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Preoperative deltoid assessment by contrast-enhanced ultrasound (CEUS) as predictor for shoulder function after reverse shoulder arthroplasty: a prospective pilot study

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Abstract

Introduction Although the deltoid represents the main motor muscle after reverse shoulder arthroplasty (RSA), its standardized preoperative assessment regarding morphology and function is still not established. Its clinical relevance and interactions with major biomechanical parameters like the medialization of the center of rotation (COR) regarding shoulder function after RSA are yet unknown. We evaluated contrast-enhanced ultrasound (CEUS) of the deltoid as possible surrogate marker for individual deltoid properties of patients receiving an RSA, and its predictive value for postoperative shoulder function.

Materials and methods 35 patients were prospectively assessed. Before and 6 months after RSA, dynamic deltoid perfusion, caliber and a combination of both (PE*caliber, named DeltoidEfficacy) was quantified by CEUS. Changes of deltoid properties and the predictive value of preoperative CEUS-based deltoid properties for shoulder function after RSA were assessed. To analyze interrelating effects with deltoid properties, COR-medialization and deltoid lengthening were quantified.

Results Deltoid caliber and perfusion significantly increased after RSA ($p=0.0004/p=0.002$). Preoperative deltoid caliber, perfusion and the combined value DeltoidEfficacy significantly correlated with shoulder function after RSA within the whole study cohort (caliber: $r=0.445$, $p=0.009$; perfusion: $r=0.593$, $p=0.001$; DeltoidEfficacy: $r=0.66$; $p=0.0002$). The predictive value of DeltoidEfficacy for shoulder function after RSA varied among patient subgroups: Multivariate regression analysis revealed the strongest prediction in patients with either very high or very low deltoid properties (Beta = 0.872, $r=0.84$, $p=0.0004$), independent from COR-medialization or deltoid lengthening. Contrary, in patients with intermediate deltoid properties, COR-medialization revealed the strongest predictive value for shoulder function after RSA (Beta = 0.660, $r=0.597$; $p=0.024$).

Conclusion Deltoid CEUS seems to allow an assessment of individual deltoid properties and deltoid adaptations after RSA. Deltoid CEUS seems to predict shoulder function after RSA and might support an identification of patients requiring special attention regarding COR positioning.

Keywords CEUS · RSA · Predictor · Deltoid assessment · Center of rotation · Reverse shoulder arthroplasty

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Introduction

Reverse shoulder arthroplasty (RSA) represents a major milestone in shoulder surgery, offering a reliable and standard surgical procedure for patients with cuff arthropathy, osteoarthritis or humeral head fractures [1, 2]. The original Grammont's prosthetic design is based on a medialization and caudalization of the glenohumeral center of rotation (COR) [3], improving the lever arm of the deltoid as main motor muscle for active forward elevation (FE) and abduction after RSA. With the ongoing development of prosthetic designs to further improve functional outcome and counteract drawbacks of Grammont's design, a large

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body of literature has greatly increased our understanding of biomechanical alterations caused by varying COR, humeral inclination or shaft lateralization, respectively, osseous impingement caused by the prosthetic design [4–8].

In contrary, although the deltoid's role as major motor muscle after RSA is adamant, very little is known about the influence of individual deltoid properties on functional outcome after RSA while preoperative deltoid assessment is yet not established. Very few studies focused on the preoperative assessment of deltoid properties, demonstrating encouraging results including functional outcome prediction after RSA by MRI-based morphologic parameters like cross-sectional area, fatty infiltration or deltoid volume [9, 10]. Although such morphological parameters seem to only partially reflect functional and biological properties of the deltoid, these studies indicate the potential of an individual deltoid assessment before RSA.

Functional biomarkers might reflect individual deltoid properties more accurately. Contrast-enhanced ultrasound (CEUS) allows dynamic quantification of perfusion in muscle tissue. Being closely linked to the responsiveness and recruitment of muscle fibers and the muscle metabolism, CEUS is suggested as a functional real-time biomarker for muscle vitality and function beyond morphologic aspects [11–15]. This quality might be of particular relevance in pathologies strongly relying on indicator muscle properties. Accordingly, dynamic muscle perfusion quantification by CEUS has already been reported as potential surrogate marker for functional muscle properties in patients with rotator cuff tears, proximal humerus factures and RSA [16–18]. In a retrospective study including 55 patients after RSA, perfusion of the deltoid muscle quantified by CEUS significantly correlated with postoperative shoulder function [17] and might be applicable to detect adaptation processes of the deltoid after RSA without major imaging artefacts as seen in MRI.

Within this prospective cohort study, we aimed to assess CEUS-based individual perioperative deltoid properties before and after RSA with special attention on the predictive value of preoperative deltoid CEUS for early shoulder function after RSA. Furthermore, we aimed to investigate interrelating effects of individual preoperative deltoid properties by CEUS with COR-medialization and deltoid lengthening in matters of shoulder function after RSA to potentially identify treatment-relevant patient subgroups.

