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

Running Title: Factors influencing ROM after RSA

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Abstract

Objectives: No study considered the impact of acromial morphology on shoulder range of motion (ROM). The purpose was to evaluate the effects of lateralization of the center of rotation (COR) and neck shaft angle (NSA) on shoulder ROM after RSA in patients with different scapular morphologies.

Methods: 3D-computer models were constructed from computed tomography (CT) scans of 12 patients with 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 0mm, 5mm and 10mm for 7 standardized motions: 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: In all models, CSA did not seem to influence ROM, but greater lateralization achieved greater ROM for all motions in all configurations. Internal and external rotation at 90° of abduction were impossible in most configurations, except in models with 25° CSA.

Conclusions: Post-operative ROM following RSA depends on multiple patient and surgical factors. This study based on computer simulation suggests that there is no influence of CSA 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 center of rotation and increased subacromial space improve range of motion in all CSA configurations.

Keywords: Reverse shoulder arthroplasty; Critical shoulder angle; Scapular morphology; Impingement; Range of motion

Article focus

- What are the effects of lateralization of the center of rotation and neck shaft angle on shoulder ROM after RSA?
- Is shoulder ROM reduced in models with greater critical shoulder angle?
- Can shoulder ROM be increased by lateralization and higher neck shaft angle?

Key messages

- Critical shoulder angle 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 of this study (up to 3 bullet points)

- First study to evaluate the impact of acromial morphology on shoulder range of motion
- Focus on glenohumeral motions 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 frequently associated with complications due to suboptimal implant positioning, which could limit the post-operative range of motion (ROM).[1-6] For these reasons, the glenoid component is often lateralized with bony or metallic offsets, 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] Whereas the lateral extension of the acromion increases the moment arm of the deltoid muscle, it increases the likelihood of impingement (Figure 1).

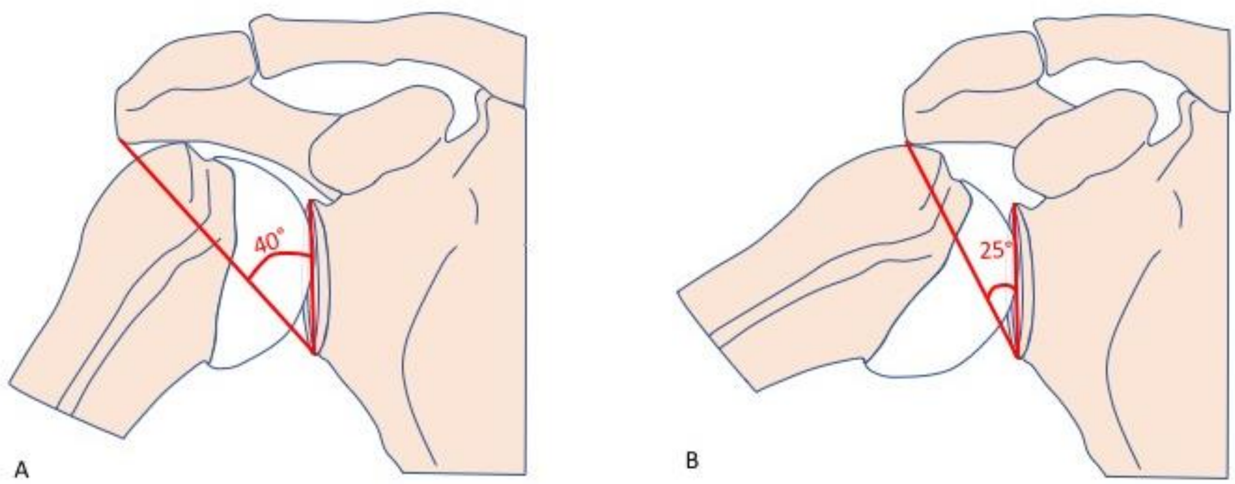

Figure 1: Illustrations of (A) critical shoulder angle, (B) acromial index.

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] (Figure 2).

Recent studies used computer simulations to determine 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 was therefore to evaluate the effects of lateralization of the center 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 greater CSA, and that it can be increased by lateralization and higher NSA.

