

# Cost and Cost Driver Analysis of Anterior Cruciate Ligament Reconstruction Using Time-Driven Activity-Based Costing

## Bone-Tendon-Bone Autograft Versus Hamstring Autograft

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**Background:** As health care transitions toward value-based care, orthopaedics has started to implement time-driven activity-based costing (TDABC) to understand costs and cost drivers. TDABC has not previously been used to study cost drivers in anterior cruciate ligament reconstruction (ACLR). The purpose of this study was to use TDABC to (1) calculate bone-tendon-bone (BTB) and hamstring ACLR total costs of care and (2) evaluate the impact of graft choice and other factors on ACLR costs.

**Methods:** Data were collected from electronic medical records for primary ACLR from the institutional patient-reported outcome registry between 2009 and 2016 in 1 ambulatory surgery center. Patients receiving allograft, revision ACLR, or concomitant meniscal repair or ligament reconstruction were excluded. The total cost of care was determined using TDABC. Multivariate regression analysis was conducted between ACLR cost and group characteristics.

**Results:** A total of 328 patients were included; 211 (64.3%) received BTB autograft and 117 (35.7%) received hamstring autograft. The mean cost was  $\$2,865.01 \pm \$263.45$  (95% confidence interval:  $\$2,829.26, \$2,900.77$ ) for BTB ACLR versus  $\$3,377.44 \pm \$320.12$  ( $\$3,318.82, \$3,436.05$ ) for hamstring ACLR ( $p < 0.001$ ). Operative time was  $103.1 \pm 25.1$  (99.7, 106.5) minutes for BTB ACLR versus  $113.1 \pm 27.9$  (108.0, 118.2) minutes for hamstring ACLR ( $p = 0.001$ ). The total implant cost was  $\$270.32 \pm \$97.08$  ( $\$257.15, \$283.50$ ) for BTB ACLR versus  $\$587.36 \pm \$108.78$  ( $\$567.44, \$607.28$ ) for hamstring ACLR ( $p < 0.001$ ). Hamstring graft ( $p = 0.006$ ) and suspensory fixation on the femoral side ( $p = 0.011$ ) were associated with increased costs.

**Conclusions:** The mean cost of care and operative time for BTB autograft ACLR are less than those for hamstring autograft ACLR. Operative time, implant choice, and graft choice were identified as modifiable cost drivers that can empower surgeons to manage primary ACLR costs while maximizing the value of the procedure.

**Level of Evidence:** Economic and Decision Analysis Level IV. See Instructions for Authors for a complete description of levels of evidence.

Anterior cruciate ligament reconstruction (ACLR) is a common procedure in the United States, with an estimated 300,000 procedures performed annually as of 2017<sup>1</sup> and a 22% increase from 2002 to 2014<sup>2</sup>. ACLRs are also increasingly costly procedures, having generated \$850,000,000 in health-care expenditures annually in 2000<sup>3</sup>. Mean costs increased from \$7,634.19 in 2005 to \$10,780.03 in 2013, and they are projected to continue rising<sup>4</sup>. ACLR costs have also been found to be highly variable<sup>4,6</sup>. This variability stems from the surgical fixation

techniques and graft options available for ACLR<sup>5-14</sup>. Bone-tendon-bone (BTB) autograft and hamstring autograft are the most common graft choices in the United States<sup>15</sup>. Orthopaedic surgeons play a substantial role in ACLR cost variability<sup>5,16,17</sup>.

In the face of excessive and continuously rising national health-care expenditures, the United States health-care system and the field of orthopaedic surgery are shifting toward incentivizing value-based care, where value is defined as the change in patient-reported outcome per dollar spent

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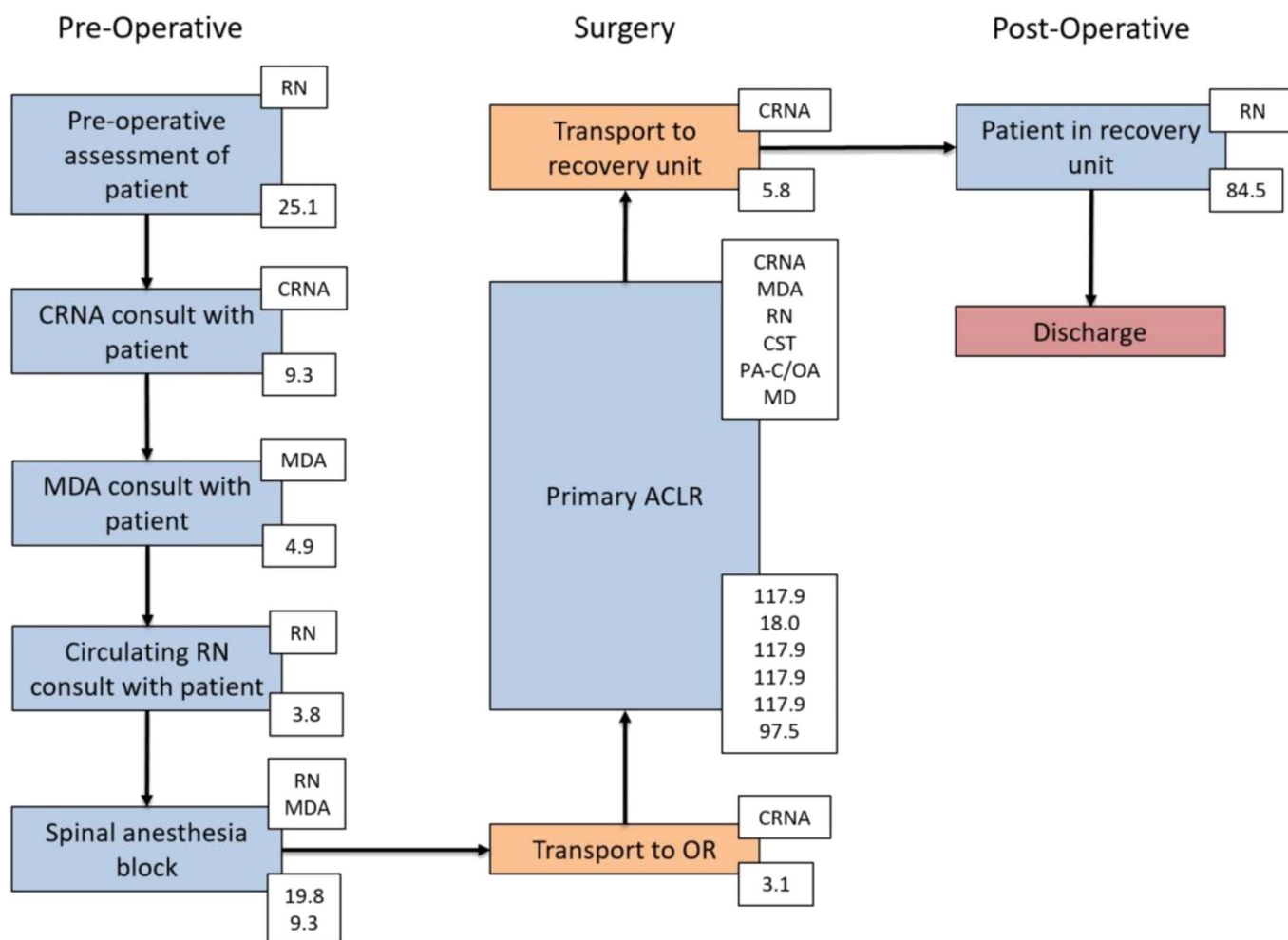


