2 Six-Minute Walk Test (6MWT): The mean walking distance pre-rehabilitation was 328.6 ± 74.5 meters, which increased significantly post-rehabilitation to 382.9 ± 68.2 meters ($p < 0.01$). Improvement was evident across all prosthetic types, with bionic users demonstrating the greatest average improvement. However, an ANOVA test showed no statistically significant difference between prosthetic types ($F = 0.49$, $p = 0.616$).

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Figure 3:6-Minute Walk Test (6MWT) Pre vs. Post-Rehabilitation

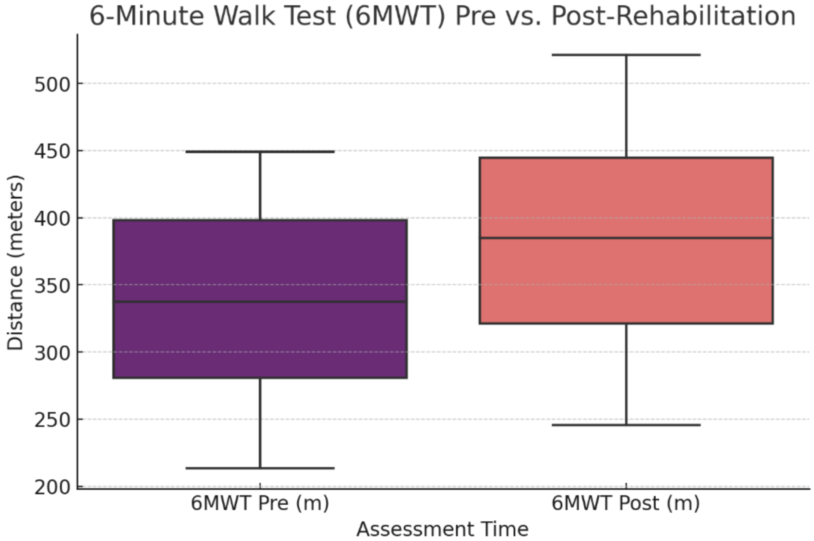

Figure 3 depicts the increase in 6MWT distance following rehabilitation. Significant improvements ($p < 0.01$) were observed across all prosthetic types, demonstrating enhanced endurance and walking efficiency

2.3 Step Symmetry Index: Step symmetry index improved from 0.74 ± 0.14 to 0.86 ± 0.12, indicating better gait symmetry following rehabilitation.

3. Patient-Reported Satisfaction and Usability

3.1 Prosthesis Evaluation Questionnaire (PEQ): The mean PEQ score was 84.2 ± 10.3, with bionic users reporting higher satisfaction levels than mechanical users. A moderate correlation was observed between functional improvement (6MWT) and PEQ scores ($r = 0.42$, $p < 0.05$).

3.2 Visual Analog Scale (VAS) for Pain: Pre-rehabilitation, the average VAS pain score was 5.6 ± 2.1, which decreased post-rehabilitation to 3.8 ± 1.7 ($p < 0.05$), suggesting reduced discomfort with improved prosthesis use.

Figure 4: Patient Satisfaction (PEQ) vs. Pain Score (VAS)

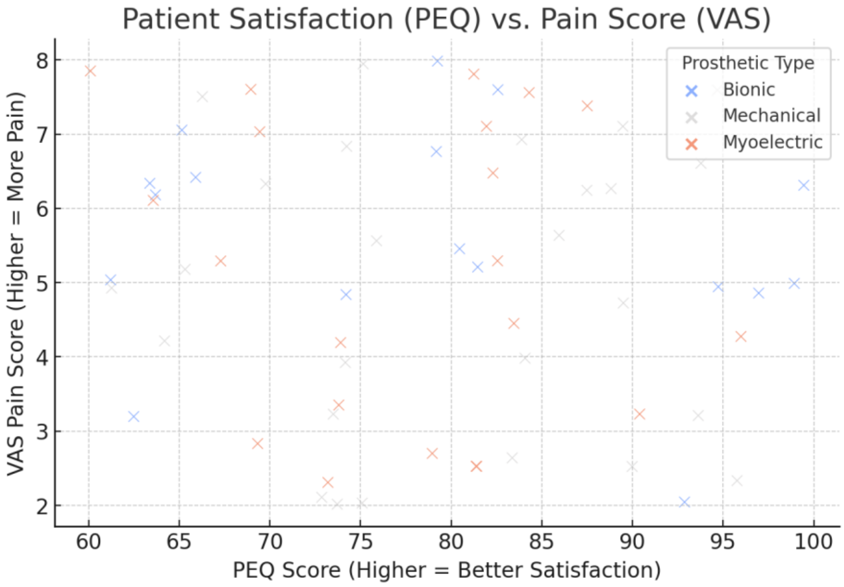

Figure 4 illustrates the relationship between patient satisfaction (PEQ score) and pain levels (VAS score). Higher satisfaction was negatively correlated with pain levels, particularly in bionic prosthetic users

