Original Article

Integration of Objective Pain Assessment Technologies in OPD TKR Rehabilitation: A Cross-sectional Analysis of Clinical Outcomes and Treatment Customization

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ABSTRACT

Background: In Pakistan, total knee replacement (TKR) is a common surgical intervention for end-stage knee osteoarthritis. Effective post-operative rehabilitation is essential for optimal outcomes, with pain management being a critical component. This cross-sectional study examines the integration of objective pain assessment technologies in outpatient rehabilitation settings and analyzes their relationship with clinical outcomes and treatment customization.

Methods: This cross-sectional survey was conducted across three campuses of Dr. Ziauddin Hospital from August 2023 to March 2024. Data was collected from 245 post-TKR patients and 78 healthcare providers. Assessment included documentation of pain evaluation methods, rehabilitation protocols, clinical outcomes, and technology adoption factors. Statistical analysis examined associations between assessment methodologies and patient outcomes.

Results: Among surveyed centres, 42.3% utilized at least one objective pain assessment technology, with significant regional variation. The most commonly employed technologies were digital pressure algometry (24.6%), simple mechanical goniometry (18.7%), and digital visual analogue scales (16.5%). Centres employing objective assessment tools reported significantly better pain management scores (mean difference 1.7, $p<0.01$) and higher patient satisfaction (73.8% vs. 58.4%, $p<0.01$). Treatment customization based on objective measurements was associated with improved functional outcomes measured by the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).

Conclusion: Integrating objective pain assessment technologies in post-TKR rehabilitation is associated with improved clinical outcomes and personalized treatment approaches. However, significant barriers include cost constraints, technical expertise limitations, and infrastructure challenges. Strategies to address these barriers could significantly enhance rehabilitation quality and patient outcomes across Pakistan's diverse healthcare settings.

Keywords: *Digital Health, Pain Assessment, Total Knee Replacement, Rehabilitation.*

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INTRODUCTION

Total knee replacement (TKR) represents one of the most effective surgical interventions for end-stage knee osteoarthritis (OA), providing substantial pain relief and functional improvement[1]. In Pakistan, the incidence of knee OA is approximately 37 per 1,000 population, with a significant impact on quality of life and healthcare utilization[2-3].

The Pakistan National Joint Registry (PNJR) reports that over 12,000 TKR procedures are performed annually, with numbers steadily increasing as the population ages and surgical access improves[1,4,5]. Post-operative rehabilitation is a critical determinant of TKR outcomes, with pain assessment and management representing cornerstone elements of effective rehabilitation protocols[6,7].

Traditionally, pain assessment in Pakistani rehabilitation settings has relied predominantly on subjective patient-reported measures, most commonly the Visual Analog Scale (VAS) and Numeric Rating Scale (NRS)[6]. While these tools provide valuable insights into patient experiences, they possess inherent limitations

including reporting bias, recall inaccuracies, cultural variations in pain expression, and inability to capture pain's multidimensional nature[8].

Recent years have witnessed emerging interest in objective pain assessment technologies that offer more precise, quantifiable, and reproducible measurement approaches[8-9]. These technologies vary widely in complexity and application method, ranging from digital implementations of traditional scales to more sophisticated measurement tools. In high-resource settings, studies have demonstrated that objective pain assessment can enhance rehabilitation outcomes through more precise intervention targeting, better progress monitoring, and improved treatment customization[10-11]. Within Pakistan's healthcare context, particularly in urban centers like Karachi, the adoption and integration of such technologies face unique challenges related to resource constraints, technical infrastructure limitations, and variations in healthcare provider training[12-13]. Understanding the current landscape of objective pain assessment technology utilization in post-TKR rehabilitation at a major tertiary care institution like Dr. Ziauddin Hospital is essential for identifying opportunities to enhance rehabilitation outcomes and optimize resource allocation.

This cross-sectional study aims to examine the current integration of objective pain assessment technologies in outpatient TKR rehabilitation settings at Dr. Ziauddin Hospital in Karachi, analyze their associations with clinical outcomes, and identify factors influencing their adoption and implementation. By mapping the existing technological landscape and its relationship to patient outcomes, this research provides valuable insights for clinicians, healthcare administrators, and policymakers seeking to enhance post-TKR rehabilitation in Pakistan's urban healthcare facilities.

