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SHOULDER & ELBOW

Effect of critical shoulder angle, glenoid lateralization, and humeral inclination on range of movement in reverse shoulder arthroplasty

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Objectives

To date, no study has considered the impact of acromial morphology on shoulder range of movement (ROM). The purpose of our study was to evaluate the effects of lateralization of the centre of rotation (COR) and neck-shaft angle (NSA) on shoulder ROM after reverse shoulder arthroplasty (RSA) in patients with different scapular morphologies.

Methods

3D computer models were constructed from CT scans of 12 patients with a critical shoulder angle (CSA) of 25°, 30°, 35°, and 40°. For each model, shoulder ROM was evaluated at a NSA of 135° and 145°, and lateralization of 0 mm, 5 mm, and 10 mm for seven standardized movements: glenohumeral abduction, adduction, forward flexion, extension, internal rotation with the arm at 90° of abduction, as well as external rotation with the arm at 10° and 90° of abduction.

Results

CSA did not seem to influence ROM in any of the models, but greater lateralization achieved greater ROM for all movements in all configurations. Internal and external rotation at 90° of abduction were impossible in most configurations, except in models with a CSA of 25°.

Conclusion

Postoperative ROM following RSA depends on multiple patient and surgical factors. This study, based on computer simulation, suggests that CSA has no influence on ROM after RSA, while lateralization increases ROM in all configurations. Furthermore, increasing subacromial space is important to grant sufficient rotation at 90° of abduction. In summary, increased lateralization of the COR and increased subacromial space improve ROM in all CSA configurations.

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Keywords: Critical shoulder angle, Reverse shoulder arthroplasty, Range of movement, Scapular morphology, Impingement

Article focus

- What are the effects of lateralization of the centre of rotation (COR) and neck-shaft angle (NSA) on shoulder range of movement (ROM) after reverse shoulder arthroplasty (RSA)?
- Is shoulder ROM reduced in shoulders with greater critical shoulder angle (CSA)?
- Can shoulder ROM be increased by lateralization and higher NSA?

Key messages

- CSA does not influence ROM after RSA.
- Lateralization increases ROM in all configurations.
- Increasing subacromial space is important to grant sufficient rotation at 90° of abduction.

Strengths and limitations

- This is the first study to evaluate the impact of acromial morphology on shoulder ROM.
- We focused on glenohumeral movements only.

Introduction

The main goal of reverse shoulder arthroplasty (RSA) is to relieve pain, restore function, and grant mobility in degenerative and cuff-deficient shoulders. Despite its success, RSA is

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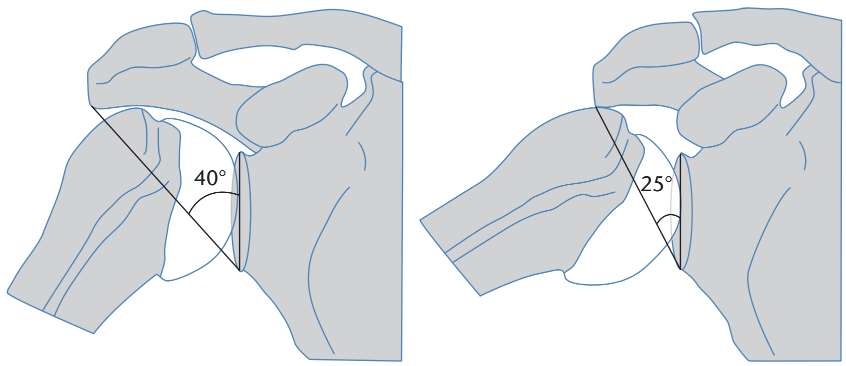

Fig. 1a Fig. 1b

Illustration of hypothesized abduction range of different shoulders: a) high critical shoulder angle (CSA) may limit abduction due to early impingement; b) low CSA may allow greater abduction before impingement.

