



The Effect of Age and Activity Level on Stem Subsidence in Total Hip Arthroplasty

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Abstract

The average length of hospital stay (LOS) following total hip arthroplasty (THA) is decreasing due to a variety of factors, including rapid patient mobilization. With increased early joint loading, certain populations, such as those with low systemic bone mineral density, may be at an increased risk for early stem instability. The purpose of this study was to determine whether activity level and patient age affect femoral stem stability and early subsidence. We retrospectively reviewed 821 patients who underwent primary cementless THA. Two cohorts were established based on LOS as a proxy for activity: (1) same calendar day discharge (SDD) and (2) multiple day stay (MDS). Descriptive patient characteristics as well as surgical and clinical data including surgical time, stem alignment, and Activity Measure for Post-Acute Care (AM-PAC) scores were collected. Stem subsidence was assessed by comparing immediate postoperative radiographs with follow-up radiographs taken no less than 3 months after surgery (9.79 ± 6.50 months). Our sample population consisted of 255 SDD (31%) and 566 MDS (69%) patients. Stem subsidence rate was significantly lower in the SDD than the MDS group (0.916 vs. 1.80 mm, $p < 0.001$). Increasing age was associated with a higher rate of stem subsidence ($\beta = 0.823$, $p < 0.001$). Increased LOS was also associated with increased age (odds ratio = 1.092, $p < 0.001$). Higher postoperative mobility determined by AM-PAC scores was not associated with shorter LOS ($p = 0.630$). The result of this study showed increased activity level does not increase rate of subsidence in THA patients, which supports the safety and efficacy of expedited recovery programs. Increased age was found to increase stem subsidence regardless of LOS.

Keywords

- ▶ THA
- ▶ total hip arthroplasty
- ▶ subsidence
- ▶ activity
- ▶ AM-PAC
- ▶ DAA

Advancements in surgical techniques and postoperative rehabilitation as well as standardization of postoperative protocols have led to earlier mobilization and patient discharge following total hip arthroplasty (THA).^{1–4} As length of stay (LOS) decreases and outpatient arthroplasty becomes increasingly common, many have sought to quantify the outcomes of these abbreviated stays. However, most of these analyses on success rates have focused on patient-centric results rather than clinical outcomes such as stem subsidence.

Femoral stem subsidence following THA has been shown to occur between 1 week and 3 months following surgery

with the largest changes occurring within the first 6 weeks.^{5–7} After 3 months, little change in subsidence is seen up to 2 years postoperatively.^{6,8} While subsidence is seen across all patient populations, poor bone quality and aging have been associated with femoral stem subsidence. Low systemic bone mineral density (BMD) delays the osseointegration of the stem while osteoporosis and aging have been well documented as having multiple negative effects on the proximal femur including: the reduction of bone density of the trochanteric cancellous bone, increased intracortical porosity, and geometric changes.^{9–12} These

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findings place older, postmenopausal females at greater risk for stem subsidence.^{9,10}

As LOS decreases, the degree of loading on the stem following surgery is rapidly increasing as patients are more rapidly mobilized, discharged home more often, and are encouraged to move around more at home. While it has been recommended to limit postoperative activity, there is significant evidence that unrestricted weight bearing following THA does not adversely affect short- or long-term subsidence in comparison to partial weight bearing.^{6,8,13,14} In addition, others have found that bone ingrowth will occur regardless of postoperative weight bearing.^{15,16} These studies showed that the time until full weight bearing status did not affect postoperative stem subsidence and that initial postoperative stem fixation may play a larger role. This suggests that subsidence outcomes are influenced less by load and activity than by the biologic processes that lead to bony ingrowth.

As a greater number of patients have fast-tracked, outpatient THA, concerns over how this immediate discharge effects patient outcomes rises. Our primary objective in the present study was to analyze the effect of age and activity on stem subsidence following THA. We hypothesize that activity will not affect femoral stem subsidence, but age may have an effect due to the low BMD common in older patients.

Methods

A retrospective study was conducted on patients who underwent a primary cementless THA at a large urban academic hospital between January 2016 and October 2017. This study was approved by the institutional review board. These cases were identified using the Current Procedure Terminology code 27130 and were collected from our institution's electronic medical record. Inclusion criteria for our study included patients whose age was greater than or equal to 18 years at the time of their surgery and underwent a primary THA. Exclusion criteria included patients who were less than 18 years old or underwent a revision THA. Baseline patient demographic data such as age, body mass index (BMI), American Society of Anesthesiologists (ASA) score, gender, race, and smoking status were collected for all qualifying patients. Additional information including surgical time, stem type, stem alignment, LOS, Boston University Activity Measure for Post-Acute Care Short Form (AM-PAC) scores, and radiographs were also collected and analyzed. All data was recorded and deidentified using the Microsoft Excel software.