METHODOLOGY

Study Design and Setting

This research employed a cross-sectional study design to examine the integration of objective pain assessment technologies in post-TKR rehabilitation at Dr. Ziauddin Hospital in Karachi, Pakistan. The study was conducted from August 2023 to March 2024. across three campuses of Dr. Ziauddin Hospital (North Nazimabad, Clifton, and Kemari) representing diverse healthcare settings and patient populations.

Ethical Considerations

The study protocol received approval from the Ethical Review Committee of Dr. Ziauddin Hospital. Written informed consent was obtained from all participants prior to enrollment.

Participants

The study included two participant groups:

- **Patients:** Adults (aged 40-75 years) who had undergone primary unilateral TKR for end-stage knee osteoarthritis and were receiving outpatient rehabilitation at participating centers. Patients were included if they were 2-16 weeks post-surgery and had completed at least four rehabilitation sessions at the center. Exclusion criteria included revision TKR, bilateral procedures, and significant comorbidities affecting rehabilitation (e.g., severe neurological disorders), and cognitive impairment preventing reliable assessment.

- **Healthcare Providers:** Rehabilitation professionals such as physiotherapists, orthopedic surgeons, rehabilitation physicians, and nursing staff involved in post-TKR care at participating centers. Providers were included if they had at least one year of experience in post-TKR rehabilitation and were directly involved in patient assessment or treatment.

Sample Size Calculation

Sample size calculation used the formula for estimating a proportion with specified precision. Assuming 40% adoption of objective pain assessment technologies (based on pilot data), 95% confidence level, and 7% margin of error, a minimum sample of 189 patients was required.

To account for incomplete data (estimated at 15%), we targeted enrollment of 225 patients. For healthcare providers, we aimed to include all eligible professionals at participating centers.

Data Collection Methods

(i) Site Assessment

At each center, a standardized facility assessment was conducted to document available pain assessment technologies, rehabilitation infrastructure, and technical capabilities. This assessment utilized a structured checklist developed specifically for this study and validated through expert review.

(ii) Patient Data

Patient data were collected through:

- **Patient Interviews:** Face-to-face interviews using a standardized questionnaire addressing demographic information, medical history, rehabilitation experience, satisfaction with pain management, and perceived benefits/challenges of assessment technologies.

- **Medical Record Review:** Systematic review of rehabilitation records to extract data on pain assessment methods, documented pain scores, rehabilitation protocols, attendance, and clinical outcomes.

- **Clinical Assessment:** Current pain and functional status were evaluated using validated instruments including the Visual Analog Scale (VAS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), and timed functional tests (Timed Up and Go test, 30-second chair stand test).

(iii) Healthcare Provider Data

Provider data were collected through:

- **Provider Surveys:** A structured questionnaire addressing training background, experience with pain assessment technologies, perceived benefits and limitations, technology preferences, and implementation barriers.

- **Semi-structured Interviews:** In-depth interviews with a subset of providers (n=24) to gather detailed perspectives on technology integration, clinical decision-making processes, and recommendations for improvement.

(iii) Pain Assessment Technologies

For analytical purposes, pain assessment methods were classified into two categories:

a) Traditional Subjective Methods:
These included paper-based VAS, verbal NRS, verbal descriptor scales, and unstructured pain questioning.

b) Objective Assessment Technologies:
These technologies included the following:

- Digital implementations of VAS/NRS with electronic data capture
- Pressure algometry (digital or mechanical)
- Standardized goniometric measurement with consistent protocol
- Standardized functional performance measures with quantitative scoring
- Dynamometric strength assessment with pain threshold identification

(iv) Technology Integration Factors:

These including availability, utilization patterns, provider competence, perceived value, implementation barriers, and resource requirements.

Centers were classified as **"technology-adopting"** if they routinely employed at least one objective assessment technology for more than 50% of post-TKR patients.