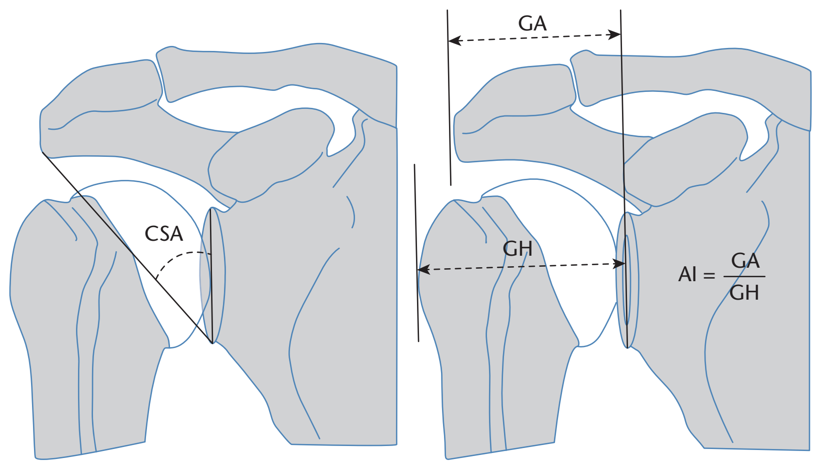

Fig. 2a Fig. 2b

Illustrations of a) critical shoulder angle (CSA), and b) acromial index (AI). GA, distance from the glenoid plane to the most lateral aspect of the acromion; GH, distance from the glenoid plane to the most lateral aspect of the proximal humeral head.

frequently associated with complications due to suboptimal implant positioning, which could limit the postoperative range of movement (ROM).[1-6] For these reasons, the glenoid component is often lateralized with bony or metallic offsets in order to prevent impingement.[6,7]

The evolution of the upper limb in humans was marked by substantial morphologic alterations within the scapula, with progressive lateral extension of the acromion,[8] and greater dominance of the deltoid, strengthening its middle abductor component.[9] Although the lateral extension of the acromion increases the moment arm of the deltoid muscle, it increases the likelihood of impingement (Fig. 1).

Several authors investigated the effects of humeral, glenoid, and scapular neck morphology on shoulder ROM[10] and scapular notching[3,4,11,12] after RSA, but none specifically considered the impact of acromial morphology represented by the critical shoulder angle (CSA)[13] or the acromial index (AI)[14] (Fig. 2). Recent studies used computer simulations to determine the effects of humeral and glenoid variations on ROM and bony impingements after RSA,[2] but none investigated how different configurations of lateralization or neck-shaft angle (NSA) affect shoulder ROM in different scapular morphologies. The purpose of the present study, therefore, was to evaluate the effects of lateralization of the centre of rotation (COR) and NSA on shoulder ROM after RSA in patients with different scapular morphologies. The hypothesis was that shoulder ROM would be reduced in models with a greater CSA, and that it can be increased by lateralization and a higher NSA.

Patients and Methods

The authors constructed 3D computer models from CT scans (acquired at 0.63 mm slice thickness) of 12 patients scheduled to receive RSA. The 12 shoulders were selected to represent a wide range of CSAs (25°, 30°, 35°, and 40°) with no bony deformity on the scapular or humeral sides, no fractural sequelae only type A1 glenoids according to the classification of Walch et al,[15] and inclination within the range described by Chalmers et al.[16] All patients provided written informed consent for the use of

Fig. 3a

Fig. 3b

The two neck-shaft angles evaluated: a) 135°; b) 145°.

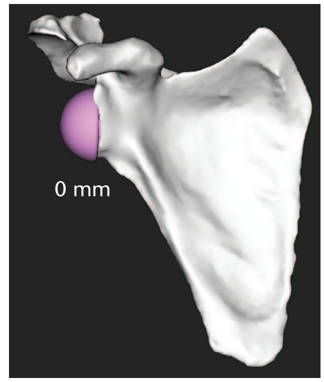

Fig. 4a

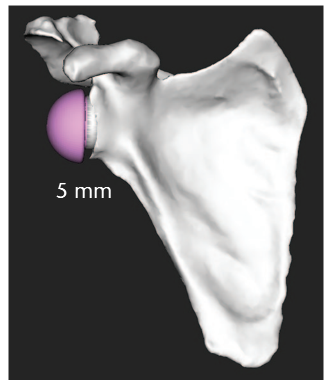

Fig. 4b

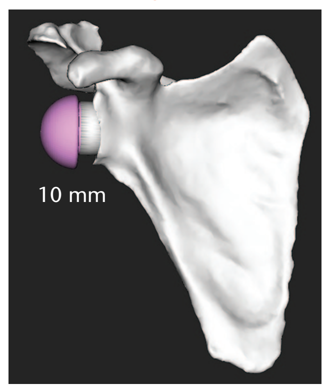

Fig. 4c

The three glenoid lateralizations evaluated: a) 0 mm; b) 5 mm; and c) 10 mm.

