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Original research

A Contemporary Classification System of Femoral Bone Loss in Revision Total Hip Arthroplasty

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ABSTRACT

Background: Current femoral bone loss classification systems in revision total hip arthroplasty were created at a time when the predominant reconstructive methods used cylindrical porous-coated cobalt-chrome stems. As these stems have largely been replaced by fluted-tapered titanium stems, the ability of these classification systems to help guide implant selection is limited. The purpose of this study was to describe a novel classification system based on contemporary reconstructive techniques.

Methods: We reviewed the charts of all patients who underwent femoral component revision at our institution from 2007 through 2019. Preoperative images were reviewed, and FBL was rated according to the Paprosky classification and compared to ratings using our institution's NCS. Rates of reoperation at the time of most recent follow-up were determined and compared.

Results: Four-hundred and forty-two femoral revisions in 330 patients with a mean follow-up duration of 2.7 years were identified. Femoral type according to Paprosky and NCS were Paprosky I (36, 8.1%), II (61, 13.8%), IIIA (180, 40.7%), IIIB (116, 26.2%), and IV (49 11.1%) and NCS 1 (35, 7.9%), 2 (364, 82.4%), 3 (8, 1.8%), 4 (27, 6.1%), and 5 (8, 1.8%). Of the 353 nonstaged rTHAs, there were 42 cases requiring unplanned reoperation (11.9%), including infection (18, 5.1%), instability (10, 2.8%), femoral loosening (5, 1.4%), and various other causes (9, 2.5%). The NCS was more predictive of reoperation than the Paprosky classification (Fisher's exact test, $P = .008$ vs $P =$ ns, respectively).

Conclusion: We present a novel femoral classification system that can help guide contemporary implant selection.

Introduction

Total joint arthroplasty is currently among the fastest growing procedures in the United States [1,2]. Despite the overall high efficacy and good survivorship of total hip arthroplasty (THA), roughly 12%-17% of patients undergoing THA will require revision THA (rTHA) at some point during the implant's lifespan, and the prevalence of rTHA is expected to rise by as much as 43%-70% by 2030 [2–4].

When planning for femoral component revision, hip arthroplasty surgeons rely upon femoral bone loss (FBL) classification systems to help facilitate communication and to guide technique and implant selection. In addition, a reliable classification system can provide a foundation for comparative outcome analysis through appropriate categorization of individual cases. The Paprosky classification is perhaps the most commonly used FBL classification system in the context of rTHA. It defines 4 types of FBL based on location and degree of residual femoral bone stock and proposes a treatment algorithm for implant selection [5,6]. Other less commonly used FBL classification systems include the D'Antonio classification (6 categories and multiple subcategories relating to bone loss severity, adopted by the American Academy of Orthopedic Surgeons) [3,7], the Mallory classification (3 types based on the bony deficits in the cortex and medullary canal) [8], and the Saleh classification (a five-point system) [9].

Current FBL classification systems, including Paprosky's, were created at a time when the workhorse revision femoral implant was

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a cylindrical porous-coated cobalt-chrome (PCC) stem. These implants were technically challenging to use, as stems of the same size were frequently not exactly of the same diameter. Even with the use of a hole gauge, often a surgeon was left to risk intraoperative fracture on one hand or stem subsidence on the other. In addition, owing to high rates of thigh pain and stress shielding associated with their use, these stems have largely been replaced by fluted tapered titanium (FTT) stems for most femoral subtypes (even those with greater than 4 centimeters of isthmic bone remaining, previously thought to be ideal for reconstruction with a cylindrical PCC stem) [10,11]. The FTT femoral stem has also gained popularity over the past 2 decades in the United States because of its capacity to achieve excellent initial stability over very short distances of isthmic femoral bone [11–13]. Because previous classification systems are largely based on implants that are no longer routinely used, their ability to help guide contemporary implant selection is limited [5].

A contemporary system would potentially help guide implant selection, facilitate provider communication, and improve risk stratification. With this study, we describe a novel classification system (NCS) for FBL in rTHA based on bone loss location, pattern, and residual bone quality. In addition, we hypothesized that the NCS would show better correlation with reoperation than the Paprosky classification.