Fig. 1 Diagram displaying the process map for an ACLR episode of care. Each box represents a stage in the episode of care, with arrows representing transitions from one stage to the other. The personnel and mean time (in minutes) involved are listed for each stage. ACLR = anterior cruciate ligament reconstruction, RN = registered nurse, CRNA = certified registered nurse anesthetist, MDA = anesthesiologist, CST = certified surgical technician, PA-C/OA = certified physician assistant/orthopaedic assistant, MD = surgeon, OR = operating room.

throughout an episode of care<sup>18</sup>. Given their influence on cost variability, orthopaedic surgeons have the opportunity to maximize value by modifying their practice to mitigate costs while preserving or improving patient care. Surgeons thus need to have access to accurate cost information and understand which surgeon-controlled variables drive costs. Accurate cost data can be hard to determine because traditional hospital accounting systems are variable<sup>19</sup> and, while useful for balancing an institutional budget, have been shown to overestimate the costs involved per episode of patient care<sup>20-22</sup>. In contrast, time-driven activity-based costing (TDABC) is a methodology that more accurately measures costs and identifies cost drivers at the patient and provider level<sup>18,20,21,23</sup>. It has been employed in multiple orthopaedic subspecialties such as trauma<sup>21</sup>, hand<sup>24</sup>, pediatrics<sup>25</sup>, and arthroplasty<sup>20,26-28</sup>. TDABC was also recently employed in the setting of ACLR, revealing significantly different costs compared with those estimated by traditional accounting methods<sup>29</sup>.

Despite this recent use of TDABC, there is still a paucity of accurate cost information in the ACLR literature. These data are even more limited for BTB and hamstring autograft ACLRs, with no prior reports on their TDABC-derived costs. Given the

TABLE I TDABC Formulae for Calculating Costs of an Episode of Care*	
Variable	Formula
Direct costs	Personnel costs + implant cost
Personnel costs	$Time \times complete \ activity \times \frac{Personnel \ annual \ salary}{Time \ worked \ per \ year} \times 80\%$
Indirect costs	$Indirect \ cost \ ratio \times direct \ costs$
Indirect cost ratio	$\frac{\sum FTE \ indirect \ services}{\sum FTE \ direct \ and \ indirect \ services}$
*TDABC = time-driven activity-based costing, and FTE = full-time equivalents.	

**TABLE II Demographics, Surgical Characteristics, and Costs of Care for the Sample Population (N = 328)\***

	BTB (N = 211; 64.3%)	Hamstring (N = 117; 35.7%)	P Value
Gender	Female: 132 (62.6%) Male: 79 (37.4%)	Female: 63 (53.9%) Male: 54 (46.1%)	0.124†
Age (yr)	22.8 ± 9.0 (21.6, 24.0)	26.5 ± 12.2 (24.2, 28.7)	<b>&lt;0.001</b> ‡
BMI (kg/m <sup>2</sup> )	24.5 ± 4.1 (24.0, 25.1)	25.1 ± 4.2 (24.4, 25.9)	0.211†
Depression	20 (9.5%)	12 (10.3%)	0.831†
Anxiety	19 (9.1%)	27 (23.1%)	<b>&lt;0.001</b> †
ASA score	1: 183 (87.6%) 2: 26 (12.4%)	1: 99 (85.3%) 2: 17 (14.7%)	0.572†
Operative time (min)	103.1 ± 25.1 (99.7, 106.5)	113.1 ± 27.9 (108.0, 118.2)	<b>0.001</b> ‡
Meniscectomy	71 (33.7%)	35 (29.9%)	0.488†
Femoral fixation	Aperture: 211 (100%) Suspensory: 0 (0%)	Aperture: 9 (7.7%) Suspensory: 108 (92.3%)	<b>&lt;0.001</b> †
Tibial fixation	Aperture: 211 (100%) Suspensory: 0 (0%)	Aperture: 101 (86.3%) Suspensory: 16 (13.7%)	<b>&lt;0.001</b> †
Implant cost	\$270.32 ± \$97.08 (\$257.15, \$283.50)	\$587.36 ± \$108.78 (\$567.44, \$607.28)	<b>&lt;0.001</b> ‡
TDABC costing	\$2,865.01 ± \$263.45 (\$2,829.26, \$2,900.77)	\$3,377.44 ± \$320.12 (\$3,318.82, \$3,436.05)	<b>&lt;0.001</b> ‡

\*The values are given as either the count (proportion) or mean ± standard deviation (95% confidence interval). Proportions in parentheses are calculated based on the number of patients with data. Significant p values are bolded. BTB = bone-tendon-bone, BMI = body mass index, ASA = American Society of Anesthesiologists, and TDABC = time-driven activity-based costing. †Chi-square test. ‡Student 2-sample t test.

substantial amount of available information on outcomes of BTB autograft and hamstring autograft ACLRs, it would be useful to accurately calculate and share their associated costs in order to empower surgeons to maximize patient value. The purposes of this study were to use TDABC to (1) calculate total costs of care for BTB and hamstring ACLR, and (2) evaluate the impact of graft choice and other factors on ACLR surgery costs. Our hypothesis was that overall costs would be higher for hamstring ACLR compared with BTB ACLR.

