Review Article

Perioperative deltoid pathologies in the setting of reverse shoulder arthroplasty: a narrative review

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Background and Objective: The reverse total shoulder arthroplasty (RSA) is a widely used innovative procedure for managing shoulder pathologies like severe rotator cuff arthropathy, osteoarthritis with significant glenoid deformity, or proximal humerus fractures. RSA prosthesis designs utilize the deltoid muscle to bypass the role of the rotator cuff, and to generate most of the force required for shoulder elevation. As such, preoperative deltoid insufficiency or injury, as well as any intraoperative or postoperative complications involving the deltoid, can significantly impact patient outcomes, rehabilitation, and recovery following RSA. The aim of our review is to highlight the critical role of the deltoid muscle in RSA and discuss the different perioperative challenges that may impact its function and the overall success of the procedure.

Methods: The PubMed/MEDLINE database was screened for studies describing or reporting perioperative deltoid or axillary nerve pathologies in the setting of RSA, from database inception until August of 2023. Articles were excluded if animals subjects were involved, or if they were written in the non-English language. Relevant search terms were used, and additional articles were retrieved from the reference lists of included articles.

Key Content and Findings: Ensuring the health and integrity of the deltoid muscle is essential for obtaining successful RSA outcomes. At the preoperative stage, deltoid insults can occur due to imbalances in glenohumeral musculature, pre-existing axillary nerve injury and subsequent deltoid atrophy, and concurrent viral infections. Remaining vigilant regarding diagnosis is important at this stage, as surgical treatment should be delayed until symptomatic resolution occurs. Intraoperatively, deltoid injuries can occur due to significant retraction, dissection, or iatrogenic fractures or nerve injuries. Conducting periodic intraoperative axillary nerve assessments and utilizing intraoperative nerve monitoring allow surgeons to potentially intervene in order to help minimize nerve damage. Postoperatively, pathologies can occur due to deltoid fatigue or acromial stress fractures. At that stage, educating patients about potential setbacks is important to set appropriate expectations and minimize injury risk.

Conclusions: Considering the importance of the deltoid in achieving proper RSA outcomes, significant attention should be garnered towards its integrity and health throughout the perioperative process.

Keywords: Atrophy; nerve monitoring; axillary nerve; acromial stress fracture; deltoid fatigue

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Introduction

Reverse total shoulder arthroplasty (RSA) is one of the most prominent innovations in the field of shoulder surgery (1-3). The procedure has become widely used and popular, and has led to breakthroughs in managing various shoulder pathologies (1-3). The design of the prosthesis allows it to bypass the need for a functional rotator cuff, allowing the ability to improve function and decrease pain in patients with severe rotator cuff arthropathy (1,2). In particular, the semi-constrained nature of the RSA depends significantly on the proper functioning of the deltoid muscle, which generates more than 50% of the required force for shoulder elevation in the scapular plane. This mechanism supports improved mobility around the prosthesis' fixed center of rotation (4,5).

The dependence of the RSA on the deltoid means that preoperative deltoid insufficiency or injury can result in devastating outcomes (6). It also means that any intraoperative or postoperative complications involving the deltoid can severely impact the patient's quality of life, rehabilitation, and recovery. Hence, the function of the deltoid plays an immense role in the success and longevity of a RSA procedure, and ensuring the health of the deltoid muscle should be a priority for the shoulder surgeon and the presenting patient (6). In this regard, surgeons should remain highly vigilant of any signs of deltoid weakness throughout the management process, as injury can occur at any point, and timely management is paramount for optimal outcomes.

Considering the importance of the deltoid in achieving a successful RSA procedure, it is imperative to highlight the multitude of pathologies that may arise perioperatively. The importance of the deltoid in RSA is often overshadowed in the literature, with limited work discussing its role in providing support for the prosthesis and ensuring successful outcomes. As such, the aim of this review is to describe the preoperative, intraoperative, and postoperative insults that can occur to the deltoid in the setting of RSA. We present this article in accordance with the Narrative Review reporting checklist (available at https://aoj.amegroups.com/article/view/10.21037/aoj-24-17/rc).