Methods

Study cohort

55 patients with written consent and confirmed eligibility were prospectively enrolled in the study. 35 patients could be entered in statistical analysis. This prospective longitudinal cohort study was conducted in accordance with the declaration of Helsinki in its most recent form, registered at the German Clinical Trials Register (DRKS00010934), approved by the local ethics committee (S626/2014) and conducted in accordance with the guidelines for strengthening the reporting of observational studies in epidemiology (STROBE) [19]. Informed consent was obtained from all individual participants included in the study. Patients exclusion criteria and examined subgroups are shown in detail referring to a consolidated standard of reporting trials (CONSORT) and standards for reporting of diagnostic accuracy (STARD) flow diagram (Fig. 1) [20, 21]. Indications for RSA were cuff tear arthropathy in 32, and trauma sequelae in three patients. Surgery was performed by three orthopedic and trauma surgeons at our institution, applying a standard deltopectoral approach. Postoperative rehabilitation followed the department`s standards, including a shoulder abduction sling for 6 weeks, immediate passive mobilization up to 90° forward elevation and abduction as well as continuous physiotherapy for 6 months.

Study protocol

Patients were examined pre-operatively and 6 months after RSA, receiving functional and ultrasonographic assessments as well as calibrated ap radiographs of the affected shoulder. CEUS examination included dynamic perfusion quantification by peak enhancement in arbitrary units (PE in a.u.) and deltoid caliber measurements in mm. Patients with susceptible regions of interest (ROI, see below) due to many reflecting arteries and fasciae as well as statistical outliers were excluded. Active FE and abduction were assessed as primary outcome measure for deltoid function. Common shoulder scores (normalized Constant Score (CS), the American Shoulder and Elbow Surgeons (ASES) Standardized Shoulder Assessment, disability of the Arm, Shoulder and Hand (DASH-score), and the SF-12 questionnaire on mental and physical health) were assessed for validation of the study cohort.

Quantification of individual deltoid properties by CEUS: perfusion and caliber

Ultrasound examinations followed a previously published and highly standardized CEUS protocol using a Siemens Acuson 3000 ultrasound scanner (Siemens Healthineers, Erlangen, Germany) with a linear probe (9L4) at 4 MHz [16, 17]. A simulated setup for the deltoid CEUS assessment is illustrated in Fig. 2. Four anatomical landmarks served as mandatory references: The humeral shaft, the humeral surgical neck, the posterior humeral circumflex artery and the teres minor muscle belly. Field depth was defined to 4.0 cm.

