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Impact of Advanced Biomechanical Prosthetics on Mobility and Quality of Life in Saudi Veterans – A Retrospective Cohort Study

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ABSTRACT

Background: Advances in prosthetic technology promise better functional outcomes for amputees, but real-world impact on veteran mobility and QoL is under-studied. We examined whether Saudi veterans using advanced biomechanical prostheses achieve superior mobility and QoL compared to those with conventional devices.

Methods: The authors describe a retrospective comparison of 214 veterans receiving advanced or conventional limb prostheses. The abstract originally called all participants lower-limb amputees; the methods and Table 1 also describe upper-limb amputees, with inconsistent group counts. Cohort definitions, follow-up, reported missingness and analytic denominators require verification against source records.

Results: Reported group outcomes are retained in the manuscript tables. The reported time points, denominators and missing-data descriptions conflict and require reconstruction and independent reanalysis before numerical findings can be interpreted.

Conclusions: The observational comparison requires separate denominators for upper- and lower-limb prosthesis users and for each follow-up time. Gait outcomes apply to the eligible lower-limb cohort. Baseline mobility and device selection should be considered when interpreting associations.

Keywords: prosthetics; amputation; veterans; mobility; quality of life; Saudi Arabia

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Introduction

Limb loss profoundly impacts functional mobility and psychosocial well-being **(1)**. Modern prosthetic devices can partially restore lost function, enabling amputees to perform daily activities more naturally. However, even with prostheses, individuals often face residual movement restrictions and reduced quality of life (QoL) **(2)**. Restoring mobility to near premorbid levels is a critical goal that depends not only on device technology but also on patient acceptance and satisfaction **(3)**.

Prior studies indicate that advanced prosthetic components—such as microprocessor-controlled knees and powered ankles—improve safety, balance, and walking efficiency **(4)**. For example, powered ankle-foot prostheses can decrease energy expenditure and increase walking speed by ~15% **(5)**. Microprocessor knees (MPKs) similarly provide more stability and adaptability than mechanical knees, leading to better functional outcomes and QoL **(6)**. A recent systematic review confirmed that MPKs outperform non-microprocessor knees in mobility and health-related QoL **(7)**. Notably, MPK use has been associated with reduced falls and enhanced confidence in ambulation **(8)**. These technological gains come at higher upfront cost, but emerging evidence suggests they may be cost-effective over time by preventing injuries and improving independence **(9)**.

Military veterans represent a unique amputee population often younger and more active than typical patients with limb loss **(10)**. Combat-related amputations in particular pose rehabilitation challenges, but advanced prosthetics have potential to greatly improve reintegration outcomes. Studies from the United States and allies have shown high satisfaction and functional benefits among veteran users of advanced prostheses. For instance, over 60% of surveyed combat amputees reported being satisfied with advanced prosthetic function and noted positive impacts on their QoL. However, up to 79% expressed dissatisfaction with issues like skin irritation and device costs, underscoring areas for improvement in prosthetic design and support. Importantly, dissatisfaction can lead to prosthesis rejection; indeed, high device abandonment rates have been observed in some veteran groups due to unmet expectations.

Materials and Methods

Study Design and Setting

We conducted a retrospective cohort study in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. The study was carried out at two military rehabilitation centers in Eastern Province, Saudi Arabia, which provide specialized prosthetic services to veterans. Medical records and prosthetic clinic databases were reviewed for the period January 2015 through December 2020. Eligible participants were identified through prosthetic supply records and follow-up assessments, ensuring comprehensive capture of veteran amputees receiving care in this system.

Participants

Inclusion criteria: Saudi military veterans (retired or active-duty at time of injury) who underwent major limb amputation (upper or lower extremity) and were fitted with a prosthetic device during the study period. We included unilateral amputees at either transfemoral, transtibial, transhumeral, or transradial levels. All participants had completed initial rehabilitation and had used their prosthesis for at least 6 months, allowing for adaptation. **Exclusion criteria:** Bilateral amputees (to avoid confounding due to greater disability burden), age over 70 (to focus on working-age veterans), and cases with insufficient follow-up data (less than 12 months of records or missing key outcomes even after attempted data retrieval).

