Comparative learning curves for early complications in anatomical and reverse shoulder arthroplasty

JCS Beazley, JP Evans, ND Furness, CD Smith

Shoulder and Elbow Unit, Royal Devon and Exeter Hospital NHS Foundation Trust, Exeter, UK

ABSTRACT

INTRODUCTION There has been a significant increase in the implantation of reverse shoulder replacements over anatomical shoulder replacements in the past five years. Few comparative data exist comparing early complication rates and learning curves. This study aimed to evaluate the early complication rates and learning curves of a single surgeon series of anatomical and reverse shoulder replacements over the first five years of independent practice.

MATERIALS AND METHODS The first 100 anatomical and 100 reverse shoulder replacements performed between July 2011 and July 2016 were reviewed to identify early complications. Cumulative sum plots were used to analyse the learning-curve effect.

RESULTS Early complications were noted in 4 anatomical and 17 reverse shoulder replacements. One of the anatomical and ten of the reverse shoulder replacements required a return to theatre within three months. The early complication rates were observed to be significantly higher in the reverse shoulder replacement group compared with the anatomical shoulder replacement group (odds ratio 4.9; 95% confidence interval 1.6–15.2, P 1/4 0.057). An inflection point on the anatomical shoulder replacement cumulative sum plot suggestive of a trend to consistent performance was reached at 16 cases. No inflection point was observed on the reverse shoulder replacement cohort.

CONCLUSIONS We observed a significantly higher early complication rate within the reverse shoulder replacement cohort, with a tenfold increase in early reoperations. In comparison to the trend seen after 16 cases for anatomical shoulder replacement, no trend was seen in the reverse shoulder replacement cohort. This either reflects the higher complication rate seen in reverse shoulder replacement or that the learning curve extends beyond 100 cases, highlighting the need for extended performance monitoring.

KEYWORDS

Shoulder arthroplasty – Complications – Learning curve

Accepted 18 February 2018

CORRESPONDENCE TO

Nicholas D Furness, E: nickfurness@me.com

Introduction

Surgical outcomes are put into sharp focus whenever a new consultant transitions into independent practice or a surgeon learns a new technique. Allied to personal reflection, there is an increasing emphasis on audit and quality control at both local and national levels. Initiatives such as Getting it Right First Time are making particular attempts to engage with clinicians in delivering clinically driven improvements, in part by consolidating specialist services to reduce the impact of learning curves on patients.¹ This is particularly relevant to shoulder arthroplasty for two reasons. First, the volume is low relative to the numbers of hip and knee replacements. The 2015/16 National Joint Registry hospital profile data demonstrate that, on average, each hospital performs 220 total hip replacements, 230 total knee replacements and only 16 total shoulder replacements (anatomical and reverse) in a year.² Second, there has been a change

over the past half decade, with an increasing number of reverse shoulder replacements (RSR) performed over anatomical shoulder replacements (ASR). The National Joint Registry demonstrates that the percentage of RSR as a proportion of any shoulder replacement increased from 31.6% to 45.3% between 2012 and 2015.²

Whenever a relatively new procedure is adopted, a learning curve inevitably follows and early ‘implantation-related’ complications are expected. There have been various attempts at characterising the learning curves for various surgical procedures, with the aim of reducing the learning curve effect on patients. These include total hip arthroplasty, unicompartmental and total knee arthroplasty, computer navigated total knee arthroplasty, hip arthroscopy, total ankle arthroplasty and developmental hip dysplasia surgery.^{3–9}

The increasing acceptance of RSR raises the potential that patients are undergoing this procedure within the learning

curve of their surgeon. Clearly, this highlights the need for performance monitoring at the individual level and while several attempts have been made to determine the size of the learning-curve effect for RSR, no consensus on the presence or size of curve has been established.^{10,11} Similarly, no literature exists evaluating the ASR learning curve.

Personal monitoring of complications is vital and, when conducted appropriately, can help to highlight deviations from expected standards. Retrospective learning-curve techniques can be helpful in establishing the presence and size of a learning curve, but they are less useful for the prospective monitoring of performance.^{10,11} The use of simple statistical models can provide information to inform service improvement at the single surgeon level. The cumulative summation (CUSUM) plot has been shown to be a novel means of prospectively monitoring performance and establishing the learning curve in lower-limb arthroplasty.^{12–14} However, its utility has not been assessed in upper-limb procedures.

