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Structural Cost Dynamics and Determinants of Hospitalization Expenditure for Anterior Cruciate Ligament (ACL) Reconstruction and Total Knee Arthroplasty Under Fee-for-Service Care

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Abstract

Background: Global healthcare costs drive ultra-short hospitalizations, but their safety remains debated. In Japan, inpatient care emphasizes functional recovery before discharge. We evaluated total hospitalization cost (THC) determinants following primary anterior cruciate ligament reconstruction (ACLR) and total knee arthroplasty (TKA) under patient-centered discharge criteria.

Methods: Retrospectively, 111 ACLR knees (Group A; median age, 19) and 121 TKA knees (Group T; median age, 75) were analyzed. Discharge required controlled pain, independent daily living, and established home support. Primary outcomes were THC, length of stay (LOS), age, sex, body mass index, and operation time, evaluated via variance decomposition and stepwise linear regression.

Results: Median LOS and THC were 25 days and ¥ 1,690,090 (\$ 10,563) for Group A, and 31 days and ¥ 2,264,260 (\$ 14,152) for Group T. LOS moderately or strongly correlated with THC (Group A: $r = 0.692$; Group T: $r = 0.777$; $p < 0.001$). Time-dependent variable costs (rehabilitation and ward care) accounted for 73.4% of THC variance in Group A and nearly 100% in Group T, while surgical costs contributed minimally. Regression confirmed LOS ($p < 0.001$) and age ($p = 0.003$) as independent THC predictors for ACLR, and LOS ($p < 0.001$) for TKA.

Conclusion: THC in major knee surgeries is overwhelmingly driven by LOS-dependent variable costs rather than surgical expenses. Value-based care requires pathways accelerating functional recovery safely.

Categories: Orthopedics

Keywords: anterior cruciate ligament reconstruction, fee-for-service system, length of stay, total hospitalization cost, total knee arthroplasty

Introduction

Anterior cruciate ligament reconstruction (ACLR) and total knee arthroplasty (TKA) are representative, highly effective surgical procedures in knee surgery, addressing functional restoration in younger populations and pain relief with functional recovery in older populations, respectively [1-3]. Driven by an expanding athletic population and a rapidly aging society, the annual volume of both procedures continues to rise globally. Consequently, escalating healthcare expenditures have emerged as a critical societal challenge threatening the sustainability of healthcare systems [4-7].

In Western healthcare systems where prospective diagnosis-related group (DRG) or bundled payment models predominate, remarkable reductions in length of hospital stay (LOS) and the adoption of outpatient or same-day surgery models have been widely reported [8,9]. However, these ultra-short hospitalization models have raised clinical concerns, including inadequate post-discharge support, persistent acute pain, impaired activities of daily living (ADL), and an increased risk of unplanned readmissions [10-12].

Conversely, while Japan has progressively implemented the Diagnosis Procedure Combination/Per-Discharge Payment System (DPC/PDPS) [13], a substantial number of institutions continue to operate under a traditional fee-for-service (FFS) reimbursement model. Coupled with robust patient protection mechanisms such as the High-Cost Medical Care Benefit System [5], there are few financial incentives for extreme early discharge. Consequently, a relatively prolonged LOS has been maintained [14-17]. Although this extended stay reflects a patient-centered approach ensuring adequate pain control and functional

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independence prior to discharge, it is frequently criticized as a primary driver of high total hospitalization costs (THC).

Most previous studies evaluating LOS in Japan have been limited to descriptive comparisons of stay duration [14–17], with scarce investigation into the structural breakdown of total expenditures - specifically distinguishing fixed costs (e.g., surgical fees and implant costs) from variable costs (e.g., daily ward management and rehabilitation fees) [4]. Crucially, existing literature often fails to distinguish between a cost category's proportional contribution to total expenditure (overall budget share) and its contribution to patient-to-patient cost variability (what drives variance between individual patients). Furthermore, under bundled or DPC systems, institutional pressure to discharge patients early - driven by step-down daily reimbursement rates - obscures the intrinsic variable cost structure associated with patient-driven functional recovery.

Therefore, this study aimed to investigate the structural cost dynamics of ACLR and TKA within a pure FFS environment, evaluating them as two distinct analytical models representing younger and older patient populations, respectively, rather than conducting a direct head-to-head comparison. Specifically, we sought to delineate two distinct financial dimensions: (1) the proportional breakdown of total expenditure components, and (2) the specific contribution of each component to overall inter-patient cost variance. Uncovering these baseline dynamics provides essential evidence for developing perioperative strategies aimed at achieving an optimal stay-balancing clinical safety, patient satisfaction, and economic rationality.