### Materials and Methods

Following institutional review board approval, the patient-reported outcome registry for a single ambulatory orthopaedic surgery center in the United States was queried for all patients treated with ACLR from 2009 to 2016 using the Current Procedural Terminology (CPT) code 29888, and a retrospective cost analysis was performed using TDABC. The patients included in the study were skeletally mature and immature individuals who received primary ACLR with either BTB or hamstring autograft following acute ACL injury. Patients who received allograft or underwent revision ACLR, concomitant meniscal repair, or concomitant ligament reconstruction were also excluded. All patients were treated in a single outpatient orthopaedic surgery center and required no inpatient stay. All patients underwent spinal anesthesia and received care according to an institutional postoperative pain protocol.

The included patients were divided into 2 groups for data collection and analysis according to whether they received

BTB autograft or hamstring autograft during the ACLR surgery. Patient and surgical characteristics were retrospectively collected via the electronic medical record (EMR). Patient characteristics included age, gender, body mass index (BMI), and the presence of anxiety or depression diagnoses. Surgical characteristics included American Society of Anesthesiologists (ASA) score, primary surgeon, operative time, whether concomitant meniscectomy was performed, graft type, femoral fixation implant type used, and tibial fixation implant type used. Implant types were classified as either aperture or suspensory fixation.

The total cost of care was determined using TDABC. Briefly, TDABC calculates the total cost of a care episode, defined as the sum of all direct and indirect costs incurred within the episode, at the patient level using 2 variables: (1) time spent by a personnel resource to perform an activity, and (2) cost per unit time of the resource under a practical capacity assumption<sup>23</sup>. Process maps to identify the personnel and time involved in performing each activity within the episode of care were generated based on observations and stopwatch times of a single observer during 10 ACLR procedures performed by a variety of surgeons<sup>21,30</sup> (Fig. 1). Preoperative and postoperative times displayed low variability and thus were extrapolated to the sample based on these observations. Operative time and personnel time in the operating room displayed more significant variability and were thus extracted directly from the EMR. Direct costs included the personnel (surgeon, nurses, surgical technician, etc.) and supplies (implants, sutures, drugs, etc.) directly involved in patient care. Personnel costs were

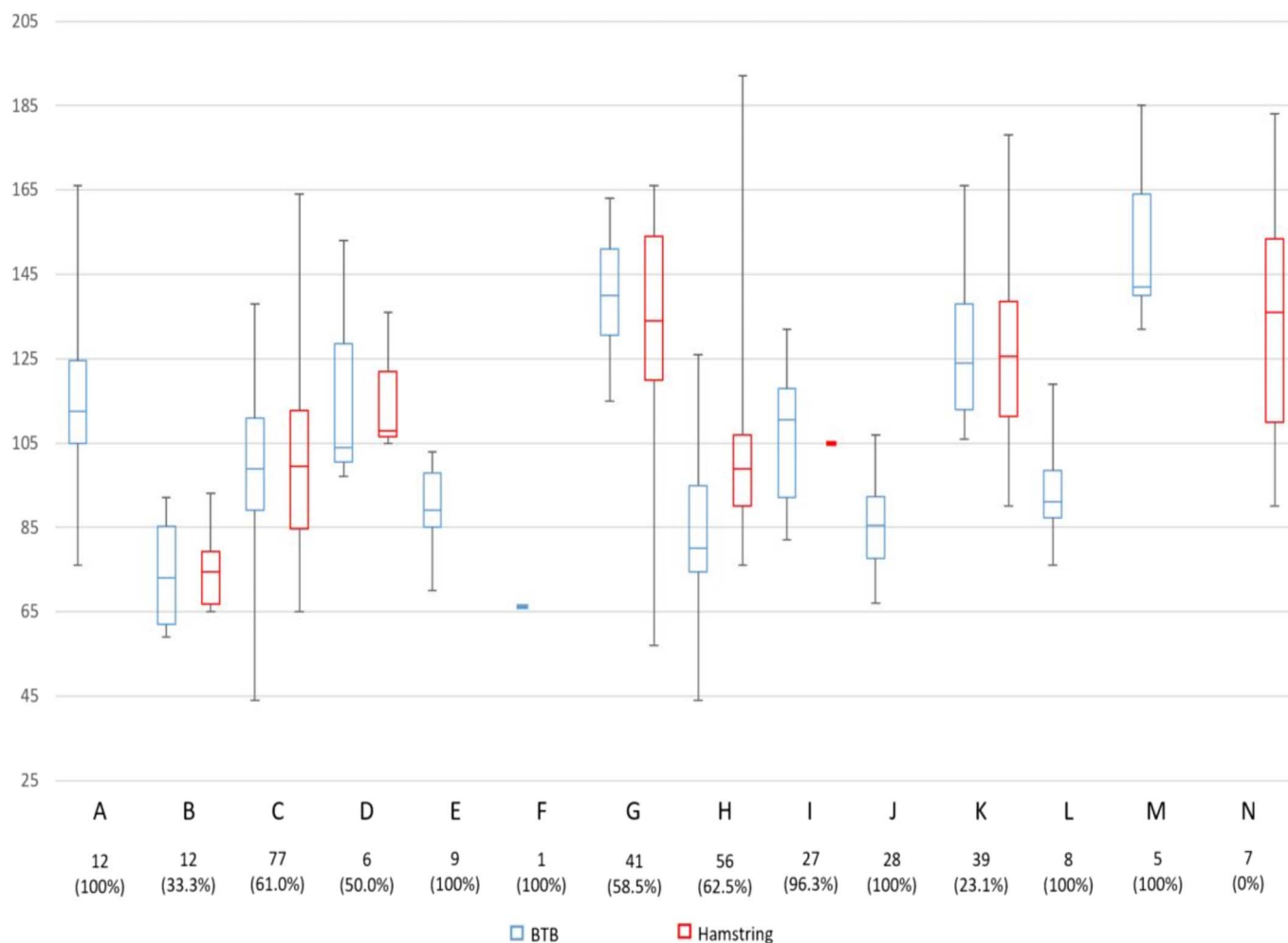


Fig. 2 Box-and-whisker box plots demonstrating the range in operative time (in minutes) for BTB (blue) and hamstring (red) ACLR according to the primary surgeon (identified as A through N). A box indicates the interquartile range, the line within the box indicates the median, and the whiskers indicate the range. Case volume of BTB ACLR and its percentage in relation to total ACLRs are reported under the x axis for each surgeon. BTB = bone-tendon-bone, ACLR = anterior cruciate ligament reconstruction.

derived from salary information, and supply costs were gathered from vendor records and the surgical center accounting department. Indirect costs included services that, while not directly used by the patient, are required for care. These include human resources (HR) management, information technology (IT) support, employee benefits, hospital administration, hospital operations infrastructure, operating theater operations, and other infrastructure costs<sup>21,31,32</sup>. Indirect costs were estimated to be 29.5% of direct costs<sup>21,31-33</sup>. To account for indirect costs at the personnel level (benefits, vacation time, sick days, etc.), a practical work capacity of 80% was assumed for all involved personnel with the exception of the surgeon<sup>21,23,31</sup>. Table I details the methods for obtaining these costs.