Methods

A comprehensive literature search using the PubMed/Medline database was conducted to search for studies describing and reporting on deltoid pathologies and complications prior to and post RSA. Literature search was conducted on August 1, 2023, and included all articles since inception of database. All articles pertaining to RSA and deltoid pathology were included, regardless of setting (primary *vs.* revision), or indication. Articles involving animal subjects and those that were written in non-English language were excluded. Utilized search terms included: "deltoid pathology", "deltoid complications", "reverse total shoulder arthroplasty", "total shoulder arthroplasty", "axillary nerve", "axillary nerve injury", "deltoid atrophy", "deltoid splitting techniques", and "nerve injury". Four authors independently ran the search. Additional sources were extracted from reference lists of retrieved articles. Our search strategy can be summarized in *Table 1*.

Table 1 Search strategy and article selection process

Items	Specification
Date of search	August 1, 2023
Databases searched	PubMed/MEDLINE
Search terms used	"Deltoid pathology", "deltoid complications", "reverse total shoulder arthroplasty", "total shoulder arthroplasty", "axillary nerve", "axillary nerve injury", "deltoid atrophy", "deltoid splitting techniques", and "nerve injury"
Timeframe	Inception of database–August 1, 2023
Inclusion and exclusion criteria	All articles pertaining to reverse shoulder arthroplasty and deltoid pathology, written in English language, were included
	Articles involving animal subjects, and those that were written in non-English language, were excluded
Selection process	Four authors independently ran the search
Additional considerations	Additional sources were extracted from reference lists of retrieved articles

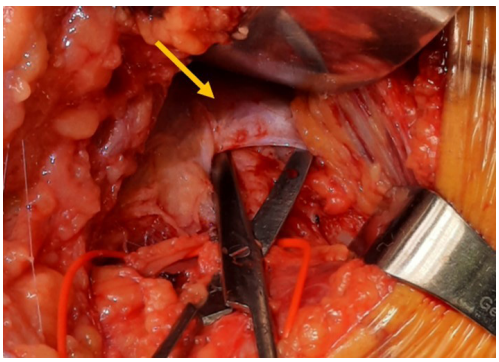

Figure 1 Patient with chronic dislocations and signs of deltoid weakness undergoes quadrilateral space exploration for axillary nerve neurolysis. The figure (orange arrow) shows fibrous tissue compressing the axillary nerve. The fibrous tissue was lysed and released in order to restore proper nerve function.

Discussion

Preoperative deltoid pathology

Patients with various shoulder pathologies can often present with signs of a weak deltoid muscle that are paramount to identify and address before surgery. Failure to do so may lead to persistent or exacerbated postoperative deficits, leading to impaired function and quality of life. As such, it is important to identify the different preoperative etiologies that can lead to deltoid insult. Preoperative risk factors, such as deltoid muscle atrophy, rotator cuff tears, and recurrent dislocations in patients scheduled for RSA, represent crucial considerations for both surgical planning and patient outcomes.

Deltoid atrophy, often accompanying chronic shoulder pathologies, or previous procedures that compromise the deltoid muscle, can lead to muscle imbalances and compromised shoulder function (7,8). This, in turn, can complicate the postoperative rehabilitation process and lead to instability and persistent deltoid weakness (7,8). The deltoid split approach is occasionally performed for open reduction internal fixation (ORIF) of proximal humerus fracture (PHF) or open rotator cuff repair (RCR) (9-11). These previous insults to the integrity of the deltoid can entail major limitations following RSA. In the setting of ORIF for PHF, a study by Traver *et al.* explored injury risk of the axillary nerve during deltoid split approach for PHF (11). The authors reported strain and progressive irreversible increase in axillary nerve length following the approach, which led to microscopic damage to its neuronal structures (11). As for deltoid atrophy following open RCR, Hata *et al.* explored postoperative thickness of the deltoid muscle in patients treated with mini-open RCR compared to those treated with conventional open RCR (12). It was reported that thickness of anterior deltoid fibers decreased significantly in the open RCR group at 6 and 12 months postoperatively, while there was no change for the mini-open RCR group, underscoring the impact of previous deltoid insults on postoperative atrophy (12). As such, it is of pivotal importance that shoulder surgeons take comprehensive surgical history of their presenting patient to ensure and confirm the integrity of their deltoid muscle, especially prior to RSA. Moreover, a holistic preoperative physical examination involving all three heads of the deltoid is essential for a full assessment of integrity and function.