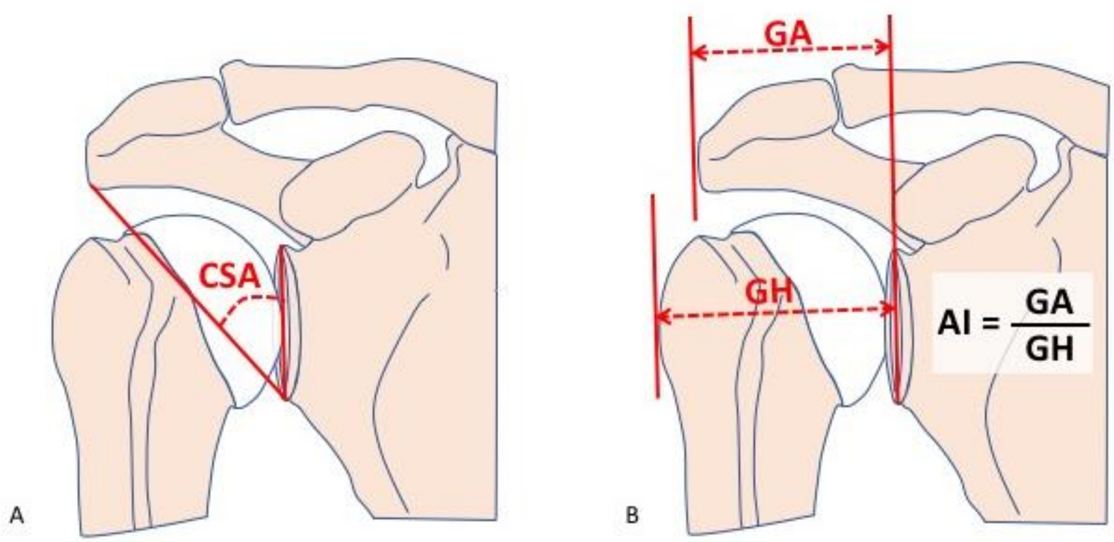

Figure 2: Illustration of hypothesized abduction range of different shoulders: (A) high CSA may limit abduction due to early impingement, (B) low CSA may allow greater abduction before impingement.

Patients and Methods

The authors constructed three-dimensional (3D) computer models from Computed Tomography (CT) scans (acquired at 0.63mm slice thickness) of 12 patients scheduled to receive RSA. In order to evaluate whether scapular bone morphology influences postoperative ROM, the 12 shoulders were selected to present analogous bony morphology with (1) no bony deformity on the scapular and humeral side, (2) humeri with no fractural sequelae, (3) type A1 glenoid according to Walch et al. classification[15] with similar inclination within the range described by Chalmers et al.[16], but to differ from one another by presenting a wide range of CSA (25°, 30°, 35° and 40°). All patients provided written informed consent for the use of 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 (Figure 1).[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 Systems, Concord, MA, USA) to simulate virtual RSA. The virtual implantations, done by engineers using shoulder pre-operative planning software, were performed under the supervision of one experienced shoulder surgeon (A.L.), who fine-tuned the choice of implant size and positioning. Scapular and humeral implants were modeled according to a standard shoulder system (Medacta International, Castel San Pietro, Switzerland).