Statistical analysis was conducted using SAS version 9.4 (SAS Institute). Categorical data are reported using frequencies and proportions, and continuous data are reported using means and accompanying standard deviations and 95% confidence intervals (CIs). Chi-square tests and Student 2-sample t

tests between the BTB group and the hamstring group were used to determine significance for categorical and continuous variables, respectively. Cost drivers were further assessed using multivariable regression analysis; a general linear model (GLM) was constructed to evaluate the impact of patient and surgical factors on the primary outcome of total ACLR cost. Significance was set at alpha = 0.05 (2-tailed).

**Source of Funding**

No funding was received for this work.

**Results**

A total of 328 patients were included in the analysis. The patients had a mean age of 24.1 years, and 59.5% were female. Of these patients, 211 (64.3%) received BTB autograft and 117 (35.7%) received hamstring autograft. Gender, BMI, and the rate of depression were comparable between the 2 groups. The BTB group was significantly younger ( $22.8 \pm 9.0$

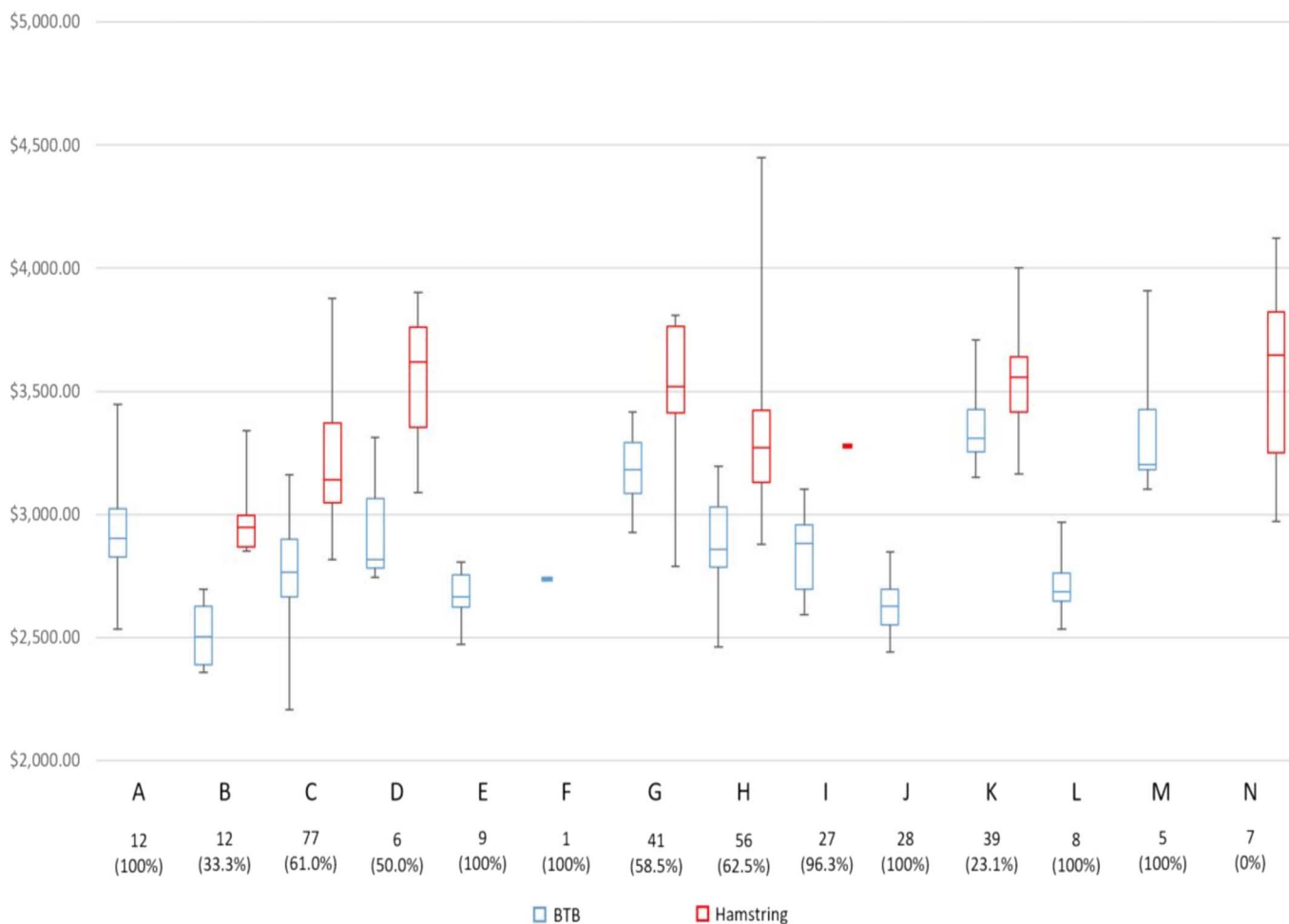


Fig. 3 Box-and-whisker box plots demonstrating the range of total cost of care (USD) for BTB (blue) and hamstring (red) ACLR according to primary surgeon (identified as A through N). A box indicates the interquartile range, the line within the box indicates the median, and the whiskers indicate the range. Case volume of BTB ACLR and its percentage in relation to total ACLRs are reported under the x axis for each surgeon. BTB = bone-tendon-bone, ACLR = anterior cruciate ligament reconstruction.

[95% CI: 21.6, 24.0] versus  $26.5 \pm 12.2$  [24.2, 28.7] years,  $p < 0.001$ ) and had a lower rate of anxiety (9.1% versus 23.1%,  $p < 0.001$ ) than the hamstring group (Table II).

