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Risk of Aseptic Revision and Periprosthetic Fracture Following Bipolar Versus Unipolar Hemiarthroplasty

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Background: Hemiarthroplasty is currently the most common treatment for displaced femoral neck fractures in the elderly. While bipolar hemiarthroplasty was developed to reduce the risk of acetabular erosion that is associated with traditional unipolar hemiarthroplasty, meta-analyses have reported similar outcomes for bipolar and unipolar hemiarthroplasty devices. The primary objective of this study was to evaluate the risks of aseptic revision and periprosthetic fracture following bipolar versus unipolar hemiarthroplasty in a large integrated health-care system in the United States.

Methods: We conducted a retrospective cohort study using data from the hip fracture registry of an integrated health-care system. Patients aged ≥60 years who underwent hemiarthroplasty for hip fracture between 2009 and 2019 were included. The primary outcome measure was aseptic revision, and the secondary outcome measure was revision for periprosthetic fracture. Cause-specific Cox proportional hazards regression was performed, with mortality considered as a competing event. In the multivariable analysis, estimates were adjusted for potential confounders such as age, sex, race/ethnicity, body mass index, American Society of Anesthesiologists classification, femoral fixation, surgeon volume, type of anesthesia, and discharge disposition.

Results: The study sample included 13,939 patients who had been treated with hemiarthroplasty by 498 surgeons at 35 hospitals. The mean follow-up time was 3.7 ± 2.9 years. The overall incidence of aseptic revision at 5 years following hemiarthroplasty was 2.8% (386). In the multivariable analysis controlling for potential confounders, bipolar hemiarthroplasty was associated with a lower risk of aseptic revision than unipolar hemiarthroplasty (hazard ratio [HR], 0.74; 95% confidence interval [CI], 0.59 to 0.94; p = 0.012). Rates of revision for periprosthetic fracture were similar between the bipolar and unipolar devices (HR, 0.79; 95% CI, 0.58 to 1.10; p = 0.16).

Conclusions: In this study of hemiarthroplasty for hip fracture in elderly patients, bipolar designs were associated with a lower risk of aseptic revision than unipolar designs. In contrast to prior research, we did not find any difference in the risk of periprosthetic fracture between the 2 designs.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

In elderly patients who sustain a displaced femoral neck fracture, arthroplasty is now considered the standard of care[1]. While the proportion of femoral neck fractures treated with total hip arthroplasty is increasing, hemiarthroplasty remains the most common treatment for older patients who sustain a displaced femoral neck fracture[2,3].

In order to reduce the risk of acetabular erosion associated with traditional unipolar hemiarthroplasty devices, bipolar devices, which feature an internal articulation between the femoral stem and the prosthetic head, were developed. However, in vivo studies have suggested that the internal articulation of bipolar devices may become fixed shortly after implantation, causing motion to occur primarily at the interface between the implant and acetabulum[4,5]. In addition, meta-analyses have generally found bipolar and unipolar hemiarthroplasty devices to be associated with similar rates of reoperation[6-9].

Recently, investigators utilized the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) to analyze 62,875 hemiarthroplasty procedures over a longer period of follow-up (range, 0 to 18 years)[10]. The authors found unipolar hemiarthroplasty to be associated with a higher rate of revision at >2.5 years (hazard ratio [HR], 1.86; 95% confidence interval

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A527).

[CI], 1.46 to 2.36; p < 0.001). However, they also found unipolar hemiarthroplasty to have a lower risk of revision for periprosthetic fracture at all time points (HR, 0.72; 95% CI, 0.59 to 0.87; p < 0.001).

The primary objective of our study was to compare the risks of aseptic revision and revision for periprosthetic fracture following bipolar versus unipolar hemiarthroplasty. The null hypothesis was that there would be no significant difference between unipolar and bipolar hemiarthroplasty for either aseptic revision or periprosthetic fracture. The secondary objective of this study was to determine the factors associated with aseptic revision following hemiarthroplasty in a large integrated health-care system in the United States.