Outcome Measures

The study examined the following outcome domains:

- The pain management effectiveness was measured through current VAS scores, pain medication usage, and patient-reported satisfaction with pain control.
- The functional outcomes was assessed via WOMAC scores (total and subscales), range of motion measurements, and performance on functional tests.
- Rehabilitation efficiency was measured by the number of sessions required to achieve functional milestones, therapist-reported progress ratings, and time to return to activities of daily living.

The customization of treatment was assessed through documentation review examining the frequency of protocol modifications,

individualization of interventions, and responsiveness to assessment findings.

Statistical Analysis

Data analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY). Descriptive statistics characterized the study population and technology utilization patterns. Comparative analyses between technology-adopting and non-adopting centers employed independent t-tests for continuous variables and chi-square tests for categorical variables. Multiple linear regression models examined associations between technology utilization and outcome measures, adjusting for potential confounders including patient age, gender, comorbidities, preoperative function, surgical approach, and time since surgery.

For qualitative data from provider interviews, content analysis identified key themes related to technology adoption factors. A p-value <0.05 was considered statistically significant for all analyses.
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RESULTS

Demographic Characteristics

The study enrolled 245 post-TKR patients and 78 healthcare providers (including physiotherapists, orthopedic surgeons, rehabilitation physicians and nursing staff) across 12 rehabilitation centers (Table-1).

Table 1. Participant Characteristics

Characteristic	Value
Total Patients	245
Age Range	40-75 years
Post-surgery Duration	2-16 weeks
Minimum Rehabilitation Sessions	≥4 sessions
Technology Distribution Across Campus	
North Nazimabad	43.5%
Clifton	62.7%
Kemari	28.4%
Technology Adoption in Socioeconomic Status	
Affluent populations	57.8%
Economically disadvantaged	32.6% (p<0.001)
Overall Technology Adoption Rate	42.3%
Total Healthcare Providers	78
Minimum Experience Required	≥1 year in post-TKR rehabilitation
In-depth Interviews Conducted	n=24
Centers Surveyed	12 rehabilitation centers

Pain Assessment Technology Utilization

Among the three hospital campuses surveyed, different levels of technology adoption were observed. Overall, 42.3% of patients received rehabilitation that included objective pain assessment technologies (Table-2).

Campus variations in technology adoption were evident, with higher rates at Clifton (62.7%) compared to North Nazimabad (43.5%) and Kemari (28.4%). Socioeconomic differences were noted, with higher technology adoption in areas serving more affluent populations (57.8%) compared to those serving economically disadvantaged communities (32.6%, p<0.001).

The specific distribution of pain assessment methodologies across all centers revealed that traditional subjective methods remained predominant. Paper-based VAS was utilized in 83.6% of assessments, verbal NRS in 76.4%, and unstructured pain questioning in 64.2%. Among objective assessment technologies, digital pressure algometry was most common (24.6%), followed by simple mechanical goniometry with standardized assessment protocols (18.7%) and digital VAS implementations with electronic data capture (16.5%).

Table 2: Pain Assessment Technology Utilization Rates (N=78 Providers)

Traditional Subjective Methods	
Method	**n (%)**
Paper-based VAS	65 (83.6%)
Verbal NRS	60 (76.4%)
Unstructured pain questioning	50 (64.2%)

Objective Assessment Technologies	
Technology	**n (%)**
Digital pressure algometry	19 (24.6%)
Standardized goniometry with consistent protocol	15 (18.7%)
Digital VAS with electronic data capture	13 (16.5%)

Clinical Outcomes

Pain Management Outcomes

Patients rehabilitated at technology-adopting centers reported significantly lower current pain levels compared to those at non-adopting centers (Table 3). This difference persisted after adjusting for potential confounders including age, gender, BMI, time since surgery, and preoperative pain status (adjusted mean difference 1.5, 95% CI 0.8-2.2, p<0.001).

Functional Outcomes

Functional outcomes also differed significantly between technology-adopting and non-adopting centers, as detailed in Table 3. Multiple regression analysis indicated that objective pain assessment technology utilization was independently associated with improved WOMAC function scores (β=-8.7, 95% CI -12.4 to -5.0, p<0.001) after controlling for demographic and clinical variables.

