ORIGINAL PAPER

CrossMark

Assessment of anatomical and reverse total shoulder arthroplasty with the scapula-weighted Constant-Murley score

Giovanni Merolla [1,2] · Ilaria Parel [2] · Andrea Giovanni Cutti [3] · Maria Vittoria Filippi [4] · Paolo Paladini [1] · Giuseppe Porcellini [5]

Abstract

Aim of the study To evaluate total (TSA) and reverse total shoulder arthroplasty (RTSA) using the Constant-Murley score (CMS) and the scapula-weighted (SW) CMS, an integrated outcome measure that takes into account the compensatory movements of the scapula.

Methods Twenty-five consecutive patients, 12 with TSA and 13 with RTSA, underwent kinematic analysis before and after shoulder replacement. Measurements included flexion (FLEX) and abduction (ABD) for the humerus and Protraction-Retraction (PR-RE), Medio-Lateral rotation (ME-LA), and Posterior-Anterior tilting (P-A) for the scapula. They were recorded at baseline (T0) and at six (T1) and 12 months (T2). Reference data were obtained from 31 control shoulders.

Results At T1, differences in CMS and SW-CMS were not significant in either group, whereas values at T2 were significantly lower in RTSA patients ($p = 0.310$ and $p = 0.327$, respectively). In TSA shoulders, the compensatory scapular movements in FLEX were all reduced from T0 to T2, whereas P-A was increased in ABD. In RTSA patients, the compensatory scapular movements in FLEX showed a general reduction at T1, with an increase in P-A at T2, whereas in ABD, all increased at T1 and decreased at T2 except for P-A, which did not decrease.

Discussion The SW-CMS showed that the physiological scapulothoracic motion was not restored in TSA and RTSA patients; it may be used as a reference for the gradual progression of deltoid and scapular muscle rehabilitation.

Conclusions The worse CMS and SW-CMS scores found in RTSA patients at six months may be due to the biomechanics of the reverse prosthesis and to the weakness of deltoid and periscapular muscles.

Keywords Shoulder osteoarthritis · Total arthroplasty · Reverse · Kinematic analysis · Constant-Murley score · Scapular dyskines

---

Level of evidence: Level II, prospective controlled study.

✉ Giovanni Merolla
giovannimerolla@hotmail.com; giovanni.merolla@auslromagna.it

1 Shoulder and Elbow Unit, D. Cervesi Hospital, Cattolica, AUSL Romagna, Ambito Rimini, Italy

2 "Marco Simoncelli" Biomechanics Laboratory, D. Cervesi Hospital, Cattolica, AUSL della Romagna, Ambito Rimini, Italy

3 INAIL Prostheses Center, Vigorso di Budrio, Italy

4 Functional Recovery and Rehabilitation Unit, AUSL della Romagna, Ambito Rimini, Italy

5 Orthopaedic and Trauma Unit, Policlinico di Modena, University of Modena and Reggio Emilia, Modena, Italy

Introduction

Total shoulder arthroplasty (TSA) ensures satisfactory mid- to long-term clinical outcomes in patients with glenohumeral arthritis [1–3], whereas results in patients with rotator cuff deficiency are poorer [4, 5]. Reverse total shoulder arthroplasty (RTSA) has thus emerged as the best treatment option for cuff tear arthropathy (CTA) and massive irreparable rotator cuff tears [6–9].

The outcomes of shoulder replacement are evaluated with standardized clinical scoring systems [10, 11], of which the Constant-Murley score (CMS) is one of those used most frequently. Its main advantages are that: (i) it is fast to complete [12]; (ii) it incorporates patient subjectivity and clinical objectivity [13]; and (iii) it has established psychometric properties [14]. The CMS was adopted by the European Society for Surgery of the Shoulder and the Elbow (SECEC) in 1991 as

the most appropriate score to assess overall shoulder function [13].

Strong interest has recently been attracted by the kinematic evaluation of anatomical and reverse shoulder prostheses, to investigate differences in active and passive shoulder motion [15], analyze specific tasks of daily living activities [16–21], and assess the contribution of the scapulothoracic joint to total shoulder motion after rehabilitation [22]. However, these studies, though providing comprehensive information on the kinematics of the replaced shoulder (scapulohumeral rhythm, scapulothoracic, and glenohumeral motion), integrate poorly with clinical data. Recently, Cutti and co-workers have developed the scapula-weighted Constant-Murley score (SW-CMS), where the CMS points for humeral elevation and abduction are weighted based on a quantitative analysis of scapular dyskinesis [23]. These authors used the CMS and the SW-CMS to evaluate a group of patients during rehabilitation after rotator cuff surgery and showed that six months after surgery only, 50% of them had fully recovered scapulohumeral coordination. The SW-CMS system has never been applied to patients subjected to TSA or RTSA. In this study, we tested two hypotheses: (H_1) that scapular kinematics is considerably altered in TSA and RTSA patients, resulting in significantly lower SW-CMS than CMS scores; and (H_2) that physiological scapular movement [24] is restored six months after the procedure in both groups of prostheses.

Materials and methods

Subjects and inclusion criteria

This was a prospective laboratory study of 25 consecutive patients who underwent kinematic analysis before and after shoulder replacement. The study was performed at our institution from April 2014 to October 2015. Twelve subjects received a TSA (Aequalis Ascend™ Flex, "TSA group") and 13 an RTSA (Aequalis™ Reversed II; "RTSA group") (Wright Medical, Memphis, TN, USA). All provided their written informed consent to participate in the study, which was approved by the institutional review board (Prot. No. 5494/20121.5/197 CEAV/IRST Meldola, Italy). The inclusion criteria were a preoperative diagnosis of primary shoulder osteoarthritis (TSA group) and CTA (RTSA group). There were no specific exclusion criteria.