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

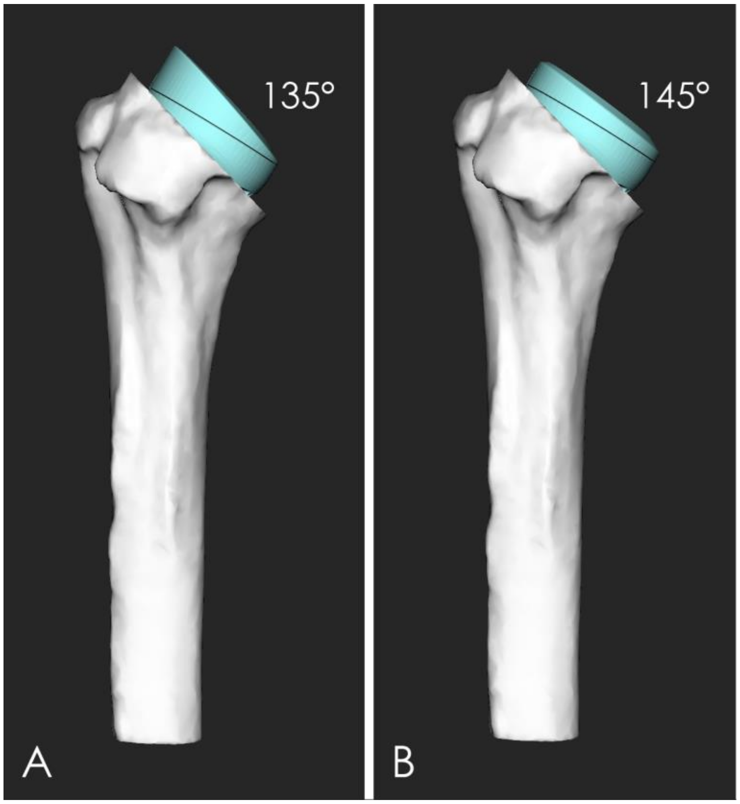

Figure 3: The two neck shaft angles evaluated: (A) 135°, (B) 145°.

The scapula was prepared 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 2mm. A glenosphere was then virtually implanted and three different lateralizations were tested (Figure 4): (a) neutral (0mm), (b) low offset (5mm), and (c) high offset (10mm).

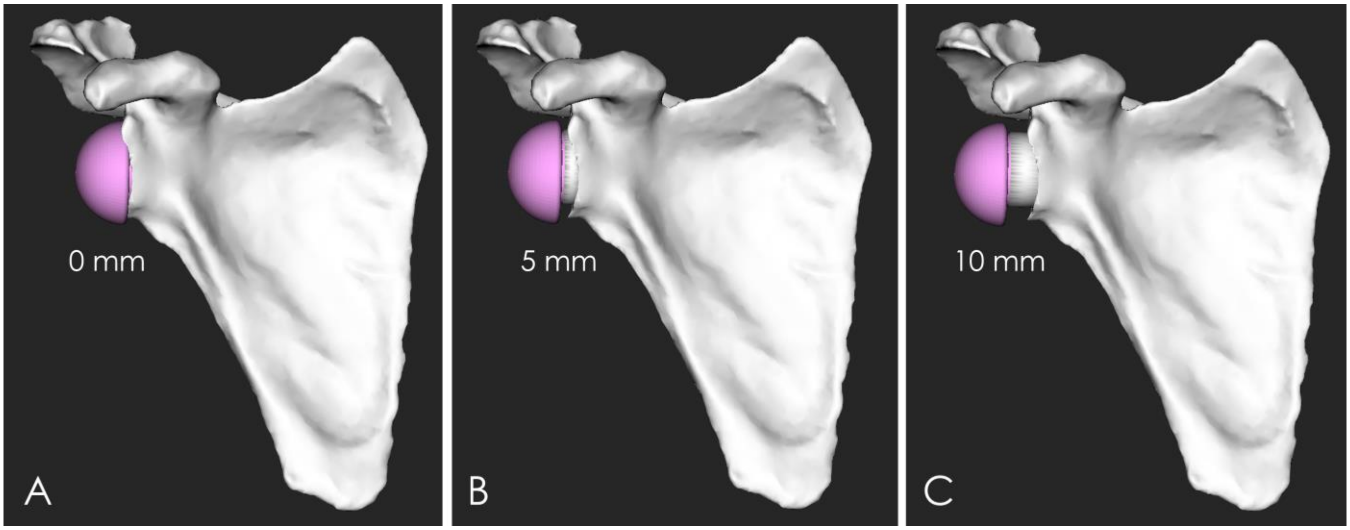

Figure 4: The three glenoid lateralizations evaluated: (A) 0 mm, (B) 5 mm and (C) 10 mm.

Kinematic simulation and impingement detection

For each configuration, shoulder ROM was evaluated by simulating 7 standardized motions: 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. In order to permit motion description in a repeatable way, bone coordinate systems were established for the scapula and humerus based on anatomical landmarks and definitions of the International Society of Biomechanics.[17] Simulation was performed with custom-made software that allowed testing of the prosthetic shoulder models with real time evaluation of impingement. Shoulder angles (3 rotations) were applied at each time step by increment of 1 degree to the prosthetic model in its anatomical frame. Then, a collision detection algorithm,[18] was used to locate any prosthetic or bony impingement, as well as of the corresponding angle of motion (Figure 5). The algorithm consisted in first projecting each point of the scapula mesh (resolution: ~16'000 polygons) onto the humeral (resolution: ~16'000 polygons) and/or stem (resolution: ~36'000 polygons) mesh, and then at determining if the point was inside the humeral or stem mesh (i.e., colliding point). At each simulation time step, each colliding point of the scapula model onto the humerus and/or stem models were documented to determine impingement zones based on the following reference system : zone 1, impingement between the polyethylene and the 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 acromion; zone 6, abutment with coracoid. All measurements were made by the same observer (CC).

