Defining the Value of Analgesia for Total Knee Arthroplasty Using Time-Driven Activity-Based Costing: A Novel Approach to Clinical Practice Transformation

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Abstract

Objective: To compare the relative value of 3 analgesic pathways for total knee arthroplasty (TKA).

Patients and Methods: Time-driven activity-based costing analyses were performed on 3 common analgesic pathways for patients undergoing TKA: periarticular infiltration (PAI) only, PAI and single-injection adductor canal blockade (SACB), and PAI and continuous adductor canal blockade (CACB). Additionally, adult patients who underwent elective primary TKA from November 1, 2017, to May 1, 2018, were retrospectively identified to analyze analgesic (pain score, opiate use) and hospital outcomes (distance walked, length of stay) after TKA based on analgesic pathway.

Results: There was no difference in patient demographic characteristics, specifically complexity (American Society of Anesthesiologists score) or preoperative opiate use, between groups. Compared with PAI, total cost (labor and material) was 1.4-times greater for PAI plus SACB and 2.3-times greater for PAI plus CACB. The addition of SACB to PAI resulted in lower average and maximum pain scores and opiate use on the day of operation compared with PAI alone. Average and maximum pain scores and opiate use between SACB and CACB were not significantly different. Walking distance and hospital length of stay were not significantly different between groups.

Conclusion: Perioperative care teams should consider the cost and relative value of pain management when selecting the optimal analgesic strategy for TKA. Despite slightly higher relative cost, the combination of SACB with PAI may offer short-term analgesic benefit compared with PAI alone, which could enhance its relative value in TKA.

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Spiraling costs are a fundamental challenge in health care delivery. Cost containment, combined with continuing improvements in quality of care, have led to the development of value-based health policies and reimbursement schedules.[1] These care models focus on optimizing health outcomes balanced with the cost to achieve these outcomes (outcome/cost),[2] as opposed to traditional fee-for-service models. The emergence of value-based health care has led to the development of bundled payments and accountable care organizations, effectively shifting cost of care and quality onto physicians and health care organizations. While this shift is expected to encourage quality improvement, accurately defining value depends upon physicians' ability to compare health outcomes in combination with reliable cost-accounting methods.

Traditionally, health care costing systems were based on the ratio of costs to charges. However, most charge-based systems are unreliable when used to measure costs because of cost shifting (ie, shifting the costs associated with health care delivery from patients to physicians) as well as the tendency to overestimate

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the cost of surgical procedures because of indirect cost allocation.[3-5] Activity-based costing (ABC) was developed as an alternative method for addressing process-oriented cost accounting and was successfully applied to smaller settings. However, it is a resource-intensive technique, requiring frequent employee reporting of time allocation and additional personnel to manage and process data for ongoing analysis. Thus, it is cumbersome and impractical for health care delivery settings. Time-driven activity-based costing (TDABC) was first proposed by Kaplan and Anderson[6] as a modified version of ABC to address the need for validity in cost analysis while considering the required resources to accomplish the analysis. Time-driven activity-based costing was an improvement over ABC because of its ability to make accurate cost analyses through estimating the individual unit cost of resource inputs as well as the time and quantity of resources required to perform an activity. This method allows identification of patient-specific resource consumption, over an episode of care, through process mapping.[7,8]

Regional anesthesia techniques are commonly utilized in perioperative multimodal analgesia strategies. However, these techniques incur additional costs, inclusive of time, supplies, and personnel involved. In the case of total knee arthroplasty (TKA), single-injection adductor canal blockade (SACB) has been reported to improve analgesia.[9] Alternatives to SACB include placement of an adductor canal catheter to provide continuous analgesia and surgeon-administered periarticular infiltration (PAI), alone or in conjunction with SACB or continuous adductor canal block (CACB). While the analgesic outcomes of these techniques have been compared in anesthesia literature, the value of incorporating each of these interventions into the episode of care for TKA is unknown.

The objective of this investigation was to describe the application of TDABC methodology to these 3 analgesic pathways for TKA and, secondarily, to consider these results in the context of analgesic and hospital outcomes to define the value of each intervention. Additionally, consideration was given to whether TDABC presents a useful financial methodology for determining the value of health care delivery in the setting of regional anesthesia and beyond.

