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REVIEW

Reverse total shoulder arthroplasty for the management of fractures of the proximal humerus: a systematic review

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Abstract Reverse total shoulder arthroplasty (RTSA) represents a good solution for the management of patients with fracture of the proximal humerus with associated severe osteoporosis and RC dysfunction. A systematic review of the literature according to the PRISMA guidelines was performed matching the following keywords: "reverse total shoulder arthroplasty"; "reverse total shoulder prostheses"; "fractures"; "fracture of the proximal humerus." Medline, EMBASE, Google Scholar, and Ovid database have been screened. Ten studies were considered in the qualitative analysis. No randomized prospective controlled trials have been found. A total of 256 patients received a RTSA for the management of fracture of the proximal humerus. There were 28 males (10.8 %) and 228 females (89.2 %). The mean age of patients was 75.5 ± 2.2 years (range 70–78 years). The mean follow-up period was 27.8 ± 21.8 months range (6–86 months). Overall, the mean Constant score was 56.7 ± 7.6 points (range 44–67.8 points), the mean DASH score was 39.9 ± 6 points (range 31.5–46.8 points), the ASES averaged 70.3 ± 6.8 points (range 65–78 points), and the OSS averaged 28.7 points (range 15–56 points). RTSA restores function and relieves pain in patients with proximal humeral fractures. However, no randomized controlled trials are available to support RTSA versus osteosintesis, anatomical prostheses or hemiarthroprotesis. Further studies are needed to evaluate the effectiveness of RTSA in the management of fracture of the proximal humerus.

Keywords Reverse total shoulder arthroplasty · Fractures proximal humerus · Shoulder · Replacement

Introduction

Several surgical options are available for the management of complex displaced fractures of the proximal humerus, such as locked or nonlocked screw plates [1], static or dynamic anterograde nailing constructs [2], anatomical prostheses [3, 4], hemiarthroplasty [5–7], and reverse total shoulder arthroplasty (RTSA) [8–10]. Locked screw plates ensure good reduction and stabilization of the fracture [11], but their use is not indicated in case of small bone fragments because of high risk of avascular necrosis [12]. Anterograde nailing constructs with auto-stable screws are useful in case of complex dislocated and displaced fractures because they guarantee a correct fixation of bone fragments, promoting the vascularization of the humeral head and decreasing the risk of necrosis [13]. Nevertheless, their use is not indicated in case of severe osteoporosis. Anatomical shoulder prosthesis or hemiarthroplasties are implanted to treat four-part displaced fractures or fracture dislocations of the proximal humerus, demonstrating good results in terms of pain relief and functional recovery [5, 14]. However, when rotator cuff (RC) is deficient, or the fixation of the tuberosities is not successfully achieved, or nonunion and malunion occur [4], functional outcomes are often disappointing [5, 15].

RTSA represents a good solution for the management of patients with fracture of the proximal humerus with associated severe osteoporosis and RC dysfunction. RTSA was

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originally developed to treat patients with massive and irreparable RC tears [16–18]. Biomechanically, RTSA changes the vertical balance of the shoulder, lowering the humerus and medializing the center of rotation of the shoulder. Thus, it improves deltoid lever arm to supply RC deficiency, restoring active anterior elevation as well as abduction. The good clinical and functional outcomes led to enlarge RTSA indications to other pathologies such as cuff tear arthropathy (CTA) [19–26], failed RC surgery [22, 27], and fractures of the proximal humerus [4, 11, 15, 28–33].

The use of RTSA is associated with two major problems: the high rate of scapular notching and compromised external rotation that impairs function and patients satisfaction [29, 30, 34]. Moreover, RTSA can be associated with other important complications such as cortical perforation, humeral shaft or glenoid fracture, acromion fracture, neurological injuries, infection, dislocation, loosening of the glenosphere, and mobilization of the glenoid component.

The aim of this study was to systematically review the functional outcomes and complications of the RTSA performed as a primary surgical procedure for the management of fractures of the proximal humerus.