Materials and Methods

Data Source

This retrospective cohort study used data obtained from the Kaiser Permanente Hip Fracture Registry, which records data on all hip fracture procedures performed in the integrated health-care system. This system covers >12 million members throughout 8 geographic regions in the U.S. and has been shown to be demographically and socioeconomically representative[11,12]. The registry data collection procedures and validation processes have been previously described[13-15]. Briefly, this surveillance tool collects detailed patient-, procedure-, implant-, and surgeon-related information, which is supplemented by integrated electronic health record (EHR) data, administrative claims data, membership data, and mortality records. Outcomes are monitored over time using electronic screening algorithms, and they are validated by trained research associates using the EHR. The registry's coverage includes 100% of the hip fracture procedures performed in Kaiser Permanente hospitals. Once entered into the registry, all of the patients are prospectively monitored until death or membership termination.

The study was approved by the Kaiser Permanente institutional review board and included an exemption from informed consent.

Inclusion and Exclusion Criteria

Patients who were aged ≥60 years and had undergone unilateral hemiarthroplasty for hip fracture at a Kaiser Permanente facility (Northern California, Southern California, Hawaii, and Northwest regions) between 2009 and 2019 were included in this study. Patients were excluded if they had metastatic cancer, a pathologic fracture, bilateral hip fracture, or prior surgery or infection in the affected hip. Patients were also excluded if information on the implant, medical comorbidities, or discharge disposition was missing (Fig. 1).

Outcomes of Interest

The primary outcome measure in this study was aseptic revision, which was selected as a clinically meaningful end point that could vary by implant type (bipolar versus unipolar). Aseptic revision was defined as any reoperation performed after the index procedure that involved an implant exchange for a reason other than infection. The secondary outcome measure

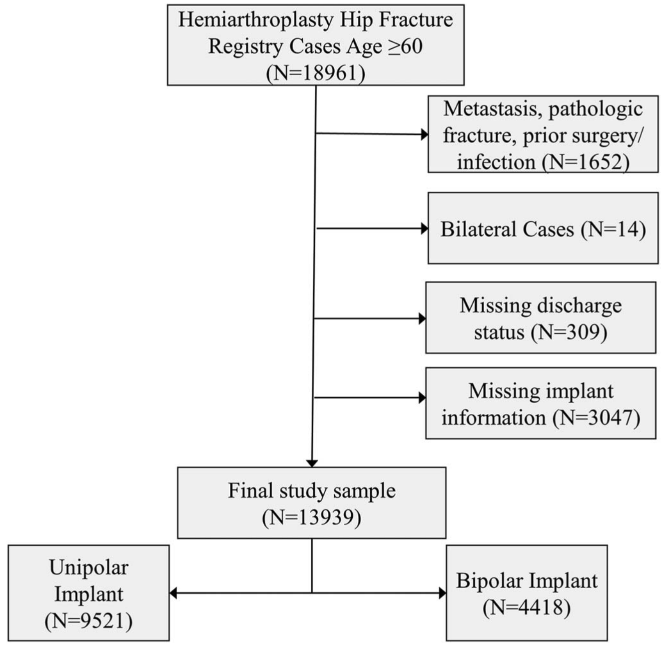

Fig. 1

Inclusion and exclusion criteria.

was revision specifically for periprosthetic fracture. Aseptic revision and revision for periprosthetic fracture were manually validated via medical record review by trained research associates to ensure accuracy, and patients were continuously followed until membership termination, death, or the end date of the study (March 31, 2020).

Exposure of Interest

The hemiarthroplasty implant type, which was categorized as unipolar or bipolar, was the exposure of interest. Implant information is recorded in the EHR at the time of surgery using barcodes, after which it is collected by the registry.

Covariates

The registry was used to identify and examine the following covariates: age group (60 to 69, 70 to 79, or ≥80 years); sex (male or female), race/ethnicity (non-Hispanic White [hereafter termed White], Black, Hispanic, Asian, or other), body mass index (BMI, <22, 22.0 to 24.9, 25.0 to 29.9, or ≥30 kg/m^2), smoking status (never, current or former, or unknown/other), American Society of Anesthesiologists (ASA) classification (1 or 2, ≥3, or unknown), femoral fixation (uncemented or cemented), time from admission to surgery (<24, 24 to 48, or >48 hours), type of anesthesia (general, regional, conversion from regional to general, or unknown), surgeon volume in the prior year (low [0 to 13 hip fracture procedures], medium [14 to 20 procedures], high [≥21 procedures], or unavailable); and discharge disposition (home or skilled nursing/other facility).

