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Journal

Current Orthopaedic Practice, 33(4)

ISSN

1940-7041

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Publication Date

2022

DOI

10.1097/bco.0000000000001131

Peer reviewed

Published in final edited form as:

Curr Orthop Pract. 2022 ; 33(4): 338–346. doi:10.1097/bco.0000000000001131.

Costs and benefits of routine hemoglobin A1c screening prior to total joint arthroplasty: a cost-benefit analysis

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Abstract

Background: Poorly controlled diabetes mellitus (DM) increases the risk for periprosthetic joint infection (PJI) after total joint arthroplasty (TJA). While institutional protocols include hemoglobin A1c (HbA1c) screening in TJA patients, the costs and benefits of routine preoperative screening have not been described.

Methods: The authors created a decision tree model to evaluate short-term costs and risk reduction for PJIs with routine screening of primary total hip arthroplasty (THA) and total knee arthroplasty (TKA) patients. Probabilities and costs were obtained from published sources. They calculated net costs and absolute risk reduction in PJI for routine screening versus no screening. The authors also performed sensitivity analyses of model inputs including probabilistic sensitivity analyses (PSAs) consisting of 10,000 Monte Carlo simulations.

Results: In patients with DM, routine screening before THA resulted in net cost savings of $81 per patient with 286 patients needing to be screened to prevent 1 PJI, while screening before TKA incurred net additional costs of $25,810 per PJI prevented. Routine screening in patients with DM undergoing THA or TKA was cost-saving across 75.5% or 21.8% of PSA simulations, respectively. In patients with no history of DM, routine screening before THA or TKA incurred net additional costs of $24,583 or $87,873 per PJI prevented, respectively.

Conclusions: Routine HbA1c screening in patients with DM prior to THA with referral of patients with elevated HbA1c for glycemic optimization may prevent PJI and reduce healthcare costs. In contrast, routine screening in patients with DM prior to TKA or in patients with no history of DM is not cost-saving.

Level of Evidence: Economic Level IV.

Keywords

A1c; cost-effectiveness; diabetes; joint replacement

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INTRODUCTION

Total joint arthroplasty (TJA) is the most common procedure for U.S. Medicare beneficiaries, incurring annual costs of over $6 billion.[1,2] Based on recent projections, the annual incidence of total hip or knee arthroplasties (THAs or TKAs) in the U.S. will reach 635,000 and 1.26 million, respectively, by 2030.[3–5] The economic burden of TJA has stimulated efforts by health payers (e.g., Medicare) to reduce costs and complications in the face of finite health-care resources,[6] including implementation of innovative payment systems such as the Bundled Payments for Care Improvement program. Consequently, recent research has focused on identifying modifiable risk factors for post-surgical complications.[7–9] Periprosthetic joint infection (PJI) is a well-studied complication, affecting approximately 1% of primary TJA procedures and causing a multifold increase in cost.[7,10–13]

Diabetes mellitus (DM) is a known risk factor for infectious complications after TJA.[14–20] Compared to patients with controlled DM, patients with poorly controlled DM, defined clinically or biochemically, are twice as likely to develop a postoperative infection.[21] Multiple studies have found an association between the risk of postoperative infection (e.g., PJI) and hemoglobin A1c (HbA1c) that was greater than 7% to 8%.[22–26] That threshold is an often cited marker for delaying TJA in favor of medical optimization in patients with DM,[27–32] despite a lack of studies on the cost-benefit profile of HbA1c screening in this population. Furthermore, in addition to existing institutional protocols for screening patients with known DM, two recent studies recommended the inclusion of patients without a prior diagnosis of DM in routine preoperative HbA1c screening protocols to prevent short-term complications such as PJI and long-term sequelae of undiagnosed DM.[27,33] While screening for type 2 DM in asymptomatic individuals is generally considered cost-effective over the long term,[34] the cost-effectiveness of routine HbA1c screening in patients without known DM specifically for preventing arthroplasty-related complications such as PJI remains unproven.

In this study, the authors aimed to evaluate the costs and benefits, in terms of PJIs prevented, of routine preoperative HbA1c screening in patients with and without known DM undergoing primary THA and TKA. This study tests the null hypothesis that routine HbA1c screening in the TJA population is not cost-saving in terms of PJIs prevented.

MATERIALS AND METHODS

Ethical Review and Study Design

Because all data used in this study is publicly available and deidentified, the Stanford University Institutional Review Board determined that it was exempt from institutional review board approval. Informed patient consent was not required.

Decision Analysis Model

Using TreeAge Pro (TreeAge Software Inc; Williamstown, MA), the authors constructed decision trees to model HbA1c screening versus no screening prior to primary THA or TKA from a U.S. health payer perspective and with a time horizon of 1 year (Figure 1,

Figure A1 [See A1 in Supplemental Digital File, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which shows decision tree scheme for routine preoperative HbA1c screening.]). In the model, patients with diabetes were divided into those above and below a predefined HbA1c threshold of greater than 7% (defined as uncontrolled DM). Patients above the HbA1c threshold were modeled to experience an increased risk of PJI, denoted by the relative risk (risk ratio). The risk ratio is defined as:

$$\frac{\text{probability of PJI in patints with uncontrolled DM}}{\text{probability of PJI in patients with controlled DM}}$$

Thus, the probability of PJI in patients with uncontrolled DM was calculated by multiplying this risk ratio by the probability of PJI in patients with controlled DM. All screening strategies also modeled a subsequent glycemic intervention for patients who screened above the threshold. This glycemic intervention had a defined success rate (Table 1) and above-threshold patients successfully treated by this intervention were considered to have controlled DM in the calculation of PJI risk. Patients with HbA1c that was less than 7% (defined as controlled DM) were not candidates for the modeled intervention because they already had controlled DM. The threshold for uncontrolled DM was varied to greater than 8% in a sensitivity analysis. In this model, PJI was treated with a two-stage revision. Probability and cost inputs for the model are shown in Table 1.

