Simple Moving Average: A Method of Reporting Evolving Complication Rates

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abstract

Surgeons often cite published complication rates when discussing surgery with patients. However, these rates may not truly represent current results or an individual surgeon’s experience with a given procedure. This study proposes a novel method to more accurately report current complication trends that may better represent the patient’s potential experience: simple moving average. Reverse shoulder arthroplasty (RSA) is an increasingly popular and rapidly evolving procedure with highly variable reported complication rates. The authors used an RSA model to test and evaluate the usefulness of simple moving average. This study reviewed 297 consecutive RSA procedures performed by a single surgeon and noted complications in 50 patients (16.8%). Simple moving average for total complications as well as minor, major, acute, and chronic complications was then calculated using various lag intervals. These findings showed trends toward fewer total, major, and chronic complications over time, and these trends were represented best with a lag of 75 patients. Average follow-up within this lag was 26.2 months. Rates for total complications decreased from 17.3% to 8% at the most recent simple moving average. The authors’ traditional complication rate with RSA (16.8%) is consistent with reported rates. However, the use of simple moving average shows that this complication rate decreased over time, with current trends (8%) markedly lower, giving the senior author a more accurate picture of his evolving complication trends with RSA. Compared with traditional methods, simple moving average can be used to better reflect current trends in complication rates associated with a surgical procedure and may better represent the patient’s potential experience. [Orthopedics. 2016; 39(5):e869-e876.]

Valid informed consent requires both the patient and the surgeon to have a clear understanding of the intervention to be performed. Inherent within consent is disclosure, which involves providing the patient with sufficient information to understand the potential benefits and risks of a procedure. Although perfect disclosure is unattainable, the surgeon should have a thorough understanding of available treatment options as well as accurate knowledge of the associated risks and benefits. Providers can gain this knowledge from the medical literature. However, much of the literature represents historical data, including publications that frequently report results from surgeries performed many years earlier. The quality of literature also can be limited, and it is often based on small cohorts, case series, and case reports. As a result, reported complication rates may not represent the current state of the art or an individual surgeon’s experience with an intervention, particularly in rapidly evolving areas.
The goal of this study was to develop a method to more accurately reflect current complication trends and improve disclosure with patients. In the financial arena, simple moving average is successfully used to evaluate trends in stock prices, financial returns, and trading volumes.\(^{10-12}\) Simple moving average is a statistical lagging indicator that acts as a filter to smooth out acute fluctuations and highlight longer-term trends. It provides investors with an accurate picture of the current value of an asset. This study was conducted to determine whether this indicator could be used to more accurately represent an individual surgeon’s current trends in complications associated with a surgical intervention.

The authors hypothesized that simple moving average could be used to represent an individual surgeon’s current complication trends associated with a surgical intervention more accurately than traditional reporting methods. The authors believe that simple moving average will help to improve disclosure, making conversations with patients more representative of their potential experience. To the authors’ knowledge, simple moving average has not been applied to the field of medicine.

Reverse shoulder arthroplasty (RSA) has revolutionized the treatment of cuff-deficient shoulder pathology.\(^{13-18}\) Although it is relatively new compared with other joint replacement procedures, the clinical success of RSA has made it increasingly popular. Over its short life span, numerous advances have occurred in RSA technology and surgical technique. Surgical skill has also increased with surgeon experience.\(^{19}\) Unfortunately, much of the medical literature reflects early experience and may not represent current outcomes. Further, complication rates in the literature vary widely, ranging from 0% to 75%.\(^{13,15,17,18,20-28}\) For these reasons, the authors believed that RSA would be an appropriate model to use in this study.

**Materials and Methods**

After institutional review board approval was obtained, a retrospective review was conducted of all RSA procedures performed by a single surgeon (S.J.H.) between April 4, 2004, and February 27, 2012, at a tertiary care academic medical institution. Abstracted data included demographic details, indications for RSA, previous surgeries, comorbidities, type of implant used, complications, timing of complications, and dates of all follow-up visits.
A total of 297 RSA procedures were performed in 297 consecutive patients. Mean age at the time of surgery was 73.0 years (range, 36.8-92.8 years). All patients, including those undergoing primary RSA (250) and revision RSA (47), were included in the study. Indications for RSA, previous surgeries, and comorbidities are shown in Table 1. Mean follow-up was 25 months (range, 3-87 months). All implanted RSA procedures were based on the Grammont reverse prostesis design.39.40 Included were 75 procedures performed with the Delta III implant (DePuy Orthopaedics Inc, DePuy Synthes, Warsaw, Indiana) and 222 procedures performed with the Trabecular Metal Reverse Shoulder System (Zimmer Inc, Warsaw, Indiana). The first 62 RSA procedures were performed with the Delta III implant, and the final 151 procedures were performed with the Trabecular Metal Reverse Shoulder System.

