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SYMPOSIUM: REVERSE TOTAL SHOULDER ARTHROPLASTY

Scapular Notching

Recognition and Strategies to Minimize Clinical Impact

Gregory P. Nicholson MD, Eric J. Strauss MD, Seth L. Sherman MD

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Abstract

Background Scapular notching is a unique complication of Grammont-style reverse total shoulder arthroplasty. While reverse total shoulder arthroplasty has revolutionized the treatment of pseudoparalysis secondary to cuff tear arthropathy, the implications of scapular notching with regard to patient function and implant stability remain unclear.

Questions/purposes We reviewed literature to determine the etiology and incidence, radiographic progression and effect on implant stability, relationship with postoperative function, and risk factors for the development of scapular notching.

Methods We reviewed PubMed, the Cochrane Central Register of Controlled Trials, and EMBASE with the terms "reverse total shoulder arthroplasty" and "scapular notching." Inclusion criteria were a level of evidence of IV (or better). Twenty-four articles were selected after manual review.

Results Scapular notching after reverse total shoulder arthroplasty is due to repetitive contact between the polyethylene of the humeral component and the inferior scapular neck during adduction, leading to erosion of the scapular neck, polyethylene wear, joint inflammation, and potential implant loosening. Scapular notching appears between 6 and 14 months postoperatively, with an incidence of 44% to 96%. Radiographic progression and effect on patient function remain controversial. Predictors of scapular notching include surgical approach, glenoid wear, preoperative diagnosis, infraspinatus muscle quality, cranial–caudal positioning, and tilt of the glenosphere.

Conclusions Improved understanding of the etiology and risk factors for scapular notching will lead to refinement in implant technology and surgical technique that may translate into improved patient function and implant longevity for Grammont-style reverse total shoulder arthroplasty.

Introduction

Conventional unconstrained total shoulder arthroplasty (TSA) designs depend on a functioning rotator cuff for implant stability and the restoration of active shoulder ROM [7, 23]. For patients with symptomatic glenohumeral osteoarthritis and a normal rotator cuff, TSA decreases pain and improves shoulder function. However, in patients who have a deficient rotator cuff, abnormal glenohumeral kinematics leads to decreased subjective satisfaction, worse radiographic results, and increased rate of complications after conventional TSA [5].

In an effort to compensate for a nonfunctioning rotator cuff in arthrosis, reverse ball-and-socket arthroplasty prostheses were developed [1]. While early reverse designs were fraught with problems, including catastrophic failure of the glenoid secondary to excessive torque and shear forces [7], instability [7], and poor active shoulder motion [1, 7], recent advances in implant technology and surgical technique have led to a greater than 30% increase in

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G. P. Nicholson, E. J. Strauss, S. L. Sherman
Division of Sports Medicine, Rush University Medical Center, Chicago, IL, USA

G. P. Nicholson (✉)
Midwest Orthopaedics at Rush, Rush University Medical Center, 1611 West Harrison Street, Suite 300, Chicago, IL 60612, USA
e-mail: orthonick@comcast.net

relative Constant-Murley scores and subjective patient satisfaction and active forward elevation increasing from 42° to 100° postoperatively [22]. Along with improved outcomes, however, the reverse TSA has been associated with unique potential complications, including the development of scapular notching.

Scapular notching is defined as glenoid neck erosion caused by repetitive mechanical abutment of the humeral component with the inferior scapular neck. This complication typically occurs within the first few months after reverse TSA [7]. The incidence of scapular notching ranges from 44% to 96% [7, 14]. Factors associated with the development of scapular notching include prosthetic design [9], surgical approach [11], positioning of the glenosphere [9, 13, 16, 18], preoperative diagnosis [11], and pattern of glenoid wear occurring during the degenerative process [11]. While early studies reported no effect of scapular notching on postoperative pain and Constant-Murley score [11], recent series with longer followup have demonstrated notching can be progressive [22] and associated with reduced shoulder ROM, strength, decreased subjective shoulder scores, decreased mean relative Constant-Murley scores, polyethylene wear, and the potential for implant loosening [16]. Due to the rising popularity of reverse TSA and the alarmingly high reported incidence of scapular notching, a greater understanding of this novel complication is paramount. Due to the relative paucity of studies, the effect of scapular notching on patient function, radiographic progression, and implant stability remains controversial.

This study is an evidence-based review of scapular notching in reverse TSA. Specific issues addressed include (1) the etiology of scapular notching; (2) the incidence of scapular notching; (3) radiographic progression and the effect on implant stability; (4) scapular notching and its relationship with postoperative ROM, strength, and function; and (5) identification of both preoperative and intraoperative risk factors for the development of scapular notching. It is our hope this review will raise clinical awareness about this important entity, expose the limitations of the current body of literature, and promote further clinical investigation.

Search Strategy and Criteria

A comprehensive search of PubMed, the Cochrane Central Register of Controlled Trials, and EMBASE was performed using the terms "reverse total shoulder arthroplasty" and "scapular notching." We initially examined all papers with a level of evidence of IV or higher. We excluded articles with Level V evidence. Initially, 67 articles were identified for "reverse total shoulder arthroplasty," 23 for "scapular notching," and 10 for a combined search. After manual review of abstracts and selected full-text articles, we retained 24 clinical, biomechanical, and review articles pertinent to the topic.