The kinematic data of 31 asymptomatic subjects (mean age, 70 years [SD, 7]; male/female ratio: 11/20; body mass index, 25.9 [SD, 4.1]) assessed for pain in the contralateral shoulder were used as control.

Of the 59 patients who were invited, 29 declined to participate because they lived more than 300 km from the hospital, while six refused their consent, leaving 25 patients (25 shoulders) with complete kinematic data. Established radiographic

criteria were used to assess glenoid morphology in TSA patients [25] and to grade CTA severity and type of glenoid erosion in RTSA patients [26, 27]. Glenoid morphology in the TSA group was graded as A1 in two patients (17%), A2 in six (50%), and B1 in four patients (33%). In the RTSA group, CTA was graded as Hamada stage 3 in two patients (15%), stage 4A in eight (62%), and stage 4B in three patients (23%), whereas glenoid erosion was rated as type E1 in eight patients (62%), E2 in four (31%), and E3 in one patient (8%).

The demographic and perioperative data of the study population are reported in Table 1.

Surgical procedures

The surgical procedures were performed through a deltopectoral approach. The subscapularis was detached by lesser tuberosity osteotomy and reattached with bone sutures.

Standard surgical procedures were used for TSA [28] and RTSA [29].

In the TSA group, the glenoid was replaced with a partially cemented convex all-polyethylene component (CortiLoc™). A curved cementless short stem, available in three different angles of inclination (127.5°, 132.5°, and 137.5°) and with an eccentric humeral head in 30° of retroversion, was used for humeral replacement.

The reverse implant was based on the Grammont design with a medialized center of rotation. The straight cementless humeral stem had a 155° neck-shaft angle with a polyethylene insert (thickness, + 6 and + 9 mm). The baseplate was fixed with four screws, and a centered glenosphere 36 mm in diameter was used in all cases.

No intraoperative complications were recorded. After surgery, the arm was immobilized in a sling for three weeks. Active mobilization was allowed after four weeks, and active exercises were begun after six weeks. Standard radiographs of the implants (Grashey anterior-posterior and axillary views) were taken at six and 12 months, to exclude any prosthetic complications that might affect the kinematic assessment.

Table 1 Demographic data of the study population

Variable	TSA group	RTSA group
Shoulders (no.)	12	13
Mean age (years) (range)	62 (55–69)	76 (68–84)
Gender (M/F) (%)	10/2 (83/17)	3/10 (23/77)
BMI (kg/m^2)	28.3	28.4
Time points (months) (range, days)		
T0	–	–
T1	6 (173–197)	6 (175–187)
T2	12 (339–455)	12 (351–367)

TSA total shoulder arthroplasty, *RTSA* reverse total shoulder arthroplasty, *M* male, *F* female, *BMI* body mass index

Instrumentation and data processing

Upper limb kinematics was recorded using a Vicon stereophotogrammetric system that included eight BONITA infrared cameras and two BONITA video cameras (Vicon, Oxford, UK) with a sampling rate of 100 Hz. Semi-rigid marker clusters applied to the skin over the upper part of the sternum, flat posterior part of the acromion, dorsolateral side of the mid-humerus, and dorsal side of the forearm [30] were used to track trunk, scapula, humerus, and forearm movements (Fig. 1). Joint angles were calculated following ISB guidelines [31] using the U.L.E.M.A. software package [30]. Anatomical landmarks were calibrated using an instrumented pointer: the ulnar and radial styloids for the forearm; the lateral and medial epicondyles for the humerus; the angulus acromialis, inferior angle, and trigonum spinae for the scapula; and C7, T8, the incisura jugularis, and the processus xiphoideus for the trunk. The glenohumeral joint centre was estimated with the functional method described by Gamage et al. [32].

Shoulder measurements were recorded at three time points: before the procedure (T0, baseline), six months (T1), and 12 months (T2) after shoulder replacement (Table 1). On each occasion, patients were asked to perform humeral elevation in the sagittal plane and the scapular plane while standing. For each task, movements began from the reference position (arms relaxed along the sides); patients were then asked to elevate the humerus to the highest level they could reach without pain and to return to the reference position. Each movement was repeated five consecutive times, and the data of the second, third, and fourth times were used for the calculations. The tasks selected as the main movements of the humerus with respect to the trunk were flexion (FLEX) for the sagittal plane and abduction (ABD) for the scapular plane [33]. The movement of the scapula with respect to the trunk was extracted. It included Protraction-Retraction (PR-RE), Medio-Lateral rotation (ME-LA), and Posterior-Anterior tilting (P-A).

Scapulohumeral coordination (SHC) was analyzed by means of coordination plots (angle-angle plots). A total number of six coordination patterns were obtained (Fig. 2): PR-RE vs FLEX; ME-LA vs FLEX; P-A vs FLEX; PR-RE vs ABD; ME-LA vs ABD; and P-A vs ABD.

Reference data

Reference data were obtained from the 31 control shoulders. Reference bands were created for the SHC plots for FLEX and ABD according to the bootstrap method as described by Cutti et al. [21].

Kinematics

The CMS was administered to all subjects at each time point according to 2008 SECEC modifications and guideline [13]. Scapular kinematics was assessed by comparing each coordination pattern to the relevant reference bands. The results of this comparison were used to analyze SHC: if the coordination pattern was within the control reference bands, the scapular movement was classified as "physiological;" otherwise, it was classified as "abnormal." These data were used to calculate the SW-CMS "scapula weighting factor" [23]. CMS and SW-CMS are described in the Table 2.

