Intraoperative fractures in shoulder arthroplasty: risk factors and outcomes

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ARTICLE INFO

Background: The incidence of shoulder arthroplasty in the United States continues to increase, and while the risk of intraoperative complications such as fracture remains relatively low, there has been little investigation into whether certain patient-specific risk factors predispose to this complication. This study characterizes the incidence of intraoperative fracture during shoulder arthroplasty and additionally hypothesizes that certain risk factors may exist in addition to potentially leading to worsened near-term outcomes.

Methods: An institutional database of shoulder arthroplasties (N = 1773; 994 anatomic, 779 reverse) was retrospectively reviewed, and the operative reports for each case were examined for documentation of an intraoperative fracture, including during which surgical step the fracture took place. Various preoperative and intraoperative factors were tested for comparative significance ($P < .05$) using chi-square and Kruskal-Wallis tests as appropriate. Length of stay, 90-day readmission, and discharge to rehabilitation or skilled nursing facility (SNF) were further examined as secondary outcomes.

Results: Twenty-one (1.2%) intraoperative fractures were documented, a majority of which occurred in reverse shoulder arthroplasties compared to anatomic procedures (overall incidence: 2.5% vs. 0.2%, $P < .001$). These most commonly occurred during either stem broaching (33%) or seating (33%) and were most likely to involve the metaphysis (53%) or greater tuberosity (33%). Five fractures occurred during revision arthroplasty, while 16 fractures occurred during primary procedures (overall incidence: 3.0 vs. 1.0%, $P = .03$). Patient factors reaching statistical significance included female gender and liver disease, while age and smoking history were notably not associated with intraoperative fracture. The fracture cohort had a significantly longer mean length of stay (2.42 vs. 2.17 days, $P < .001$). While the rates of 90-day readmission and discharge to SNF/rehab were higher in the fracture cohort, these values did not reach statistical significance.

Conclusion: Intraoperative fractures are a rare complication (1.2%) in shoulder arthroplasty, with reverse shoulder arthroplasty, revision cases, and female gender associated with an elevated overall risk. While these patients had a longer inpatient hospitalization, the substantially higher rates of 90-day readmission and discharge to SNF/rehab did not reach significance in our limited institutional cohort. The aforementioned incidence and risk factors serve as crucial evidence for use during the preoperative counseling process with patients as part of a shared decision-making model.

The incidence of shoulder arthroplasty worldwide has increased substantially in recent years.[15,19] Despite this increase, rates of

intraoperative complications such as neurovascular injury or intraoperative fracture have fortunately remained relatively low, with the literature reporting rates ranging from 0.6% to 3% for intraoperative fracture specifically.[4,9,18,26] A variety of patient factors may impact the likelihood that these complications will occur, yet there is limited evidence published to date with respect to intraoperative fractures, in part likely due to their relative infrequency.

Factors associated with some postoperative complications may also be implicated in intraoperative fractures. Bohsali et al, 2017, found that patient age > 70 years and female sex are risk factors for glenoid component failure after reverse shoulder arthroplasty.[7] Other studies have found an association between specific Charleston Comorbidity Index variables and higher postoperative complication rates after shoulder arthroplasty, similar to previously described factors such as body mass index (BMI) and tobacco use.[10,21,22] Consensus regarding the effect of these variables on risk of postoperative complication has not yet been reached, however, as other studies have failed to find an association between patient factors such as BMI, medical comorbidities, tobacco use, and certain demographic factors.[16,17] Despite this lack of consensus, these variables outlined in the literature may form a starting point for investigation of risk factors for intraoperative adverse events given their possible association with postoperative complications.

When considering intraoperative complications specifically, there are even less published data examining whether patient-specific risk factors exist, likely given their relative scarcity and that a very large cohort size would be needed to adequately power studies. Using the National Joint Registry of England, Wales, and Northern Ireland, comprised of 12,559 primary shoulder arthroplasties, Cowling et al found the incidence of all intraoperative complications to be 2.5%, the most frequent of which was intraoperative fracture at 1.6%.[13] Several risk factors notably reached significance for their association with intraoperative fracture, including age greater than 85 years, female gender, avascular necrosis, and trauma. A lower risk of complication was found when using a superior approach relative to a deltopectoral approach and also when using a resurfacing construct instead of stemmed prostheses such as total shoulder arthroplasty, reverse shoulder arthroplasty, or hemiarthroplasty. This study was the first of its kind to examine the effect of surgical approach on intraoperative complication rates, in addition to examining many of the risk factors noted previously that are frequently associated with postoperative complications. Their findings present an opportunity to define additional patient-specific variables that may assist surgeons and patients alike during the preoperative counseling process regarding their individualized risk for intraoperative complications such as fracture.