This study aimed to assess the volume, timing and characteristics of early (less than 12 months) complications, which we believed are more likely to represent technical error rather than implant or cuff failure,^{15,16} following the first five years of practice in RSR and ASR undertaken by a fellowship-trained shoulder surgeon in the UK.

Materials and methods

The first 100 consecutive primary ASRs and RSRs performed by a single surgeon equating to five years of practice as a consultant were identified from the senior author's logbook. Prior to commencement of the consultant post, the senior surgeon had experience of 63 shoulder arthroplasties, 36 of which were ASR with the remainder RSR. Any patient who had undergone previous arthroplasty surgery on the same joint was excluded from the study. All the identified patients' electronic records and radiographs were reviewed to identify complications, the timing of the complications and outcome.

All prostheses were implanted after a single dose of teicoplanin and gentamicin on induction. All patients had thromboembolic deterrent stockings and mechanical compression calf pumps without chemoprophylaxis unless deemed high risk, in accordance with British Elbow and Shoulder Society guidelines.¹⁷ All shoulder arthroplasties were performed through a deltopectoral approach. For ASR, a stemless humeral component was used unless the bone quality of the humeral metaphysis was unsuitable; in these cases, a cemented stem was used instead (9%). A cemented, all-poly keeled glenoid component was used in all cases. Reverse shoulder replacements were performed with Gramont style prostheses, with the humeral component implanted in five degrees of retroversion.

We classified complications into major or minor, as has been previously described by Kempton *et al.*¹¹ Minor complications included those for which little or no treatment was required, with all others classified as major. Reoperation was defined as any return to theatre, regardless of whether an open procedure took place. Complications were included

for analysis if they occurred within 12 months of the primary procedure.^{15,16} Complications were grouped according to timing and classified as intraoperative, less than 6 weeks postoperative, 6 weeks to 3 months and 3 months to 12 months. Statistical analysis to identify any difference between groups was performed using chi-squared and Fisher's exact tests. Odds ratios were also calculated, together with 95% confidence intervals. Analysis was performed with GraphPad (Graphpad Software, La Jolla, CA) and Stata Release 14 (StataCorp LLC, College Station, Texas).

Performance data were presented graphically as CUSUM plots¹² with limits derived from a sequential probability ratio test.^{12,14} This method is derived from quality control in the industrial setting and is being increasingly used in health care, including surgeon monitoring in orthopaedics.^{12–15} The CUSUM value is a running sum of increments and decrements, with a predefined ratio between these figures.¹⁸ Graphically, a downward slope represents 'success' and an upward slope represents 'failure'. Upper and lower boundary lines can be plotted with a sequential probability ratio technique that uses four defined parameters; type I (α) error, type II (β) error, acceptable (p_0) and unacceptable (p_1) failure rates. In the most cited review of shoulder arthroplasty complications, Bohsali *et al.*¹⁹ reported a mean complication rate ranging from 10% to 16%. These figures were used as the acceptable and unacceptable failure rates, respectively. By convention, the probability of a type I error was 0.05 and a type II error 0.2. From these four variables, the values for success (s), failure ($1-s$) and upper (h_1) and lower (h_0) decision limits were derived (Table 1). When a failure (complication) occurs, the constant ' $1-s$ ' is added to the cumulative score, when a success occurs, the variable ' s ' is subtracted from the score. Graphically, if the line crosses the lower decision limit from above, this indicates that the actual failure rate does not differ from the acceptable failure rate (10%) with a type II error probability of 0.20. If the line crosses the upper decision limit from below, that indicates that the actual failure rate is equal to the unacceptable failure rate (16%) with a type I error probability of 0.05. When the line is between these bounds, no statistical inference can be made.^{12,15}

Results

Anatomical shoulder replacements

Between May 2011 and July 2016, the senior author performed 100 ASRs. The average age at time of operation was 72.2 years (range 49–92 years). The indications for ASR are shown in Table 2.