Eligible veteran amputees were classified into two cohorts based on the type of prosthetic device received:

• **Advanced Prosthesis Group:** Veterans fitted with next-generation biomechanical prosthetics, defined as devices incorporating microprocessor-controlled joints (e.g., Otto Bock C-Leg, Genium knee, or powered ankle-foot systems) or myoelectric multi-articulating upper limb prostheses. These devices feature embedded sensors and adaptive control that dynamically adjust to user movement.

• **Conventional Prosthesis Group:** Veterans using traditional mechanical prostheses without microprocessor or powered components (e.g., mechanical knee joints with fixed cadence and energy-storing feet, or body-powered upper limb prostheses).

A total of 239 veteran amputees met criteria, of which 214 had adequate data for analysis after medical record review. The Advanced group comprised 113 veterans and the Conventional group 101 veterans.

Baseline characteristics are reported in Table 1 and require verification. Table 1 lists more transfemoral than transtibial amputations in each group. The subgroup and exposure counts require reconciliation with the narrative.

Table 1. Demographic and clinical characteristics of veteran amputee cohorts. Values are n (%) or mean ± SD. P-values compare Advanced vs. Conventional using χ^2 for categorical and t-test for continuous variables.

Characteristic	Advanced Prosthesis (n=113)	Conventional Prosthesis (n=101)	*P*-value
Age (years)	40.9 ± 10.2	42.0 ± 9.1	0.45
Male sex, n (%)	109 (96.5%)	95 (94.1%)	0.34
Level of amputation			
– Transfemoral (above knee)	61 (54.0%)	50 (49.5%)	0.51
– Transtibial (below knee)	42 (37.2%)	40 (39.6%)	0.72
– Upper limb (any level)	10 (8.8%)	11 (10.9%)	0.60
Cause of amputation			
– Combat trauma	83 (73.5%)	72 (71.3%)	0.72
– Non-combat trauma	20 (17.7%)	18 (17.8%)	0.98
– Vascular (diabetes/PVD)	7 (6.2%)	8 (7.9%)	0.59
– Other medical	3 (2.7%)	3 (3.0%)	0.90
Time since amputation (years)	3.4 ± 1.8	3.6 ± 2.0	0.52
Comorbid diabetes, n (%)	9 (8.0%)	12 (11.9%)	0.32
Comorbid hypertension, n (%)	17 (15.0%)	15 (14.9%)	0.98
Baseline independent ambulation (%)	89 (78.8%)	77 (76.2%)	0.67
Follow-up duration (months)	26.1 ± 6.3	25.4 ± 5.9	0.39

Outcome Measures

We extracted multiple outcome measures from patient records and the hospital's amputee clinic database to comprehensively assess mobility, quality of life, and safety outcomes:

• **Functional Mobility:** The 6-minute walk test (6MWT) distance (meters) and the Timed Up-and-Go (TUG) test (seconds) were the primary objective mobility outcomes. These standardized tests were administered by physical therapists during routine follow-up at approximately 6, 12, and 24 months post-prosthesis fitting, per clinic protocol. We also recorded each patient's K-level (functional ambulation category) as documented by the prosthetist.

• **Quality of Life:** We used the 36-Item Short Form Survey (SF-36) as a generic QoL measure. Physical Component Summary (PCS) and Mental Component Summary (MCS) scores (normalized to population mean 50±10) were collected at 12 and 24 months via patient self-report questionnaires in their charts. Where SF-36 data were missing, we noted if any other QoL instrument (e.g., WHOQOL-BREF) was present.

• **Patient Satisfaction:** Although not a primary endpoint, we extracted any documentation of patient-reported satisfaction with the prosthesis or prosthetic services for descriptive context. This included narrative clinic notes and any completion of standardized satisfaction surveys (e.g., Prosthesis Evaluation Questionnaire, Orthotics and Prosthetics Users' Survey satisfaction module). We categorized satisfaction qualitatively (satisfied/neutral/dissatisfied) when explicit documentation was available.

• **Safety/Complications:** We recorded prosthetic-related adverse events. The key safety outcome was incidence of falls requiring medical attention (clinic visit or hospitalization) during follow-up. We also noted skin breakdown issues, device malfunctions, and need for major prosthesis repairs or replacements.

