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Factors that predict postoperative motion in patients treated with reverse shoulder arthroplasty

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Background: Reverse shoulder arthroplasty (RSA) has proven to be a useful yet inconsistent tool to manage a variety of pathologic conditions. Factors believed to lead to poor postoperative range of motion (ROM) may be associated with preoperative diagnosis, poor preoperative ROM, and surgical factors such as inability to lengthen the arm. The purpose of this study was to analyze multiple factors that may be predictive of motion after RSA. Our hypothesis is that intraoperative ROM is most predictive of postoperative ROM.
Methods: Between February 2003 and April 2011, 540 patients (217 men and 323 women) treated with RSA were evaluated with measurements of preoperative, intraoperative, and postoperative ROM at a follow-up, where ROM was found to have plateaued at 1 year as determined by a pilot study. A regression analysis was performed to define independent predictive factors of postoperative active ROM.
Results: Intraoperative forward flexion was the strongest predictor of final postoperative ROM, followed by gender and preoperative ROM. Age and arm lengthening were not significant independent predictors. Controlling for gender and preoperative ROM, patients with an intraoperative elevation of 90° gained 29° in postoperative forward elevation ($P < .001$), 120° gained approximately 40° in postoperative forward elevation ($P < .001$), 150° gained approximately 56° in postoperative forward elevation ($P < .001$) and 180° gained approximately 62° in postoperative forward flexion ($P < .001$).
Conclusions: Intraoperative forward flexion is the strongest predictor of postoperative ROM. Surgeons may use intraoperative motion as a powerful decision-making tool regarding soft tissue tension in RSA.
Level of evidence: Level III, Retrospective Cohort Study, Treatment Study.

Keywords: Reverse shoulder arthroplasty; prognosis; preoperative motion; intraoperative motion; multivariable regression

Reverse shoulder arthroplasty (RSA) is a commonly used procedure for management of difficult shoulder problems such as massive and irreparable rotator cuff tears with and without glenohumeral arthritis, rotator cuff dysfunction secondary to proximal humeral fractures, and

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revision shoulder arthroplasty.[3,4,6-10,14,16,22,24,27,28] Overall, patients have improved restoration of function as a result. However, some inconsistency occurs in certain pathologies, such as patients with severe fatty infiltration of the teres minor,[21] previous arthroplasty,[26] management of certain fracture sequelae,[17] and even in patients with rotator cuff deficiency with or without glenohumeral arthritis. Poor outcomes still exist despite consistent technique applied by the surgeon.[2,6,7,15,18,27,28] These variable outcomes have been explained in various reports and are thought to be related to preoperative diagnosis,[6,27] patient gender,[19,25] preoperative motion,[5] and arm lengthening.[11,13]

A concept in total knee arthroplasty is that patients with poorer intraoperative motion are more likely to experience a reduction in postoperative motion. This implies that, despite the resolution of the mechanical failure and high friction of the articulation with arthroplasty, some influence of the soft tissues is responsible for the limits of patient function.[20] Similarly, the ability to achieve improvements in final motion in anatomic shoulder arthroplasty corresponds to the ability to correct soft tissue contracture, which can be evaluated intraoperatively.[1] In RSA, a great deal of controversy exists regarding the methods to ideally assess intraoperative soft tissue tension. The ideas that a joint should have a certain tightness—so-called decoaptation and coaptation[9]—or that the conjoint tendon should have a certain tension, are all subjective, with little to no objective support in the literature.

Furthermore, there are contrasting beliefs about what priorities should be accomplished during surgical reconstruction, with some authors striving for lengthening of the arm with the belief that deltoid tensioning may improve function.[11-13] Whether this can be justified is unclear, however, because the possible overtensioning may inherently lead to a reduction in intraoperative motion. Therefore, the goal of what tension or looseness of the novo joint should be accomplished at the time of surgery is unclear. To further understand which factors accurately predict outcome in RSA, we studied the importance of patient diagnosis, patient sex, preoperative range of motion (ROM), arm lengthening, and intraoperative ROM. We hypothesized that intraoperative ROM was the most predictive factor in outcome.

Methods

Inclusion criteria for the study were the presence of prospectively collected intraoperative forward flexion available in the patient's medical record between February 2003 and April 2011 and having undergone a RSA by the senior author (M.A.F.). A total of 802 patients met these criteria.

