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The Impact of Prior Fragility Fractures on Complications After Total Hip Arthroplasty: A Propensity Score–Matched Cohort Study

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ABSTRACT

Background: The impact of prior fragility fractures and osteoporosis treatment before total hip arthroplasty (THA) on postoperative complications is unclear. The purpose of this study was to characterize the effect of prior fragility fractures and preoperative osteoporosis treatment on short-term complications and secondary fragility fractures after THA.

Methods: A propensity score–matched retrospective cohort study was conducted using a commercially available database to (1) characterize the impact of prior fragility fractures on rates of short-term complications after THA and (2) evaluate if osteoporosis treatment before arthroplasty reduces risk of postoperative complications. Rates of periprosthetic fracture, revision THA, and fragility fractures were compared via multivariable logistic regression.

Results: After 1:1 propensity score matching, 2188 patients were assigned to each cohort. Patients with a fragility fracture in the 3 years preceding THA were more likely to sustain a periprosthetic fracture (1 year: 1.7% vs 1.0%, odds ratio [OR] 1.89; 2 years: 2.1% vs 1.1%, OR 1.82), fragility fracture (1 year: 4.7% vs 1.1%, OR 3.59; 2 years: 6.7% vs 1.7%, OR 3.21), and revision THA (1 year: 2.7% vs 1.7%, OR 1.65; 2 years: 3.1% vs 1.9%, OR 1.58). Among patients with a prior fragility fracture, only 13.8% received osteoporosis pharmacotherapy before THA. Rates of all complications were statistically comparable postoperatively for patients with and without pre-THA osteoporosis treatment.

Conclusions: Fragility fractures within 3 years before THA are associated with significantly increased risk of periprosthetic fracture, all-cause revision, and secondary fragility fractures postoperatively. Preoperative osteoporosis treatment may not decrease risk of postoperative complications.

Introduction

Osteoporosis affects more than 54 million Americans and is the most prevalent chronic musculoskeletal condition worldwide [1]. Characterized by the loss of structural integrity of trabecular bone, it is defined by the World Health Organization (WHO) as a bone mineral density T-score less than −2.5 via dual-emission x-ray absorptiometry, which predisposes an individual to an increased risk of fracture [2-4]. Fragility fractures, which are those caused by low-impact trauma equal to a fall from standing height or less, represent a significant and growing cause of morbidity in the United States [2,5]. The lifetime risk of sustaining a fragility fracture has been estimated to be as high as 50% for women and 22% for men [6]. Between 2013 and 2014, fragility fractures were responsible for more than 540,600 hospitalizations and 935,700 visits to an emergency department by Americans aged 50 and older [5]. Notably, these rates are likely a significant underestimate, and the true incidence of fragility fractures is likely much higher given the frequency of incidental diagnoses, asymptomatic fractures, and increasing prevalence of osteoporosis in an expanding elderly population [3,7-9].

Fragility fractures tend to occur at sites with high proportions of trabecular bone, and the most commonly affected skeletal areas

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include the hip, humerus, wrist, femur, and vertebral column [5,10,11]. Morbidity and mortality escalate substantially after a fracture, and many patients experience long-term deficits in mobility, function, and quality of life [5,11]. Hip fractures are particularly pernicious accounting for 14% of all fractures, yet responsible for 72% of related health-care expenditure [12]. Patients with hip fracture exhibit up to an eight-fold increase in all-cause mortality for the 3 months in the acute postoperative setting and a mortality rate up to 30% within 1 year [13,14]. A prior fragility fracture has been demonstrated to be strongly predictive of a future fragility fracture [15]. A recent study found that 11.3% of patients who sustained a fragility fracture suffered a second fragility fracture within 3 years, nearly 58% of which involved the hip independent of initial fracture site [9].

Periprosthetic fractures have been broadly observed to occur after less than 1% of total hip arthroplasty (THA) and total knee arthroplasty; however, they are associated with significantly increased mortality [16]. Short-term morbidity is significantly higher than that experienced after native hip fractures, and the 5-year mortality risk for patients undergoing revision THA for periprosthetic fracture has been reported to be 60% for high-risk patients [17,18]. Two well-documented risk factors for periprosthetic fracture are osteoporosis and advanced age [16]. Seventy-five percent of periprosthetic fractures are reportedly caused by low-energy trauma, mirroring the etiology of fragility fractures [16]. As over 90% of THA are performed on patients older than 50 years, an estimated 25% of patients undergoing THA have an osteoporosis diagnosis at the time of surgery [19-21]. While substantial evidence exists linking osteoporosis and advanced age to periprosthetic fracture after total joint arthroplasty, the impact of a prior fragility fracture on the prevalence of similar postoperative complications has not been studied.

The purpose of this study was to characterize the effect of a prior fragility fracture on rates of short-term joint complications and incident fragility fractures including periprosthetic fractures after primary THA. We hypothesize that a prior fragility fracture is associated with increased risk of postoperative periprosthetic fracture and revision THA at medium-term follow-up. A secondary goal was to determine if osteoporosis pharmacotherapy before THA reduces the risk of postoperative complications and secondary fragility fractures among patients with a recent history of fragility fracture.

Material and methods

Patient records were queried from PearlDiver (PearlDiver Inc., Fort Wayne, IN), a commercially available administrative claims database of deidentified inpatient and outpatient data. Current Procedural Technology (CPT) and International Classification of Diseases, Ninth and Tenth Revision (ICD-9/ICD-10), diagnosis codes were used to identify eligible patients and outcomes. The database contains the medical records of approximately 122 million patients across the United States from 2010 through 2019 which are collected by an independent data aggregator. All payors including commercial, private, and government health plans are represented. Institutional review board exemption was granted for this study as provided data were deidentified and compliant with the Health Insurance Portability and Accountability Act. For the sake of protecting patient identities, the PearlDiver software only reports exact patient counts when defined groups have at least 11 patients; if defined cohorts are smaller, "−1" is reported. When such instances arose in the present study, a value of 5 (median between 1 and 10) was assigned for the patient count. No outside funding from the commercial, government, or nonprofit sectors was received for this study.