The present study aimed to characterize the baseline incidence of intraoperative fracture as documented in operative reports in a very large institutional patient population, including the most commonly involved surgical steps, and hypothesized that certain risk factors may have an association with intraoperative fracture, an adverse event which may also contribute to worsened near-term outcomes.

Materials and methods

Patient selection

Data of all patients aged 18 years and older who underwent primary or revision anatomic or reverse shoulder arthroplasty at a large health system between June 2013 and May 2019 were compiled into an institutional database (N = 1773; 994 anatomic, 779 reverse). This database was compiled by querying for the appropriate Current Procedural Terminology (CPT) codes. Each case included in the database was treated by 10 fellowship-trained surgeons at a tertiary referral center, all of whom used a deltopectoral approach and multiple implants/systems. Hemiarthroplasty cases were excluded from this database because of their progressively decreasing utilization as a result of narrowing indications. The database was retrospectively reviewed for the presence of intraoperative fracture via inspection of operative notes, and both the

Table 1
Indication for surgery, fracture location, and step during which intraoperative fracture occurred.

	Frequency
Indication	
Rotator cuff arthropathy	10 (47.6%)
Pain or complication from prior arthroplasty	5 (23.8%)
Glenohumeral arthritis or AVN	5 (23.8%)
Proximal humerus fracture	1 (4.8%)
Location	
Greater tuberosity	7 (33.3%)
Metaphyseal	8 (38.1%)
Diaphyseal	6 (28.5%)
Operative step	
Exposure	2 (9.5%)
Baseplate preparation	1 (4.8%)
Removal of prior stem	2 (9.5%)
Reaming	2 (9.5%)
Broaching	7 (33.3%)
Seating	7 (33.3%)

AVN, avascular necrosis.

step during which the fracture occurred as well as the stem type (metaphyseal vs. diaphyseal) were recorded. Stems were grouped based on the region of the humerus used for primary fixation. We defined the stem as diaphyseal if the stem engaged with the diaphysis with an ingrowth surface and depends on cortical contact. Metaphyseal stems relied on metaphyseal bone for primary fixation with the ingrowth surface engaging the proximal humerus. Metaphyseal stems in this study were short stems, while diaphyseal stems were long stems. Stemless implants were included in this study. Each case included in the fracture cohort had the fracture confirmed by inspection of intraoperative and/or postoperative radiographs. Institutional review board approval was obtained before collecting any patient-related information.

Data variables

Sociodemographic and comorbidity data were pulled in an automated fashion from the electronic medical record in a retrospective manner. Patient demographics included age, gender, and BMI. Additional relevant preoperative and intraoperative factors collected included laterality, American Society of Anesthesiologists (ASA) class, duration of surgery, partner status, smoking status, and the presence of certain relevant Elixhauser comorbidities: chronic anemia, rheumatoid arthritis, congestive heart failure, chronic obstructive pulmonary disease, diabetes, hypothyroidism, liver disease, renal failure, and electrolyte disorder. Bone density was not routinely collected during the study period and, when available, was often found to be out of date; as a result, this variable was not included in this study. Length of stay, 90-day readmission, and discharge to rehabilitation or skilled nursing facility (SNF) were examined as secondary outcomes. Fractures were characterized on postoperative radiographs as either metaphyseal or diaphyseal in location.

Statistical analysis

Data for continuous variables were presented as means with standard deviations. Statistical significance was calculated using the Kruskal-Wallis test for these variables. Data for categorical variables were presented with counts and percentages. The threshold for statistical significance was set at a *P* value of 0.05 for all tests. A power analysis was deferred in this setting given the very low overall incidence of intraoperative fractures, which would

Table 2
Patient demographics, intraoperative factors, and Elixhauser comorbidities.