Patient Population

Our cohort consisted of 821 consecutive patients who underwent primary cementless THA. A single surgeon at a tertiary, urban, academic institution performed all surgeries using a direct anterior approach (DAA). All patients had one of two stem designs (Anthology [Smith & Nephew] or Accolade [Stryker Orthopedics]). The choice for same-day discharge (SDD) versus inpatient stay was made through a shared decision-making process between surgeon and patient.

We retrospectively divided the cohort into two groups: (1) patients who had SDD ($n = 255$) and (2) patients who had a

multiple day inpatient stay (MDS) ($n = 566$). The SDD cohort consisted of 50% females and 50% males with an average age of 58.98 ± 8.47 years. The MDS cohort was comprised of 64% females and 36% males with an average age of 67.17 ± 10.27 years. The SDD cohort was discharged with limited restrictions regarding activity and weight-bearing status while the MDS cohort had a longer hospital LOS with limited opportunities to be mobile in the hospital compared with patients at home. With less assistance, greater independence, and few limitations concerning activity, SDD patients would have had a higher activity levels compared with the MDS patients who had their activity limited by hospital environment and staff.

Radiologic Evaluation

Postoperative anterior-posterior radiographic images of the hip were used to measure stem subsidence. Subsidence was measured through a comparison of most recent radiographs to immediate postoperative radiographs. The time between immediate postoperative and follow-up radiographs ranged from 3 months to 2 years. Before measurements were taken, radiographic calibration utilizing the known femoral head size was completed for each image. Measuring procedures for each image started by drawing a line parallel to the long-axis of the femoral stem followed by two perpendicular lines placed at the level of the femoral stem shoulder and the superior tip of the greater trochanter. The perpendicular distance between these parallel lines were noted (**Fig. 1**). Differences between immediate postoperative and follow-up images were recorded as stem subsidence. Radiographic analysis was performed by two trained observers (J.G. and J.P.), who both agreed on the methodology that would be used throughout the measurement process. To ensure consistency, they performed alignment and subsidence measurements for the first 10 patients in the study cohort together. The interrater reliability of the first 10 measurements as calculated by the Cohen's kappa was 0.719 which demonstrates substantial agreement between the two raters and is on the higher end of interrater reliability among other studies examining subsidence.^{17,18} This same method used to measure subsidence was utilized to assess stem alignment (neutral, varus, valgus). The degree of varus or valgus angulation was defined as the angle formed between the central shaft of the stem and the medial or lateral endosteal cortices, respectively. As previously described in the literature, a stem was categorized into varus or valgus alignment if the angle deviated ≥ 5 degrees from neutral.¹⁹⁻²¹

AM-PAC Score Analysis

The Boston University AM-PAC assessment is used to evaluate an individual's ability to execute important functional activities.²² We recorded and analyzed the scores of the first inpatient AM-PAC test that each patient performed. AM-PAC raw scores were converted into Centers for Medicare and Medicaid Services G-code modifiers based on Mediware's (Mediware, Lenexa, KS) conversion chart and were subsequently analyzed.²³ Modifier CH, which indicates 0% impairment, was used as our control for comparison. Other modifiers include CI (at least 1% but less than 20% impaired), CJ (at least 20% but less than 40% impaired), and CK (at least