Statistical analysis

The distribution of humeral elevation angles and of CMS and SW-CMS scores was assessed separately for the TSA and the RTSA group, and the data from each time point (T0, T1, and T2) were evaluated separately for each group. The Lilliefors normality test was used to confirm the normality of data distribution. A two-way repeated measures ANOVA ($p < .05$) was performed to assess the differences between the two independent variables, score (CMS, SW-CMS) and time point (T0, T1, T2), and their interaction (score × time point). Again,
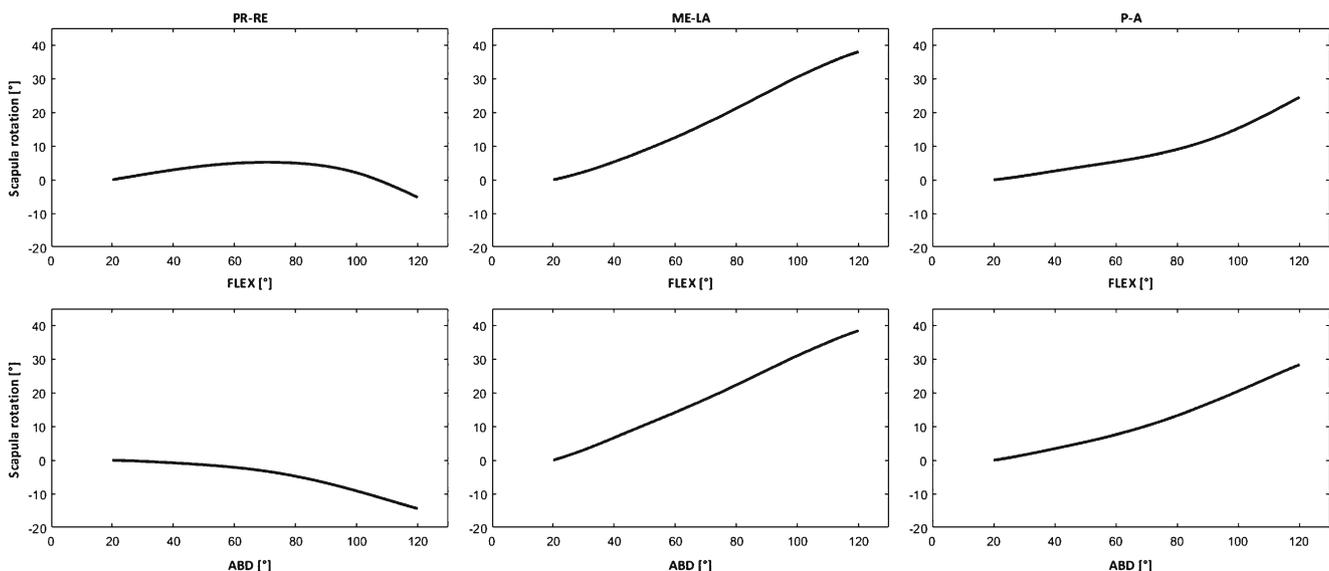
Fig. 1 Kinematic marker setup

Fig. 2 Scapulohumeral coordination patterns

this was done separately for the TSA and the RTSA group. Boxplots and paired two sample *t* tests were used to compare the data distribution of each score at each time point and the humeral elevation angles at each time point.

Table 2   Constant-Murley and SW-Constant-Murley scores and their calculation

CMS		SW-CMS		
Pain (0 ÷ 15)		Pain (0 ÷ 15)		
Activity level (0 ÷ 10)		Activity level (0 ÷ 10)		
Arm positioning (0 ÷ 10)		Arm positioning (0 ÷ 10)		
Strength Of Abduction (0 ÷ 25)		Strength of abduction (0 ÷ 25)		
Range of motion (0 ÷ 40) = FLEX + ABD + EXT-ROT + INT-ROT		Range of motion (0 ÷ 40) = FLEX + ABD + EXT-ROT + INT-ROT		
FLEX (forward flexion) (0 ÷ 10)		FLEX (forward flexion) (0 ÷ 10) = F × W_{FE}		
0–30	0 pnt	F (0 ÷ 10) = 0–30	0 pnt	W_{FE} (0 ÷ 1) = W_{FE_PRRE} + W_{FE_MELA} +
30–60	2 pnt	30–60	2 pnt	W_{FE_PA} + W_{FE_BONUS}
60–90	4 pnt	60–90	4 pnt	SHC within bands:
90–120	6 pnt	90–120	6 pnt	A) PR-RE vs FLEX ➜ W_{FE_PRRE} = 0.3
120–150	8 pnt	120–150	8 pnt	B) ME-LA vs FLEX ➜ W_{FE_MELA} = 0.3
150–180	10 pnt	150–180	10 pnt	C) P-A vs FLEX ➜ W_{FE_PA} = 0.3
				If A, B, C are true then W_{FE_BONUS} = 0.1
ABD (lateral elevation) (0 ÷ 10)		ABD (lateral elevation) (0 ÷ 10) = A × W_{AA}		
0–30	0 pnt	A (0 ÷ 10) = 0–30	0 pnt	W_{AA} (0 ÷ 1) = W_{AA_PRRE} + W_{AA_MELA} +
30–60	2 pnt	30–60	2 pnt	W_{AA_PA} + W_{AA_BONUS}
60–90	4 pnt	60–90	4 pnt	SHC within bands:
90–120	6 pnt	90–120	6 pnt	A) PR-RE vs ABD ➜ W_{AA_PRRE} = 0.3
120–150	8 pnt	120–150	8 pnt	B) ME-LA vs ABD ➜ W_{AA_MELA} = 0.3
150–180	10 pnt	150–180	10 pnt	C) P-A vs ABD ➜ W_{AA_PA} = 0.3
				If A, B, C are true then W_{AA_BONUS} = 0.1
EXT-ROT (external rotation) (0 ÷ 10)		EXT-ROT (external rotation) (0 ÷ 10)		
INT-ROT (internal rotation) (0 ÷ 10)		INT-ROT (internal rotation) (0 ÷ 10)		

CMS, Constant-Murley Score; *SW-CMS*, scapula-weighted Constant-Murley Score; *SHC*, scapulohumeral coordination; *FLEX*, flexion; *ABD*, abduction; *EXT-ROT*, humerus external rotation; *INT-ROT*, humerus internal rotation; *PR-RE*, scapula Protraction-Retraction; *ME-LA*, scapula Medio-Lateral Rotation; *P-A*, scapula Posterior-Anterior tilting

Results

Preoperative glenoid morphology in TSA group and the grade of CTA and glenoid erosion in RTSA group did not affect CMS and SW-CMS scores.