Concurrent rotator cuff tears and recurrent shoulder dislocations are commonly encountered symptoms in prospective RSA patients, leading to increased instability and reduced shoulder function, thereby increasing the complexity of surgical intervention. Yoon *et al.* demonstrated the importance of preoperative assessment of deltoid muscle volume prior to RSA, and the impact of other musculature on RSA outcome (8). Their study included 35 patients who all underwent preoperative magnetic resonance imaging, pre- and postoperative radiography, and numerous functional studies at 1 year follow-up (8). Results showed that underlying rotator cuff tears negatively correlated with prognoses following RSA (8). Chronic rotator cuff tears can lead to loss of mobility and function in the shoulder joint, and this in turn, can lead to atrophy of the deltoid muscle due to lack of use. In addition, shoulder dislocations can lead to a partial or complete axillary nerve injury over time, consequently leading to deltoid dysfunction (13,14). These injuries can be due to direct trauma to the nerve in the acute setting, or long-term pressure affecting the nerve due to chronic dislocations (13,14). Chronic dislocations are particularly deleterious as they can present in an indolent fashion, and can be underdiagnosed in the clinical setting. Fibrous tissue in the quadrilateral space, resulting from repeated dislocations, can exert pressure on the nerve and lead to axillary nerve palsy (*Figure 1*) (13,14). Elderly patients are especially vulnerable in this setting (15), and evidence of deltoid weakness should be meticulously explored through clinical examination and electromyographic studies.

Pre-existing nerve insults can also lead to deltoid atrophy prior to RSA. This can be due to previous iatrogenic axillary nerve injuries in patients with prior surgery to the shoulder, concomitant cervical radiculopathies that affect the axillary

nerve, and preoperative viral infections and their sequalae (5,11,16,17). As mentioned above, previous surgery to the shoulder joint can introduce axillary nerve injuries that can lead to postoperative deltoid weakness and failure (11). Cervical radiculopathies, as well can result in significant injuries to the deltoid muscle, especially when present at the level of C4/C5, and this has been addressed by many studies in the literature (16). In these cases, it has been shown that cervical spine surgery can help relieve the symptoms, and as such, it is recommended that patients be evaluated by a cervical spine specialist before being considered for an RSA (16). Viral infections can also constitute a concern for procedures like RSA (5,17). Complications involving brachial plexopathies, such as Parsonage-Turner syndrome, present unique challenges prior to surgery. These patients should not be indicated for an RSA and must be counseled that their condition is often self-resolving. Preoperative viral screening is necessary to consider in this setting, as clinical symptoms may include signs of deltoid weakness and infection may necessitate postponing procedures to allow for adequate recovery. Surgeons must also carefully evaluate the extent of nerve damage and muscle involvement to tailor the surgical approach and postoperative therapy to each patient's specific needs.

Intraoperative deltoid complications

Intraoperative deltoid injuries can significantly alter the postoperative course of the RSA patient, and these often occur due to iatrogenic insults to the axillary nerve or due utilizing deltoid-splitting approaches. It is difficult to quantify the incidence of intraoperative neurologic deltoid injuries during RSA, since early postoperative clinical manifestations may be asymptomatic (18,19). This may also be explained by the limited neurologic evaluation due to post-operative discomfort and functional constraint, as well as the possibility that some nerve damage may be temporary and resolve before a complete clinical examination (18,19). One study by LiBrizzi *et al.* looked at the rate of clinically evident intra-operative axillary nerve injuries in total shoulder arthroplasty (TSA), and reported an incidence rate of 0.7% (20). Another systematic review of 188 articles by North *et al.* determined the rate nerve injury in revision RSA and primary RSA was 2.4% and 1.3%, respectively (21). With regards to axillary nerve injuries, rates in both primary and revision RSAs to be 0.61% and 0.55%, respectively (21). Nerve injury can be caused by surgical dissection, compression by retractors or hematoma, excessive mobilization of the upper extremity, vascular injury, iatrogenic fracture, cement leakage, and inter-scalene nerve block complications (22-24). While the reported rate of intraoperative axillary nerve injuries may seem low, it is important that surgeons remain vigilant throughout the surgery in order to help mitigate or prevent any potential insults. This can be achieved using intraoperative nerve monitoring (IONM) and conducting periodic nerve assessments during the procedure.