A total of 14 surgeons performed BTB and/or hamstring ACLRs in the study period. Operative time in the BTB group was  $103.1 \pm 25.1$  (99.7, 106.5) minutes, which was lower than the time of  $113.1 \pm 27.9$  (108.0, 118.2) minutes in the hamstring group ( $p = 0.001$ ) (Table II). Surgeon case volume and operative time varied substantially within each type of ACLR (Fig. 2). Comparable proportions of concomitant meniscectomies were performed in the 2 groups ( $p = 0.488$ ). The BTB group used exclusively aperture fixation (100.0% for both femoral and tibial fixation), whereas the hamstring group used suspensory fixation for the femur in 92.3% of ACLRs and for the tibia in 13.7% of ACLRs ( $p < 0.001$ ).

The mean total cost of care for BTB ACLR was  $\$2,865.01 \pm \$263.45$  ( $\$2,829.26, \$2,900.77$ ), which was significantly lower than the cost for hamstring ACLR at  $\$3,377.44 \pm \$320.12$

( $\$3,318.82, \$3,436.05$ ) ( $p < 0.001$ ) (Table II). The total cost of care displayed a wide range when stratified by surgeon and graft type (Fig. 3). Total implant costs were significantly lower for the BTB group at  $\$270.32 \pm \$97.08$  ( $\$257.15, \$283.50$ ) than for the hamstring group at  $\$587.36 \pm \$108.78$  ( $\$567.44, \$607.28$ ) ( $p < 0.001$ ). Multivariable regression analysis identified that increased costs associated with use of hamstring autograft ( $\beta = \$272.76$  [ $\$78.61, \$466.90$ ],  $p = 0.006$ ) and use of suspensory fixation on the femur ( $\beta = \$253.45$  [ $\$57.75, \$449.15$ ],  $p = 0.011$ ) were associated with increased total ACLR costs (Table III). No patient factors, including age and diagnosis of anxiety, were found to increase ACLR costs (all  $p \geq 0.209$ ). Performance of concomitant meniscectomy was also not associated with increased ACLR costs ( $p = 0.297$ ).

### Discussion

As the United States health-care system and reimbursement models transition toward prioritizing value-based care, it



**TABLE III GLM Evaluating the Association of the TDABC-Derived Cost of ACLR with Potential Procedural Covariates and Patient Comorbidities (N = 328) \***

Parameter	$\beta$	95% CI	P Value
Hamstring graft type†	\$272.76	\$78.61, \$466.90	<b>0.006</b>
Suspensory femoral fixation‡	\$253.45	\$57.75, \$449.15	<b>0.011</b>
Suspensory tibial fixation‡	\$68.60	-\$86.90, \$224.09	0.386
Age	-\$2.17	-\$5.56, \$1.22	0.209
BMI	-\$2.97	-\$10.83, \$4.89	0.458
ASA score	-\$11.93	-\$106.83, \$82.97	0.805
Depression	-\$7.59	-\$133.81, \$118.63	0.906
Anxiety	\$57.88	-\$51.67, \$167.43	0.299
Meniscectomy	\$35.83	-\$31.59, \$103.25	0.297

\*Significant p values are bolded. GLM = general linear model,  $\beta$  = regression beta coefficient, CI = confidence interval, TDABC = time-driven activity-based costing, ACLR = anterior cruciate ligament reconstruction, BMI = body mass index, and ASA = American Society of Anesthesiologists. †Bone-tendon-bone was the reference group. ‡Aperture fixation was the reference group.

is crucial for orthopaedic surgeons to gather accurate cost information and relate it to patient outcome data in order to identify interventions that optimize value. ACLR is a common procedure, but the investigation and reporting of costs are highly limited. This study retrospectively applied TDABC to patients undergoing BTB autograft ACLR and hamstring autograft ACLR. BTB autograft ACLR costs less than hamstring autograft ACLR (\$2,865.01 versus \$3,377.44,  $p < 0.001$ ). The BTB group was found to have a shorter mean operative time (103.1 versus 113.1 minutes,  $p = 0.001$ ; post-hoc power, 89.6%) as well as lower mean implant costs (\$270.32 versus \$587.36,  $p < 0.001$ ; post-hoc power, 100%) per ACLR than did the hamstring group (Fig. 4). Multivariable linear regression analysis revealed that use of hamstring autograft ( $\beta = \$272.76$ ,  $p = 0.006$ ) and use of femoral suspensory fixation ( $\beta = \$253.45$ ,  $p = 0.011$ ) were variables that significantly increased costs and contributed to the cost discrepancies between BTB ACLR and hamstring ACLR.

Current ACLR cost literature is limited and diverse, which can make it difficult for surgeons to gain an accurate understanding of ACLR costs. Most of the existing literature reports a wide range of costs using reimbursement information from traditional hospital accounting systems, which inaccurately represent costs of care. Recent analyses have reported mean procedural costs per ACLR as low as \$2,039.09 and as high as \$11,431.57, with minimum to maximum costs of individual procedures ranging from \$392.80 to  $> \$14,157.30^{4,6}$ . More recently, a study reported an overall mean cost of \$5,242.25 per

ACLR using TDABC compared with \$10,318 using the institution's accounting system; the latter is almost twice as high as the cost determined using TDABC<sup>29</sup>. In addition to this variability, ACLR costs in the literature are presented in diverse ways such as inpatient versus outpatient costs<sup>12</sup>, costs based on timing of surgery<sup>34</sup>, and costs based on graft type<sup>7-14</sup>, which may further complicate the dissemination of accurate cost information.

Only a few studies have reported costs for both BTB autograft and hamstring autograft ACLRs, and these have all had limitations similar to those in the general ACLR cost literature<sup>12-14</sup>. Bonsell reported a mean of \$7,459 for total hospital charges (including both inpatient and outpatient procedures) per BTB autograft ACLR, which was significantly higher than the mean of \$6,444 for hamstring autograft ACLR<sup>12</sup>. Forssblad et al. reported a higher mean cost of €436 for hamstring autograft ACLR versus €197 for BTB autograft ACLR (\$523.20 versus \$236.40<sup>6</sup>)<sup>13</sup>. Genuario et al. conducted a cost-effectiveness analysis that estimated ACLR costs according to graft type from prior literature and reported a lower mean of \$5,375 per hamstring autograft ACLR versus \$5,582 per BTB autograft ACLR<sup>14</sup>. In contrast, the present TDABC analysis revealed a significantly lower mean cost per BTB autograft ACLR (\$2,865.01) versus hamstring autograft ACLR (\$3,377.44). The present analysis also demonstrated TDABC-derived ACLR costs that were notably lower than those reported by studies using traditional accounting systems, consistent with the findings of Koolmees et al.<sup>29</sup>.