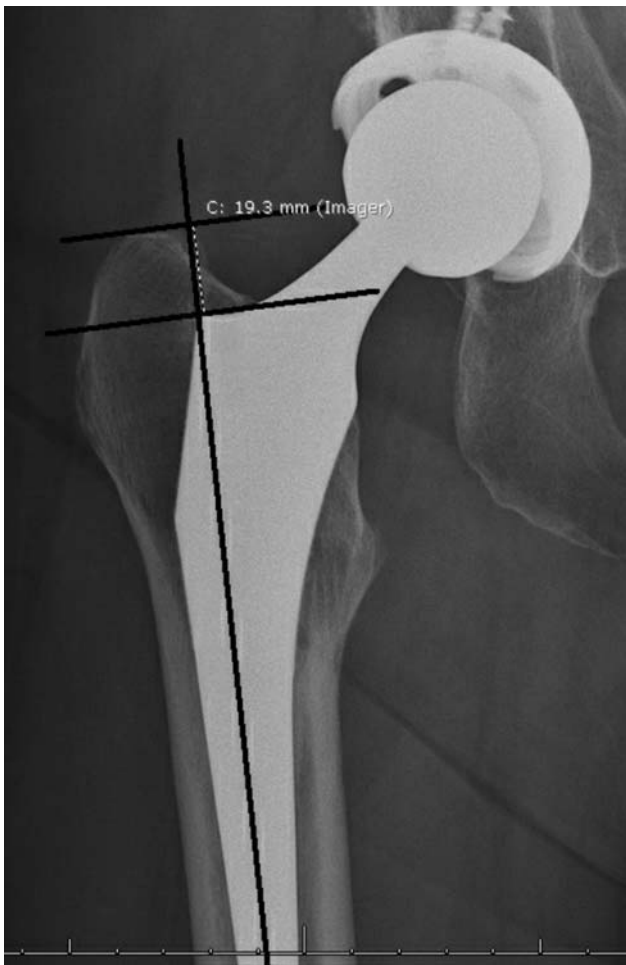


Fig. 1 Example of how subsidence measurements were made on radiographic images.

40% but less than 60% impaired).²³ We had no cases of CL, CM, or CN (60–100% impairment).

Statistical Analysis

Descriptive data are represented as means ± standard deviation. Independent sample, two-sided *t*-tests were used to test for significant differences between continuous variables and chi-square tests for categorical variables. Multivariable linear regression models were utilized to study the association between independent predictors including age, gender, BMI, stem type, stem alignment, surgical time, and the dependent variable, subsidence. Binary regression models were used to examine the relation of the covariates of age, gender, BMI, stem type, stem alignment, surgical time on the dependent variable, and LOS. Regression coefficients were calculated with 95% confidence intervals (CIs), which we used to describe significance of association. A *p*-value of less than 0.05 was considered to be significant. All statistical analyses were performed using SPSS v. 25 (IBM Corporation).

Results

The primary objective of this study was to determine if activity and patient age impacted femoral stem subsidence. In a 22-

month period, we identified 821 patients who underwent a primary DAA THA by a single surgeon with 255 qualifying for the SDD cohort and 566 for the MDS cohort (► **Table 1**). Statistically significant demographic differences were observed between the two groups with a significantly larger percentage of females and older patients in the MDS cohort ($p < 0.001, p < 0.001$; ► **Table 1**). Patients with higher BMIs and those who were more at risk according to the ASA physical status were also found more often in the MDS group ($p < 0.001, p < 0.001$; ► **Table 1**). While there was a statistical difference in surgical time between the two groups (69.46 ± 10.67 vs. 70.99 ± 14.32 minutes, $p < 0.001$; ► **Table 2**) when controlling for differences in demographic data, there was no clinical

Table 1 Patient demographic data for the two cohorts: same-day discharge (SDD) and the greater than 24-hour discharge groups (MDS)

Patient demographics			
	Same-day discharge (n = 255)	Greater than 24 h (n = 566)	<i>p</i> -Value ^a
Age (y)	58.98 ± 8.47	67.17 ± 10.27	< 0.001
Gender			< 0.001
Female	127	362	
Male	128	204	
BMI (kg/m ²)	26.61 ± 4.01	27.65 ± 5.07	< 0.001
ASA			< 0.001
1	30	15	
2	216	345	
3	9	197	
4	0	9	
Median	1.95	2.35	
Race			0.670
White	232	520	
Other race	23	46	
Smoking status			0.022
Current	19	34	
Former	78	230	
Never	158	302	
AM-PAC score			0.006
CL	0	3	
CK	12	63	
CJ	11	15	
CI	12	15	
CH	89	164	

Abbreviations: AM-PAC, Activity Measure for Post-Acute Care; ASA, American Society of Anesthesiologists; BMI, body mass index.

^a*p*-Values are derived from two-tailed *t*-test or chi-square tests for categorical values.

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significance. Stem type and stem alignment did not significantly differ between cohorts ($p = 0.260, p = 0.566$; ► **Table 2**).