Background: The Grammont-style Reverse TSA

Compared to prior attempts at reverse TSA, the design proposed by Grammont in the late 1980s moved the center of joint rotation both medially and inferiorly [1]. Medialization of the center of rotation creates a mechanical advantage for the deltoid muscle, increasing its lever arm and allowing for a greater recruitment of deltoid fibers during active shoulder motion [1, 7]. Portions of the deltoid initially medial to the native glenohumeral joint center of rotation become active abductors and elevators in their new lateral position. Distalization further increases the efficiency of the deltoid during shoulder motion through elongation and an associated increase in its resting tension. The biomechanical advantages of the new center of rotation allow a more effectively functioning deltoid muscle to substitute for deficiency of the superior rotator cuff. However, while active forward elevation and abduction are improved by the longer deltoid lever arm afforded by the medial and inferior position of the joint center of rotation, external rotation may be compromised after reverse TSA. This occurs as a consequence of less deltoid present posterior to the center of rotation with a smaller external rotation moment coupled with loss of tension within the posterior rotator cuff musculature.

An additional biomechanical advantage of the Grammont concept was the placement of the center of rotation in direct contact with the glenoid surface (a neckless component design). This positioning minimized the potential for implant loosening by decreasing the shear forces experienced by the glenoid component and converting the torque generated during deltoid contraction to compressive forces at the implant–bone interface [1, 7]. The superoinferior positioning effect of deltoid contraction in a rotator cuff deficient shoulder that plagued glenoid component survival in earlier reverse models could now be captured and transformed from a loosening force into an elevation/abduction moment [10].

Based on the biomechanical principles put forth by Grammont, reverse TSA reliably reduces pain and improves shoulder function by increasing active abduction and forward elevation in patients with massive rotator cuff tears and rotator cuff tear arthropathy. Werner et al. [22] retrospectively evaluated 58 patients with painful pseudoparalysis secondary to massive rotator cuff tears managed with reverse TSA. At a mean followup of 38 months, the authors noted improvements in subjective shoulder function (18% preoperatively to 56% postoperatively), mean Constant-Murley score (29 to 64), and mean Constant-Murley pain score (5.2 to 10.5). Active forward elevation improved from 42° to 100° and abduction from 43° to 90°. While the incidence of complications and rate of revision surgery were high in this series (50% and 33%, respectively), subjective shoulder scores improved from 18% preoperatively to 56% postoperatively, leading the authors to conclude reverse TSA is an effective salvage procedure for cases of painful pseudoparalysis in rotator cuff deficiency. Similar findings were reported by Wall et al. [21] in their evaluation of 191 reverse TSA cases in 186 patients with a mean age of 72.7 years. At a mean followup of 39.9 months, the mean Constant-Murley score had improved from 23 before surgery to 60 after surgery. Mean active forward elevation in this cohort increased from 86° to 137° and 173 of the 186 patients (93%) were either satisfied or very satisfied with their function. Cuff et al. [3] prospectively evaluated the outcomes after reverse TSA in 94 patients (96 shoulders) with rotator cuff tear arthropathy followed for a minimum of 2 years postoperatively. Improvements were seen in the mean American Shoulder and Elbow Surgeons (ASES) score (30 preoperatively to 77.6 postoperatively), mean ASES pain score (15 to 41.6), and mean Simple Shoulder Test score (1.8 to 6.8). Mean active abduction increased from 61° to 109.5°, forward elevation from 63.5° to 118°, and external rotation from 13.4° to 28.2°. Subjectively, 82% of patients from this cohort rated their result as good to excellent. While the extent of improvement varies between these and other studies evaluating outcomes after reverse TSA, postoperative clinical scores are consistently good and patient satisfaction levels are high.

Along with the improvements in active shoulder motion that the medialized and inferiorized center of rotation of a Grammont-style reverse TSA provides, the biomechanics of this nonanatomic prosthesis creates the potential for changes in the scapular neck evident on postoperative radiographs. Some early authors considered the development of a scapular notch a natural consequence of reverse TSA with little clinical implication [22]. Others view scapular notching as a postoperative complication, supporting this belief with evidence of a correlation between the extent of postoperative scapular neck erosion and worse clinical outcomes with reduced shoulder ROM, reduced strength, polyethylene wear, and the potential for implant loosening [11].

Etiology and Classification of Scapular Notching

Scapular notching after reverse TSA describes the erosion of bone of the scapular neck secondary to mechanical abutment of the humeral implant with adduction of the upper extremity [7, 11, 13] (Fig. 1). Bone loss of the scapular neck may be present directly inferior to the implanted glenosphere or may extend anterior or posterior depending on implant design, positioning of the glenosphere, and version of the implanted humeral component.

Assessing the presence of a notch is made using a true AP view of the shoulder in the scapular plane. This view provides a direct look at the glenosphere and the scapular neck without overlap from the humeral component. In addition to evaluating the inferior scapular neck for evidence of bony erosion, the AP view also allows for a review of glenosphere cranial-caudal positioning and tilt. The typical postoperative radiographic workup after a reverse TSA also includes an axillary view, which can be assessed for extension of the notch to the anterior and posterior aspects of the inferior scapular neck.