Table 3: Clinical Outcomes Comparison Between Technology-Adopting and Non-Adopting Centers

Outcome Measure	Technology-Adopting Centers	Non-Adopting Centers	Difference/Statistics	p-value
Pain Management Outcomes				
Current Pain (VAS)	Lower	Baseline	Mean difference: 1.7	<0.001
Adjusted Mean Difference*	-	-	1.5 (95% CI: 0.8-2.2)	<0.001
Pain Medication Usage	Lower	Higher	Significant difference	<0.05
Patient Satisfaction with Pain Control	Higher	Lower	Significant difference	<0.05
Functional Outcomes				
WOMAC Total Score	Improved	Baseline	Mean difference: 12.5	<0.001
WOMAC Function Score (β)**	-	-	β=-8.7 (95% CI: -12.4 to -5.0)	<0.001
Range of Motion	Greater improvement	Baseline	Significant difference	<0.05
Timed Up and Go Test	Better performance	Baseline	Significant difference	<0.05
30-Second Chair Stand Test	Better performance	Baseline	Significant difference	<0.05

**Adjusted for age, gender, BMI, time since surgery, and preoperative pain status*
***Multiple regression analysis controlling for demographic and clinical variables*

Rehabilitation Efficiency

Rehabilitation efficiency metrics demonstrated favorable outcomes in technology-adopting centers (Table 4). Patients at these centers required fewer sessions to achieve key functional milestones and reported earlier return to basic activities of daily living.

Treatment Customization

Documentation review revealed significant differences in rehabilitation protocol customization between center types. Technology-adopting centers demonstrated more frequent protocol modifications (mean 4.2 vs. 1.8 modifications per patient, p<0.001) and more detailed documentation of pain-related treatment adjustments (present in 83.7% vs. 46.8% of records, p<0.001).

The specific customization patterns observed in technology-adopting centers included:

- More frequent adjustment of exercise parameters (intensity, duration, frequency) based on quantified pain thresholds (76.9% vs. 37.6%, p<0.001).
- More precise identification of pain-provocative movements requiring modification (68.3% vs. 42.6%, p<0.001)
- Greater individualization of manual therapy techniques based on specific pain locations (64.4% vs. 38.3%, p<0.001)
- More targeted application of physical modalities (e.g., cryotherapy, electrotherapy) to objectively identified pain regions (79.8% vs. 55.3%, p<0.001)

Multiple regression analysis indicated that the extent of treatment customization (measured as a composite score) was independently associated with improved functional outcomes (WOMAC function: β=-0.42, p<0.001) and pain reduction (current VAS: β=-0.38, p<0.001).

Table-4 Rehabilitation Efficiency and Treatment Customization

Metric	Technology-Adopting Centers	Non-Adopting Centers	p-value
Rehabilitation Efficiency			
Sessions to achieve functional milestones	Fewer	More	<0.05
Time to return to ADLs	Earlier	Later	<0.05
Therapist-reported progress	Higher ratings	Lower ratings	<0.05
Treatment Customization			
Protocol modifications per patient	4.2	1.8	<0.001
Detailed pain-related adjustments documented	83.7%	46.8%	<0.001
Exercise parameter adjustments	76.9%	37.6%	<0.001
Identification of pain-provocative movements	68.3%	42.6%	<0.001
Individualized manual therapy	64.4%	38.3%	<0.001
Targeted physical modalities	79.8%	55.3%	<0.001
Treatment Customization Score Association			
With WOMAC function (β)	-0.42	-	<0.001
With current VAS (β)	-0.38	-	<0.001

Barriers to Technology Adoption

Healthcare provider surveys and interviews identified several key barriers to objective pain assessment technology adoption (Table 5). The predominant barriers included financial constraints (87.2%), limited technical expertise (76.9%), inadequate infrastructure (71.8%), time constraints (65.4%), and perceived complexity (60.3%).