• **Reintegration Outcomes:** As exploratory outcomes, we noted rates of return-to-work or active duty (for those still enlisted) and any sports participation reported, to gauge broader impacts on life roles.

Data Management and Missing Data Handling

Data were abstracted onto a standardized form by two independent reviewers, with a third resolving discrepancies. For continuous outcomes like 6MWT and SF-36 scores, if multiple observations were available (e.g., both 12 and 24-month values), we used the latest value for main analyses, and earlier values for longitudinal analyses. Approximately 12% of subjects had at least one missing SF-36 summary score (often due to not returning a mail-in survey). Missing data patterns were examined (Table 2) – most missingness occurred in QoL measures and in a few 6MWT entries for those who missed follow-up visits. We assumed data were missing at random conditional on observed covariates (e.g., health status).

To reduce bias from missing data, we employed multiple imputation by chained equations (MICE). We created 20 imputed datasets including all covariates and outcomes (mobility scores, QoL scores, age, etc.), using logistic or predictive mean matching models appropriate to variable type. Imputation models included group membership (advanced vs. conventional) and key outcomes to inform the missing values. This approach is preferable to complete-case analysis as it retains information and more accurately reflects uncertainty due to missingness. The imputation procedure and convergence diagnostics are detailed in Supplementary File 1. For comparison, primary analyses were performed on both imputed data and complete cases; results were very similar, increasing confidence in the robustness of findings.

Table 2. Patterns of missing data for key outcomes (pre-imputation). Shaded cells indicate missing values. Percentages are out of total N=214.

Missing Data Pattern	Frequency (%)	6MWT	TUG	SF-36 PCS	SF-36 MCS
Complete data (no missing outcomes)	178 (83.2%)	✔	✔	✔	✔
Missing SF-36 only	20 (9.3%)	✔	✔	✘	✘
Missing 6MWT only	6 (2.8%)	✘	✔	✔	✔
Missing TUG only	4 (1.9%)	✔	✘	✔	✔
Missing both 6MWT and SF-36	3 (1.4%)	✘	✔	✘	✘
Other patterns (random single values)	3 (1.4%)	✘	✘	✔	✔
Total cases (%) with any missing	**36 (16.8%)**				

Key: ✔ = observed; ✘ = missing. PCS = Physical Component Summary; MCS = Mental Component Summary.

Statistical Analysis

We first described baseline differences between the Advanced and Conventional prosthesis cohorts using appropriate univariate tests (Table 1). The primary analysis compared mobility and QoL outcomes between groups at follow-up. For continuous outcomes (6MWT distance, TUG time, PCS, MCS), we used linear regression models adjusting for baseline age, amputation level (above vs. below knee or elbow), and months since amputation. Adjusted mean differences with 95% confidence intervals (CIs) were calculated. We checked

model assumptions and, when necessary, log-transformed skewed variables (TUG times were log-normal; results back-transformed for reporting).

For binary outcomes (e.g., return to work yes/no) or dichotomized QoL (high vs. low QoL, defined as PCS or MCS ≥50), we performed logistic regression, reporting adjusted odds ratios (OR) and 95% CIs. Notably, we examined the association between prosthetic type (advanced vs. conventional) and odds of high QoL, controlling for potential confounders.

We also conducted survival analysis for time-to-first fall requiring medical care. Kaplan-Meier curves were constructed for each group and compared via log-rank test. We then fitted a Cox proportional hazards model adjusting for age and other covariates to estimate the hazard ratio (HR) of fall-related injury in Advanced vs. Conventional users. Proportional hazards assumption was assessed using Schoenfeld residuals (no significant violations were found).

Longitudinal changes from 12 to 24 months in mobility and QoL were analyzed with mixed-effects models (random intercept for each patient) to utilize all available data points and assess within-person improvements. An interaction term between time and group tested whether Advanced users had greater improvement over time than Conventional.

All primary analyses were performed on the multiply imputed datasets, combining estimates using Rubin's rules for inference). As sensitivity analysis, we repeated analyses on complete cases only (listwise deletion of missing data). The results were consistent; any differences are noted in text.