Prior studies have associated longer operative time<sup>8,12,13,16,17</sup>, certain particular fixation implants<sup>5,11,13,14,16,35</sup>, patient demographic factors<sup>17</sup>, and additional meniscal procedures<sup>16,17,36</sup>, including meniscectomies<sup>36</sup>, with higher costs. Contrary to conventional thought, the present study demonstrated that, on average, performing a hamstring ACLR required a longer time than a BTB ACLR did. In line with TDABC principles, this longer operative time likely contributed to the significant cost differences between the groups. The hamstring group also had higher implant costs compared with the BTB group, which is consistent with prior reports<sup>13,35</sup>. The hamstring group exhibited a notably higher frequency of suspensory fixation implant use compared with the BTB group, which was found to significantly impact total ACLR cost in the multivariable regression analysis. Implant contracts can vary greatly between institutions and facilities, which may greatly affect the overall cost of ACLR, and this study represents only a single facility and may therefore not be broadly generalizable. Although prior studies have considered patient demographics<sup>17</sup> and meniscectomies<sup>36</sup> as factors that impact ACLR costs, the GLM revealed no significant cost contributions from these variables. In the present analysis, operative time, fixation implant type, and graft type were found to be cost drivers in ACLR surgery. More specifically, the use of suspensory implants associated with the hamstring autograft, alongside the longer operative time associated with hamstring ACLR, rendered use of hamstring autograft a cost driver, resulting in higher total costs of care associated with hamstring ACLR. These 3 variables are all under surgeon influence, representing an example of how

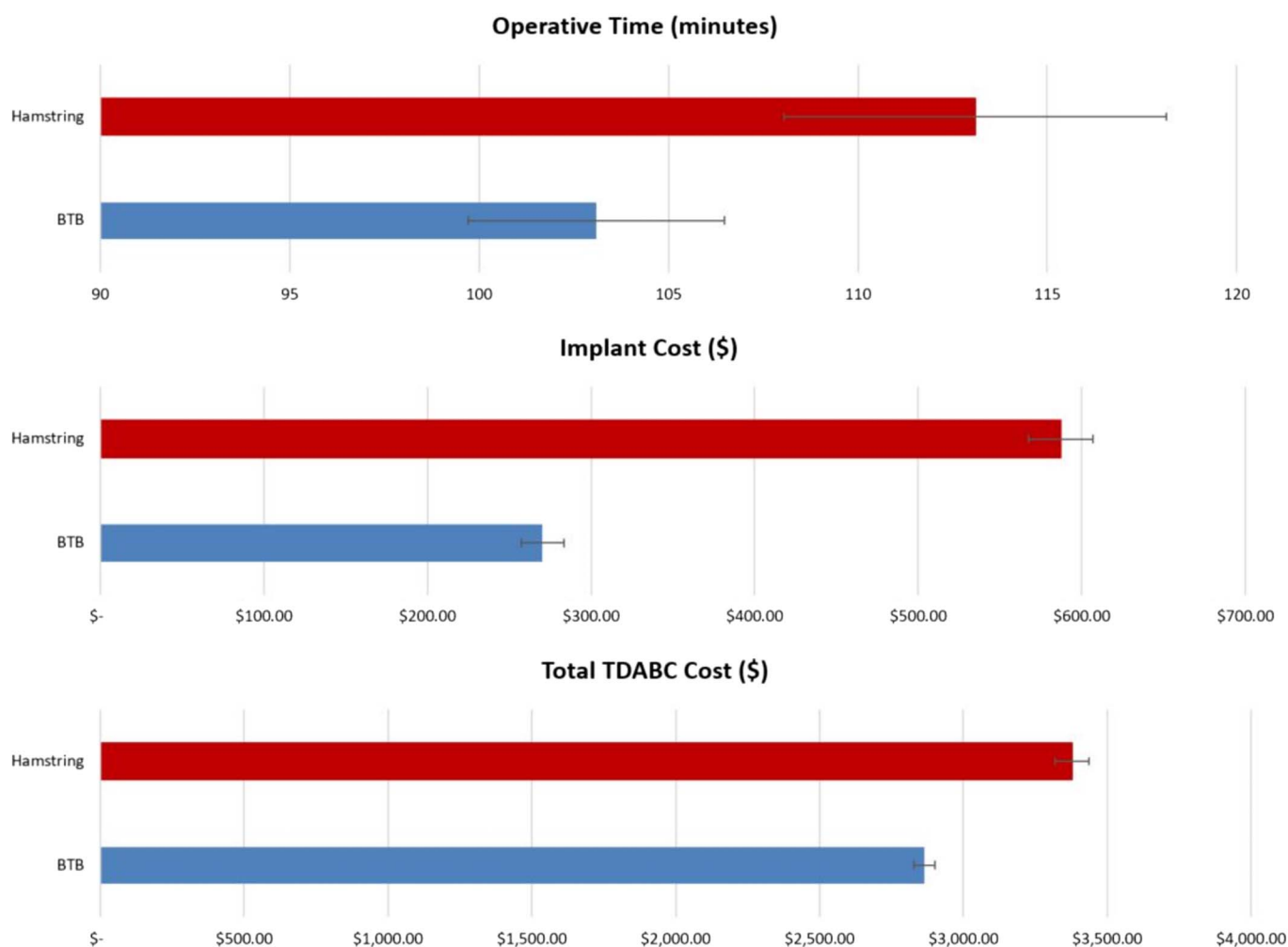


Fig. 4 Comparison of BTB versus hamstring autograft ACLR with respect to operative time and TDABC costs. Overall, BTB autograft ACLR took less time and cost less than hamstring autograft ACLR. The values are shown as the mean and 95% CI. BTB = bone-tendon-bone, ACLR = anterior cruciate ligament reconstruction, TDABC = time-driven activity-based costing.

TDABC can be used not only to derive accurate costs but also to identify provider-level factors that can lead to variability in costs, and hence in patient value. The wide ranges in surgeon-specific case volume, operative time, and total costs of care that were observed in this study similarly suggest that the 3 variables are under surgeon influence and can be impacted by the culture and practices that different institutions endorse.