Materials and methods

We undertook a systematic review of the literature according to the PRISMA guidelines with a PRISMA checklist and algorithm, and already validated in our setting. Two independent reviewers separately conducted the search. The search was performed on January 14, 2016. All journals were considered, and all relevant studies were analyzed. To qualify for the study, an article had to be published in a peer-reviewed journal. Articles were initially screened for relevance by title and abstract, excluding articles without an abstract and obtaining the full-text article if the abstract did not allow the investigators to assess the defined inclusion and exclusion criteria.

Two investigators separately reviewed the abstract of each publication and then performed a close reading of all papers to minimize selection bias. Moreover, a cross-reference research of the selected articles was performed to obtain other relevant articles. All articles reporting clinical and functional outcomes, as well as complications following RTSA performed as a primary surgery for the management of fractures of the proximal humerus, were taken into account. The following databases were screened: Medline, EMBASE, Google Scholar, and Ovid. Given the linguistic capabilities of the authors, articles in other languages than English, French, Spanish, German, or Italian were excluded. The following key words were matched: "reverse total shoulder arthroplasty"; "reverse total shoulder prostheses"; "fractures"; "fracture of the proximal humerus."

We included articles that reported about patients with fracture of the proximal humerus managed with RTSA; presented a sufficient description of fracture with imaging (radiographs or CT scan); had an adequate description of the type of fracture (or used Neer, Duparc, OTA or AO-Muller classifications); clearly described the type of RTSA implanted; reported a sufficient description of the surgical intervention; completely described the clinical condition of the patients (using clinical scores, measuring ROM); had an appropriate description of the follow-up period; and presented a detailed report of the complications, outcome measures, and outcome scores. Missing data pertaining to these parameters warranted exclusion from this systematic review.

Literature reviews, case reports, case series, conference abstracts, posters, studies on animals, cadavers or in vitro, biomechanical reports, tumoral studies, technical notes, letters to editors, and instructional course were excluded. We also excluded articles about RTSA for revision of proximal humerus fracture sequelae.

Furthermore, we exclude studies with follow-up shorter than 6 months and with no information on surgical intervention, complications, diagnosis, imaging, clinical outcomes, radiographic outcomes, and statistical analysis.

The inclusion and exclusion criteria are summarized in (Table 1) (INCL-EXCL criteria). The categorical variables were reported as frequency with percentage. Continuous variable data were reported as mean ± standard deviation or range as minimum and maximum values. In all studies, P values <0.5 were considered statistically significant.

Results

The literature search and the inclusion–exclusion criteria lead to 13 articles eligible for the study. Of those articles, three were excluded because they reported outcomes of the same sample of patients at different follow-up times [29, 35]. For this reason, ten studies were considered in the qualitative analysis. Of these, 3 were cohort studies (27.2 %) [30, 31, 36] with historical control, 2 prospective cohort studies (18.2 %) [32], 3 retrospective cohort studies (36.4 %) [30, 33, 37, 38], and 2 studies (18.2 %) [29, 39] with unclear design.

Demographic results

A total of 256 patients received RTSA for the management of fracture of the proximal humerus. All prostheses were implanted as primary surgery. There were 28 males

Table 1 Inclusion and exclusion criteria

Inclusion criteria	
Databases	Medline, EMBASE, Google Scholar, and Ovid
Key words	"Reverse total shoulder arthroplasty"; "reverse total shoulder prostheses"; "fractures"; "fracture of the proximal humerus"
Article's language	English, French, Spanish, German, Italian
Level of evidence	Oxford center of EBM, levels I, II, III, IV
Diagnosis	Fracture of the proximal humerus
type of surgery	Reverse total shoulder arthroplasty (RTSA)
Outcomes assessment	Clinical: clinical questionnaires, clinical scores functional: measuring range of motion (ROM) imaging: radiographs; CT scan
Minimum follow-up time	6 months
Exclusion criteria	
Type of study	Literature reviews, case reports, case series, conference abstracts, committee posters, studies on animals, on cadavers, biomechanical reports, tumoral studies, technical notes, letters to editors, instructional course
Diagnosis	No imaging assessment of the type of fracture. No description of the type of fracture
Management	Conservative, nonoperative management, operative management performed as revision surgery
Outcomes measures	No information on diagnosis, follow-up, imaging assessment of the prostheses, clinical examination, clinical postoperative outcomes, clinical scores, clinical questionnaires, statistical analysis of the relative outcomes

(10.8 %) and 228 females (89.2 %). The male-to-female ratio was 0.1.