With repetitive mechanical contact between the polyethylene cup of the humeral component and the inferior scapular neck, wear of the polyethylene may compound a notch by provoking a biologic response, leading to chronic inflammation of the joint capsule, local osteolysis, and the potential for implant loosening [13, 20]. Additionally, wear of the polyethylene cup occurring with scapular notching may be associated with a loss of joint constraint [1]. With continued erosion of the inferomedial aspect of the cup, its effective depth is reduced, creating the potential for joint instability.

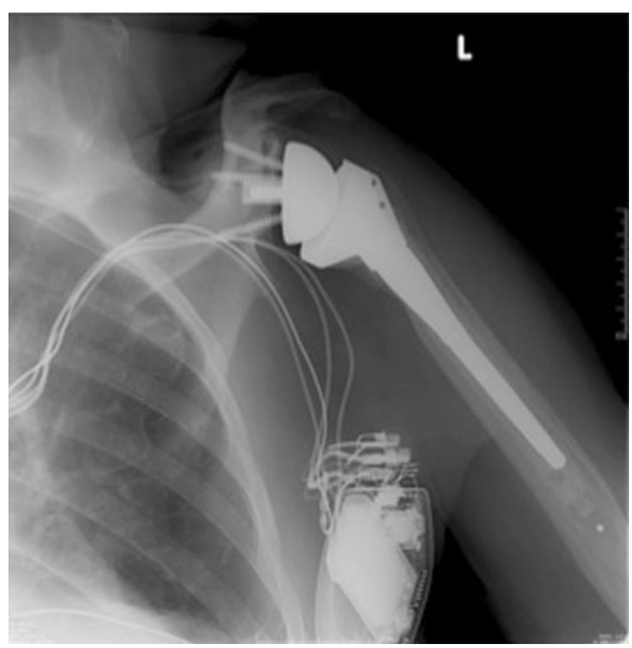

Fig. 1 An AP view of the left shoulder demonstrates notching of the inferior scapular neck after reverse TSA. Bony erosion of the inferior scapular pillar is evident to the level of the inferior stabilization screw of the glenosphere.

Nyffeler et al. [12] recently reported a postmortem retrieval analysis of a Delta III reverse TSA obtained 8 months after implantation from a 91-year-old man who had been treated for painful pseudoparalysis secondary to a massive, irreparable rotator cuff tear. At the patient's last followup visit 3 months postoperatively, he was doing well clinically, having recovered 90° of active forward elevation and abduction. Radiographs demonstrated a small notch at the lateral border of the scapula and a radiolucent line on the posterior aspect of the glenosphere. Gross evaluation of the retrieved postmortem specimen demonstrated progression of the scapular notch with erosion of the inferior portion of the glenoid and scapular neck, leaving the most inferior portion of the glenosphere unsupported by bone. Radiographs of the specimen confirmed an extensive scapular notch extending beyond the inferior fixation screw. Examination of the polyethylene cup demonstrated erosion of its medial aspect, down to the metal epiphysis of the humeral implant. Samples of the patient's thick joint capsule showed histologic evidence of a chronic foreign-body reaction with macrophages and multinucleated giant cells surrounding bone debris and polyethylene fragments.

Sirveaux et al. [18] established a method for describing the extent of postoperative scapular neck erosion (Fig. 2). In the Nerot-Sirveaux classification, a Grade 1 notch describes a defect contained within the inferior pillar of the scapular neck. Erosion of the scapular neck to the level of the inferior fixation screw of the glenosphere baseplate describes a Grade 2 notch. Grade 3 scapular notching indicates extension of the bone loss over the lower fixation screw while a Grade 4 defect describes progression to the undersurface of the baseplate.

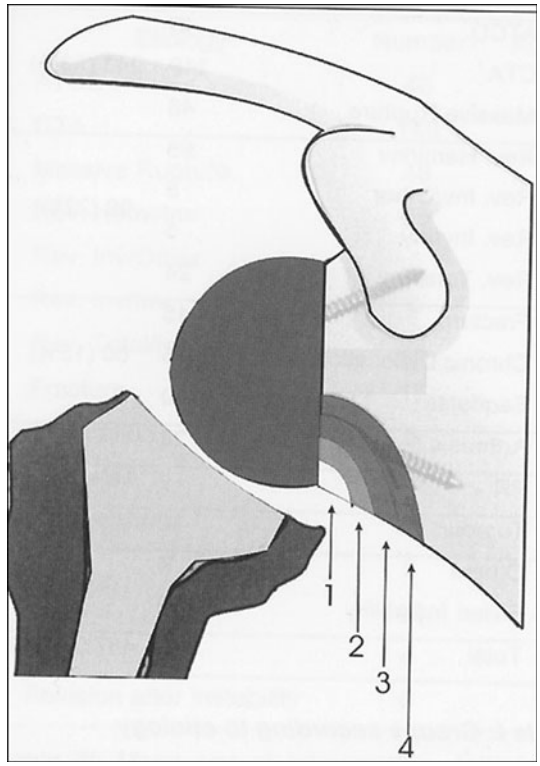

Fig. 2 The Nerot-Sirveaux grading system for postoperative scapular notching after reverse TSA is illustrated. A Grade 1 notch is a defect contained within the inferior pillar of the scapular neck. A Grade 2 notch is erosion of the scapular neck to the level of the inferior fixation screw of the glenosphere baseplate. A Grade 3 notch is extension of the bone loss over the lower fixation screw. A Grade 4 notch is progression to the undersurface of the baseplate. Reproduced with permission and copyright © of the British Editorial Society of Bone and Joint Surgery from Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff: results of a multicentre study of 80 shoulders. *J Bone Joint Surg Br.* 2004;86:388–395.