Methods

Data collection and patient demographics

After obtaining approval from our institution's review board, we identified all patients who underwent revision THA at our institution from January 1, 2007, through December 31, 2019. Charts were reviewed, and patients were excluded if they did not undergo revision of the femoral component at the time of surgery. Demographic data were collected, including age at the time of revision, sex, indication for surgery, existing femoral implant type, revision femoral implant type, date of most recent radiographic and clinical follow-up, and implant fixation at the time of most recent follow-up.

Prerevision plain radiographs were reviewed, and all femora were classified according to both the Paprosky classification and our institution's NCS (Fig. 1 and 3, Appendix). Classifications were performed by one of the senior authors (AJS), who is a fellowship-trained arthroplasty surgeon with greater than 10 years of experience. The Paprosky system is made up of 5 types (implant types recommended by the original authors in parenthesis): type I, minimal metaphyseal bone loss and intact diaphysis (primary metaphyseal-filling hip stem of choice); type II, extensive metaphyseal bone loss and intact diaphysis (metaphyseal- or diaphyseal-engaging stem); type IIIA, severe nonsupportive metaphyseal bone loss with greater than 4 cm intact isthmic bone (PCC stem); type IIIB, severe metaphyseal bone loss with less than 4 cm isthmic bone (FTT stem); type IV, extensive metaphyseal and diaphyseal bone loss with nonsupportive femoral bone throughout (no definitive reconstruction type recommended, APC, proximal femoral replacement, impaction grafting suggested) [14,15]. The NCS is made up of 5 types: type 1, metaphysis intact and supportive of a proximally engaging stem; type 2, metaphysis deficient and diaphysis supportive of conical or cylindrical reaming; type 3, diaphysis will not support conical/cylindrical reaming and greater than 13 cm of circumferential bone intact measured from the intercondylar notch; type 4, less than 13 cm but greater than 6 cm of bone measured from the intercondylar notch and adequate cortical bone (cortical thickness 2.5 mm or greater) to support compressive force; type 5, none of the above.

The distinctions in this classification system are based on the minimum host bone requirements for stable reconstruction. The presence of 13 cm of distal bone allows for conventional proximal femoral replacement stems, which are typically 13 cm or less in length and require this amount of bone proximal to the

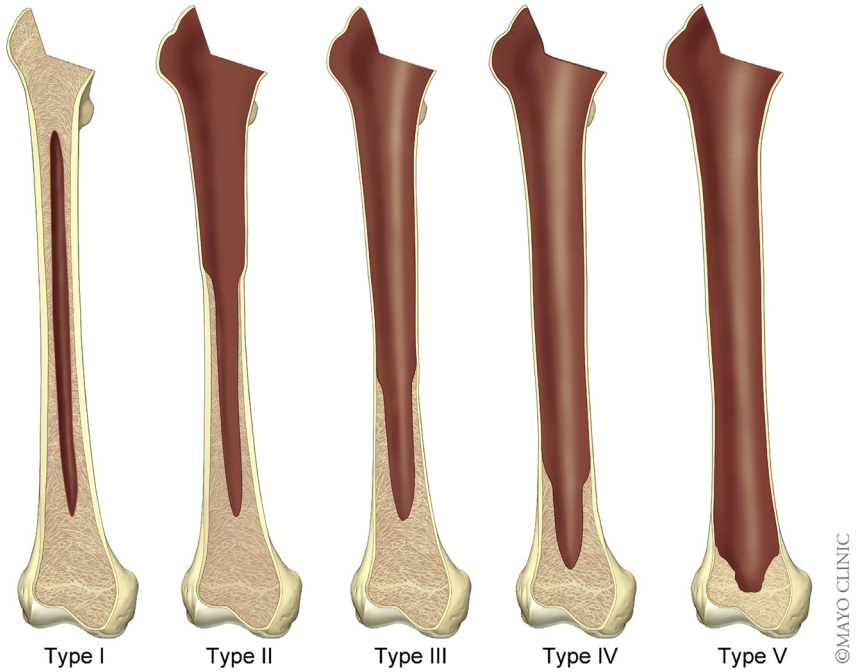

Figure 1. Type 1, normal metaphyseal bone supportive of primary femoral component; type 2, intact isthmus supportive of conical reaming; type 3, cortical thinning and diaphyseal ectasia with bone loss beyond the isthmus, not supportive of conical reaming, but with at least 13 cm of bone remaining measured from the intercondylar notch; type 4, less than 13 cm of remaining bone measured from the intercondylar notch, and presence of minimum cortical thickness of 2.5 millimeters over a length of at least 6 centimeters; type 5, none of the above.

