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A United States Medicare Population–Based Cost-Effectiveness Analysis of Cemented Stem Fixation When Treating Femoral Neck Fractures

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ABSTRACT

Background: The number of hip fractures in the United States continues to increase each year. Current guidelines recommend cemented femoral fixation when performing hemiarthroplasty (HA) and total hip arthroplasty (THA). Yet, more than half of femoral neck fractures in older patients are treated with cementless femoral fixation in the United States. This study examined the costs and quality-adjusted life years of cemented and cementless femoral fixation for HA and THA procedures at the population level in the United States using data from the American Joint Replacement Registry.

Methods: A Markov model was created for 11,339 Medicare patients aged 65 to 74, 75 to 84, and 85-plus years in the American Joint Replacement Registry. We simulated the expected impact on costs and health outcomes over five years if all patients received the same femoral fixation method for both HA and THA based on age. Revision, dislocation, and mortality rates, costing data, and health utilities from registry data and published literature were used to populate the model. We simulated outcome uncertainty with probabilistic sensitivity analysis.

Results: By switching entirely to cemented fixation, Medicare can achieve annual cost savings for these patients of $5.0 million (95% uncertainty interval [UI]: −$0.6 to $8.0 million) and 1,356 (95% UI: −618 to 3,362) quality-adjusted life years. Cost-effectiveness was observed in 92% of simulations. Extrapolated over the annual incidence of hip fractures treated with arthroplasty in the US Medicare population, this could equate to $126.6 million (95% UI: −$15.0 to $201.2 million) in annual cost savings.

Conclusions: Cementless fixation remains the dominant mode of fixation for hip fractures in the United States. This cost-effectiveness study suggests potential cost savings and improved quality of life from switching to cemented femoral fixation for femoral neck fractures for both HA and THA, primarily due to lower postoperative complication rates.

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Femoral neck fractures (FNFs) have reached epidemic proportions in the United States, with an estimated 300,000 annual cases expected by 2030 [1]. Hip fracture is more common in older patients, and incidence is expected to increase considerably as the population ages [2,3]. Compared to other developed countries, the United States spends considerably more per patient on treating hip fracture [1,4]. This makes it crucial to assess how the health burden and costs of hip fracture management can be reduced through existing strategies.

The decision of whether to perform cemented or cementless (press-fit) fixation of the femoral stem for FNFs has been the subject of considerable debate [5]. Increasingly, studies report lower rates of revision surgeries [6], periprosthetic fractures [7,8], and costs [9] following cemented femoral fixation when compared to cementless fixation. Older fracture patients are particularly likely to experience a greater rate of complications from cementless femoral stems [10]. Yet, cementless fixation remains the more common approach in the United States; the 2024 report from the American Joint Replacement Registry (AJRR) shows that in patients aged 80 years and older, more than half of the patients received a cementless femoral stem [11].

Surgeons in the United States may prefer cementless stems for a variety of reasons or may be unfamiliar with techniques required for cemented procedures [12,13]. However, concerns that cemented femoral fixation is associated with increased postoperative mortality have been unsupported by evidence [14], and practice guidelines recommend cemented stems in fracture patients [15,16]. As the prevalence and costs of fractures continue to increase, it is timely to assess whether adherence to these guidelines would lead to changes in costs and outcomes at the population level. Studies have not yet examined the economic impact of shifting toward cemented femoral fixation in older fracture patients in the United States, where cementless femoral fixation predominates.

We conducted a population-level simulation study to estimate the incremental changes to costs and quality of life associated with providing entirely cemented or entirely cementless arthroplasty for FNF in a Medicare population. We compared these policies to the baseline of current rates of cemented and cementless procedures in patients aged > 65 years. We estimated the impact on the US health care system in terms of costs and quality-adjusted life years (QALYs) to assess whether a shift toward a standard fixation type could reduce costs and improve patient outcomes.

Methods

This study used nonidentifiable aggregate data or results from published literature and was thus exempt from institutional review board approval under Title 45 of the US Code of Federal Regulations section 46.104. The data and code are freely available at https://github.com/robinblythe/US_fixation_method, and a full list of model parameters is provided in the Supplement. The Consolidated Health Economic Evaluation Reporting Standards checklist can be found in the Supplement.

