Technology and Cost-Effectiveness in Knee Arthroplasty: Computer Navigation and Robotics

Michael L. Swank, MD, Martha Alkire, CNP, Michael Conditt, PhD, and Jess H. Lonner, MD

Abstract

Our aim in this article is to describe the impact that navigation technology has had on the market share of a community hospital and, specifically, to determine whether a high-volume surgeon using these technologies actually costs the hospital more than other surgeons at the same hospital and more than national means. In addition, we develop a comparable cost-effectiveness model for robotic technology in unicompartmental knee arthroplasty to demonstrate the potential cost-effectiveness at the same hospital.

Introducing new technologies (eg, computer navigation and, more recently, robotics) into the operating room has an undeniable initial capital equipment cost or lease (approximately $150,000-$300,000 for navigation, up to $800,000 for robotics), a per-case disposable cost, and operational costs.[1] Opponents of these technologies argue that these incremental costs are unjustified or unnecessary. Proponents of these technologies have demonstrated that, if the technologies are able to lower revision rates to a specific level, then they may be cost-effective.[2,3] It has been predicted that, after 10 years of computer navigation use in total knee arthroplasty (TKA), revision rates would have dropped by 1.6%, resulting in a relative cost-per-case reduction of $1,100 for computer navigation ($13,200) compared with conventional knee replacement ($14,300).[4] Long-term data regarding whether navigation prolongs implant life or decreases costly revisions are limited because of the relatively recent and slow implementation of imageless systems. Study results have shown that there is an incremental cost of $871 more per case when using computer navigation versus conventional guides.[2] As the volume of arthroplasties increases, the cost lessens a mean of $463 per primary TKA, making computer navigation more cost-effective. Navigation can lengthen operation times by 11 to 18 minutes, possibly more during the learning curve.[5] Surgeons who have trained residents assisting in pin placement have demonstrated decreased overall operating time.[6]

> **"...if the technologies are able to lower revision rates to a specific level, then they may be cost-effective."**

Cost-effectiveness data from actual use of either navigation or robotic technology are scant. Most authors use statistical models or hypothetical scenarios. Dong and Buxton[7] addressed cost-effectiveness in navigated TKAs, but impeding factors caused their model to overestimate, by $430/case, the cost of computer-assisted surgery (CAS). Navigation costs can be justified if intraoperative and postoperative complications can be reduced through use of navigation. Navigation has demonstrated both decreased blood loss[8] and cerebrovascular emboli,[9] thus providing cost savings associated with less transfusion, less unnecessary and wasted autologous blood donation, and decreased cost of hospitalization.

Lack of data has contributed to the slow adoption of these precision technologies. Only 3% to 5% of knee replacements involve navigation technology, despite some evidence that navigation improves radiographic alignment in TKA.[2,5,10-19] Navigation is advocated particularly when there are complex posttraumatic deformities or when hardware makes use of intramedullary instruments impossible or impractical.[6] Diminishing reimbursements have contributed to resistance to adoption of computer navigation technology. Rising costs of implants (up to 50% of the expense of joint replacement service lines), coupled with decreased margins, payer mix, and lower reimbursement, influence decision makers (hospitals, surgeons) when they consider adopting new technology. Category III *Current Procedural Terminology (CPT)* tempo-

Dr. Swank is Director, Joint Replacement Program, Jewish Hospital, Cincinnati, Ohio, and President, Cincinnati Orthopaedic Research Institute, Cincinnati, Ohio.
Ms. Alkire is Clinical Nurse Practitioner, Cincinnati Orthopaedic Research Institute, Cincinnati, Ohio.
Dr. Conditt is Director of Clinical Research, MAKO Surgical, Fort Lauderdale, Florida.
Dr. Lonner is Director, Knee Replacement Surgery, Pennsylvania Hospital, Philadelphia, Pennsylvania, and Director, Philadelphia Center for Minimally Invasive Knee Surgery, Philadelphia, Pennsylvania.

Address correspondence to: Michael L. Swank, MD, Cincinnati Orthopaedic Research Institute, 9825 Kenwood Road, Suite 200, Cincinnati, OH 45242 (e-mail, MSwank2789@aol.com).