A two-sided $P<0.05$ was considered statistically significant. We did not adjust for multiple comparisons given the focused hypotheses on mobility and QoL, but we interpret secondary outcomes with caution. Statistical analyses were conducted using R version 4.1 and SPSS version 26. This study was reviewed and approved by the King Faisal University Institutional Review Board (KFU-IRB-2021-APR-Clinic-028). A waiver of informed consent was granted due to the retrospective design using de-identified data.

Results

Cohort Characteristics and Follow-up

The source reports 207 of 214 participants completing 12 months and 198 completing 24 months, although the methods specify at least 12 months of records as an eligibility criterion. Five conventional users reportedly switched to advanced devices and were censored. These definitions, time points and censoring require verification.

Mobility Outcomes

Six-Minute Walk Distance: At last follow-up, veterans with advanced prosthetics walked significantly farther on the 6MWT than those with conventional devices (mean 402.6 m vs. 356.7 m). Table 3 displays the unadjusted and adjusted comparisons. After adjusting for age and amputation level, the Advanced group had a 46.3-meter greater 6MWT distance on average (95% CI: 25.1 to 67.5 m; P<0.001). This represents a clinically meaningful difference, exceeding the minimal important difference (~30 m) for this test in amputees. Improvements over time were also greater: from 12 to 24 months, Advanced users increased 6MWT by mean 30 m vs. 15 m in Conventional (interaction P=0.04).

Timed Up-and-Go (TUG): Advanced-prosthesis users had faster TUG times (better mobility) than Conventional (mean 10.2 s vs. 12.8 s; Table 3). Adjusted analysis estimated an average TUG time 2.1 s shorter in Advanced users (95% CI: –3.4 to –0.9; P<0.001). This corresponds to a substantial functional benefit, as a TUG > 12 seconds often indicates mobility impairment risk. The proportion of patients with TUG ≤10 s was 58% in Advanced vs. 36% in Conventional (P=0.002). These results align with expectations that microprocessor knees provide more efficient gait, thus improving dynamic mobility.

K-Level and Assistive Device Use: At follow-up, 91% of Advanced cohort were classified as K3 or K4 ambulators (community ambulatory with varying pace) compared to 75% of Conventional ($\chi^2=10.5$, P=0.001). Fewer

Advanced users required walking aids: 18% occasionally used a cane vs. 35% of Conventional (χ^2=6.2, P=0.013). These secondary indicators further support superior mobility with advanced prosthetics.

Table 3. Mobility and functional outcomes at 24-month follow-up by prosthesis type. Values shown are mean ± SD or % (n), with adjusted between-group differences from linear regression (for continuous measures) or odds ratios (for categorical), controlling for age and amputation level.

Outcome	Advanced Prosthesis (n=113)	Conventional Prosthesis (n=101)	Adjusted Difference (95% CI)	*P*
6-minute walk distance (m)	402.6 ± 79.5	356.7 ± 75.4	+46.3 m (+25.1 to +67.5)	<0.001**
Timed Up-and-Go (seconds)	10.2 ± 3.5	12.8 ± 4.1	–2.1 s (–3.4 to –0.9)	0.001**
K3/K4 ambulatory level, %	91.2% (103/113)	74.5% (75/101)	OR 3.28 (1.56–6.91)	0.002**
Uses assistive device, %	17.7% (20/113)	34.7% (35/101)	OR 0.41 (0.22–0.78)	0.006**
Returned to work (by 24 mo)	68.1% (77/113)	52.5% (53/101)	OR 1.87 (1.08–3.24)	0.025*

Note: **Bold** indicates statistical significance (*P*<0.05). OR = odds ratio for Advanced vs. Conventional. Returned to work defined as gainful employment or active duty resumption for those eligible.

The advanced prosthesis cohort's gains in mobility are consistent with international reports. For instance, a clinical trial by Kaufman et al. found that even limited ambulators improved walking speed and balance confidence when using MPK knees. Our real-world data similarly suggest that advanced technology enables higher functional mobility in a veteran population. Importantly, these mobility benefits translated into tangible life outcomes: 68% of advanced-users had returned to work by 2 years vs. 52% of conventional-users (Table 3; OR 1.87, P=0.025). This suggests that enhanced mobility may facilitate greater societal participation.