Study Population and Data Collection

While the AJRR does not contain economic data, registries are useful for economic modeling [17] as they can be used to combine observed rates with published literature to estimate cost-effectiveness [9]. We obtained aggregated data from the AJRR database for all US Medicare patients aged $\geq$ 65 years who underwent hemiarthroplasty (HA) or total hip arthroplasty (THA) for FNF from January 1, 2019, to December 31, 2019.

Table 1
Number of Primary Arthroplasty Procedures for Femoral Neck Fractures in 2019 for Hemiarthroplasty and Total Hip Arthroplasty in the American Joint Replacement Registry (AJRR), Split by Fixation Method and Age Group.

Procedure	Fixation Method	Age 65 to 74 years	Age 75 to 84 years	Age ≥85 years
Hemiarthroplasty	Cemented	565	1,489	2,279
	Cementless	925	1,847	2,077
Total hip arthroplasty	Cemented	138	169	131
	Cementless	815	649	255

In most instances, AJRR data are collected through a secure American Academy of Orthopaedic Surgeons (AAOS) Registry Program web-based data portal and harvested in real-time on a recurring basis from hospital information technology applications that meet registry specifications. Inclusion within the AJRR is determined by the presence of specific procedure codes or types of procedures performed that match approved codes listed in the AJRR data specifications. All procedures are assigned a unique case identifier, which allows for the collation of demographics, procedural details, complications, and readmissions. All AJRR patients who underwent a primary hip joint arthroplasty or revision surgery were identified using International Classification of Diseases-10 and Current Procedural Terminology codes in both the AJRR and the Centers for Medicare & Medicaid Services (CMS) data set. Registry data are audited both internally and externally.

We stratified patients into three cohorts by age: 65 to 74 years, 75 to 84 years, and 85 years and over. For each age group, the following summary data were extracted from the registry: the prevalence of cemented and cementless HA and THA; annual mortality rates over five years; and annual all-cause revision rates (hereafter referred to simply as “revisions”) for cemented and cementless HA and THA over five years. We also obtained the average duration in minutes of both primary and revision surgeries for HA and THA. The number of surgeries performed by arthroplasty type, fixation method, and age are presented in Table 1.

Data Analyses

The purpose of economic models is often to combine information from multiple data sources to estimate the costs and health benefits of a policy when primary data are unavailable. We developed a Markov model in which patients probabilistically transition between different health states, including revision surgery and dislocation, based on their current health state [18]. Markov models assume a patient can only be in a single health state at a time, aggregating the costs and utilities accumulated by time spent in each health state. Different policies (cemented or cementless fixation) lead to different transition probabilities, costs, and outcomes, and the model compares the aggregated costs and QALYs for all patients over the model’s time horizon [18].

A time horizon of five years was selected based on the advanced age of the patient population. All Medicare patients who underwent a primary hip arthroplasty following FNF entered the simulation at the point of primary surgery. Patients could then probabilistically transition to various states: the postoperative stable state, dislocation, revision surgery, or death (Figure 1). As our data set did not contain dislocations or the outcome following dislocation, we were required to make the simplifying assumption that patients who underwent closed reduction returned to the stable state if dislocation occurred. For example, if a patient suffered a dislocation within the first year of the primary procedure and then recovered, they would spend the first year in the dislocation state before returning to the stable state in the second year.

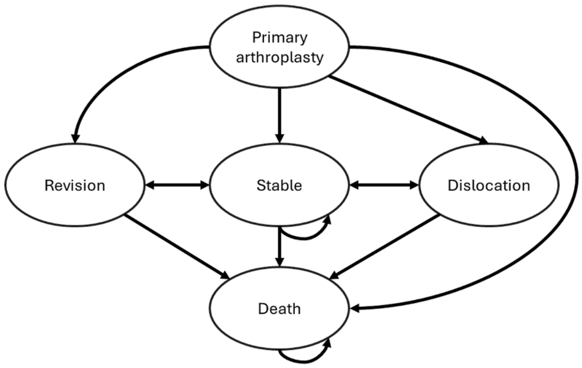

Figure 1. Markov model structure. Patients move from primary arthroplasty through the model over 5 years. Arrows denote possible patient transitions between states; patients cannot leave the death state once they have entered it.