The authors only examined the postoperative complication of PJI because of its considerable morbidity and cost. They made several assumptions: 1) Although studies have characterized a 2-to-3-fold increased risk of PJI with uncontrolled DM,[21,35] there is no universal HbA1c threshold that defines uncontrolled DM. This study is based on recent data showing an increased risk of PJI above HbA1c of 7% to 8%.[22,23] Other studies have found an increased risk of postoperative infection at comparable HbA1c thresholds.[24,36] Due to data showing that the risk of PJI increases linearly through HbA1c of 7% without sharp discontinuity, the authors assumed that differences in risk with using HbA1c thresholds of 7% or 8% were negligible. Therefore, they applied the risk ratio of PJI with uncontrolled diabetes (Table 1) to all patients with HbA1c greater than or equal to the threshold. 2) All patients achieving HbA1c below the threshold were considered to have controlled DM with a lower risk of PJI. 3) They modeled a preoperative glycemic intervention consisting of three visits to a primary care physician or endocrine specialist, evaluation by a dietician with one follow-up and one group session, and pharmacologic therapy.[37,38] To account for variations in intervention cost based on individual needs, the authors performed additional sensitivity analyses on that variable.

Probabilities and Costs

All probabilities were obtained from published sources. Since there were no published estimates for the prevalence of uncontrolled diabetes in patients with undiagnosed DM in the arthroplasty literature, the authors utilized data from a national, cross-sectional study to calculate the prevalence ratio:[39]

$$\frac{\text{prevalence of uncontrolled DM in patients with undiagnosed DM}}{\text{prevaence of uncontrolled DM in patients with diagnosed DM.}}$$

By multiplying this ratio by the prevalence of uncontrolled DM in arthroplasty patients with diagnosed DM (denominator), they obtained the estimate for the prevalence of uncontrolled DM in arthroplasty patients with undiagnosed DM (numerator). Given the low incidence of PJI, the odds ratio for PJI with uncontrolled DM was approximated as a risk ratio. When prevalence data were available from multiple sources, they were pooled into a single estimate.

All costs were obtained from published sources or from publicly available Centers for Medicare and Medicaid Services (CMS) datasets and adjusted to 2020 U.S. dollars using the consumer price index. The authors derived the cost of the index TJA using previous methods.[40] The cost of pharmacologic therapy was modeled to be equivalent to an 8-month supply of metformin. Since their time horizon was 1 year, no discounting was required.

Sensitivity Analyses

The authors performed one-way sensitivity analyses by varying inputs within their 95% confidence intervals (where available) or from 50% to 150% of their base value. To simultaneously account for uncertainty in all model inputs, they performed probabilistic sensitivity analyses (PSAs) consisting of 10,000 Monte Carlo simulations with sampling from uncertainty distributions of each model input. When uncertainty estimates were unavailable, they assumed a coefficient of variation of 10%. The authors modeled probabilities using beta distributions, risks using log-normal distributions, and costs using normal distributions. All inputs used for the sensitivity analyses are provided in Table A1 (See A1 in Supplemental Digital File, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which shows ranges used in sensitivity analyses and probabilistic sensitivity analysis parameters.).

RESULTS

HbA1c Screening in Patients With Diabetes Mellitus

Table 2 illustrates the costs and benefits of routine HbA1c screening (including both screening and subsequent intervention) compared to no screening. Screening patients with DM undergoing THA resulted in a net cost savings of $81 per patient, with 286 patients needing to be screened to prevent a single PJI. The cost savings of screening was most sensitive to the probabilities of PJI and success rate of lowering HbA1c (Figure A2, in Supplemental Digital File, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which is a tornado diagram showing the sensitivity to variation in model inputs.). Generally, screening saved money if the overall probability of PJI was high, the risk of PJI with uncontrolled DM was high, or the glycemic intervention was more effective or less costly. Thus, screening remained cost-saving if the probability of PJI with controlled DM was greater than 0.6%, the risk ratio of PJI (which is multiplied with the probability of PJI with controlled DM to obtain the probability of PJI with uncontrolled DM) with uncontrolled DM was greater than 2.0%, and the success rate of lowering HbA1c was greater than 36.4%

(Table 3). Routine screening saved money if intervention cost less than $553 (Figure 2A). When the HbA1c threshold was increased to greater than 8%, screening patients with DM undergoing THA resulted in a net cost savings of $22 per patient, with 983 patients needing to be screened to prevent a single PJI.