Complications within three months were noted to have occurred in four patients (Table 3). Of these complications, one was considered a major complication in which the patient required early revision following collapse of a stemless prosthesis at day two following the procedure. In the remaining three patients, a crack was observed in the glenoid following preparation, but no additional fixation was required. At final follow-up, no late complications in this group were identified. No complications presented between 3 and 12 months.

Table 1 Cumulative summation variables and derived values.

Variable	Value
p0 acceptable failure rate	0.10
p1 unacceptable failure rate	0.16
α probability of the type I error	0.05
β probability of the type II error	0.20
$P = \ln (p1/p0)$	0.20
$Q = \ln [(1 - p0)/(1 - p1)]$	0.03
$s = Q/(P + Q)$	0.13
$1 - s$	0.87
$a = \ln [(1 - \beta)/\alpha]$	1.20
$b = \ln [(1 - \alpha)/\beta]$	0.68
$h0 = -b / (P + Q)$	-2.89
$h1 = a / (P + Q)$	5.14

Table 2 Indications for anatomical (ASR) and reverse shoulder replacements (RSR).

Indication	ASR	RSR
Osteoarthritis	94	0
Fracture	0	22
Post-internal fixation	3	3
Avascular necrosis	1	0
Cuff tear arthropathy	0	70
Rheumatoid arthritis	2	4
Chronic dislocation	0	1
Total	100	100

Reverse shoulder replacements

Between July 2011 and July 2016, the senior author performed 100 RSRs. The average age at time of operation was 75.5 years of age (range 61–90 years). The indications for RSR are shown in Table 2.

A total of 18 complications were noted to have occurred in 17 patients. The type of complication and outcome is shown

in Table 4. Eleven complications were classified as major complications and seven as minor complications. Of these complications, 10 patients required a return to theatre for 11 operations. One patient required revision of reverse to a large hemiarthroplasty following dislocation. No additional complications occurred between 3 and 12 months.

The one case of deep infection occurred in a patient undergoing RSR for proximal humeral fracture. One dislocation, one ulnar nerve neuropathy and one humeral calcar crack occurred in the patients undergoing RSR for trauma. None of the patients being converted from a failed locking plate fixation to a RSR sustained a complication. We observed that the overall complication and reoperation rate were similar in both the trauma and non-traumatic indications for surgery for RSR.

The overall complication rate was observed to be significantly higher in the RSR group as compared with the ASR group, with an odds ratio of 4.9 (95% confidence interval 1.6–15.2, $P = 0.0057$, Fisher's exact test 0.0046). The major complication rate was found to be even higher with an odds ratio of 12.2 (95% confidence interval 1.5–96.6, $P = 0.005$, Fisher's exact test 0.005).

Performance monitoring

The CUSUM plot shown in Figure 1 shows a main inflection point at 16 cases for ASR, after which point a trend of improved performance is demonstrated. The ASR plot crosses the lower decision limit at case 40, where the failure rate is equal to the defined 10% complication rate within the bounds of a type II error probability of 0.2. The RSR plot does not demonstrate any clear inflection point, implying an extended learning curve or higher complication rate. Although the upper decision limit was not breached, statistical inference regarding complication rate cannot be made, as the plot remains between the decision limits.

Discussion

This study has shown the early complication rate and performance characteristics associated with shoulder arthroplasty for a surgeon in their early career. We have shown that early complications occur within the first three months postoperatively and the remaining patients in both groups appear to have a well-functioning implant. Clearly, the effect of an early complication on the longevity of the

Table 3 Summary of complications for anatomical shoulder replacements (sequential case number in brackets).

Complication	Number	Reoperation	Timing	Outcome
Fracture (13, 16, 90)	3	0	Intraoperative	Glenoid # noted on insertion of glenoid keel maker. Stable and no additional fixation needed. No adverse effect ($n = 3$)
Loose humeral implant (77)	1	1	< 6 weeks	Removal of stemless and revision to cemented stem on day 2
Total	4	1		

Table 4 Summary of complications for reverse shoulder replacements (sequential case number shown in brackets). One patient with a dislocation also sustained an ulna nerve neuropraxia that required release, requiring two reoperations.