The number of patients who underwent revision surgery in the following cycle for any reason would be based only on the number of patients who were in the stable state to avoid potential double counting from moving patients directly from dislocation to revision. Our model did not contain different causes for revision, as they were not able to be modeled due to the low frequency of each cause when stratified by age, arthroplasty, and fixation type.

A health care sector perspective was applied [19], in which costs reflect the direct costs of healthcare delivery, regardless of the payer, not including out-of-pocket costs. This was a cost-utility study; utility values are generally attributed to the patient regardless of the perspective applied.

As of 2023, there were 58.8 million Medicare beneficiaries aged ≥ 65 years according to the CMS [20]. Based on the estimated rate of hip fractures in the US Medicare population in 2023 [21], the number of Medicare FNF patients in 2023 was 286,861. We assumed that registry patients broadly represented the US Medicare population and extrapolated our results to national annual savings.

Model Inputs

Model inputs are summarised in Table 2. We obtained cost data from a combination of publicly available reports, published research, and correspondence with the AJRR. Implant costs were taken from the 2023 Hip and Knee Implant Review by Orthopedic Network News [22]. We averaged the cost of the top five constructs for HA and THA, which account for over 93% of all procedures, reflecting the mean cost of an implant at the population level. The costs of primary surgery were estimated by combining the cost per minute of operating theater (OT) time [23] with the number of minutes required for each surgery type by fixation method, the cost of each combination of prostheses (cemented, cementless, HA, THA), and any accessory products, including cement. Annual revision surgery costs based on Medicare claims data were obtained from Koenig et al. [24] using a weighted average of costs to incorporate variability from both septic and aseptic revisions. Dislocation and recovery costs were taken from Luzzi et al. [25]. All costs were converted to 2024 USD, and costs and QALYs were discounted at 3%, selected from the US consumer price index.

We attached distributions of utility values to each health state from published literature, assuming a constant health utility value

Table 2
Parameters Used in Economic Model.

Parameter	Estimate	Distribution	Source
Costs			
Minute of OT time	$46.04	Gamma (2.030, 22.675)	Smith et al. (2022)
Antibiotic cement (two packs)	$362.00	Fixed	Orthopedic Network News (2023)
Cement mixing towers	$100.00	Uniform (85, 115)	Orthopedic Network News (2023)
Cementless screw (each)	$53.00	Fixed	Orthopedic Network News (2023)
HA prosthesis (bipolar)	$2,390.50	Normal (2390.5, 262.246)	Orthopedic Network News (2023)
HA prosthesis (monopolar)	$1,658.50	Normal (1658.5, 129.085)	Orthopedic Network News (2023)
THA prosthesis (cemented)	$4,388.00	Normal (4388.0, 164.219)	Orthopedic Network News (2023)
THA prosthesis (cementless)	$5,109.70	Gamma (123.206, 41.848)	Orthopedic Network News (2023)
Aseptic revision	$62,714.64	Gamma (1079.724, 56.392)	Koenig et al. (2018)
Infected revision	$94,068.87	Gamma (142.787, 639.616)	Koenig et al. (2018)
Dislocation	$17,417.00	Gamma (9.553, 1819.097)	Luzzi et al. (2018)
Probabilities			
Initial dislocation rates for cemented HA	0.029	Beta (252, 23,270)	Fu et a.l (2023)
Initial dislocation rates for cementless HA	0.086	Beta (117, 8342)	Fu et al. (2023)
Initial dislocation rates for cemented THA	0.025	Beta (33, 4035)	Heckmann et al. (2021)
Initial dislocation rates for cementless THA	0.046	Beta (102, 11,680)	Heckmann et al. (2021)
Annual probability increment of dislocation	0.005	Fixed	Poignard et al. (2011)
Number of cementless screws required (1, 2, or 3)	0.333	Dirichlet (0.55, 0.24, 0.21)	AJRR correspondence
Probability of revision THA without infection	0.891	Beta (702, 86)	Koenig et al. (2018)
Revision rates, years 1 to 5 after primary procedure	See Supplement	Beta distributions	AJRR correspondence
Duration of procedure in minutes			
Primary HA	78.4	Normal (78.400, 0.384)	AJRR correspondence
Primary THA	92.68	Normal (92.682, 0.887)	AJRR correspondence
Cement application	7.25	Gamma (32.478, 0.223)	Parker et al. (2010)
Health utilities			
Hip dislocation	0.379	Beta (9.77, 15.95)	Enocson et al. (2009)
Revision arthroplasty	0.350	Beta (36.94, 68.59)	Zampelis et al. (2014)
Stable cemented HA	0.660	Beta (97.973, 50.471)	Keating et al. (2006)
Stable cementless HA	0.580	Beta (48.651, 35.230)	Langslet et al. (2013)
Stable cemented THA	0.740	Beta (5468.776, 1921.462)	Pennington et al. (2013)
Stable cementless THA	0.730	Beta (5526.679, 2044.114)	Pennington et al. (2013)