Screening patients with DM undergoing TKA incurred additional net costs of $25,810 per PJI prevented. Similarly to above, screening saved money if the overall probability of PJI was high, the risk of PJI with uncontrolled DM was high, or the glycemic intervention was more effective or less costly. Screening became cost-saving when the probability of PJI with controlled DM was greater than 1.4%, risk ratio of PJI with uncontrolled DM was greater than 2.0, success rate of lowering HbA1c was greater than 85.6% (Table 3), or cost of intervention was less than $220 (Figures 2B, A3 [in Supplemental Digital File, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which has tornado diagram showing the sensitivity to variation in model inputs.]) When the HbA1c threshold was increased to greater than 8%, screening patients with DM undergoing TKA incurred additional net costs of $29,470 per PJI prevented.

In the PSA, routine screening saved money 75.5% of the time in THA and 21.8% of the time in TKA. Distributions of incremental costs and absolute risk reduction in PJI across 10,000 Monte Carlo simulations are shown (Figure 3, A4 [See A4 in Supplemental Digital Content, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which shows distribution of absolute risk reduction in PJI with routine HbA1c screening compared to no screening.]).

HbA1c Screening in Patients With No History of Diabetes Mellitus

In patients with no history of DM (i.e., a population containing undiagnosed DM cases), screening incurred additional net costs of $5 to $12 per patient screened and $24,583 to $87,873 per PJI prevented in the base case (Table 2). When the HbA1c threshold was increased to greater than 8%, screening patients with no history of DM incurred additional net costs of $142,423 to $243,069 per PJI prevented. Routine screening in THA patients without known DM saved money when the probability of PJI with controlled DM was greater than 1.4%, the risk ratio of PJI with uncontrolled DM was greater than 3.3%, the success rate of lowering HbA1c was greater than 83.7% (Table A2 [See A2 in Supplemental Digital File, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which shows sensitivity of results to probability of achieving HbA1c target of less than 7% in patients with no history of diabetes mellitus.]), or the cost of an HbA1c test was less than $4.97 (Figure A5 [See A5 in Supplemental Digital Content, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which displays tornado diagram showing the sensitivity to variation in model inputs.]). The authors varied the prevalence of undiagnosed DM for THA patients, showing that screening saved money when prevalence was greater than 14.3% (Figure 4).

In contrast, routine screening in TKA patients without known DM was never cost-saving across the ranges of model inputs tested or at any prevalence of DM (Figure A6, A7 [See A6 and A7 in Supplemental Digital Content, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which displays tornado diagram showing the sensitivity to variation in model inputs, and sensitivity analysis showing the preferred strategy across

a range of values for prevalence of undiagnosed diabetes and relative risk of PJI in uncontrolled diabetes vs. controlled diabetes in patients with no history of DM undergoing TKA.]). In this population, a PSA showed that routine screening saved money 20.2% of the time in THA and 3.9% of the time in TKA (Figure 3, A4 [See A4 in Supplemental Digital Content, Supplemental Digital Content 1, http://links.lww.com/COP/A59, which shows distribution of absolute risk reduction in PJI with routine HbA1c screening, compared to no screening in patients.]).

DISCUSSION

Interpretation

This study showed that routine preoperative HbA1c screening (with a subsequent glycemic intervention) in patients with DM undergoing THA saves money at the 1-year time horizon, with 286 patients needing to be screened to prevent a PJI. Routine screening in the other groups modeled in this study did not reduce costs in the short-term as related to prevention of PJI. The difference in cost-benefit profile between THA and TKA was attributable to the difference in the risk ratio of PJI in patients with uncontrolled DM undergoing those procedures. The difference in cost-benefit profile between patients with known DM and patients without known DM is attributable to the low prevalence of DM. Thus, routine preoperative screening of patients with DM undergoing THA saved money. In contrast, screening TKA patients with DM or THA/TKA patients with no history of DM incurred additional net costs per PJI prevented.

Although two recent studies have advocated for routine HbA1c screening in all arthroplasty patients,[27,33] the short-term costs and benefits of screening were unknown. Shohat et al.[33] provided a brief estimate of screening costs based only on HbA1c assay cost, but the costs or efficacy of subsequent interventions required to achieve adequate glycemic control were not incorporated. Since the purpose of screening before TJA is to prevent postoperative complications such as PJI, economic analyses would benefit from the inclusion of those interventions. These results suggest that incorporation of routine HbA1c screening into preoperative care pathways for THA with referral of patients found to have uncontrolled DM for medical optimization represents a low-burden intervention that would yield net cost savings.

Furthermore, while the evidence shows that elevated HbA1c is associated with an increased risk of PJI,[41] identification of a specific threshold for intervention has been elusive.[22–24] This may be due to a linear relationship between HbA1c and risk of PJI.[42] Yet, despite those limitations, at least two studies advocate for routine HbA1c screening in arthroplasty patients.[27,33] While this analysis faces similar limitations in the shortage of high-quality, prospective evidence on specific HbA1c thresholds, the authors' results suggest that HbA1c screening in some populations (i.e., THA patients with DM) is likely to provide more value (lower cost-benefit ratios) compared to others (e.g., THA/TKA patients without known DM). Institutions with limited resources might want to consider prioritizing patients with DM and those undergoing THA. Institutions considering expansion of their screening programs to include patients without known diabetes should consider the cost per PJI prevented relative to alternative methods for optimizing PJI risk (e.g., smoking cessation).