To estimate annual household income and educational attainment, we used the Geographically Enriched Member Sociodemographics (GEMS) datamart. The validity of using geocoding techniques to estimate the income and educational

TABLE I Patient Implant, Hospital, and Procedure Characteristics*

	Unipolar		Bipolar		Total	
Characteristic	N	%	N	%	N	%
Patient characteristics						
Age in yr						
60-69	798	8.4	390	8.8	1,188	8.5
70-79	2,276	23.9	1,193	27.0	3,469	24.9
≥80	6,447	67.7	2,835	64.2	9,282	66.6
Sex						
Female	6,614	69.5	3,060	69.3	9,674	69.4
Male	2,907	30.5	1,358	30.7	4,265	30.6
Race/ethnicity						
White	7,830	82.2	3,419	77.4	11,249	80.7
Black	473	5.0	143	3.2	616	4.4
Hispanic	604	6.3	492	11.1	1,096	7.9
Asian	614	6.5	364	8.2	978	7.0
Educational attainment†						
Some high school or less	1,159	12.2	585	13.2	1,744	12.5
High school diploma	1,988	20.9	958	21.7	2,946	21.1
Some college or associate degree	2,996	31.5	1,339	30.3	4,335	31.1
Bachelor's degree or more	3,378	35.5	1,536	34.8	4,914	35.2
Annual income†						
<$25,000	1,549	16.3	685	15.5	2,234	16.0
$25,000-$49,999	1,905	20.0	822	18.6	2,727	19.6
$50,000-$74,999	1,652	17.4	756	17.1	2,408	17.3
$75,000-$149,999	2,854	30.0	1,373	31.1	4,227	30.3
≥$150,000	1,561	16.4	782	17.7	2,343	16.8
BMI in kg/m^2						
<22	3,679	38.6	1,600	36.2	5,279	37.9
22.0-24.9	2,579	27.1	1,190	26.9	3,769	27.0
25.0-29.9	2,431	25.5	1,182	26.8	3,613	25.9
≥30.0	741	7.8	413	9.4	1,154	8.3
Missing	91	1.0	33	0.8	124	0.9
Smoking status						
Never	4,969	52.2	2,358	53.4	7,327	52.6
Current or former	4,377	46.0	1,972	44.6	6,349	45.5
Unknown/other	175	1.8	88	2.0	263	1.9
ASA classification						
1 or 2	2,022	21.2	1,009	22.8	3,031	21.7
≥3	6,945	72.9	3,072	69.5	10,017	71.9
Unknown	554	5.8	337	7.6	891	6.4
No. of Elixhauser comorbidities						
0	194	2.0	111	2.5	305	2.2
1	639	6.7	290	6.6	929	6.7
2	1,100	11.6	483	10.9	1,583	11.4
3	1,388	14.6	670	15.2	2,058	14.8
4	1,579	16.6	714	16.2	2,293	16.5
≥5	4,621	48.5	2,150	48.7	6,771	48.6
Implant characteristics						
Femoral fixation						
Uncemented	4,490	47.2	2,228	50.4	6,718	48.2
Cemented	5,031	52.8	2,190	49.6	7,221	51.8

continued

TABLE I (*continued*)

Characteristic	Unipolar		Bipolar		Total	
	N	%	N	%	N	%
Hospital and procedure-related factors						
Time from admission to surgery						
<24 hr	2,215	23.3	985	22.3	3,200	23.0
24-48 hr	6,693	70.3	3,185	72.1	9,878	70.9
>48 hr	613	6.4	248	5.6	861	6.2
Type of anesthesia						
General	2,449	25.7	984	22.3	3,433	24.6
Conversion from regional to general	3,127	32.8	1,349	30.5	4,476	32.1
Regional	3,943	41.4	2,084	47.2	6,027	43.2
Unknown	2	0.02	1	0.02	3	0.0
Surgeon volume (prior year)						
Low (0-13)	2,287	24.0	1,279	29.0	3,566	25.6
Medium (14-20)	1,878	19.7	1,178	26.7	3,056	21.9
High (≥21)	4,090	43.0	1,321	29.9	5,411	38.8
Unavailable	1,266	13.3	640	14.5	1,906	13.7
Discharge disposition						
Home	2,220	23.3	917	20.8	3,137	22.5
Skilled nursing/other facility	7,301	76.7	3,501	79.2	10,802	77.5
Total	9,521	100.0	4,418	100.0	13,939	100.0

*BMI = body mass index, and ASA = American Society of Anesthesiologists. †Probability from household information in census.

attainment of managed health-care system members has been established previously[16]. For household income, ZIP codes were used for all patients to estimate the probability that their annual income fell into the following categories: <$25,000, $25,000 to $49,999, $50,000 to $74,999, $75,000 to $149,999, or ≥$150,000. Likewise, census tracts were used for each patient to estimate the probability that educational attainment fell into the following 4 categories: some high school or less, high school graduate, some college or an associate degree, or a bachelor's degree or more. Reference levels were set at the national average ($50,000 to $74,999 for annual household income, and high school graduate for educational attainment).

