

Characterisation of Variability and Investigation of Factors Influencing Maximum Coronal Abduction and Forward Elevation in Post-Operative rTSA Subjects

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1. Introduction

The variability in *in vivo* coronal abduction (CA) and forward elevation (FE) capacity in rTSA (reverse total shoulder arthroplasty) subjects, and possible sources of this variability, remain to be explored using gold-standard biplane fluoroscopy. Maximum humeral CA and FE are relevant because they indicate the ability of the patient to perform specific functions requiring interaction with the global space (i.e. reaching a shelf).

Our aims were to:

1. quantify maximum CA and FE in post-operative rTSA patients, including comparison with healthy controls
2. determine whether scapular global posture, age, sex, and humeral starting position correlate with maximum CA and FE in rTSA patients

2. Methods

2.1 Dataset

We analysed 18 rTSA subjects and 20 healthy subjects using an open-source biplanar fluoroscopy dataset (Henninger 2025). One rTSA subject was excluded from CA analysis and one healthy subject from FE analysis due to inability to perform the motion or a recording gap.

2.2 Measurements

Scapular upward rotation (SUR), internal rotation (SIR), and tilt (ST) were measured in a neutral rest

position (static trials) using a patient-global coordinate system (Moroder et al. 2022), with the superoinferior axis defined by the global gravity vector and the patient mediolateral and anteroposterior axes defined using thorax and sternum skin markers. Maximum CA was quantified by projecting the humeral shaft long axis (determined by a cylinder fit) into the patient-global-coronal plane. Maximum FE was defined by projecting the humeral long axis into the patient-global-sagittal plane. Postures and maximum CA/FE were projected into subject-global planes to maximize clinical interpretability.

We analysed maximum FE/CA instead of analysing final minus start position because subtracting the starting position may misrepresent the functional reaching capacity of subjects starting with a more abducted arm.

Differences between maximum CA and FE in healthy subjects and rTSA patients were compared using t-tests (for FE, which was normally distributed) and Wilcoxon rank sum tests (for CA, which was non-normally distributed) with Bonferroni correction. Distribution was assessed with QQ plots. The effects of age, sex, SUR, SIR, ST, and starting humeral elevation on rTSA maximum CA and FE were analysed using a linear model with separate models for FE and CA. Analyses were performed in RStudio (2026, R 4.5.2).

3. Results and discussion

The rTSA population tended to have reduced maximum CA and FE compared to healthy subjects (Fig. 1 a,b,