Despite guidelines for referring patients with elevated HbA1c for preoperative optimization,[43] there are few prospective studies on the efficacy of glycemic interventions prior to TJA. An effective strategy for lowering HbA1c prior to bariatric surgery included referrals to nutritionists, psychologists, and exercise physiologists with medication adjustments.[44] Other proven strategies vary from diabetes education and dietary changes to exercise and pharmacologic therapy.[45–48] Recognizing the benefits of a multimodal approach, one institution has established a multidisciplinary care pathway for glycemic optimization prior to spine surgery.[38] Moreover, elective surgery itself may provide a strong incentive for lifestyle changes,[49] thus augmenting the efficacy of screening protocols. Although the authors could not model every glycemic intervention shown to be effective, they modeled a representative intervention and provide cost and efficacy thresholds that any intervention must achieve in order to save money. (Figure 2).

Limitations and Future Perspectives

This study should be viewed in light of its limitations. Since no randomized studies of preoperative glycemic interventions in TJA patients exist, the risk reduction realized by lowering HbA1c might be more or less than expected, which would alter the cost savings and efficacy of screening. Further, glycemic optimization may require more intensive, costlier interventions, which would increase net costs. Alternatively, multidisciplinary clinics may achieve better outcomes at lower cost,[38] which would be well-suited for patients requiring intensive interventions. As better evidence emerges from existing multidisciplinary programs, future iterations of this model can be adjusted accordingly. The authors also did not consider reduced quality-of-life attributable to delaying TJA for glycemic interventions. Since glycemic optimization could take months,[37,44] the reduced quality-of-life in the interim would attenuate the benefits of risk reduction. Finally, they chose a time horizon of 1 year to accurately reflect the underlying literature.[24] Although this limits comparison with the bundle time horizon that other studies have used,[40] their results are still applicable to health payers and systems making short-term resource-allocation decisions. Due to their focus on short-term, TJA-specific costs and benefits, the authors also did not consider long-term diabetes-related or other sequelae avoided by screening and treatment, which would further increase the effectiveness of screening.[50]

CONCLUSIONS

In summary, this cost-effectiveness analysis shows that routine HbA1c screening in THA patients with DM reduces the risk of PJI at a net cost savings over the 1-year time horizon while screening in TKA patients with DM or THA/TKA patients without DM does not save money. These results can be used to inform the development of care pathways for glycemic optimization prior to TJA to achieve higher value care.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Financial disclosure:

Dr. Robin Kamal has received funding from the National Institutes of Health and the Orthopaedic Research and Education Foundation. Dr. William Maloney reports a financial relationship with Zimmer-Biomet and Stryker. The authors report no conflicts of interest.

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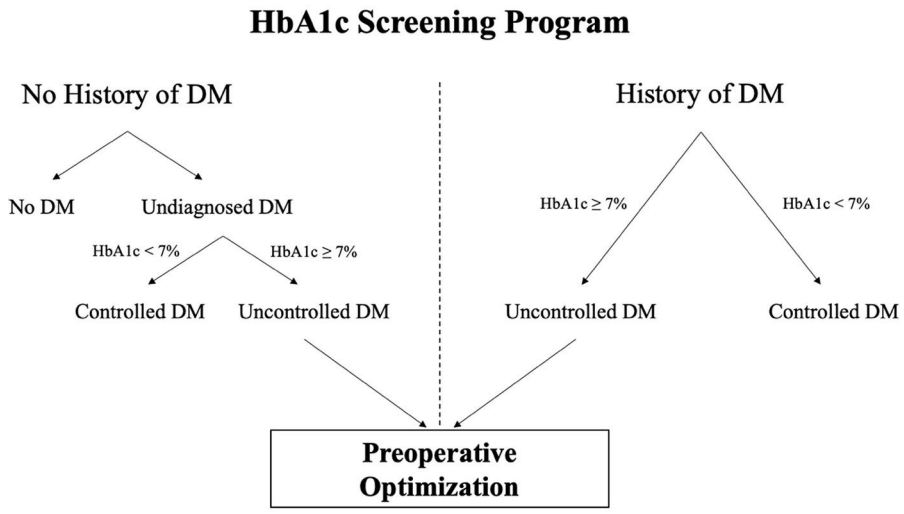


Figure 1.

Model of routine hemoglobin A1c (HbA1c) screening programs in patients with or without a history of diabetes mellitus (DM). Patients with a history of DM can be identified by a review of their medical record and/or clinical interview.

