INTRODUCTION
Since its introduction in 1993 by French orthopedic surgeons Paul Grammont, Pierre Trouilloud and Emmanuel Baulot, the Reverse Total Shoulder Arthroplasty (RSA) has pioneered restoration of function and range of motion (ROM) to patients with shoulder arthropathy without a functional rotator cuff. Building on concepts from the late 1980’s, the first few generations were met with a multitude of complications, including complete failure of the implant. Through its evolution, this monumental operation has become possible by designing a prosthesis that deviates from the normal anatomy of the shoulder by effectively reversing the articular contact surfaces of the glenohumeral joint so that the stability and force of the moment arm relies primarily on a functioning deltoid rather than the cuff itself. This design is essential in patients that who have undergone multiple failed arthroplasties or irreparable tears of the rotator cuff, chronic instability, or recurrent dislocation of the glenohumeral joint, comminuted or non-union fractures of the proximal humerus or humeral head, lytic destruction of proximal humerus or humeral head by a tumor, osteonecrosis of the humeral head, and degenerative or rheumatoid arthritis degradation of the glenohumeral joint. Since this product is relatively new to market and the longevity of the prosthesis is not known, the option of RSA is generally reserved for patients aged 65 and older. Currently, there are 20 companies globally that produce the RSA prosthesis and the evolution of independent designs and revisions are in response to the development of our understanding of the complications and functional limitations of the implant. In this article we review the developments in prosthetic modifications as well as the recognized complications of RSA. We also report on some preventative measures regarding the RSA complications.

MATERIALS AND METHODS
Search strategy
We conducted a systematic literature search of the PubMed database from the last decade (through August 2013) by using “Reverse Shoulder Arthroplasty” and “complications” as required search terms. This yielded 348 article results.

Inclusion criteria
There were 3 criteria for inclusion of a study for this paper: The study 1) provided relevant and applicable information on the relation between RSA and its perioperative complications; 2) provided guidance and/or suggestions for minimizing complications of RSA; and 3) published in the English language.

Assessment of study quality and data extraction
The 38 studies fulfilling the inclusion criteria were independently examined and their main characteristics were recorded by two of the authors (E. C., W. N.) in groups reflecting specific complications of RSA.

COMPPLICATIONS
While the range of complications addressed in this paper is not complete and inclusive, it does address the most common complications as well as those unique to this procedure. In this article, we divide the complications into three sections that are significant for RSA: glenoid, humeral, and non-specific.

GLENOID
Glenoid Instability
One of the main contributors to prosthetic implant failure following reverse shoulder arthroplasty is glenoid component loosening. This loosening historically occurs 1–3 years post-operatively and is secondary to poor initial glenoid component fixation.

Fundamental glenoid baseplate design includes four possible points for fixation. While intuition would guide a surgeon to utilize as many possible points of fixation as bone stock will accommodate, James et al. stipulates that the superior and inferior screws are the most critical for initial glenoid component fixation. It is important to note that if bone stock and patient anatomy afford the opportunity for additional fixation by adding an anterior and/or posterior screw; their addition is not critical for adequate glenoid component fixation and cannot be relied on as the primary points of fixation. The spine and trauma literature in 1999 suggested that post-operative component strength is greatly influenced by screw length and the use of bicortical locking screws delivers superior stability as compared to unicortical. To increase stability, the use of divergent screw patterns with premeditated trajectories provides the greatest component fixation.

Hoenig et al. cites that the addition of a long posterior screw (versus the standard length) in patients with severe osteoporosis or pre-existing bone defects can generate increased stability by penetrating deep into the scapular spine. Similarly, in patients where bone stock is of concern, it is vital that the surgeon is deliberate during the reaming process because for every 1 mm of reaming beyond the level needed for appropriate component

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seating, an additional 5% of available bone stock has been sacrificed.

A radiologic analysis published in 2011 serves as a comprehensive guide for proposed screw trajectories for baseplate fixation by using anatomical landmarks and proposed endpoints for optimal purchase based on predicted areas of increased cortical density. In order to accommodate both maximum surface contact of implant-to-prepared glenoid site of fixation, as well as preplanned screw trajectories, the use of a variable angle locking screw baseplate fixture is recommended.

With the understanding that baseplate position is quintessential for adequate primary fixation, it would be considered highly prudent to use intraoperative CT guidance programs to acquire optimal glenoid component baseplate positioning.