Am J Orthop. 2009;38(2 suppl):32-36.

Table I. Comparative Charge Data[23]

DRG 81.54	Medicare	CAS (MLS)	Hospital	National
	Statistics			
2004				
Charges	$33,518	$30,816	$32,359	$33,722
Length of stay (days)	4	2.9	3.2	3.9
Discharge home rate	25%	39%		30%
2005				
Charges	$35,830	$32,638	$35,055	$35,946
Length of stay (days)	4	2.6	3	3.8
Discharge home rate	28%	71%*		33%
2006				
Charges	$39,124	$33,376	$37,444	$39,064
Length of stay (days)	3.8	2.5	2.9	3.7
Discharge home rate	31%	77%*		36%

Abbreviations: DRG, diagnosis-related group; CAS, computer-assisted surgery; MLS, Michael L. Swank, MD.

rary codes for computer-assisted TKA and total hip arthroplasty (THA), passed in 2004, can track use and expense. Only after a lengthy evaluation can the category III code be converted to a category I code, which offers payment. Another substantial reimbursement barrier is the appeals process. The 2004 Centers for Medicare and Medicaid Services (CMS) *International Classification of Diseases Ninth Revision* of procedural codes for hip and knee navigation provides a cost basis for future analysis of use and costs.[6]

Even less evidence exists for use of newer robotic technology, and the larger capital equipment purchase required for this technology clearly could be an impediment to adoption. Early data on robotic unicompartmental knee arthroplasty (UKA) appear promising, with improved Western Ontario and McMaster Universities Osteoarthritis Index and Knee Society scores at 6 weeks and 3 months.[15] Robotic technology offers reproducibility and reliability with preoperative planning to achieve consistent results and accuracy of implant alignment in UKA.[20]

Our aim in this article is to describe the impact that navigation technology has had on the market share of a community hospital and, specifically, to determine whether a high-volume surgeon using these technologies actually costs the hospital more than other surgeons at the same hospital and more than national means. In addition, we develop a comparable cost-effectiveness model for robotic technology in UKA to demonstrate the potential cost-effectiveness at the same hospital.

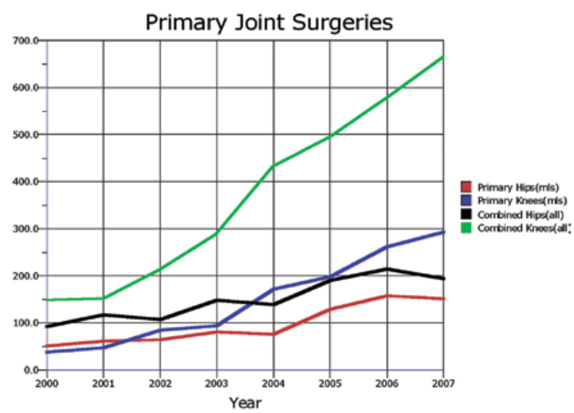
Computer Navigation for Total Knee Arthroplasty

One of the authors, Michael L. Swank, MD (MLS), practices at a 200-bed community hospital that performs more than 1,000 joint replacements a year. A computer navigation system for arthroplasty surgery was purchased in 2001, and the first navigated knee replacement was performed in December of that year. When imageless software became available in March 2002, MLS performed all primary knee replacements with this technology. No direct marketing funds or advertising was provided by the hospital or by the author to promote this technology. The study consisted of reviewing medical use data (MIDAS database) at MLS's institution and comparing the direct costs of medical care, length of stay (LOS), and discharge disposition to his peers at the institution.

To determine the impact of this technology on the hospital and the author's practice, we reviewed hospital joint replacement volume as reported by CMS standards from 2000 to 2007. Furthermore, to determine the cost-effectiveness of this technology for MLS versus other physicians at the hospital, we compared the aggregate per-case charge data for 2007. Finally, to determine cost-effectiveness versus national standards, we compared the author's cost data with published Medicare data for 2004 and 2005.