We used the Elixhauser Comorbidity Index to assess for the following comorbidities in the year prior to the hemiarthroplasty procedure: alcohol abuse, anemia, chronic pulmonary disease, coagulopathy, congestive heart failure, dementia, depression, diabetes mellitus, drug abuse, fluid or electrolyte disorder, hypertension, hypothyroidism, liver disease, neurological disorders, paralysis, Parkinson disease, peripheral vascular disease, pulmonary circulation disease, psychosis, renal insufficiency, rheumatoid arthritis, solid tumor without metastasis, valvular disease, and weight loss[17,18].

Statistical Analysis

Categorical data were summarized using absolute frequencies and percentages. We first assessed the effect of hemiarthroplasty implant type (bipolar versus unipolar) on aseptic revision, using a cause-specific multivariable Cox proportional hazards model. Aseptic revision and mortality were regarded as competing events and modeled as time-to-event outcomes using cause-specific Cox proportional hazards regression. Patients who underwent septic revision or membership termination, or reached the study end date, were censored. In the multivariable analysis of aseptic revision, estimates were adjusted for the following potentially confounding factors: age, sex, race/ethnicity, BMI, ASA classification, Parkinson disease, alcohol abuse, anemia, femoral fixation, surgeon volume, type of anesthesia, and discharge disposition. Covariates were considered to be potentially confounding factors if they changed risk estimates by >10% or were deemed to be clinically relevant a priori. We adjusted for correlations among hemiarthroplasty procedures performed by the same operating surgeon through a robust covariance matrix estimator in a marginal model that grouped patients from the same operating surgeon in a cluster. This process was repeated to evaluate revision that was specifically due to periprosthetic fracture. The Gray test was used to evaluate the cause-specific cumulative incidence functions for the hemiarthroplasty implant types (unipolar and bipolar) by outcome, with adjustment for age and type of femoral fixation (uncemented or cemented).

In the analysis of factors that were potentially associated with aseptic revision (predictor analysis), univariate statistics were calculated for each predictor category with ≥5 events. Implant design as well as all previously specified covariates were considered. Predictors were fitted with a full time-dependent Cox proportional hazards regression model; HRs and 95% CIs were determined. The cause-specific hazards

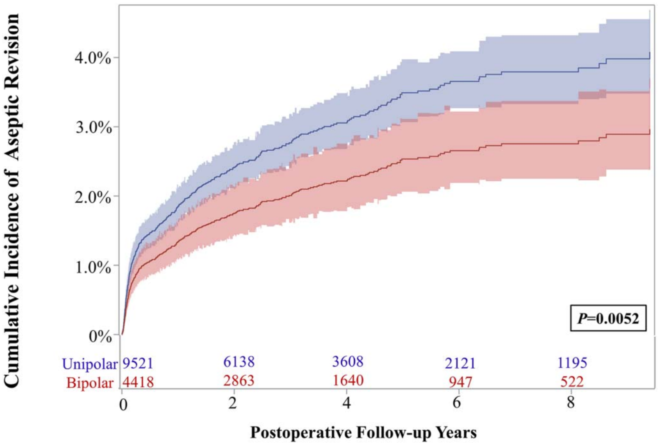

Fig. 2
Cause-specific cumulative incidence of aseptic revision by hemiarthroplasty implant type (2009 to 2019). Shading indicates the 95% CI.

model enabled estimation of the association between predictors and aseptic revision in patients who were currently event-free (i.e., patients who were still alive and had not undergone revision surgery). Model fit was assessed using a stepwise methodology for selection of the best subset of predictors as indicated by the delta AIC (change in Akaike information criterion compared with a full model containing all predictors). Predictors were added until the decrease in the delta-AIC value compared with the prior model was no longer >2. The prior model, considered to represent the set of independent predictors that gave the best fit, was then chosen as the final model. Results from the final multivariable model are presented below.