Complications were identified and grouped based on severity (minor or major) and timing (acute or chronic). Minor complications were defined as those that did not require further operative intervention and did not adversely affect clinical outcomes. All other complications were considered major.31-33 Acute complications were defined as those occurring within 3 months of surgery. Complications occurring later were considered chronic.

Complication rates were first calculated with traditional methods: dividing the number of patients who had a complication by the total number of patients.32 Simple moving average was calculated for all complications as well as for acute, chronic, minor, and major complications at various lag periods. Simple moving average is the unweighted mean of the previous n data points, or lag. In this study, n was defined as the last number of surgeries performed with a minimum follow-up of 3 months (to capture all acute complications). For simple moving average to evaluate chronic complication trends, n was defined as the last number of surgeries performed with a minimum 1-year follow-up (to provide a longer capture period). Each new surgery performed ($S_{n+1}$) was added to the sum, and the initial surgery in the previous simple moving average ($S_{n(n-1)}$) was dropped, creating a new simple moving average.11,12 In other words, a series of snapshot averages is calculated with a chosen sample size. As each new case is added to the series, the earliest case is dropped to maintain the chosen lag, and the new average is calculated. Thus, the serial averages (simple moving averages) provide a view of the average complications over time.

Table 2
Complication Profile in 297 Patients With Reverse Shoulder Arthroplasty

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (N=62)</th>
<th>Patients (n=50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity of complication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Major</td>
<td>49</td>
<td>37</td>
</tr>
<tr>
<td>Dislocation</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Repeat (2x)</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Recurrent (3x)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Scapular spine</td>
<td>9a</td>
<td></td>
</tr>
<tr>
<td>Acromion</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Humerus</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Transient neuropathy</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Brachial plexopathy</td>
<td>3a</td>
<td></td>
</tr>
<tr>
<td>Median neuropathy</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Deep infection</td>
<td>3</td>
<td>3a</td>
</tr>
<tr>
<td>Mechanical failure</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Glenosphere fracture</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Data as patients drop out of the capture period more quickly. Larger lags can become too filtered and may not show current trends. There is no statistical method to determine the optimal lag. Thus, in this study, simple moving average curves were evaluated at lags of 10, 25, 40, 50, 75, and 100 patients to visually determine which lag most accurately represented current complication trends. Each simple moving average was visually evaluated and compared with the traditional complication rate from this series and with rates in the literature.

In addition, to validate trends seen with simple moving average, all surgeries were sorted chronologically and divided into
Sixty-two complications occurred in 50 patients (16.8%). Of these complications, 13 were minor and 49 were major, and 36 were acute and 26 were chronic. A detailed complication profile is shown in Table 2. Eight failures requiring revision surgery occurred. Four shoulders were converted to hemiarthroplasty for recurrent instability (2 cases), metaglenoid failure (1 case), and baseplate fixation failure (1 case). Two patients were treated definitively for deep infection with articulating antibiotic cement spacers. One patient underwent revision RSA for glenosphere dissociation, and the other underwent 2-stage revision for treatment of deep infection.

Calculated simple moving average curves for all complications at various lags are shown in Figure 1. These show decreasing complication trends over time. This study found that a lag of 75 patients best represented these trends because it was large enough to filter out sporadic events, yet small enough to represent complication trends. The average capture window (follow-up) for each patient in this lag was 26.2 months (range, 17.1-34.9 months). This simple moving average showed a decrease in the rate of all complications, from an initial rate of 17.3% to the current rate of 8%. Similar decreasing trends were observed with major complications (from 12.0% to 2.7%) and chronic complications (from 8.0% to 1.3%). No change in trend was seen with acute or minor complications. These results are shown graphically with occurrence plots based on the severity (Figure 2) and timing of complications.
Corresponding simple moving average curves are shown in Figure 4 and Figure 5, respectively.