Complication	Number	Reoperation	Timing	Outcome
Dislocation (23, 50, 54, 55, 69)	5	5	< 6 weeks	Open reduction (<i>n</i> = 3), closed reduction (<i>n</i> = 1), revision to megahead (<i>n</i> = 1)
Fracture (28, 53, 73, 92)	4	0	Intraoperative	Glenoid # noted on insertion of base plate, no adverse effect (<i>n</i> = 2), humeral calcar crack noted on insertion of stem, cerclage wired, no adverse effect (<i>n</i> = 2)
Ulna nerve neuropathy (23, 59, 78)	3	1	< 6 weeks	Transient neuropraxia with full recovery (<i>n</i> = 2), ulna nerve release at elbow, with subsequent full recovery (<i>n</i> = 1)
Wound infection (24, 66)	2	2	< 6 weeks	Deep (<i>n</i> = 1), superficial (<i>n</i> = 1), washout with no recurrence (<i>n</i> = 2)
Dissociation of glenosphere (3)	1	1	< 6 weeks	Complete recovery after revision of baseplate and glenosphere
Haematoma (25)	1	1	< 6 weeks	Washout on day of surgery, no adverse effect
Acromial fracture (97)	1	1	6–12 weeks	Open reduction internal fixation
Axillary vein injury (18)	1	0	Intraoperative	No adverse effect
Total	18	11

implant affected is not yet known. It is also apparent that there is a significant difference in the early complication rate between RSR and ASR. According to our data, the RSR carries a threefold early complication rate and a tenfold early reoperation rate in comparison with ASR. CUSUM plots have highlighted the particular need for continued monitoring of RSR outcomes, up to and beyond the first

100 cases given the long learning curve and high complication rate seen.

For the RSR, dislocation was the most common complication and occurred within the first six weeks of implantation (no other dislocations were found during the five-year period of the study). Following the fourth dislocation (patient 55) in the RSR group, modifications to the immediate postoperative protocol during hospital admission were made to ensure that patients avoided extension past neutral. Following these changes, only one further dislocation occurred in 45 patients (2%). This demonstrates the importance of postoperative instructions, as well as patient selection and operative technique, all of which form part of surgeon experience and a learning curve.²⁰ A dislocation rate of 5% is comparable with others studies, with Zumstein’s systematic review quoting an overall dislocation rate of 4.7%,²¹ and Alentorn-Gel *et al.*²² quoting a dislocation rate of 4.4% in a systematic review of 1118 patients.

Intraoperative fractures occurred in similar numbers in both groups (3–4%) and, if found to be stable on the glenoid side, did not appear to be problematic (no early loosening was seen in either group during the five-year period of the study). We observed three cases of ulnar nerve transient neurapraxia in our RSR cohort. Previous studies have observed transient nerve injuries in up to 45% of patients.²³

The 2% (one superficial and one deep) infection rate in the RSR group and 0% in the ASR group reflects the infection rate observed in other studies.^{24–26} It is presumed there is a larger dead-space in the RSR, both in the bursa and behind the glenosphere, in comparison with the ASR.²⁷

Ten per cent of the anatomical replacements were unsuitable for a stemless prosthesis owing to poor metaphyseal bone stock. A cemented stemmed prosthesis should be available when using these implants.

Multiple studies have reported highly variable complication rates for reverse shoulder arthroplasty, ranging from 0% to 75%.^{28–32} Separate meta-analyses of ASR and RSR complications have shown differences between the two rates. Bohsali *et al.*³³ published a 14.7% complication rate for 2810 ASRs, compared with a 24% complication rate reported in a meta-analysis by Zumstein *et al.*²¹ for 782 RSRs. Although these were slightly different cohorts of patients, it is striking how our early complication rate significantly differed between our groups (odds ratio 4.9; 95% confidence interval 1.6–15.2, $P = 0.0057$). Kiet *et al.*³⁴ directly compared a series of ASR and RSR performed at their institution by two surgeons and found no differences in rate of major complications (ASR 15%; RSR 15%; $P = 0.808$) or revision surgeries (ASR 11%; RSR 9%) at two years. It is of note that the majority of Kiet *et al.*'s ASR complications were late complications either from cuff tear or glenoid loosening, in contrast to predominantly early complications in the RSR cohort.³⁴ This may explain the differences observed in our complication rates.