PATIENTS AND METHODS

TDABC Analysis

Time-driven activity-based costing analysis was conducted using the methodology described by Kaplan.[10] A multidisciplinary team involved in each phase of care was commissioned to identify the chronological steps, personnel, equipment, space, and supply costs of providing 3 analgesic techniques for patients undergoing primary TKA: PAI alone, PAI plus SACB, or PAI plus CACB. Interviews were conducted with experienced leaders and team members in each clinical area to develop a detailed, step-by-step process map for each analgesic pathway during TKA. Specifically, we considered each step of the process unique to that method of pain management, staff involved with each step, and mean time involvement of each staff member for each step. All other perioperative process steps not associated with pain management for the total episode of care were assumed to be identical among pathways. Mean per-minute cost for each resource expended, also known as the *capacity cost rate*, was generated and multiplied by its time expended on each step. The total cost for each analgesic pathway was obtained by adding the costs of individual resources consumed as the patient proceeded through the care pathway. In addition to the creation of process maps, drug, supply, and resource costs were obtained from institutional information systems to further compare pathways.

Analgesia, Activity, and Hospital Outcomes

Mayo Clinic Institutional Review Board approval was obtained for assessment of clinical outcomes in this study. Patients aged 18 years or older who underwent elective, primary TKA performed by 1 of 6 high-volume and fellowship-trained orthopedic surgeons from November 1, 2017, to May 1, 2018, were identified by retrospective query from the Department of Anesthesiology and Perioperative Medicine Perioperative Data Mart. The Perioperative Data Mart is a validated institutional data warehouse containing detailed information regarding aspects of a patient's