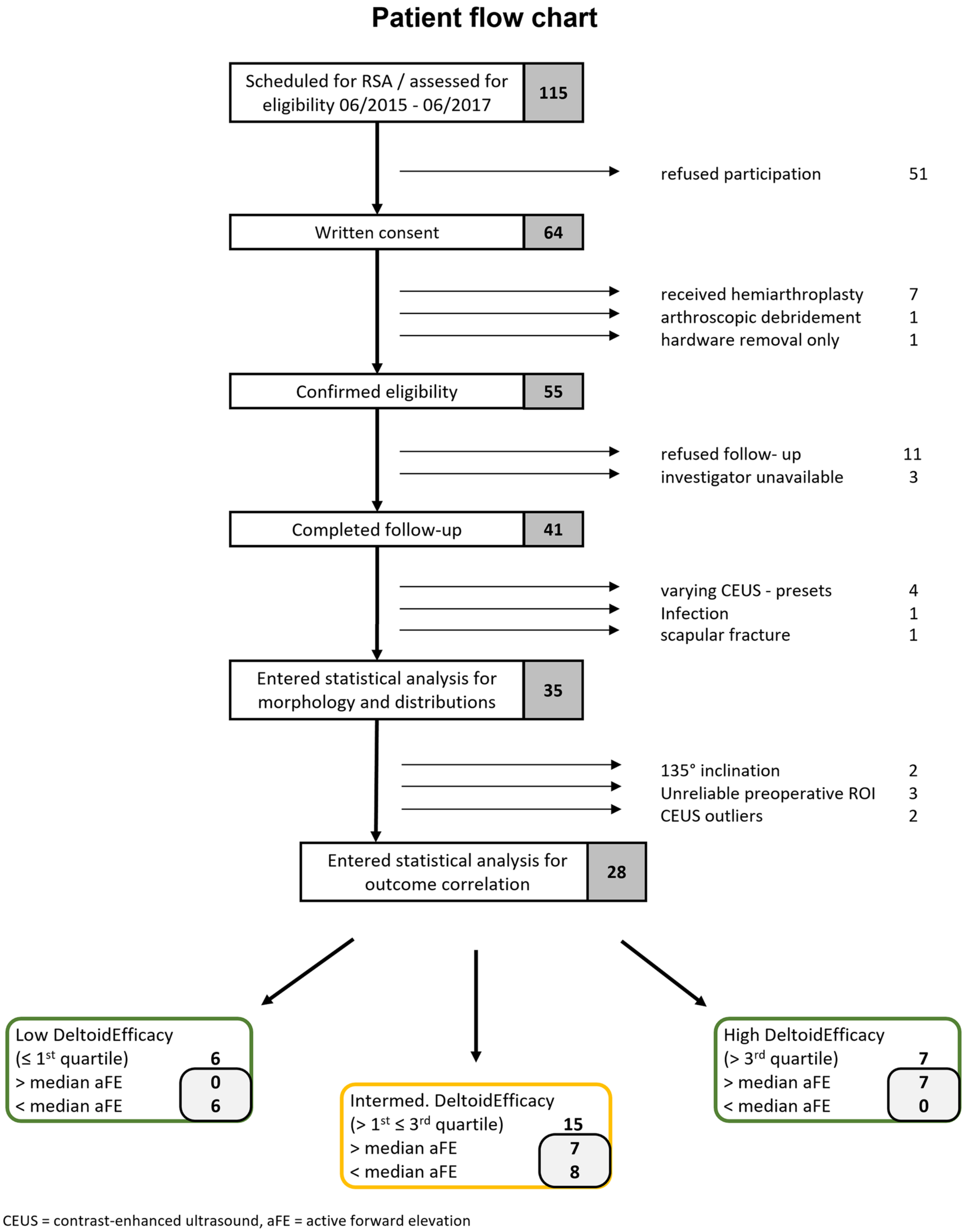


Fig. 1 Patient flow chart

The deltoid caliber was quantified by three measurements in conventional B-Mode from the proximal, middle and distal aspect of the cross section of the underlying teres minor in a perpendicular angle to the deltoid's external fascia and the mean value was generated. Deltoid perfusion quantification was conducted in the Siemens-specific Cadence™ contrast pulse sequencing mode for CEUS. Focal depth was set to 3 cm to avoid acoustic wave-induced disturbance of the SonoVue® (Bracco Imaging, Milan, Italy) microbubbles [22]. Patients activated their deltoid muscle with a standard exercise (60 s of straight lateral arm raise) to saturate muscle perfusion, followed by the application of a 2.4 ml SonoVue®

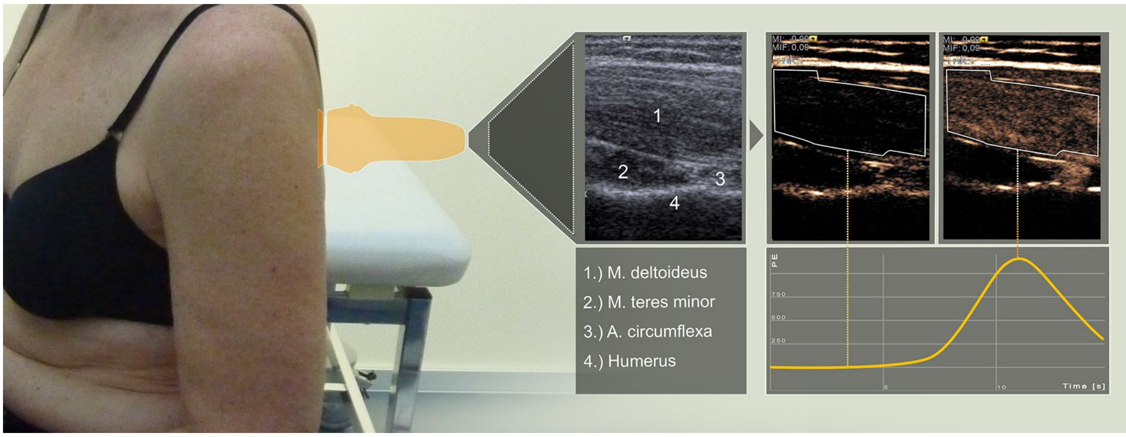


Fig. 2 CEUS examination setup with probe positioning at the dorsolateral part of the deltoid muscle. Left top rectangle: B-Mode of the sectional plane with anatomical landmarks, as indicated in the left bottom rectangle. Middle top rectangle shows the Siemens-specific Cadence™ contrast pulse sequencing mode before, the right top rectangle after application and inflow of the contrast agent. The bottom right rectangle indicates the dynamic time–intensity-curve of the contrast agent, representing the peak enhancement

bolus in an antecubital peripheral vein, flushed with 10 ml 0.9% saline solution. A 90 s videoclip was then recorded in line with the most recent recommendations of the EFSUMB [23]. Videoclips were postprocessed with the designated VueBox® 5.3 software (Bracco Imaging, Milan, Italy). The entire visible deltoid muscle was marked as the ROI, excluding large arteries or fasciae. Time–intensity curves were generated and several dynamic perfusion parameters were quantified, e.g., Peak Enhancement (PE) and the Wash-in Perfusion Index (WiPI) in arbitrary units (a.u.), having been applied for the assessment of the deltoid muscle perfusion in previous studies [16, 17]. Statistical analysis is shown for PE, reflecting a muscle-volume-independent parameter for peak enhancement of the blood flow in the deltoid muscle. To combine muscle-volume-independent perfusion and deltoid muscle size, we introduced a combined value including deltoid perfusion and deltoid caliber (PE in a.u. * caliber in mm), further named "DeltoidEfficacy" as potentially improved surrogate marker for functional deltoid properties.