intercondylar notch to fully be seated in the canal. The 6 cm length distinction is the minimum length needed for the anchor plug of a device that uses compressive osseointegration. Below this amount, total femur is the remaining option. In essence, the NCS recognizes that the vast majority of Paprosky types are now treated with FTT stems and thus condenses the Paprosky type 2, 3A, and 3B subtypes into a single category (type 2, supportive of conical reaming). It further expands the Paprosky type 4 into 3 separate categories (type 3, 4, and 5) based on specific radiographic landmarks.

Statistical analysis

Descriptive statistics for demographic variables among all patients were determined, and unplanned reoperations were analyzed for patients not undergoing staged revision at the time of the index procedure. Unplanned reoperations were labeled as revision for any reason, revision for infection, revision for instability, revision for aseptic loosening of the femoral stem, and other causes. Categorical variables were compared using the Fisher's exact test of statistical significance with alpha set to <0.05.

Implant survival was determined using the Kaplan-Meier method, and survival curves were compared using the log-rank method. Multivariable Cox regression models were made using unplanned reoperation for any reason, for infection, and for instability as the dependent variables and backward stepwise elimination of independent variables, including demographics and femoral classification type. Hazard ratios between femoral classification subtypes were compared with alpha set to <0.05.

Statistical analysis was performed using JMP Pro (SAS Institute, Cary, NC).

Results

Four-hundred and forty-two femoral revisions were performed in 330 patients during the study period. The mean patient age was 70.4 (range, 29 − 93), and the cohort included more males (196, 59.4%) than females (134, 40.6%, $P < .001$). The mean follow-up was 2.7 years (median, 1.6 years; range, 0 to 12 years).

The indication for femoral revision included aseptic loosening (153 cases, 34.6%), second-stage reimplantation for periprosthetic joint infection (116 cases, 26.2%), first-stage revision for infection (92 cases, 20.8%), periprosthetic fracture (27 cases, 6.1%), adverse local tissue reaction to metal debris (18 cases, 4.1%), repeat first-stage revision for infection (18 cases, 4.1%), instability (7 cases, 1.6%), fractured femoral stem (4 cases, 0.9%), conversion to THA from bipolar (4 cases, 0.9%), and other reasons (3 cases, 0.7%).

The femur was classified as Paprosky type IIIA in 180 cases (40.7%), IIIB in 116 cases (26.2%), II in 61 cases (13.8%), IV in 49 cases (11.1%), and I in 36 cases (8.2%) and NCS type 2 in 364 cases (82.4%), 1 in 35 cases (7.9%), 4 in 27 cases (6.1%), 3 in 8 cases (1.8%), and 5 in 8 cases (1.8%). Femoral implants used for each femoral type at the time of revision according to both the Paprosky classification and the NCS are listed in Table 1.

Three-hundred and fifty-three index revisions (79.9% of the entire cohort) were performed without the intention of a planned second-stage reoperation. Among these cases, there were 42 unplanned reoperations (11.9%) for infection (18 cases, 5.1%), instability (10 cases, 2.8%), aseptic loosening of the femoral stem (5 cases, 1.4%), periprosthetic fracture (2 cases, 0.6%), removal of a symptomatic cerclage cable (2 cases, 0.6%), adverse local tissue reaction to metal debris (1 case, 0.3%), fractured modular taper junction (1 case, 0.3%), lateral femoral cutaneous nerve exploration (1 case, 0.3%), sciatic nerve exploration (1 case, 0.3%), and psoas impingement (1 case, 0.3%; Fig. 2A and 2B). Fourteen femoral components were revised (3.9%) for infection (7 cases), aseptic loosening (5 cases), fractured modular taper (1 case), and instability (1 case).