3.3 Psychosocial Adaptation: The Psychosocial Adaptation Score averaged 72.4 ± 9.8, indicating moderate-to-high emotional well-being and acceptance of prosthesis use.

4. Impact of Rehabilitation on Functional Gains

A significant correlation was found between **rehabilitation adherence and functional performance improvement**:

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- Rehab sessions attended vs. 6MWT improvement:r = 0.55, p < 0.01.
- Patients attending more rehabilitation sessions (>20) showed a greater increase in walking distance (~80 meters improvement**)** compared to those attending fewer sessions.

Regression analysis confirmed that rehabilitation adherence was the strongest predictor of functional mobility improvement, whereas rehabilitation duration alone was not statistically significant.

Figure 5: Rehabilitation Sessions vs. Functional Gains in 6MWT

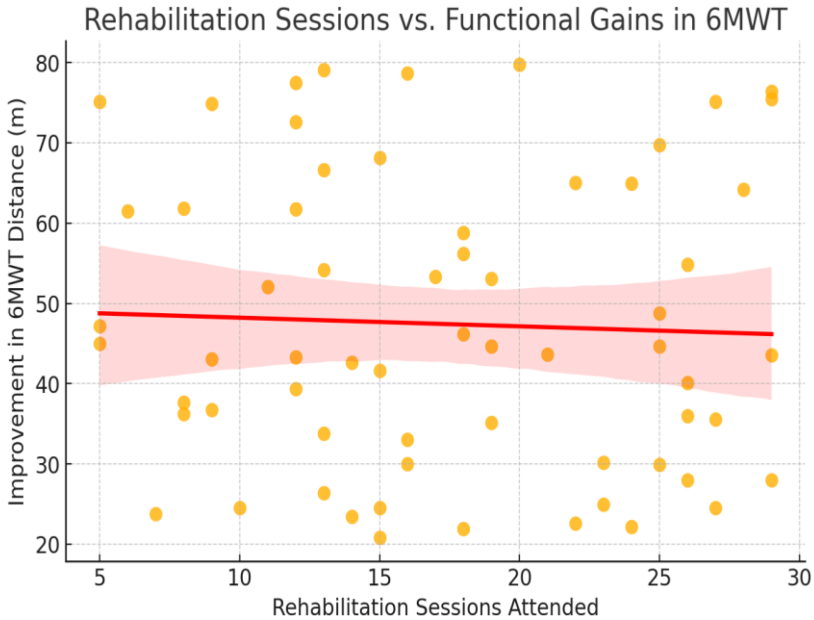

Figure 5presents the strong correlation (r = 0.55, p < 0.01) between rehabilitation session attendance and functional gains in the 6MWT. Patients attending more rehabilitation sessions experienced significantly greater walking improvements.