The mean age of patients was 75.5 ± 2.2 years (range 70–78 years). The right shoulder was involved in 53 cases (45.7 %) and the left shoulder in 63 cases (54.3 %). In other 154 patients (59.1 %), the shoulder side was not reported. The dominant arm was injured in 48 (18.5 %) patients while in 211 patients (81.5 %), these data were not reported.

The mean follow-up period was 27.8 ± 21.8 months range (6–86 months). A total of 12 patients (3.5 %) were lost to follow-up due to death, moved to other cities, or unknown reasons.

Imaging assessment

Fractures of the proximal humerus were diagnosed in all patients using radiographs and/or CT scans. Radiographs in anteroposterior view with the arm in neutral position were performed in all patients (100 %) while anteroposterior view with the arm externally and internally rotated was performed in 103 patients (39.8 %). The radiographic scapular-lateral view was performed in 205 patients (79.2 %) while Lamy's view was performed in 95 patients (36.7 %). CT scans were performed in 109 patients (42.1 %).

Postoperative scapular notching was graded according to Sirveaux's classification in 114 patients (44 %), Valenti's classification in 35 patients (13.5 %), and Nerot's classification in 39 patients (15 %). In other 71 patients (27.5 %), scapular notching was assessed postoperatively with radiographs, but not graded with a specific classification system.

Fractures classification

Fractures of the proximal humerus were classified according to the following classification systems: Neer [40], Duparc [41], AO-Muller, and OTA [42].

A total of 115 fractures (44.4 %) were classified according to Neer's classification system: there were 2 type II fractures (1.7 %); 15 type III fractures (13 %); 98 type IV fractures (85.3 %). Twenty fractures (7.7 %) were classified according to Duparc's classification: there were 3 type II fractures (15 %); 13 type III fractures (65 %); 4 type III fractures (20 %). Nineteen fractures (7.4 %) were graded as "grade C" according to AO-Muller's classification. Twenty fractures (7.7 %) were classified according to OTA classification: there were 5 B2 fractures (25 %); 7 C2 fractures (35 %); 8 C3 fractures (40 %). Eighty-five fractures (32.8 %) were classified as complex comminuted fractures of the proximal humerus. Moreover, there were 40 fracture dislocations (12.7 %).

Type of prostheses

The mean time from injury to surgery was 10 ± 4.4 days (range 3–15 days) in 182 patients (71 %), while in 74 patients (29 %), these data were not reported.

Delta III® reverse shoulder prostheses (DePuy Orthopaedics, Warsaw, IN, USA) [32, 35, 38, 39] were

implanted in 141 patients (52 %), Aequalis® reverse prostheses (Tornier SAS, Montbonnot, France) [30, 37] in 50 patients (18.4 %), SMR Modular Shoulder System® (Lima-LTO, San Daniele del Friuli, Italy) [5, 36] in 28 patients (10.3 %), Arrow® reverse shoulder prosthesis (FhOrthopaedics, Mulhouse) [33] in 29 patients (11.1 %), Encore® reverse shoulder prosthesis (Encore Medical, Austin, Texas, USA) in 13 patients [31] (4.8 %), and the Zimmer® anatomical shoulder reversed prostheses (Zimmer, Warsaw, IN, USA) [38] in 9 patients (3.4 %). Table 2 summarize surgical approaches and type of prostheses implanted.

A total of 151 RTSAs (58.3 %) were cemented. Of these, 43 (28.5 %) received gentamicin-loaded cement. The remaining 108 RTSAs (41.7 %) were implanted without cement.

Immobilization and rehabilitation

The postoperative immobilization period was reported for 214 patients (82.6 %), and it averaged 20 ± 15.6 days (range 0–42 days). The same group of patients (82.6 %) started the rehabilitation protocol at an average of 10 ± 9 days (range 2–30 days) from surgery.