Annual revision rates for each age group and arthroplasty type can be found in the code repository and supplement. Gamma distributions are represented by shape and scale parameters. All model inputs are estimated with uncertainty, which was propagated through to the results.
OT, operating theater; HA, hemiarthroplasty; THA, total hip arthroplasty; AJRR: American Joint Replacement Registry.

for the duration of each annual cycle. Health utility in the stable state, pertaining to a patient's quality of life after primary hip arthroplasty due to FNF, varied by procedure type and time elapsed since the primary procedure; utility in the stable state within the first year after the primary procedure was slightly lower than in the second through fifth years, reflecting improvements in health-related quality of life between the primary procedure and 12-month follow-up [26,27]. For hip dislocation, we used the utility estimate reported by Enocson et al. [28] of health utility measured at four months postsurgery in patients who experienced a single dislocation. The utility of the revision state was difficult to estimate, as waiting times for revision surgery are estimated to range up to six months [29], and patients likely suffer deteriorating quality of life while waiting [30]. We therefore used the pre-revision utility value reported by Zampelis et al. [31], assuming that patients returned to the stable state at the start of the following cycle. Death had a utility of zero.

Transition probabilities to model the movement between stable, revision, and death states were taken from AAOS registry data. All-cause annual mortality rates for each age group at each year following the primary procedure were included to avoid overestimation from assuming all patients survive to five years post-arthroplasty. Revision rates were calculated for each prosthesis type, age, and fixation method from AAOS data using the annual probability of revision observed for each year following the primary procedure. Similar to prior economic models [9], dislocation rates were obtained for each fixation type [32,33] and increased by 0.5% each year following the primary procedure [34]. Revision rates by group and year following primary surgery are shown in Figure S1.

Uncertainty Estimation

To reduce bias, economic models may apply distributions of likely values to represent uncertainty in selected parameters [35]. We applied probabilistic sensitivity analysis, sampling from a range of plausible distributions 50,000 times to propagate uncertainty through to the results. This method is commonly applied in economic studies, including those that assess cost-effectiveness in hip arthroplasty, to mitigate the potential bias in the choice of cost, utility, and transition probability inputs [36].

Transition probabilities and utility values were sampled from beta distributions. Probabilities of 0 cannot be obtained from a beta distribution, and rather than assume an event frequency when none were observed in the registry, we interpolated probabilities where possible and used Beta(0.1, 10,000) otherwise based on the number of patients who were in the registry. Parameter transformation was conducted using the ShinyPrior tool [37], a moment-based estimator, and the LaplacesDemon R package [38].

Cost-Effectiveness Analysis and Changes to Provider Time

Cost-effectiveness is typically measured by calculating the incremental costs and QALYs of some policy relative to the current state, then dividing incremental costs by QALYs gained. If this figure is less than some threshold value, it is cost-effective. We applied the most common willingness-to-pay per QALY threshold used by US cost-effectiveness analysis studies of $100,000 [39]. Where a policy is both cost saving and QALY gaining compared to the status quo, the policy is considered to "dominate" its alternative, and a rational decision maker should always choose to implement it [40].