The correctness of the proportional hazards assumption was assessed in each analysis by incorporating an interaction term between time and each modeled variable. A violation of the proportional hazards assumption would be indicated if the interaction was significant ($p < 0.05$). Missing data for categorical variables were analyzed as a separate category. Data analysis was performed using SAS Enterprise Guide (version 7.13; SAS Institute). All of the tests were 2-sided, and significance was defined as $p < 0.05$.

Source of Funding

There was no external funding source for this study.

Results

The study sample included 13,939 patients who had been treated with hemiarthroplasty by 498 surgeons at 35 hospitals. Two-thirds of patients were aged ≥80 years (66.6%; 9,282), and 69.4% of patients (9,674) were female. The majority of patients (71.9%; 10,017) had an ASA classification of ≥3. The hemiarthroplasty implant was unipolar in 68.3% (9,521) and bipolar in 31.7% (4,418). Cemented fixation was used in 51.8% (7,221) of the procedures (Table I). The distribution of Elixhauser comorbidities is listed in Appendix Table I, and the most common femoral stems that are utilized are listed in Appendix Table II. The mean (and standard deviation) follow-up time was 3.7 ± 2.9 years.

The overall incidence of aseptic revision at 5 years after hemiarthroplasty was 2.8% (386 of 13,939), including 4.5% (95% CI, 3.4% to 5.8%) for patients aged 60 to 69 years, 3.2% (95% CI, 2.6% to 3.8%) for patients aged 70 to 79 years, and 2.4% (95% CI, 2.1% to 2.7%) for patients aged ≥80 years. The average time to aseptic revision (and standard deviation) was 1.2 ± 1.7 years. Figure 2 shows the adjusted incidence of aseptic revision during follow-up by implant type. In the multivariable analysis that adjusted for potential confounders, bipolar hemiarthroplasty was associated with a lower risk of aseptic revision compared with unipolar hemiarthroplasty (HR, 0.74; 95% CI, 0.59 to 0.94; p = 0.012) (Table II).

The rate of periprosthetic fracture during follow-up was 1.4% (193 of 13,939), and the average time to fracture was 1.3 ± 1.9 years. Figure 3 shows the adjusted incidence of revision for periprosthetic fracture during follow-up by implant type. In the multivariable analysis, there was no difference between bipolar and unipolar hemiarthroplasty with regard to periprosthetic fracture (HR for bipolar, 0.79; 95% CI, 0.58 to 1.10; p = 0.16) (Table III).

In the predictor analysis of aseptic revision, bipolar hemiarthroplasty and cemented fixation were associated with a lower risk, while alcohol abuse, depression, and psychosis were associated with a higher risk (Table IV).

Discussion

In this study of nearly 14,000 hemiarthroplasty procedures in elderly individuals enrolled in a large integrated health-care system in the U.S., the overall rate of aseptic revision was 2.8%

TABLE II Association Between Bipolar Versus Unipolar Hemiarthroplasty and Aseptic Revision in Patients Undergoing Hemiarthroplasty for Hip Fracture (N = 13,939)

		Univariate Analysis		Multivariable Analysis*	
Implant Type	Crude Rate of Aseptic Revision	Hazard Ratio (95% CI)	P Value	Hazard Ratio (95% CI)	P Value
Bipolar	2.2% (99/4,418)	0.75 (0.59-0.94)	**0.012**	0.74 (0.59-0.94)	**0.012**
Unipolar	3.0% (287/9,521)	Reference		Reference	

*Adjusted for age, sex, race/ethnicity, body mass index, American Society of Anesthesiologists classification, Parkinson disease, alcohol abuse, anemia, femoral fixation, surgeon volume, type of anesthesia, and discharge disposition.

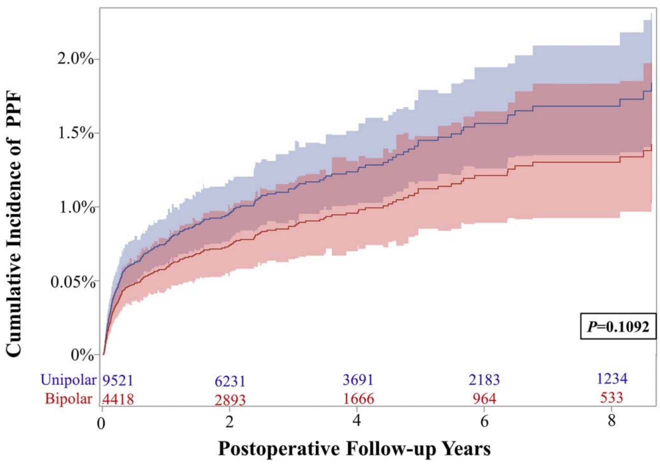

Fig. 3

Cause-specific cumulative incidence of periprosthetic fracture (PPF) by hemiarthroplasty implant type (2009 to 2019). Shading indicates the 95% CI.