The humeral elevation angles and the distribution of CMS and SW-CMS scores were normal in both patient groups. The score distribution at each time point is reported in Fig. 3. The score and time point results of the two groups are summarized in Table 3. The FLEX and ABD kinematic data at each time point are reported in Table 4.

In TSA patients (Fig. 4), analysis of the kinematic data showed that both FLEX and ABD increased significantly from T0 to T2; in particular, FLEX increased by 21% from T0 to T1 and by 11% from T1 to T2, whereas ABD increased by 18% from T0 to T1 and by 20% from T1 to T2. In these patients, the compensatory scapular movements in FLEX were all reduced from T0 to T2, whereas in ABD, they were all reduced except P-A (from 29 at T0 to 36 at T2). ME-LA was the scapular movement showing the greatest compensation both in FLEX (29%) and ABD (57%). At T2, scapular motion without compensation (all scapular angles within the relevant reference bands) was recorded in six TSA patients during FLEX and in one patient during ABD. However, none of the TSA patients showed complete recovery of physiological scapular movements during FLEX and ABD.

In RTSA patients (Fig. 5), kinematic data analysis demonstrated significant improvement (> 50%) in humeral elevation from T0 to T1 and a small, non-significant improvement from T1 to T2. The compensatory scapular movements in FLEX showed a general reduction at T1 and an even greater reduction in ME-LA at T2, whereas they increased in P-A. In ABD, the compensation movements increased at T1, except in ME-LA. At T2, ME-LA and PR-RE decreased further, whereas P-A did not decrease. Indeed, P-A was by far the scapular
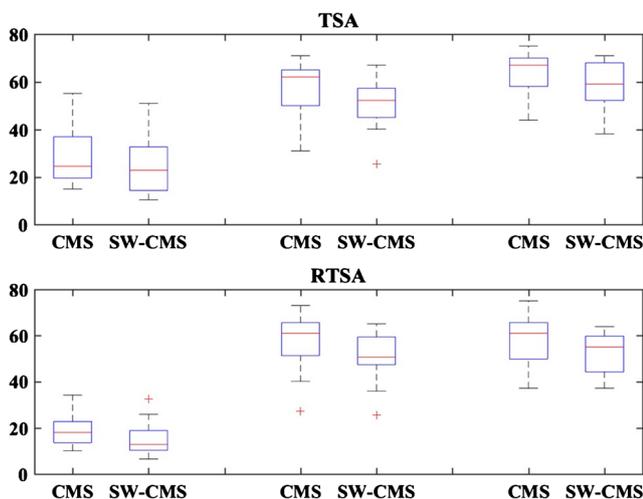
Table 3 Significance of scores and time points in TSA and RTSA group patients

		TSA	RTSA
Repeated measures two-way ANOVA			
Scores (CMS, SW-CMS)		$p < 0.0001$	$p = 0.0004$
Time points (T0, T1, T2)		$p < 0.0001$	$p < 0.0001$
Scores × time points		$p = 0.0374$	$p = 0.0576*$
Paired *t* test			
CMS vs SW-CMS	T0	$p = 0.0023$	$p < 0.0001$
	T1	$p < 0.0001$	$p = 0.0014$
	T2	$p = 0.0001$	$p = 0.0019$
CMS	T0 vs T1	$p < 0.0001$	$p = 0.0002$
	T1 vs T2	$p = 0.0211$	$p = 0.3109*$
SW-CMS	T0 vs T1	$p < 0.0001$	$p = 0.0001$
	T1 vs T2	$p = 0.0073$	$p = 0.3279*$

TSA total shoulder arthroplasty, *RTSA* reverse total shoulder arthroplasty, *CMS* Constant-Murley Score, *SW-CMS* scapula-weighted Constant-Murley Score

T0: baseline; T1: 6 months; T2: 12 months

Significance was set at $p < 0.05$; *not significant

rotation showing the greatest compensation both in FLEX (50% of patients) and in ABD (71%). Compensation generally began between 70 and 80° of humeral elevation. Complete recovery of physiological FLEX and ABD (all scapula angles within the reference bands) was seen in six and two RTSA patients, respectively; two patients recovered both FLEX and ABD completely.

Table 4 Values of the humeral angle in flexion and abduction at the three time points

	Time points	TSA	RTSA
Mean ± SD			
FLEX	T0	84 ± 24	68 ± 15
	T1	102 ± 22	103 ± 23
	T2	113 ± 25	107 ± 18
ABD	T0	84 ± 31	60 ± 23
	T1	100 ± 31	94 ± 32
	T2	119 ± 29	107 ± 28
Paired *t* test			
FLEX	T0 vs T1	$p = 0.0690$	$p = 0.0001$
	T1 vs T2	$p = 0.2605$	$p = 0.5819$
	T0 vs T2	$p = 0.0081$	$p < 0.0001$
ABD	T0 vs T1	$p = 0.2366$	$p = 0.0053$
	T1 vs T2	$p = 0.1288$	$p = 0.2879$
	T0 vs T2	$p = 0.0098$	$p = 0.0001$

SD standard deviation, *TSA* total shoulder arthroplasty, *RTSA* reverse total shoulder arthroplasty, *FLEX* flexion, *ABD* abduction