A propensity score–matched retrospective cohort study was conducted to (1) characterize the impact of prior fragility fractures on rates of short-term complications after primary THA (CPT-27,130) and (2) evaluate if osteoporosis treatment before arthroplasty reduces risk of postoperative complications among patients with prior fragility fractures. Fragility fractures were defined by ICD-9/10 diagnosis codes for primary closed fractures of the hip, wrist, spine, pelvis, and humerus. Hip fragility fractures were defined by ≥1 inpatient claim(s) (any diagnostic position), while all other fracture locations were defined by either (1) ≥1 inpatient claim(s) (any diagnostic position) or (2) ≥1 outpatient claim(s). In addition, to ensure the fragility-based etiology of the fractures, fractures with an ICD trauma code on a claim within 7 days before or 7 days after the index fracture claim were excluded. A history of fragility fracture was defined as at least one of the aforementioned criteria within 3 years before joint replacement.

Prearthroplasty osteoporosis pharmacotherapy criteria were defined by at least one drug claim between the dates of the prior fragility fracture and joint replacement. Generic drug codes were used to identify prescription claims filed for the following medications: alendronate, risedronate, ibandronate, zoledronic acid, raloxifene, denosumab, teriparatide, abaloparatide, and calcitonin. These codes are cross-mapped to eleven-digit National Drug Codes on patients' charging records. A full list of fracture diagnosis codes and drug codes used is provided in Supplemental Table 1.

In order to limit potential transfer bias due to patients leaving or joining the data set during the follow-up period, only patients with continuous database enrollment for at least 2 years after arthroplasty were included. As such, to capture a 3-year preoperative period of fragility fracture history and a 2-year follow-up for evaluating complications, only primary THAs performed on patients aged 50 years and older between January 1, 2013, and December 31, 2017, were included in the analysis. In order to ensure complications tied to the index THA, patients with contralateral hip surgery including but not limited to THA, hemiarthroplasty, and conversion to THA during the 2-year follow-up were excluded. Patients with metastatic cancer, infectious indications, contraindications to first-line pharmacotherapy for osteoporosis (eg, Roux-en-Y bypass for bisphosphonates), and various metabolic diseases that predispose to low bone density were excluded. In addition, to capture only elective THA cases, patients with a hip fracture claim within 30 days before or on the same day as THA were excluded. A complete list of codes used to define inclusion/exclusion criteria is available in Supplemental Table 1.

Rates of postoperative complications after THA were compared for (1) patients with and without a prior fragility fracture, and (2) among patients with a prior fragility fracture, patients with and without osteoporosis treatment before THA. Complications assessed included periprosthetic fracture, all-cause revision joint arthroplasty, and fragility fractures at 1 and 2 years postoperatively. Fragility fractures during the follow-up period were defined using the same criteria as preoperative fractures. The diagnostic and procedural codes used to define each complication are available in Supplemental Table 2.

Statistical analysis

Statistical analyses were performed using R statistical software (R Project for Statistical Computing, Vienna, Austria) integrated within the PearlDiver software with an α level set to 0.05. Baseline demographic and clinical characteristics were obtained for all patients, including age, sex distribution, body mass index (BMI), insurance plan type, United States region, average Elixhauser Comorbidity Index score, and major comorbidities. Categorical variables were compared with chi-square analysis, and continuous variables were compared with Welch's t test or the Mann-Whitney U test.

For comparing outcomes among patients with and without a prior fragility fracture, propensity score matching was performed using a logistic regression model accounting for the following clinical variables: age, gender, insurance plan type, US region, diabetes mellitus, tobacco use, rheumatoid arthritis, chronic kidney disease, and dementia. Propensity scores represent the conditional probability of assignment to a "test" group and can be used to control for multiple observed covariates that are associated with both the exposure and outcome. The propensity score was used to match patients with a prior fragility fracture and patients with no fracture history using a fixed 1:1 ratio and a caliper of 0.20 to achieve nearest neighbor matching without replacement. Rates of postoperative complications were compared with multivariable logistic regression controlling for age, gender, Elixhauser Comorbidity Index score, and baseline diagnoses of rheumatoid arthritis, osteoporosis, and dementia to calculate adjusted odds ratios with corresponding 95% confidence intervals.

Matching was not performed for the secondary analysis of osteoporosis treatment before joint replacement because of small sample sizes of the treatment cohorts, which would prevent adequate statistical power from being achieved. Rates of postoperative complications for patients with vs without osteoporosis treatment before THA were compared with multivariable logistic regression controlling for the same variables mentioned previously. Post hoc power analyses were performed for the primary and secondary outcomes to assess power at an α of 0.05.

Results

A total of 169,766 patients who underwent THA met all inclusion criteria (Fig. 1). Within this cohort, 2189 (1.3%) patients had a prior fragility fracture in the last 3 years while 167,577 (98.7%) patients did not. There were considerable baseline demographic differences between the patient populations with vs without prior fragility fractures, including average age, patient sex distribution, region, plan type, and prevalence of major comorbidities (Table 1). Following 1:1 propensity score matching, 2188 patients were assigned to each cohort. Matching eliminated much of the baseline differences yielding comparable base populations. Despite matching, a significantly greater proportion of patients with a prior fragility fracture had a diagnosis of dementia (2.5% vs 1.1%, $P < .001$). Other baseline diagnoses significantly more prevalent in the cohort with a prior fragility fracture after matching included osteoporosis diagnoses (24.9% vs 6.3%, $P < .001$) and vitamin D deficiency (23.7% vs 18.7%, $P < .001$).