Revision rates for both types of prosthesis appear to be comparable with the 2016 Australian Joint Registry, which reported a 5.4% and 4.7% seven-year revision rate for ASR and RSR, respectively.⁵⁵ This clearly does not mirror the complication or reoperation rates.

This is the first study to report a learning curve for ASR. We observed that the trend for consistent performance was reached at 16 cases and complication rate below 10%, with statistical significance seen at 40 cases. Several authors have published their learning curves for RSR, but no consensus on the presence or size of curve has been established. Groh *et al.*¹⁰ failed to show a learning-curve effect, but Kempton *et al.*⁴¹ demonstrated an early complication-based learning curve for RSR of approximately 40 cases. Walsh *et al.*³⁶ demonstrated a significant decrease in complication rate from 19% to 10.8% between their first 240 and second 240 RSRs but noted a concurrent significant change in their indications, which may have accounted for the drop in complication rate. Gallo *et al.*³⁷ noted a 16% instability complication rate in the first 57 RSRs performed at a single institution. Our findings corroborate the reported lack of a clear early learning curve and the need for monitoring beyond the first 100 cases, which in this series represented five years of practice.

The use of CUSUM analysis has not been reported in upper-limb arthroplasty; however, the simple computations and graphical representation has clear utility in prospective monitoring of cases and the authors considered that it was a more useful technique than simply taking an arbitrary cut-off point and comparing an early group with a later group. The weighting of the upward and downward deflection has the effect of drawing the attention to negative changes in practice earlier than simply plotting the cumulative number of failures. The upper boundary line can be used as an aid to warn of deteriorating performance and it is more versatile than traditional audits of practice.

The authors recognise that there are limitations to this form of process evaluation. The choice of acceptable and unacceptable complication rates was derived from a literature search and hence may not be representative. However, we consider that the size of the analysis chosen offers the best and most recognised evidence available. The complication rates for ASR and RSR are recognised to be different in contemporaneous literature. In our CUSUM analysis, we have treated the bounds of acceptability the same for all procedures. Although individual analysis could easily be constructed for each operative type, for the purposes of this study, comparison of procedure was required. It was also thought that it was both important to represent a simple and repeatable methodology, accessible for every surgeon to undertake personal analysis without complex statistical packages.

It is important to note that the senior author has a high-volume arthroplasty practice, undertaking an average of 20 ASRs and 20 RSRs per year. The relationship between surgical volume and outcomes has been studied in detail. Jain *et al.*³⁸ showed that complication rates in hospitals where ten or more shoulder replacements were undertaken every year were significantly lower than in hospitals where between five and ten procedures were undertaken. Birkmeyer *et al.*³⁹ demonstrated a direct relationship between surgeon volume and patient length of stay. Surgeons undertaking 15 or more cases a year were classed as high volume, equating to 1.6 inpatient days. This was compared with low volume surgeons, performing less than 5 cases a year and an average length of stay of 2.5 days.

It is also relevant that the senior author undertook a fellowship in the UK at the same institution, using the same implants and with a similar ratio of stemmed to unstemmed ASR. There has been no change in the indication for ASR or RSR over the study period. The frequency of ASR and RSR can be seen in Table 5. There was no significant trend favouring either prosthesis over the five-year period.

The patient characteristics in the ASR and RSR cohorts may be different and could introduce a degree of confounding bias, but the threefold difference in complication rate is still noteworthy. Orthopaedic training and fellowships are all unique and, as such, the starting point for each surgeon is different. However, the data collected and

Table 5 Frequency of anatomical (ASR) and reverse shoulder replacements (RSR) over five-year period of study.

Year	ASR	RSR
1	11	15
2	28	19
3	25	29
4	15	22
5	21	15
Total	100	100

methodology used are readily available to the specialist upper-limb surgeon, so could be broadly employed to monitor practice.