Variable	Fracture cohort (N = 21)	Non fracture cohort (N = 1752)	P value
Age	72.09	68.62	.94
BMI	31.90	30.35	.65
ASA	2.86	2.64	.45
Gender (female)	**17 (81%)**	**985 (56.2%)**	**.02***
Surgery (reverse)	**19 (90.5%)**	**760 (43.4%)**	**<.001***
Surgery (revision)	**5 (23.8%)**	**167 (9.5%)**	**.03***
Laterality (right)	8 (38.1%)	965 (55.1%)	.12
Partner status (no partner)	9 (42.9%)	585 (33.4%)	.36
Smoker (yes)	9 (42.9%)	884 (50.5%)	.49
Chronic anemia	1 (4.8%)	175 (10%)	.43
Rheumatoid arthritis	2 (9.5%)	160 (9.1%)	.95
CHF	2 (9.5%)	85 (4.9%)	.32
COPD	2 (9.5%)	337 (19.2%)	.26
Diabetes	4 (19%)	253 (14.4%)	.55
Hypothyroidism	4 (19%)	251 (14.3%)	.54
Liver disease	**2 (9.5%)**	**44 (2.5%)**	**.04***
Renal failure	2 (9.5%)	157 (9%)	.93
Electrolyte disorder	3 (14.3%)	99 (5.7%)	.09

BMI, body mass index; *ASA*, American Society of Anesthesiologists; *CHF*, congestive heart failure; *COPD*, chronic obstructive pulmonary disease.
Continuous variables are reported as means. Categorical variables are reported as counts and percentages. Bolded values indicate risk factors that reached statistical significance.
*$P < .05$.

Results

Twenty-one cases (1.2%) involving an intraoperative fracture were documented in operative reports and were included in the final cohort. Indications for surgery included rotator cuff arthropathy (N = 10, 47.6%), pain and/or complication associated with a prior arthroplasty (N = 5, 23.8%), glenohumeral arthritis or avascular necrosis (N = 5, 23.8%), and proximal humerus fracture (N = 1, 4.8%). The intraoperative fractures were further classified by the operative step during which they occurred: exposure/dislocation (N = 2, 9.5%), baseplate preparation (N = 1, 4.8%), prior stem removal (N = 2, 9.5%), reaming (N = 2, 9.5%), broaching (N = 7, 33.3%), and seating (N = 7, 33.3%) (Table I). In 20 of 21 cases, the intraoperative fracture involved the humerus (one involved the glenoid), and of these cases, 19 (95%) stems were metaphyseal-fitting while only 1 (5%) stem was diaphyseal-fitting.

Differences in age, BMI, and ASA score did not reach statistical significance when compared to the larger institutional database of shoulder arthroplasty procedures which did not have an intraoperative fracture (N = 1752). As a categorical variable, elevated BMI (either >35 or >30) did not reach statistical significance ($P = .79$, $P = .67$) for an association with intraoperative fracture. However, gender did reveal an association, occurring more often in females than in males (81% in fracture cohort vs. 56.2% in nonfracture cohort, $P = .02$). Among Elixhauser comorbidities selected for their potential relevance to bone health, the percentage of patients with liver disease was slightly higher in the fracture cohort (N = 2, 9.5%) than that in the larger institutional cohort (N = 44, 2.5%, $P = .04$), similar to electrolyte disorder which also trended toward significance. Smoking history, renal failure, rheumatoid arthritis, and laterality notably did not reach or trend toward statistical significance ($P = .49$, $P = .93$, $P = .95$, and $P = .12$, respectively), and no other comorbidities reached significance in our cohort of 21 cases (Table II).

Nineteen of the 21 cases included in the fracture cohort occurred during reverse shoulder arthroplasty procedures (90.5% vs. 9.5%, $P < .001$), resulting in an overall intraoperative fracture incidence of 2.5% for reverse shoulder arthroplasties and 0.2% for anatomic procedures. Of note, in the entire cohort (N = 1773), those patients who underwent reverse shoulder arthroplasty were significantly older than patients undergoing anatomic procedures ($P < .0001$) and also had higher ASA scores ($P < .0001$). Five fractures occurred during a revision arthroplasty while sixteen fractures occurred during a primary procedure (overall rate: 3.0% vs. 1.0%, $P = .03$). When examining revision arthroplasties in isolation, further analysis did not reveal any statistically significant difference in gender between the fracture and nonfracture cohorts ($P = .83$). With respect to location, there were 7 intraoperative fractures of the greater tuberosity (33.3%), 8 metaphyseal fractures (38.1%), and 6 diaphyseal fractures (28.5%). Most intraoperative fractures were repaired with cerclage wires and/or suture fixation, while one case required a plate.