Hospital Joint Volume

The data presented in the Figure represents all primary total hip and total knee surgeries performed at the Jewish Hospital for the years represented compared with the total hip and total knee surgeries performed by MLS only.



	2000	2001	2002	2003	2004	2005	2006	2007
Primary Hips(mls)	50	61	64	81	75	129	157	151
Primary Knees(mls)	37	47	85	94	171	197	261	292
Combined Hips(all)	92	117	106	148	139	190	215	194
Combined Knees(all)	148	151	213	289	433	495	579	665

Figure. Primary joint surgeries by year, 2000-2007.

Table II. Total Knee Arthroplasty Data (MLS MIDAS Data)

Year	N	LOS (days)	Charge ($)
2004	138 MLS 355 Total	2.9 3.2	30,816 32,359
2005	178 MLS 471 Total	2.6 3.0	32,638 35,055
2006	219 MLS 516 Total	2.5 2.9	33,376 37,444
2007	284 MLS 624 Total	2.4 2.7	33,801 38,877
2008	145 MLS 532 Total	2.5 2.6	36,410 40,956

Abbreviations: MLS, Michael L. Swank, MD; LOS, length of stay; MIDAS, Models of Infectious Disease Agent Study.

Comparative Charge Data

Comparative charge data from available Medicare and national (all-payer) data were available for 2004 through 2006. MIDAS database/medical use review data were compared with the Medicare and national data for total charges, LOS, and percentage of patients discharged home rather than to inpatient rehabilitation or a skilled facility. MLS's computer-assisted volume of knees was compared with the combined hospital surgeon data, predominantly using the conventional method of joint replacement (next highest volume surgeon). TKA charges for the author in 2004 (3 years after he began using CAS) was $30,816 per case using navigation compared with the national mean of $33,722 (significant at $P<.001$; SE, 0.07) (Tables I, II). MLS demonstrated LOS of less than 3 days for all hip and knee arthroplasties using CAS, as compared with the 3- and 4-day Medicare, national, and combined hospital data (Tables I, II). The author's discharge-to-home rate was 71%, triple that of Medicare, national, and combined hospital data for 2005–2006 (Tables I, II).

In fiscal year 2007, doctors at the hospital performed 624 primary TKAs, 284 (45%) of which were by MLS. Mean charge per TKA for the entire hospital was $38,877, and mean LOS was 2.7 days. Mean per-case charges for CAS-TKAs performed by MLS were $33,801, and LOS was 2.4 days. Overall, for the institution, 78% of the knees were discharged to home compared with 86% of TKAs performed by MLS (Tables I, II).

Robotic Surgery for Unicompartmental Knee Arthroplasty

Successful clinical outcomes after UKA depend on accurate component alignment, which can be difficult to achieve with manual instrumentation. Computer navigation can help make implantation accurate by guiding the position of the surgical cutting guides or the implant within the patient. However, continuing to rely on manual cutting blocks and alignment jigs in combination with the smaller exposure inherent in UKA surgery has left room for improvement in this procedure. A newly developed technology uses haptic robotics in place of traditional UKA instrumentation. The difference is that traditional UKA instrumentation can be used to determine where the resection should be made, but conventional saws and guides are still used, whereas haptic robots determine the appropriate resection and guide resection with novel "smart tools" and unique precision.

The accuracy of bone resection with conventional CAS still relies on how accurately the surgeon places the cutting and alignment jigs relative to the CAS guidance and how accurately the cutting saw executes the resection. In contrast, robotically assisted orthopedic surgery eliminates the need for manual cutting blocks and alignment jigs, reducing soft-tissue disruption. In addition, through surgeon-interactive tactile feedback, the robotic system not only allows the surgeon to plan a resection that meets the needs of a particular patient but ensures that the resection is executed precisely according to plan. This feedback provides levels of accuracy, precision, and safety not capable with conventional CAS techniques. It also brings a level of participation that allows the surgeon to operate the system and not just evaluate the information. However, this technology comes at a significant initial capital equipment cost to the hospital.