Acromial and Scapular Fracture
The design of the RSA prosthesis specifically requires a functional deltoid muscle for its operation. The deltoid contracts to draw the humerus up and around the center of rotation of the reverse oriented glenohumeral joint. The deltoid muscle can be divided into three sections with the lateral portion being the largest contributor to abduction forces. Since the lateral deltoid originates at the superior process of the acromion, it is intuitive as to why it is absolutely critical to have a functional acromion. In primary glenoid component positioning preoperative planning, it is paramount to consider bone stock, glenosphere diameter, medial versus lateralization of the baseplate, and especially deltoid tensioning as these all contribute to the incidence of perioperative acromial fractures. Early RSA related acromial fractures are associated with poor functional results and therefore, early detection and definitive treatment must be achieved. According to Hattrup, while conservative treatment of perioperative acromial fractures did perform better than preoperative dispositions, the functional outcomes were still markedly inferior to those with operational acromions. In a study by Crosby et al, the identification and classification of three types of acromial fractures were addressed following RSA and recommendation of corrective treatment was advised. Type I, which is described as small avulsion fractures of the anterior acromion, and healed without operative intervention. Type II was classified as fractures through the anterior acromion just posterior to the acromioclavicular joint and type III were fractures of the posterior acromion or scapular spine. Type II and III required operative fixation and the average time of appearance was ten months.

It is important to note that even though preoperative acromial lesions are worrisome in RSA, they alone, are not an absolute contraindication for the procedure. There are multiple etiologies for postoperative posterior shoulder pain following RSA implantation. Many are benign and simply attributable to expected postoperative pain and discomfort, but if clinical suspicion of an acromial and/or scapular fracture is present, investigation must be prompt and thorough. While ordering a radiographic shoulder series is an appropriate first step in identifying the source of postoperative pain, negative radiograph results alone are not sufficient to rule out an acromial or scapular fracture. If clinical exam and subjective concerns raise suspicion of a fracture, it is highly suggested that a CT scan be conducted in order to determine if additional intervention will be necessary.

Glenoid Component Failure and Glenosphere Disengagement
Failure of the glenoid component and/or glenosphere disengagement can result in central screw breakage. The screw breakage is often secondary to excessive torque applied at shearing angles beyond the intended rotation of the prosthesis or due to excessive and repetitive impacting at similar angles. The intense loading at susceptible angles can also be accomplished following the migration of the humeral component beyond the designed articulation parameters in cases such as severe scapular notching. The range of complications that can occur following this deviation by the distal prosthesis component are sub-clinical glenosphere partial disengagement with retained function to catastrophic failure of the implant following central screw breakage. As discussed in the section on acromial fractures, preexisting bone defects (such as osteoporosis or poor bone stock) are not contraindications for the implementation of RSA. However, alteration of surgical technique is advised when these defects are present. The use of a scapular spine centerline, bone grafting when indicated, and the application of a larger glenosphere are examples of the surgical technique alterations that should be considered in appropriate cases. Just as discussed for baseplate fixation, the use of CT navigation systems with appropriate software to ensure optimal purchase in quality bone stock will increase stability and reduce micromotion.

Scapular notching
Scapular notching is by far the most common complication encountered following the installation of RSA prosthesis. There has been a significant rise in the interest and research on the subject with many proposed theories about reducing the incidence by altering implant design and component positioning. Scapular notching occurs during abduction, external rotation and resting position of the arm. The lesion is formed by the direct contact of the posterior-inferior portion of the humeral cup with the inferior scapular pillar inciting erosion of the scapula just inferior and medial to the glenoid component baseplate. This erosion can become severe enough to allow migration of the proximal humerus medially and therefore applying excess stress on the glenoid component via direct contact of the liner and inferior screw. These additional stresses can lead to loosening and/or failure of the glenoid component. There have been several proposed mechanisms to reduce the incidence of scapular notching including: increased glenosphere diameter, eccentric and lateral offset of the glenosphere, inferior tilt of the baseplate, and humeral component design modifications. While each of these suggested modifications may, in some way, lower the incidence of scapular notching, they can lead to a new set of complications if they are applied independently. It has been suggested that the most effective way to reduce the incidence of scapular notching is to increase the diameter of the glenosphere to over 36mm with a lateralized center of rotation with regard to the native retroversion of the patient’s humerus. Berhouet et al recommend the intermediate size of 39mm, as the larger diameters are hard to work with. However, in multiple other studies that are discussed in other sections of this paper, lateral offset can lead to additional deltoid tensioning and possible glenoid component loosening. De Biase et al proposed

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an eccentric design of the glenosphere central screw that reduced the incidence of impingement and subsequent notching by lowering the center of rotation and overlapping the lower glenoid rim but not overhanging the inferior border of the baseplate. While theoretically, the eccentric design, lateral offset, and inferior tilt contribute to reduction in scapular notching, their application has led to an increase in component loosening and possible breakage of the central screw secondary to stress concentration and/or direct contact.\textsuperscript{17,18,19}