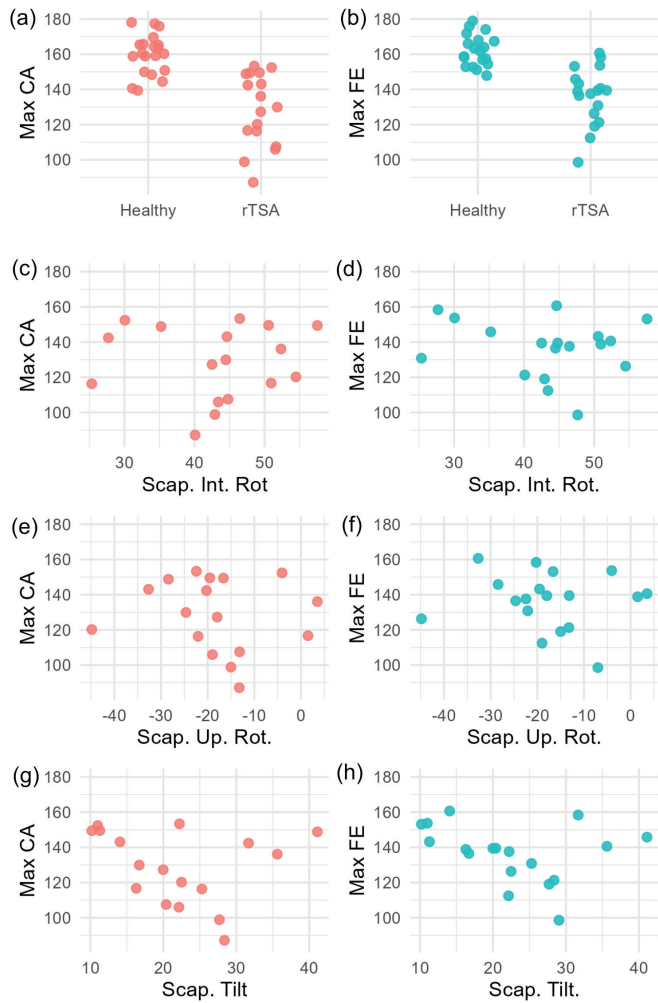


Figure 1. Comparison of max. CA (a) and FE (b) between healthy and rTSA. In rTSA subjects, no clear linear effects of scapular posture on max CA (c,e,g) and FE (d,f,h).

Credit: ECH and MvB.

Table 1, $p < 0.00001$). rTSA patients exhibited higher variability in CA and FE (higher standard deviation (SD), Table 1). Scapular global posture at rest, age, sex, or humeral starting position did not significantly impact maximum CA or FE in rTSA subjects (Fig. 1c-h). However, when excluding the 2-3 outliers at the extremes of ST, there is an apparent visible trend of decreasing CA and FE with ST. Studies with higher sample sizes are needed to investigate this further.

Other studies found that patient posture influences simulated range of motion (ROM) (Lappen et al. 2025), but that study isolated effects of scapular posture on collision-free glenohumeral range of motion, whereas various other factors may affect maximum CA and

FE *in vivo*. Additionally, the simulation study did not account for soft tissue limits or active range of motion capacity. Clinical studies have also shown that abduction and flexion clinical ROM differs between posture categories (Moroder et al. 2024), although the effect was small, and may not be detected in a smaller study such as ours. In addition to the small sample size, the healthy – rTSA comparison in our study is limited by lack of age matching, with the rTSA cohort being older and with a narrower age range, although age did not affect maximum humeral CA or FE in the rTSA cohort. We analysed posture in a relaxed starting position, but starting posture for specific trials may differ in anticipation on the movement and affect maximum CA/FE. Finally, we did not investigate humeral rotation, which may also influence CA and FE and should be incorporated into future analyses.

Table 1. Summary statistics and effect of parameters on max CA and FE. SD indicated by (), range indicated by [].

	Healthy	rTSA
Max CA	160 (11) [139–178]	129 (21) [87–153]
Starting Hum. Elev. CA	12 (6) [3–25]	16 (8) [5–33]
Max FE	162 (9) [148–179]	136 (16) [99–161]
Starting Hum. Elev. FE	6 (5) [1–18]	9 (8) [1–26]
SUR	-14 (11) [-36–6]	-18 (12) [-45–4]
SIR	47 (7) [28–60]	43 (9) [25–58]
ST	16 (10) [-5–38]	23 (9) [10–41]
Age	42 (17) [22–66]	70 (8) [58–85]
Sex	F 10; M 10	F 6; M 12

Credit: ECH and MvB.

4. Conclusions

rTSA subjects exhibit considerable variability in post-operative maximum CA/FE. Given that humeral CA and FE in global space are a combination of thorax global position, scapulothoracic orientation, and

glenohumeral orientation, further work is needed to elucidate factors influencing post-operative CA and FE capacity in rTSA.

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Conflict of Interest Statement

The authors declare no conflict of interest.

Contributor Roles

ECH: Conceptualization, Methodology, Investigation, Data Curation, Writing original draft, Validation, Formal analysis, Visualization, Project administration; MvB: Investigation, Validation, Formal analysis, Visualization Writing- review & editing; HBH: Resources, Writing- review & editing; SJF: Supervision: Writing- review & editing, PM: Supervision, Funding acquisition, Writing- review & editing.

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Data, software, code availability

Biplane dataset: <https://doi.org/10.5281/zenodo.10972004>

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