at 5 years postoperatively. In comparison with unipolar devices, bipolar devices were associated with a lower risk of aseptic revision (HR, 0.74; 95% CI, 0.59 to 0.94; p = 0.012). With regard to revision for periprosthetic fracture, no difference in risk was observed between the 2 devices.

The rate of subsequent aseptic revision observed in this study (2.8%) is similar to the rate of 2.6% reported previously by investigators using the AOANJRR[10]. Even among the youngest individuals in this study (age 60 to 69 years at the time of hemiarthroplasty), the rate of aseptic revision was just 4.5% at 5 years postoperatively. This implies that if a surgeon in the health-care system deemed a patient to be suitable for hemiarthroplasty, it was unlikely that subsequent revision would be required.

Prior studies have also sought to compare the outcomes associated with bipolar and unipolar hemiarthroplasty implants. Zhou et al. conducted a meta-analysis of 8 randomized controlled trials (RCTs) comprising 1,100 patients; they detected no differences in postoperative Harris hip scores or reoperation[6]. Jia et al. analyzed 10 RCTs comprising 1,190 patients; they found bipolar hemiarthroplasty to be associated with better hip function and less pain, although there were no differences in the rate of reoperation[8]. In a meta-analysis of 6 RCTs comprising 982 patients, Yang et al. found bipolar hemiarthroplasty to be associated with a lower rate of acetabular erosion (1.2% versus 5.5%, p = 0.01); they also did not observe any differences in the rate of reoperation (p > 0.05)[7]. Similarly, Filippo et al. analyzed 27 studies (16 RCTs and 11 nonrandomized trials) that included 4,511 patients; they also found bipolar hemiarthroplasty to have a lower risk of acetabular erosion than unipolar hemiarthroplasty, but the rate of revision was similar[9].

More recently, Farey et al. used the AOANJRR to follow 62,875 hemiarthroplasty procedures. The authors argued that registry data could serve as an important adjunct to RCTs since the large number of patients, coupled with longer-term follow-up, had the potential to identify differences in outcomes that may occur infrequently and after several years. In their study, they found no difference in revision rates before 2.5 years (HR, 0.98; 95% CI, 0.85 to 1.13; p = 0.79), but there was a significantly higher risk of revision in the unipolar group after this time point (HR, 1.86; 95% CI, 1.46 to 2.36; p < 0.001)[10]. Our results are consistent with these prior findings: we also found bipolar hemiarthroplasty to be associated with a significantly lower risk of aseptic revision when compared with unipolar hemiarthroplasty.

Interestingly, Farey et al. also found bipolar hemiarthroplasty to be associated with a higher risk of revision for periprosthetic fracture when compared with unipolar hemiarthroplasty[10]. Leonardsson et al., reporting on 23,509 hemiarthroplasty procedures from the Swedish Hip Arthroplasty Register (2005 to 2010), likewise found bipolar designs to be associated with a higher risk of revision for periprosthetic fracture. However, the results of the latter study were somewhat atypical in that bipolar hemiarthroplasty was also found to be associated with higher rates of all-cause reoperation, reoperation for dislocation, and reoperation for infection[19]. The specific mechanisms by which bipolar hemiarthroplasty could increase the risk of periprosthetic fracture remain uncertain.

By contrast, in our study, bipolar hemiarthroplasty was not found to convey any added risk of periprosthetic fracture in comparison with unipolar hemiarthroplasty after controlling for potential confounders (e.g., cemented versus uncemented fixation of femoral implants). Additional research

TABLE III Association Between Bipolar Versus Unipolar Hemiarthroplasty and Periprosthetic Fracture in Patients Undergoing Hemiarthroplasty for Hip Fracture (N = 13,939)

		Univariate Analysis		Multivariable Analysis*	
Implant Type	Crude Rate of Periprosthetic Fracture	Hazard Ratio (95% CI)	P Value	Hazard Ratio (95% CI)	P Value
Bipolar	1.2% (52/4,418)	0.80 (0.58-1.10)	0.17	0.79 (0.58-1.10)	0.16
Unipolar	1.5% (141/9,521)	Reference		Reference	

*Adjusted for age, sex, race/ethnicity, body mass index, American Society of Anesthesiologists classification, Parkinson disease, alcohol abuse, femoral fixation, surgeon volume, and discharge disposition.