The Incidence of Scapular Notching

Scapular notching tends to first appear in the early postoperative period, with most reports describing radiographic evidence of scapular neck erosion between 6 weeks and 14 months postoperatively [7]. Since first described by Sirveaux [17] in 1997, other authors have documented scapular notching after reverse TSA is a frequent postoperative occurrence, with a reported incidence ranging from 44% to 96% of cases utilizing the Grammont-type reverse TSA with the same implant geometry [1, 2, 11, 16, 18, 20, 22] (Table 1). In a review of 77 consecutive shoulders in 76 patients treated with a reverse TSA for massive, irreparable rotator cuff tears, Simovitch et al. [16] noted postoperative scapular notching in 34 cases (44% incidence). In 23 shoulders, the notch was present in the posterior aspect of the inferior scapular neck, with anterior notching evident in six cases. Of the 34 cases, six were classified as Grade 1, 14 as Grade 2, 12 as Grade 3, and two

Table 1. Reported incidence of postoperative scapular notching

Study	Mean followup (months)	Percent incidence of scapular notching
Valenti et al. [19] (2001)	60	86%
Favard et al. [6] (2001)	45	65%
Boulahia et al. [2] (2002)	16	61%
Sirveaux et al. [18] (2004)	44	64%
Boileau et al. [1] (2005)	40	74%
Werner et al. [22] (2005)	38	96%
Simovitch et al. [16] (2007)	44	44%
Seebauer [15] (2006)	39	94%
Levigne et al. [11] (2006)	47	62%
Wierks et al. [24] (2009)	9	55%

as Grade 4. In that series, notching was radiographically evident at a mean of 4.5 months postoperatively, with no cases demonstrating scapular erosion after 14 months of followup. Clinical series published by Levigne et al. [11], Sirveaux et al. [18], and Boileau et al. [1] reported scapular notching with a slightly higher incidence, 62%, 63.6%, and 74%, respectively. Postoperative notching was nearly universal in Werner et al.'s [22] retrospective evaluation of 58 patients with painful pseudoparalysis treated with reverse TSA. Of the 48 patients with available postoperative radiographs, evidence of inferior scapular neck erosion was present in 96%, with 54% of the notches classified as either Grade 1 or 2 and 46% as Grade 3 or 4.

Radiographic Progression and Effect of Scapular Notching on Implant Survivorship

Whether or not scapular notching progresses over time continues to be debated in the orthopaedic literature. In the clinical studies reported by Werner et al. [22] and Simovitch et al. [16], the extent of the scapular notch appeared to plateau over time. Of their 46 cases where a scapular notch was seen in the early postoperative period, Werner et al. [22] noted 38 (79%) had no evidence of progression at 1 year of followup, with the remainder increasing by a maximum of one grade at the time of final evaluation at a mean of 38 months. Simovitch et al. [16] reported their cases of scapular notching stabilized at a mean of 18 months postoperatively, with no evidence of size or grade progression at 24 months of followup. However, other studies have demonstrated the extent of scapular notching after reverse TSA can increase with the length of followup. In Levigne et al.'s [11] large clinical series, radiographic evidence of notch progression was evident between 1 and 2 years of followup and between 2 and 3 years of followup, with increases in the percentage of cases with Grade 3 and 4 inferior scapular neck erosion over time.

A negative impact of scapular notching on implant survivorship has been reported by both Delloye et al. [4] and Vanhove and Beugnies [20]. In the small series of five cases of Delloye et al. [4] treated with reverse TSA, progression of scapular notching led to glenosphere loosening in two patients requiring surgical revision. While these studies are presently the only reports of glenosphere loosening secondary to scapular notching, the relatively short-term followups reported in other clinical studies may preclude a conclusion of the impact of notching on implant survivorship at this time. Despite a lack of clinical impact of scapular notching in the series reported by Levigne et al. [11], postoperative radiographs demonstrated a correlation between the presence and size of a notch with the development of radiolucencies around both the humeral and glenoid components as followup time increased. It is likely, with longer followup, the precise impact of scapular notching on the clinical outcome and survival of reverse TSA will be better understood.