their data and images for research and publishing purposes. The CSA was measured on frontal views of the scapula and defined by the angle between the line connecting the superior and inferior poles of the glenoid and the line connecting the lateral edge of the acromion to the inferior pole of the glenoid (Fig. 2).[13]

Computer models and prosthetic scenarios. The humerus and scapula were segmented to reconstruct bony surfaces using imaging software Mimics (Materialize NV, Leuven, Belgium) and were then imported into computer-aided design software SolidWorks (Dassault Systemes, Concord, Massachusetts) to simulate virtual RSA. The virtual implantations, carried out by engineers (including CC) using shoulder preoperative planning software,[17] were performed under the supervision of one experienced shoulder surgeon (AL), who fine-tuned the choice of implant size and positioning. Scapular and humeral implants were modelled according to a standard shoulder system (Medacta International SA, Castel San Pietro, Switzerland).

A humeral cut was simulated at 135° at the anatomic humeral neck. An inlay stem (Shoulder System; Medacta International) was positioned in 20° of retroversion for each of the 12 scapular models. A reverse metaphysis + 0 mm/0° was numerically assembled onto a standard humeral diaphysis. An asymmetric polyethylene liner was then positioned on the stem to obtain either a humeral inclination of 135° or 145° (Fig. 3).

The scapula was prepared in order to obtain neutral inclination and version. A circular baseplate was implanted at the inferior part of the glenoid surface in order to obtain an inferior overhang of 2 mm. A glenosphere was then virtually implanted and three different lateralizations were tested (Fig. 4): a) neutral (0 mm); b) low offset (5 mm); and c) high offset (10 mm).

Kinematic simulation and impingement detection. For each configuration, shoulder ROM was evaluated by simulating seven standardized movements: abduction; adduction; forward flexion; extension; internal rotation with the arm at 90° of abduction; external rotation with the arm at 10° of abduction; and external rotation with the arm at 90° of abduction. In order to permit movement description in a repeatable way, bone coordinate systems were established for the scapula and humerus

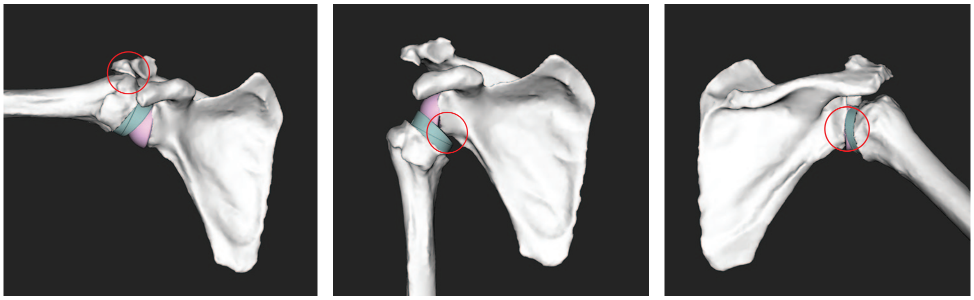

Fig. 5a Fig. 5b Fig. 5c

Type of impingements: a) abutment between the greater tuberosity and the acromion at maximal abduction; b) polyethylene contact with the scapular pillar (inferior notching) occurring at internal rotation; and c) impingement between the polyethylene and the posterior glenoid during external rotation with abduction.