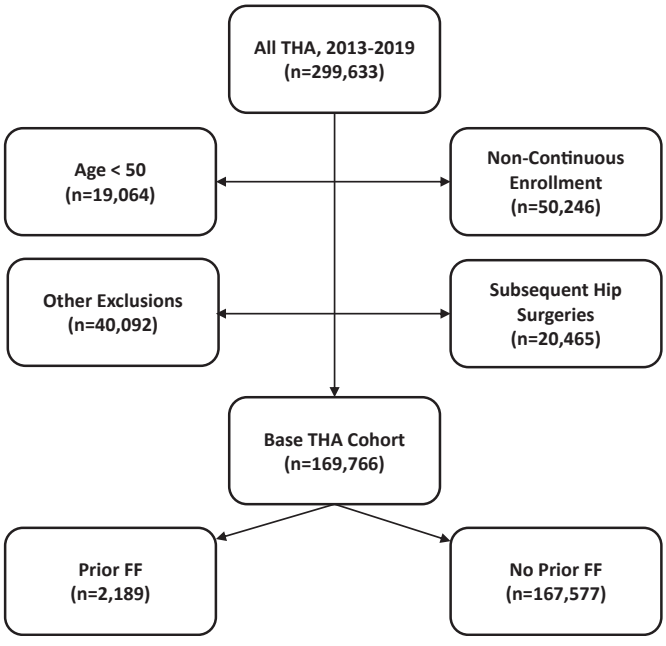

Figure 1. Flowchart showing identification of base unmatched THA cohorts. FF, fragility fracture.

Outcomes were compared for patients with and without a prior fragility fracture at 1 and 2 years postoperatively (Table 2). After THA, periprosthetic fractures, secondary fragility fractures, and all-cause revision were all significantly more likely at both 1 and 2 years for patients with a history of fragility fractures (all $P < .05$). A post hoc power analysis of each primary outcome showed that the study was adequately powered (>90%) to detect significant differences in rates of all outcomes.

Among the 2189 patients that underwent THA and had a prior fragility fracture, 303 (13.8%) filed at least one claim for osteoporosis pharmacotherapy between their fracture and THA (Table 3). Alendronate was the most common medication on claims filed (64.7%) in the treatment cohort (Supplementary Table 3). At 1-year follow-up, rates of periprosthetic fracture, secondary fragility fractures, and revision THA were higher in the treatment group. At 2 years, rates of periprosthetic fracture and revision THA were lower in the treatment group while the rate of secondary fragility fractures was higher. However, all outcomes were statistically comparable at both 1 and 2 years postoperatively for the treatment vs no treatment cohorts. Post hoc power analyses showed that the sample sizes are likely underpowered (<80%) to detect significant differences for all secondary outcomes.

Discussion

The present study demonstrates that a history of fragility fracture correlates with increased rates of complications after THA. Among patients who underwent THA, periprosthetic fractures and fragility fractures were significantly more likely at both 1 and 2 years postoperatively for patients with a prior fragility fracture. Furthermore, all-cause revision after THA was also significantly more likely for patients with a previous fragility fracture at both postoperative intervals. In patients who underwent THA with a history of fragility fracture, rates of periprosthetic fracture, secondary fragility fractures, and all-cause revision were statistically comparable at both 1 and 2 years postoperatively between patients that filed at least one claim for osteoporosis pharmacotherapy before THA and patients that did not receive pharmacotherapy. However, post hoc power analyses showed that the study was underpowered to evaluate these secondary outcomes.

Surgeons make decisions during THA regarding hip stem geometry and method of fixation such that understanding the risk profile of each patient is paramount. In patients undergoing THA with Dorr type C bone or increased risk of fracture, surgeons may choose press-fit femoral stem geometries that have increased stability to rotational and axial forces [22]. In patients with severely compromised bone and risk factors, cemented stems or prophylactic cerclage wires may be indicated [23]. The present study found significantly increased risk of periprosthetic fracture, fragility fracture, and all-cause revision for patients with a history of fragility fracture as compared to matched controls with no fracture history. This result highlights the significance of fragility fractures with respect to preoperative risk stratification, patient counseling, and intraoperative planning. Certain comorbidities such as dementia have also been linked to significantly higher risk of falls and secondary fragility fractures [24]. As higher rates of dementia persisted in the cohort with a prior fragility fracture despite matching across

Table 1
Baseline demographic data for unmatched and matched THA cohorts.