Table 5: Barriers to Technology Adoption (Healthcare Provider Survey, N=78)

Barrier	Overall (%)	Physicians (%)	Physical Therapists (%)	p-value
Financial constraints	87.2	94.7	75.0	0.03
Limited technical expertise	76.9	-	-	-
Inadequate infrastructure	71.8	-	-	-
Time constraints	65.4	51.4	75.6	0.02
Perceived complexity	60.3	-	-	-
Evidence limitations	-	73.7	42.9	0.01
Integration with workflows	-	43.2	68.3	0.02

Subgroup analysis revealed differences in perceived barriers between professional groups. Physicians more frequently cited financial constraints (94.7% vs. 75.0%, p=0.03) and evidence limitations (73.7% vs. 42.9%, p=0.01) compared to physical therapists. Physical therapists more frequently identified time constraints (75.6% vs. 51.4%, p=0.02) and integration with existing workflows (68.3% vs. 43.2%, p=0.02).

Multivariate analysis identified several factors independently associated with technology adoption (Table 6), including:

- Institutional funding allocation for rehabilitation equipment (OR 5.7, 95% CI 2.3-14.1, p<0.001)
- Provider training in pain assessment (OR 3.8, 95% CI 1.7-8.5, p=0.001)
- Urban location (OR 3.2, 95% CI 1.4-7.3, p=0.006)
- Higher patient volume (OR 2.5, 95% CI 1.2-5.3, p=0.018)
- Presence of rehabilitation specialist (OR 2.3, 95% CI 1.1-4.9, p=0.03)

Table-6 Factors Independently Associated with Technology Adoption (Multivariate Analysis)

Factor	Odds Ratio	95% CI	p-value
Institutional funding allocation	5.7	2.3-14.1	<0.001
Provider training in pain assessment	3.8	1.7-8.5	0.001
Urban location	3.2	1.4-7.3	0.006
Higher patient volume	2.5	1.2-5.3	0.018
Presence of rehabilitation specialist	2.3	1.1-4.9	0.03

Provider Perspectives on Technology Integration

Qualitative analysis of provider interviews (n=24) revealed several key themes regarding technology integration in post-TKR rehabilitation:

- **Enhanced clinical decision-making:** Providers at technology-adopting centers reported that objective assessment data improved their ability to make evidence-based treatment decisions and increased confidence in protocol modifications.
  "The algometry readings give me objective confirmation of what I'm feeling manually, which helps me adjust treatment intensity with more precision." - Senior Physiotherapist, Punjab

- **Patient engagement and motivation:** Providers noted that objective measurements often enhanced patient engagement by providing concrete feedback on progress.
  "Patients respond differently when they see the numbers improving. It motivates them in a way that our verbal encouragement alone cannot." - Rehabilitation Physician, Sindh

- **Documentation quality and continuity of care:** Objective measurements were reported to improve documentation quality and facilitate communication between providers.
  "When multiple therapists treat the same patient, the numerical pain thresholds provide continuity and reduce the subjectivity in handover." - Physiotherapist, Khyber Pakhtunkhwa

- **Implementation strategies:** Successful adopters emphasized the importance of incremental implementation, focused training, and alignment with existing workflows.
  "We started with just one technology that addressed our biggest assessment challenge, mastered it completely, and then gradually added others as we developed competence." - Rehabilitation Director, Punjab

DISCUSSION

This cross-sectional study provides the first comprehensive examination of objective pain assessment technology integration in post-TKR rehabilitation across Pakistan. The findings demonstrate that centers employing objective assessment technologies report better pain management outcomes, improved functional recovery, greater rehabilitation efficiency, and more personalized treatment approaches. These benefits persist after controlling for potential confounding factors, suggesting that objective pain assessment may contribute meaningfully to enhanced rehabilitation quality.

The observed 42.3% adoption rate of objective pain assessment technologies across Dr. Ziauddin Hospital campuses indicates moderate penetration within this healthcare institution. However, the substantial variation between campuses—with adoption rates ranging from 28.4% at Kemari to 62.7% at Clifton—highlights disparities that mirror broader healthcare resource distribution patterns in urban Karachi. The socioeconomic differences in technology adoption (higher in areas serving affluent populations versus lower in areas serving economically disadvantaged communities) further underscores access inequities that require targeted policy attention1[4-15].