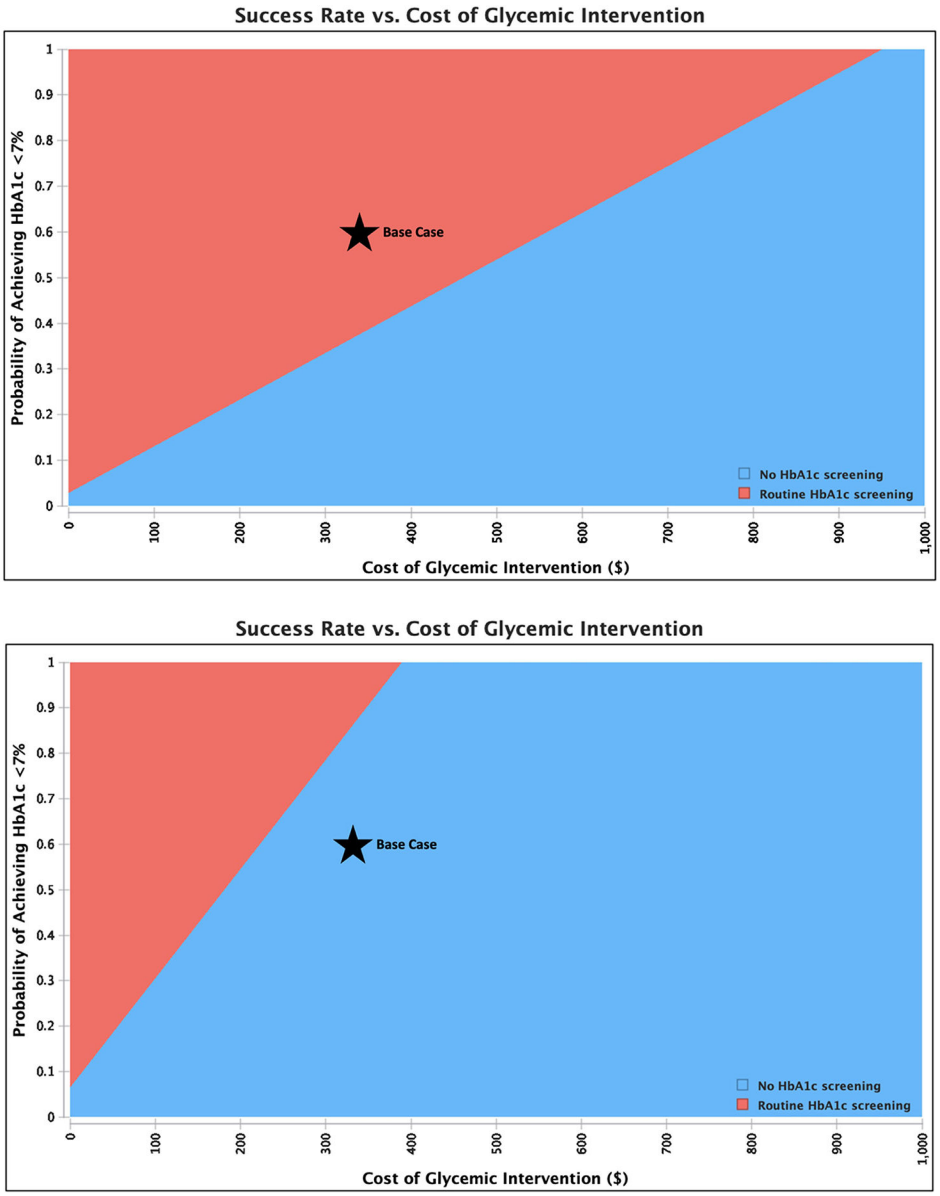
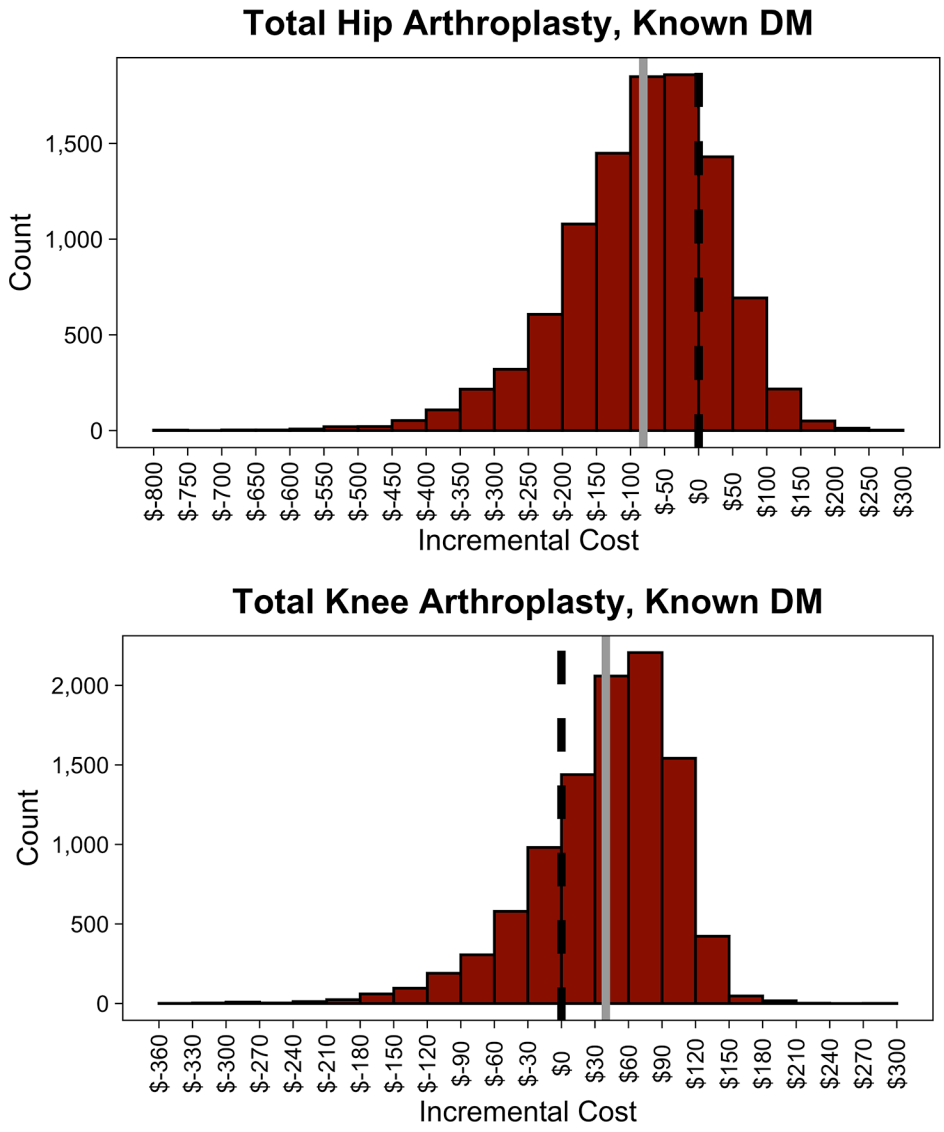


Figure 2.