Clinical Relevance of Scapular Notching

The clinical relevance of scapular notching is similarly controversial in the literature, with some authors reporting no impact on postoperative function [1, 11, 22] and overall outcome and others describing a negative correlation between a scapular notch and the results after reverse TSA [16, 18]. Levigne et al. [11] reported no correlation between the presence or grade of scapular notching with postoperative ROM, pain score, or Constant-Murley score. Similarly, in the studies published by Werner et al. [22] and Boileau et al. [1], notching apparently had no effect on any objective or subjective clinical result or postoperative complication. Other clinical studies have reported contrasting observations, noting a direct association between the presence and extent of scapular notching and lower Constant-Murley and subjective shoulder scores. Sirveaux et al. [18] found cases with more extensive notching (Grades 3 and 4) had lower postoperative Constant-Murley scores. Compared to those without evidence of a postoperative scapular notch, patients with notching in the series reported by Simovitch et al. [16] had lower mean Constant-Murley scores, a lower subjective shoulder score, inferior shoulder strength, and worse postoperative ROM with 17° less active forward elevation and 16° less abduction. Additionally, the authors demonstrated a negative correlation between notch size/progression and inferior outcomes for each parameter in their analysis.

Predictors of Scapular Notching and Strategies for Avoiding or Minimizing Its Development

As the incidence and potential implications of scapular notching have been appreciated to a greater extent in the orthopaedic literature, authors have attempted to identify factors associated with its development after reverse TSA. Predictors of scapular notching include chosen surgical approach, anatomic variations of glenoid wear during the degenerative process, patients' preoperative diagnosis, condition of the infraspinatus muscle, implant design, cranial–caudal positioning of the glenosphere baseplate, and tilt of the glenosphere.

In their review of the causes and consequences of scapular notching, Levigne et al. [11] noted postoperative scapular notching was seen more frequently in patients treated for a diagnosis of rotator cuff tear arthropathy with a narrowed acromiohumeral distance (incidence of 76% compared to 38% in posttraumatic cases) and in those with MRI evidence of Grade 3 or 4 fatty infiltration of the infraspinatus muscle. The type of degenerative erosion of the glenoid also impacted the development of postoperative scapular notching, with glenoids having superior erosion (Type E2 glenoid wear) associated with the highest incidence (Fig. 3). Cases treated via an anterosuperior surgical approach had a higher incidence of scapular notching than those approached through the deltopectoral interval (86% versus 56%). Studies by a number of other authors report the importance of glenosphere baseplate positioning and tilt on the development of a postoperative scapular notch [9, 13, 16, 18]. In one series [16], the craniocaudal positioning of the glenosphere baseplate was the most important predictor of postoperative scapular notching. The authors' clinical findings were consistent with those of several biomechanical studies [9, 13] showing inferior placement of the glenosphere baseplate allowing inferior overhang of the glenosphere improved impingement-free adduction and abduction angles compared with more superior baseplate positioning. However, these studies did not address the durability of an implant placed in such an inferior position. In a separate biomechanical study, Gutierrez et al. [8] evaluated the impact of the angle of glenosphere baseplate implantation on component stability. Compared to baseplates implanted in a neutral or a superiorly tilted position, those implanted with a slight (15°) inferior tilt had the most compressive forces under the baseplate during loading with the least amount of tensile forces and the smallest amount of micromotion. Based on their data, the authors concluded a slight inferior tilt to the glenosphere baseplate during implantation may limit the incidence of mechanical failure during physiologic loading.

Other implant design parameters, including humeral neck-shaft angle, center of rotation offset, and glenosphere diameter, have also been assessed for their contribution to the biomechanics of scapular notching. In a laboratory reverse TSA model, Gutierrez et al. [9] found, among these parameters, reducing the humeral component neck-shaft angle (greater varus angle) had the greatest impact on creating impingement-free adduction followed by inferior placement of the glenosphere baseplate relative to the native glenoid. Lateralization of the center of rotation (increased offset) improved overall ROM in their model. Based on their findings, the authors concluded glenospheres with an increased distance from the glenoid to the center of rotation (lateral offset) and inferior placement provided for greater potential ROM while a prosthesis with a varus neck-shaft angle allowed for improved impingement-free adduction.

