Reverse Total Shoulder Arthroplasty

Subjects: Orthopedics

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Reverse total shoulder arthroplasty (RTSA) is designed to medialize the glenohumeral joint center of rotation through offset lateralisation and inferiorization of the humerus, thereby increasing the deltoid moment arm.

reverse total shoulder arthroplasty | scapular spine fracture | design parameters | biomechanics

1. Introduction

The indications for reverse total shoulder arthroplasty (RTSA) are broad and include irreparable rotator cuff tear or arthropathy [1][2][3][4][5][6], complex proximal humerus fractures in elderly patients [7][8][9][10], and revision arthroplasty [11]. RTSA is designed to medialize the glenohumeral joint center of rotation through offset lateralisation and inferiorization of the humerus, thereby increasing the deltoid moment arm. This in turn decreases the required deltoid force to combat gravity during abduction [12]. However, the inherent change in upper limb biomechanics, whilst offering advantages such as increased abduction and stability [13], results in increased stresses on the acromion and scapular spine [14]. Acromial and/or scapular spine fractures are relatively common complications of RTSA, occurring in up to 10% of patients [15][16][17][18][19][20][21][22]. These fractures have been associated with a substantial decline in outcomes with a reduced range of motion [22][23] and increased pain [24]. The management of these fractures, particularly Levy zone II and III fractures [15][20][25][26] is challenging [20][24][27] and associated with high rates of malunion or non-union [16][17][20][22]. As a result, there has been increasing interest in preventing these fractures from occurring in the first place [16][17][20][22].

Patient factors such as female gender, osteoporosis, or acromial anatomy have been identified as risk factors for acromial and scapular spine fractures after RTSA [28][29][30]. Implant factors, such as increased lateralization of the glenoid component, were proposed to play a significant role in increasing stress on the acromion [31][32]. It has also been suggested that combined medialization and proximalisation of the glenoid component, and hence the joint center of rotation, is associated with acromial fractures [33]. While lowering of the humerus is thought to increase acromial stress through excessive tensioning of the deltoid [27][34], humeral lateralization may have a protective effect against fracture [33]. The exact biomechanics of acromial and scapular spine strain patterns remain poorly understood.

2. Factors Influencing Acromial and Scapular Spine Strain after Reverse Total Shoulder Arthroplasty

The effects of humeral and glenoid lateralization of a non-Grammont design are to bring the lesser and greater tuberosities to a more anatomic position than with the traditional medialized design and to facilitate two important aspects [35]: (1) Increased resting tension of the remaining rotator cuff and deltoid, thus increasing compressive forces on the joint and thus increasing joint stability [31][32][36][37]; and (2) increased wrapping of the deltoid, thus increasing the horizontal stability through compressive force [38][39]. Besides these improved biomechanics of modern RTSA, changing the glenoid offset can have adverse effects, such as reducing the moment arm of the deltoid muscle as well as creating large bending moments at the base-plate fixation, which may create an environment where fixation failure is more likely [40].

One of the main findings of this study was that glenoid lateralization significantly and consistently increased acromial and scapular spine stress and strain. As lateralization of the center of rotation reduces the moment arm of the deltoid muscle, increased deltoid forces for abduction are necessary [31][32]. This leads to an increased acromion and scapular spine strain [13][32]. Glenoid lateralization can improve clinical and radiographic outcomes, but it can also be associated with increased acromial and scapular spine strain, and should therefore be considered as a risk factor of acromion and scapular spine fractures, following RTSA.

Inferiorization of the glenosphere uniformly reduced acromial stress across the included studies. This is likely due to the lengthening of the deltoid and a shift in the center of rotation towards a larger deltoid moment arm for abduction. An increased moment arm reduces deltoid forces, thereby reducing forces directly applied to the acromion [14]. In a cadaveric model including 8 shoulders, RTSA with a 2.5-mm glenosphere inferiorization compared to a 4-mm lateralized glenosphere resulted in a reduction in deltoid force to abduct the arm [41]. Therefore, glenosphere inferiorization in combination with glenosphere lateralization (if desired) may neutralize acromion and scapular spine strain, although glenoid lateralization seems to have a larger effect on acromial stress than inferiorization [42].

Lateralization of the humerus has shown variable effects on acromial and/or scapular spine strains. Wong et al. [42] showed in a computational study that, during abduction, lateralization of the humerus increased acromial stress, whereas medialization of the humerus results in significantly decreased acromial stress. The authors believe that this was due to the decreased passive stretch and tensioning of the deltoid with humeral medialization. Shah et al. [29] incrementally increased humeral lateralization and found that onlay system lateralization results in significant deltoid lengthening. This results in a subsequent increase in passive tension in the deltoid and the overall force acting on the acromion and scapular spine, which therefore, increases strain. On the other hand, Kerrigan et al. [43] reported that humeral lateralization caused significant decreases in scapular spine strain during abduction. They hypothesized that increasing humeral lateralization results in a larger moment arm for the deltoid in abduction, which decreased the deltoid force necessary to abduct, which reduces acromial and scapular strain. Accordingly, Giles et al. [31] further demonstrated in a cadaveric model that humeral lateralization decreased the deltoid force required for active abduction due to the increased muscle moment arm. Based on these results, humeral lateralization results in two effects that interplay: (1) It increases the passive tension of the deltoid, resulting in increased force acting on the acromion and scapular spine and (2) it increases the muscle moment arm and therefore decreases the active force necessary for active abduction. The more dominant effect may depend on a number of factors, including implant design. Furthermore, because all the involved studies have used onlay humeral trays, there may be some differences in effects on an inlay model.