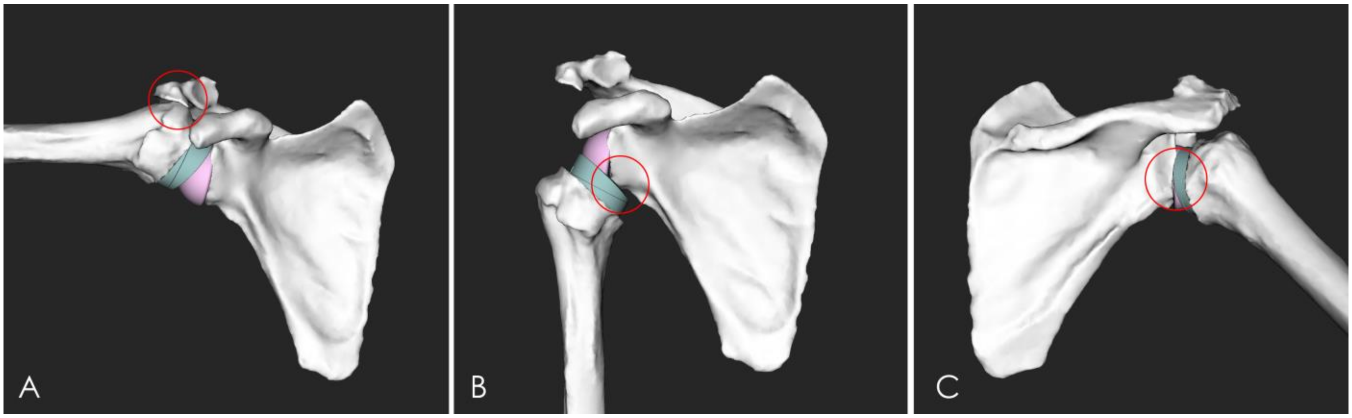

Figure 5: Type of impingements: (A) abutment between the greater tuberosity and the acromion at maximal abduction, (B) polyethylene contact with the scapular pillar (inferior notching) occurring at internal rotation, (C) impingement between the polyethylene and the posterior glenoid during external rotation with abduction.

Results

In all 3D models with <40° CSA, maximum abduction was achieved with greater lateralization (10mm) and higher NSA (145°), while maximum adduction was achieved with greater lateralization (10mm) but lower NSA (135°) (Figure 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 1).