Sensitivity analysis showing the preferred (least costly) strategy across a range of values for intervention cost and probability of achieving hemoglobin A1c (HbA1c) less than 7% in patients with diabetes mellitus (DM) undergoing total hip arthroplasty or total knee arthroplasty. The base case is shown by the star. Routine HbA1c screening saves money compared to not screening when the cost of intervention is low and/or the success rate of lowering HbA1c is high.



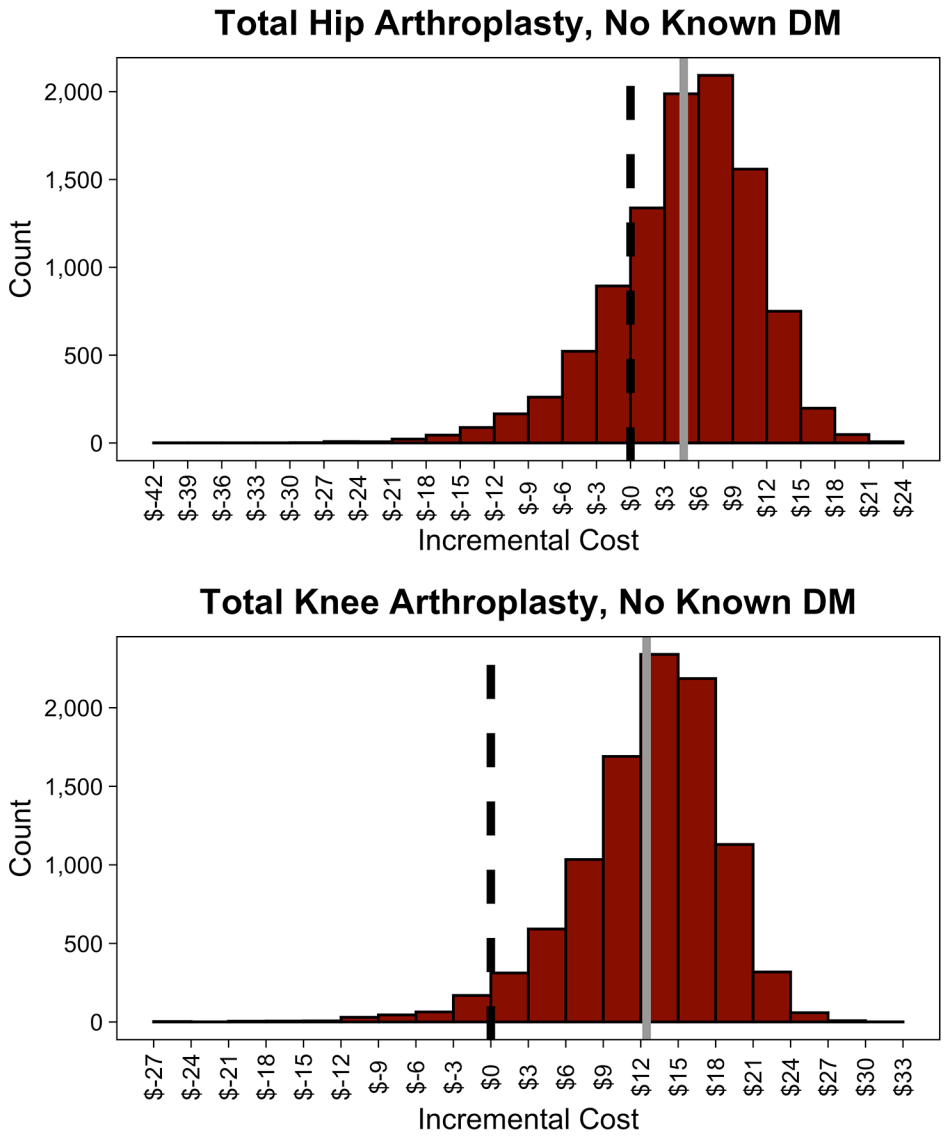
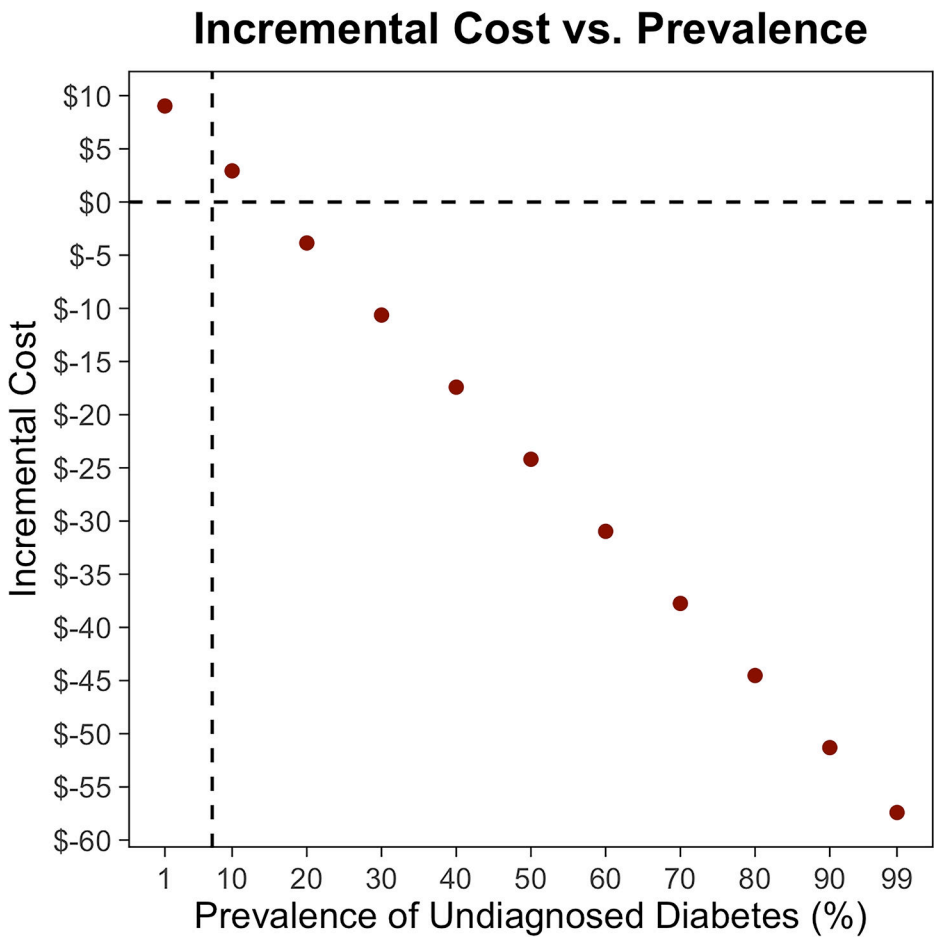