The proportion of patients undergoing unplanned reoperation for any reason was highest for Paprosky type IV (10 of 34 cases, 29.4%), followed by type IIIB (11 of 98 cases, 11.2%), type IIIA (15 of 150 cases, 10.0%), and type II (4 of 43 cases, 9.3%), and NCS type 3 (4 of 8 cases, 50%), followed by type 5 (2 of 7 cases, 28.6%), type 4 (2 of 15 cases, 13.3%), type 2 (33 of 292 cases, 11.3%), and type 1 (1 of 31 cases, 3.2%). Reoperation for any reason was significantly associated with NCS type, but not with Paprosky type using Fisher's exact test ($P < .008$ vs $P = .053$).

Using unplanned reoperation for any reason as the endpoint, NCS type 3 femora had a significantly higher likelihood of revision (odds ratio 7.8 vs NCS type 2, 95% confidence interval [CI]: 1.9-32.9). Using unplanned reoperation for infection as the endpoint, NCS type 5 femora had a significantly higher likelihood of revision (odds ratio 8.6 vs NCS type 2, 95% CI: 1.5-48.5). Using unplanned reoperation for instability as the endpoint, NCS type 3 femora had a significantly higher likelihood of revision (odds ratio 24.4 vs NCS type 2, 95% CI: 4.9 − 122.9).

Discussion

The incidence of rTHA is expected to increase dramatically in the coming years [1,2]. Femoral revisions are less common than head and liner exchanges, isolated acetabular revisions, and other types of revisions. They can be challenging and require meticulous preoperative planning. Key to this planning process is the appropriate

Table 1
Femoral component type used at the time of index revision procedure by femoral bone loss classification.

Femoral type	Primary implant[a]	%	FTT	%	ALCS	%	APC	%	Compress	%	PFR	%	Total femur	%	Resection arthroplasty	%	Total	%
Paprosky type																		
I	22	61.1	4	11.1	10	27.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	**36**	**8.1**
II	14	23.0	27	44.3	20	32.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	**61**	**13.8**
IIIA	28	15.6	115	63.9	37	20.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	**180**	**40.7**
IIIB	10	8.6	80	69.0	21	18.1	1	0.9	1	0.9	2	1.7	0	0.0	1	0.9	**116**	**26.2**
IV	0	0.0	8	16.3	21	42.9	0	0.0	9	18.4	5	10.2	6	12.2	0	0.0	**49**	**11.1**
Novel type																		
1	29	82.9	0	0.0	6	17.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	**35**	**7.9**
2	45	12.4	234	64.3	84	23.1	0	0.0	0	0.0	0	0.0	0	0.0	1	0.3	**364**	**82.4**
3	0	0.0	0	0.0	0	0.0	1	12.5	0	0.0	7	87.5	0	0.0	0	0.0	**8**	**1.8**
4	0	0.0	0	0.0	17	63.0	0	0.0	10	37.0	0	0.0	0	0.0	0	0.0	**27**	**6.1**
5	0	0.0	0	0.0	2	25.0	0	0.0	0	0.0	0	0.0	6	75.0	0	0.0	**8**	**1.8**
Total	**74**	**16.7**	**234**	**52.9**	**109**	**24.7**	**1**	**0.2**	**10**	**2.3**	**7**	**1.6**	**6**	**1.4**	**1**	**0.2**	**442**	**100.0**

ALCS, antibiotic-laden cement spacer; APC, allograft-prosthetic composite; FTT, fluted tapered titanium stem; PFR, proximal femoral replacement.
[a] Includes porous-coated cylindrical cobalt chrome stems.