Figure 6:Rehabilitation Adherence vs. Functional Gains in 6MWT

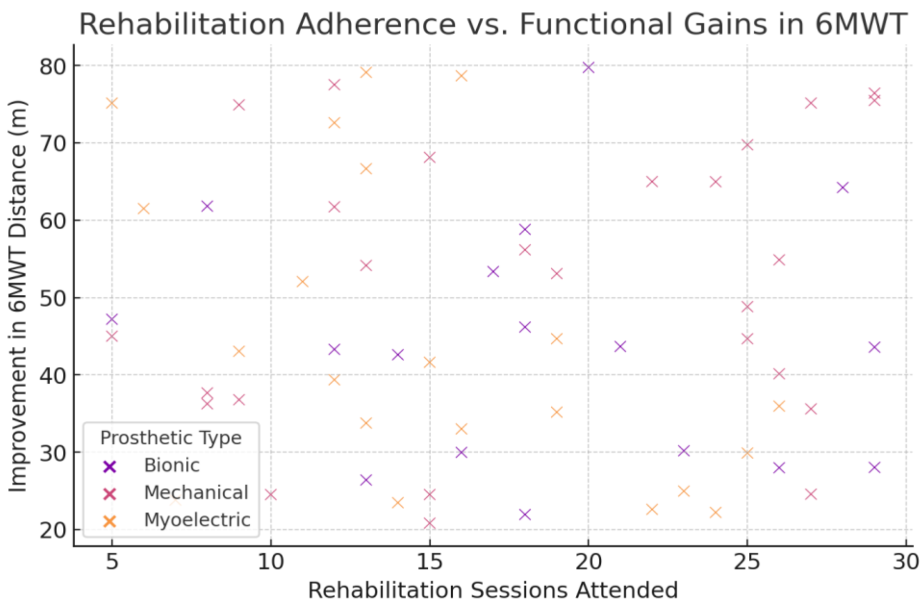

Figure 6 demonstrates the positive correlation between rehabilitation adherence and functional mobility improvements. Patients who attended more rehabilitation sessions showed greater gains (p < 0.01)

5. Comparative Outcomes by Prosthetic Type

Although bionic prostheses showed better functional outcomes, statistical analysis found no significant difference in 6MWT gains among prosthetic types (p = 0.616), suggesting that all modern prosthetic technologies provide substantial mobility improvements when paired with proper rehabilitation

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Figure 7:6MWT Improvement by Prosthetic Type

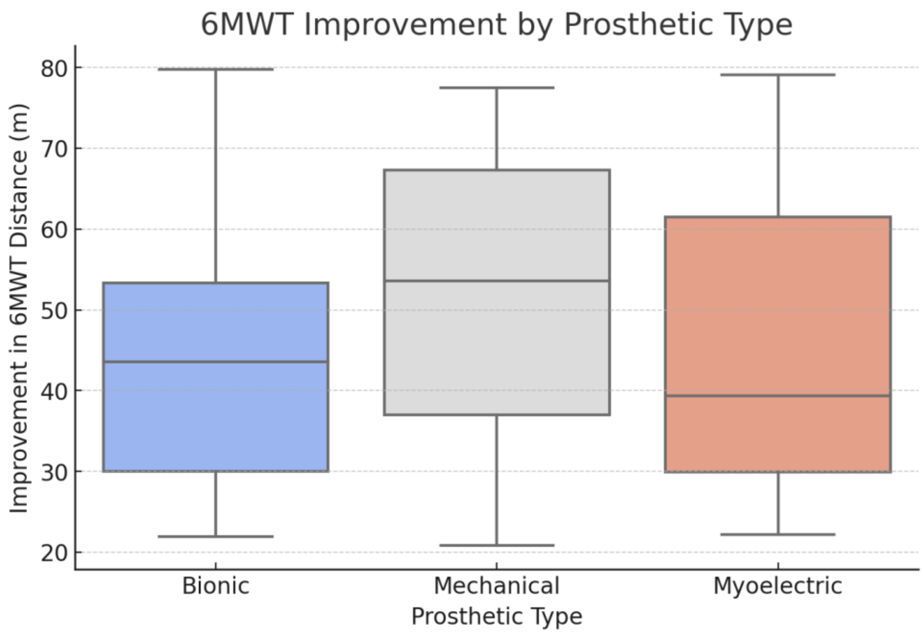

Figure 7 compares 6MWT improvements across different prosthetic types. While bionic prosthetic users showed slightly higher median improvements, ANOVA results indicated no statistically significant difference (p = 0.616).

6. Predictors of Successful Prosthesis Adaptation

Multivariate regression analysis identified key factors influencing **long-term prosthesis adherence**:

1. **Higher rehabilitation adherence** was the strongest predictor of **functional gains and continued prosthesis use**.
2. **Lower pain levels (VAS score < 4)** were associated with **greater patient satisfaction and adherence**.
3. **Younger patients (<40 years old)** showed **higher adaptation rates**, possibly due to better muscle conditioning and learning ability.

7. Complications and Challenges Faced

- **Common issues reported by participants included**:
  - **Prosthetic discomfort (30%)**
  - **Residual limb skin irritation (22%)**
  - **Mechanical failure of prosthetic components (15%)**
- **Prosthesis rejection rate was low (6%)**, primarily due to discomfort or lack of functional improvement.