Characteristics	Unmatched			Matched		
	Prior FF (n = 2189)	No prior FF (n = 167,577)	*P* value	Prior FF (n = 2188)	No prior FF (n = 2188)	*P* value
Sex, female (%)	1587 (72.5)	94640 (56.5)	<.001	1586 (72.5)	1602 (73.2)	.61
Age, mean ± SD	69.0 ± 7.7	66.4 ± 8.1	<.001	69.1 ± 7.7	68.9 ± 7.8	.521
Age range (%)						
50-59	325 (14.8)	39760 (23.7)	<.0001	325 (14.9)	338 (15.4)	.613
60-69	669 (30.6)	61029 (36.4)	<.001	669 (30.6)	666 (30.4)	.948
70-74	342 (15.6)	25418 (15.2)	.580	342 (15.6)	337 (15.4)	.867
75+	853 (39.0)	41370 (24.7)	<.001	852 (38.9)	847 (38.7)	.901
Plan type (%)						
Cash	5[a] (0.2)	134 (0.08)	<.001	5[a] (0.23)	5[a] (0.23)	1
Commercial	1336 (61.0)	108356 (64.7)	.94	1336 (61.1)	1319 (60.3)	.621
Government	28 (1.3)	2935 (1.8)	.32	28 (1.3)	26 (1.2)	.891
Medicaid	67 (3.1)	3538 (2.1)	.57	66 (3.0)	54 (2.5)	.309
Medicare	747 (34.1)	51246 (30.6)	<.001	747 (34.1)	782 (35.7)	.281
Unknown	5[a] (0.2)	1368 (0.8)	1	5[a] (0.23)	5[a] (0.23)	.422
BMI (%)[b]						
<30	440 (20.1)	24223 (14.5)	.11	440 (20.1)	391 (17.9)	.064
30-35	298 (13.6)	22948 (13.7)	<.001	298 (13.6)	312 (14.3)	.571
35-40	203 (9.3)	16650 (9.9)	<.001	203 (9.3)	217 (9.9)	.505
>40	184 (8.4)	14705 (8.8)	.05	183 (8.4)	159 (7.3)	.195
Region (%)						
Northeast	396 (18.1)	50625 (30.2)	<.001	396 (18.1)	384 (17.6)	.664
South	642 (29.3)	36478 (21.8)	<.001	642 (29.3)	650 (29.7)	.817
Midwest	854 (39.0)	58395 (34.8)	<.001	853 (39.0)	863 (39.4)	.781
West	294 (13.4)	21900 (13.1)	.64	294 (13.4)	287 (13.1)	.789
N/A	5[a] (0.2)	179 (0.1)	.92	5[a] (0.23)	5[a] (0.23)	1
Osteoporosis diagnosis (%)	546 (24.9)	6542 (3.9)	<.001	545 (24.9)	137 (6.3)	<.001
ECI, mean ± SD	7.8 ± 4.2	5.6 ± 3.6	<.001	7.8 ± 4.2	6.4 ± 3.7	<.001
Comorbidities (%)						
Diabetes mellitus	939 (42.9)	65311 (39.0)	<.001	938 (42.9)	944 (43.1)	.879
Vitamin D deficiency	520 (23.8)	27568 (16.5)	<.001	519 (23.7)	410 (18.7)	<.001
Tobacco use	833 (38.0)	39656 (23.7)	<.001	832 (38.0)	825 (37.7)	.852
Rheumatoid arthritis	220 (10.0)	9547 (5.7)	<.001	219 (10.0)	231 (10.6)	.584
Dementia	56 (2.6)	1150 (0.7)	<.001	55 (2.5)	24 (1.1)	<.001
Chronic kidney disease	292 (13.3)	13259 (7.9)	<.001	292 (13.3)	243 (11.1)	.027

[a] Exact counts under 11 are unavailable in PearlDiver. A patient count of 5 (median between 1 and 10) was assigned in such instances.
[b] BMI data was available for 51% and 47% of unmatched patients with and without a prior fragility fracture, respectively; BMI data was available for 51% and 49% of matched patients with and without a prior fragility fracture, respectively.ECI, Elixhauser Comorbidity Index; FF, fragility fracture; SD, standard deviation.

this diagnosis, identification of dementia as a risk factor for falls and related sequelae even in the absence of prior fragility fractures may be warranted. In addition, only 13.8% of patients with a fragility fracture filed a claim for pharmacologic therapy after a fragility fracture even with documented treatment by an orthopedic surgeon for a subsequent elective THA. However, this study demonstrated that short-term implementation of pharmacotherapy did not decrease the periprosthetic fracture risk in patients who had fragility fractures before THA. This suggests that once a patient has a fragility fracture, selection of implant type and fixation method remains important despite short-term pharmacotherapy.

The findings of the present study suggest that initiating pharmacotherapy after a fragility fracture may not decrease the risk of complications after a fragility fracture and supports efforts of the Own the Bone program to have both male and female patients screened for osteoporosis at the appropriate age as a preventative tool [25]. These medications may take longer to provide a protective

Table 2
Outcomes at 1 and 2 years postoperatively for matched THA cohorts, history of fragility fracture vs no prior fragility fracture.

Complication	Prior FF (n = 2188)	No prior FF (n = 2188)	OR (95% CI)
PPFx, n (%)			
1 y	38 (1.7)	21 (1.0)	1.89 (1.10-3.33)
2 y	47 (2.1)	25 (1.1)	1.82 (1.11-3.06)
FF, n (%)			
1 y	103 (4.7)	25 (1.1)	3.59 (2.31-5.78)
2 y	147 (6.7)	38 (1.7)	3.21 (2.23-4.74)
Revision, n (%)			
1 y	60 (2.7)	37 (1.7)	1.65 (1.08-2.55)
2 y	67 (3.1)	42 (1.9)	1.58 (1.06-2.39)

CI, confidence interval; FF, fragility fracture; PPFx, periprosthetic fracture; revision, all-cause revision THA; OR, odds ratio.

Table 3
Outcomes for patients with a fragility fracture history, received treatment vs no treatment before total hip arthroplasty.

Complication	Treatment (n = 303)	No treatment (n = 1886)	OR (95% CI)
PPFx, n (%)			
1 y	5[a] (1.7)	32 (1.7)	1.41 (0.51-3.33)
2 y	5[a] (1.7)	41 (2.2)	0.91 (0.34-2.09)
FF, n (%)			
1 y	21 (6.9)	82 (4.3)	1.23 (0.71-2.03)
2 y	29 (9.6)	118 (6.3)	1.16 (0.73-1.80)
Revision, n (%)			
1 y	5[a] (1.7)	51 (2.7)	1.03 (0.46-2.08)
2 y	5[a] (1.7)	58 (3.1)	0.89 (0.40-1.77)

CI, confidence interval; FF, fragility fracture; PPFx, periprosthetic fracture; revision, all-cause revision THA; OR, odds ratio.
[a] Exact counts under 11 are unavailable in PearlDiver. A patient count of 5 (median between 1 and 10) was assigned in such instances.

benefit after a fragility fracture, or may not be able to restore bone quality of this population to a level equivalent to patients without prior fragility fracture. However, as the treatment cohort in this study was defined as patients with a fragility fracture at any point within 3 years before THA and at least one subsequent pharmacologic claim, a wide range of possible treatment lengths were included. Therefore, our results do not rule out potential risk reduction with osteoporosis treatment after a fragility fracture but instead suggest prearthroplasty treatment alone may not reduce risk of THA complications for patients with a prior fracture within 3 years and with at least minimal treatment exposure before THA. The inadequate power (<80%) of the sample sizes in the secondary analysis further reinforces the inability to make definitive claims regarding the utility of prearthroplasty short-term osteoporosis treatment. Future randomized controlled trials are warranted to ascertain the potential of preoperative osteoporosis treatment protocols in reducing postoperative complications after THA and to investigate the impact of fragility fractures on the efficacy of such interventions.