based on anatomical landmarks and definitions of the International Society of Biomechanics.[18] Simulation was performed with custom-made software that allowed testing of the prosthetic shoulder models with real-time evaluation of impingement. Shoulder angles (three rotations) were applied at each timepoint by increments of 1° to the prosthetic model in its anatomical frame. A collision detection algorithm[19] was then used to locate any prosthetic or bony impingement, as well as of the corresponding angle of movement (Fig. 5). The algorithm consisted of first projecting each point of the scapular mesh (resolution: approximately 16000 polygons) onto the humeral (resolution: approximately 16000 polygons) and/or stem (resolution: approximately 36000 polygons) mesh, and then of determining if the point was inside the humeral or stem mesh (i.e. colliding point). At each simulation timepoint, each colliding point of the scapular model onto the humeral and/or stem models was documented to determine impingement zones based on the following reference system: zone 1, impingement between the polyethylene and anterior glenoid; zone 2, impingement between the polyethylene and the superior glenoid; zone 3, impingement between the polyethylene and the posterior glenoid; zone 4, polyethylene contact with the scapular pillar (inferior notching); zone 5, abutment with the acromion; and zone 6, abutment with the coracoid. All measurements were made by the same observer (CC).

Results

In all 3D models with a CSA of < 40°, maximum abduction was achieved with greater lateralization (10 mm) and a higher NSA (145°), while maximum adduction was achieved with greater lateralization (10 mm) but a lower NSA (135°; Fig. 6). Higher lateralization shifted impingement zones during abduction, from the superior glenoid to the acromion, but did not displace impingement zones in adduction away from the inferior glenoid (Table I).

In general, forward flexion, extension, and external rotation at 10° of abduction improved with greater lateralization (Fig. 7). Internal and external rotation at 90° of abduction were impossible in most configurations, except in models with a CSA of 25°.

Discussion

Many studies report the influence of implant and surgical factors on the ROM of the shoulder after RSA.[2,20-23] Improvements in surgical techniques and implant design have led to better postoperative outcomes.[21,24-27] However, there is a high variability of postoperative shoulder ROM reported in the literature,[28,29] which suggests the influence of other unidentified factors. To the authors' knowledge, no published studies have investigated how different configurations of lateralization and NSA affect shoulder ROM in different scapular morphologies. In the present study, based on computer simulations, we aimed to identify the effects of lateralization and NSA on shoulder ROM after RSA in patients with different scapular morphologies. Our main finding was that, contrary to our hypothesis, CSA does not seem to influence ROM after RSA, while lateralization increases ROM in all configurations.

CSA. Our results did not confirm our hypothesis that increasing the CSA reduces ROM. On the contrary, the greatest degrees of abduction were observed in a model with a CSA of 40°. We, however, found that impingement occurred mainly in the acromion zone, independently of the CSA.

Lateralization. We found that lateralization improved the ROM in all directions, independently of the CSA and NSA, except in models with a CSA of 40°. This finding is consistent with two earlier studies of RSA, based on sawbones[21] and computer models,[20] which found that lateralization increased ROM during abduction and adduction. Recently, Werner et al,[23] who conducted a computer-simulated study on 20 patients, found that lateralization led to a significant increase in adduction, forward flexion, and extension, but not abduction. In line with our findings, they observed that, during abduction, lateralization led to impingement at the acromion rather than the superior glenoid zone. In fact, Gutiérrez et al[30]