T0: baseline; T1: 6 months; T2: 12 months

Significance was set at $p < 0.05$; *not significant

Fig. 3 CMS and SW-CMS score distribution at each time point
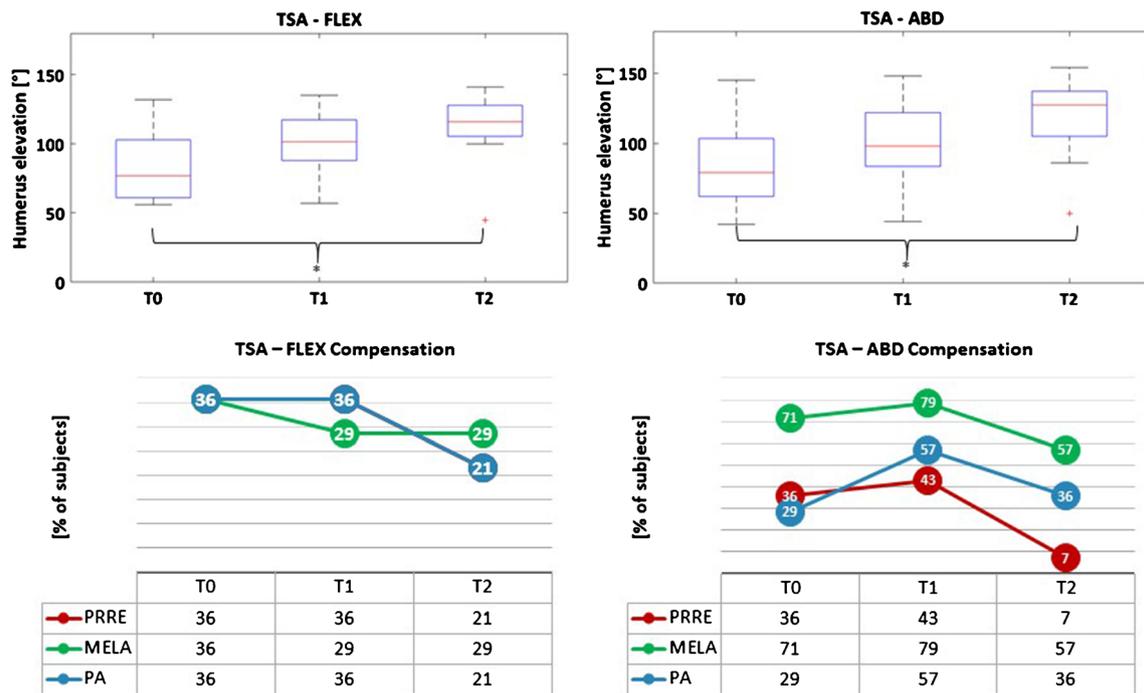
Fig. 4 Humeral elevation angles and percentage of TSA patients showing scapula compensation movements in flexion (FLEX) and abduction (ABD). TSA total shoulder arthroplasty, PRRE Protraction-Retraction, ME-LA Medio-Lateral rotation, PA Posterior-Anterior tilting

Discussion

Kinematic analysis is a valuable technical support to assess the contribution of the glenohumeral and scapulothoracic joint to arm elevation after shoulder replacement and provides useful information to understand whether and how TSA and RTSA implants succeed in replicating active shoulder motion.

The novelty of the present study lies in the utilization of an integrated outcome scoring method, the SW-CMS system, which takes into account the effects of scapular dyskinesis on the clinical outcomes of shoulder arthroplasty. The study shows that CMS and SW-CMS were both sensitive to changes from baseline to six and 12-month follow-up. The preoperative and post-operative SW-CMS values were both significantly lower than the CMS scores. This demonstrated H_1 of the study and is in line with the findings reported by Cutti et al. in patients subjected to arthroscopic rotator cuff repair [23]. Interestingly, the difference between CMS and SW-CMS scores found at each follow-up in our RTSA group was greater than the eight points of minimal clinically important difference (MCID) reported by Torrens et al. in similar patients [34], whereas there are no published data on MCID in TSA patients. Moreover, the CMS scores of our two groups showed a difference greater than the 18 points of "individual relative CMS" without standardization described by Blonna et al. [35]. The TSA patients experienced significant improvements in CMS and SW-CMS scores at both time points, whereas the RTSA patients showed improvement in both scores at T1 but did not improve further at T2. The increased scapular

compensatory movements seen in both groups at T2 go against H_2 of the study.

The differences in shoulder mobility and scapular compensation found between TSA and RTSA patients deserve some considerations. The TSA prostheses were implanted in patients with primary osteoarthritis and an intact rotator cuff, where restoration of joint congruity and perception of motion are expected to improve shoulder function [36]. This may explain the gain in mobility and the reduction in scapular compensation found in TSA patients at 12 months. However, the kinematic studies demonstrated that even though TSA improves mobility in specific tasks, it does not restore full abduction at six months, due to impaired proprioception or pathological motion patterns [16]. Moreover, Maier et al. have reported that proprioception measured by an active angle-reproduction test had remained unchanged or deteriorated three years after shoulder arthroplasty, and that the deterioration was more marked in the hemiarthroplasty than in the TSA group [37]. The effects of TSA on shoulder proprioception are debated. The increase in shoulder mobility in our TSA patients was similar to the one reported by Maier et al. [37], and it is reasonably assumed that worsening of proprioception affected post-operative shoulder mobility and scapular compensation.