The intraoperative fracture cohort had a significantly longer duration of surgery (mean: 2.87 vs. 2.14 hours, $P < .001$) and a longer hospital stay postoperatively (mean: 2.42 vs. 2.17 days, $P < .0001$) than the comparison cohort of nonfracture cases. While the fracture cohort trended toward higher rates of 90-day readmission (9.5% vs. 3.4%) and a higher utilization of SNF/rehab (19% vs. 11%), neither of these secondary outcomes reached statistical significance (Table III).

Discussion

As shoulder arthroplasty becomes an increasingly popular option for patients with degenerative conditions of the shoulder, identifying risk factors for adverse perioperative outcomes remains a priority in this setting. While a wide variety of research studies have examined postoperative outcomes both in terms of functionality and complications,[2,6,23-25,32] few groups have examined the incidence and risk factors for intraoperative fractures. Despite their relative infrequency, patients and providers alike may benefit from this information for use during the preoperative counseling process.

In the present study, we found the overall incidence of intraoperative fracture during shoulder arthroplasty procedures to be

require a prohibitively large cohort to adequately power differences in the incidence of risk factors examined.

Table 3
Secondary outcomes after shoulder arthroplasty.

Secondary outcome	Fracture cohort (N = 21)	Non fracture cohort (N = 1752)	P value
Duration of surgery	2.87	2.14	<.001*
Length of stay	2.42	2.17	<.001*
Discharge location (SNF/Rehab)	4 (19%)	192 (11%)	.24
90-Day readmission	2 (9.5%)	60 (3.4%)	.13

SNF, skilled nursing facility.
Continuous variables reported as means. Categorical variables reported as counts and percentages.
    *P < .05.

1.2%. This compares favorably to rates of intraoperative fracture reported in the literature, which range from 0.6% to 3%.[1,4,7,9,13,14,18,26,27] Singh et al found the overall incidence of intraoperative fracture to be 1.5% in an institutional cohort of over 2500 primary anatomic total shoulder arthroplasties and 1400 hemiarthroplasties over a 33-year period, although the study was limited by its lack of inclusion of patients undergoing reverse shoulder arthroplasties and revision procedures.[26] Similarly, a 2017 study by Cowling et al that examined a registry database of 12,559 primary shoulder arthroplasties from the National Joint Registry found the rate of intraoperative fracture to be 1.6%.[13] Although this study holds advantages in terms of sample size and geographic diversity for detecting these rare events, the authors acknowledge the limitations of registries. These include inconsistent surgeon reporting of complications and the possibility of residual confounding during data analysis.

We additionally observed significantly higher rates of intraoperative fracture in reverse shoulder arthroplasty than those in anatomic procedures (2.5 vs. 0.2%, *P* < .001). These findings compare favorably to prior work citing an incidence of intraoperative fracture during reverse shoulder arthroplasty that ranges from 2% to 7%.[5,8,11,28,31] Wierks et al[31] reported the incidence of intraoperative humeral fracture to be as high as 9% while Boileau et al found the incidence to be 2.2% in a limited series of patients (N = 22 and N = 45, respectively).[8] Owing to these small sample sizes, even a single additional fracture leads to a large increase in overall incidence, a common challenge when studying this complication at an institutional (rather than registry) level. Our study includes a larger cohort of reverse arthroplasties, making a significant contribution to the literature with regard to the incidence of intraoperative fracture during these procedures. The increased incidence of intraoperative fractures during reverse shoulder arthroplasty observed in our cohort is not fully understood. This finding may be related to the older patient demographics in this group with potentially more advanced osteopenia, as well as humeral manipulation and retraction to prepare for glenosphere placement. We did observe that patients who underwent reverse shoulder arthroplasty were significantly older and had higher ASA scores than those who underwent anatomic procedures, but age overall notably did not reach significance in our cohort. In addition, comparatively higher mechanical stresses may arise during reduction and dislocation of provisional or final components in reverse shoulder arthroplasty. Finally, stem geometry requiring any significant metaphyseal bone removal to accommodate the implant may increase the risk of intraoperative fracture.