There are several limitations to this study. First, as the PearlDiver database only provides data on a particular group of patients during a specific time period, sampling bias is present. By only measuring joint complications 2 years after the index arthroplasty procedure, this analysis is limited to short-term data and excludes long-term complications. With the complex nature of medical billing, there is a possibility of coding bias through manual entry of diagnosis/procedural codes. Furthermore, as this study includes patient data from both before and after 2015, both ICD-9 and ICD-10 codes were used. As diagnosis codes do not match exactly across ICD-9 and ICD-10, a translator application was used to identify corresponding codes. Coding errors are inherent with any analysis of administrative claims data; however, a study by the Centers for Medicare and Medicaid demonstrates such instances made up only 1.0% of payments in 2019 [26]. In addition, by limiting the preoperative window to 3 years for fragility fracture evaluation, it is possible some patients in the "non-fragility fracture" cohort had a prior fragility fracture before this period. Furthermore, as prior literature shows only one in 3 vertebral fractures are clinically identified, more patients could have had prior undiagnosed fragility fractures [27]. An additional limitation is that, by defining prearthroplasty pharmacotherapy exposure as at least one claim for any osteoporosis medication at any time between the dates of the index fracture and THA, it is possible that some patients included in the "treatment" cohort did not receive clinically adequate treatment exposure. As the benefit of osteoporosis medications is well-established, this limitation may misconstrue the potential impact of preoperative osteoporosis treatment on reducing rates of postoperative complications. Furthermore, although the power analysis showed the number of patients included in the primary analysis possessed adequate power (>90%), the sample sizes in the secondary analysis were underpowered (<80%). In addition, postoperative pharmacotherapy exposure was not examined which could influence clinical outcomes. Given the limitations of using claims to infer exposure, the efficacy of pharmacotherapy to reduce postoperative complications remains unclear, and future research is warranted. Various supplements (eg, calcium and vitamin D) were excluded from the criteria used to define osteoporosis pharmacotherapy. As these medications are available over the counter, more included patients with a prior fragility fracture could have been treated with such pharmacotherapy before THA. Another limitation is that, although propensity score matching and multivariable regression were used, other confounders could have influenced the results. Although rates of certain comorbidities remained significantly different at baseline, double adjustment via multivariable logistic regression was used to limit potential confounding effects when evaluating prior fragility fractures as an independent risk factor. Finally, as is a limitation of many database studies, BMI data were not universally available for all included patients, and therefore, our adjustment for BMI was incomplete.

Further research investigating optimal perioperative management strategies and intraoperative implant type and fixation techniques for THA candidates with osteoporosis is warranted. This population of patients has an increased risk profile that, with recognition and appropriate screening, can be mitigated with surgical techniques and perioperative care during THA.

Conclusions

Fragility fractures within 3 years before THA are associated with significantly increased risk of periprosthetic fracture, all-cause revision, and secondary fragility fractures postoperatively. Surgeons should recognize this increased risk even in the absence of a formal osteoporosis diagnosis. Among patients with a history of fragility fracture, starting osteoporosis pharmacotherapy within 3 years before THA may not significantly mitigate the risk of these postoperative complications.

Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: O. C. Lee is an AAOS delegate to the Board of the United States Bone and Joint Initiative and US Subcommittee Chair of the Fragility Fracture Network. G. N. Guild is a paid consultant for and received reserach support from Smith & Nephew; has stock or stock options in Total Joint Orthopaedics; is a member in the AAHKS Education Committee. W. F. Sherman is a critical evaluator for AAOS and is in the Knee Program Committee of AAOS.

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Appendix

Supplemental Table 1
ICD-9/10 and CPT codes used to define inclusion/exclusion criteria and base populations.