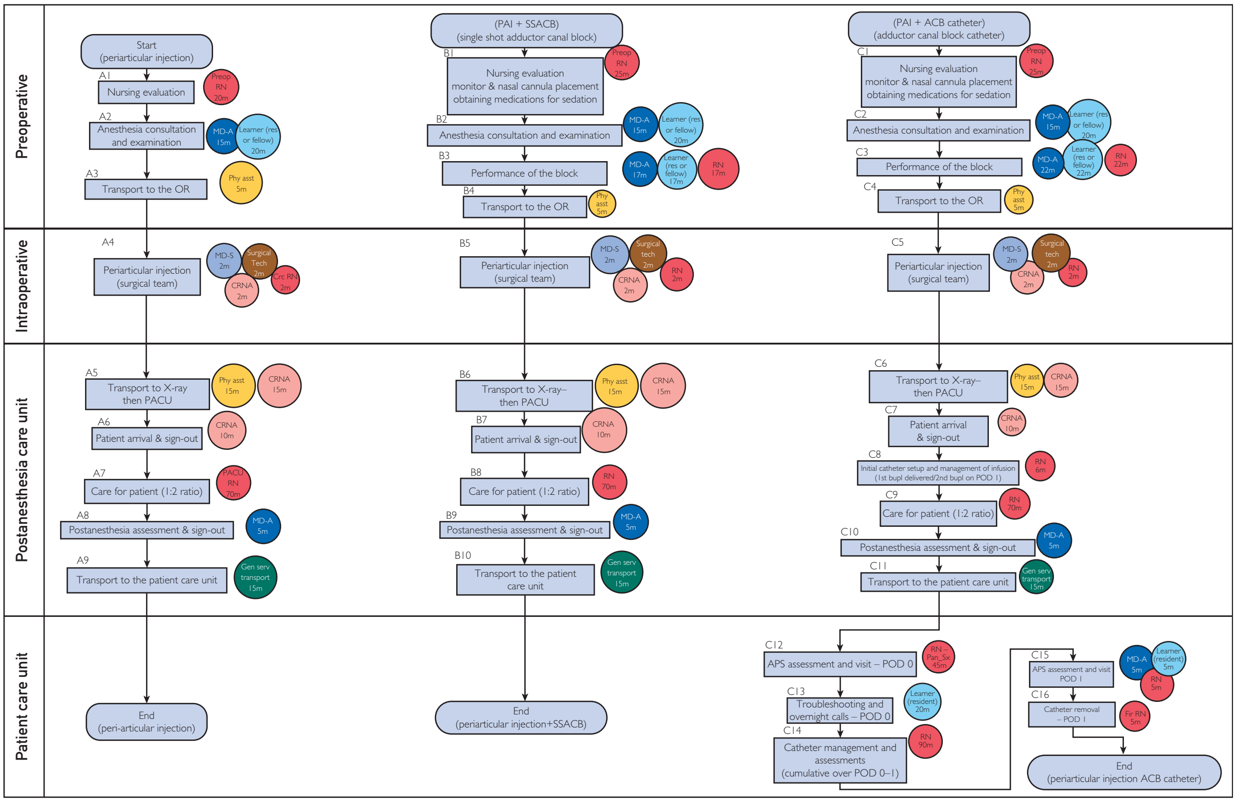

FIGURE. Time-driven activity-based costing process map of analgesic options during total knee arthroplasty. APS, acute pain service; Bupi, bupivacaine; CRNA, certified registered nurse anesthetist; Gen serv, general service; MD-A, anesthesiologist; MD-S, surgeon; OR, operating room; Circ (?) RN, circulating registered nurse; PACU, postanesthesia care unit; PAI, periarticular infiltration; Phy asst, physician assistant; Flr (?) RN, floor registered nurse; POD, postoperative day; Preop, preoperative; res, resident; RN, registered nurse; SSACB, single-shot adductor canal block; Sx (?), service; tech, technician.

surgical encounter (eg, demographic information, American Society of Anesthesiologists physical status score, preoperative opiate use, procedural descriptions, locations, start and stop times, detailed physiologic information, vital signs, ventilator data, laboratory information, transfusions, and medication and fluid administration).[11,12] Study inclusion was restricted to the first elective primary TKA performed at Mayo Clinic during the study period. Patients who declined research authorization were excluded per government statute (Minnesota, United States). The choice of the 3 analgesic pathways (PAI, PAI plus SACB, and PAI plus CACB) was based on standardized regimens at the time, reflecting a practice shift toward inclusion of motor-sparing analgesic techniques like PAI as well as use of SACB vs CACB during a 1-year collaborative practice improvement project between our orthopedic surgery and anesthesiology departments.[13,14] Ultimately, the choice of technique was based on the current personal preferences of the surgeon and the discretion of the attending anesthesiologist.

Periarticular infiltration was performed by the surgeon intraoperatively using a standardized weight-based solution including ropivacaine, epinephrine, and ketorolac diluted in 0.9% normal saline distributed in a total of 120 mL. First-case adductor canal blocks (ACBs) were performed in the operating room immediately prior to initiation of anesthesia, while non—first-case ACBs were performed in a preprocedure block area. Under sterile conditions, adductor canal blockade

TABLE 1. Patient Demographic Characteristics and Operative Data[a,b]

Variable	PAI only (n=134)	PAI + SACB (n=61)	PAI + CACB (n=65)	*P* value[c]
Age (y)	66 (59.8-73)	69 (64-75.5)	67 (61.5-75)	.17
Female sex	81 (60.4)	45 (73.8)	41 (63.1)	.18
BMI (kg/m^2)	33.4 (29.8-39.0)	33.9 (30.0-39.8)	33.4 (28.7-40.8)	.79
ASA PS				
1	0 (0.0)	0 (0.0)	2 (3.1)	.31
2	55 (41.0)	27 (44.3)	21 (32.3)	
3	66 (49.3)	30 (49.2)	37 (56.9)	
4	2 (1.5)	NA	1 (1.5)	
Missing	11 (8.2)	4 (6.6)	4 (6.2)	
Opiate use at time of operation	18 (13.4)	8 (13.1)	9 (13.8)	.99
Spinal anesthesia	95 (70.9)	54 (88.5)	46 (70.8)	.01[d]

[a] ASA PS, American Society of Anesthesiologists physical status; BMI, body mass index; CACB, continuous adductor canal block; PAI, periarticular infiltration; SACB, single-injection adductor canal block.

[b] Summary statistics are presented as median (interquartile range) for continuous data or No. (percentage) for categorical data.

[c] *P* values from Kruskal-Wallis (continuous variables) or χ^2 (categorical variables) tests.

[d] Significant differences for PAI vs PAI + SACB (*P*=.004), PAI + SACB vs PAI + CACB (*P*=.01).