Our study additionally observed a higher rate of intraoperative fracture in revision cases vs. primary arthroplasty (3% vs. 1%). Although prior literature demonstrates a similar trend, our rate is somewhat lower than what has been previously published. Ingoe et al reported the rate to be 3.5%[20] in a larger registry study, whereas smaller case series have reported much higher rates, ranging from 16% to 24.3%.[3,29] Ingoe et al attributed this large discrepancy in part due to underreporting by the surgeons of minor and inconsequential fractures confined to the metaphysis, a characteristic possibly minimized by our study design which involved scrutinizing operative notes themselves for documentation of intraoperative fracture.[20] In addition, these studies included cohorts of varying characteristics: Wagner et al[29] and Cisneros et al[12] focused on revision of reverse arthroplasty, while Ingoe et al[20] and Antoni et al[3] included revisions of anatomic procedures, hemiarthroplasty, and reverse shoulder arthroplasty.

Given the aforementioned prevalence, especially in procedures of higher risk, understanding which patients may have a higher likelihood of intraoperative fracture may help anticipate and prevent these complications. While there are limited studies to date studying risk factors for intraoperative fracture, our study presents advantages in terms of both breadth of candidate risk factors as well as near-term outcomes. In the present study, female gender and presence of liver disease were associated with increased risk of intraoperative fracture. To our knowledge, this is the first study to report liver disease as a factor associated with intraoperative fracture, although, at this time, its clinical relevance remains in speculation. Analysis of BMI as both a continuous and categorical variable did not reveal any underlying association although one may exist and was simply not detected in our limited cohort. Several other studies have identified female gender as a risk factor for intraoperative complications, possibly secondary to poorer bone quality. These studies, however, consistently reported advanced age as an additional risk factor, unlike the present study.[4,13,27,29,30]

We additionally observed fractures localized to the greater tuberosity in one-third of the intraoperative fracture cohort. The remaining fractures were classified as metaphyseal (53.3%) or diaphyseal (28.5%) in location. Our results are similar to findings of a 2009 study by Athwal et al, who in a cohort of 45 intraoperative fractures observed 19 (42%) greater tuberosity, 16 (36%) diaphyseal fractures, and 6 (13%) metaphyseal fractures.[4] Three involved both the greater tuberosity and humeral shaft, while another involved both the greater and lesser tuberosity.[4] Singh et al in a more recent study documented a cohort of 47 intraoperative fractures (13 humeral shaft, 21 greater tuberosity, 3 humeral head and neck, 3 humeral metaphysis, 5 glenoid fractures, and 2 fractures with unclear location).[26]

To our knowledge, this is the first study to examine near-term adverse outcomes in the setting of intraoperative fractures. These patients were noted to have an increased length of stay as well as increased rates of 90-day readmission and discharge to SNF/rehab, and despite these trends, only length of stay reached statistical significance. Preliminarily, these findings may offer reassurance to patients when counseling regarding the risks of surgery but do merit further investigation in larger sample sizes as the trend

toward significance for 90-day readmission may reflect an actual clinical reality. Furthermore, the increased length of stay in our cohort may reflect the increased patient complexity related to some of the risk factors we detected, such as reverse shoulder arthroplasty and revision status, rather than any intrinsic effects related to the intraoperative fracture itself.

There were several limitations to this study. This study is subject to all the inherent limitations of a retrospective institutional cohort, which may limit generalizability. Our institutional cohort, however, may hold advantages over registry-level databases both in accuracy and diversity of variables we were able to include in our final analysis. In addition, there was a large asymmetry in our cohort sizes, as the intraoperative fracture cohort had only 21 patients compared to over 1700 in the comparison cohort, and given the low overall incidence of this complication, this limitation is shared with other studies on the topic. This may have also impacted our ability to detect some statistically significant associations due to lack of statistical power. We chose to report raw P values to allow for easy interpretation, but statistical significance observed may also be considered in the context of a Bonferroni correction for repeated measurements. Finally, we decided not to include hemiarthroplasty procedures in our final cohort, which may alter the risk profile seen in this study compared to other studies where hemiarthroplasties were included, perhaps as a salvage procedure. This procedure is associated with greater risk in the literature and is now being performed less frequently than anatomic and reverse procedures. This may contribute to some of the reported differences between incidence of intraoperative fracture found in our study and that in other studies discussed in this article.

Despite these limitations, the present study provides further evidence of intraoperative fracture as a rare complication in shoulder arthroplasty and, additionally, is the first to identify patients undergoing reverse shoulder arthroplasties or revision procedures may be at greatest risk for this complication. While these patients may have a somewhat longer inpatient stay, patients may be counseled that near-term postoperative outcomes appear similar, although this certainly merits longer term follow-up paired with functional outcomes to help determine postoperative recovery from these complications.