Market for Unicompartmental Knee Arthroplasty

The first issue to consider is whether the market size warrants the up-front capital expenditure for this technology. In 2007, approximately 45,000 UKAs and 633,000 primary knee arthroplasties were performed. The market is likely much larger. Authors of an unpublished Duke University survey reported that, of the patients whose physicians recommended TKA or THA, a staggering 92% of men and 88% of women chose not to undergo these surgical procedures. These data translate to a potential derived primary knee arthroplasty market of 6 million cases. Assuming that approximately 10% of knee arthroplasties are UKAs, the current market potential is for 600,000 UKAs. Review of the literature reveals a broad range of findings, with incidence of medial osteoarthritis at 4% to 50%. Riddle and colleagues[21] found that UKA incidence in the United States is growing at a rate of 32.5%, as compared with 9.4% for TKA.

Increased Volume of UKA and TKA

Clinical volume growth is expected with this novel technology. For instance, the first robotic-arm–assisted UKA was performed in June 2006. At the inaugural site, the surgeon's personal UKA volume increased from 21 cases during the year immediately preceding robotic-arm technology implementation to 65 robotic-arm–assisted UKA implantations during the first year of clinical use—representing 310% growth in 1 year. During the same year, the surgeon's TKA volume increased from 295 to 448 cases, a 13% increase. This represents growth of 28% across all knee arthroplasty procedures, clearly exceeding the typical 7% to 8% organic annual growth predicted from Medicare knee arthroplasty procedural data. This "halo" effect is the result of a limited degree of public relations initiatives and primarily results from word-of-mouth patient references.

Cost-Effectiveness of UKA Versus TKA

Robertsson and colleagues[22] compared the cost of implants and hospital stay of UKA versus TKA based on the expenses incurred for the index procedure while taking into account the number of revisions to be expected. Risk for revision was estimated with survival statistics from the Swedish Registry; also estimated were risk for second revision and risk for infection. Compared with TKA patients, UKA patients had a 2-day-shorter hospital stay and fewer serious complications. Robertsson and colleagues concluded that UKA in appropriate patients represents a cost savings over TKA.

Return on Investment for the Hospital

Mean contribution profit for UKA (diagnosis-related group [DRG] 470, 81.54) is highly dependent on many factors, including patient age/payer mix, hospital cost-efficiencies, and ratio of reimbursement capture relative to charges. For this analysis, the per-case conservative contribution profit assumption is $3,500. A preoperative computed tomography (CT) scan, part of the robotic UKA protocol (*CPT* 73700), generates $125 for the hospital. Mean LOS for TKA is 3.7 days compared to 1 day for a robotic UKA. At a mean hospital cost of $450 per nonsurgical day, the net LOS cost savings of doing robotic UKA is $790 (LOS cost savings of $1,215 times the payer-mix Medicare [DRG 544, 81.54] of 65%). Mean cost of the robotic UKA implants ($3,700) is less than the mean cost of TKA ($4,500). Thus, the per-case contribution margin for an inpatient robotic UKA is $5,090.

Recent coding and coverage changes instituted by CMS may have changed this landscape considerably, and orthopedic surgical service providers may be rewarded for executing UKA on an outpatient basis. Hospital outpatient reimbursement is higher than inpatient reimbursement for UKA. Under *CPT* 27446/Ambulatory Payment Classification 681, hospital outpatient payments have increased dramatically over the past 2 years, from $12,643 to $17,495 per case. For operators of ambulatory surgery centers (ASCs), payments for UKA are now based on Medicare's final January 2008 ASC rule, allowing reimbursement at a discounted payment of 65% of the mean hospital outpatient payment. So, under *CPT* 27446, an ASC would receive $11,372 (or 65% of the hospital outpatient department payment of $17,496). The difference makes the contribution profit for outpatient robotic UKA $10,290. With an estimated inpatient/outpatient mix of 25%/75%, mean contribution profit is then $5,790.

If we assume incremental increases in the number of robotic UKA procedures and TKA procedures—50 and 20 (respectively) in year 1, 70 and 30 (respectively) in year 2, and 90 and 40 (respectively) in year 3—then return on investment occurs in just more than 2 years with a single application.