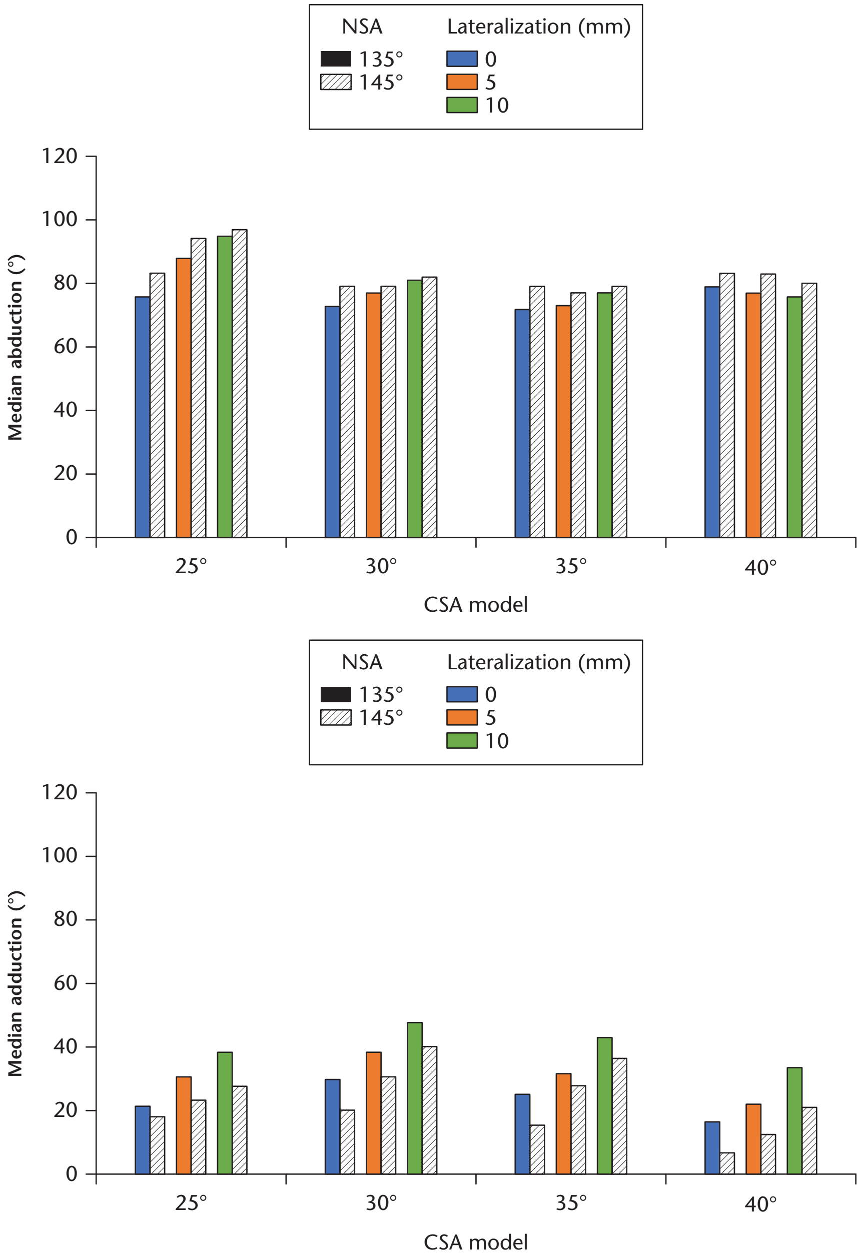

Fig. 6

Bar charts comparing median abduction and adduction ranges for different critical shoulder angle (CSA) models. NSA, neck-shaft angle.

had also suggested that decreased articular constraint in RSA, hence increased lateral offset of the humeral component, may be associated with decreased ROM because of impingement on the acromion at small abduction angles.

Humeral neck-shaft angle. We found that a higher NSA increased the range of abduction and decreased the range of adduction, independently of the CSA and lateralization. This corroborates with earlier studies that also found that a higher NSA increases abduction.[2,20,22,23] By contrast, Roche et al,[31] in their computational analysis of a Grammont-style implant, found no correlation between NSA and ROM, although they found that decreasing NSA by 5° lowered the inferior and superior impingement points.

Subacromial space. Internal rotation in abduction is important to activities of daily living. Interestingly, internal and external rotation at 90° of abduction were impossible in most configurations due to inexistent subacromial space. We suggest that, in these configurations, eccentric positioning of the glenosphere could create subacromial space.[2]

The limitations of this study are typical of computer-based simulations. First, we focused on glenohumeral

Table I. Location of impingement and range of movement (ROM; °) when impingement occurred