To account for the statistically significant differences in demographic and surgical data, linear regressions were utilized to compare stem subsidence with a variety of factors. The model showed that of all the variables examined, only increases in LOS and age were found to be associated with higher stem subsidence ($p < 0.001, p < 0.001$; ► **Table 3**). AM-PAC scores were not found to correlate with stem subsidence in our model ($p = 0.634$; ► **Table 3**).

Several binary regressions were run to determine if there was a difference in complication rates between the two cohorts when controlling for differences in the demographic data. While one fracture was recorded for the SDD cohort and six for the MDS group, which ranged from 5 days to 1 year postoperatively, models showed that there were no statistical differences in periprosthetic fracture rates (0.40% vs. 1.09%, $p = 0.995$; ► **Table 4**). There were no dislocations in either cohort. The 90-day readmission rates were also found to be insignificantly different between the groups with only one readmission for the SDD cohort and 24 for the MDS cohort (0.39 vs. 2.47%, $p = 0.533$; ► **Table 4**). Patients who were readmitted within 90 days had a 53.1% decreased odds of being in the SDD cohort (odds ratio [OR], 0.469; 95% CI; $p = 0.533$; ► **Table 4**). Readmission results were fully powered to show a significant difference (power of 86.27% [$\alpha = 0.10$]).

An additional binary regression was run to determine which variables contributed to a MDS. Models showed that increased age led to a 9.6% higher OR of being in the MDS cohort ($p < 0.001$; ► **Table 5**). Additionally, higher BMI led to 6% increase in OR for being in the MDS cohort while being male is associated with a 267% increased OR ($p = 0.009$; $p < 0.001$; ► **Table 2**). Initial high-impairment AM-PAC scores were not associated with longer LOS ($p = 0.630$; ► **Table 5**).

Table 2 Surgical characteristics between the same-day discharge (SDD) and the greater than 24-hour discharge groups (MDS)

Surgical characteristics			
	Same-day discharge (n = 255)	Greater than 24 h (n = 566)	p-Value ^a
Surgical time (min)	69.46 ± 10.67	70.99 ± 14.32	< 0.001
Subsidence (mm)	0.916 ± 0.86	1.80 ± 1.91	< 0.001
Stem			0.260
Anthology	127	362	
Accolade	128	204	
Stem alignment			0.566
Neutral	235	531	
Varus	19	29	
Valgus	1	6	

Note: Analysis accounts for differences in demographic data.
^ap-Values are derived from a binary logistic and linear regressions.

Table 3 Multivariate linear regression analysis of stem subsidence

Linear regression for stem subsidence		
	Unstandardized β	p-Value ^a
LOS	0.823	0.002
Age	0.023	0.042
BMI	0.005	0.837
ASA	0.115	0.621
Gender	0.134	0.574
Race	-0.010	0.981
Smoking	0.099	0.481
Surgical length	-3.341×10^{-5}	0.997
Stem	0.000	0.999
AM-PAC	0.041	0.634

Abbreviations: AM-PAC, Activity Measure for Post-Acute Care; ASA, American Society of Anesthesiologists; BMI, body mass index; LOS, length of stay.

^ap-Values are derived from a multivariate linear regression.

Discussion

With population growth and increased life expectancy, the demand for THA is expected to continue to increase.¹⁹ At the same time, there are institutional and patient-driven pressures for shorter hospital stays and faster rehabilitation. It has previously been thought that early mobilization places patients at an increased risk of early femoral stem subsidence. This can lead to hip instability, periprosthetic fracture, limb length discrepancy, and other complications, possibly requiring revision surgery. While stem subsidence is a major concern, much of the published literature on early mobilization following THA focuses on patient-centered outcomes and do not examine clinical outcomes.^{7,24} The goal of this study is therefore to report how activity affects stem subsidence among all patients who undergo a cementless primary THA.