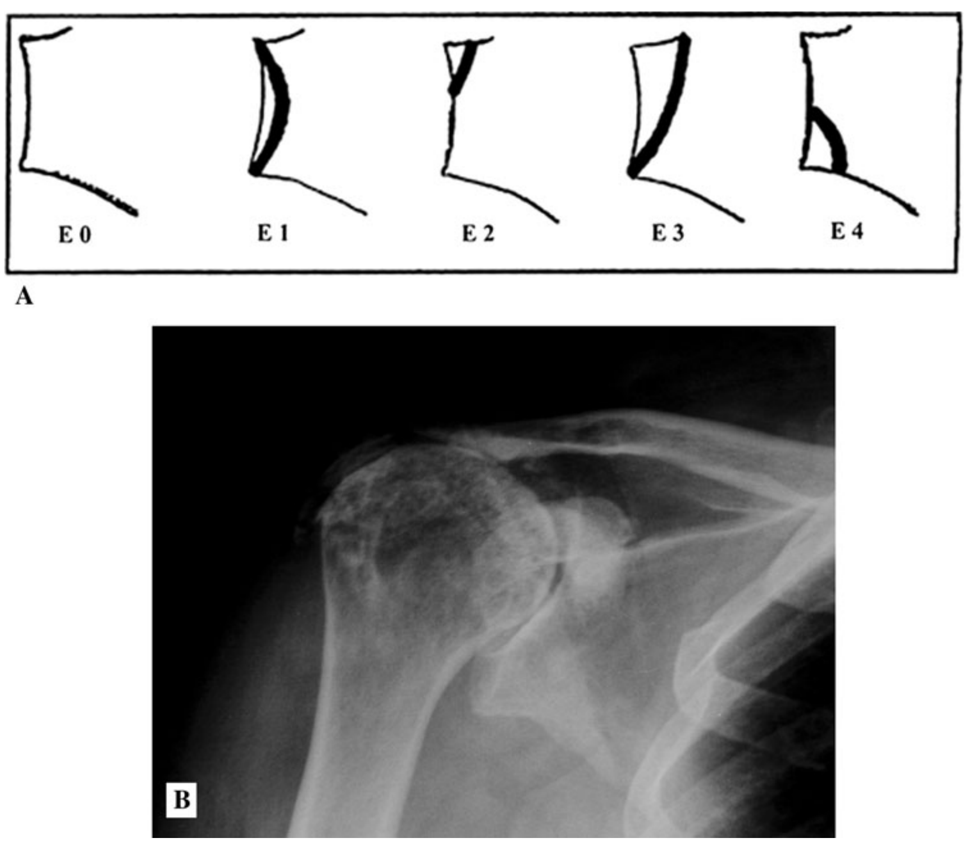

Fig. 3A–B (**A**) The Favard classification of types of glenoid erosion associated with rotator cuff arthropathy is illustrated: E0 = superior humeral head migration without erosion of the glenoid; E1 = concentric erosion of the glenoid; E2 = erosion limited to the superior part of the glenoid; E3 = erosion extending to the inferior part of the glenoid; and E4 = erosion predominantly located at the inferior part of the glenoid Reprinted from Levigne C, Boileau P, Favard L, Garaud P, Mole D, Sirveaux F, Walch G. Scapular notching in reverse shoulder arthroplasty. *J Shoulder Elbow Surg.* 2008;17:925–935, with permission from Elsevier. (**B**) An AP view demonstrates a right shoulder with evidence of a Type E2 glenoid.

Discussion

We provided an evidence-based review of scapular notching, a novel complication unique to reverse TSA. This study addressed key questions relating to the etiology and incidence of scapular notching, radiographic progression and the effect on implant stability, the relationship between scapular notching and clinical outcomes, and the identification of preoperative and intraoperative risk factors for the development of this complication. We also emphasized strategies aimed at recognizing risk factors for scapular notching and described both technique-related and implant design-related ways to minimize or avoid scapular notching.

The limitations of this review parallel the deficiencies in the current body of literature on scapular notching. There are only a handful of clinical studies addressing this problem. The majority are short or medium term, nonrandomized, and noncontrolled and involve heterogeneous patient populations, a variety of implant types, and differing surgical techniques. Despite this lack of standardization, much headway has been made with regard to defining the scope of the problem, its root causes, and its effect on patient outcome. The highlights of the current body of knowledge are summarized below.

Scapular notching after reverse TSA describes the erosion of bone of the scapular neck secondary to mechanical abutment of the humeral implant with adduction of the upper extremity [7, 11, 13]. With repetitive mechanical contact between the polyethylene cup of the humeral component and the inferior scapular neck, wear of the polyethylene may compound a notch by provoking a biologic response, leading to chronic inflammation of the joint capsule, local osteolysis, and the potential for implant loosening [13, 20]. Additionally, this may lead to loss of joint constraint, creating the potential for joint instability [1]. The Nerot-Sirveaux classification has been developed to characterize scapular notching. A Grade 1 notch describes a defect contained within the inferior pillar of the scapular neck. A Grade 2 notch involves erosion of the scapular neck to the level of the inferior fixation screw of the glenosphere baseplate. A Grade 3 scapular notch indicates extension of the bone loss over the lower fixation screw, while a Grade 4 defect describes progression to the undersurface of the baseplate.

Scapular notching tends to first appear in the early postoperative period, with most reports describing radiographic evidence of scapular neck erosion between 6 weeks and 14 months postoperatively [7]. The reported incidence ranges from 44% to 96% of cases [1, 2, 11, 16, 18, 20, 22]. Simovitch et al. [16] noted postoperative scapular notching in 44% of cases. In that series, notching was radiographically evident at a mean of 4.5 months postoperatively, with no cases demonstrating scapular erosion after 14 months of followup. Clinical series published by Levigne et al. [11], Sirveaux et al. [18], and Boileau et al. [1] reported scapular notching with a slightly higher incidence, 62%, 63.6%, and 74%, respectively. Another series by Werner et al. [22] demonstrated a near-universal presence of notching, finding evidence of inferior scapular neck erosion in 96%, with 54% of the notches classified as either Grade 1 or 2 and 46% as Grade 3 or 4.

Radiographic progression of scapular notching remains controversial in the literature. Studies by Werner et al. [22] and Simovitch et al. [16] demonstrate the extent of the scapular notching plateaus over time, while Levigne et al. [11] report contradictory results. Werner et al. [22] noted 79% of patients had no evidence of progression at 1 year of followup, with the remainder increasing by a maximum of one grade at the time of final evaluation at a mean of 38 months. Simovitch et al. [16] similarly reported stabilization at a mean of 18 months postoperatively, with no evidence of progression at 24 months of followup. However, other studies have demonstrated scapular notching can increase with the length of followup. Levigne et al. [11] reported radiographic evidence of notch progression between 1 and 2 years of followup and between 2 and 3 years of followup, with increases in the percentage of cases with Grades 3 and 4 inferior scapular neck erosion over time. Further clinical studies are necessary to evaluate this controversial topic.