CSA, °	Lat° (mm)	NSA, °	Abduction		Adduction		Forward flexion		Extension		ER ABD 10°		IR ABD 90°		ER ABD 90°	
			Loc*	ROM, °	Loc	ROM, °	Loc	ROM, °	Loc	ROM, °	Loc	ROM, °	Loc	ROM, °	Loc	ROM, °
25	0	135	2	76 (72 to 82)	4	22 (20 to 40)	1, 6	53 (47 to 104)	3, 4, 5	101 (59 to 105)	4	82 (74 to 84)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	5	135	2, 5	88 (85 to 89)	4	32 (31 to 44)	1, 6	74 (68 to 112)	3, 5	105 (94 to 112)	4	98 (87 to 101)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	10	135	2, 5	95 (88 to 102)	4	40 (37 to 45)	1, 5, 6	98 (89 to 136)	3, 5	109 (103 to 118)	4	111 (100 to 111)	-, 5	180 (0 to 180)	5	0 (0 to 14)
	0	145	2, 5	83 (82 to 89)	4	19 (13 to 28)	1, 6	57 (49 to 101)	4	24 (16 to 33)	4	71 (68 to 76)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	5	145	2, 5	94 (90 to 95)	4	24 (19 to 38)	1, 6	70 (69 to 114)	3, 5	102 (82 to 105)	4	95 (82 to 98)	-, 5	180 (0 to 180)	5	9 (0 to 11)
	10	145	2, 5	97 (94 to 101)	4	29 (28 to 36)	1, 6	93 (86 to 126)	3, 5	103 (81 to 108)	4	113 (92 to 118)	-	180 (180 to 180)	5	17 (5 to 17)
30	0	135	2, 5	73 (66 to 75)	4	31 (30 to 47)	1, 6	77 (72 to 87)	5	96 (89 to 112)	4	82 (80 to 96)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	5	135	2, 5	77 (72 to 79)	4	40 (28 to 55)	1, 6	94 (77 to 95)	5	93 (92 to 121)	4	94 (75 to 102)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	10	135	5	81 (79 to 82)	4	50 (33 to 61)	6	103 (99 to 108)	5	97 (96 to 127)	4	106 (105 to 108)	5	0 (0 to 0)	5	0 (0 to 0)
	0	145	2, 5	79 (77 to 80)	4	21 (15 to 33)	1, 6	75 (75 to 84)	4, 5	88 (24 to 117)	4	74 (72 to 95)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	5	145	5	79 (77 to 84)	4	32 (15 to 43)	1, 6	90 (77 to 96)	3, 4, 5	91 (21 to 104)	4	95 (72 to 102)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	10	145	5	82 (78 to 87)	4	42 (25 to 51)	6	104 (91 to 111)	4, 5	96 (84 to 124)	4	110 (109 to 117)	5	0 (0 to 0)	5	0 (0 to 0)
35	0	135	2, 5	72 (68 to 75)	4	26 (20 to 29)	1, 6	69 (53 to 80)	4, 5	56 (31 to 93)	4	62 (55 to 69)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	5	135	5	73 (72 to 74)	4	33 (31 to 38)	1, 6	88 (52 to 99)	4, 5	53 (50 to 102)	4	71 (61 to 80)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	10	135	5	77 (73 to 78)	4	45 (37 to 48)	6	98 (83 to 117)	3, 4, 5	106 (73 to 111)	4	97 (72 to 99)	5	0 (0 to 0)	5	0 (0 to 0)
	0	145	5	79 (69 to 79)	4	16 (16 to 23)	1, 6	78 (50 to 83)	4	24 (23 to 25)	4	62 (55 to 68)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	5	145	5	77 (72 to 79)	4	29 (17 to 35)	6	92 (52 to 100)	3, 4	49 (26 to 90)	4	80 (63 to 83)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	10	145	5	79 (79 to 79)	4	38 (35 to 42)	6	100 (87 to 115)	4, 5	108 (68 to 112)	4	101 (92 to 106)	5	0 (0 to 0)	5	0 (0 to 0)
40	0	135	2, 5	79 (72 to 86)	4	17 (13 to 29)	6	71 (67 to 85)	3, 4, 5	89 (30 to 94)	4	70 (69 to 85)	2, 5	0 (0 to 0)	2, 5	0 (0 to 0)
	5	135	2, 5	77 (72 to 99)	4	23 (17 to 31)	6	74 (69 to 90)	4, 5	95 (28 to 97)	4	78 (65 to 94)	-, 2, 5	0 (0 to 180)	2, 5	0 (0 to 66)
	10	135	5	76 (75 to 106)	4	35 (29 to 37)	6	96 (80 to 104)	4, 5	97 (97 to 100)	4	91 (87 to 102)	-, 5	0 (0 to 180)	5	0 (0 to 0)
	0	145	2, 5	83 (79 to 99)	4	7 (6 to 18)	1, 6	71 (64 to 86)	4	27 (6 to 42)	4	60 (53 to 75)	-, 5	0 (0 to 180)	-, 5	0 (0 to 180)
	5	145	2, 5	83 (76 to 114)	4	13 (7 to 23)	6	73 (73 to 88)	3, 4, 5	87 (13 to 97)	4	73 (50 to 91)	-, 5	0 (0 to 180)	-, 5	0 (0 to 180)
	10	145	5	80 (77 to 113)	4	22 (19 to 24)	6	96 (78 to 107)	3, 5	84 (84 to 97)	4	89 (87 to 97)	-, 5	0 (0 to 180)	-, 5	0 (0 to 180)