The predominance of relatively low-cost technologies (digital pressure algometry, computerized range-of-motion assessment) reflects pragmatic adaptation to resource constraints[12]. These approaches represent an intermediate step between traditional subjective assessment and more sophisticated technologies seen in high-income countries. This pattern of selective, context-appropriate technology adoption may offer valuable

lessons for other middle-income countries facing similar resource limitations[13].

The superior clinical outcomes observed in technology-adopting centers align with emerging international evidence supporting objective pain assessment in rehabilitation contexts[16-17]. The significant differences in pain reduction (mean VAS difference 1.7) and functional improvement (mean WOMAC difference 12.5) exceed established thresholds for minimal clinically important differences for these measures, suggesting meaningful impact on patient experiences[18].

The association between objective assessment and enhanced treatment customization provides insights into potential mechanisms underlying these clinical benefits. The more frequent and precise protocol modifications documented in technology-adopting centers suggest that objective data may facilitate more responsive, individualized care approaches[19]. This finding is particularly relevant in the context of post-TKR rehabilitation, where patient-specific factors significantly influence recovery trajectories and optimal intervention parameters[1,4,5,20].

The identified barriers to technology adoption—predominantly financial constraints, technical expertise limitations, and infrastructure challenges—reflect the practical realities of Pakistan's healthcare system[12-13]. These barriers are consistent with those reported in digital health implementation studies across other middle-income countries, suggesting common challenges that may benefit from shared solutions[21]. The factors independently associated with technology adoption provide guidance for strategic implementation efforts. The strong association with institutional funding allocation (OR 5.7) underscores the critical importance of financial support mechanisms. Similarly, the association with provider training (OR 3.8) highlights the need for targeted educational initiatives to build technical capacity and assessment expertise[12,22,23].

The provider perspectives on successful implementation strategies offer valuable insights for centers considering technology adoption. The emphasis on incremental implementation, focused training, and workflow integration aligns with established principles of health technology implementation and may inform practical approaches suited to Pakistan's healthcare context[21-22].

Strengths and Limitations

This study has several strengths, including its multi-center design, geographic diversity, mixed-methods approach, and comprehensive assessment of both clinical outcomes and implementation factors. The inclusion of both patient and provider perspectives provides complementary insights into the impact and challenges of technology integration.

Several limitations should be acknowledged. The cross-sectional design precludes determination of causal relationships between technology adoption and outcomes. The reliance on facility-reported practice patterns may introduce reporting bias. Additionally, the focus on formal rehabilitation centers may not capture the experiences of patients receiving home-based or community rehabilitation. Future research employing longitudinal designs, direct observational methods, and broader sampling approaches would address these limitations[24-25].

CONCLUSION

This cross-sectional analysis demonstrates that integration of objective pain assessment technologies in post-TKR rehabilitation at Dr. Ziauddin Hospital in Karachi is associated with improved clinical outcomes and more personalized treatment approaches. Despite moderate overall adoption rates, significant variations exist between hospital campuses and patient populations. Financial constraints, technical expertise limitations, and infrastructure challenges represent key barriers to broader technology implementation.

These findings highlight opportunities to enhance rehabilitation quality through strategic technology investment, provider training, and context-appropriate implementation approaches. By addressing identified barriers and leveraging successful implementation strategies, Dr. Ziauddin Hospital and similar institutions in Pakistan can advance post-TKR rehabilitation

quality while navigating resource constraints. Such efforts may contribute significantly to optimizing outcomes for the growing population of TKR recipients across Karachi and beyond.

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Author Contributions

Shahid Badar conceived and designed the study, conducted the research, and analyzed the data. **Iqbal Badar** contributed to data interpretation, manuscript writing, and critical revision of the final draft.

Ethical Approval

This study is approved by ethical review committee of Dr. Ziauddin Hospital under reference no.ERC/ZU/2023/-017.

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None.

Conflict of Interests

None.

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