(single and continuous) was performed at the midpoint between the anterior superior iliac spine and adductor tubercle as described by Lund et al.[15] An initial dose of 10 to 15 mL 0.5% bupivacaine with epinephrine 1:200,000 was used for SACB and CACB. In patients who received CACB, on completion of the operation and arrival in the recovery area, the ACB catheter was connected to a continuous infusion pump programmed to deliver 0.1% bupivacaine at 10 mL/h until the morning of postoperative day (POD) 2. Patients received general or spinal anesthesia at the discretion of the attending anesthesiologist. Remaining preoperative and postoperative systemic analgesia was standardized per institutional practice protocol.[13]

Demographic information was collected, including age, sex, body mass index, American Society of Anesthesiologists physical status, and opiate use at the time of operation as well as method of primary anesthesia (spinal, general). In addition, clinical outcome data on analgesia, ambulation, and hospital length of stay (LOS) was collected. Specifically, analgesic outcomes included postoperative average and maximum pain score and opiate use on PODs 0 to 2 as well as total hospital opiate use. Pain was assessed with the 0 (no pain) to 10 (severe pain)—point visual analog scale. Nurses, who were unaware of the ongoing clinical trial, performed pain assessments as part of their clinical care for all patients. All opiate consumption was converted to morphine milligram equivalents using standard conversions. Distance ambulated (in feet) during physical therapy was collected on PODs 0 to 2.

Statistical Analyses

Data are summarized using median (25th to 75th percentile) for continuous variables and frequency counts and percentages for categorical variables. Comparisons across multiple groups were made using the Kruskal-Wallis test for continuous data or the χ^2 test for categorical data. Comparisons between groups with continuous data were made using a Mann-Whitney test. Statistical significance was assumed at $P<.05$. All analyses were performed using JMP Pro statistical software, version 14.1.0 (SAS Institute).

RESULTS

TDABC Analysis

A detailed process map was created for each pathway (Figure). Inclusion of SACB and CACB added additional process steps in the preoperative phase for placement of the nerve block,

TABLE 2. Analgesic, Inpatient Rehabilitation, and Hospital Outcomes[a,b]

Variable	PAI only (n=134)	PAI + SACB (n=61)	PAI + CACB (n=65)	*P* value[c]
VAS pain				
POD 0 avg	2.2 (1.3-3.8)	1.5 (0.4-2.8)	1.8 (0.0-3.9)	.007[d]
POD 0 max	6.0 (5-7.3)	5.0 (2-7)	6.0 (4-7.5)	.006[e]
POD 1 avg	4.5 (3.2-5.7)	4.4 (3-5.2)	4.1 (2.8-5.3)	.45
POD 1 max	7.0 (5-8)	7.0 (5-8)	7.0 (4.5-8)	.96
POD 2 avg	4.4 (3-5.8)	4 (3.5-5.4)	4 (2.5-5.5)	.46
POD 2 max	7.0 (5-8)	7.0 (5-8)	6.0 (4-8)	.86
Opiate use (in MME)				
POD 0	22.5 (4.2-45)	11.3 (0-33.8)	11.3 (0-44.2)	.01[f]
POD 1	56.3 (21.1-112.5)	33.8 (11.3-84.4)	56.3 (0-110.1)	.18
POD 2	19.7 (0-67.5)	0 (0-45)	11.3 (0-73.1)	.23
Total	112.5 (33.8-243.9)	78.8 (14.1-135)	101.3 (16.9-231.9)	.10
Ambulation (ft)				
POD 0 PM	73 (34-179.5)	61 (19-140)	39.5 (18.8-151)	.25
POD 1 AM	103 (49.8-211)	100.5 (51.5-217.5)	102.5 (27.5-174)	.48
POD 1 PM	125 (46.5-249.5)	134 (75.8-243.3)	139 (90-228)	.68
POD 2 AM	119 (63-168)	104.5 (50.5-187.5)	151 (67-220)	.48

[a] avg, average; CACB, continuous adductor canal block; max, maximum; MME, morphine milligram equivalents; PAI, periarticular infiltration; POD, postoperative day; SACB, single-injection adductor canal block; VAS, visual analog scale.

[b] Summary statistics are presented as median (interquartile range).

[c] *P* values from Kruskal-Wallis tests.

[d] Significant difference for PAI vs PAI + SACB (Mann-Whitney test, *P*=.001).

[e] Significant differences for PAI vs PAI + SACB (Mann-Whitney test, *P*=.002) and PAI + SACB vs PAI + CACB (Mann-Whitney test, *P*=.04).

[f] Significant difference for PAI vs PAI + SACB (Mann-Whitney test, *P*=.004).

and CACB further added process steps to the postoperative phase for management of the peripheral nerve catheter and local anesthetic infusion. The process costs (labor and materials) of PAI, PAI plus SACB, and PAI plus CACB were $392.27, $538.65, and $912.50, respectively. Compared with PAI alone, total cost (labor and material) was 1.4-times greater for providing PAI plus SACB and 2.3-times greater for providing PAI plus CACB.