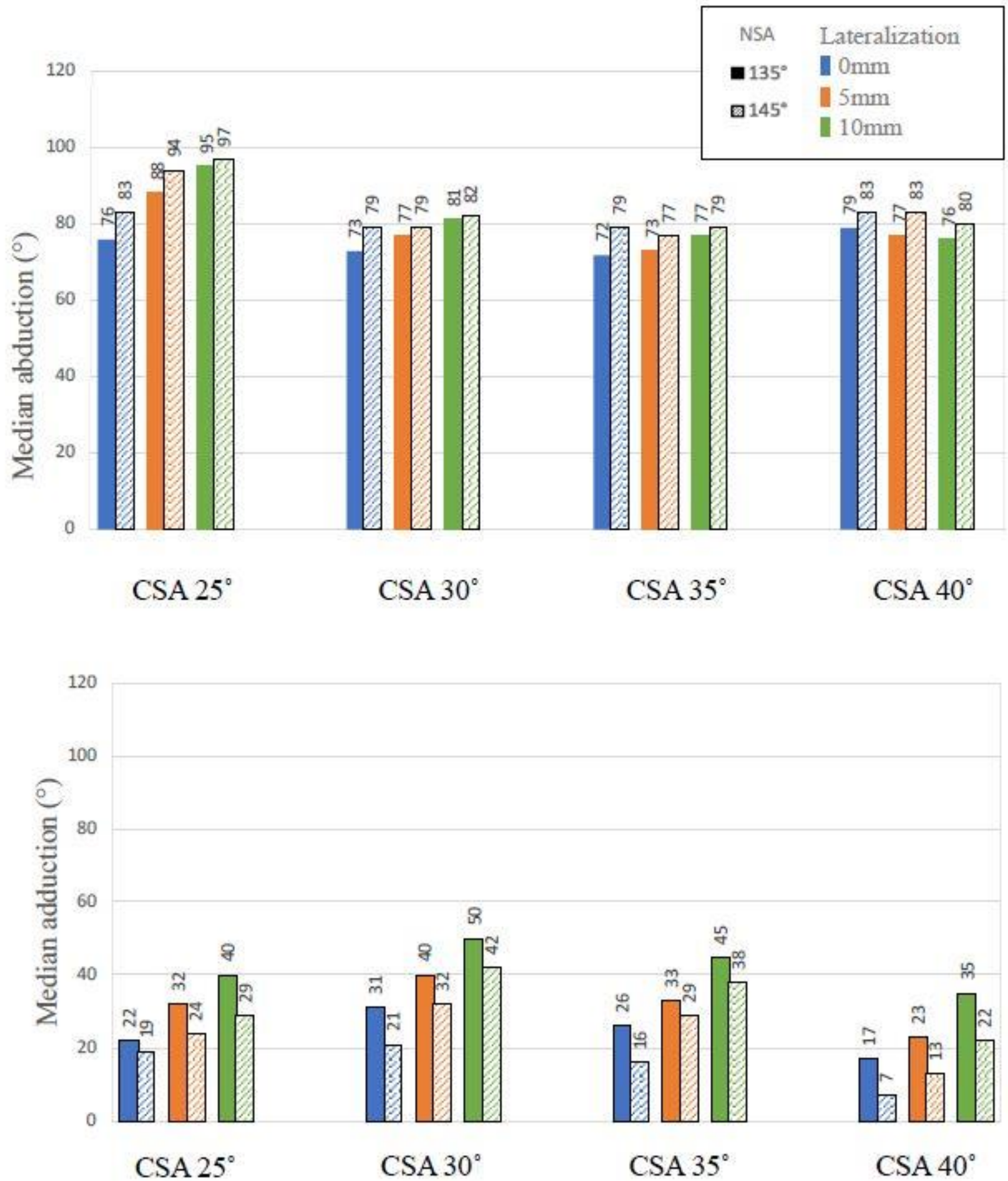

Figure 6: Bar charts comparing median abduction and adduction range for different CSA models.