Providers should seek accurate costing at the patient level in order to identify and perform interventions of high value. Traditional hospital accounting methods that govern most of the data in the literature use a top-to-bottom approach that distributes the total cost incurred by hospitals to patient services and assumes maximum efficiency of resources, enabling variable facility-dependent costs to distort the interventional costs at the level of the patient<sup>21,23</sup>. In contrast, TDABC provides a bottom-to-top costing methodology that uses the time required to complete an activity and cost per unit of time to itemize direct costs per intervention, all while assuming a more realistic

practical resource capacity that is neglected in traditional systems<sup>18,21,23</sup>. In other words, TDABC focuses on providing more accurate and detailed cost data that are directly influenced by the patient, provider, and personnel factors per episode of care, rendering it an ideal methodology for patient-level value analysis (PLVA)<sup>18,30,37</sup>. While cost-effectiveness is frequently assessed via cost-utility analysis at the population level, as has been done for ACLR<sup>14,34,38</sup>, PLVA provides a more granular value analysis on a per-patient basis<sup>37</sup> that better approximates the methods used by newer reimbursement systems to incentivize value in health care. TDABC and PLVA thus help reveal areas amenable to cost containment and afford orthopaedic surgeons the opportunity to inform themselves regarding, and improve, the value and cost-effectiveness of their procedures.

This study has limitations. It is a retrospective review involving out-of-date dollar values from >6 years ago. Inherent limitations of TDABC methodology include the inability to predict societal costs outside of the episode of care as well

as difficulty in calculating indirect costs<sup>21,31-33</sup>. The study was unable to assess the impact of implant variable details (e.g., type of screw used, fixed versus adjustable loop, use of hybrid fixation, single versus double fixation) on costs. Factors such as operative time and subsequent costs are dependent on surgeon training and volume, which vary substantially among surgeons and institutions. The study institution contracted with multiple implant suppliers, increasing cost variability and limiting the generalizability of the results. The study also excluded patients receiving concomitant procedures and was limited to a single center whose available resources may differ from those of other institutions, further limiting generalizability. The study did not evaluate costs or outcomes after surgery. Despite its limitations and the caution that is warranted regarding the interpretation of its results, however, the study accurately quantified institutional costs, and it presents a model of cost and cost-driver analysis that could benefit individual surgeons and health-care centers and systems regardless of the location at which it is implemented.

### Conclusions

BTB autograft ACLR exhibited lower mean total TDABC-derived costs of care and shorter operative time compared with hamstring autograft ACLR. Longer operative time and use of suspensory fixation implants, and thus use of hamstring autograft, were identified as cost drivers associated with higher total cost of care per ACLR, whereas patient factors and concomitant meniscectomy did not impact costs. This is the first study to use the more accurate costing methodology of TDABC to provide cost and cost driver data on the 2 most common

types of ACLR performed in the United States, allowing surgeons to maximize patient value and adapt to the value-centric shift in health-care economics. ■

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### References

- Rosas S, Kurowicki J, Hughes M, Sabeh K, Sheu J, Baraga M. National age and gender-specific costs in anterior cruciate ligament reconstruction by a single nationwide private payer. *Surg Technol Int*. 2017 Dec 22;31:285-93.
- Herzog MM, Marshall SW, Lund JL, Pate V, Mack CD, Spang JT. Incidence of anterior cruciate ligament reconstruction among adolescent females in the United States, 2002 through 2014. *JAMA Pediatr*. 2017 Aug 1;171(8):808-10.
- Griffin LY, Agel J, Albohm MJ, Arendt EA, Dick RW, Garrett WE, Garrick JG, Hewett TE, Huston L, Ireland ML, Johnson RJ, Kibler WB, Lephart S, Lewis JL, Lindenfeld TN, Mandelbaum BR, Marchak P, Teitz CC, Wojtys EM. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg*. 2000 May-Jun;8(3):141-50.
- Herzog MM, Marshall SW, Lund JL, Pate V, Spang JT. Cost of outpatient arthroscopic anterior cruciate ligament reconstruction among commercially insured patients in the United States, 2005-2013. *Orthop J Sports Med*. 2017 Jan 27;5(1):2325967116684776.
- Archibald-Seiffer N, Jacobs JC Jr, Saad C, Jevsevar DS, Shea KG. Review of anterior cruciate ligament reconstruction cost variance within a regional health care system. *Am J Sports Med*. 2015 Jun;43(6):1408-12.
- Saltzman BM, Cvetanovich GL, Nwachukwu BU, Mall NA, Bush-Joseph CA, Bach BR Jr. Economic analyses in anterior cruciate ligament reconstruction: a qualitative and systematic review. *Am J Sports Med*. 2016 May;44(5):1329-35.
- Barrera Oro F, Sikka RS, Wolters B, Graver R, Boyd JL, Nelson B, Swiontkowski MF. Autograft versus allograft: an economic cost comparison of anterior cruciate ligament reconstruction. *Arthroscopy*. 2011 Sep;27(9):1219-25.
- Cole DW, Ginn TA, Chen GJ, Smith BP, Curl WW, Martin DF, Poehling GG. Cost comparison of anterior cruciate ligament reconstruction: autograft versus allograft. *Arthroscopy*. 2005 Jul;21(7):786-90.
- Cooper MT, Kaeding C. Comparison of the hospital cost of autograft versus allograft soft-tissue anterior cruciate ligament reconstructions. *Arthroscopy*. 2010 Nov;26(11):1478-82.
- Greis PE, Koch BS, Adams B. Tibialis anterior or posterior allograft anterior cruciate ligament reconstruction versus hamstring autograft reconstruction: an economic analysis in a hospital-based outpatient setting. *Arthroscopy*. 2012 Nov;28(11):1695-701.
- Nagda SH, Altobelli GG, Bowdry KA, Brewster CE, Lombardo SJ. Cost analysis of outpatient anterior cruciate ligament reconstruction: autograft versus allograft. *Clin Orthop Relat Res*. 2010 May;468(5):1418-22.
- Bonsell S. Financial analysis of anterior cruciate ligament reconstruction at Baylor University Medical Center. *Proc (Bayl Univ Med Cent)*. 2000 Oct;13(4):327-30.
- Forssblad M, Valentin A, Engström B, Werner S. ACL reconstruction: patellar tendon versus hamstring grafts—economical aspects. *Knee Surg Sports Traumatol Arthrosc*. 2006 Jun;14(6):536-41.
- Genuario JW, Faucett SC, Boubliek M, Schlegel TF. A cost-effectiveness analysis comparing 3 anterior cruciate ligament graft types: bone-patellar tendon-bone autograft, hamstring autograft, and allograft. *Am J Sports Med*. 2012 Feb;40(2):307-14.
- Arnold MP, Calcei JG, Vogel N, Magnussen RA, Clatworthy M, Spalding T, Campbell JD, Bergfeld JA, Sherman SL; ACL Study Group. ACL Study Group survey reveals the evolution of anterior cruciate ligament reconstruction graft choice over the past three decades. *Knee Surg Sports Traumatol Arthrosc*. 2021 Nov;29(11):3871-6.
- Karns MR, Jones DL, Todd DC, Maak TG, Aoki SK, Burks RT, Yoo M, Nelson RE, Greis PE. Patient- and Procedure-Specific Variables Driving Total Direct Costs of Outpatient Anterior Cruciate Ligament Reconstruction. *Orthop J Sports Med*. 2018 Aug 6;6(8):2325967118788543.
- Bokshan SL, Mehta S, DeFroda SF, Owens BD. What are the primary cost drivers of anterior cruciate ligament reconstruction in the United States? A cost-minimization analysis of 14,713 patients. *Arthroscopy*. 2019 May;35(5):1576-81.
- Kaplan RS, Witkowski M, Abbott M, Guzman AB, Higgins LD, Meara JG, Padden E, Shah AS, Waters P, Weidemeier M, Wertheimer S, Feeley TW. Using time-driven activity-based costing to identify value improvement opportunities in healthcare. *J Healthc Manag*. 2014 Nov-Dec;59(6):399-412.
- West TD, Balas EA, West DA. Contrasting RCC, RVU, and ABC for managed care decisions. A case study compares three widely used costing methods and finds one superior. *Healthc Financ Manage*. 1996 Aug;50(8):54-61.