One intraoperative factor that has been shown to lead to axillary nerve injury is distalization of the humerus when conducting an RSA (25). Marion *et al.* conducted a cadaveric study of 16 shoulder specimens in order to evaluate the effect of lateralization and distalization, when conducting an RSA (25). The authors then assessed the strain and stretching of the axillary nerve in different positions (25). They concluded that while lateralization did not lead to any stretch or strain, distalization can change the tension of the axillary nerve and can lead to irreversible injury that can debilitate deltoid function (25). Another intraoperative factor that can lead to intraoperative deltoid muscle rupture is the inappropriate development of the deltopectoral interval. Performing a deltopectoral approach without meticulous care to the relevant soft tissue can lead to soft tissue damage, deltoid retraction and potential soft tissue stripping, and this can lead to functional compromise in the muscle. Deltoid injury can also occur during RSA due to excessive retraction of the humerus when preparing the glenoid. As such, physicians should be wary and vigilant about the anatomy of the joint and the soft tissue structures when operating, as well as the anatomic changes induced by the prosthesis on their patients. They should also try to avoid excessive humeral distalization or humeral retraction during RSA in order to avoid nerve injury, and subsequent deltoid dysfunction.

Patients with a suspected intraoperative axillary nerve injury may benefit from an electromyogram (EMG) and nerve conduction studies which may help understand the severity of the neurologic injury and guide the subsequent management (26-28). These additional electrodiagnostic studies should be performed 3 weeks post-operatively since Wallerian degeneration occurs around 10 to 14 days in proximal muscles such as the deltoid (26,29,30). In doing so, we allow for potential reinnervation to occur and avoid any unnecessary procedures (26). This is important especially in intra-operative nerve injuries since most of them are transient and resolve quickly (20,31,32). If serial clinical and electrodiagnostic assessment do not show evidence

Figure 2 Intraoperative nerve monitoring in the setting of reverse total shoulder arthroplasty can help detect possible intraoperative nerve dysfunction, and can allow the surgeon to intervene in order to help mitigate and avoid postoperative nerve injury.

of improvement at 3 months post-operatively, surgical exploration and interventions may be considered (33). In this setting, operative options can include axillary nerve neurolysis or nerve grafting procedures (34-36). Several studies in the literature have shown good outcomes in patients with axillary nerve injuries who underwent these procedures (34-36).

Postoperative complications

Classically, deltoid dysfunction following RSA occurs due to axillary nerve palsy or muscle dehiscence but acromial fractures have also been reported to be one of the causes (37,38). The frequency of acromial fractures in the setting of RSA has been variably reported in literature, ranging from 1% to 7% prevalence (39). Levy *et al.* developed a classification system for acromial fractures following RSA, with higher grade fractures involving greater portions of the deltoid origin (39). Type I fractures involve part of the middle portion of the deltoid, type II involve the entirety of the middle deltoid and part of the posterior deltoid while type III encompasses both the middle and the posterior deltoid origin completely (39). The diagnosis of acromial fractures following RSA should be made using computed tomography (CT) scan for proper evaluation when suspected. It has also been noted that fractures involving the acromial base at the spine of the scapula tend to have worse outcomes, mainly due to the fact that there is greater involvement of the deltoid origin (39). While conservative management consisting of watchful monitoring and periodic examination is often required for most acromial stress fractures, those that remain painful, are significantly displaced, or result in non-union can be managed operatively using open reduction and fixation or arthroscopic excision (37,40).

On another note, the concept of deltoid "fatigue" has been introduced as one of the postoperative pathologies that can occur to the deltoid following RSA (41). The biomechanical concept of RSA involves medialization of the rotational center, which increases the moment arm leading to recruitment of the deltoid muscle (42). This non-anatomic nature of the RSA prosthesis has led to the development of the concept of deltoid fatigue as a sequela that later translates into long term loss of overhead range of motion (41). However, a study by Schoch *et al.* showed that deltoid fatigue and dysfunction in RSA shoulder was progressive in nature and differed only slightly to the fatigue that was noted in non-diseased shoulders when matched for several factors (41). With the increasing indications for RSA, it has been used to a greater extent in cuff-intact shoulders. A study by Hill *et al.* examined the effect of RSA on the deltoid musculature and rotator cuff, and tried to quantify it using the cross-sectional area (CSA) of the posterosuperior rotator cuff and deltoid (43). The results, in general, showed a decrease in the size of the posterosuperior cuff CSA and an increase in deltoid CSA postoperatively regardless of etiology. However, patients with rotator cuff tear arthropathy were more likely to have a decline in both muscle groups (43). Additionally, it has been indicated that RSA in patients with an intact rotator cuff were less likely to result in acromial stress fractures, which led the authors to support the notion of preserving the supraspinatus when possible (43,44).