Predicted Case

As mentioned, doctors at MLS's hospital performed 624 primary TKAs in 2007. Of these procedures, 39 (6%) were UKAs.

"This scenario would result in the hospital completely recouping the entire cost of the robotic technology in 2 years..."

Unpublished Duke University study results suggest that, in MLS's community, there is a pool of more than 5,700 patients who have osteoarthritis and would benefit from knee arthroplasty, and, at a minimum, 10%, or 570 patients, have unicompartmental disease and would be potential candidates for UKA. Yet, only 39 UKAs were performed at the hospital, making its potential market almost 50% larger than the current knee arthroplasty volume. If 63 UKAs were performed there, and the patients were discharged on postoperative day 1 (POD1) instead of on the hospital mean of POD2 for total knees, the potential cost savings in a single year, with the added reimbursement for the unicompartmental procedure, would be $186,529 for the 24 additional cases and $303,109 for the current unicompartmental replacements. Total yearly incremental revenue to the hospital by Medicare fee schedules alone would be $489,638 for 2007.

Furthermore, assuming the hospital continues to develop its knee business at a rate of 15% per year, as it has for the past 5 years, the annual unicompartmental procedure volume would grow to approximately 72 the next year and another $559,587 in (incremental revenue and) cost savings without any increase in business over the historical growth. This scenario would result in the hospital completely recouping the entire cost of the robotic technology in 2 years in this community hospital setting, even without an assumed incremental increase in market share.

Conclusions

For new orthopedic technology to be widely adopted, there must be a favorable net revenue for institutions, less strain on systems, improved patient outcomes with implant durability, and increased demand from consumers. CAS has been cost-effective without increasing the burden on hospital work flow or increased operating room time. Mean charges for navigation, LOS, and discharge to home can be significantly lower than CMS, national, or combined hospital charges.

Applying the cost estimates of robotic technology for UKA demonstrates that even the relatively expensive capital equipment cost of robotic technology can easily be regained within a 2-year period without assuming any increase in market share, which likely grossly underestimates the net positive economic impact of these technologies.

From a patient's perspective, the rapid recovery, extended implant durability, and decreased revision rates that may be possible with the accuracy of robotic arm technology in UKA or bicompartmental arthroplasty may in fact be … priceless.

Authors' Disclosure Statement

Dr. Swank wishes to disclose that he is a paid consultant to BrainLAB and DePuy Orthopaedics. Dr. Lonner wishes to disclose that he is a consultant for and a shareholder in MAKO Surgical Corp. Dr. Conditt wishes to disclose that he is an employee of MAKO Surgical Corp. Ms. Alkire reports no actual or potential conflict of interest in relation to this article.

The authors acknowledge the grant from MAKO Surgical Corp. in support of publishing this supplement.