In consideration of the individual concepts and results that each of the components of implant configuration offer in reduction of scapular notching, a calculated numerical evaluation to ascertain the most stable configuration of glenosphere diameter, eccentric and lateral offset, as well as inferior tilt must be surmised to achieve the optimal combination of these parameters. It is important to note that in the study conducted by Edwards et al\textsuperscript{20}, inferior tilt alone did not influence scapular notching and this finding should place emphasis on the other parameters in regards to hierarchy. One additional area of interest that has not been heavily regarded in the research is that of humeral cup design. It has also been advised that an indentation of the posterior-inferior aspect of the humeral cup would decrease contact as well as reduce impingement.\textsuperscript{21}

**HUMERAL**

**Polyethylene liner deterioration**

The design of the RSA effectively reverses the glenohumeral joint configuration and changes the anatomical architecture in a way that contradicts with the placement of other anatomical structures. One such structure that is affected by the implant is the scapula. By tensioning the deltoid and ensuring repair and functionality of the subscapularis tendon, the surgeon creates a constrained joint. The constraint serves the purpose of stability but the new geometry brings the humeral component in contact with the inferior scapular pillar. This contact is secondary to the medialization of the glenohumeral joint, which is unfortunately the most stable configuration. Continued contact with the scapular pillar as well as the inferior glenoid baseplate screw is concerning for rim wear of the polyethylene liner. If the liner becomes worn too much, this can lead to loosening of the prosthetic components and possibly recurrent dislocations. The presence of scapular notching in combination with liner rim wear greater than or equal to a grade 2 should prompt consideration of removal of the inferior glenoid baseplate screw.\textsuperscript{22}

**Humeral component loosening**

Humeral component loosening is a relatively rare complication of RSA and has historically been associated with the design of the implant or to surgical errors during the implantation procedure.\textsuperscript{1} Loosening of the humeral component can occur as a result of intraoperative humeral metaphysis and/or diaphysis fracture that can occur during reaming as well as implant fixation. The surgeon must consider bone quality as well as the possible impact of lytic bone lesion relative to adjacent bone stock. In the incidence of severe osteoporosis or bone stock degeneration in RA or lytic bone tumors, the length of the stem, the diameter of the prosthetic metaphysis and the use of cement for fixation all need to be considered.

**Shoulder instability and/or dislocation**

Stability of the shoulder is attained with respect to the prosthesis by medializing the center of rotation and humeral distalization. By extending the length of the humerus, the deltoid is stretched creating tension for greater action of the lever arm. Too much tension created by humeral distalization can lead to recurrent dislocations and possible component loosening. A small study conducted by Lädermann et al\textsuperscript{23} purposed one method to achieve appropriate deltoid tensioning via preoperative comparison to the contralateral shoulder radiographs. As discussed earlier, the medial position lends to a much greater incidence of scapular notching. In an attempt to correct this, multiple studies have been performed focusing on lateralizing the center of rotation during implantation in efforts to both reduce the incidence of scapular notching as well as increase ROM, specifically internal and external rotation. By lateralizing the center of rotation, Henninger et al. found a decreased incidence of scapular notching and therefore an increase in joint stability. However, the lateralization changes the geometry in such a way that creates a disproportionate tension on the deltoid leading to an increase in abduction forces and lends itself to greater vulnerability to serious complications. The increase in deltoid tension can lead to increased deltoid pain, acromial stress fractures, and glenoid component loosening.\textsuperscript{24} In addition, the lateralization has led to scapular fractures and failure of glenoid baseplate fixation including screw breakage and dismantling.\textsuperscript{1} In order to create a surgical field that accommodates the lateralization, the surgeon must use the deltopectoral approach which carries a longer recovery period as well as longer operative times that increase the incidence of infections.\textsuperscript{25} While deltoid positioning remains one of the most influential factors relating to stability of the shoulder following RSA, the presence of a reparable or functional subscapularis tendon follows as a close second. The presence of a functional subscapularis tendon is vital in creating a compressive force on the prosthesis in order to prevent anterior or posterior displacement. A non-salvageable subscapularis tendon is generally found in shoulders that have undergone multiple failed arthroplasties, comminuted and/or proximal humerus non-union fractures, and fixed dislocations.\textsuperscript{26} Another factor affecting the stability of the shoulder is the history of an infection. The highest rates of infections were seen in a fracture sequelae group as well as patients that have subscapularis insufficiency.\textsuperscript{27}