Conclusion

As shoulder arthroplasty has become an increasingly common procedure, rates of intraoperative complications, including fracture, have remained relatively low. This study found the rate of intraoperative fracture to be 1.2% with female gender, reverse shoulder arthroplasty, and revision cases found to be associated with an elevated overall risk. Although patients found to have an intraoperative fracture had longer inpatient hospitalizations, their rates of both discharge to SNF/rehab and of 90-day readmission failed to reach statistical significance in our limited cohort. The incidence and risk factors above provide information of great value for surgeons and patients during the preoperative counseling process with patients as part of a shared decision making model.

Disclaimers:

References

1. Aldinger P, Raiss P, Rickert M, Loew M. Complications in shoulder arthroplasty: an analysis of 485 cases. Int Orthop 2010;34:517-24. https://doi.org/10.1007/s00264-009-0780-7.
2. Alentorn-Geli E, Gonzalo S, Torrens C, Wright T. Reverse shoulder arthroplasty. Part 2: systematic review of reoperations, revisions, problems, and complications. Int J Shoulder Surg 2015;9:60-7. https://doi.org/10.4103/0973-6042.154771.
3. Antoni M, Barthoulot M, Kempf J, Clavert P. Revisions of total shoulder arthroplasty: clinical results and complications of various modalities. Orthop Traumatol Surg Res 2016;102:297-303. https://doi.org/10.1016/j.otsr.2016.01.009.
4. Athwal G, Sperling J, Rispoli D, Cofield R. Periprosthetic humeral fractures during shoulder arthroplasty. J Bone Joint Surg Am 2009;91:594-603. https://doi.org/10.2106/JBJS.H.00439.
5. Barco R, Savvidou O, Sperling J, Sanchez-Sotelo J, Cofield R. Complications in reverse shoulder arthroplasty. EFORT Open Rev 2017;1:72-80. https://doi.org/10.1302/2058-5241.1.160003.
6. Berman J, Mata-Fink A, Kassam H, Blaine T, Kovacevic D. Predictors of length of stay and discharge disposition after shoulder arthroplasty: a systematic review. J Am Acad Orthop Surg 2019;27:e696-701. https://doi.org/10.5435/JAAOS-D-18-00244.
7. Bohsali K, Bois A, Wirth M. Complication of shoulder arthroplasty. J Bone Joint Surg Am 2017;99:256-69. https://doi.org/10.2106/JBJS.16.00935.
8. Boileau P, Watkinson D, Hatzidakis A, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14:147S-61S. https://doi.org/10.1016/j.jse.2004.10.006.
9. Cameron B, Iannotti J. Periprosthetic fractures of the humerus and scapula: management and prevention. Orthop Clin North Am 1999;30:305-18.
10. Chalmers P, Gupta A, Rahman Z, Bruce B, Romeo AA, Nicholson GP. Predictors of early complications of total shoulder arthroplasty. J Arthroplasty 2014;29:856-60. https://doi.org/10.1016/j.arth.2013.07.002.
11. Cheung E, Willis M, Walker M, Clark R, Frankle M. Complications in reverse total shoulder arthroplasty. J Am Acad Orthop Surg 2011;19:439-49.
12. Cisneros L, Atoun E, Abraham R, Tsvieli O, Bruguera J, Levy O. Revision shoulder arthroplasty: does the stem really matter? J Shoulder Elbow Surg 2016;25:747-55. https://doi.org/10.1016/j.jse.2015.10.007.
13. Cowling P, Holland P, Kottam L, Baker P, Rangan A. Risk factors associated with intraoperative complications in primary shoulder arthroplasty. Acta Orthop 2017;88:587-91. https://doi.org/10.1080/17453674.2017.1362155.
14. Cuomo F, Checroun A. Avoiding pitfalls and complications in total shoulder arthroplasty. Orthop Clin North Am 1998;29:507-18.
15. Day J, Lau E, Ong K, Williams GR, Ramsey ML, Kurtz SM. Prevalence and projections of total shoulder and elbow arthroplasty in the United States to 2015. J Shoulder Elbow Surg 2010;19:1115-20. https://doi.org/10.1016/j.jse.2010.02.009.
16. Donigan J, Frisella W, Haase D, Dolan L, Wolf B. Pre-operative and intraoperative factors related to shoulder arthroplasty outcomes. Iowa Orthop J 2009;29:60-6.
17. Farng E, Zingmond D, Krenek L, Soohoo N. Factors predicting complication rates after primary shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:557-63. https://doi.org/10.1016/j.jse.2010.11.005.
18. Groh G, Heckman M, Wirth M, Curtis R, Rockwood CJ. Treatment of fractures adjacent to humeral prostheses. J Shoulder Elbow Surg 2008;17:85-9. https://doi.org/10.1016/j.jse.2007.05.007.
19. Harjula J, Paloneva J, Haapakoski J, Kukkonen J, Aarima V. Increasing incidence of primary shoulder arthroplasty in Finland - a nationwide registry study. BMC Musculoskelet Disord 2018;19:245. https://doi.org/10.1186/s12891-018-2150-3.
20. Ingoe H, Holland P, Cowling P, Kottam L, Baker PN, Rangan A. Intraoperative complications during revision shoulder arthroplasty: a study using the National Joint Registry Dataset. Shoulder Elbow 2017;9:92-9. https://doi.org/10.1177/1758573216685706.
21. Leschinger T, Raiss P, Loew M, Zeifang F. Total shoulder arthroplasty: risk factors for intraoperative and postoperative complications in patients with primary arthritis. J Shoulder Elbow Surg 2017;26:71-7. https://doi.org/10.1016/j.jse.2016.08.001.
22. Linberg C, Sperling J, Schleck C, Cofield R. Shoulder arthroplasty in morbidly obese patients. J Shoulder Elbow Surg 2009;18:903-6. https://doi.org/10.1016/j.jse.2009.02.006.
23. Lung B, Kanjiya S, Bisogno M, Komatsu D, Wang E. Preoperative indications for total shoulder arthroplasty predict adverse postoperative complications. JSES Open Access 2019;3:99-107. https://doi.org/10.1016/j.jses.2019.03.003.
24. Roberson T, Bentley J, Griscom J, Kissenberth MJ, Tolan SJ, Hawkins RJ, et al. Outcomes of total shoulder arthroplasty in patients younger than 65 years: a systematic review. J Shoulder Elbow Surg 2017;26:1298-306. https://doi.org/10.1016/j.jse.2016.12.069.
25. Samitier G, Alentorn-Geli E, Torrens C, Wright T. Reverse shoulder arthroplasty. Part 1: systematic review of clinical and functional outcomes. Int J Shoulder Surg 2015;9:24-31. https://doi.org/10.4103/0973-6042.150226.
26. Singh J, Sperling J, Schleck C, Harmsen W, Cofield R. Periprosthetic fractures associated with primary total shoulder arthroplasty and primary humeral head replacement: a thirty-three-year study. J Bone Joint Surg Am 2012;94:1777-85. https://doi.org/10.2106/JBJS.J.01945.