To date, only case reports describe a negative impact of scapular notching on implant survivorship. Delloye et al. [4] and Vanhove and Beugnies [20] report progression of scapular notching leading to glenosphere loosening in small series of patients. Short-term followup in larger clinical studies precludes any meaningful conclusions with regard to the impact of notching on implant stability. Levigne et al. [11] did show a correlation between the presence and size of a notch with the development of radiolucencies around both the humeral and glenoid components as followup time increased. It is likely, with longer followup, the precise impact of scapular notching on the clinical outcome and survival of reverse TSA will be better understood.

The clinical relevance of scapular notching is similarly controversial in the literature, with some authors reporting no impact on postoperative function [1, 11, 22] and overall outcome and others describing a negative correlation between a scapular notch and the results after reverse TSA [16, 18]. Studies by Levigne et al. [11], Werner et al. [22], and Boileau et al. [1] reported there was no correlation between the presence or grade of scapular notching and any objective or subjective clinical measure or postoperative complication. Other clinical studies noted a direct association between the presence and extent of scapular notching and lower Constant-Murley and subjective shoulder scores. Sirveaux et al. [18] found cases with more extensive notching (Grades 3 and 4) had lower postoperative Constant-Murley scores. Simovitch et al. [16] similarly found lower mean Constant-Murley scores, lower subjective shoulder score, inferior shoulder strength, and worse postoperative ROM in patients with scapular notches compared with those without this complication. Further research is needed to clarify the conflicting results from these clinical series.

There are known predictors of scapular notching that can be categorized into several different groups. Patient-specific risk factors for scapular notching include rotator cuff tear arthropathy with a narrowed acromiohumeral distance (incidence of 76% compared to 38% in posttraumatic cases), glenoids with superior erosion (Type E2 glenoid wear), and MRI evidence of Grade 3 or 4 fatty infiltration of the infraspinatus muscle [11]. Surgical technique is also a risk factor, with the anterosuperior approach having a higher incidence of scapular notching than those approached through the deltopectoral interval (86% versus 56%) [11]. Neutral or superiorly tilted baseplates increase the risk of scapular notching compared with inferior glenoid tilt. Several studies demonstrate allowing inferior overhang of the glenosphere improved impingement-free adduction and abduction angles [9, 13, 16, 18]. It has also been shown baseplates implanted with a slight (15°) inferior tilt had the most compressive forces under the baseplate during loading with the least amount of tensile forces and the smallest amount of micromotion [9, 13, 16, 18]. Other predictive factors relating specifically to implant design will be described in a later section.

In an effort to avoid or minimize the development of a postoperative notch, surgeons should take these predictors of notching into account during the preoperative workup, operative procedure, and postoperative followup. Preoperatively, a diagnosis of rotator cuff arthropathy should prompt the surgeon to evaluate the condition of the glenoid, looking for evidence of superior wear (Type E2 or E3 glenoid) and the condition of the patient's infraspinatus on MRI. In cases where the preoperative workup indicates the potential for scapular notching, a deltopectoral surgical approach may be warranted to ensure appropriate implant positioning. Intraoperatively, during exposure and preparation of the glenoid, an effort can be made to ensure the glenosphere baseplate is implanted as inferior on the native glenoid as possible to foster inferior overhang of the glenosphere component. Superior glenoid wear can be visually confirmed and preferential reaming can be performed to promote a slight inferior tilt to the implanted glenosphere baseplate (10°–20°). The senior author (GPN) uses hand reamers on the glenoid, reaming until a "subchondral smile" of cancellous bone can be seen on the inferior aspect of the glenoid (Fig. 4). Superior defects that remain subsequent to hand reaming can be bone grafted, ensuring the glenosphere baseplate is not placed with a superior tilt. The glenosphere can be sized appropriately to allow for 2 to 3 mm of inferior overhang, which will promote postoperative ROM, stability, and minimization of notch development with humeral adduction. Additionally, the surgeon should be aware of the implant options available with respect to their system of choice, such as humeral component neck-shaft angle, lateral offset of the center of rotation, glenosphere sizes, and depth of the polyethylene cup. Postoperatively, the surgeon should be vigilant in his or her assessment of followup radiographs, evaluating the inferior aspect of the scapula for evidence of notch development and progression. By noting the position of the glenosphere relative to the inferior aspect of the glenoid and its tilt on postoperative radiographs, patients at risk for notch development can be identified and followed closely.