Description	Code(s)
THA	CPT-27130
Fragility fracture diagnosis codes	
Hip	ICD-9-D-82000:ICD-9-D-82009, ICD-9-D-82020:ICD-9-D-82022, ICD-9-D-8208, ICD-9-D-73314, ICD-10-D-S72001A, ICD-10-D-S72002A, ICD-10-D-S72009A, ICD-10-D-S72011A, ICD-10-D-S72012A, ICD-10-D-S72019A, ICD-10-D-S72021A, ICD-10-D-S72022A, ICD-10-D-S72023A, ICD-10-D-S72031A, ICD-10-D-S72032A, ICD-10-D-S72033A, ICD-10-D-S72041A, ICD-10-D-S72042A, ICD-10-D-S72043A, ICD-10-D-S72091A, ICD-10-D-S72092A, ICD-10-D-S72099A, ICD-10-D-S72101A, ICD-10-D-S72102A, ICD-10-D-S72109A, ICD-10-D-S72141A, ICD-10-D-S72142A, ICD-10-D-S72143A, ICD-10-D-S72231A, ICD-10-D-S72232A, ICD-10-D-S7223XA, ICD-10-D-M84451A, ICD-10-D-M84452A, ICD-10-D-M84453A, ICD-10-D-M84459A, ICD-9-D-73314, ICD-10-D-M80051A, ICD-10-D-M80052A, ICD-10-D-M80059A, ICD-10-D-M80851A, ICD-10-D-M80852A, ICD-10-D-M80859A
Spine	ICD-9-D-80500, ICD-9-D-80501, ICD-9-D-80502, ICD-9-D-80503, ICD-9-D-80504, ICD-9-D-80505, ICD-9-D-80506, ICD-9-D-80507, ICD-9-D-8052, ICD-9-D-8054, ICD-9-D-8058, ICD-9-D-8060, ICD-9-D-80600:ICD-9-D-80609, ICD-9-D-80620:ICD-9-D-80629, ICD-9-D-8064, ICD-9-D-8068, ICD-9-D-73313, ICD-10-D-S129XXA, ICD-10-D-S12000A, ICD-10-D-S12001A, ICD-10-D-S12100A, ICD-10-D-S12101A, ICD-10-D-S12200A, ICD-10-D-S12201A, ICD-10-D-S12300A, ICD-10-D-S12301A, ICD-10-D-S12400A, ICD-10-D-S12401A, ICD-10-D-S12500A, ICD-10-D-S12501A, ICD-10-D-S12600A, ICD-10-D-S12601A, ICD-10-D-S22009A, ICD-10-D-S32009A, ICD-10-D-S3210XA, ICD-10-D-S322XXA, ICD-10-D-S14101A, ICD-10-D-S14102A, ICD-10-D-S14103A, ICD-10-D-S14104A, ICD-10-D-S14111A, ICD-10-D-S14112A, ICD-10-D-S14113A, ICD-10-D-S14114A, ICD-10-D-S14121A, ICD-10-D-S14122A, ICD-10-D-S14123A, ICD-10-D-S14124A, ICD-10-D-S14131A, ICD-10-D-S14132A, ICD-10-D-S14133A, ICD-10-D-S14134A, ICD-10-D-S14151A, ICD-10-D-S14152A, ICD-10-D-S14153A, ICD-10-D-S14154A, ICD-10-D-S14105A, ICD-10-D-S14106A, ICD-10-D-S14107A, ICD-10-D-S14115A, ICD-10-D-S14116A, ICD-10-D-S14117A, ICD-10-D-S14125A, ICD-10-D-S14126A, ICD-10-D-S14127A, ICD-10-D-S14135A, ICD-10-D-S14136A, ICD-10-D-S14137A, ICD-10-D-S14155A, ICD-10-D-S14156A, ICD-10-D-S14157A, ICD-10-D-S24101A, ICD-10-D-S24102A, ICD-10-D-S24111A, ICD-10-D-S24112A, ICD-10-D-S24131A, ICD-10-D-S24132A, ICD-10-D-S24151A, ICD-10-D-S24152A, ICD-10-D-S24103A, ICD-10-D-S24104A, ICD-10-D-S24113A, ICD-10-D-S24114A, ICD-10-D-S24133A, ICD-10-D-S24134A, ICD-10-D-S24153A, ICD-10-D-S24154A, ICD-10-D-S34109A, ICD-10-D-S34119A, ICD-10-D-S34129A, ICD-10-D-S32009A, ICD-10-D-S34101A, ICD-10-D-S34111A, ICD-10-D-S34121A, ICD-10-D-S32019A, ICD-10-D-S34102A, ICD-10-D-S34112A, ICD-10-D-S34122A, ICD-10-D-S32029A, ICD-10-D-S34103A, ICD-10-D-S34113A, ICD-10-D-S34123A, ICD-10-D-S32039A, ICD-10-D-S34104A, ICD-10-D-S34114A, ICD-10-D-S34124A, ICD-10-D-S32049A, ICD-10-D-S34105A, ICD-10-D-S34115A, ICD-10-D-S34125A, ICD-10-D-S32059A, ICD-10-D-S14109A, ICD-10-D-S24109A, ICD-10-D-S34109A, ICD-10-D-S34139A, ICD-10-D-M4850XA, ICD-10-D-M8008XA, ICD-10-D-M8448XA, ICD-10-D-M8468XA, ICD-9-D-73313, ICD-9-D-73315, ICD-10-D-M8008XA, ICD-10-D-M8088XA