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

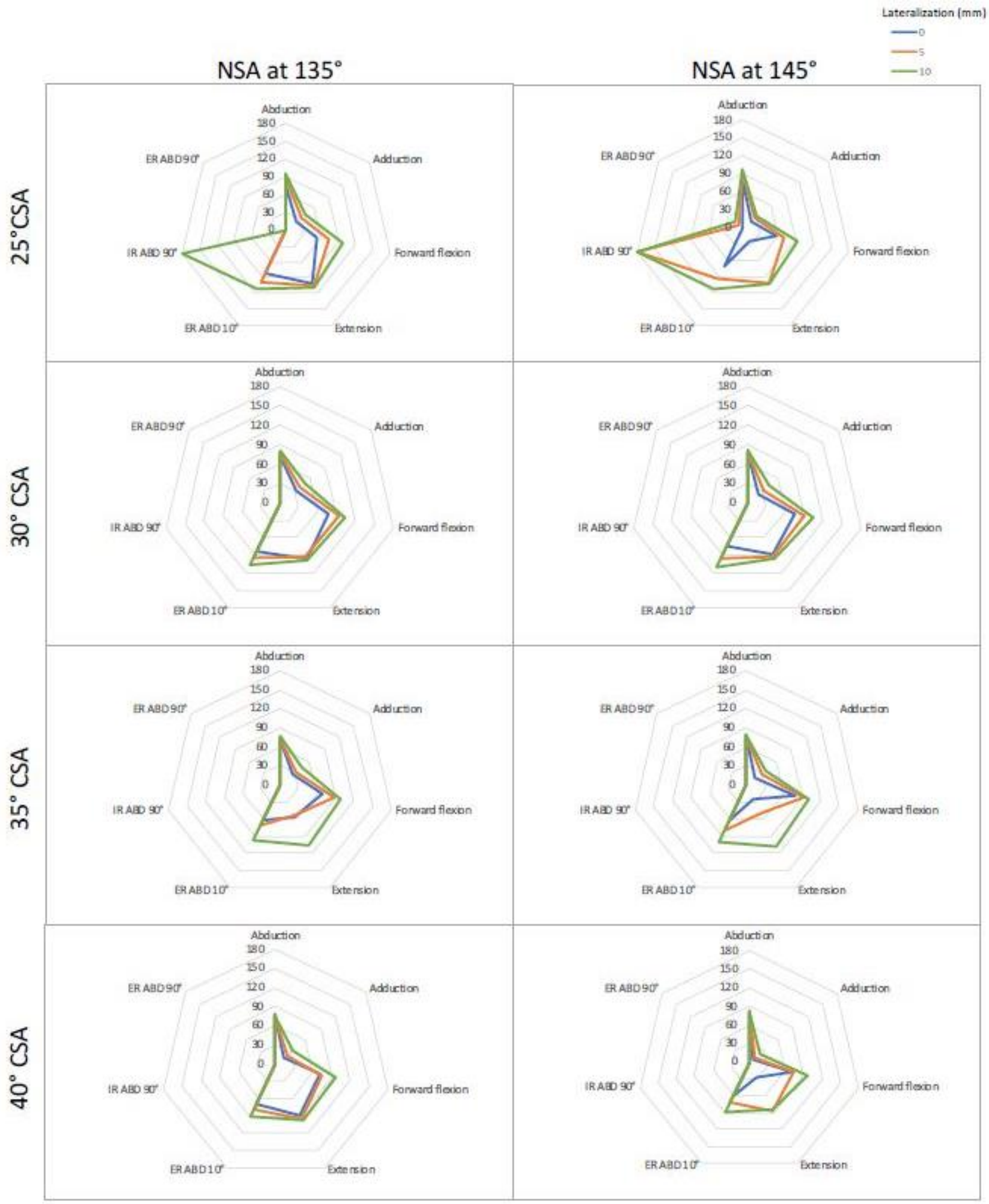

Figure 7: Radar charts illustrating median ROM at different degrees of lateralization for different CSA models.

Discussion

Many studies report the influence of implant and surgical factors on shoulder ROM after RSA.[2,19-22] Improvements in surgical techniques and implant design have led to better post-operative outcomes.[20,23-26] However, there is a high variability of post-operative shoulder ROM reported in the literature,[27,28] which suggests the influence of other unidentified factors. To the authors' knowledge, no published studies 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 influence ROM after RSA, while lateralization increases ROM in all configurations.

CSA

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

Lateralization

We found that lateralization improved the ROM in all directions, independently of CSA and NSA, except in models with CSA=40°. This finding is consistent with two earlier studies of RSA, based on sawbones[20] and computer models,[19] which found that lateralization increased ROM during abduction and adduction. Recently, Werner et al.[22], 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, Gutierrez et al.[29] 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 higher NSA increased range of abduction and decreased range of adduction, independently from CSA and lateralization. This corroborates earlier studies that also found that higher NSA increases abduction.[2,19,21,22] By contrast, Roche et al.[30], in their computational analysis of a Grammont-style implant, found no correlation between NSA and ROM, although they found that decreased NSA by 5° lowered inferior and superior impingement points by 5°.

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]

Limitations

The limitations of this study are typical of computer-based simulations. First, we focused on glenohumeral motions and could not consider scapulothoracic motions. Second, in an anatomic shoulder, soft tissue tensions may alter the actual ROM achieved. Third, real movements can involve compensatory motions, 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 COR by increasing glenoid component offset, but not by increasing humeral component offset, which also plays an important part in shoulder ROM.[2].

Conclusions

Post-operative 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 to grant sufficient rotation at 90° of abduction.

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Table 1 Location of impingement and ROM (°) when impingement occurred

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

* 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, ER: External Rotation, IR: Internal Rotation, Lat°: Lateralization, NSA: Neck Shaft Angle, ROM: Range of Motion