27. Steinmann S, Cheung E. Treatment of periprosthetic humerus fractures associated with shoulder arthroplasty. J Am Acad Orthop Surg 2008;16:199-207. https://doi.org/10.5435/00124635-200804000-00003.

28. Valenti P, Boutens D, Nerot C. Delta 3 reversed prosthesis for osteoarthritis with massive rotator cuff tear: long-term results (5 years). In: *Shoulder prosthesis: Two to ten year follow-up*. Montpellier: Sauramps; 2001. p. 253-9.

29. Wagner E, Houdek M, Elhassan B, Sanchez-Sotelo J, Cofield RH, Sperling JW. What are risk factors for intraoperative humerus fractures during revision reverse shoulder arthroplasty and do they influence outcomes? Clin Orthop Relat Res 2015;473:3228-34. https://doi.org/10.1007/s11999-015-4448-x.

30. Waterman B, Dunn J, Bader J, Urrea L, Schoenfeld AJ, Belmont PJ. Thirty-day morbidity and mortality after elective total shoulder arthroplasty: patient-based and surgical risk factors. J Shoulder Elbow Surg 2015;24:24-30. https://doi.org/10.1016/j.jse.2014.05.016.

31. Wierks C, Skolasky R, Ji J, McFarland E. Reverse total shoulder replacement: intraoperative and early postoperative complications. Clin Orthop Relat Res 2009;467:225-34. https://doi.org/10.1007/s11999-008-0406-1.

32. Zumstein M, Pinedo M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2011;20:146-57. https://doi.org/10.1016/j.jse.2010.08.001.