TABLE IV Predictors of Aseptic Revision in Patients Undergoing Hemiarthroplasty for Hip Fracture (N = 13,939)*

Characteristic	Crude Rate of Aseptic Revision	Univariate Analysis		Multivariable Analysis	
		Hazard Ratio (95% CI)	P Value	Hazard Ratio (95% CI)	P Value
Patient characteristics					
Age in yr					
60-69	4.5%	**1.73 (1.28-2.33)**	**<0.001**		
70-79	3.2%	**1.27 (1.01-1.59)**	**0.044**		
≥80	2.4%	Reference			
Sex					
Female	2.9%	1.13 (0.90-1.41)	0.30		
Male	2.5%	Reference			
Race/ethnicity					
White	2.9%	Reference			
Black	3.3%	1.16 (0.74-1.82)	0.53		
Hispanic	2.2%	0.77 (0.51-1.16)	0.21		
Asian	1.3%	**0.46 (0.27-0.81)**	**0.006**		
Educational attainment†					
Some high school or less	2.8%	0.86 (0.19-3.89)	0.84		
High school diploma	2.8%	Reference			
Some college or associate degree	2.7%	0.62 (0.14-2.80)	0.53		
Bachelor's degree or more	2.8%	1.03 (0.39-2.75)	0.95		
Annual income†					
<$25,000	2.8%	1.91 (0.41-9.04)	0.41		
$25,000-$49,999	2.9%	2.19 (0.33-14.7)	0.42		
$50,000-$74,999	2.8%	Reference			
$75,000-$149,999	2.8%	3.29 (0.66-16.4)	0.15		
≥$150,000	2.5%	1.11 (0.30-4.11)	0.88		
BMI in kg/m^2					
<22	2.4%	0.79 (0.61-1.02)	0.073		
22.0-24.9	3.0%	Reference			
25.0-29.9	2.9%	0.95 (0.73-1.24)	0.71		
≥30.0	3.4%	1.12 (0.78-1.61)	0.55		
Smoking status					
Never	2.7%				
Current or former	2.9%	1.11 (0.91-1.36)	0.31		
Unknown/other	1.1%	0.38 (0.12-1.18)	0.094		
ASA classification					
1 or 2	3.5%	Reference			
≥3	2.6%	**0.79 (0.63-1.00)**	**0.045**	0.82 (0.65-1.03)	0.081
Unknown	2.1%	**0.55 (0.34-0.89)**	**0.015**	**0.56 (0.35-0.92)**	**0.022**
No. of Elixhauser comorbidities					
0-1	3.1%	Reference			
2	3.2%	1.09 (0.72-1.66)	0.69		
3	3.1%	1.07 (0.71-1.59)	0.76		
4	2.6%	0.91 (0.61-1.37)	0.65		
≥5	2.6%	0.97 (0.68-1.38)	0.86		
Elixhauser comorbidities‡					
Alcohol abuse	4.0%	**1.55 (1.06-2.26)**	**0.023**	1.44 (0.99-2.11)	0.060
Anemia deficiencies	2.7%	0.97 (0.78-1.20)	0.75		
Chronic pulmonary disease	2.7%	0.98 (0.78-1.24)	0.88		
Coagulopathy	3.5%	1.17 (0.87-1.58)	0.31		
Congestive heart failure	2.6%	0.98 (0.75-1.28)	0.89		

continued

TABLE IV (*continued*)