Conclusions

This study is the first to demonstrate the complication rates and performance characteristics of a new consultant shoulder surgeon in their first five years of practice. The CUSUM technique provides clear graphical representations of the utility and requirement of practice monitoring in arthroplasty procedures, with particular relevance to RSR. Surgeons and patients should be aware that the RSR is not a benign procedure and carries around a 10% chance of early reoperation. This does not appear to be the case for the ASR, although further work should be undertaken to confirm these results in other operative series.

The learning curve is not well defined for the RSR and may extend beyond the first 100 cases or may just reflect the higher complication rate in the RSR when compared with ASR. This shows the importance of prospective monitoring of performance in shoulder arthroplasty, especially when undertaking RSR.

References

- Briggs T. *A National Review of Adult Elective Orthopaedic Services in England: Getting It Right First Time*. London British Orthopaedic Association; 2015.
- National Joint Registry for England and Wales. *13th Annual Report 2016*. Hemel Hempstead; NJR; 2016.
- Brun OL, Månsson L, Nordsletten L. The direct anterior minimal invasive approach in total hip replacement: a prospective departmental study on the learning curve. *Hip Int* 2017; 0. doi: 10.5301/hipint.5000542.
- Hamilton WG, Ammeen D, Engh CA Jr, Engh GA. Learning curve with minimally invasive unicompartmental knee arthroplasty. *J Arthroplasty* 2010; **25**(5): 735–740.
- Cheng CH, Cheng YT, Chen JS. A learning curve of total knee arthroplasty (TKA) based on surgical volume analysis. *Arch Gerontol Geriatr* 2011; **53**(1): e5–9.
- Jenny JY, Miehke RK, Giurea A. Learning curve in navigated total knee replacement: a multi-centre study comparing experienced and beginner centres. *Knee* 2008; **15**(2): 80–4.
- Mehta N, Chamberlin P, Marx RG *et al*. Defining the learning curve for hip arthroscopy: a threshold analysis of the volume-outcomes relationship. *Am J Sports Med* 2018; 363546517749219.
- Clement RC, Krynetskiy E, Parekh SG. The total ankle arthroplasty learning curve with third-generation implants: a single surgeon's experience. *Foot Ankle Spec* 2013; **6**(4): 263–270.
- Jain N, Jowett A, Clarke N. Learning curves in orthopaedic surgery: a case for super-specialisation? *Ann R Coll Surg Engl* 2007; **89**(2): 143–146.
- Groh GI, Groh GM. Complications rates, reoperation rates, and the learning curve in reverse shoulder arthroplasty. *J Shoulder Elbow Surg* 2014; **23**(3): 388–394.
- Kempton LB, Ankerson E, Wiater JM. A complication-based learning curve from 200 reverse shoulder arthroplasties. *Clin Orthop Relat Res* 2011; **469**(9): 2,496–2,504.
- Zhang Q, Zhang Q, Guo W *et al*. The learning curve for minimally invasive Oxford phase 3 unicompartmental knee arthroplasty: cumulative summation test for learning curve (LC-CUSUM). *J Orthop Surg Res* 2014; **9**: 81.
- Lee, YK, Biau DJ, Yoon BH *et al*. Learning curve of acetabular cup positioning in total hip arthroplasty using a cumulative summation test for learning curve (LC-CUSUM). *J Arthroplasty* 2014; **29**(3): 586–589.
- Biau DJ, Milet A, Thévenin F *et al*. Monitoring surgical performance: an application to total hip replacement. *J Eval Clin Pract* 2009; **15**(3): 420–424.
- Kohan EM, Chalmers PN, Salazar D *et al*. Dislocation following reverse total shoulder arthroplasty. *J Shoulder Elbow Surg* 2017; **26**(7): 1,238–1,245.
- Gerber C, Pennington SD, Nyffeler RW. Reverse total shoulder arthroplasty. *J Am Acad Orthop Surg* 2009; **17**: 284–295.