Femoral stem subsidence has been found to usually occur within the first few weeks following surgery and remains relatively unchanged between the 3-month and 2-year follow-up.⁶⁻⁸ As a result, we were able to collect data on a large patient population who had follow-up radiographs between 3 months and 2 years post-THA. Upon splitting our sample population into SDD and MDS groups and controlling for differences in demographic data, we found that LOS was affected by age, with older patients staying in the hospital for multiple days (OR, 1.092; 95% CI: 1.07-1.12; $p < 0.001$; ► **Table 5**). This confirms previous findings which show that older patients either opt for or are assigned an inpatient admission and are kept longer due to preexisting conditions.^{4,25} Results also showed that higher BMI and being male is associated with a MDS (OR, 1.070, 95% CI: 1.04-1.11, $p = 0.46$; OR, 3.668, 95% CI: 2.03-4.55, $p < 0.001$; ► **Table 5**). Otero et al showed that obesity and the male gender are significant risk factors that affects complication rates in total

Table 4 Logistic regression analysis of complication data post-THA

Logistic regression for complication data				
	Periprosthetic fractures		90-day readmission	
	Odds ratio	p-Value ^a	Odds ratio	p-Value ^a
LOS	0.996	0.997	0.469	0.533
Age	1.078	0.115	1.011	0.772
BMI	1.053	0.548	1.101	0.138
Gender ^b	1.972	0.447	0.709	0.709
Race ^c	0	0.997	0	0.997
Smoking ^d		0.739		0.92
Former smoker	6.7 × 10 ⁶	0.996	1.954	0.519
Current smoker	3.4 × 10 ⁶	0.997	1.516	0.702
ASA	0.812	0.801	1.048	0.909
Stem	1.869	0.436	1.014	0.225
Surgical length	1.05	0.005	0.999	0.972

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; LOS, length of stay; THA, total hip arthroplasty.

^ap-Values are derived from binary logistic regressions.

^bFemale gender was used as the reference.

^cWhite race was used as the reference.

^dNonsmoker was used as the reference.

joint arthroplasty (TJA) which could explain why these patients were more often kept in the hospital for longer period.²⁶ Other studies corroborate these finding and have shown that obesity and being male leads to longer LOS and longer inpatient rehabilitation stays following TJA.^{27,28} Higher ASA scores, which are associated with greater comorbidities, were also shown to lead to longer LOS (►Table 5). These findings coincide with other studies which have shown similar results and correlate this increase in LOS to the fact that these patients are more at risk for complications.^{27,28}

When examining the factors which effect subsidence in elective primary DAA THA, we found that increasing age is related to increased stem subsidence. Published results on stem subsidence following cementless THA vary greatly with an average range of subsidence between 0.45 and 2.23 mm.^{8,29–34} Each cohort consisted of only patients that underwent THA with the DAA and the mean subsidence in our study was within the accepted range noted in the literature which suggests that approach does not affect subsidence outcomes. While excessive stem subsidence was not observed, there was a significant difference between cohorts with the less active MDS group experiencing greater subsidence than the SDD group (1.80 vs. 0.92mm, *p* < 0.001). Following THA, it has been shown that younger patients may have comparable activity levels to older patients.²⁴ If mechanical causes were responsible for subsidence, the expectation would be similar subsidence levels. However, our results showed that aging was associated with a slight increase in subsidence, which implies that another mechanism is affecting the subsidence in these older patients ($\beta = 0.023$, *p* < 0.001). Additionally, our findings that increased load due to BMI or activity does not affect subsidence

Table 5 Logistic regression analysis of whether a patient remained in the hospital for greater than or less than 24 hours

Logistic regression for LOS		
	Odds ratio	p-Value ^a
Age	1.092	< 0.001
BMI	1.070	0.046
ASA	9.298	< 0.001
Gender ^b	3.668	< 0.001
Race ^c	0.921	0.866
Smoking ^d		0.698
Former smoker	1.541	0.505
Current smoker	1.736	0.408
Surgical length	1.025	0.082
Stem	0.606	0.078
AM-PAC ^e		0.630
CL	0.340	0.560
CK	0.106	0.745
CJ	1.059	0.303
CI	2.516	0.113

Abbreviations: AM-PAC, Activity Measure for Post-Acute Care; ASA, American Society of Anesthesiologists; BMI, body mass index; LOS, length of stay.

^ap-Values are derived from a binary logistic regression.

^bFemale gender was used as the reference.

^cWhite race was used as the reference.

^dNonsmoker was used as the reference.

^eAM-PAC score: "CH" was used as the reference.

would also suggest that there is an additional nonmechanical reason for the increase in subsidence with age ($p = 0.837$). While there is some evidence that poor bone quality has been overemphasized, many studies have shown that low BMD, which is associated with aging, will delay osseointegration of the stem and may result in migration.^{9,12} Additional aging effects such as postmenopausal status and osteoporosis have also been linked with increased risk of stem subsidence.^{9,10} Analysis has shown that decreases in BMD such as those related to aging and osteoporosis have a negative effect on the proximal femur resulting in the reduction of bone density of the trochanteric cancellous bone, increased intracortical porosity, and geometric changes.^{11,12} While the scope of our study did not examine the causes of stem subsidence, our results correlated with increased stem subsidence risk associated with comorbidities that directly relate to an increase in age.