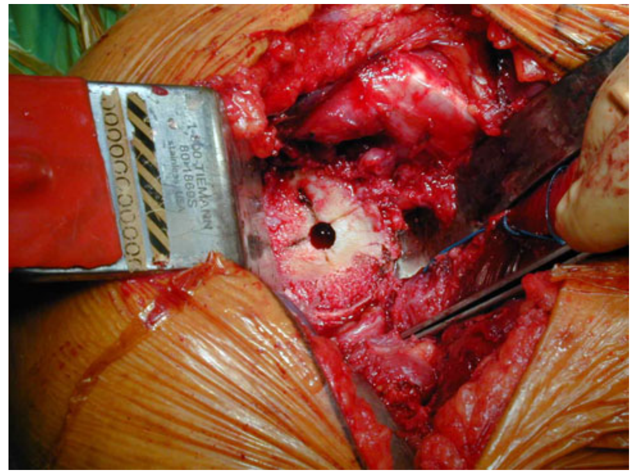

Fig. 4 The glenoid is reamed by hand until a "subchondral smile" of cancellous bone is seen on the inferior aspect of the glenoid. Once this level is reached, any superior glenoid defects that remain can be bone grafted to ensure the glenosphere baseplate is not implanted with a superior tilt.

With recent clinical and biomechanical studies proposing alterations in implant design and surgical technique in an effort to reduce the incidence and impact of scapular notching, the question arises whether we can respect Grammont's main principles while at the same time provide improved outcomes in the absence of notching. A new reverse TSA was recently designed incorporating the Grammont principles of medialization and inferiorization of the center of rotation of the glenoid component while incorporating some design initiatives to minimize potential abutment of the medial aspect of the humeral component against the inferior scapular neck. These design and surgical technique issues were in response to what had been clinically seen and what had been learned by basic studies discussed in this paper. The senior author (GPN) is a designer and received royalties for this implant. First utilized in March 2006, the design of the Trabecular Metal™ Reverse Shoulder System (Zimmer, Inc, Warsaw, IN) respects the proven Grammont principles of inferiorization and medialization of the glenoid center of rotation while incorporating certain design characteristics to prevent scapular notching. The metallic neck-shaft angle is 143° and the polyethylene component has a 7° angle, thus creating a total neck-shaft angle of 150°. This 5° difference from other reverse TSA designs allows for better adduction of the arm without mechanical abutment. Additionally, this implant design is low profile with no metallic material above the humeral osteotomy. The Trabecular Metal™ glenosphere baseplate has a 3-mm pad on its back surface, creating a small lateral offset when implanted onto the glenoid surface (Fig. 5). These design characteristics coupled with operative technique improvements focusing on inferior glenosphere placement with an inferior tilt have shown radiographically a decreased incidence of scapular notching at 6 months (0%) and at 14 months (8%) in an ongoing clinical series.

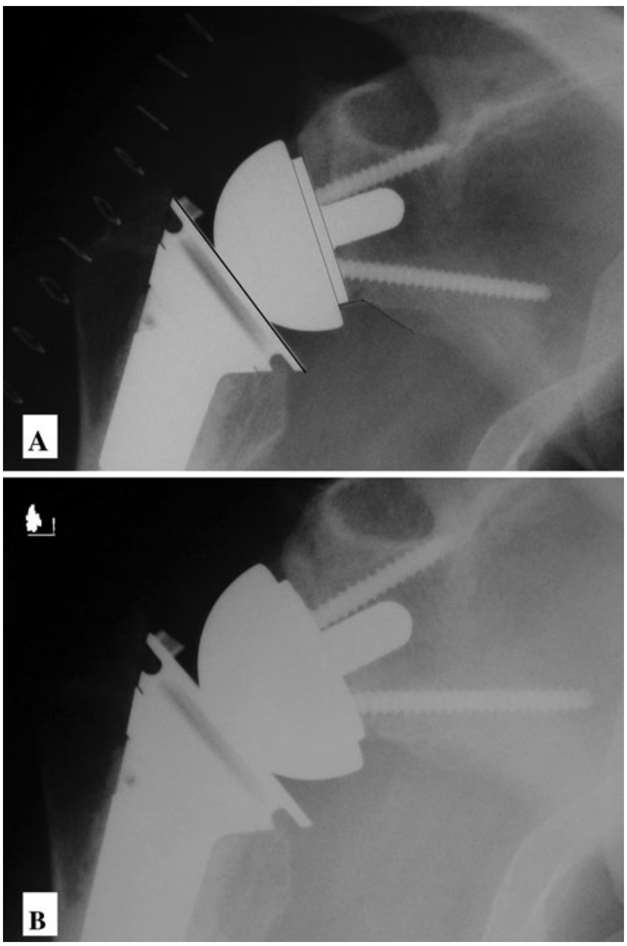

Fig. 5A–B (**A**) An immediate postoperative AP radiograph shows a TSA using the Trabecular Metal™ Reverse Shoulder System implanted into the right shoulder for treatment of rotator cuff tear arthropathy. Implant design characteristics of the differing neck-shaft angle (thick black line) and the 3-mm Trabecular Metal™ pad on the back of the baseplate (thin parallel lines) to provide a small offset are seen. These characteristics coupled with inferior placement of the glenosphere (thin curved line on scapular pillar) with an inferior tilt help minimize the potential for postoperative scapular notching. (**B**) An AP radiograph of the same patient at 2 years of followup shows no evidence of scapular notching.

While the results of reverse TSA continue to improve and the indications for its use are expanding, there is clearly a need for better understanding of the complication of scapular notching. At this time, the effects of scapular notching on patient function, radiographic progression, and implant stability remain controversial. It is our hope this review has raised clinical awareness about this important entity, exposed the limitations of the current body of literature, and helped to promote further clinical investigation.

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