Pelvis	ICD-9-D-8080, ICD-9-D-8082, ICD-9-D-80841, ICD-9-D-80842, ICD-9-D-80849, ICD-9-D-8088, ICD-10-D-S32401A, ICD-10-D-S32402A, ICD-10-D-S32409A, ICD-10-D-S32501A, ICD-10-D-S32502A, ICD-10-D-S32501A, ICD-10-D-S32502A, ICD-10-D-S32509A, ICD-10-D-S32301A, ICD-10-D-S32302A, ICD-10-D-S32309A, ICD-10-D-S32601A, ICD-10-D-S32602A, ICD-10-D-S32609A, ICD-10-D-S32810A, ICD-10-D-S32811A, ICD-10-D-S3282XA, ICD-10-D-S3289XA, ICD-10-D-S329XXA, ICD-10-D-M84454A
Wrist	ICD-9-D-81340:ICD-9-D-81347, ICD-9-D-73312, ICD-10-D-S5290XA, ICD-10-D-S52531A, ICD-10-D-S52532A, ICD-10-D-S52539A, ICD-10-D-S52541A, ICD-10-D-S52542A, ICD-10-D-S52549A, ICD-10-D-S52501A, ICD-10-D-S52502A, ICD-10-D-S52509A, ICD-10-D-S52601A, ICD-10-D-S52602A, ICD-10-D-S52609A, ICD-10-D-S52111A, ICD-10-D-S52112A, ICD-10-D-S52119A, ICD-10-D-S52521A, ICD-10-D-S52522A, ICD-10-D-S52529A, ICD-10-D-S52011A, ICD-10-D-S52012A, ICD-10-D-S52019A, ICD-10-D-S52621A, ICD-10-D-S52622A, ICD-10-D-S52629A, ICD-10-D-S52011A, ICD-10-D-S52012A, ICD-10-D-S52019A, ICD-10-D-S52621A, ICD-10-D-A52622A, ICD-10-D-S52629A, ICD-10-D-M84431A, ICD-10-D-M84432A, ICD-10-D-M84439A, ICD-9-D-73312, ICD-10-D-M80031A, ICD-10-D-M80032A, ICD-10-D-M80039A, ICD-10-D-M80831A, ICD-10-D-M80832A, ICD-10-D-M80839A
Humerus	ICD-9-D-81200:ICD-9-D-81209, ICD-9-D-81220, ICD-9-D-81221, ICD-9-D-81240:ICD-9-D-81249, ICD-9-D-73311, ICD-10-D-S42201A, ICD-10-D-S42202A, ICD-10-D-S42209A, ICD-10-D-S42211A, ICD-10-D-S42212A, ICD-10-D-S42213A, ICD-10-D-S42214A, ICD-10-D-S42215A, ICD-10-D-S42216A, ICD-10-D-S42291A, ICD-10-D-S42292A, ICD-10-D-S42293A, ICD-10-D-S42294A, ICD-10-D-S42295A, ICD-10-D-S42296A, ICD-10-D-S42251A, ICD-10-D-S42252A, ICD-10-D-S42253A, ICD-10-D-S42254A, ICD-10-D-S42255A, ICD-10-D-S42256A, ICD-10-D-S42291A, ICD-10-D-S42292A, ICD-10-D-S42293A, ICD-10-D-S42294A, ICD-10-D-S42295A, ICD-10-D-S42296A, ICD-10-D-S42301A, ICD-10-D-S42302A, ICD-10-D-S42309A, ICD-10-D-S42391A, ICD-10-D-S42392A, ICD-10-D-S42399A, ICD-10-D-S42401A, ICD-10-D-S42402A, ICD-10-D-S42409A, ICD-10-D-S42411A, ICD-10-D-S42412A, ICD-10-D-S42413A, ICD-10-D-S42414A, ICD-10-D-S42415,A ICD-10-D-S42416A, ICD-10-D-S42431A, ICD-10-D-S42432A, ICD-10-D-S42433A, ICD-10-D-S42434A, ICD-10-D-S42435A, ICD-10-D-S42436A, ICD-10-D-S42451A, ICD-10-D-S42452A, ICD-10-D-S42453A, ICD-10-D-S42454A, ICD-10-D-S42455A, ICD-10-D-S42456A, ICD-10-D-S42441A, ICD-10-D-S42442A, ICD-10-D-S42443A, ICD-10-D-S42444A, ICD-10-D-S42445A, ICD-10-D-S42446A, ICD-10-D-S42461A, ICD-10-D-S42462A, ICD-10-D-S42463A, ICD-10-D-S42464A, ICD-10-D-S42465A, ICD-10-D-S42466A, ICD-10-D-S42471A, ICD-10-D-S42472A, ICD-10-D-S42473A, ICD-10-D-S42474A, ICD-10-D-S42475A, ICD-10-D-S42476A, ICD-10-D-S42491A, ICD-10-D-S42492A, ICD-10-D-S42493A, ICD-10-D-S42494A, ICD-10-D-S42495A, ICD-10-D-S42496A, ICD-10-D-M84421A, ICD-10-D-M84422A, ICD-10-D-M84429A, ICD-9-D-73311, ICD-10-D-M80011A, ICD-10-D-M80012A, ICD-10-D-M80019A, ICD-10-D-M80021A, ICD-10-D-M80022A, ICD-10-D-M80029A, ICD-10-D-M80811A, ICD-10-D-M80812A, ICD-10-D-M80819A, ICD-10-D-M80821A, ICD-10-D-M80822A, ICD-10-D-M80829A
Other	ICD-9-D-73310, ICD-9-D-73316, ICD-9-D-73319, ICD-10-D-M8000XA, ICD-10-D-M80041A, ICD-10-D-M80042A, ICD-10-D-M80049A, ICD-10-D-M80061A, ICD-10-D-M80062A, ICD-10-D-M80069A, ICD-10-D-M80071A, ICD-10-D-M80072A, ICD-10-D-M80079A, ICD-10-D-M8080XA, ICD-10-D-M80841A, ICD-10-D-M80842A, ICD-10-D-M80849A, ICD-10-D-M80861A, ICD-10-D-M80862A, ICD-10-D-M80869A, ICD-10-D-M80871A, ICD-10-D-M80872A, ICD-10-D-M80879A
Exclusion criteria	