Characteristic	Crude Rate of Aseptic Revision	Univariate Analysis		Multivariable Analysis	
		Hazard Ratio (95% CI)	P Value	Hazard Ratio (95% CI)	P Value
Dementia	2.0%	0.90 (0.66-1.23)	0.52		
Depression	3.6%	**1.46 (1.13-1.90)**	**0.004**	**1.50 (1.15-1.95)**	**0.002**
Diabetes mellitus	2.4%	0.87 (0.67-1.12)	0.28		
Drug abuse	4.7%	1.69 (0.88-3.28)	0.12		
Fluid/electrolyte disorder	2.8%	1.02 (0.82-1.26)	0.89		
Hypertension	2.7%	0.94 (0.74-1.19)	0.61		
Hypothyroidism	2.8%	1.04 (0.82-1.32)	0.77		
Liver disease	4.1%	**1.62 (1.05-2.52)**	**0.031**		
Neurological disorders	2.6%	0.99 (0.79-1.24)	0.94		
Paralysis	2.9%	1.08 (0.71-1.63)	0.73		
Parkinson disease	2.9%	1.35 (0.74-2.47)	0.32		
Peripheral vascular disease	2.3%	**0.81 (0.66-1.00)**	**0.047**		
Pulmonary circulation disease	2.7%	0.92 (0.55-1.54)	0.76		
Psychosis	3.7%	**1.41 (1.10-1.81)**	**0.008**	**1.36 (1.06-1.75)**	**0.018**
Renal insufficiency	2.5%	0.91 (0.73-1.12)	0.37		
Rheumatoid arthritis	2.8%	1.07 (0.71-1.62)	0.75		
Solid tumor without metastasis	1.8%	0.69 (0.40-1.19)	0.18		
Valvular disease	1.5%	**0.53 (0.37-0.77)**	**0.001**		
Weight loss	2.7%	0.97 (0.73-1.28)	0.81		
Implant characteristics					
Design					
Unipolar	3.0%	Reference			
Bipolar	2.2%	**0.75 (0.59-0.94)**	**0.012**	**0.73 (0.58-0.91)**	**0.007**
Femoral fixation					
Uncemented	3.7%	Reference			
Cemented	1.9%	**0.53 (0.43-0.65)**	**<0.0001**	**0.54 (0.44-0.67)**	**<0.0001**
Hospital and procedure-related factors					
Time from admission to surgery					
<24 hr	2.6%	Reference			
24-48 hr	2.8%	1.09 (0.85-1.39)	0.49		
>48 hr	2.9%	1.11 (0.71-1.73)	0.65		
Type of anesthesia					
General	3.0%	Reference			
Conversion from regional to general	2.9%	0.92 (0.71-1.19)	0.51		
Regional	2.6%	0.83 (0.65-1.06)	0.14		
Surgeon volume (prior year)					
Low (0-13)	3.3%	1.09 (0.86-1.39)	0.48	0.94 (0.71-1.23)	0.641
Medium (14-20)	3.0%	1.00 (0.77-1.29)	0.99	0.88 (0.69-1.13)	0.315
High (≥21)	2.9%	Reference			
Unavailable	1.3%	0.69 (0.44-1.06)	0.087	**0.64 (0.41-1.00)**	**0.048**
Discharge disposition					
Home	3.4%	Reference			
Skilled nursing/other facility	2.6%	**0.77 (0.61-0.96)**	**0.020**		

*BMI = body mass index, and ASA = American Society of Anesthesiologists. †For educational attainment and annual income, the values represent an estimated average using the sum of the probability distribution. ‡For Elixhauser comorbidities, the reference category is absence of the comorbidity.

on this topic may be required to definitively determine whether there are, in fact, links between periprosthetic fracture and bipolar hemiarthroplasty.

Our results should be considered in the context of our study design. The procedures in this study were performed by nearly 500 surgeons at 35 hospitals, which may heighten generalizability. In addition, the data source for this study was a hip fracture registry combined with the EHR of a large integrated health-care system in the U.S. (rather than a billing database)[20]. However, our study also has limitations. Although we controlled for potential confounders in the multivariable analysis, there remains the possibility of residual confounding (i.e., incomplete controlling). As the risk factor analysis was exploratory in nature, the identified factors need to be confirmed with further study. While the duration of follow-up was relatively short for an arthroplasty study (mean of 3.7 years), this value exceeds the median survival following hip fracture (3.42 years[21]). However, longer-term follow-up may be necessary to determine the outcome of patients who undergo hemiarthroplasty at a younger age (e.g., 60 to 69 years). Additionally, it should be noted that our results represent associations but not necessarily causation.

In summary, our findings indicate that bipolar hemiarthroplasty may confer a lower risk of aseptic revision following femoral neck fracture in elderly individuals than unipolar hemiarthroplasty, without any additional risk of revision for periprosthetic fracture. Given that bipolar implants typically cost more than unipolar implants, cost-effectiveness studies may be required to determine the circumstances under which the additional cost of the bipolar device is worthwhile.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A528). ■

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