The increased scapular compensation movements in P-A— found in our RTSA patients at T2 in FLEX and at T1 and T2 in ABD—reflect the distinctive biomechanics of this implant, which provides appropriate deltoid tension and scapular muscle strength to enable arm elevation. Deltoid and periscapular
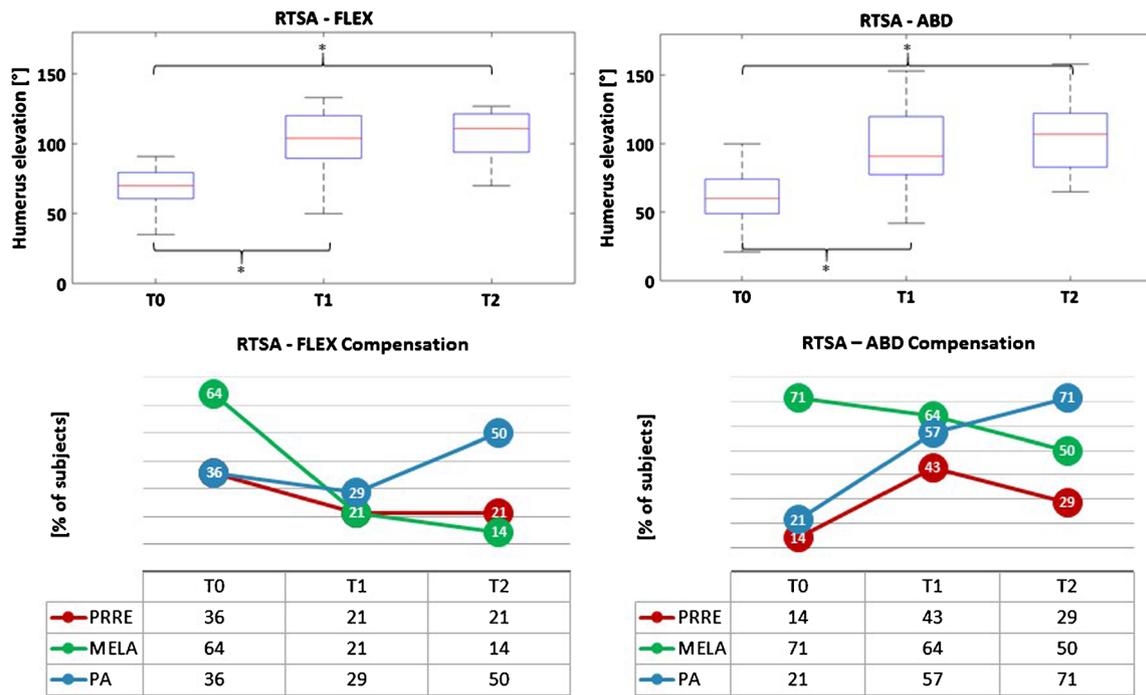
Fig. 5 Humeral elevation angles and percentage of RTSA patients showing scapula compensation movements in flexion (FLEX) and abduction (ABD). RTSA reverse total shoulder arthroplasty, PRRE Protraction-Retraction, ME-LA Medio-Lateral rotation, PA Posterior-Anterior tilting

muscle weakness may explain the poorer flexion and greater scapular compensation experienced by RTSA compared with TSA patients and, especially, the increased posterior tilt seen in RTSA patients at 6 months. A recent clinical study has described a reduction in shoulder mobility six months after reverse arthroplasty, which the authors ascribed to chronic deltoid de-conditioning and lack of rotator cuff function [38]. Wolff and Rosenzweig recommend strengthening the anterior deltoid and periscapular muscles to improve shoulder flexion and support the increased demand for scapular movement [39].

Data on the effects of scapular muscle weakness after RTSA are still limited.

In their study of the kinematic difference between TSA and RTSA patients, Alta et al. found that the anatomical design of the TSA implant contributes to wider active thoracohumeral motion and that the TSA group exhibited greater passive than active range of motion (ROM) compared with the TSA group [15]. Other papers have reported that RTSA patients had not regained the full active ROM in early- and mid-term follow-up evaluations [40, 18]. These findings are in line with the lower flexion and abduction values found in our RTSA patients compared with TSA group at T2. Other researchers have described an increased contribution of scapulothoracic rotation (i.e., ME-LA) to overall shoulder motion compared with asymptomatic shoulders [37, 17, 41]. These findings are also in line with the increased ME-LA compensation found in our study, where we have also recorded increased scapular tilting

compensation (i.e., P-A) that was not found by Lee and co-workers [41].

The use of reference data from a control group and the homogeneity of the two patient subset in terms of surgical indication and type of procedure are the main strengths of the study. Its chief limitations include (i) the small size of the study population; (ii) the lack of a normal contralateral shoulder for comparisons; and (iii) the age and gender difference between the patients of the two groups.

Notably, the age difference reflects the authors' preference for implanting RTSA prostheses in elderly subjects with severe shoulder impairment. The TSA prostheses were implanted in patients with primary osteoarthritis and an intact rotator cuff.

Altogether, the SW-CMS provides fresh insight on the contribution of the scapulothoracic joint to TSA and RTSA function and may be used as a reference for the gradual progression of deltoid and scapular muscle rehabilitation.

Conclusion

The SW-CMS system is a reliable, integrated tool to assess the effects of scapular dyskinesis on shoulder arthroplasty. The SW-CMS scores were significantly lower than the CMS scores in both TSA and RTSA patients at all time points, thereby demonstrating that scapular kinematics is considerably altered in both patient groups of the study.

Physiological scapulothoracic motion was not restored in either group, a finding that failed to demonstrate H2 of our study. The lower CMS and SW-CMS scores measured in RTSA patients after 6 months compared with the TSA group may be due to the biomechanics of the reverse prosthesis and the weakness of deltoid and periscapular muscles. The kinematic findings of this study can be used to develop a shoulder rehabilitation protocol directed at reducing scapular compensation movements.

Compliance with ethical standards

IRB approval was obtained from the institutional review board of the Coordinator Center in Cattolica, Italy (Prot. No. 5494/2012 I.5/197 CEAV/IRST Meldola, Italy).