- 20.** Akhavan S, Ward L, Bozic KJ. Time-driven activity-based costing more accurately reflects costs in arthroplasty surgery. *Clin Orthop Relat Res.* 2016 Jan;474(1):8-15.
- 21.** McCreary DL, White M, Vang S, Plowman B, Cunningham BP. Time-driven activity-based costing in fracture care: Is this a more accurate way to prepare for alternative payment models? *J Orthop Trauma.* 2018 Jul;32(7):344-8.
- 22.** Koolmees D, Bernstein DN, Makhni EC. Time-driven activity-based costing provides a lower and more accurate assessment of costs in the field of orthopaedic surgery compared with traditional accounting methods. *Arthroscopy.* 2021 May;37(5):1620-7.
- 23.** Kaplan RS, Anderson SR. Time-driven activity-based costing. *Harv Bus Rev.* 2004 Nov;82(11):131-8, 50.
- 24.** Koehler DM, Balakrishnan R, Lawler EA et al. Endoscopic versus open carpal tunnel release: A detailed analysis using time-driven activity-based costing at an academic medical center. *J Hand Surg.* 2019;44(1):62.e1-e9.
- 25.** Waters PM. Value in pediatric orthopaedic surgery health care: the role of time-driven activity-based cost accounting (TDABC) and standardized clinical assessment and management plans (SCAMPs). *J Pediatr Orthop.* 2015 Jul-Aug;35(5)(Suppl 1):S45-7.
- 26.** Palsis JA, Brehmer TS, Pellegrini VD, Drew JM, Sachs BL. The cost of joint replacement: comparing two approaches to evaluating costs of total hip and knee arthroplasty. *J Bone Joint Surg Am.* 2018 Feb 21;100(4):326-33.
- 27.** Carducci MP, Gasbarro G, Menendez ME, Mahendraraj KA, Mattingly DA, Talmo C, Jawa A. Variation in the cost of care for different types of joint arthroplasty. *J Bone Joint Surg Am.* 2020 Mar 4;102(5):404-9.
- 28.** Menendez ME, Lawler SM, Shaker J, Bassoff NW, Warner JJP, Jawa A. Time-driven activity-based costing to identify patients incurring high inpatient cost for total shoulder arthroplasty. *J Bone Joint Surg Am.* 2018 Dec 5;100(23):2050-6.
- 29.** Koolmees D, Ramkumar PN, Hessburg L, Guo E, Bernstein DN. Time-driven activity-based costing for anterior cruciate ligament reconstruction: a comparison to traditional accounting methods. *Arthrosc Sports Med Rehabil.* 2021;3(1):e39-45.
- 30.** Wise KL, Parikh HR, Okelana B, et al. Measurement of value in rotator cuff repair (RCR): patient-level value-analysis (PLVA) for the one-year episode-of-care measuring value in RCR over one-year. *J Shoulder Elbow Surg.* 2022 Jan;31(1):72-80.
- 31.** Kaplan RS, Porter ME. The Big Idea: How to solve the cost crisis in health care. *Harv Bus Rev.* 2011 Sep;89(9):46-52, 4, 6-61.
- 32.** Porter ME. What is value in health care? *N Engl J Med.* 2010 Dec 23;363(26):2477-81.
- 33.** Parikh HR, O'Hara N, Levy JF, Cunningham BP. Value denominator: The fundamentals of costing for orthopaedic surgeons. *J Orthop Trauma.* 2019 Nov;33(Suppl 7):S56-61.
- 34.** Mather RC 3rd, Hettrich CM, Dunn WR, Cole BJ, Bach BR Jr, Huston LJ, Reinke EK, Spindler KP. Cost-effectiveness analysis of early reconstruction versus rehabilitation and delayed reconstruction for anterior cruciate ligament tears. *Am J Sports Med.* 2014 Jul;42(7):1583-91.
- 35.** Noyes FR, Butler DL, Grood ES, Zernicke RF, Hefzy MS. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. *J Bone Joint Surg Am.* 1984 Mar;66(3):344-52.
- 36.** Lester JD, Gorbaty JD, Odum SM, Rogers ME, Fleischli JE. The cost-effectiveness of meniscal repair versus partial meniscectomy in the setting of anterior cruciate ligament reconstruction. *Arthroscopy.* 2018 Sep;34(9):2614-20.
- 37.** McCreary DL, Dugarte AJ, Vang S, Plowman B, Williams BR, Parikh HR, Cunningham BP. Patient-level value analysis: an innovative approach to optimize care delivery. *J Orthop Trauma.* 2019 Nov;33(Suppl 7):S49-52.
- 38.** Mather RC 3rd, Koenig L, Kocher MS, Dall TM, Gallo P, Scott DJ, Bach BR Jr, Spindler KP; MOON Knee Group. Societal and economic impact of anterior cruciate ligament tears. *J Bone Joint Surg Am.* 2013 Oct 2;95(19):1751-9.