A pilot study was performed to determine the time point of postoperative rehabilitation where forward flexion plateaued after RSA. An analysis of patient-matched data of ROM from a random sampling of the 802 patients with 3, 6, 12, 24, and 36 months of follow-up data was performed with the purpose of evaluating what would be the minimal amount of time for the postoperative motion related to the surgery to plateau to ascribe the improvement in motion most related to the arthroplasty. The data were used to determine minimum and maximum follow-up time for recording of postoperative motion. If a difference between the pilot study comparisons was 5° or less, the patient's forward elevation was deemed to have plateaued. Therefore, ultimate use of that follow-up time period and data was allowed in our study. The analysis excluded patients who sustained a postoperative complication that would affect the postoperative motion; thus, 23 patients with postoperative complications such as acromial fracture ($n = 14$) or instability ($n = 9$) during the postoperative data collection period were excluded.

Ultimately, 540 of 802 patients with average follow-up of 19 months (range, 1-3 years) were retrospectively reviewed, of which 239 were excluded due to missing short-term or long-term follow-up. Among these excluded patients, 68 did not have preoperative follow-up, 56 had less than 3 months of follow-up, 46 had between 3 and 6 months of follow-up, and 69 had between 6 months and 1 year of follow-up. No patients were excluded due to preoperative diagnosis; the study included patients with rotator cuff deficiency without arthritis, cuff tear arthropathy, acute 3-part or 4-part proximal humeral fracture dislocations, proximal humeral fracture sequelae, infection, and revision arthroplasty.

ROM analysis

Preoperative and postoperative ROM assessment was performed using a digital goniometer on a videorecorded physical examination according to a previously published ROM protocol.[7] Patients were asked not to go beyond the point of pain or discomfort. Measurements were performed by an independent observer (B.J.C.) blinded to study design and purpose, and when unavailable, every patient completed a questionnaire that included self-assessed ROM indicated by marking the highest attainable motion on a picture that correlates with videorecorded measurements.[18,23] These measurements were taken from follow-up data that was closest to 2 years postoperative.

Intraoperative forward flexion (IFF) was determined by the senior surgeon (M.A.F.) after final implantation of the components and repair of the subscapularis in the operating room and was recorded in the operative report in 30° increments ranging between 0° and 180°. This was performed under a consistent combined regional and general anesthetic technique and patient positioning. At the time of measurement, the senior surgeon was blinded to study design. To compensate for potential observer bias, random samples from surgical videos of the patients in the study were measured for intraoperative ROM by the operating surgeon (M.A.F.) and an independent observer not involved in the surgical management of the patients. The operating surgeon had a high intraobserver correlation ($r = 0.717$). The independent observer measurements were also highly correlated with the operating surgeon ($r = 0.727$).

Radiographic analysis

Adequate preoperative and postoperative x-ray images were available for 457 of the 540 patients in the cohort. Those excluded had severe boney destruction of their proximal humerus or acromion, the preoperative x-ray film was deficient, or visualization of the greater tuberosity or deltoid tuberosity was unclear. Following a

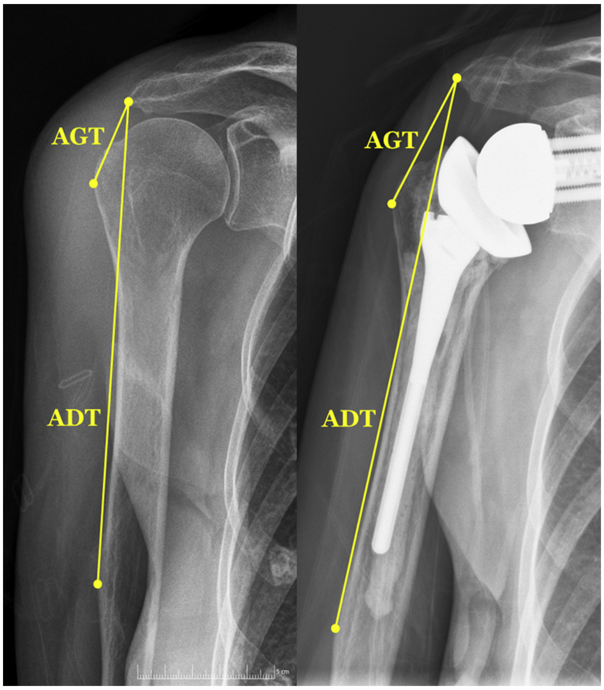

Figure 1 Method for determining arm lengthening by measuring the difference in distance between the acromion and the greater tuberosity (*AGT*) and between the acromion and the deltoid tuberosity (*ADT*) on preoperative and postoperative radiographs.