A potential reason for the prevalence of cementless fixation is the shorter operating time, reported by Parker et al. to be 7.2 (95% confidence interval: 4.8 to 9.7) minutes per procedure [41]. We calculated the anticipated increase in OT time required to cement all hips for all Medicare patients and compared this to the change in OT time expected from a change in revision rates following a policy shift to cemented fixation. To illustrate changes in resource use, we multiplied the expected change in closed reductions of hip dislocations by the additional emergency department time required to perform the procedure and the emergency department waiting time for patients [42].

Results

Switching from current practice to cemented fixation across all 11,339 Medicare registry patients and age groups led to $5.0 million (95% uncertainty interval [UI]: −$0.6 to $8.0 million) saved and 1,356 (95% UI: −618 to 3,362) QALYs gained over five years. This equates to a savings of $441 (95% UI: −$52 to $701) per patient and a gain of 0.12 (95% UI: −0.1 to 0.3) QALYs. Probabilities of cost savings, QALY gains, and cost-effectiveness overall were 97, 92, and 92%, respectively (Table 3).

Switching to cementless fixation led to an increase in costs of $3.2 million (95% UI: −$0.5 to $4.9 million) and a loss of −1,142 (95% UI: −2,858 to 548) QALYs or a per-patient cost increase of $285 (95% UI: −$40 to $431) and a QALY loss of −0.1 (95% UI: −0.3 to 0.1). Probabilities of cost savings, QALY gains, and cost-effectiveness overall were 3, 9, and 9%, respectively (Table 3).

Our analysis showed that both overall and when stratified by age group, cemented fixation dominated both standard care and cementless fixation. Cemented fixation was more expensive at the point of primary surgery, despite the lower prosthesis costs compared to cementless stems, but these costs were nearly always outweighed by revision and dislocation costs. The exception was for patients aged $\geq$ 85 years, where the high baseline mortality rate meant that costs were largely determined by the initial cost of surgery. These results are presented in Table 3 and visualized in Figure 2. Results in other groups were primarily driven by higher revision rates, especially in the first year following cementless fixation (Figure S1).

Extrapolating results of cemented fixation nationally, assuming the registry represents 11,339/286,261 (4%) of CMS patients, we estimated annual cost savings of $126.6 million (95% UI: −$15.0 to $201.2 million) and QALY gains of 34,302 (95% UI: −15,644 to 85,056) for the Medicare program. Under a cementless fixation program, additional costs would be $81.8 million (95% UI: −$11.3 to $123.6 million) annually, with −28,880 (95% UI: −72.3 to 13.9 million) QALYs lost.

Impact on OT and Emergency Time

The trade-off between time spent cementing the femoral stem in OT and revisions showed that cementing all femoral stems would require an additional 769 (95% UI: 521 to 1,066) hours of OT time annually across 11,339 Medicare patients who were in the AJRR registry. However, this would be accompanied by an anticipated decrease of 114 (95% UI: 112 to 117) revision surgeries with a mean duration of around two hours, reducing the net time increase for cementing to around 541 hours. Clinicians would save 10 hours (95% UI: zero to 20) per year in time required for closed reductions of prosthesis dislocations, and patients would spend 358 (95% UI: 21 to 706) fewer hours in the emergency department each year.

Table 3
Incremental Cost and QALY Estimates by Fixation Method, Prosthesis Type, and Age Group.

Prosthesis	Age in years	Incremental Costs	Incremental QALYs	% Cost Saving	% QALY Gaining	% Cost-Effective
Cemented fixation						
Hemiarthroplasty	65 to 74	−$459,196	276.4	92.6	90.4	90.7
	75 to 84	−$1,907,301	504.9	99.2	90.5	91.1
	≥85	−$1,021,606	499.0	92.7	90.2	90.6
Total hip arthroplasty	65 to 74	−$1,107,065	39.5	98.5	98.4	99.5
	75 to 84	−$620,202	27.8	94.1	98.2	99.2
	≥85	$109,747	8.2	23.4	96.5	93.6
Cementless fixation						
Hemiarthroplasty	65 to 74	$280,482	−168.8	7.4	9.6	9.3
	75 to 84	$1,537,613	−407.0	0.8	9.5	8.9
	≥85	$1,120,963	−547.5	7.3	9.8	9.4
Total hip arthroplasty	65 to 74	$187,454	−6.7	1.5	1.6	0.5
	75 to 84	$161,501	−7.2	5.9	1.8	0.8
	≥85	−$56,380	−4.2	76.6	3.5	6.4

The three rightmost columns report the percentage of simulations that were cost-saving, led to a net increase in quality-adjusted life years, or were cost-effective relative to a willingness-to-pay threshold of USD 100,000.
QALY, quality-adjusted life year.