Prevention

Cautious awareness of the various causes of nerve injury during multiple potential stages in RSA is essential. This awareness can allow the surgeon to implement preventative strategies that effectively mitigate the associated neurologic risks. IONM is a preventative intervention that has been employed across multiple orthopedic procedures, including spine and shoulder surgery (*Figure 2*) (23,45-49). IONM can allow surgeons to proactively anticipate, diagnose, and intervene intraoperatively when impending nerve dysfunction is detected, thereby effectively mitigating the risk of postoperative nerve injuries (50-52). IONM involves continuously monitoring transcranial electrical motor evoked potentials (MEPs), somatosensory evoked potentials (SSEPs), and/or free-run EMG of the upper extremity

musculature innervated by the axillary, musculocutaneous, radial, median, and ulnar nerves (50,51). A reduction in the amplitude of MEPs greater than a pre-determined threshold produces a nerve alert, which signifies an impending nerve injury and is reported to the operating surgeon (50-52).

Several studies have evaluated the efficacy of IONM in diagnosing and minimizing nerve injuries in primary and revision RSAs (18,23,50-54). In a case series of 15 patients who underwent primary RSA with IONM, Shinagawa *et al.* recorded a total of 31 nerve alerts in 11 patients (52). The authors showed that 29 (93.5%) of the nerve alerts recovered, 1 after removing the retractors, 26 after placing the arm in neutral position, and 2 recovered spontaneously (52). Of the two patients that did not recover, one had a partial deltoid paralysis despite no direct axillary nerve injury observed, and one had transient numbness in the median nerve area of the thumb that may have been caused by the brachial plexus block (52). Another retrospective cohort study by Patel *et al.* reported on the use of IONM and nerve injury rates in 44 shoulders that underwent revision TSA (73% were RSAs) (51). The authors reported that 15 MEP alerts occurred in ten operations (22.7%), of which seven involved the axillary nerve and one involved multiple major nerves of the brachial plexus (51). However, no patients had any major or minor nerve injury postoperatively (51). While 4 (9.1%) patients developed distal peripheral neuropathy, all four had prior neurologic symptoms (51). As such, the study showed that the threshold at which nerve monitoring alerts are transmitted may be below the threshold of actual clinical significance (51). That being said, IONM may still provide preventive utility in patients who are at high risk for intraoperative nerve injuries, like those undergoing revision surgery.

Attention should be paid regarding indirect causes of nerve trauma during RSA, such as minimizing the positioning of the arm in the extremes of motion (23,50). Nagda *et al.* reported that in all cases where the signal returned completely, placing the arm in extremes of positioning was the cause of the nerve alert (23). This nerve event may be secondary to slowly stretching the brachial plexus, placing particularly the axillary nerve at risk of injury (18,23,50). In addition to positioning of the arm, factors such as body mass index, lengthening of the arm, and retractor placement during exposure can affect this stretch and result in reduced MEPs (18,50). Knowledge of the anatomic relationship of the axillary nerve within the shoulder is also imperative to avoid any direct trauma. The axillary nerve faces an increased risk of injury at three distinct anatomic landmarks: near the inferior border of the subscapularis, the inferior glenoid rim, and the posterior humeral metaphysis (18). Thus, care should be taken when mobilizing the subscapularis as well as during implantation of RSA (18). In addition, it is very important for the surgeon to meticulously and periodically palpate the axillary nerve during the procedure, in order to guide safe retractor placement and to assess appropriate nerve tension throughout the surgery.

Finally, a complete and thorough preoperative neurological examination should be performed and documented in order to accurately assess the patient for any new neurological deficits postoperatively. While all patients should be appropriately counseled on the risk of nerve injuries during RSA, Nagda *et al.* found that patients with both a history of previous open shoulder surgery and decreased passive external rotation with the arm at the side (<10°) carry a significantly higher risk of nerve injuries and should be adequately informed (23).