While we found that age has a correlation with stem subsidence in both the SDD and MDS group, we determined that early activity after surgery, using SDD as a proxy, does not negatively impact stem subsidence levels, which supports our hypothesis of a nonmechanical mechanism for subsidence. Patients with a SDD were assumed to be more active as they would have to be more mobile in a nonclinical setting. We found that patients who remained in the hospital for longer had higher rates of subsidence than SDD patients ($\beta = 0.823$, $p = 0.002$). While these findings suggest that increased activity does not lead to increased stem subsidence, our statistical analyses did not include comorbidities, which may have contributed to the increased LOS of the MDS cohort. The patients who are chosen for inpatient admission often have a greater number of coexisting comorbidities and may have decreased preoperative ambulatory function which could skew our results.⁴ Since LOS and activity level are not directly comparable, additional research is required to confirm the effect of early activity level on stem subsidence as well as other comorbidities that influence LOS. However, these results suggest that increased postoperative mobilization following direct anterior THA does not negatively impact stem subsidence.

In addition to having no negative effect on subsidence, our data showed that postoperative activity level had little effect on complication data. Results showed no difference in fracture rates or number of dislocations within 90 days between the two cohorts. While not fully powered to show a difference in fracture rates between cohorts, our rate of incidence for the MDS group, 1.09%, corresponded with data from the Mayo Clinic Joint registry which finds an incidence of approximately 1.1% of periprosthetic fractures in patients who underwent press-fit femur implants as part of a THA, while our SDD group was less than this accepted rate of incidence, 0.40%.³⁵ It follows that despite a patient's LOS, the DAA does not negatively impact periprosthetic fracture incidence rates. Additionally, these results suggest that postoperative activity levels do not negatively impact fracture rates. We also found that a MDS was not correlated with a higher likelihood of being readmitted 90 days postoperatively when controlling for factors that we found to

effect LOS including age, gender, BMI, and ASA class (OR, 0.469; 95% CI: 0.39–1.30, $p = 0.533$). Several variables that we were unable to take into account, which other studies find could be affecting readmission rates, include additional comorbidities and socioeconomic issues.³⁶ However, our results suggest that activity level does not affect readmission rates.

While we found that increased age is associated with stem subsidence, our research shows that there are other comorbidities that may contribute to stem subsidence after THA. Comorbidities that may contribute to poor bony integration of the stem, as often seen in older patients and patients with longer LOS, may influence these differences. With further research to identify risk factors for stem subsidence, we can better select the proper technique for stem fixation for each patient and decrease the risk of complications after THA. Such improvements have the potential to increase patient satisfaction and decrease complications and the cost associated with THA.

There are several limitations to this study that should be noted, including its retrospective design. Additionally, all THA cases were performed by a single surgeon at one institution, which may limit the generalizability of the study. Only two THA implant types were utilized, also potentially limiting extrapolation of the results to other stem types. Additionally, our study is limited by the fact that we do not know exactly how much activity or mobility the patients in either cohort had following their procedure. However, our study design attempted to mitigate this limitation as the SDD patients were not told to limit their activity and mobilization at home while the MDS cohort had their activity restricted during their hospital stay due to the environment and staff.

Conclusion

The results of this study demonstrated that when SDD is taken as a proxy for postoperative activity level, press-fit stems in SDD patients do not subside more than press fit stems in patients who were in the hospital for multiple days (i.e., less active patient cohort). Furthermore, we found that the rates of subsidence and periprosthetic fractures following DAA THA were not higher than those of historical database reports. These findings suggest that femoral stem subsidence is more dependent on the biologic ability of the bone to osseointegrate with the implant and with osteoporosis than the extent of early mechanical loading. We caution surgeons to carefully consider the use of press-fit implants in the more elderly populations regardless of discharge disposition or activity level.

Conflict of Interest

Dr. Schwarzkopf reports grants and personal fees from Smith & Nephew and Intellijoint, personal fees from Gauss Surgical, outside the submitted work. Dr. Davidovitch reports other income from Radlink, Scherer Medical, Exactech, and Medtronic, outside the submitted work.

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