Clinical Outcomes

Demographic information is summarized in Table 1. There were no differences in demographic characteristics among the 3 groups. Spinal anesthesia was used more often in patients also receiving PAI plus SACB. Analgesic outcomes, opiate use, and ambulation are summarized in Table 2. Regarding analgesia, use of PAI plus SACB provided better analgesia (lower average and maximum pain score and lower opiate use), on POD 0 compared with PAI alone. This benefit did not extend beyond the day of operation. Further, the use of CACB did not improve analgesic outcomes at any time point compared with SACB. Postoperative ambulation was not significantly affected by choice of analgesic technique. Overall, median hospital LOS was 2.2 days. There was no significant difference in LOS between the PAI, PAI plus SACB, and PAI plus CACB groups (2.2 days, 2.2 days, and 2.3 days, respectively; *P*=.61).

DISCUSSION

The ideal perioperative analgesic regimen during TKA has 2 primary goals: (1) to provide adequate pain control for the patient and (2) to enhance mobilization and physical therapy efforts, which can decrease LOS and potentially improve medical and surgical outcomes. In this observational study, we documented the successful use of TDABC methodology to determine the value of 3 different analgesic pathways for TKA, comparing relative costs and outcomes data, to assist our anesthesiology department in determining optimal perioperative patient care based on value.

Previous research has documented analgesic benefit of SACB or PAI for pain management after TKA. However, there have been inconsistencies regarding the benefit of combining SACB and PAI, with some results revealing significantly reduced pain scores with ambulation[16] and others revealing no significant difference in reported pain, opioid consumption, or time to hospital discharge.[17,18] The results from our observational study revealed substantially lower average and maximum pain scores as well as lower opioid consumption with PAI plus SACB on POD 0 compared with PAI alone, and this trend continued into POD 1 but was not statistically significant. These findings would support the notion that the addition of SACB to PAI may offer modest short-term analgesic benefit compared with the use of PAI alone. An important potential analgesic confounder to acknowledge is the higher use of spinal anesthesia among patients also receiving PAI plus SACB. Although spinal anesthesia is typically favored over general anesthesia because of overall lower risk for postoperative complications and possibly shorter hospital LOS,[19-21] there is limited evidence suggesting that primary anesthesia type (spinal vs general) directly impacts postoperative pain. Although spinal anesthesia results in profound transient sensorimotor blockade of the lower extremities, short-acting and low-dose local anesthetics are commonly used to facilitate rapid return of lower extremity strength and sensation to enable early postoperative rehabilitation. Therefore, although a greater proportion of patients in the PAI plus SACB group received spinal anesthesia, it is our opinion that this factor did not contribute to observed differences in short-term analgesia.

While the outcomes data provide one portion of our value equation, cost must also be considered when making clinical practice decisions. Using TDABC methodology, we found that PAI alone had the lowest relative cost of the 3 analgesic regimens. The addition of an SACB increased costs by 1.4 times that of PAI alone; the addition of CACB increased costs by 2.3 times that of PAI alone. We believe that these costing models suggest that it is reasonable and more cost-efficient to adopt a practice inclusive of SACB with PAI for analgesia during primary TKA because of the marginal cost increases with added value vs the addition of CACB, which increases costs by more than 60% without a corresponding change in analgesia, largely due to increased postoperative resource utilization. Compared with the total process cost for undergoing TKA, the relative cost differences under consideration are small. However, in systems-based care in which 2000 to 2500 procedures are performed per year, a $200 to $400 per-patient savings translates into substantial institutional savings, assuming patient experience is not lessened.

Taking into consideration both outcomes and cost data obtained in our observational study, we can begin to elucidate the true value (outcomes/cost) of each of these analgesic pathways. The addition of CACB to PAI did not result in substantially different pain scores, opioid consumption, hospital LOS, or postoperative ambulation compared with PAI alone. Given the 2.3-times increase in cost compared to PAI alone, our findings suggest that the overall clinical value of CACB in TKA is low and should not be incorporated into routine clinical practice but rather on an individual patient basis. The clinical value of the addition of a SACB to PAI based on our data is less clear. The SACB plus PAI group did have substantially lower pain scores and opioid consumption on POD 0 with a non—statistically significant trend toward improved pain control on POD 1; however, there were no major differences in any other hospital outcome measures. This modest analgesic benefit would tend to increase the relative value of SACB plus PAI, but it is unclear if this increase in value is sustained when considering the marginal 1.4 times increase in cost compared with PAI alone.