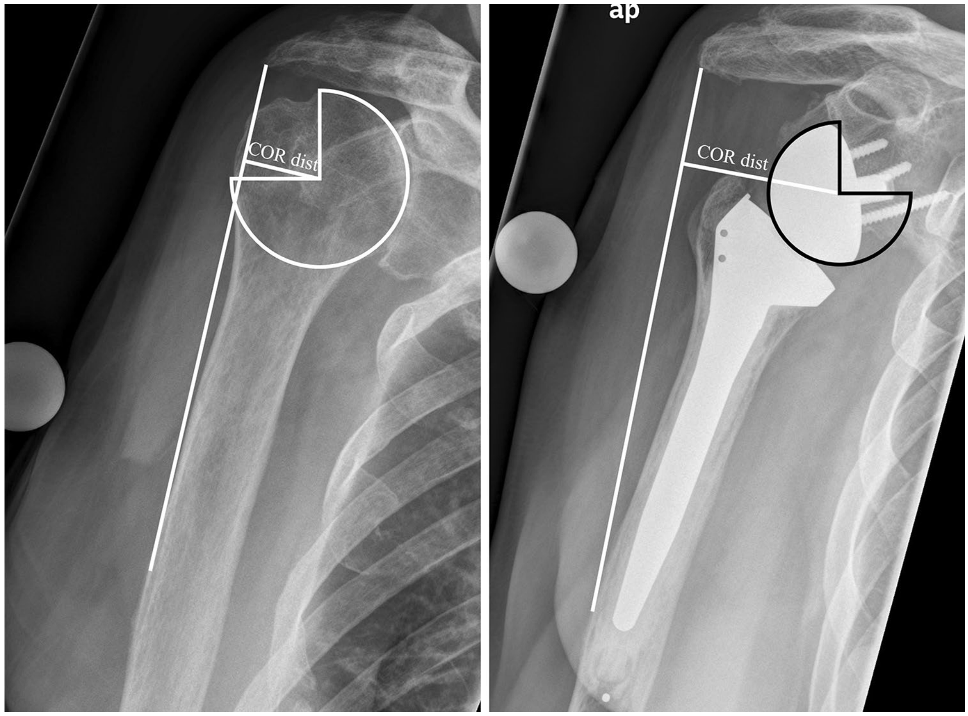
Radiologic assessment of COR-medialization and deltoid lengthening

COR-medialization directly influences the deltoid lever arm and therefore necessary deltoid properties after RSA. To investigate outcome relevant interfering effects with preoperative deltoid properties detected by CEUS, COR-medialization and deltoid lengthening were assessed on calibrated ap radiographs using TraumaCad software (Brainlab, Munich, Germany). COR-medialization was assessed by placing a best-fit circle around the humeral head in preoperative radiographs and the glenosphere postoperatively, tracing the deltoid muscle from the inferior-lateral tip of the acromion to the middle of the deltoid tuberosity, as previously described [24]. Changes of pre- and postoperative distances from the circle center perpendicular to the deltoid muscle represent the COR-medialization (Fig. 3). The deltoid length was defined as the distance between the inferolateral tip of the acromion to the midpoint of the deltoid tuberosity (Fig. 3). Absolute and relative changes were calculated.

Statistical analysis

Statistical analyses were conducted in cooperation with the local Institute of Medical Biometry and Biostatistics, using SPSS software version 25.0 (IBM Corp., Armonk, New York, USA). Differences of pre-/postoperative perfusion and caliber measurements were calculated by paired Student's *t* tests. Predictive value of continuous preoperative deltoid parameters with postoperative outcome was assessed by Pearson's or Spearman's correlation and uni-/multivariate linear regression analysis. To evaluate whether patients with low preoperative deltoid CEUS properties can be clearly discriminated from patients with high deltoid preoperative properties, patients were assigned into four subgroups, based on the natural distribution of the preoperative DeltoidEfficacy, with the quartiles serving as cutoff values (1st quartile: 1761; 2nd quartile: 3775; 3rd quartile: 8217) (Fig. 4). For subgroup analysis, Spearman's correlation was applied for continuous values, Mann–Whitney *U*-, Kruskal–Wallis- and Chi^2 tests for categorical values. Outliers were defined as mean value ± 2 Stdev. Reported *p* values are two-sided.

Fig. 3 Radiographic measurement of the center of rotation distance and the deltoid length before (**a**) and after (**b**) reverse shoulder arthroplasty. *COR dist* center of rotation distance



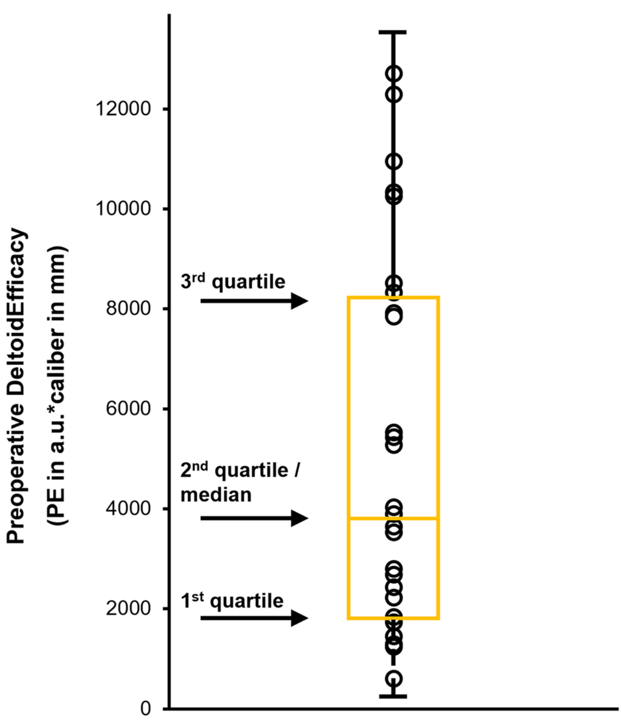


Fig. 4 Distribution of preoperative DeltoidEfficacy. Overlaid yellow box indicates first and third quartile and interquartile range. Median is indicated by yellow line. Whisker represents the 1.5-fold interquartile distance above the upper quartile and below the lower quartile

Results

Patient characteristics and functional outcome

Out of 55 enrolled patients, 14 patients could not be follow-up, two patients were excluded due to postoperative complications (one infection, one scapular fracture) and four patients due to irregular presets during the CEUS investigations. 35 patients entered statistical evaluation for distributions. For outcome-related statistics two patients with varying humerosocket inclination (135°), three patients with an unreliable ROI and two statistical outliers (± 2 Stdev.) were excluded according to the study protocol. The mean age of the cohort was 74.4 ± 6.3 years (range 60.6–87.4), 22 patients were female, 13 male. Follow-up was at a mean of 189 days after surgery (range 175–199). Pre- and postoperative ROM and functional outcome scores showed representative values compared to previously published study cohorts after RSA [2, 25–27] (Table 1). Mean COR-medialization was 23.5 mm (range 4–37.2 mm), mean deltoid lengthening was 22.7 mm (range 4.1–46.7 mm), and mean deltoid lengthening ratio was 1.15 (1.03–1.35), being in line with previous reports [28–33].