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Materials And Methods

Study design and patient selection

This retrospective observational study was approved by the Institutional Review Board, which waived the requirement for informed consent due to the retrospective nature of the study. All data were anonymized, and confidentiality was maintained throughout the study.

Consecutive primary arthroscopic ACLRs (105 patients, 111 knees) performed by two senior orthopedic surgeons between April 2017 and July 2026 were retrospectively reviewed (Table 1). The inclusion criteria for the ACLR group were primary ACL injury, age ≥ 12 years, and a minimum follow-up of one month. Isolated ACLR was performed in 48 knees, while 63 knees underwent concomitant procedures (meniscal surgery or anterolateral ligament reconstruction). The exclusion criteria were revision ACLR, multi-ligament injuries, severe osteoarthritis, previous lower extremity surgery/fracture, or simultaneous tibial osteotomies. To evaluate cost structures across different patient demographics and surgical complexity, consecutive primary TKAs (106 patients, 121 knees) performed by a single surgeon for primary knee osteoarthritis during the same period were analyzed as a separate cohort (Table 1). The inclusion criteria were primary end-stage knee osteoarthritis and a minimum follow-up of one month. The primary implant used was the LCS Complete Knee System (100 knees; DePuy Synthes, Warsaw, IN, USA). Following the discontinuation of the LCS system, the ATTUNE Knee System (21 knees; DePuy Synthes) was utilized for subsequent cases. Bilateral cases were managed via staged, planned procedures. The exclusion criteria for the TKA group were secondary osteoarthritis (e.g., rheumatoid arthritis or post-traumatic arthritis), revision arthroplasties, or previous knee surgeries including tibial osteotomies.

Parameter	ACL group (n = 105, 111 knees)	TKA group (n = 106, 121 knees)	Test statistic	p-value
Sex (male/female)	53/58	14/107	$\chi^2 = 38.41^*$	<0.001*
Age (years)	19 (17, 36) (12-56)	75 (71, 78) (58-88)	U = 13,425.0	<0.001
Height (cm)	165 (158, 172) (150-190)	151 (146, 155) (137-172)	U = 1,291.5	<0.001
Weight (kg)	64 (55, 72) (42-118)	59 (54, 68) (43-105)	U = 5,833.5	0.124
BMI (kg/m ²)	23 (21, 25) (17-41)	26 (24, 29) (17-42)	U = 3,491.5	<0.001
Operative time (min)	122 (106, 141) (68-241)	60 (55, 68) (42-113)	U = 13,431.0	<0.001
Postoperative hospital stay (days)	25 (21, 30) (7-46)	31 (28, 38) (17-63)	U = 2,803.0	<0.001

TABLE 1: Patient demographics

Data are presented as median (interquartile range) (range).

* Chi-square test; all other comparisons were performed using the Mann-Whitney U test.

ACL: anterior cruciate ligament; TKA: total knee arthroplasty; BMI: body mass index

Perioperative management and surgical technique

ACLR was performed using standard portals with either a hamstring tendon graft (48 knees) or a bone-patellar tendon-bone graft (63 knees). TKA was executed via a standard medial parapatellar approach using cementless femoral and cemented tibial components without patellar resurfacing or lateral retinacular release.

To standardize perioperative pathways and eliminate fall risks associated with motor block from regional anesthesia during early mobilization, all patients in both groups received general anesthesia combined with standardized oral and intravenous multimodal analgesia. Peripheral nerve blocks and local infiltration analgesia were intentionally omitted.

Postoperative rehabilitation and discharge criteria

Physical therapy was initiated on postoperative day 1. For isolated ACLR, isometric exercises began on day 1, followed by partial weight-bearing and range of motion (ROM) exercises after one week of immobilization, progressing to full weight-bearing at three weeks. Rehabilitation was appropriately delayed for cases with concomitant procedures. For TKA, full weight-bearing with crutches and ROM exercises were permitted as tolerated.

Discharge was granted strictly when three patient-centered criteria were fulfilled: controllable postoperative pain with oral analgesics, independence in ADL confirmed by a physical therapist, and established domestic support systems for home return.