Limitations

To our knowledge, this narrative review is the first to discuss perioperative deltoid pathologies in the setting of RSA. However, we do have limitations. The clinical studies discussed in this review may be limited by their retrospective nature. While these studies describe potential pathologies, further research is required to delineate the incidence, subsequent effects on patient satisfaction and quality of life, and available treatment options.

Conclusions

The integrity of the deltoid muscle constitutes a crucial factor in determining the success of the RSA. As such, assessing the health and condition of this muscle is pivotal for ensuring good patient outcomes and high levels of patient satisfaction. It is important to recognize that deltoid pathologies and complications can occur at different stages of the RSA: preoperatively, intraoperatively, and postoperatively (*Figure 3*). At the preoperative stage, deltoid problems can occur as a result of pre-existing nerve injury, deltoid atrophy due to muscle imbalances or previous insults, and post-viral brachial neuritis. At this stage, it is important to remain vigilant and delay the procedure until adequate treatment or resolution of symptoms occurs. At the intraoperative stage, deltoid problems can occur due to nerve injuries as a result of significant retraction, anatomic dissection, or iatrogenic fractures among others. Injury can also occur if the approach used was a deltoid split, which

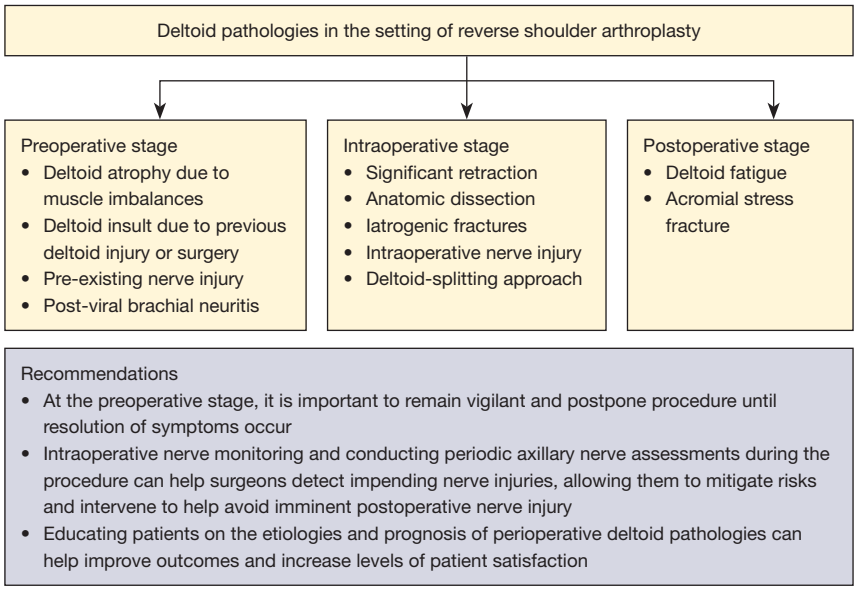

Figure 3 Perioperative deltoid pathologies in the setting of reverse shoulder arthroplasty.

compromises the integrity of the deltoid in order to obtain exposure. In these instances, it is important for the surgeon to properly protect and monitor the nerve throughout the case, and to consider the use of intraoperative neuromonitoring for prevention. Finally, postoperative deltoid pathologies can also pose a significant problem for the RSA patient. These can occur as a result of acromial fractures or due to latent deltoid fatigue. Educating patients on the etiologies and prognosis of these injuries is pivotal in order to obtain proper outcomes and achieve high levels of patient satisfaction. A properly functioning deltoid muscle is crucial to the success of RSA, and as such, it demands significant attention throughout the perioperative process.

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None.

Footnote

Reporting Checklist: The authors have completed the Narrative Review reporting checklist. Available at https://aoj.amegroups.com/article/view/10.21037/aoj-24-17/rc

Peer Review File: Available at https://aoj.amegroups.com/article/view/10.21037/aoj-24-17/prf

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All clinical procedures performed in this review were in accordance with the ethical standards of the institutional and/or

national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent for publication of this article and accompanying images was not obtained from the patient or the relatives after all possible attempts were made. That being said, we made sure the clinical images used had no identifying information about the identity of the respective patients.

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