Table I Independent variable analysis of correlations with postoperative forward flexion

Variable	Spearman ρ	*P*
Preoperative ER	0.187	<.001
Forward flexion		
Preoperative	0.251	<.001
Intraoperative	0.418	<.001
Distance change		
AGT	0.059	.209
ADT	0.053	.308
Age	0.056	.191

ADT, acromion and the deltoid tuberosity; *AGT*, acromion and the greater tuberosity; *ER*, external rotation.

similar method as a study of arm lengthening by Jobin et al,[11] scaled measurements were made for this study by 2 observers (D.G.S. and B.J.C.) on preoperative and postoperative x-ray images between the inferolateral acromion and the most prominent portion of the greater tuberosity and deltoid tuberosity (Fig. 1). The differences were recorded as the acromial greater tuberosity (AGT) distance and acromial deltoid tuberosity (ADT) distance. The intraclass correlation coefficient (ICC) between the 2 observers was studied.

Statistical analysis

Preoperative diagnosis, sex, age, preoperative motion, arm lengthening (via AGT and ADT), and intraoperative motion were examined with univariate statistical analysis (Mann-Whitney *U* test and the Spearman ρ). Variables that were significant on univariate analysis were selected for evaluation in the multivariable regression analysis to identify significant independent predictors of postoperative forward elevation. Statistical analysis was performed using SPSS software (SPSS Inc, Chicago, IL, USA). A *P* value of <.05 was considered statistically significant.

Table II Effect of preoperative diagnosis on outcome

Diagnosis*	Absent (°)†	Present (°)‡	*P* value
Failed shoulder arthroplasty	150 (20-180)	114 (10-180)	<.001
Sequelae of proximal humeral fracture	140 (10-180)	130 (30-180)	.397
Infection	140 (10-180)	120 (30-180)	.016
Acute proximal humeral fracture	140 (10-180)	150 (40-180)	.800
Massive cuff tear without arthritis	133 (10-180)	150 (40-180)	.001
Cuff tear arthropathy	128 (10-180)	150 (20-180)	<.001

* Data are shown as mean (range) degrees.
† Absent means the patients did not have the diagnosis.
‡ Present means the patients had the diagnosis.

Table III Distribution of intraoperative forward flexion results

Intraoperative forward flexion	Frequency (%)
30°-60°	49 (9.1)
90°	102 (18.9)
120°	121 (22.4)
150°	196 (36.3)
180°	72 (13.3)
Total	540 (100.0)

Results

Pilot study results

Follow-up analysis was performed between 3 and 6 months in 284 patients, 6 and 12 months in 290, 1 and 2 years in 245, and 2 and 3 years in 60. No differences were found between 2-year and 3-year follow-up (mean change, 1°; 95% confidence interval [CI], −7° to 9°; *P* = .973). Statistically significant differences were found between 1-year and 2-year follow-up (mean change, 5°; 95% CI, 0°-10°; *P* = .011), between 6 months and 1 year (mean change, 8°; 95% CI, 4°-12°; *P* < .001), and between 3 and 6 months (mean change, 9°; 95% CI, 5°-13°; *P* < .001).

Univariate variable analysis

Details of the univariate variable analysis are presented in Table I.