Outcome measures and cost parameters

The primary outcome was THC and its four main subcomponents: (1) ward management fees, (2) surgical fees, (3) procedure-related costs (anesthesia, single-use materials, and implant costs), and (4) disease-specific rehabilitation fees. Secondary outcomes included patient demographics (age, sex, body mass index (BMI)), operative time, and LOS, evaluated for their influence on THC.

Statistical analysis

Statistical analyses were performed using R (version 4.6.1; R Foundation for Statistical Computing, Vienna, Austria). For patients who underwent staged bilateral procedures, each surgical episode was treated as an independent observation for statistical analysis, given that the secondary procedure was performed after complete functional recovery and independence in ADL from the initial surgery. Continuous variables were assessed for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests, along with Q-Q plots. Non-normally distributed data were expressed as median and interquartile range (IQR) and compared using the Mann-Whitney U test. Categorical variables were compared using the chi-square test. Correlations were evaluated using Spearman's rank correlation coefficient (r), categorized as strong (0.70-1.0), moderate (0.40-0.69), and weak (0.20-0.39).

To identify the primary drivers of THC variability, variance decomposition was performed across four cost components. The contribution of each component was calculated as its covariance with THC divided by the total variance of THC, expressed as a percentage. Nonparametric bootstrapping (10,000 resamples) was used to estimate 95% confidence intervals (CIs).

Additionally, to identify patient-related factors associated with THC, multiple linear regression analysis was performed with THC as the dependent variable. Age, sex, LOS, BMI, and operation time were considered candidate independent variables. Variable selection was performed using a bidirectional stepwise procedure based on the Akaike information criterion (AIC), allowing both forward selection and backward elimination. The variables retained in the final model were considered factors independently associated with THC. All statistical tests were two-sided, and a p-value < 0.05 was considered statistically significant. Statistical significance was set at a two-tailed p < 0.05. For all statistical tests, corresponding test statistics (e.g., Mann-Whitney U, χ^2 , Spearman's r, t-value, or F-value) are reported alongside p-values in the text and table legends.

Results

Overview of LOS and THC

In the ACL group, the median LOS was 25 days (IQR: 21-30 days), and the median THC was ¥1,690,090 (IQR: ¥1,487,490-¥1,844,845; equivalent to \$10,563 USD at 1 USD = 160 JPY). No significant sex-based difference in THC was observed (female: ¥1,670,965 vs. male: ¥1,725,500; Mann-Whitney U test, U = 1709.0, p = 0.311).

In the TKA group, the median LOS was 31 days (IQR: 28-38 days), and the median THC was ¥2,264,260 (IQR: ¥2,154,320-¥2,447,780; \$14,152 USD). Similarly, no significant sex-based difference was detected (female: ¥2,260,550 vs. male: ¥2,332,105; Mann-Whitney U test, U = 185.0, p = 0.185).

Correlation analysis between THC and patient factors

In both groups, LOS exhibited a moderately or strongly positive correlation with THC (Spearman's rank correlation: ACL: r = 0.692, t = 10.021, p < 0.001; TKA: r = 0.777, t = 13.393, p < 0.001). Age also showed a weak, though statistically significant, correlation with THC in both groups (Spearman's rank correlation: ACL: r = 0.209, t = 2.228, p = 0.028; TKA: r = 0.237, t = 2.660, p = 0.009). Operative time and BMI demonstrated no significant correlation with THC in either cohort (Table 2).

Table with 7 columns: Group, ACL (rs, t, p-value), TKA (rs, t, p-value). Rows include LOS, Age, Operative time, and BMI.

TABLE 2: Single linear correlation analysis (Spearman's rank correlation) between total hospital cost (THC) and patient demographic factors

rs: Spearman's rank correlation coefficient; LOS: length of stay; ACL: anterior cruciate ligament; TKA: total knee arthroplasty; BMI: body mass index

Statistical significance was evaluated using Spearman's rank correlation test. Values represent Spearman's correlation coefficients (rs), test statistics (t), and corresponding p-values.

Structural cost breakdown

Proportional breakdown comparisons using the Mann-Whitney U test revealed significant differences between groups in procedure-related costs (U = 2,286.5, p < 0.001) and rehabilitation fees (U = 10,112.0, p < 0.001) (Table 3). No significant differences were observed in the proportions of ward management fees (U = 6,227.5, p = 0.354) or surgical technique fees (U = 7,516.0, p = 0.117) (Table 3).