Discussion

This study suggests that, at a population level, cemented femoral fixation for FNF can lead to both cost savings and improved outcomes for US Medicare patients. While implant costs differ by fixation type, cost savings in the cemented groups were driven by the increase in revision and dislocation rates. For example, the revision rate nearly doubled in the age 75 to 84 years group as a consequence of moving from a default policy of cemented to cementless fixation. While we were not able to incorporate reasons for revision surgery in our model due to identifiability requirements and small sample sizes post-stratification, we were advised by the AAOS that infection was generally the most common reason for revision among all age groups. Periprosthetic fracture was a common factor in revisions of cementless but not cemented hips, potentially leading to differences in revision rates between the two groups (Figure S1) [43].

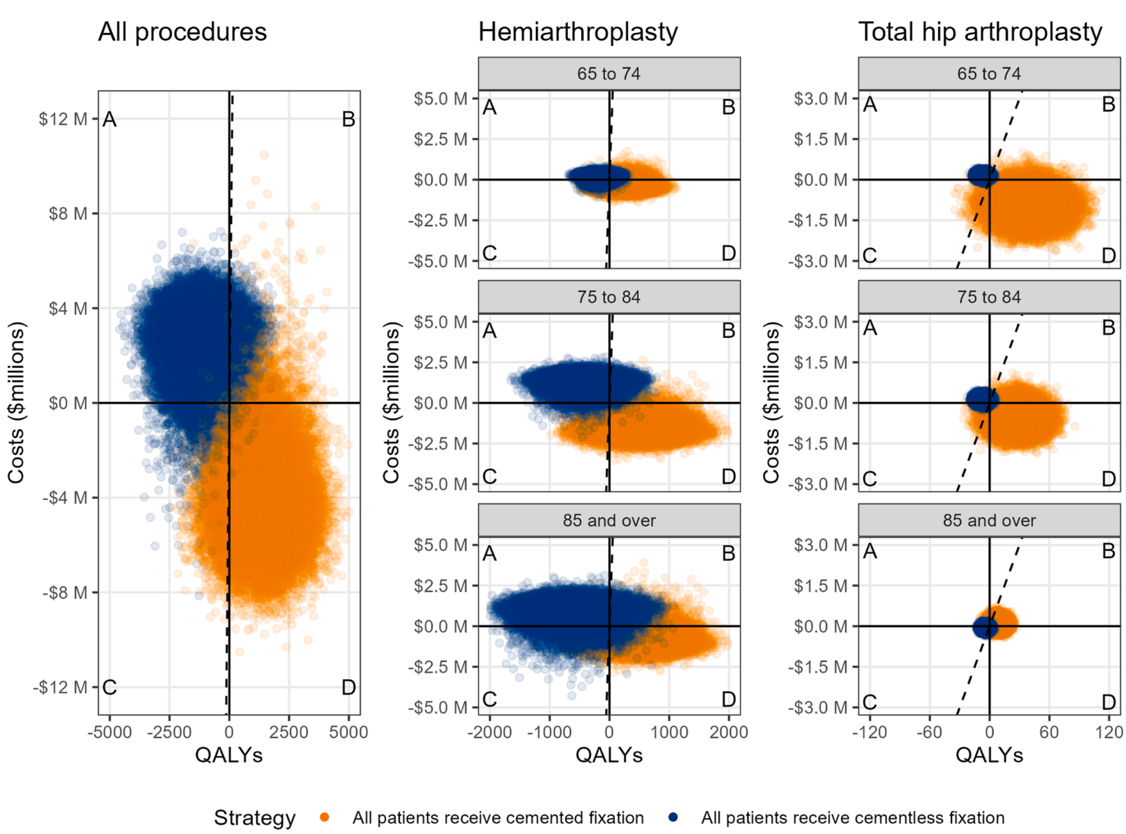

Figure 2. Cost-effectiveness of fixation policy overall (left column) and by prosthesis type and age (center and right columns). The dashed line denotes the willingness-to-pay threshold of USD 100,000. The panels in each graphic refer to different cost-effectiveness decisions. (A) More costly, less effective; (B) More costly, more effective; (C) Less costly, less effective; (D) Less costly, more effective. Note that the slope of the dashed line is the same in each panel, but the axes vary to improve legibility. QALY. Quality-Adjusted Life Year.