Quality of Life Outcomes

SF-36 Scores: Veterans with advanced prosthetics reported better health-related quality of life on both physical and mental domains (Table 4). The adjusted mean PCS in the Advanced group was 48.5 (±8.7) vs. 42.3 (±9.1) in Conventional, with an adjusted difference of +5.7 points (95% CI: 3.0 to 8.4; P<0.001). Likewise, the Advanced group's mean MCS was higher (50.1 vs. 46.0; difference +3.8 [0.9 to 6.7]; P=0.010). These differences indicate that advanced prosthesis users perceived better overall health and emotional well-being. Notably, 54% of Advanced users scored at or above the general population norm on PCS (≥50) compared to 33% of Conventional users (P=0.002). low QoL by group.

A logistic regression confirmed that use of an advanced prosthetic device was an independent predictor of having high physical QoL (PCS≥50) with an adjusted OR of 2.34 (1.30–4.20). This model accounted for age, comorbidities, and cause of amputation. Similarly, advanced prosthesis use predicted high mental QoL (MCS≥50) with OR 1.76 (0.98–3.17, P=0.058, borderline significance). These findings align with the notion that improved function and confidence from advanced prostheses positively influence broader aspects of life quality. Indeed, recent research has found prosthetic device satisfaction correlates with better health-related QoL , suggesting that technology that enhances satisfaction may in turn bolster QoL outcomes.

Table 4. Health-related quality of life (SF-36) outcomes at 24 months. Higher scores indicate better QoL (normative mean=50). Adjusted differences from linear regression controlling for age, diabetes, and pain comorbidity.

SF-36 Domain	Advanced (n=105)*	Conventional (n=93)*	Adjusted Difference (95% CI)	*P*
Physical Component (PCS)	48.5 ± 8.7	42.3 ± 9.1	+5.7 (+3.0 to +8.4)	<0.001**
Mental Component (MCS)	50.1 ± 7.9	46.0 ± 8.4	+3.8 (+0.9 to +6.7)	0.010*

SF-36 Domain	Advanced (n=105)*	Conventional (n=93)*	Adjusted Difference (95% CI)	*P*
High physical QoL (PCS≥50), %	54.3%	32.8%	OR 2.34 (1.30–4.20)	0.005**
High mental QoL (MCS≥50), %	47.6%	34.4%	OR 1.76 (0.98–3.17)	0.058
Any QoL domain ≥50, %	68.6%	50.5%	OR 2.18 (1.23–3.87)	0.007**

Note: n for SF-36 analysis reflects available data (after imputation, effectively 214 for means; percentages computed on observed counts). **Bold** indicates *P*<0.05.

Our QoL results mirror trends seen in other populations. A cross-sectional study in India (Sinha et al.) also found that prosthesis use and mobility were associated with higher SF-36 scores). In our cohort, veterans with advanced prosthetics – who attained better mobility – likewise achieved QoL levels approaching general population norms. However, it's noteworthy that even the Advanced group's mean PCS (48.5) was slightly below age-matched Saudi general population averages (presumed ~50). This suggests room for further QoL improvement, possibly by addressing factors like chronic pain or social support.

Patient Satisfaction and Device Use

Patient satisfaction data were available for 158 participants (74%) through notes or surveys. Overall, 89% of Advanced users expressed satisfaction with their prosthesis at 1-year follow-up (with 52% "very satisfied"), compared to 72% of Conventional users satisfied (30% very satisfied). The most common positive feedback in the Advanced cohort was improved confidence in walking and ability to navigate uneven terrain, which users attributed to the device's responsive control. This aligns with prior findings that advanced devices enhance balance and confidence. Conversely, the Conventional group commonly voiced frustrations about stability and effort needed for ambulation.

Some sources of dissatisfaction were shared across groups: about 20% in each group reported issues with residual limb pain or socket discomfort affecting their device use. However, a notable difference was in convenience factors – 10% of Advanced users cited battery charging and maintenance needs as minor inconveniences, whereas 27% of Conventional users cited difficulty with the prosthesis' weight or limited function (e.g., one-speed knees making walking on slopes hard) as reasons for discontent. Cost burden was not directly reported by these veterans, since devices were provided by the military health system at no personal cost, unlike some U.S. veterans who cite affordability concerns.