Figure 3.

Distributions of incremental cost per patient of routine hemoglobin A1c (HbA1c) screening compared to no screening in patients with diabetes mellitus (DM) undergoing total hip arthroplasty (THA) (A), with diabetes mellitus undergoing total knee arthroplasty (TKA) (B), with no history of diabetes mellitus undergoing THA (C), and with no history of diabetes mellitus undergoing TKA across 10,000 Monte Carlo simulations (D). The dotted black line in each plot shows the indifference point. The solid gray line in each plot shows the mean incremental (net) cost. Negative incremental costs indicate that routine HbA1c screening is less costly than no screening and vice versa. Routine HbA1c screening in THA patients with DM on average saves money. Routine HbA1c screening in TKA patients with DM or total joint arthroplasty patients without a history of DM does not save money on average.



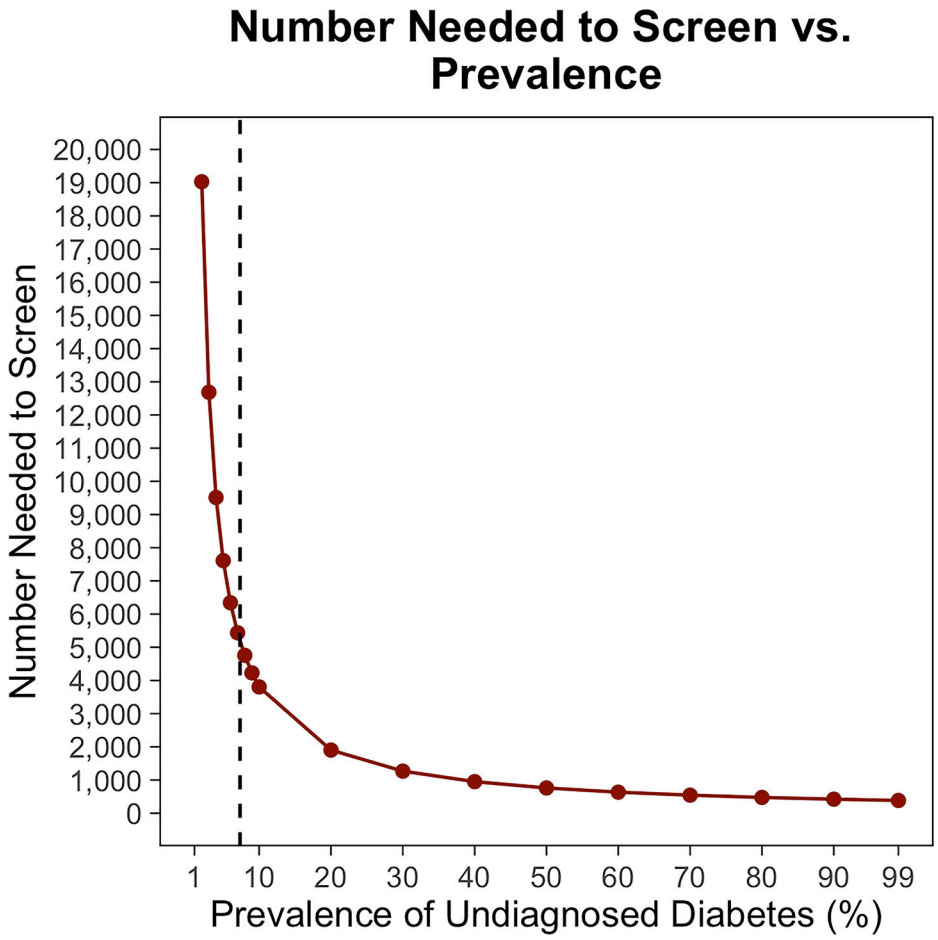


Figure 4.