Outcomes assessment

Clinical outcomes were evaluated using the Constant–Murley shoulder score [43] in 219 patients (84.5 %), the Disability of Arm, Shoulder, and Hand score (DASH) [44] in 123 patients (47.5 %), the American Shoulder and Elbow Surgeons score (ASES) [45] in 60 patients (23.2 %), and the Oxford Shoulder score (OSS) [46] in 10 patients (3.9 %).

Functional outcomes were assessed measuring active ROM of the operated shoulder in 206 patients (79.5 %). The following movements were considered: anterior elevation; abduction; external rotation with the arm in adduction; external rotation with the arm at 90° of abduction; internal rotation (Table 3).

Clinical outcomes

Overall, the mean Constant score was 56.7 ± 7.6 points (range 44–67.8 points), the mean DASH score was 39.9 ± 6 points (range 31.5–46.8 points), the ASES averaged 70.3 ± 6.8 points (range 65–78 points), and the OSS averaged 28.7 points (range 15–56 points).

Functional outcomes

The mean anterior elevation was 113.4° ± 14.7° (range 95.7°–139°), the mean abduction was 97° ± 12.1 (range 86°–112.5°), the mean external rotation with the arm in adduction was 11.8° ± 10° (range 0°–27°), the mean external rotation with the arm at 90° of abduction was 35.5° ± 9.1° (range 25°–49°), and the mean internal rotation was 38° ± 13.1°.

Complications

Complications were reported in all studies. We divided complications as follows: medical complications,

Table 2 Surgical approach and type of prostheses implanted

Authors	Deltopectoral	Superolateral	Anterolateral	Juxta-acromial
Delta III® (DePuy Orthopaedics, Warsaw, IN, USA)				
Bufquin et al. [39]	20	23		
Cazeneuve et al. [29]			35	
Gallinet et al. [30]		24		
Gallinet et al. [30]		19		
Klein et al. [32]				20
Aequalis® (Tornier SAS, Montbonnot, France)				
Gallinet et al. [30]		20		
Lenarz et al. [37]	30			
SMR Modular Shoulder System® (Lima-LTO, San Daniele del Friuli, Italy)				
Terragnoli et al. [70]		18		
Young et al. [36]	10			
Arrow® (Fh-Orthopaedics, Mulhouse)				
Valenti et al. [33]		29		
Encore® (Encore Medical, Austin, Texas, USA)				
Reitman et al. [31]	13			
Zimmer® anatomical shoulder reversed prostheses (Zimmer, Warsaw, IN, USA)				
Gallinet et al. [38]		9		

Table 3 Reasons of exclusion of studies

Author, journal, and year of publication	Reason of exclusion
Cazeneuve et al. [47]	Duplicate; same patients with different length of follow-up (Cazeneuve et al. [68])
Cazeneuve et al. [35]	Duplicate; same patients with different length of follow-up (Cazeneuve et al. [68])
Cazeneuve et al. [29]	Duplicate; same patients with different length of follow-up (Cazeneuve et al. [68])
Boileau et al. [4]	Sequelae of fractures of the proximal humerus: no RTSA as primary surgery
Garrigues et al. [55]	No description of the type of prosthesis; no exact description of number of Delta III or Aequalis implanted
Grassi et al. [56]	No primary RTSA procedures; only RTSA for fracture sequelae
Ji et al. [57]	Only 5 patients with fracture of the proximal humerus; no stratification of results according to etiology
Kilic et al. [58]	No primary RTSA procedures; only RTSA for fracture sequelae
Levy et al. [59]	Indication of RTSA: failed hemiarthroplasty
Martinez et al. [60]	Proximal humeral atrophic nonunion: no primary fracture
Martinez et al. [61]	No primary RTSA procedures; only RTSA for fracture sequelae
Postacchini et al. [62]	RTSA for the treatment for failed hemiarthroplasty in patients with fracture of the proximal humerus
Rasmussen et al. [63]	Epidemiologic study; no description of fracture assessment; no report on clinical, functional, and radiographic outcomes
Wall et al. [64]	Review paper
Wall et al. [65]	Review paper
Wellmann et al. [66]	No primary RTSA procedures; only RTSA for fracture sequelae
Willis [67]	Malunion treated with RTSA; no fractures

intraoperative complications, and postoperative complications. Moreover, we evaluated radiographic complications considering tuberosity repair and scapular notching.