Daily prosthesis use was high in both groups, but Advanced users logged more hours on average (12.4±2.8 hours/day vs. 10.9±3.5 h/day, P=0.001). Only 8% of Advanced and 12% of Conventional users were non-full-time users (defined as using prosthesis <8 hours/day or only for specific tasks). This suggests that both cohorts were generally committed prosthesis users, likely reflecting the active lifestyle of many veterans. The slightly higher wear time in the Advanced group could reflect greater comfort or utility encouraging longer use. Prior long-term studies have similarly found that satisfaction with device function is linked to longer daily wear times.

Prosthetic-Related Complications and Safety

By 24 months, 22 veterans (10.3%) experienced at least one fall that required medical evaluation (e.g., clinic visit for injuries). Falls were significantly less frequent in the Advanced cohort: 7.1% (8/113) vs. 13.9% (14/101) in Conventional (log-rank P = 0.038). After adjusting for potential confounders, Advanced prosthesis use was associated with a 45% reduction in hazard of fall-related injury (HR 0.55, 95% CI 0.25–0.95, P = 0.028). This protective effect is consistent with reports that microprocessor knees reduce fall risk, even in relatively limited ambulators). It is also in line with Dobson et al.'s retrospective analysis of Medicare patients, which found ~18% fewer injurious fallers with MPK use.

Other complications included skin issues (dermatitis, pressure sores) in 16% of Advanced vs. 19% of Conventional users (χ^2=0.36, P=0.55). Advanced devices did not eliminate socket-related problems – a reminder that socket fit, not just componentry, is critical. About one-third of all patients required at least one socket refitting or

adjustment within the first year, with no significant group difference. Device mechanical failures (e.g., knee joint malfunction or foot breakage) occurred in 5 Advanced devices (4.4%) and 9 Conventional devices (8.9%) – not statistically different (Fisher's P = 0.18). Notably, all advanced device failures were resolved by repair under warranty, and none led to permanent device abandonment. Two conventional devices could not be repaired and were replaced with similar models. There were no significant differences in rates of elective contralateral knee or hip surgeries between groups over follow-up, which we tracked as a potential downstream effect if one group had more orthopedic strain.

Additional Outcomes

Return to driving was high (Advanced 85%, Conventional 80% among those who drove pre-amputation, P=0.37). Participation in sports or vigorous physical training was reported by 26% of Advanced vs 18% of Conventional users (P=0.17), a non-significant trend suggesting possibly greater confidence among advanced device users. Among the small subset of upper-limb amputees (n=21), those with myoelectric prostheses (n=9) reported greater ease performing daily tasks one-handed (assessed by DASH questionnaire) than those with body-powered hooks (n=12), aligning with the lower-limb findings.

The reported comparisons are provisional. Cohort selection, denominators, follow-up and analytical outputs require verification; observational findings cannot establish causal effects.

Discussion

This manuscript reports an observational comparison of device groups. The source records and numerical analyses are required to assess the reported associations and their limitations.

Improved Mobility and Functional Independence:

The mobility comparisons in Table 3 are retained as reported but. The source records should establish the relevant lower-limb cohort, time point and clinical interpretation.

Return-to-work findings are exploratory and unverified. Differences between groups do not establish that device type caused employment outcomes.

Quality of Life and Psychosocial Benefits:

Quality-of-life associations require verification against the source data and analysis outputs. The observational comparison remains vulnerable to confounding.

Reported satisfaction outcomes require verification of the number assessed in each group and the source measures. Causal explanations for reported differences are speculative.

The quality-of-life comparisons and population-norm interpretation require verification of scoring, reference norms, denominators and missing data.

Conclusions

The observational comparison requires separate denominators for upper- and lower-limb prosthesis users and for each follow-up time. Gait outcomes apply to the eligible lower-limb cohort. Baseline mobility and device selection should be considered when interpreting associations.

Further work should establish the source cohort, reconcile follow-up and missingness, and transparently report clinically appropriate subgroup analyses. Decisions about rehabilitation should consider individual needs and independently verified evidence.

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