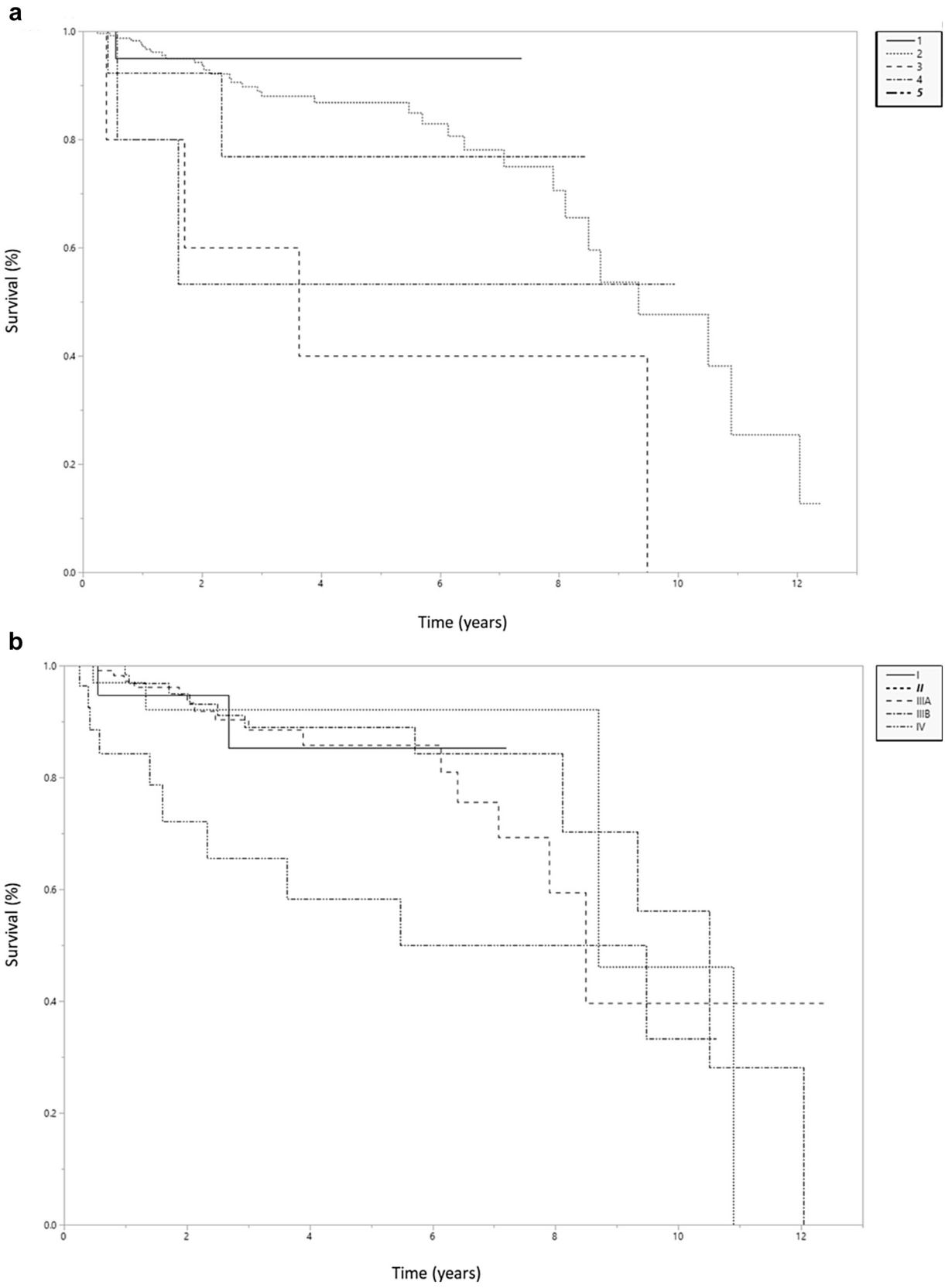

Figure 2. (a) Kaplan-Meier survival curve showing implant survival by novel classification type using reoperation for any reason as the endpoint. (b) Kaplan-Meier survival curve showing implant survival by Paprosky classification type using reoperation for any reason as the endpoint.

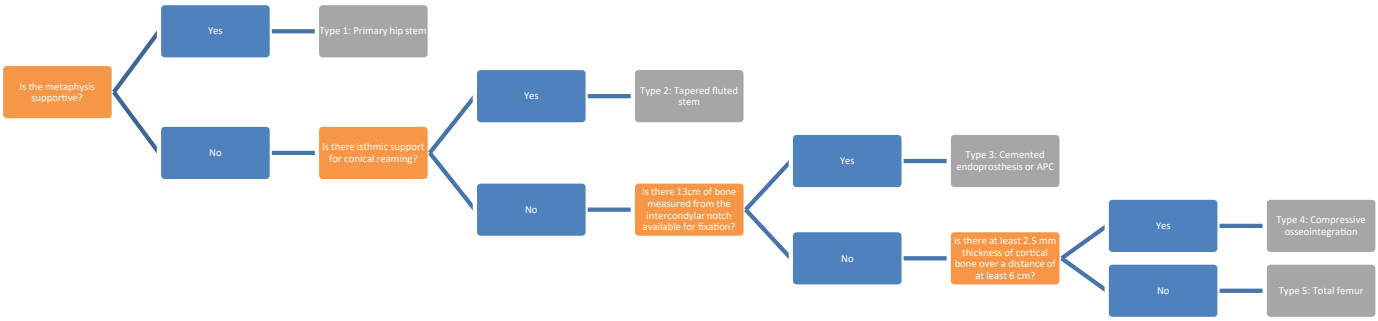

Figure 3. Flow diagram of novel classification system of femoral bone loss for revision total hip arthroplasty. APC, allograft-prosthetic composite.