- British Elbow and Shoulder Society. *VTE Guidelines for Shoulder and Elbow Surgery*. 2013. <https://www.evidence.nhs.uk/Search?q=VTE+guidelines&syn=False> (cited March 2018).
- Bolsin S, Colson M. The use of the Cusum technique in the assessment of trainee competence in new procedures. *Int J Qual Health Care* 2000; **12**(5): 433–438.
- Bohsali KI, Wirth MA, Rockwood CA Jr. Complications of total shoulder arthroplasty. *J Bone Joint Surg Am* 2006; **88**: 2,279–2,292.
- Blackwood C, Dixon J, Reilly P, Emery RJ. Legal and psychological considerations for obtaining informed consent for reverse total shoulder arthroplasty. *Shoulder Elbow* 2017; **9**(1): 15–22.
- Zumstein MA, 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**(1): 146–157.
- Alentorn-Geli E, Samitier G, Torrens C, Wright TW. Reverse shoulder arthroplasty. Part 2: Systematic review of reoperations, revisions, problems, and complications. *Int J Shoulder Surg* 2015; **9**(2): 60–67.
- Lädermann A, Lubbeke A, Mëlis B *et al*. Prevalence of neurologic lesions after total shoulder arthroplasty. *J Bone Joint Surg Am* 2011; **93**(14): 1,288–1,293.
- Naveed MA, Kitson J, Bunker TD. The Delta III reverse shoulder replacement for cuff tear arthropathy: a single-centre study of 50 consecutive procedures. *J Bone Joint Surg Br* 2011; **93**: 57–61.
- Nolan BM, Ankerson E, Wiater JM. Reverse total shoulder arthroplasty improves function in cuff tear arthropathy. *Clin Orthop Relat Res* 2010; **469**: 2,476–2,482.
- Gonzalez JF, Alami GB, Baque F *et al*. Complications of unconstrained shoulder prostheses. *J Shoulder Elbow Surg* 2011; **20**: 666–682.
- Smith CD, Guyver P, Bunker TD. Indications for reverse shoulder replacement: a systematic review. *J Bone Joint Surg Br* 2012; **94**(5): 577–578.
- Wierks C, Skolasky RL, Ji JH, McFarland EG. Reverse total shoulder replacement: intraoperative and early postoperative complications. *Clin Orthop Relat Res* 2009; **467**: 225–234.
- Cheung E, Willis M, Walker M *et al*. Complications in reverse total shoulder arthroplasty. *J Am Acad Orthop Surg* 2011; **19**: 439–449.
- Wall B, Nové-Josserand L, O'Connor DP *et al*. Reverse total shoulder arthroplasty: a review of results according to etiology. *J Bone Joint Surg Am* 2007; **89**: 1,476–1,485.
- Cuff D, Pupello D, Virani N *et al*. Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency. *J Bone Joint Surg Am* 2008; **90**: 1,244–1,251.
- Guery J, Favard L, Sirveaux F *et al*. Reverse total shoulder arthroplasty: survivorship analysis of eighty replacements followed for five to ten years. *J Bone Joint Surg Am* 2006; **88**: 1,742–1,747.
- Bohsali KI, Wirth MA, Rockwood CA Jr. Complications of total shoulder arthroplasty. *J Bone Joint Surg Am* 2006; **88**: 2,279–2,292.
- Kiet TK, Feeley BT, Naimark M *et al*. Outcomes after shoulder replacement: comparison between reverse and anatomic total shoulder arthroplasty. *J Shoulder Elbow Surg* 2015; **24**(2): 179–185.
- Australian Orthopaedic Association National Joint Replacement Registry. *Annual Report 2016: Hip, Knee and Shoulder Arthroplasty*. Adelaide: AOANJRR; 2016.
- Walch G, Bacle G, Lädermann A *et al*. Do the indications, results, and complications of reverse shoulder arthroplasty change with surgeon's experience? *J Shoulder Elbow Surg* 2012; **21**: 1,470–1,477.
- Gallo RA, Gamradt SC, Mattern CJ *et al*. Instability after reverse total shoulder replacement. *J Shoulder Elbow Surg* 2011; **20**(4): 584–590.
- Jain N, Pietrobon R, Hocker S *et al*. The relationship between surgeon and hospital volume and outcomes for shoulder arthroplasty. *J Bone Joint Surg Am* 2004; **86**: 496–505.
- Birkmeyer JD, Siewers AE, Finlayson EV *et al*. Hospital volume and surgical mortality in the United States. *N Engl J Med* 2002; **346**: 1,128–1,137.