References

1. Roberson TA, Bentley JC, Griscom JT, Kissenberth MJ, Tolan SJ, Hawkins RJ et al (2017) Outcomes of total shoulder arthroplasty in patients younger than 65 year : a systematic review. J Shoulder Elbow Surg 26:1298–1306. https://doi.org/10.1016/j.jse.2016.12.069

2. Sowa B, Bochenek M, Bülhoff M, Zeifang F, Loew M, Bruckner T et al (2017) The medium- and long-term outcome of total shoulder arthroplasty for primary glenohumeral osteoarthritis in middle-aged patients. Bone Joint J 99-B:939–943. https://doi.org/10.1302/0301-620X.99B7.BJJ-2016-1365.R1

3. Merolla G, Cerciello S, Marenco S, Fabbri E, Paladini P, Porcellini G (2018) Comparison of shoulder replacement to treat osteoarthritis secondary to instability surgery and primary osteoarthritis: a retrospective controlled study of patient outcomes. Int Orthop 2018. doi: https://doi.org/10.1007/s00264-018-3969-9

4. Crosby LA, Wright TW, Yu S, Zuckerman JD (2017) Conversion to reverse total shoulder arthroplasty with and without humeral stem retention: the role of a convertible-platform stem. J Bone Joint Surg Am 99:736–742. https://doi.org/10.2106/JBJS.16.00683

5. Wagner E, Houdek MT, Griffith T, Elhassan BT, Sanchez-Sotelo J, Sperling JW et al (2015) Glenoid bone-grafting in revision to a reverse total shoulder arthroplasty. J Bone Joint Surg Am 97:1653–1660. https://doi.org/10.2106/JBJS.N.00732

6. Petrillo S, Longo UG, Papalia R, Denaro V (2017) Reverse shoulder arthroplasty for massive irreparable rotator cuff tears and cuff tear arthropathy: a systematic review. Musculoskelet Surg 101:105–112. https://doi.org/10.1007/s12306-017-0474-z

7. Sevivas N, Ferreira N, Andrade R, Moreira P, Portugal R, Alves D et al (2017) Reverse shoulder arthroplasty for irreparable massive rotator cuff tear: a systematic review with meta-analysis and meta-regression. J Shoulder Elbow Surg 26:e265–e277. https://doi.org/10.1016/j.jse.2017.03.039

8. Zilber S, Camana E, Lapner P, Haritinian E, Nove Josserand L (2018, 2018) Reverse total shoulder arthroplasty using helical blade to optimize glenoid fixation and bone preservation: preliminary results in thirty five patients with minimum two year follow-up. Int Orthop. https://doi.org/10.1007/s00264-018-3891-1

9. Dauzère F, Arboucalot M, Lebon J, Elia F, Bonnevialle N, Mansat P (2017) Evaluation of thirty eight cemented pegged glenoid components with variable backside curvature: two-year minimum follow-up. Int Orthop 41:2353–2360. https://doi.org/10.1007/s00264-017-3635-7

10. Lo IKY, Litchfield RB, Griffin S, Faber K, Patterson SDKA (2005) Quality-of-life outcome following hemiarthroplasty or total shoulder arthroplasty in patients with osteoarthritis. a prospective randomized trial. J Bone Joint Surg Am 87-A:2178–2185

11. Sciascia AD, Morris BJ, Jacobs CAET (2017) Responsiveness and internal validity of common patient-reported outcome measures following total shoulder arthroplasty. Orthopedics 40:513–519. https://doi.org/10.3928/01477447-20170327-02

12. Angst F, Schwyzer HS, Aeschlimann A, Simmen BRGJ (2011) Measures of adult shoulder function Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH) and Its Short Version (QuickDASH), Shoulder Pain and Disability Index (SPADI), American Shoulder and Elbow Surgeons (ASES) Society Standardized Shoulder A. Arthritis Care Res 63:S174–S188. https://doi.org/10.1002/acr.20630

13. Constant GC, Emery RJH, SØjbjerg JO, Gohlke F, Boileau P (2008) A review of the Constant score: modifications and guidelines for its use. J Shoulder Elbow Surg 17:355–361. https://doi.org/10.1016/j.jse.2007.06.022

14. Roy J-S, MacDermid JC, Woodhouse LJ (2010) A systematic review of the psychometric properties of the Constant-Murley score. J Shoulder Elbow Surg 19:157–164. https://doi.org/10.1016/j.jse.2009.04.008

15. Alta TD, de Toledo JM, Veeger HE, Janssen TW, Willems WJ (2014) The active and passive kinematic difference between primary reverse and total shoulder prostheses. J Shoulder Elbow Surg 23:1395–1402. https://doi.org/10.1016/j.jse.2014.01.040

16. Kasten P, Maier M, Wendy P, Rettig O, Raiss P, Wolf S et al (2010) Can shoulder arthroplasty restore the range of motion in activities of daily living? A prospective 3D video motion analysis study. J Shoulder Elbow Surg 19:59–65. https://doi.org/10.1016/j.jse.2009.10.012

17. Kwon YW, Pinto VJ, Yoon J, Frankle MA, Dunning PE, Sheikhzadeh A (2016) Kinematic analysis of dynamic shoulder motion in patients with reverse total shoulder arthroplasty. J Shoulder Elbow Surg 21:1184–1190. https://doi.org/10.1016/j.jse.2011.07.031

18. Maier MW, Caspers M, Zeifang F, Dreher T, Klotz MC, Wolf SI et al (2014) How does reverse shoulder replacement change the range of motion in activities of daily living in patients with cuff tear arthropathy? A prospective optical 3D motion analysis study. Arch Orthop Trauma Surg 134:1065–1071. https://doi.org/10.1007/s00402-014-2015-7

19. Maier MW, Niklasch M, Dreher T, Zeifang F, Rettig O, Klotz MC et al (2014) Motion patterns in activities of daily living: 3-year longitudinal follow-up after total shoulder arthroplasty using an optical 3D motion analysis system. BMC Musculoskeletal Disorders 15:244. https://doi.org/10.1186/1471-2474-15-244