Medical complications occurred in 15 patients (5.8 %). Seven patients present infection (2.6 %), 1 sustained a deep venous thrombus (0.4), 3 developed a reflex sympathetic dystrophy syndrome (1.2 %), 3 a complex pain regional syndrome (1.2 %), and 1 patient had a lymphedema (0.4 %).

Intraoperative complications occurred in 12 patients (4.6 %). 1 (0.4 %) brachial plexopathy, 1 (0.4 %) deltoid paresis, 1 (0.4 %) radial nerve injury, 1 (0.4 %) ulnar nerve injury, 3 (1.2 %) median nerve injury and 3 (1.2 %) axillary nerve injury, 1 (0.4 %) fracture of the glenoid and 1 (0.4 %) fracture of the acromion.

Postoperative complications occurred in 9 patients (3.5 %). Five patients had a dislocation. Of these, 3 were anterior dislocations (60 %). One patient (0.4 %) had humeral stem loosening, 1 patient (0.4 %) developed hematoma and another patient (0.4 %) developed the separation of the muscular flap following the superolateral approach. Nine patients (2.9 %) underwent revision surgery for the management of complications.

Scapular notching was the most common radiographic complication, occurring in 82 patients (31.7 %), followed by 55 cases (21.2 %) of tuberosity malunion/nonunion or resorption, and ectopic ossification in 28 patients (10.8 %).

According to Sirveaux classification, there were 22 grade I (26.8 %), 7 grade II (8.5 %), 5 grade III (6.1 %), and 7 grade IV cases (8.5 %) of scapular notching. According to Valenti's classification, there were 5 grade II (6.1 %), 4 grade III (4.9 %), and 3 grade IV cases (3.7 %) of scapular notching. According to Nerot's classification, there were 7 grade I (8.5 %), 6 grade II (7.3 %), and 3 grade III cases (3.7 %) of scapular notching. In the remaining 13 patients (15.9 %), the scapular notching was not graded, even if it was present.

Discussion

Complex comminuted displaced fractures of the proximal humerus represent one of the most difficult situations to treat in shoulder surgery, remaining a major problem in orthopedics.

In the last decade, the use of RTSA, initially developed to manage massive and irreparable RC tears in old patients with or without glenohumeral arthritis, has been extended to trauma. After our literature search, we had to exclude 3 studies [29, 35, 47] because they reported outcomes of the same sample of patients with different lengths of follow-up, and our inclusion and exclusion criteria allowed us to consider only 10 articles for this systematic review.

No randomized prospective control trials have been found in the literature on the topic. This finding represents an important limitation to define the real efficacy of RTSA in the management of fractures of the proximal humerus.

Patients with complex fractures of the proximal humerus are often elderly. The mean age of patients of the studies

included in this review was 75.5 years, ranging from 70 to 78 years, with a standard deviation of 2.2 years. At this age, patients usually present a severe deficiency of the RC due to fatty degeneration or muscle atrophy [48]. Moreover, since 89.2 % of patients affected by fracture of the proximal humerus were women, many of them may present osteoporosis. For these reasons, different fixation techniques produce poor clinical and functional outcomes, with high failure rate, and the RTSA seems to be the best surgical option for these patients. However, Bufquin et al. [39] found that elderly patients had a lower Constant score compared to younger patients, but this difference was not statistically significant.

Not many studies compared functional results of reverse prosthesis and hemiarthroplasty in complex fractures of the proximal humerus. Young et al. [36] found no statistical difference in OSS and ASES between reverse prosthesis group and hemiarthroplasty group. On the other hand, Gallinet et al. [30] reported higher postoperative Constant score after RTSA than after hemiarthroplasty, and in the study of Boyle et al. [5], the RSA group had a significantly better five-year OSS than the hemiarthroplasty group (41.5 vs. 32.3; $P = 0.022$). We found 8.1 % of perioperative complication in patients with proximal humerus fractures managed with RTSA. However, the complication rate of RTSA is lower than the overall complication rates of hemiarthroplasty that has been reported between 11.6 % [49] and 19 % [50].