The effect of changing NSA on the shoulder range of motion and scapular notching has been studied extensively [44][45][46][47][48][49]. Implants with more anatomical or varus humeral angles produce increased adduction and external rotation [47], and are less prone to scapular impingement [44]. The impact of the humeral neck-shaft angle on scapular spine strain is less clear and was assessed in one of the included studies [43]. It was found that varying NSA did not influence scapular spine strain in any of the four planes of elevation. This may be because humeral inclination has little [47] or no effect [43] on humeral offset. Thus, more varus humeral component NSA may offer the advantage of reduced scapular notching whilst having minimal impact on scapular spine strain.

Acromial morphology has been shown to influence the distribution of strain on the acromion as well as the scapular spine. Shah. et al. [29] described the influence of acromial and scapular spine orientation in the parasagittal plane on strain patterns. A flatter scapular spine in combination with a more posteriorly oriented acromion resulted in a significantly higher strain burden on the scapular spine in comparison to the acromion. Conversely, a more vertically oriented scapular spine in combination with a more anteriorly oriented acromion resulted in a significantly higher strain on the acromion than on the scapular spine. The exact mechanism by which anatomical changes in the scapula influence acromial and scapular spine strain is unclear. Furthermore, another (unknown) factor to consider in order to predict strain tendencies during preoperative planning of RTSA is the influence of thoracic kyphosis [50].

The coracoacromial ligament plays a role in transmitting forces acting on the acromion to the coracoid process and vice versa [51][52]. Taylor et al. [30] showed in a cadaveric study that transecting the coracoacromial ligament results in significantly increased scapular spine strain at all abduction angles. The authors suggest that the coracoacromial ligament alters strain patterns along the acromion and scapular spine. This is a result of the counterbalance role of the coracoacromial ligament. The deltoid creates a cantilever as a result of the shape of the acromion, resulting in the bending of the acromion and therefore raising the strain affecting the scapular spine. This is normally counteracted by the coracoacromial ligament and therefore transection results in an alteration of strain patterns along the acromion and scapular spine [30]. Clinically, preserving the coracoacromial ligament was associated with a significant reduction of acromial stress reactions and occult fractures following RTSA in a study involving 265 patients [53]. Therefore, maintaining the coracoacromial ligament integrity may be a modifiable risk factor for acromial fractures following RTSA.

The location of the acromion or scapular spine fracture not only influences patient outcome, but also plays an important role in the choice of treatment [17][18][22]. Based on the Levy classification [20], type II fractures are most common (50%), followed by type III (38%), and type I fractures (12%). The four biomechanical studies that analysed the influence of the Levy zones on acromial and scapular spine strain [14][43][54][55] confirmed this finding by observing the highest stress and strain values in zone II and III, respectively. In the study by Zeng et al. [55], strain was highest in zone II. Wong et al. [54] also located the highest stress in Levy zone II, followed by zone III and zone I. Similarly, Kerrigan et al. [43] measured highest strain in zone II. In a study by Lockhart et al. [14], the stress in zone II was the greatest regardless of implant configuration, loads, and plane of elevation, followed by zone III and zone I.

The Levy zones also play a relevant role in the treatment of acromial and scapular spine fractures. Type I and some type II fractures can be treated non-operatively [24], with a moderate union rate of about 50% and an acceptable functional outcome [17][22]. Type III fractures are challenging to treat as the broad deltoid muscle insertion and poor fragment bone stock compromise stable fixation [15][20][25][26]. Although open reduction and internal fixation is the preferred treatment method, it is associated with a high non-union rate [16][22][56][57]. Similarly, non-operative management with an abduction splint is also associated with a high non-union rate and does not reveal superior results over surgical fixation [16][22]. The resulting tilt of the most lateral scapular fragment leads to impingement, reduced range of motion, and ongoing pain [23]. Therefore, acromial and scapular spine fractures after RTSA are not only a common problem but also hard to treat [15][17][24][58][59].

There are several limitations to this study. Firstly, PROSPERO registration was conducted after completion of this systematic review. However, the study protocol was strictly followed and has not been changed during the conduction of this study nor before submission to PROSPERO. Secondly, the included studies reported on varying implant factors that could affect stress on the acromion. In all, there was limited data to allow meta-analysis. Nonetheless, a comprehensive description of data and comparison were possible to derive a meaningful discussion. Thirdly, the studies involved were either computational analyses or cadaveric studies. These have inherent limitations in replicating results in in-vivo biomechanics and physiology. However, these studies were conducted with consistent design and testing protocols in the exclusion of other potential interfering variables, such as the rotator cuff. This provides accurate results on true strain/stress response at the acromion and scapular spine resulting from altered deltoid forces. Fourthly, the base implant models were varied with differing NSA between studies. The impact of this in interpreting and comparing results is uncertain. Finally, acromial and scapular spine fractures are the result of bony stress of a certain cross-sectional area exceeding the bony strength in this area.

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