References

1. Mathias JM. Orthopedic navigation: questions about long-term results and costs. *OR Manager*. 2007;23(9):1, 15, 17.
2. Novak EJ, Silverstein MD, Bozic KJ. The cost-effectiveness of computer-assisted navigation in total knee arthroplasty. *J Bone Joint Surg Am.* 2007;89(11):2389-2397.
3. Slover JD, Tosteson AN, Bozic KJ, Rubash HE, Malchau H. Impact of hospital volume on the economic value of computer navigation for total knee replacement. *J Bone Joint Surg Am*. 2008;90(7):1492-1500.
4. Bauwens K, Matthes G, Wich M, et al. Navigated total knee replacement. A meta-analysis. *J Bone Joint Surg Am*. 2007;89(2):261-269.
5. Bathis H, Perlick L, Tingart M, Luring C, Zurakowski D, Grifka J. Alignment in total knee arthroplasty: a comparison of computer-assisted surgery with the conventional technique. *J Bone Joint Surg Br.* 2004;86(5):682-687.
6. Beringer DC, Patel JJ, Bozic KJ. An overview of economic issues in computer-assisted total joint arthroplasty. *Clin Orthop.* 2007;(463):26-30.
7. Dong H, Buxton M. Early assessment of the likely cost-effectiveness of a new technology: a Markov model with probabilistic sensitivity analysis of computer-assisted total knee replacement. *Int J Technol Assess Health Care*. 2006;22(2):191-202.
8. Kalairajah Y, Simpson D, Cossey AJ, Verrall GM, Spriggins AJ. Blood loss after total knee replacement: effects of computer-assisted surgery. *J Bone Joint Surg Br.* 2005;87(11):1480-1482.
9. Kalairajah Y, Cossey AJ, Verrall GM, Ludbrook G, Spriggins AJ. Are systemic emboli reduced in computer-assisted knee surgery? A prospective, randomised, clinical trial [published correction appears in *J Bone Joint Surg Br.* 2006;88(10):1407]. *J Bone Joint Surg Br.* 2006;88(2):198-202.
10. Anderson KC, Buehler KC, Markel DC. Computer assisted navigation in total knee arthroplasty: comparison with conventional methods. *J Arthroplasty*. 2005;20(7 suppl 3):132-138.
11. Bäthis H, Perlick L, Tingart M, Lüring C, Perlick C, Grifka J. Radiological results of image-based and non-image-based computer-assisted total knee arthroplasty. *Int Orthop*. 2004;28(2):87-90.
12. Bolognesi M, Hofmann A. Computer navigation versus standard instrumentation for TKA: a single-surgeon experience. *Clin Orthop.* 2005;(440):162-169.
13. Chauhan SK, Scott RG, Breidahl W, Beaver RJ. Computer-assisted knee arthroplasty versus a conventional jig-based technique. A randomised, prospective trial. *J Bone Joint Surg Br.* 2004;86(3):372-377.
14. Chin PL, Yang KY, Yeo SJ, Lo NN. Randomized control trial comparing radiographic total knee arthroplasty implant placement using computer navigation versus conventional technique. *J Arthroplasty*. 2005;20(5):618-626.
15. Cobb J, Henckel J, Gomes P, et al. Hands-on robotic unicompartmental knee replacement: a prospective, randomised controlled study of the Acrobot system. *J Bone Joint Surg Br.* 2006;88(2):188-197.
16. Confalonieri N, Manzotti A, Pullen C, Ragone V. Computer-assisted technique versus intramedullary and extramedullary alignment systems in total knee replacement: a radiological comparison. *Acta Orthop Belg*. 2005;71(6):703-709.
17. Kim SJ, MacDonald M, Hernandez J, Wixson RL. Computer assisted navigation in total knee arthroplasty: improved coronal alignment. *J Arthroplasty*. 2005;20(7 suppl 3):123-131.
18. Mihalko WM, Boyle J, Clark LD, Krackow KA. The variability of intramedullary alignment of the femoral component during total knee arthroplasty. *J Arthroplasty.* 2005;20(1):25-28.
19. Mielke RK, Clemens U, Jens JH, Kershally S. Navigation in knee endoprosthesis implantation—preliminary experiences and prospective comparative study with conventional implantation technique [in German]. *Z Orthop Ihre Grenzgeb.* 2001;139(2):109-116.
20. Sinha RK. Outcomes of robotic arm–assisted unicompartmental arthroplasty. *Am J Orthop*. 2009;38(2 suppl):20-22.
21. Riddle DL, Jiranek WA, McGlynn F. Yearly incidence of unicompartmental knee arthroplasty in the United States. *J Arthroplasty*. 2008;23(3):408-412.
22. Robertsson O, Borgquist L, Knutson K, Lewold S, Lidgren L. Use of unicompartmental instead of tricompartmental prostheses for unicompartmental arthrosis in the knee is a cost-effective alternative. 15,437 primary tricompartmental prostheses were compared with 10,624 primary medial or lateral unicompartmental prostheses. *Acta Orthop Scand*. 1999;70(2):170-175.
23. Agency for Health Care Quality and Research. *National Health Statistics 2004–2006*. Available at: http://hcupnet.ahrq.gov/HCUPnet.jsp. Accessed November 9, 2008.