Changes of deltoid properties after RSA

Dynamic deltoid muscle perfusion significantly increased from a mean preoperative PE of 308.5 a.u. to a mean PE of 508.8 a.u. ($p = 0.0023$) 6 month after RSA (Fig. 5a). Likewise, the deltoid caliber increased from a mean of 15.7 mm

Table 1 Functional and radiographic changes after RSA within the study cohort

	Preoperative median (IQR)	Postoperative median (IQR)	*p*
Constant	17 (12; 23)	62 (41; 77)	< 0.00001
ASES	25 (17; 38)	75 (43; 80)	< 0.00001
DASH	70 (53; 83)	34 (13; 52)	< 0.00001
aFE (°)	70 (30; 90)	128 (93; 148)	< 0.00001
Abduction (°)	60 (40; 70)	110 (90; 140)	< 0.00001
SF-12 Phys	30 (27; 35)	39 (34; 48)	0.002
SF-12 Ment	44 (38; 51)	54 (48; 60)	< 0.00001
COR (mm)	19 (7; 28)	42 (31; 52)	< 0.00001
Deltoid length	151 (143; 159)	176 (161; 188)	< 0.00001

p level of significance, *aFE* active forward elevation, *COR* center of rotation, *IQR* interquartile range

to a mean of 17.9 mm 6 months after RSA ($p = 0.0004$) (Fig. 5b). Deltoid perfusion was independent from deltoid lengthening, smoking habits, diabetes, age, gender or body mass index (BMI).

Preoperative deltoid CEUS significantly correlates with deltoid function after RSA

We assessed whether preoperative deltoid CEUS is predictive for deltoid function after RSA, reflected by active FE and abduction. The preoperative deltoid caliber significantly correlated with postoperative active FE and abduction (FE: $r = 0.445$, $p = 0.009$; abduction: $r = 0.373$, $p = 0.033$) (Table 2). Preoperative dynamic perfusion (PE) of the deltoid muscle revealed a significant and stronger correlation with deltoid function after RSA in our study cohort (aFE: $r = 0.593$, $p = 0.001$; abduction: $r = 0.367$, $p = 0.012$) (Table 2). The combined value DeltoidEfficacy revealed the strongest correlation with postoperative active FE and abduction within the whole study cohort (active FE: $r = 0.661$, $p = 0.0001$; abduction: $r = 0.530$, $p = 0.004$) (Table 2 and Fig. 6a, b. For improved synopsis, further statistical analyses are shown for active FE only. With a correlation coefficient of $r = 0.90$ between active FE and abduction, all described effects were comparable for abduction, yet slightly weaker.

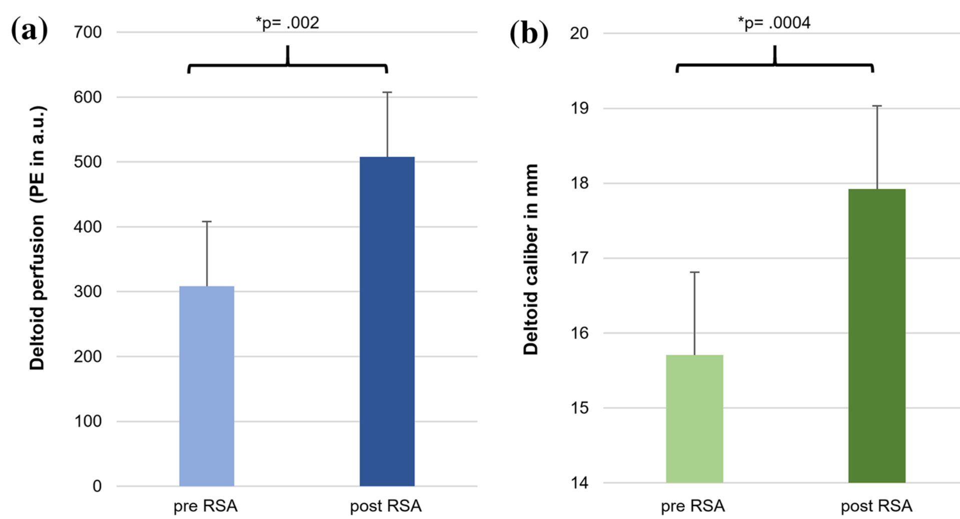


Fig. 5 **a** Pre- and postoperative deltoid perfusion (PE in a.u.) and **b** Pre- and postoperative deltoid caliber (in mm) of affected shoulders. Bars indicate mean values; error bars indicate standard deviation. Black brackets indicate statistically compared groups, *p* indicates significance

Table 2 Correlation of preoperative deltoid properties with active FE and abduction after RSA