Our analysis shows that the time savings of cementless fixation are unlikely to outweigh the increased costs of revisions, as despite saving around 7 minutes per procedure on average, the overall costs to CMS resulting from the baseline level of cementless procedures could exceed $126 million annually. Based on these findings, payers should consider whether reimbursement for cementless hips should account for possible differences in revision rates. Guidelines produced by the National Institute on Health and Care Excellence in England and the AAOS in the United States strongly recommend cemented femoral fixation for geriatric FNF [15,16]; our results suggest this recommendation is cost-effective.

Surgeons may prefer cementless fixation due to a perception that cemented procedures have higher mortality than cementless procedures. However, these fears are not supported by evidence. Large registry studies have confirmed that there is insufficient evidence of an increase in mortality rate from cemented hip arthroplasty after adjusting for demographics and comorbidities [6,14]. Indeed, it is possible that mortality may be lower for patients who received cemented hips [44], potentially due to the association between revision surgery and morbidity and mortality [45]. We therefore suggest that concerns over increased mortality from the use of cement should not influence fixation type based on the current literature.

The prevalence of primary hip arthroplasty following hip fracture is expected to increase as the population continues to age [2]. As the number of HA and THA procedures increases, the number of revision surgeries will likely also increase. This is concerning for both health care providers and payers, as the increased demand is likely to be met by increasingly lower reimbursements from CMS [46]. Results from Acuña et al. show that after adjusting for inflation, reimbursement rates for both femoral and acetabular component revisions dropped by 27.5% from 2002 to 2019. A switch to cemented arthroplasty could help limit the effect of this phenomenon.

Potential Limitations

A potential limitation of our study was in the potential for confounding due to factors influencing the choice of fixation method. It was possible that the fixation choice may have been based on factors unrelated to the preferences of the patient or surgeon. Procedures may be chosen for patients based on their presurgical risk factors to minimize complications from cement or anesthesia time, potentially affecting our results; our model assumes that changes in costs and outcomes are solely due to fixation type rather than underlying risk factors. We were not able to obtain comorbidity data from the registry; however, based on results from Heckmann et al. [33], it is likely that patients who received cemented arthroplasty were older and more comorbid than those who received cementless arthroplasty. In addition, a randomized trial by Taylor et al. found that fracture patients who were randomized to cementless fixation experienced greater complication rates and worse Oxford hip scores, with no difference in postoperative mortality [47]. We welcome further randomized or causal inferential studies to investigate the potential impact of this confounder and note that greater certainty can be obtained through routine collection of QALYs in US surgical patients.

Our study specifically focused on revision and dislocation rates for hip fracture patients. Our results may not generalize to fixation method recommendations for osteoarthritis patients, who may experience different revision and dislocation rates, outcomes, and costs [48], or younger patients, who may have different treatment goals. Our article reflects the impact of the fixation method at the policy level for CMS, rather than as a treatment rule for individual patients.

Economic models typically require simplifying assumptions as results are extrapolated from summary data to population-level estimates. We applied data from multiple sources in our models, including published literature, and could not be certain that these parameters were truly reflective of the US Medicare population. This was mitigated by the use of sampling from model input distributions. Several of the model parameters, specifically on health utility and the increasing risk of dislocation over time, may have deviated between the date of this study and the date of previous research. Orthopaedic implants improving over time in terms of complication rates and comfort would therefore lead to the potential for bias in our study, and the orthopaedic literature should seek to continuously track health-related quality of life due to implant choice.