Five complications in 4 patients were not captured with a lag of 75 patients. These complications, which occurred after the individual patients had dropped out of the simple moving average, included 3 scapular spine fractures, 1 dislocation, and 1 deep infection.

Complication rates for consecutive groups of 75 patients over the series showed a similar trend toward fewer complications, including all complications (from 25.3% to 8.0%, \(P<.01\)), major complications (from 21.3% to 4.2%, \(P=.002\)), and chronic complications (from 14.7% to 2.8%, \(P=.003\)). As with simple moving average, no significant change in trends was observed for acute or minor complications (Table 3).

Traditional complication rates with revision RSA (21.3%, 10 of 47) did not significantly differ from those with primary RSA (16.0%, 40 of 250) (\(P<.40\)). The type of implant had no significant effect on traditional complication rates (Delta III implant, 22.7%, 17 of 75; Trabecular Metal Reverse Shoulder System, 14.9%, 33 of 222) (\(P<.15\)). Using simple moving average, complication trends seen with the Trabecular Metal Reverse Shoulder System decreased from 16.0% to 8.0% over time. Trends with the Delta III implant could not be evaluated. A single simple moving average value (21.3%) could be calculated because this study included only 75 procedures performed with the Delta III implant.

**Discussion**

Complication rates reported in the medical literature may not accurately represent current trends associated with a surgical procedure or an individual surgeon’s experience. Published complication rates with RSA are highly variable and do not provide surgeons or patients with a clear picture of what they can expect. Further contributing to this variability is the lack of consistency in defining complications.\(^{17}\) When calculated traditionally, the RSA complication rate of 16.8% is consistent with a number of published rates\(^{15,18,22}\) but this rate differs from many others\(^{13,21,23,24,26-28}\) Although this complication rate provides an accurate assessment of the overall experience of the senior author, it does not reflect current practice trends (8.0%), and it may overestimate the risks facing current patients. Simple moving average provides a more accurate picture of current experience with RSA. This information can help to facilitate a more effective conversation and accurate disclosure with the patient who is considering surgery.

The decreasing complication trends seen in this series may be the result of improvements in surgical technique and gains in surgical skill with experience over time. A learning curve with RSA has been observed\(^{19}\) and it is reasonable to assume that other surgeons would see similar decreasing trends in RSA complication rates with experience. Implementation of simple moving average by other surgeons is needed to provide a better understanding of evolving complication trends with RSA. These studies may help to outline the utility of simple moving average for evaluating surgeon learning curves and maturity for RSA or other surgical procedures.

It is unclear whether the choice of implant had any effect on complication trends in this series. A trend toward fewer complications was observed with
simple moving average with the Trabecular Metal Reverse Shoulder System. However, direct comparison between the 2 implants could not be performed because the number of Delta III implants allowed for only 1 simple moving average. When traditional complication rates were compared, no significant difference was observed based on the implant used. This may be related to similarities in the design of these implants, which were both based on Grammont principles and are of similar generations. It is likely that similar trends in simple moving average would be observed with the Delta III implant. However, different implant designs and changes in technique may affect complication trends.

Other practical applications for simple moving average can be hypothesized. Evaluation of simple moving average curves in this study showed fluctuations in complication trends, representing periods of increased and decreased numbers of complications. These changes, whether positive or negative, could provide the individual surgeon with a clear, simple method to evaluate practice trends. A sudden increase in complication trends seen on simple moving average might alert the surgeon to investigate possible causes, facilitating improvements in practice patterns and patient care.

The use of simple moving average also may help to improve the current understanding of changes in complication profiles unique to procedures as they evolve. This study showed that the rates of chronic and major complications decreased over time, whereas the rates of acute and minor complications remained unchanged. This finding suggests that with increased surgeon experience, improved understanding, and advances in technology, some complications may become less common. Simple moving average may improve the understanding of evolving complication profiles associated with any surgical procedure.