	Caliber in mm		Perfusion (PE in a.u.)		DeltoidEfficacy (PE * Caliber)	
	r	*p*	*r*	*p*	*r*	*p*
Correlation with						
aFE	0.445	.009*	0.593	.001*	0.661	.0001*
Abduction	0.373	.033*	0.467	.012*	0.530	.004*

r correlation coefficient, *p* level of significance, *aFE* active forward elevation, *PE* peak enhancement, *a.u.* arbitrary units

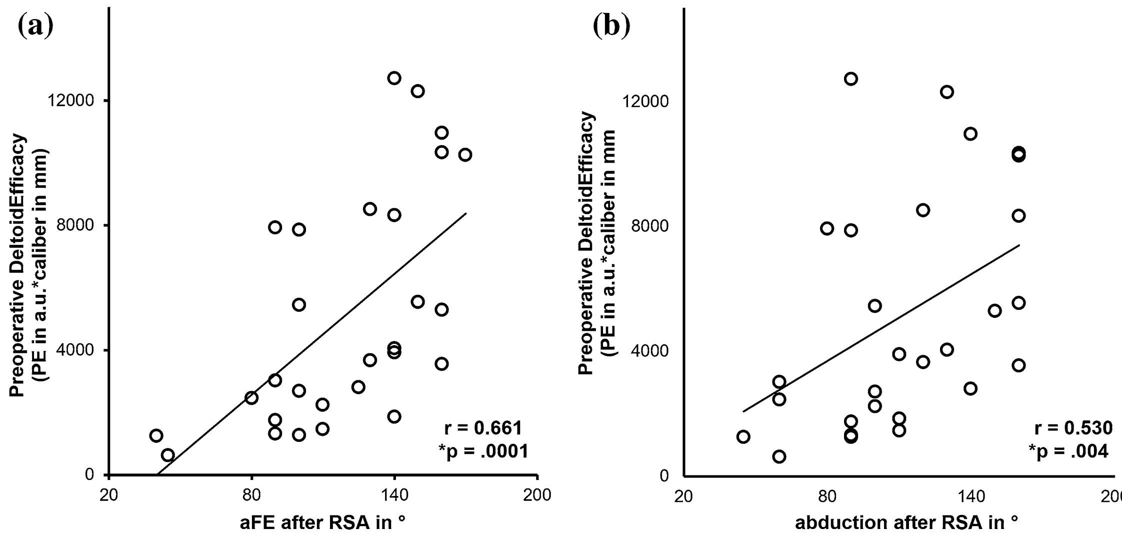


Fig. 6 Dot Plot for preoperative DeltoidEfficacy and **a** active forward elevation as well as **b** abduction after RSA. *r* correlation coefficient, *p* level of significance, *aFE* active forward elevation

Preoperative deltoid CEUS seems to discriminate between patients achieving good or poor deltoid function after RSA

Clinical translation of novel outcome predictors largely depends on their discriminatory power. Accordingly, we evaluated, whether preoperative deltoid CEUS can clearly discriminate patients according to their deltoid function after RSA. We therefore assigned all patients into four subgroups, with the quartiles of DeltoidEfficacy serving as cutoff values (Fig. 4). The four subgroups significantly differed regarding postoperative deltoid function, showing a titratable effect (<1st quartile: 79°, 1st <> 2ndquartile: 117°, 2nd <> 3rd quartile: 126°, > 3rd quartile: 150°, $p=0.005$, Kruskal–Wallis) and the strongest variations between patients with very low, respectively, very high deltoid properties ($p=0.001$, Mann–Whitney *U*) (Fig. 7a).

In the next step we assessed the percentage of patients achieving an above or below median postoperative active FE within each subgroup. Interestingly, all patients with very high preoperative deltoid CEUS properties (DeltoidEfficacy above 3rd quartile) achieved an active FE above the median, whereas all patients with very low preoperative deltoid CEUS properties (DeltoidEfficacy below 1st quartile) presented an active FE below the median (Chi^2 $p=0.003$) (Fig. 7b). In contrast, patients with intermediate deltoid CEUS properties (DeltoidEfficacy between 1st and 3rd quartile) could not be clearly discriminated according to an above/below median active FE after RSA (Fig. 7b).

Since these observations imply a varying predictive strength of preoperative deltoid CEUS for postoperative active FE among the patient subgroups, we re-evaluated its predictive value only within the patient subgroups with high discriminatory power (very high and very low deltoid properties). Correlation of preoperative deltoid CEUS (DeltoidEfficacy) with postoperative active FE after RSA increased to strong $r=0.84$ ($p=0.003$), and linear regression analysis confirmed an increased and very strong predictability within these patient subgroups (Table 3). In contrast, reassessing only patient subgroups with intermediate deltoid CEUS properties revealed no significant correlation with postoperative deltoid function anymore (Table 3).

Interacting effects of preoperative deltoid properties and COR-medialization on deltoid function after RSA

Medialization of the COR directly affects the deltoid`s lever arm and therefore necessary deltoid properties to achieve a certain deltoid function [5]. In line with this, we could detect a moderate, yet significant correlation of the amount of COR-medialization with postoperative active abduction and FE ($r=0.410$, $p=0.034$; $r=0.507$, $p=0.007$) within the whole study cohort (Table 3). Since COR-medialization coeffects with individual deltoid properties regarding active FE after RSA, we performed multivariate regression analysis to identify their effector strengths for deltoid function after RSA. Within the whole study cohort, preoperative deltoid CEUS (DeltoidEfficacy) was the major effector for deltoid function after RSA (Table 3).