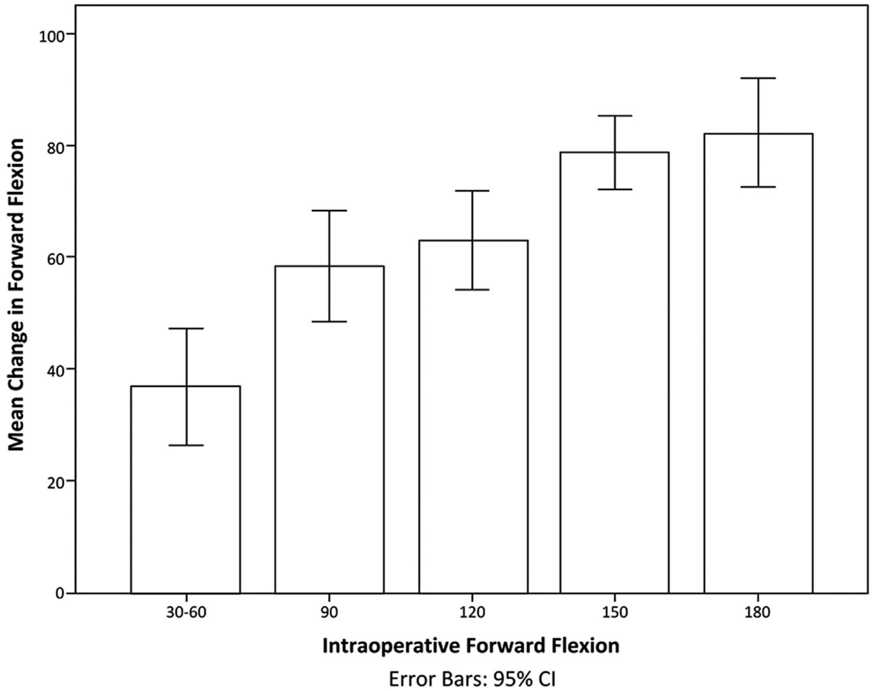

Figure 2 Change between preoperative and postoperative forward elevation with respect to each level of measured intraoperative forward elevation. *CI*, confidence interval.

Preoperative diagnosis

Preoperative diagnosis was determined from operative reports or patient radiographs. The diagnoses tracked included acute proximal humeral fracture in 11 patients, sequela of proximal humeral fractures in 30, cuff tear arthropathy in 266, massive cuff tear without arthritis in 71, failed shoulder arthroplasty in 165, and infection in 24. Among the diagnoses, infection, revision, massive cuff tear without arthritis, and cuff tear arthropathy were statistically different in the final postoperative forward elevation. Patients with infections or revisions had significantly less postoperative forward flexion than the rest of the population (median, 120° vs 40°; $P = .016$; median, 114° vs 150°; $P < .001$, respectively). In contrast, massive rotator cuff tears without arthritis averaged more (median, 150° vs median 133°; $P = .001$) and cuff tear arthropathy averaged more (median, 150° vs 128°; $P < .001$). Outcome data for each diagnosis can be found in Table II.

Patient age and sex

The study patients were an average age of 70 years (range, 30-90 years). Age was not correlated with final postoperative ROM ($\rho = 0.056$, $P = .191$) but was adjusted for in the regression model for estimation purposes.

The study included 217 men and 323 women. Gender proved to be a significant variable in the univariate analysis. The median postoperative ROM was 150° (range, 20°-180°) for men compared with 130° (range, 10°-180°) for women ($P < .001$ by Mann-Whitney *U* test).

Arm lengthening

The change in AGT and in ADT represented arm lengthening in our study. Average AGT and ADT changes were 1.89 cm (range, −2.18 to 4.92 cm) and 2.06 cm (range, −3.17 to 7.70 cm), respectively. There was no significant correlation with outcome regarding lengthening for AGT ($P = .209$) or ADT ($P = .308$). There was a high ICC between the 2 observers regarding AGT measurements of 0.94 (95% CI, 0.88-0.97) with a smaller agreement on ADT measurements, ICC of 0.77 (95% CI, 0.51-0.89).

Preoperative ROM

Preoperative forward flexion averaged 62° (range, 0°-180°), and preoperative external rotation averaged 20° (range, −60° to 90°). Preoperative forward flexion and external rotation were both correlated significantly with postoperative ROM ($\rho = 0.251$, $P < .001$; $\rho = 0.187$, $P < .001$, respectively).

Intraoperative ROM

IFF is also an important independent variable for postoperative outcome (see distribution in Table III). Patients' change between preoperative and postoperative ROM at each level of IFF is shown in Figure 2. When the change between preoperative and postoperative flexion was calculated for each IFF level, significant differences were found when 90°, 120°, 150°, and 180° of IFF was compared with ≤60° (all $P < .01$).