*Location of the impingement zone (1, anterior glenoid; 2, superior glenoid; 3, posterior glenoid; 4, inferior glenoid; 5, acromion; 6, coracoid; -, no impingement)
CSA, critical shoulder angle; Lat°, lateralization; Loc, location of impingement; NSA, neck-shaft angle; ER, external rotation; IR, internal rotation; ABD, abduction; ROM: range of movement

Fig. 7

Radar charts illustrating median range of movement (ROM) at different degrees of lateralization for different critical shoulder angle (CSA) models. NSA, neck-shaft angle; ER, external rotation; IR, internal rotation; ABD, abduction.

movements and could not consider scapulothoracic movements. Second, in an anatomic shoulder, soft-tissue tensions may alter the actual ROM achieved. Third, real movements can involve compensatory movements, such as internal or external rotation of the humerus during abduction, to avoid early impingement and achieve greater degrees of abduction than those reported in this study. Fourth, we evaluated the effects of lateralization of the COR by increasing glenoid component offset, but not by increasing humeral component offset, which also plays an important part in shoulder ROM.[2]

In conclusion, postoperative ROM following RSA depends on multiple patient and surgical factors. This study, based on computer simulations, suggests that CSA does not influence ROM after RSA, while lateralization increases ROM in all configurations. Furthermore, increasing subacromial space is important in order to grant sufficient rotation at 90° of abduction.