classification of FBL, a step that helps to guide technique and implant selection. This study describes a novel classification system for FBL based on contemporary reconstruction methods. As might be expected, the vast majority of femoral revisions were classified as type 2 (supportive of conical reaming). However, a substantial number of cases in this series demonstrated more pronounced bone loss and were deemed inappropriate for reconstruction with an FTT stem. The more precise characterization of bone loss according to the NCS was associated with improved correlation with reoperation compared with the Paprosky classification.

Currently available FBL classification systems in revision THA were created at a time when the use of FTT stems was largely reserved for cases with less than 4 cm of scratch-fit isthmic contact to support a PCC stem [3,5,11,16]. The success of FTT stems in these challenging cases, coupled with unacceptably high incidences of thigh pain and stress shielding associated with the use of PCC stems (particularly those greater than 18 mm in diameter), led to the widespread adoption of FTT stems for almost all femoral subtypes in rTHA [6,11,13,17]. In this series, the vast majority of aseptic femoral revisions used a FTT stem (234 cases, 69.9% of aseptic revisions and 52.9% of all cases). The rate of implant loosening in this group of patients was low, seen in only 4 cases (1.2% of aseptic revisions). Two of these cases were in patients with concomitant periprosthetic fracture at the time of femoral revision, and the other 2 cases used stem sizes toward the upper limits of implant availability. As has been reported in prior studies, except in extreme cases, our data suggest that if the revision surgeon can preoperatively template a conically reamed femoral implant, the risk of re-revision due to implant loosening is low.

For cases with more severe bone loss that cannot be reconstructed with a conically reamed FTT stem, currently available classification systems do not differentiate between femoral types and instead typically combine such cases into a single category (eg, Paprosky type IV). Previous studies have elucidated the challenges presented by Paprosky type IV femora and have described a wide variety of treatment options including impaction grafting, compressive osseointegration, allograft-prosthetic composite reconstruction, proximal femoral endoprosthetic reconstruction, and total femoral endoprosthetic reconstruction [6,18,19], but there is currently no unifying classification system that may help the surgeon to decide which of these options to choose. The NCS types 3, 4, and 5 build upon the Paprosky type IV group and provide specific radiographic criteria to help identify features that may be conducive to specific types of femoral reconstruction. With this system, we do not advocate for one reconstructive method over another, rather the purpose of the NCS is to provide the revision hip surgeon with an algorithmic method of evaluating preoperative radiographs based on contemporary implants. Some of the reconstructive methods described in this study, such as compressive osseointegration, may be unfamiliar to even an experienced revision hip arthroplasty surgeon. While the purpose of this article is not to provide a comprehensive literature review, there is certainly ample evidence to suggest that these implants can provide a durable solution [20–22]. Similar to previous reports, we found a higher rate of reoperation among types 3, 4, and 5 (50.0%, 13.3%, and 28.6%, respectively) than among types 1 and 2 femora (3.2% and 11.3%, respectively) [6,18,23].

The more detailed NCS was able to detect differences in outcomes among cases with severe bone loss, which is not possible using currently available classification systems that use a single category for these outlier cases. Type 3 femoral defects had the highest likelihood of revision for any reason (odds ratio 7.8 vs type 2 defects, $P < .01$) and revision for instability (odds ratio 24.4 vs type 2 defects, $P < .001$), whereas the type 5 femoral defects had the highest likelihood of revision for infection (odds ratio 8.6 vs type 2 defects, $P < .05$). As all proximal femoral replacements with the exception of those using compressive osseointegration in this series were cemented, we postulate that the higher likelihood of instability seen with type 3 femoral defects is potentially due to the difficulty with obtaining appropriate implant version when proximal bony landmarks are no longer available, coupled with the inability to change this version with certain endoprosthetic designs once the stem has been cemented into place [24,25]. Landmarks that can be useful in these cases include a perpendicular line to the posterior condylar axis and the linea aspera. A total femoral component (typically used for type 5 defects) already has a version built into the implant and uses a rotating-hinge knee mechanism that may help to offset some of the version issues seen with cemented endoprosthetic implants. We hypothesize that the increased risk of revision for infection among type 5 defects is likely related to the high burden of foreign material and the extensive soft tissue exposure typically required for these cases. In some cases, particularly those with prior periprosthetic joint infection, our practice has moved toward prophylactic coating the surface of these implants with high-dose antibiotic cement.