Based on biomechanical studies, an implant configuration of 20 degrees retroversion would also theoretically increase the intrinsic stability without over limiting ROM.\textsuperscript{28,29} Another avenue of prosthetic stability is fully un-cemented trabecular metal of the humeral stem. The advantages this has over cemented stems are that there is a decrease in operative time, and therefore a decreased rate of infection, and ease of component retrieval should the need for revision arise.\textsuperscript{25}

Beyond the concept of an un-cemented stem, the use of a stemless humeral component has also been considered. In cases where preservation of bone stock is a desire, the stemless humeral component implants have proved to be a viable option that have produced comparable results compared to traditional implants.\textsuperscript{26}

In evaluating all factors that contribute to stability of the shoulder following RSA, outcomes of treatment involving early instability
are generally poor. Surgical approach is one of the last factors that contribute to stability and must be considered in preparation for a RSA procedure. Risk of instability appears to be higher for the deltopectoral approach as compared to anterosuperior approach (5.1% vs. 0.8%) secondary to the preservation of the subscapular tendon in the anterosuperior.

Reduced ROM
Limitations in range of motion following RSA procedures are generally secondary to the medialization and glenoid baseplate tilt. The best recognized resolution for increasing ROM and extended internal and external rotation is lateralization of the baseplate, but as discussed in previous sections, the consequences far outweigh the added benefit. Another recommendation is the humeral stem positioning should not be retroverted and the use of a modular baseplate at various degrees of rotation in an eccentric position could theoretically improve ROM and external rotation. However, as we have learned, the retroversion of approximately 20 degrees of the humeral component greatly improves prosthetic stability. It is important to note that both of these studies were not conducted in vivo but rather were biomechanical experiments. A new glenoid design manufactured by Aston Medical shows early promise in reducing the incidence of scapular notching as well as improved range of motion. In their design, they altered the neck-shaft angle and extended the inferior coverage.

NON-SPECIFIC COMPLICATIONS
There is a subset of complications that are inherent to all forms of arthroplastic surgery. While we mention some of them in this section, they are certainly not all inclusive but are unique to RSA and included methods for successful treatment or suggestions for their avoidance. Some of the most common (non-specific) complications encountered following RSA prosthetic implementation are postoperative infection, hematomas, and peripheral neuropathies.

Postoperative infections
We recognize that each case must take into account the individual patient’s disposition. In otherwise healthy patients, treatment of perioperative acute infections less than two months should include culture, irrigation and debridement, appropriate IV antibiotics, and component retention. Treatment of subacute (2-12 months) and chronic infections (>12 months) should initially be treated with component removal and placement of an antibiotic spacer until it can be confirmed that the infection is clear.

Based on the historical culture findings in infected RSA components, special attention should be paid to low virulence organisms including but not limited to P. acnes. Some institutions have adopted the practice of using clindamycin as perioperative prophylactic antibiotic regimes.

According to the results of Nowinski et al., the application of antibiotic loaded cement assisted in the reduction of deep infections for primary RSA with short-term follow-up.

Brachial/ Peripheral nerve palsies
Neurological lesions, when they occur, may also be attributed to surgical dissection, retractor compression, vascular lesions, mobilization of the arm, or scalene block. Surgical experience with the procedure, operative exposure approaches, and development of surgical technique will contribute to the reduction in postoperative peripheral neuropathies. However, it is important to note that the superior and posterior glenoid baseplate component screws pose the greatest risk for suprascapular nerve damage and in preoperative planning it is paramount to consider the screw trajectories in order to avoid nerve damage. It is also been recommended that the use of short locking screws for primary fixation provides appropriate stability while reducing the risk of suprascapular nerve damage.

Multiple studies have analyzed the advantages and drawbacks of the anterosuperior approach compared to the deltopectoral approach. While the anterosuperior approach has been proven overall more effective and less impacted by the major complications, with regard to peripheral neuropathies, the anterosuperior approach does include possible axillary nerve damage.

CONCLUSION
With regard to the myriad of complications associated with RSA prosthetic implants, it is important to note that no single component modification is sufficient in improving the functional outcome without potentiating secondary adverse events. In each of the sections we tried to represent the collaborative findings in the contemporary literature and make educated recommendations for improved patient satisfaction. We recognize the limitations of this paper in that brand-specific prosthetic complications were not addressed, preoperative indications were not categorized, and postoperative functional scales to measure improvement were not regarded. To promote the evolution of prosthetic design that attempts to reduce the incidence of the major complications of RSA, it is essential that communication between the surgeons performing the procedure and the prosthetic manufacturers be continuous.

REFERENCES

Image from FXRX Orthopaedics & Bracing’s website: http://fxrxcinc.com/wp-content/uploads/2014/03/Reverse-Total-Shoulder.png

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