In total hip arthroplasty (THA) patients with no history of diabetes mellitus (DM), the relationship between prevalence of undiagnosed diabetes and incremental cost per patient of routine hemoglobin A1c (HbA1c) screening (A) andnumber needed to screen to prevent a single periprosthetic joint infection (PJI) (B). The vertical dotted lines show the base case. The horizontal dotted line indicates the indifference point. Negative incremental costs indicate that routine HbA1c screening is less costly than no screening and vice versa. As the prevalence of undiagnosed DM increases, routine HbA1c screening in THA patients with no history of DM saves more money and the number needed to screen to prevent a single PJI decreases.

Table 1.

Model Input Parameters.

	Input parameter	Estimate (95% CI)	Reference
Probabilities	Prevalence of undiagnosed DM in TJA population		
	Total hip arthroplasty	52/709	33
	Total knee arthroplasty	71/574	33
	Prevalence of uncontrolled diabetes in patients with DM		
	HbA1c ≥7%	7,571/21,005	24,42,50
	HbA1c ≥8%	146/1,645	24
	Ratio of uncontrolled diabetes† in patients with no history of DM compared to patients with DM	0.746 (0.598 – 0.930)	39
	Probability of PJI		
	Baseline, all		
	Total hip arthroplasty	15/5,060	11
	Total knee arthroplasty‡	69/6,859	11
	Patients with controlled DM		
	Total hip arthroplasty	69/6,859	22
	Total knee arthroplasty‡	147/14,921	23
	Relative risk of PJI with uncontrolled DM		
	Total hip arthroplasty	2.6 (1.9 – 3.4)	22
	Total knee arthroplasty	1.7 (1.2 – 2.4)	23
	Probability of intervention success		
	HbA1c target <7%	35/59	37
	HbA1c target <8%	21/30	37
Costs	Cost of primary TJA	$21,106	CMS
	Cost of HbA1c test	$9.71	CLFS
	Cost of glycemic intervention		
	Evaluation and management*	$76.15	CMS
	Medical nutrition initial evaluation	$38.25	CMS
	Medical nutrition follow-up	$33.20	CMS
	Medical nutrition group session	$17.32	CMS
	Metformin 500 mg (8-month supply)	$12.20	FSS
	Cost of two-stage revision		
	Hip	$59,714 (56,421 – 64,189)	51
	Knee	$58,211 (55,463 – 62,420)	51

†Calculated using their data.

[‡]Since the estimate for rate of PJI in patients with controlled DM is similar to the baseline rate, the authors used the same lower estimate for both inputs in the analysis of patients with no known history of DM.

[*]By primary care physician or endocrine specialist.

CI, confidence interval. DM, diabetes mellitus. HbA1c, hemoglobin A1c. TJA, total joint arthroplasty. PJI, periprosthetic joint infection. CMS, Centers for Medicare and Medicaid Services. CLFS, Clinical Lab Fee Schedule. FSS, Federal Supply Schedule.

Table 2.

Costs and outcomes of HbA1c screening strategies.

	Strategy*	Cost	Probability of PJI	Number needed to screen†
Total hip arthroplasty	*Patients with diabetes mellitus*			
	No HbA1c screening	$22,059	1.5962%	-
	Routine HbA1c screening	$21,979	1.2460%	286
	Patients with no history of diabetes mellitus			
	No HbA1c screening	$21,333	0.0038%	-
	Routine HbA1c screening	$21,338	0.0036%	5,189
Total knee arthroplasty	*Patients with diabetes mellitus*			
	No HbA1c screening	$21,830	1.2429%	-
	Routine HbA1c screening	$21,869	1.0900%	654
	Patients with no history of diabetes mellitus			
	No HbA1c screening	$21,693	1.0091%	-
	Routine HbA1c screening	$21,706	0.9949%	7,046

PJI, periprosthetic joint infection. HbA1c, hemoglobin A1c.

*All strategies include screening and subsequent glycemic intervention.

†Number needed to screen to prevent a single PJI.

Table 3.

Sensitivity of results to probability of achieving HbA1c target of less than 7% in patients with diabetes mellitus.

Probability of achieving HbA1c <7%	Incremental cost per patient		Number needed to screen to prevent one PJI	
	THA	TKA	THA	TKA
1%	$125	$127	16,944	38,805
10%	$93	$113	1,694	3,880
20%	$58	$98	847	1,940
30%	$23	$83	565	1,293
40%	−$13	$68	424	970
50%	−$48	$53	339	776
60%	−$83	$38	282	647
70%	−$118	$23	242	554
80%	−$153	$8	212	485
90%	−$189	−$7	188	431
100%	−$224	−$22	169	388

HbA1c, hemoglobin A1c. PJI, periprosthetic joint infection. THA, total hip arthroplasty. TKA, total knee arthroplasty. Negative incremental costs indicate that HbA1c screening is less costly than no screening and vice versa.