When we reassessed multivariate effects within patient subgroups with very high or very low deltoid CEUS properties, deltoid CEUS was an even more dominant effector for active FE after RSA, widely independent from the

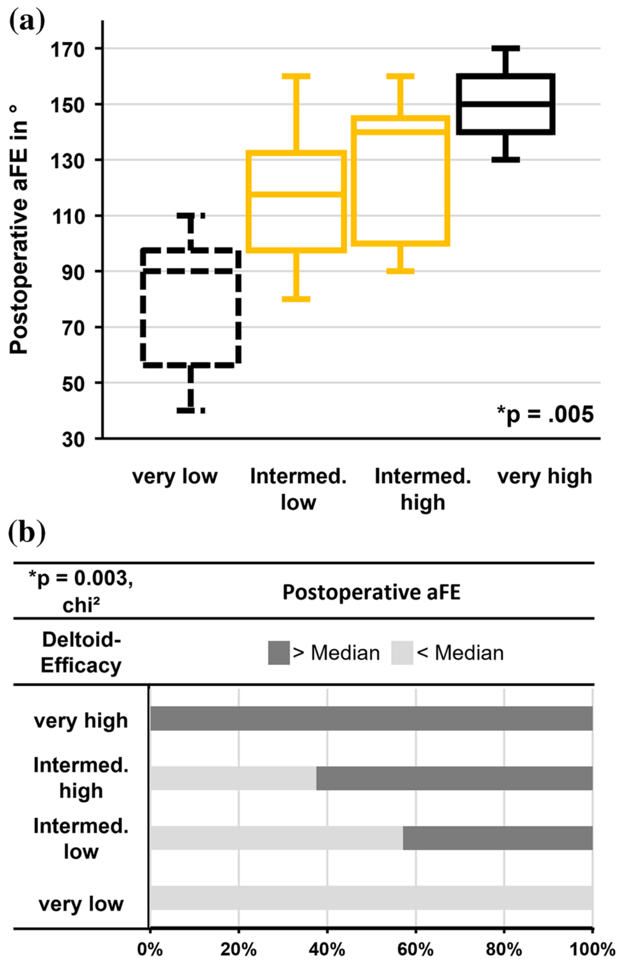


Fig. 7 **a** Significantly varying mean active FE after RSA in patient subgroups with varying preoperative DeltoidEfficacy. **b** Percentage of patients achieving above/below median active FE within each subgroup. *P* level of significance, *aFE* active forward elevation

COR-medialization (Table 3). In these subgroups, no significant correlation could be detected between COR-medialization and deltoid function (Table 3).

Contrary, in patient subgroups with intermediate deltoid CEUS properties, COR-medialization revealed its strongest correlation with deltoid function ($r=0.597$, $p=0.024$). In these patients, multivariate regression analysis identified COR-medialization, but not preoperative deltoid CEUS as the major effector for postoperative active FE (Table 3). Demonstrated correlations for deltoid CEUS and COR-medialization were independent of the possible confounders deltoid lengthening, age, body mass index or gender.

Table 3 Correlation and regression analysis of DeltoidEfficacy and COR with active FE

Correlation with active FE	Whole study cohort			Very high/very low DeltoidEfficacy			Intermediate DeltoidEfficacy		
	r		*p*	*r*		*p*	*r*		*p*
DeltoidEfficacy	0.661		0.0001*	0.836		0.0004*	0.070		0.784
COR	0.507		0.007*	0.419		0.154	0.597		0.024*
Linear regression, dependent variable: active FE									
	B	Beta	*p*	*B*	Beta	*p*	*B*	Beta	*p*
Univariate									
DeltoidEfficacy	0.006	0.597	0.001*	0.007	0.865	0.0001*	−0.001	−0.090	0.749
Multivariate									
DeltoidEfficacy	0.005	0.560	0.004*	0.008	0.872	0.001*	−0.004	−0.316	0.248
COR	0.839	0.165	0.354	−0.063	−0.13	0.397	4.086	0.660	0.027*

r correlation coefficient, *p* level of significance, *aFE* active forward elevation, *COR* medialization of the center of rotation, *B* regression coefficient

Discussion

In this prospective study we assessed CEUS-based individual perioperative deltoid properties and detected a strong prediction for shoulder function after RSA as well as outcome-relevant interactions with the amount of COR-medialization in certain patient subgroups.

One major design rationale of RSA relies on a medialization of the COR, increasing the deltoid lever arm and enabling improved deltoid function for active FE and abduction in most patients. Despite numerous studies investigating biomechanical effects of varying prosthetic designs, COR-medialization and deltoid lengthening [5, 32–34], very little is known about the influence of individual patients' deltoid properties on functional outcome, respectively, adaptation processes of the deltoid after RSA. An assessment of patients' individual deltoid properties has not been established yet and remains highly demanding. Whereas it is not only unclear which parameter best reflects functional muscle properties, preoperative assessment of, e.g., abduction strength is associated with a relevant bias caused by pain, and painless detection of morphologic parameters like muscle volume or fatty infiltration by MRI seem to only in part reflect complex functional muscle properties. Dynamic parameters like muscle perfusion, respectively, combined values, might better reflect muscle properties and have already been described as surrogate markers for muscle function and vitality in previous studies [16–18, 35]. We therefore applied CEUS to assess the deltoid in patients receiving an RSA and could observe a significant increase of deltoid perfusion and caliber 6 months after RSA. These changes appear well compatible with an increased postoperative demand and might well reflect deltoids adaptation processes after RSA. CEUS therefore seems applicable to assess functional properties and monitor changes of the deltoid muscle, without the drawback of imaging artefacts applying, e.g. MRI.