Multivariable regression analysis

In the initial regression model, age, preoperative external rotation, and all of the preoperative diagnoses were

Table IV Initial multivariable regression analyses

Variable	β (95% CI)	*P* value
Male gender	8.91 (2.45-15.37)	<.001
Age	0.12 (−0.22 to 0.45)	.503
Preoperative FF	0.17 (0.08-0.27)	<.001
Preoperative ER	0.10 (−0.01 to 0.21)	.079
Revision	−12.23 (−25.00 to 0.55)	.061
Infection	−4.17 (−20.08 to 11.73)	.607
Massive cuff tear	−2.76 (−17.64 to 12.11)	.716
Cuff tear arthropathy	−3.75 (−16.28 to 8.78)	.557
Intraoperative FF*		
180°	54.49 (39.71-69.28)	<.001
150°	49.37 (36.44-62.31)	<.001
120°	36.06 (23.25-48.86)	<.001
90°	28.06 (15.31-40.81)	<.001

CI, confidence interval; *ER*, external rotation; *FF*, forward flexion.
* Reference ≤60°.

Table V Final multivariable regression model

Variable	β (95% CI)	*P*
Male gender	8.26 (1.80-14.72)	.012
Preoperative FF	0.20 (0.11-0.29)	<.001
Intraoperative FF*		
180°	62.16 (48.42-75.91)	<.001
150°	56.32 (44.39-68.25)	<.001
120°	40.16 (27.60-52.73)	<.001
90°	29.39 (16.57-42.20)	<.001

CI, confidence interval; *FF*, forward flexion.
* Reference ≤60°.

nonsignificant predictors of postoperative forward flexion (Table IV). After nonsignificant factors were removed, the final model indicated that IFF was the strongest predictor of final postoperative ROM, followed by preoperative ROM and gender (Table V). Compared with patients with an IFF of ≤60°, patients with intraoperative elevation of 90° gained approximately 29° in postoperative forward elevation ($P < .001$), 120° gained approximately 40° in postoperative forward elevation ($P < .001$), 150° degrees gained 56° in postoperative forward elevation ($P < .001$), and 180° degrees gained 62° in postoperative forward elevation ($P < .001$).

Discussion

Because IFF was the most powerful predictor of postoperative motion, the importance of critically trialing in the operative room cannot be overstated. If a surgical tactic such as additional soft tissue release or decrease in component size can yield another 30° or even 60°, according to our model, a postoperative gain of approximately 20° or 30° could be expected (Fig. 2). Assuming no frank dislocation or instability during intraoperative trialing, tensioning of the soft tissue structures or a certain subjective shuck to a prosthesis may be less important to postoperative result than simply the ability to forward elevate the arm. Gender and preoperative motion were also predictive, albeit to a lesser degree, and are also important prognostic factors that surgeons should consider because deconditioning or muscle mass may be predictive.

Significantly, previous studies should be re-examined, because this factor of intraoperative motion was not considered. For example, the change in preoperative motion vs postoperative forward elevation is frequently reported in various studies and often attributed to certain factors: preoperative diagnosis,[27] preoperative motion,[5] or arm lengthening.[11] Conclusions could possibly have been suggested without due consideration of this hidden variable.

Preoperative diagnosis has long been thought to be a significant variable in postoperative outcome.[27] In fact, according to our univariate analysis, it is indeed an important determining factor. When all factors are examined together (including intraoperative motion), however, preoperative diagnoses became nonsignificant. Wall et al[27] suggest that post-traumatic arthritis patients and revision patients often fare worse. This may be the case, but our results would suggest that perhaps that these patients obtained poor intraoperative motion more often than not due to the soft tissue of the patient, and if accounted for, these diagnoses would not be prognostically relevant. In addition, previous results from our institution have also suggested that revisions behave inherently differently than a primary cuff deficiency.[6] This too would suggest that we have missed this hidden variable of intraoperative motion in our previous studies as well.

Preoperative motion as a prognostic factor has been suggested in previous reports but has not been previously studied. Clark et al[5] suggested that differences in outcomes between groups could be attributed to patients on average having less preoperative forward elevation; however, this is largely an assumption that had not previously been described in the literature. In our study, this is a prognostic variable but is not as essential as IFF.