20. Postacchini R, Paoloni M, Carbone S, Fini M, Santilli V, Postacchini F et al (2015) Kinematic analysis of reaching movements of the upper limb after total or reverse shoulder arthroplasty. J Biomech 48:3192–3198. https://doi.org/10.1016/j.jbiomech.2015.07.002

21. Veeger HE, Magermans DJ, Nagels J, Chadwick EK, van der Helm FC (2006) A kinematical analysis of the shoulder after arthroplasty during a hair combing task. Clin Biomech 21:S39–S44. https://doi.org/10.1016/j.clinbiomech.2005.09.012

22. Toledo D, Loss JF, Janssen TW, van der Scheer JW, Alta TD, Willmes WJ et al (2012) Kinematic evaluation of patients with total and reverse shoulder arthroplasty during rehabilitation exercises with different loads. Clin Biomech 21:S39–S44

23. Cutti AG, Parel I, Pellegrini A, Paladini P, Sacchetti R, Porcellini G et al (2016) The Constant score and the assessment of scapula dyskinesis: Proposal and assessment of an integrated outcome measure. J Electromyogr Kinesiol 29:81–89. https://doi.org/10.1016/j.jelekin.2015.06.011

24. Cutti AG, Parel I, Raggi M, Petracci E, Pellegrini A, Accardo AP et al (2014) Prediction bands and intervals for the scapulo-humeral coordination based on the Bootstrap and two Gaussian methods. J Biomech 47:1035–1044. https://doi.org/10.1016/j.jbiomech.2013.12.028

25. Michael J, Bercik KK, Yalizis MMG, Chaoui J, Gilles W (2016) A modification to the Walch classification of the glenoid in primary glenohumeral osteoarthritis using three-dimensional imaging. J Shoulder Elbow Surg 25:1601–1606. https://doi.org/10.1016/j.jse.2016.03.010

26. Favard L, Lautmann S, Sirveaux F, Oudet D, Kerjean Y (2001) Hemiarthroplasty versus reverse arthroplasty in the treatment of osteoarthritis with massive rotator cuff tear. In: Walch G, Boileau P, Mole´ D, eds. 2000 Shoulder Prostheses. Two to yen years follow-up. Paris: Sauramps Medical, :261–268

27. Hamada K, Yamanaka K, Uchiyama Y, Mikasa T, Mikasa M (2011) A radiographic classification of massive rotator cuff tear arthritis. Clin Orthop Relat Res 469:2452–2460. https://doi.org/10.1007/s11999-011-1896-9

28. Merolla G, Ciaramella G, Fabbri E, Walch G, Paladini P, Porcellini G (2016) Total shoulder replacement using a bone ingrowth central peg polyethylene glenoid component: a prospective clinical and computed tomography study with short- to mid-term follow-up. Int Orthop 40:2355–2363. https://doi.org/10.1007/s00264-016-3255-7

29. Wall B, Nové-Josserand L, O'Connor DP, Edwards TB, Walch G (2007) Reverse total shoulder arthroplasty: a review of results according to etiology. J Bone Joint Surg Am 89:1476–1485. https://doi.org/10.2106/JBJS.F.00666

30. Jaspers E, Monari D, Molenaers G, Feys H, Desloovvere K (2014) U.L.E.M.A. - upper limb evaluation in movement analysis: open source custom made MATLAB based software. Gait Posture 39:S76–S77

31. Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C et al (2005) 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 38:981–992

32. Gamage SS, Lasenby J (2002) New least squares solutions for estimating the average centre of rotation and the axis of rotation. J Biomech 35:87–93

33. Kontaxis A, Cutti AG, Johnson GR, Veeger HE (2009) A framework for the definition of standardized protocols for measuring upper-extremity kinematics. Clin Biomech 24:246–253. https://doi.org/10.1016/j.clinbiomech.2008.12.009

34. Torrens C, Guirro P, Santana F (2016) The minimal clinically important difference for function and strength in patients undergoing reverse shoulder arthroplasty. J Shoulder Elbow Surg 25:262–268. https://doi.org/10.1016/j.jse.2015.07.020

35. Blonna D, Scelsi M, Marini E, Bellato E, Tellini A, Rossi R et al (2012) Can we improve the reliability of the Constant-Murley score? J Shoulder Elbow Surg 21:4–12. https://doi.org/10.1016/j.jse.2011.07.014

36. Cuomo F, Birdzell MG, Zuckerman JD (2005) The effect of degenerative arthritis and prosthetic arthroplasty on shoulder proprioception. J Shoulder Elbow Surg 14:345–348. https://doi.org/10.1016/j.jse.2004.07.009

37. Maier MW, Niklasch M, Dreher T, Wolf SI, Zeifabg F, Loew M (2012) Proprioception 3 years after shoulder arthroplasty in 3D motion analysis: a prospective study. Arch Orthop Trauma Surg 132:1003–1010. https://doi.org/10.1007/s00402-012-1495-6

38. Collin P, Matsukawa T, Denard PJ, Gain S, Läderman A (2017) Preoperative factors influence the recovery of range of motion following reverse shoulder arthroplasty. Int Orthop 41:2135–2142. https://doi.org/10.1007/s00264-017-3573-4

39. Wolff AL, Rosenzweig L (2017) Anatomical and biomechanical framework for shoulder arthroplasty rehabilitation. J Hand Ther 30:167–174. https://doi.org/10.1016/j.jht.2017.05.009

40. Bergmann JH, de Leeuw M, Janssen TW, Weeger DH, Willems WJ (2008) Contribution of the reverse endoprosthesis to glenohumeral kinematics. Clin Orthop Relat Res 466:594–598. https://doi.org/10.1007/s11999-007-0091-5

41. Lee KW, Kim YI, Kim HY, Yang DS, Lee GS, Choy WS (2016) Three-dimensional scapular kinematics in patients with reverse total shoulder arthroplasty during arm motion. Clin Orthop Surg 8:316–324. https://doi.org/10.4055/cios.2016.8.3.316