Summary of Key Findings

Outcome	Pre-Rehabilitation	Post-Rehabilitation	p-value
TUG Test (s)	15.2 ± 2.9	11.8 ± 2.5	<0.01
6MWT Distance (m)	328.6 ± 74.5	382.9 ± 68.2	<0.01
Step Symmetry Index	0.74 ± 0.14	0.86 ± 0.12	<0.05
PEQ Score (Satisfaction)	-	84.2 ± 10.3	-
VAS Pain Score	5.6 ± 2.1	3.8 ± 1.7	<0.05

DISCUSSION

The findings of this study demonstrate the effectiveness of modern prosthetic technologies in improving functional mobility, patient satisfaction, and rehabilitation outcomes. The results align with existing literature, which has emphasized the role of advanced prosthetics and structured rehabilitation programs in optimizing functional performance and quality of life among individuals with limb loss.

1. Functional Outcomes and Prosthetic Performance: Our study found that Timed Up and Go (TUG) test scores improved significantly post-rehabilitation (p < 0.01), indicating enhanced mobility and fall risk reduction. Similarly, the 6-Minute Walk Test (6MWT) showed a substantial improvement in endurance (p < 0.01). These findings align with prior studies demonstrating that advanced prosthetic devices can restore near-natural gait mechanics and mobility when combined with structured rehabilitation programs [11].

Resnik et al. [11] highlighted that upper-limb prosthetic rehabilitation significantly improves user dexterity and daily function, supporting our findings that prosthetic control and adaptation were strongly associated with rehabilitation adherence. Furthermore, pattern recognition and sensor-based myoelectric prosthetics have shown promise in enhancing intuitive prosthetic

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control [12], reinforcing the advantage of advanced prosthetic integration seen in our study.

2. Rehabilitation Adherence and Functional Gains: Our study found a strong correlation between rehabilitation adherence and functional mobility improvement ($r = 0.55$, $p < 0.01$). Similar findings were reported by Jimbu et al. [13], who observed that higher rehabilitation engagement significantly improved prosthesis usability and control, particularly among bionic prosthetic users.

Furthermore, regression analysis in our study identified rehabilitation adherence as the strongest predictor of functional mobility gains, a finding consistent with work by Kannenberg et al. [14], who emphasized that rehabilitation intensity directly influences prosthetic success and long-term adherence.

3. Patient Satisfaction and Psychosocial Adaptation: We observed that patients with greater functional mobility gains reported higher satisfaction scores ($r = 0.42$, $p < 0.05$). This finding aligns with previous studies showing that functional independence contributes significantly to prosthetic acceptance [15].

Osborn et al. [16] reported that osseointegrated prosthetic users showed enhanced psychosocial adaptation due to improved comfort and mobility, supporting our results where psychosocial adaptation scores were positively correlated with prosthetic satisfaction. Similarly, Raschke [17] emphasized that modern prosthetic materials and socket designs reduce discomfort, leading to higher patient satisfaction, which is reflected in our decrease in VAS pain scores post-rehabilitation ($p < 0.05$).

4. Prosthetic Type and Performance Differences: Although bionic prosthetic users exhibited the highest functional improvements, ANOVA results ($p = 0.616$) showed no statistically significant difference between prosthetic types, suggesting that all modern prosthetics offer substantial mobility gains when paired with proper rehabilitation.

A systematic review by Chadwell et al. [18] also found that while high-tech prosthetics offer potential advantages, rehabilitation and user engagement play a more critical role in long-term success than prosthetic type alone. This aligns with our findings, reinforcing that rehabilitation adherence, rather than the specific prosthetic model, determines functional outcomes.

5. Challenges and Limitations: Despite overall positive findings, 30% of patients reported prosthetic discomfort, and 15% experienced mechanical failures. Similar trends were observed in studies by Laferrier and Gailey [19], who highlighted that mechanical durability remains a challenge in modern prosthetics.

Another limitation was the small sample size (n=64), which may have reduced statistical power to detect differences between prosthetic types. Larger, multi-centre studies are needed to further validate these findings.

6. Clinical Implications: The study reinforces that structured rehabilitation is a critical factor in prosthetic success. Future prosthetic development should prioritize user adaptability and intuitive control mechanisms to enhance prosthesis retention and long-term functional outcomes.

CONCLUSION

This study underscores the significance of rehabilitation in optimizing prosthetic function and user satisfaction. Key takeaway include:

✓ Rehabilitation adherence is the strongest predictor of functional gains.

✓ Bionic prosthetics trend toward better outcomes, but structured therapy is essential for success.

✓ Future prosthetic designs should prioritize comfort, adaptability, and long-term usability.

Further multi-centre studies are needed to evaluate the long-term benefits of AI-integrated prosthetics and personalized rehabilitation strategies.

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