(*continued on next page*)

Supplemental Table 1 (*continued*)

Description	Code(s)
Traumatic fractures	ICD-9-D-E800:ICD-9-D-E848, ICD-9-D-E916:ICD-9-D-E919, ICD-9-D-E9288, ICD-9-D-E9289, ICD-9-D-E9290, ICD-9-D-E9291, ICD-9-D-E957:ICD-9-D-E959, ICD-9-D-E960:ICD-9-D-E966, ICD-9-D-E968:ICD-9-D-E979, ICD-9-D-E987:ICD-9-D-E989, ICD-9-D-E999, ICD-10-D-V00:ICD-10-D-V99, ICD-10-D-W09:ICD-10-D-W17, ICD-10-D-X34:ICD-10-D-X39, ICD-10-D-X79:ICD-10-D-X83, ICD-10-D-Y00:ICD-10-D-Y04, ICD-10-D-Y08:ICD-10-D-Y09, ICD-10-D-Y29:ICD-10-D-Y38
Prior revision THA	CPT-27134, CPT-27137, CPT-27138
Active hip infection	ICD-9-D-73005, ICD-9-D-73015, ICD-9-D-73025, ICD-9-D-73035, ICD-9-D-71105, ICD-9-D-6143, ICD-9-D-6144, ICD-10-D-M86051, ICD-10-D-M86052, ICD-10-D-M86059, ICD-10-D-M8608, ICD-10-D-M86151, ICD-10-D-M86152, ICD-10-D-M86159, ICD-10-D-M8618, ICD-10-D-M86251, ICD-10-D-M86252, ICD-10-D-M86259, ICD-10-D-M8628, ICD-10-D-M86351, ICD-10-D-M86352, ICD-10-D-M86359, ICD-10-D-M8638, ICD-10-D-M86451, ICD-10-D-M86452, ICD-10-D-M86459, ICD-10-D-M8648, ICD-10-D-M86551, ICD-10-D-M86552, ICD-10-D-M86559, ICD-10-D-M8658, ICD-10-D-M009
Primary hip surgeries during follow-up	CPT-27130, CPT-27125, CPT-27132, CPT-27265, CPT-27266, CPT-27245, CPT-27244, CPT-27120
Achalasia	ICD-9-D-5300, ICD-10-D-K220
Multiple myeloma	ICD-9-D-20300, ICD-9-D-20301, ICD-9-D-20302, ICD-10-D-C9002, ICD-10-D-C9001, ICD-10-D-C9000
Paget's disease	ICD-9-D-7310, ICD-9-D-7311, ICD-10-D-M880, ICD-10-D-M881, ICD-10-D-M88811, ICD-10-D-M88812, ICD-10-D-M88819, ICD-10-D-M88821, ICD-10-D-M88822, ICD-10-D-M88829, ICD-10-D-M88831, ICD-10-D-M88832, ICD-10-D-M88839, ICD-10-D-M88841, ICD-10-D-M88849, ICD-10-D-M88851, ICD-10-D-M88852, ICD-10-D-M88859, ICD-10-D-M88861, ICD-10-D-M88862, ICD-10-D-M88869, ICD-10-D-M88871, ICD-10-D-M88872, ICD-10-D-M8888, ICD-10-D-M8889, ICD-10-D-M889, ICD-10-D-M9060, ICD-10-D-M90621, ICD-10-D-M90641, ICD-10-D-M90651, ICD-10-D-M90652, ICD-10-D-M90661, ICD-10-D-M90671, ICD-10-D-M90672, ICD-10-D-M9068, ICD-10-D-M9069
Hyperparathyroidism	ICD-9-D-25200, ICD-9-D-25201, ICD-9-D-25202, ICD-9-D-25208, ICD-9-D-58881, ICD-10-D-E210, ICD-10-D-E211, ICD-10-D-E212, ICD-10-D-E213, ICD-10-D-N2581
Drug allergy	ICD-9-D-V148, ICD-10-D-Z888
Hyperthyroidism	ICD-9-D-24290, ICD-9-D-24200, ICD-10-D-E0590, ICD-10-D-E0500, ICD-10-D-E0520, ICD-10-D-E0591
Metastatic cancer	ICD-9-D-1960:ICD-9-D-1999, ICD-10-D-C770:ICD-10-D-C809
Esophageal varices	ICD-9-D-4560, ICD-9-D-4561, ICD-10-D-I8500, ICD-10-D-I8501
Esophageal stricture	ICD-9-D-5303, ICD-10-D-Q393
Barrett esophagus	ICD-9-D-53085, ICD-10-D-K2270, ICD-10-D-K22710, ICD-10-D-K22711, ICD-10-D-K22719
Roux-en-Y Bypass	CPT-43621, CPT-43633, CPT-43644
Cachexia	ICD-9-D-7994, ICD-10-D-R64
Other	
Osteoporosis	ICD-10-D-M810, ICD-10-D-M818, ICD-9-D-73300, ICD-9-D-73301, ICD-9-D-73309, ICD-9-D-73302, ICD-9-D-73303
Vitamin D deficiency	ICD-9-D-2689, ICD-10-D-E559
Pharmacotherapy	
Alendronate	GENERIC_DRUG-ALENDRONATE_SODIUM GENERIC_DRUG-ALENDRONATE_SODIUM/VITAMIN_D3
Risedronate	GENERIC_DRUG-RISEDRONATE_SOD/CALCIUM_CARB GENERIC_DRUG-RISEDRONATE_SODIUM
Ibandronate	GENERIC_DRUG-IBANDRONATE_SODIUM
Zoledronic acid	GENERIC_DRUG-ZOLEDRONIC_AC/MANNITOL/0.9NACL GENERIC_DRUG-ZOLEDRONIC_ACID GENERIC_DRUG-ZOLEDRONIC_ACID/MANNITOL&WATER GENERIC_DRUG-ZOLEDRONIC_ACID/MANNITOL-WATER
Raloxifene	GENERIC_DRUG-RALOXIFENE_HCL
Denosumab	GENERIC_DRUG-DENOSUMAB
Teriparatide	GENERIC_DRUG-TERIPARATIDE
Abaloparatide	GENERIC_DRUG-ABALOPARATIDE
Calcitonin	GENERIC_DRUG-CALCITONIN_SALMON_SYNTHETIC

Supplemental Table 2
Codes used to define complications.

Complication	Code(s)
Periprosthetic fracture	ICD-9-D-99644, ICD-10-D-M9701XA, ICD-10-D-M9702XA, ICD-10-D-T84040A, ICD-10-D-T84041A
Fragility fractures	See Supplemental Table 1
Revision THA	CPT-27134, CPT-27137, CPT-27138

Supplemental Table 3
Breakdown of most common osteoporosis medications on claims filed by patients after a fragility fracture.

Medications	Patients	Claims	Average RX length (d)	Average RX CoPay
Total	303	1836	46	$21.85
ALENDRONATE_SODIUM	196	1136	46.39	$5.45
CALCITONIN_SALMON_SYNTHETIC	29	164	35.23	$14.71
DENOSUMAB	16	25	78.08	$52.84
IBANDRONATE_SODIUM	46	167	54.4	$35.75
RALOXIFENE_HCL	15	84	41.79	$24.33
RISEDRONATE_SODIUM	20	112	56.18	$65.87
TERIPARATIDE	21	146	32	$101.41
ZOLEDRONIC_ACID/MANNITOL-WATER	−1[a]	−1[a]	227.5	$0.00

[a] To protect patient identities, "−1" is reported by the PearlDiver software when patient/claim counts are less than 11.