Parameter	ACL group (%)	TKA group (%)	Test statistic	p-value
Hospitalization/management fee	26.7	25.9	U = 6,227.5	0.354
Surgical fee	25.0	24.1	U = 7516.0	0.117
Surgical materials and supply costs	19.6	25.7	U = 2,286.5	<0.001
Rehabilitation fee	28.7	24.3	U = 10,112.0	<0.001

TABLE 3: Comparison of medical cost proportions between the ACL and TKA groups

Data are presented as percentages (or median proportions, if percentages represent group medians). Comparisons were performed using the Mann-Whitney U test.

Group comparisons were performed using the Mann-Whitney U test. Test statistics (U values) and p-values are reported for each cost component.

ACL: anterior cruciate ligament; TKA: total knee arthroplasty

Variance decomposition of cost components

Variance decomposition analysis demonstrated that in the ACL group, rehabilitation fees contributed most to THC variance (44.6%), followed by ward management fees (28.8%) and procedure-related costs (23.1%) (Table 4). In contrast, in the TKA group, rehabilitation fees (55.3%) and ward management fees (44.6%) accounted for nearly 100% of the variance, whereas surgical and procedure-related costs contributed 0% (Table 4).

Parameter	ACL group: proportion of variance (%)	ACL group: 95% CI	TKA group: proportion of variance (%)	TKA group: 95% CI
Hospitalization/management fee	28.8	22.1 to 36.5	44.6	39.7 to 49.7
Surgical fee	3.5	-1.0 to 8.1	0.0	0.0 to 0.0
Surgical materials and supply costs	23.1	15.0 to 30.8	0.0	-1.0 to 1.3
Rehabilitation fee	44.6	39.2 to 50.4	55.3	50.4 to 60.6

TABLE 4: Proportion of variance explained by each cost component relative to total hospital cost

CI: confidence interval; ACL: anterior cruciate ligament; TKA: total knee arthroplasty

Stepwise multiple linear regression analysis

Using THC as the dependent variable and clinical factors (LOS, age, sex, BMI, operation time) as independent variables, stepwise regression identified LOS ($\beta = 0.700$, $t = 10.875$, $p < 0.001$) and age ($\beta = 0.193$, $t = 2.997$, $p = 0.003$) as independent predictors of THC in the ACL group (overall model: $F(2, 108) = 68.12$, $p < 0.001$, adjusted $R^2 = 0.550$) (Table 5). In the TKA group, LOS ($\beta = 0.847$, $t = 17.400$, $p < 0.001$) was the sole independent predictor of THC (overall model: $F(1, 119) = 302.8$, $p < 0.001$, adjusted $R^2 = 0.716$) (Table 5).

Variables	B	SE	β	t	p-value	95% CI
ACL group						
Intercept	8,23,833	76,673	-	10.745	<0.001	671,986 to 975,680
Age	4,814	1,606	0.193	2.997	0.003	1,633 to 7995
Length of hospital stay	29,509	2,713	0.700	10.875	<0.001	24,136 to 34,882
TKA group						
Intercept	14,87,598	48,543	-	30.580	<0.001	1,391,478 to 1,583,718
Length of hospital stay	24,809	1,426	0.847	17.400	<0.001	21,985 to 27,633

TABLE 5: Results of multiple linear regression analysis using stepwise selection

B: unstandardized regression coefficient; SE: standard error; β : standardized regression coefficient; CI: confidence interval; ACL: anterior cruciate ligament; TKA: total knee arthroplasty

Discussion

The principal finding of this study is that under an FFS system devoid of institutional discharge pressure, LOS is the single most dominant expenditure-related factor of THC in both ACLR and TKA. Crucially, by distinguishing overall cost proportions from variance drivers, our analysis revealed that inter-patient variance in THC was overwhelmingly driven by time-dependent variable costs - specifically rehabilitation and ward management fees - rather than fixed surgical or implant expenses. Additionally, age was identified as an independent predictor of higher THC in the ACLR cohort.