References

1. **Boileau P, Moineau G, Roussanne Y, O'Shea K.** Bony increased-offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid fixation. *Clin Orthop Relat Res* 2011;469:2558-2567.
2. **Lädermann A, Denard PJ, Boileau P, et al.** Effect of humeral stem design on humeral position and range of motion in reverse shoulder arthroplasty. *Int Orthop* 2015;39:2205-2213.
3. **Lévigne C, Boileau P, Favard L, et al.** Scapular notching in reverse shoulder arthroplasty. *J Shoulder Elbow Surg* 2008;17:925-935.
4. **Lévigne C, Garret J, Boileau P, et al.** Scapular notching in reverse shoulder arthroplasty: is it important to avoid it and how? *Clin Orthop Relat Res* 2011;469:2512-2520.
5. **Sirveaux F, Favard L, Oudet D, et al.** 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-B:388-395.
6. **Werner BS, Böhm D, Abdelkawi A, Gohlke F.** Glenoid bone grafting in reverse shoulder arthroplasty for long-standing anterior shoulder dislocation. *J Shoulder Elbow Surg* 2014;23:1655-1661.
7. **Athwal GS, MacDermid JC, Reddy KM, et al.** Does bony increased-offset reverse shoulder arthroplasty decrease scapular notching? *J Shoulder Elbow Surg* 2015;24:468-473.
8. **Inman V, Saunders M, Abbott M.** Observations on the function of the shoulder joint. *J Bone Joint Surg [Br]* 1944;26-B:1-30.
9. **Grammont PM.** Place de l'ostéotomie de l'épine de l'omoplate avec translation, rotation, élévation de l'acromion dans les ruptures chroniques de la coiffe des rotateurs. *Lyon Chir* 1979;55:327-329.
10. **Berhouet J, Garaud P, Favard L.** Evaluation of the role of glenosphere design and humeral component retroversion in avoiding scapular notching during reverse shoulder arthroplasty. *J Shoulder Elbow Surg* 2014;23:151-158.
11. **Mizuno N, Denard PJ, Raiss P, Walch G.** The clinical and radiographical results of reverse total shoulder arthroplasty with eccentric glenosphere. *Int Orthop* 2012;36:1647-1653.
12. **Werner BS, Chaoui J, Walch G.** Glenosphere design affects range of movement and risk of friction-type scapular impingement in reverse shoulder arthroplasty. *Bone Joint J* 2018;100-B:1182-1186.
13. **Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C.** Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint? A radiological study of the critical shoulder angle. *Bone Joint J* 2013;95-B:935-941.
14. **Nyffeler RW, Meyer D, Sheikh R, Koller BJ, Gerber C.** The effect of cementing technique on structural fixation of pegged glenoid components in total shoulder arthroplasty. *J Shoulder Elbow Surg* 2006;15:106-111.
15. **Walch G, Badet R, Boulahia A, Khoury A.** Morphologic study of the glenoid in primary glenohumeral osteoarthritis. *J Arthroplasty* 1999;14:756-760.
16. **Chalmers PN, Beck L, Granger E, Henninger H, Tashjian RZ.** Superior glenoid inclination and rotator cuff tears. *J Shoulder Elbow Surg* 2018;27:1444-1450.
17. **Charbonnier C, Chague S, Schmid J, et al.** Analysis of hip range of motion in everyday life: a pilot study. *Hip Int* 2015;25:82-90.
18. **Wu G, van der Helm FC, Veeger HE, et al.** ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--part II: shoulder, elbow, wrist and hand. *J Biomech* 2005;38:981-992.
19. **Charbonnier C.** Extreme hip movements based on optical motion capture. PhD thesis.: University of Geneva, 2010. https://archive-ouverte.unige.ch/unige:5996 (date last accessed 20 May 2019).
20. **Gutiérrez S, Comiskey CA IV, Luo ZP, Pupello DR, Frankle MA.** Range of impingement-free abduction and adduction deficit after reverse shoulder arthroplasty. Hierarchy of surgical and implant-design-related factors. *J Bone Joint Surg [Am]* 2008;90-A:2606-2615.
21. **Gutiérrez S, Levy JC, Frankle MA, et al.** Evaluation of abduction range of motion and avoidance of inferior scapular impingement in a reverse shoulder model. *J Shoulder Elbow Surg* 2008;17:608-615.
22. **Virani NA, Cabezas A, Gutiérrez S, et al.** Reverse shoulder arthroplasty components and surgical techniques that restore glenohumeral motion. *J Shoulder Elbow Surg* 2013;22:179-187.
23. **Werner BS, Chaoui J, Walch G.** The influence of humeral neck shaft angle and glenoid lateralization on range of motion in reverse shoulder arthroplasty. *J Shoulder Elbow Surg* 2017;26:1726-1731.
24. **Ackland DC, Patel M, Knox D.** Prosthesis design and placement in reverse total shoulder arthroplasty. *J Orthop Surg Res* 2015;10:101.
25. **Barco R, Savvidou OD, Sperling JW, Sanchez-Sotelo J, Cofield RH.** Complications in reverse shoulder arthroplasty. *EFORT Open Rev* 2017;1:72-80.
26. **Boulahia A, Edwards TB, Walch G, Baratta RV.** Early results of a reverse design prosthesis in the treatment of arthritis of the shoulder in elderly patients with a large rotator cuff tear. *Orthopedics* 2002;25:129-133.
27. **Cuff D, Pupello D, Virani N, Levy J, Frankle M.** Reverse shoulder arthroplasty for the treatment of rotator cuff deficiency. *J Bone Joint Surg [Am]* 2008;90-A:1244-1251.
28. **Trouilloud P, Gonzalvez M, Martz P, et al.** Duocentric® reversed shoulder prosthesis and Personal Fit® templates: innovative strategies to optimize prosthesis positioning and prevent scapular notching. *Eur J Orthop Surg Traumatol* 2014;24:483-495.
29. **Valenti PH, Boutens D, Nerot C.** Delta 3 reversed prosthesis for osteoarthritis with massive rotator cuff tear: long term results (> 5 years). In: Walch G, Boileau P, Molé D, eds. *2000 Shoulder Prostheses. . .two to ten year follow-up.* Montpellier: Sauramps Médical, 2001:253-259.
30. **Gutiérrez S, Luo ZP, Levy J, Frankle MA.** Arc of motion and socket depth in reverse shoulder implants. *Clin Biomech (Bristol, Avon)* 2009;24:473-479.
31. **Roche C, Flurin PH, Wright T, et al.** An evaluation of the relationships between reverse shoulder design parameters and range of motion, impingement, and stability. *J Shoulder Elbow Surg* 2009;18:734-741.

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