While cases with severe bone loss can certainly present a myriad of challenges, the type 1 femoral defect should not be overlooked. These defects were initially described to account for femoral revisions involving essentially a “normal” or “primary” femur. Indeed, 6 of the type 1 femora in this series were hip resurfacing implants that provided essentially normal bone stock after femoral neck osteotomy. Examples given in the original

description of the Paprosky type I classification included a loose Austin-Moore implant with well-preserved bone stock that would accept most primary implants [3]. Many of the stem types associated with the original type I femoral defect description are no longer widely used, thus while the NCS type 1 accounts for cases where a primary implant could be used, there are nuances that have not been described by previous classification systems. There are a wide variety of primary hip stems available today, and a useful classification system has been previously described [26]. Each stem has a unique feature that may be conducive to any particular type 1 defect. For example, after removal of an antibiotic-laden cement spacer, the proximal metaphysis may be better suited to accept a fit-and-fill type of femoral implant than a medial-lateral flat wedge taper design. The former stem likely provides better rotational stability and antero-posterior bony contact than a stem with less fill in the antero-posterior dimension.

This study is not without limitations. First, this is a retrospective study of a relatively rare indication for revision hip arthroplasty, and although we included all cases performed over a 13-year period, we did not perform a formal power analysis to define appropriately sized study groups. It is certainly possible that other differences between the classification systems exist that we were unable to detect because of our limited sample size. To our knowledge, however, this is the single largest series of femoral revisions in the English literature, and increasing the sample size would not have been possible without combining data from other institutions. Second, we did not perform an interobserver analysis of the NCS. However, the categories which comprise the NCS are based on landmarks previously established by older classification systems which have been shown to have good interobserver reliability. Future research would certainly be useful to establish an interobserver rating and to compare interobserver reliability to previous classification systems. Third, the current analysis did not evaluate variables such as ASA class, operative time, or other variables that are likely surrogates of case complexity. The purpose of this study was to describe the NCS and not necessarily perform an exhaustive analysis of all potential predictor variables, but future research perhaps using a separate patient population would certainly be useful in looking at additional variables. Fourth, the distribution of cases with the NCS was not as uniform as with Paprosky's system; however, we believe that the advantages gained by expanding the Paprosky type 4 into 3 categories and condensing the Paprosky types 2, 3A, and 3B into a single category far outweigh any disadvantages of this unevenness. Indeed, there are many examples of useful classification systems in orthopedic surgery that do not maintain an even spread among subtypes. Finally, our study did not distinguish between modular vs nonmodular stems, although prior literature has shown that excellent outcomes were achieved for both [27], a finding that is supported in our analysis of the NCS type 2 femoral defects.

We present a novel FBL classification system that can help guide contemporary implant selection. The NCS is consistent with contemporary rTHA femoral stems and reconstructive techniques, and it is a better predictor of reoperation than current classification systems. This system can facilitate surgeon decision-making, improve clinical communication, and provide a basis for more precise rTHA outcomes research.

Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: M. J. Spangehl and A. J. Schwartz are Arthroplasty Today Editorial Board members. M. J. Spangehl is a Journal of Arthroplasty Editorial Board Member. M. J. Spangehl and A. J. Schwartz are AAHKS Board/Committee members. A. J. Schwartz is a member of Technical Expert Panel Centers for Medicare and Medicaid Services. M. J. Spangehl received research support from Stryker and Depuy/Synthes. M. J. Spangehl has stock/stock options in Sonoran Biosciences. M. J. Spangehl received royalties from Bodycad.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.artd.2021.02.004.

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