Considering that patients' individual deltoid properties are most likely relevant for functional outcome after RSA, Yoon et al. and Wiater et al. demonstrated a significant correlation of preoperative deltoid muscle volume, respectively, cross-sectional area with functional outcome after RSA [9, 10]. In line with these reports, we observed a significant correlation of the deltoid caliber with shoulder function after RSA. Yet, deltoid perfusion by CEUS showed a stronger correlation, and the strongest correlation as well as predictive value could be detected for the combined value (DeltoidEfficacy). Since general outcome scores are relevantly confounded by attributes not directly related to the deltoid function, we suggested active FE and abduction as the most suitable and easy to assess outcome measure for postoperative deltoid function, representing the major function of the deltoid and being sparsely affected by other motor muscles after RSA. Accordingly, Yoon et al. [10] reported correlation of deltoid volume with active FE. Wiater et al. [9] reported a correlation of deltoid cross-sectional area with outcome scores, but also an unexpected lack of correlation with active FE in their study cohort, suggesting this to result from a superior effect of biomechanical advantages after RSA over individual deltoid properties. However, it could also be explained by confounding effects of COR-medialization or deltoid lengthening, which have not been evaluated in the study. Both have been reported to affect active FE after RSA in several studies, yet their clinical relevance is still a controversy being discussed [5, 24, 33, 36–38]. Whereas a significant correlation of deltoid lengthening with active FE after RSA was reported in 35 patients by Jobin et al. [24], another study reported a significant negative correlation [38]. Other studies, including larger study cohorts ($n=457$, resp. $n=183$) could not detect significant correlations [32, 33, 39]. In line with these studies, we could not detect a significant correlation of deltoid lengthening with active FE in our study cohort.

Jobin et al. reported no correlation of the COR distance with active FE, whereas Sabesan et al. reported a significant correlation of the COR with postoperative active FE in 144 patients [24, 38]. In our small study cohort, we observed a moderate correlation of the COR-medialization with active FE after RSA.

The inconsistency of the reported correlations remains surprising, especially for COR-medialization with its proven rationale. Yet, we should keep in mind, that active FE after RSA always relies on both—biomechanical parameters and individual deltoid properties. Considering that to our knowledge all published studies investigated either one of them, but not their interactions might represent one major and yet unsolved flaw of the currently available literature. This circumstance especially facilitates the risk that counterbalancing co-effects have been missed and clinically relevant patient subgroups within the study cohorts remained undetected. Accordingly, translation of a potential novel outcome predictor strongly relies on its discriminatory power: whereas a correlation of deltoid CEUS with shoulder function after RSA might be of diagnostic and academic value, its clinical impact remains limited, since it would most likely not change the treatment decision in a patient with continuously painful cuff arthropathy. Yet, its clinical value might lie within the identification of treatment relevant patient subgroups, benefiting from certain prosthetic designs or an individually adapted COR positioning [9]. Our subgroup analysis supports the plausible hypothesis, that patients with exceptionally high deltoid properties might deploy good deltoid function even with a less favorable deltoid lever arm, whereas patients with very low deltoid properties might not do so even with a favorable deltoid lever arm. In both, COR-medialization is expected to be of limited relevance for active FE after RSA. Contrarywise, patients whose deltoid function is less determined by their deltoid properties (intermediate deltoid properties) seem to be more dependent on a further medialized COR to achieve a good active FE/abduction after RSA.

Several limitations apply to this preliminary study. First, a substantial number of enrolled patients could not be included in the final analysis, caused by many elderly patients refusing the follow-up with application of the contrast agent, but also procedural barriers of this new method like varying CEUS presets and the cautious handling with potentially invalid ROIs or statistical outliers, resulting in a low statistical power and the potential for selection bias. These aspects can probably be improved in future validation studies. Second, we did not distinguish our patients according to heterogeneous cuff status, preoperative function or shaft lateralization. To reduce therefrom interfering effects, we focused on deltoid function as outcome measure, and only included patients with comparable prosthetic designs regarding shaft lateralization or humerosocket inclination. Yet we cannot rule out that other biomechanical aspects might interfere with the demonstrated results. Third, radiographic assessment of the COR-medialization is error-prone due to variations in ray paths and can only approximate the true deltoid lever arm. Due to the short follow-up period of 6 months, the presented data need to be validated in longer follow-up and independent validation studies. Despite these limitations, the presented data suggest an assessment of preoperative deltoid properties as promising aspect in the effort to further improve individual functional outcome after RSA.

Conclusion

Contrast-enhanced ultrasound seems applicable to assess individual deltoid properties before RSA and monitor adaptation changes of the deltoid after RSA. Individual deltoid assessment by CEUS seems to be predictive for shoulder function after RSA and might allow an identification of patient subgroups, that potentially benefit from special attention to the COR positioning when implanting a RSA. Preoperative deltoid assessment by CEUS might therefore contribute to the identification of a best patient-specific trade-off regarding active FE/abduction, rotation, scapular notching and osseous impingement after RSA.

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Compliance with ethical standards

Conflict of interest None of the authors, their immediate family, and any research foundation with which they are affiliated did receive any financial payments or other benefits from any commercial entity related to the subject of this article.

Ethical approval The prospective longitudinal cohort study was approved by the ethics committee of the University of Heidelberg (S626/2014) and registered at the German Clinical Trials Register (DRK S00010934).

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