Lädermann et al[13] studied lengthening of the humerus in relation to postoperative forward elevation and found no correlation; however, there were significant differences between varying amounts of arm lengthening and postoperative elevation. Jobin et al,[11] in a case series of just 37 patients, described deltoid lengthening of 38 mm to be a factor to correlate with postoperative forward flexion. In our study, these suggested variables were not at all significant during univariate analysis or in our multivariable regression of the 457 radiographs available. This also suggests that intraoperative motion was potentially superior in a subset of patients from the Jobin et al study, and when factored into their regression analysis, perhaps the effect of lengthening would be dampened.

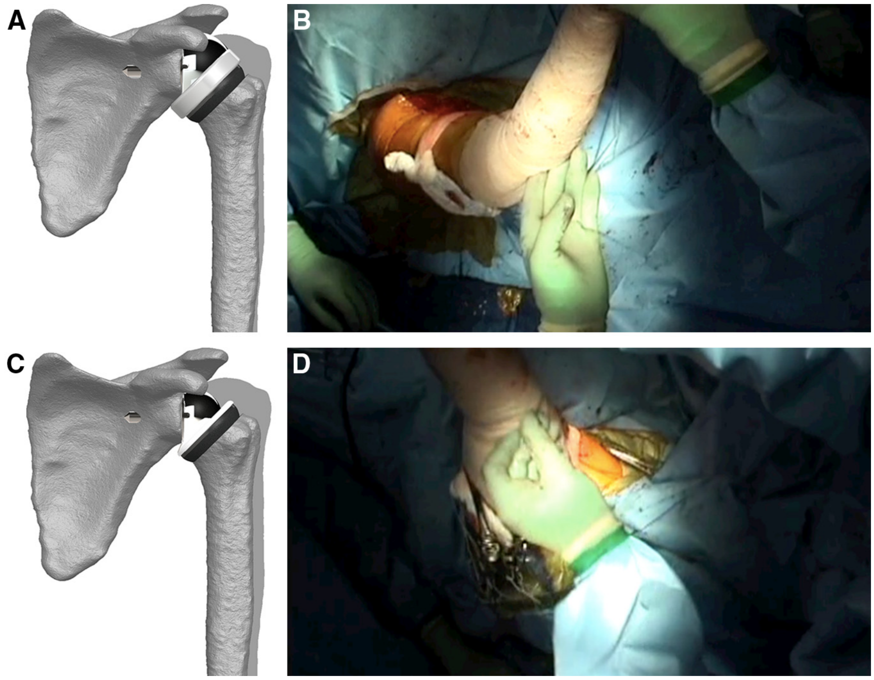

Figure 3 Demonstrates a (**A**) reverse shoulder arthroplasty with a 36-N glenosphere with its (**B**) subsequent intraoperative forward flexion (IFF) vs a smaller 32-4 glenosphere. Note the decreased offset of the humerus with the larger component. (**C**) The apparent overstuffing of the joint is due to an increased distalization in the larger implant. (**D**) Improved IFF demonstrated after changing the glenosphere to a smaller 32-4.

This study has some weaknesses. As with all regression analysis, correlation does not always imply causation. Furthermore, the senior author consistently made all measurements himself in the operating room in a usual fashion, without the aid of a digital goniometer; however, intraoperative surgical videos reviewed by an independent evaluator had a strong correlation ($r = 0.727$). Also, this study only studied IFF as it relates to postoperative forward flexion. Future studies will be necessary to study the correlation between IFF, other postoperative motion parameters, and patient outcome scores.

Conclusion

When analyzing factors that may influence outcome, the variable of intraoperative motion should be accounted for in controls to avoid assumptions from possible confounding variables such as arm lengthening and preoperative diagnosis. Surgeons should be aware that final functional outcome is directly dependent on motion achieved in the operating room. Therefore, strategies to maximize intraoperative motion, while not sacrificing the ultimate prosthetic stability, should be used. The use of appropriately sized implants for the patient (Fig. 3), appropriate soft tissue releases, ensuring satisfactory bone cuts, and possible release of the subscapularis repair are all possible strategies for maximizing IFF. As Dr Matsen commonly states (personal communication), the surgeon is indeed the method.

Disclaimer

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