When determining whether to adopt SACB plus PAI into clinical practice, given unclear relative value compared with PAI alone, it is important to keep 2 factors in mind. First, the use of dual analgesic techniques provides overlap that mitigates the risk of failure of a single technique. Second, despite only isolated statistically significant benefits in pain control with SACB plus PAI, the trend toward improved postoperative analgesia may still be worth the increased costs due to aggregation of marginal gains. This theory[22] revolves around the idea that with a 1% improvement in every aspect of patient care throughout the episode of care, small gains accumulate to yield sizable improvements. Indeed, additive effects of many modest improvements throughout a patient's arc of care have consistently been found in larger practice optimization efforts.[13,14]

Our study certainly has limitations to note. First, hospital outcomes measures (LOS, pain scores, opioid consumption, postoperative ambulation) were assumed to be influenced primarily by the modality of regional technique the patient received (PAI alone vs SACB plus PAI vs CACB plus PAI) and did not account for surgical technique or other patient-specific factors, such as comorbidities, chronic pain diseases with baseline opioid consumption and opioid tolerance, baseline ambulation, and non—analgesia-related indications for increasing hospital LOS. Lack of control of these factors could make it more difficult to document statistically significant benefits from the addition of an SACB despite small gains being present. However, the costs incurred in order to perform proper randomized controlled trials may outweigh the value gained. Second, it is uncertain whether statistical significance with regard to the short-term analgesic benefit observed with the addition of SACB amounts to clinical significance. The evidence supporting early ambulation after TKA[23-25] suggests that improved analgesia on POD 0 would minimize the pain barrier to patient ambulation. However, this theory was not supported by our data, likely due to confounding factors such as patient baseline ambulation, variability in patient pain tolerance, and individual postoperative complications. Further, other outcomes not collected in this study, namely, patient satisfaction, are substantially impacted by efficacy of analgesia and may assist in elucidating value in future applications of this methodology. These considerations must be accounted for before deciding to adopt additional intervention, such as adding SACB to PAI for TKA, as these small gains may still play a major role in overall quality improvement.

One phenomenon observed in our study is the inability of CACB plus PAI to provide the same statistically significant analgesic benefit on POD 0 as SACB plus PAI when compared with PAI alone. Prospective trials have reported superior analgesia, postoperative ambulation, and functional recovery with CACB alone compared with SACB alone.[26] Our data are limited due to unavoidable selection bias, as the patients receiving CACB plus PAI were determined at the discretion of the attending anesthesiologist based on patient-specific factors, namely, chronic pain, which can be a major confounding factor in measuring opioid consumption and pain scores. Further, we are unaware of any prospective randomized controlled trials that have specifically compared the analgesic benefits of SACB plus PAI and CACB plus PAI. Thus, it may be possible that the addition of PAI to SACB or CACB diminishes the difference in analgesic benefit gained from each when applied individually, as each analgesic pathway in our study had clinically satisfactory pain outcomes. If true, it would further support our conclusion that routine implementation of CACB plus PAI has less added value than PAI alone or SACB plus PAI.

Time-driven activity-based costing methodology allows for accurate and transparent cost comparisons between various regional anesthetic techniques that are offered for TKA as well as evaluation of resource utilization. Other applications of TDABC have also been described, such as bundled payment reimbursement systems and operational improvement and cost reduction.[7,8,27] With so many potential applications, we believe that TDABC is a powerful tool allowing for efficient and accurate cost analysis, which can support health care improvement and clinical practice transformation in any value-based health care model.

CONCLUSION

In this study, the use of PAI with standardized multimodal perioperative analgesia provided statistically similar pain control, early postoperative rehabilitation, and hospital LOS at the lowest relative cost. The use of SACB, when added to PAI, may offer modest short-term analgesic benefit compared with PAI alone, thus increasing the relative value of SACB plus PAI. Continuous adductor canal blockade does not appear to increase value (outcomes/cost) in the overall care of patients undergoing TKA, particularly considering a 2.3-times cost increase (vs PAI) and its additional resource utilization, particularly postoperatively (vs PAI and SACB plus PAI).

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Abbreviations and Acronyms: **ABC,** activity-based costing; **ACB,** adductor canal block; **CACB,** continuous adductor canal block; **LOS,** length of stay; **PAI,** periarticular infiltration; **POD,** postoperative day; **SACB,** single-injection adductor canal block; **TDABC,** time-driven activity-based costing

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