While LOS strongly correlated with THC in both procedures, the underlying cost profiles displayed distinct structural contrasts between proportional composition and variance contribution. In TKA, procedure-related costs occupied a substantial proportion of overall expenditure due to high implant prices, which enlarged the overall cost denominator. However, because implant and surgical fees are relatively fixed per procedure, their contribution to inter-patient cost variance was virtually zero. Conversely, ACLR involved lower initial hardware costs but required high-density, high-frequency postoperative rehabilitation aimed at sports return. This interplay resulted in rehabilitation fees accounting for both a high proportion of total cost and the largest share of cost variance in the ACL group (44.6%). Most strikingly, in TKA, inter-patient expenditure variability was nearly entirely (99.9%) explained by LOS-dependent variable costs (rehabilitation: 55.3%, ward management: 44.6%). Importantly, the minimal contribution of surgical fees to inter-patient cost variance should not be misinterpreted as a lack of financial importance or cost-reduction potential. Because surgical technique fees are strictly regulated and fixed per procedure under the FFS system, they exhibit virtually zero variance across patients. Consequently, while surgical fees do not drive the cost differences between individual patients, they remain a major baseline component of the total financial expenditure. This distinction underscores that surgical fees define the fixed structural cost threshold, whereas LOS-dependent variable costs dictate the incremental variance among patients. These findings demonstrate that while surgical and implant fees determine the baseline financial threshold, clinical strategies targeting cost optimization should focus on LOS rationalization and perioperative pathway efficiency rather than attempting to reduce intraoperative expenses.

The median LOS observed in our cohort (ACL: 25 days, TKA: 31 days) is substantially longer than the ultra-short or outpatient models common in Western countries under prospective payment systems. However, rapid discharge models in the West have been increasingly criticized for elevated post-discharge complication rates, uncontrolled acute pain, inadequate home support, and higher emergency readmission rates [10,12]. In Japan's traditional FFS framework, extended stays have historically been utilized to ensure acute pain control, functional independence, and domestic support prior to discharge. However, because our study did not directly evaluate post-discharge complication rates, readmissions, or patient-reported outcome measures (PROMs), we cannot conclude that prolonged hospitalizations inherently guarantee superior functional recovery or clinical safety. Rather, these observations highlight a structural opportunity: achieving an optimal stay - balancing payer cost-containment with high-quality functional recovery - remains a critical objective for orthopedic surgeons.

To safely facilitate earlier discharge and reduce LOS-dependent costs, risk-stratified perioperative management strategies integrated with Enhanced Recovery After Surgery (ERAS) protocols represent a promising prospective approach [19,20]. For instance, targeted prehabilitation could be offered to older patients to optimize physical reserve prior to surgery [21,22]. Furthermore, adopting advanced multimodal analgesia combined with motor-sparing regional nerve blocks (e.g., adductor canal blocks) may facilitate

immediate postoperative ambulation without increasing fall risks [23–26]. Although regional anesthesia was historically restricted in our protocol to avoid falls, implementing modern motor-sparing techniques in future pathways could enable safe LOS reduction while maintaining patient safety and recovery quality.

This study has several limitations. First, its single-center retrospective design may introduce selection bias and regional socio-demographic influences, necessitating validation in prospective multi-center cohorts. Second, clinical complexity metrics such as the Charlson Comorbidity Index [27] and detailed socio-economic factors (e.g., living status) were not included in the multivariate models. Third, while the ACLR cohort included both isolated procedures and concomitant surgeries (e.g., meniscal repairs), our multivariable regression model was restricted to standard demographic and perioperative parameters (age, LOS, sex, BMI, and operative time) and did not explicitly adjust for specific graft choices, concomitant procedures, or surgical complexity. Fourth, using administrative billing data precluded direct evaluation of PROMs (e.g., the Knee Injury and Osteoarthritis Outcome Score (KOOS) [28], Knee Society Score (KSS) [29], EuroQol 5-Dimension (EQ-5D) [30]), long-term functional recovery, or post-discharge readmission rates; thus, no definitive conclusions regarding comparative clinical efficacy or safety between short and long stays can be drawn. Finally, absolute monetary values from an FFS system cannot be directly generalized to prospective DRG or bundled payment systems. Nonetheless, evaluating cost dynamics in an unconstrained FFS environment uniquely allowed us to reveal the intrinsic cost behavior unimpeded by artificial financial incentives.

Conclusions

Under an FFS system guided by patient-centered criteria, THCs for major knee surgeries are overwhelmingly determined by LOS and time-dependent variable costs, rather than fixed surgical expenses. Because this study did not assess PROMs or readmission rates, prolonged stay should not be assumed to inherently improve clinical outcomes or safety. Instead, optimizing healthcare value requires implementing prospective pathways - such as targeted prehabilitation and motor-sparing regional anesthesia within ERAS protocols - to safely streamline recovery, rationalize LOS, and maintain clinical safety.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

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