The use of simple moving average to report complication trends has some inherent limitations. No statistical method has been described for determining an appropriate lag time when using simple moving average in any application. The lag, or rolling number of cases selected, depends on the movement of interest, whether short, intermediate, or long term. A smaller lag may not capture later events but can show acute trends, where-

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**Table 3**

<table>
<thead>
<tr>
<th>Type of Complication</th>
<th>Total (N=297)</th>
<th>Group 1 (n=75) Patients 1-75</th>
<th>Group 2 (n=75) Patients 76-150</th>
<th>Group 3 (n=75) Patients 151-225</th>
<th>Group 4 (n=72) Patients 226-297</th>
<th>( P^a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any</td>
<td>50 (16.8%)</td>
<td>19 (25.3%)</td>
<td>13 (17.3%)</td>
<td>12 (16.0%)</td>
<td>6 (8.3%)</td>
<td>.004</td>
</tr>
<tr>
<td>Major</td>
<td>37 (12.5%)</td>
<td>15 (20.0%)</td>
<td>11 (14.7%)</td>
<td>9 (12.0%)</td>
<td>3 (4.2%)</td>
<td>.002</td>
</tr>
<tr>
<td>Minor</td>
<td>13 (4.4%)</td>
<td>4 (5.3%)</td>
<td>3 (4.0%)</td>
<td>3 (4.0%)</td>
<td>3 (4.0%)</td>
<td>.83</td>
</tr>
<tr>
<td>Chronic</td>
<td>23 (7.7%)</td>
<td>11 (14.7%)</td>
<td>6 (8%)</td>
<td>4 (5.3%)</td>
<td>2 (2.8%)</td>
<td>.003</td>
</tr>
<tr>
<td>Acute</td>
<td>28 (9.4%)</td>
<td>9 (12%)</td>
<td>7 (9.3%)</td>
<td>8 (10.7%)</td>
<td>4 (5.6%)</td>
<td>.24</td>
</tr>
</tbody>
</table>

*Cochran-Armitage trend test.
*One patient had both an acute and a chronic complication.
as a larger lag may capture rare or later complications but may not show desired trends.

In the current study, a lag of 75 patients provided the best visual representation of trends in complications. However, this lag did not capture 5 complications in 4 patients that occurred after these patients had been dropped from the simple moving average. As a result, these complications were not represented. It is important to note, however, that rare or late complications can be missed with traditional reporting methods as well. In addition, simple moving average is not a good measure for reporting longevity or survivorship of implants. Guery et al. reported a significant decrease in RSA survivorship after 72 months. The current series would require a lag of at least 250 patients to capture a minimum 72-month follow-up. Increasing the lag to capture such long-term failures would substantially affect the ability of simple moving average to show current trends.

Smaller lag times also provide decreased filter effect, potentially leading to abrupt changes in observed trends. This decreased filtration effect can be seen in the sporadic variation within simple moving average for shorter lags. Greater lag times can be used to reduce this variation and improve the filtration effect. However, as noted earlier, long lag times may lose representative trends. Appropriate lag times may differ for individual surgeons and specific surgical interventions. Further studies are needed to better understand how to determine appropriate lag times for a given simple moving average.

The concept of applying simple moving average to medicine is novel. As a result, there are some limitations to this study. No statistical methods are available to analyze the significance of evolving trends observed with simple moving average. This study applied the Cochran-Armitage trend test to detect significance in trends in 4 consecutive groups of 75 patients to determine whether the observed decreasing trend was significant. Although the overall trend was significant, it is not known whether patient-to-patient changes in simple moving average were also significant. Further, this study represents the experience of a single surgeon. Although the use of simple moving average proved helpful in determining this surgeon’s evolving experience with RSA, the simple moving averages reported in this study may not represent overall current complication trends for RSA. This limitation, however, is shared by traditional reporting methods that also often represent a single surgeon’s experience.

Despite these limitations, changes in complication trends with RSA were seen with the use of simple moving average in this study, suggesting that this can be a useful method for reporting current complication trends. The success seen in this model suggests that simple moving average could be used successfully to evaluate complication trends associated with any surgical procedure or individual surgeon. Further investigation is needed to better understand the use and potential application of simple moving average in the medical field.

**Conclusion**

Simple moving average can be used to accurately represent an individual surgeon’s current complication trends associated with a surgical intervention. In this study, simple moving average successfully reflected current complication trends and provided a more accurate picture of the senior author’s experience with RSA. The current data suggest significant improvement in complication rates over time with RSA. This study introduced a novel alternative method for reporting complication trends and provided a valuable framework for future studies. The authors believe that, compared with traditional methods, simple moving average can more accurately represent a patient’s potential experience and help to improve disclosure.