The AJRR captures all-cause revision and fixation of periprosthetic fractures; other methods are not captured. In addition, the AJRR only captures a segment of the arthroplasty population, as it is not a federally mandated registry. However, in a representative analysis with the AJRR and the National Inpatient Sample study comparing demographics, it was deduced that the AJRR was generalizable among the US population [35].

Conclusions

At the population level, cemented fixation in US Medicare patients who undergo arthroplasty for FNF is likely cost-effective, leading to lower costs and better patient outcomes.

CRediT authorship contribution statement

Robin Blythe: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Antonia F. Chen:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Nicholas Graves:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Ayushmita De:** Writing – review & editing, Writing – original draft, Project administration, Data curation. **Kimberly R. Porter:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Ross Crawford:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Bryan D. Springer:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation, Conceptualization.

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Appendix

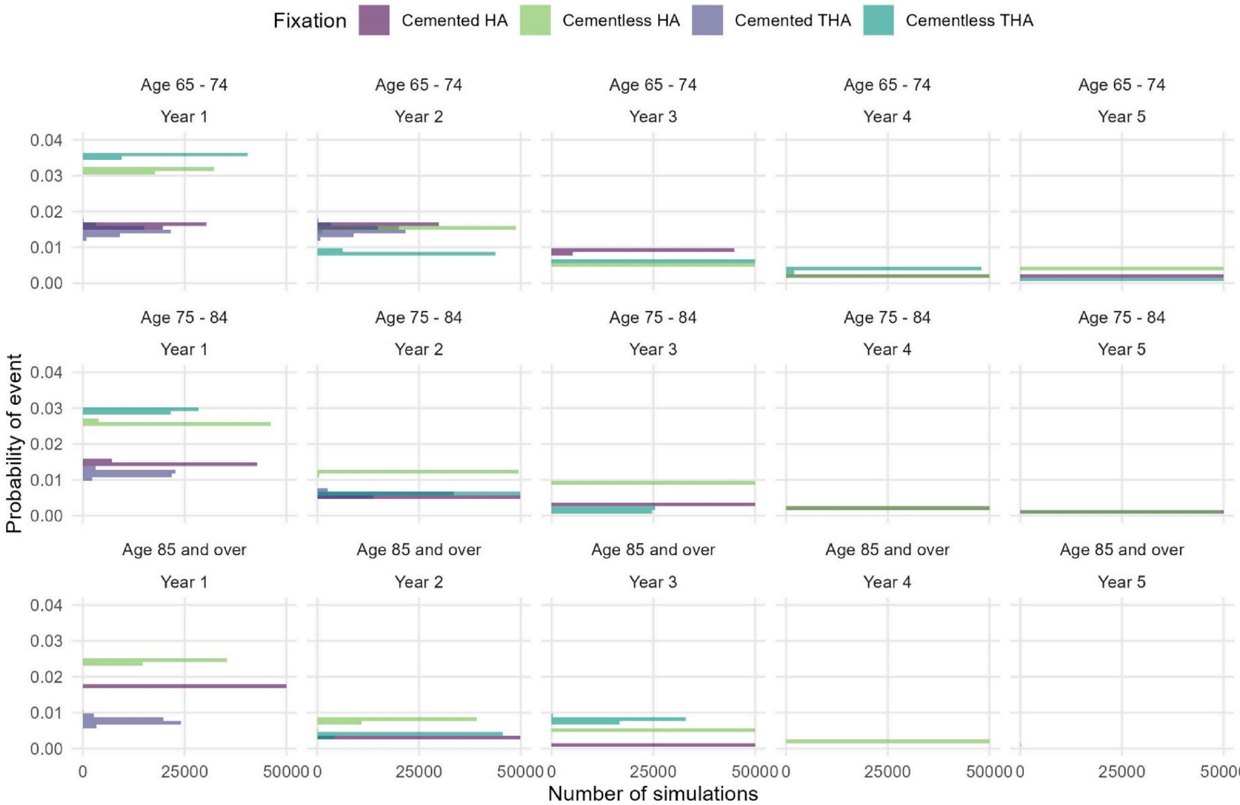

Figure S1. Revision rates by age category and year. Colors denote fixation type. HA, hemiarthroplasty; THA, total hip arthroplasty.