Several studies demonstrated that the tuberosity union quality is crucial, to provide good functional results in patients with fractures of the proximal humerus managed with hemiarthroplasty [4, 5, 15]. Indeed, poor outcomes are reported when tuberosity fixation is not possible during surgery, when malunion or nonunion occurs, or when the consolidation of tuberosity is not achieved in its anatomical position [38]. Tuberosity nonunion or malunion is less debilitating in patients managed with RTSA because the implant design allows active elevation thanks to the deltoid. For this reason, RTSA can be considered in the setting of acute three-part and four-part proximal humerus fractures and fracture/dislocations that demonstrate poor potential for tuberosity healing (i.e., comminuted tuberosities, osteoporotic bone) [51]. However, secure tuberosity fixation should be attempted in each case, since successful union can result in the preservation of external rotation [39]. Gallinet et al. [38] reported better results in terms of mobility (anterior elevation, abduction, external and internal rotation ROM), as well as total Constant score and DASH score when tuberosity repair was performed. Moreover, patients with anatomical consolidation of the tuberosity achieved better results compared to patients in which nonunion or malunion of tuberosities occurred. Valenti et al. [33] reported similar results, showing that patients who had their greater tuberosity and lesser tuberosity reinserted had a significantly better external rotation with the arm at the side. On the other hand, clinical results reported by Bufquin et al. [39] seemed not to be influenced by the healing of the tuberosities. Klein et al. [32] used the juxta-articular approach without acromial osteotomy, removing tuberosities without reattaching the RC. The mean Constant score was 68.75, and the external rotation ROM was 25° at a mean follow-up of 33.3 months. Cazeneuve et al. [29] used the anterolateral approach without reattaching the tuberosity. The mean Constant score was 53 at a mean follow-up of 86 months.

Scapular notching represents another important complication of RTSA, limiting functional results and its use in trauma. Scapular notching has been found in 31.7 % of cases. It is frequently observed 1 year after prosthesis implantation [52], and its incidence increases over the years [35, 47, 53]. Furthermore, the extent of scapular notching progresses with the length of follow-up and determines a low Constant score when it is associated with abnormal humeral images (41 points vs. 57 points in patients with isolated scapular notching) [35, 47, 53]. Sadoghi et al. [27] did not identified any correlation between scapular notching and clinical outcomes at 24–42 months of follow-up, while after 60 months scapular notching was positively correlated with pain section of the Constant score and active ROM. However, no other studies assessed the relationship between scapular notching and clinical or functional outcomes. Another frequent complication affecting outcomes is ectopic ossification, which occurs in 10.8 % of cases. Patients who did not develop ectopic ossifications had statistically significantly better internal rotation ROM.

Major strength of the present study is the use of the PRISMA statement with a PRISMA checklist and algorithm. Using PRISMA guidelines, as we did in our previous study [54], the risk of errors during data extraction and evaluation is substantially reduced. Another important strength is that, in order to avoid bias, all articles were screened blindly by two independent reviewers who extracted the same data from the papers. Furthermore, the restricted inclusion and exclusion criteria of the present systematic review allowed us to consider in our qualitative analysis only high-quality studies conducted in a strict scientific fashion (using objective methods of outcome assessment). In this manner, we reduced the risk of bias that is common in systematic reviews studies.

Some limitations of our study must be underlined. Firstly, the main limitation is represented by the lack of randomized prospective control trials included in our qualitative analysis. Secondly, the results that we report should be considered with caution taking into account the nature of the present study. Thirdly, we include studies

with a minimum follow-up of 6 months, without stratifying results in relationship with the length of follow-up. Fourthly, we include only articles reporting about RTSA performed as primary surgery, without considering studies reporting the use of RTSA performed as a revision surgery. Furthermore, we include only 10 studies reporting about 259 patients. We know that this sample of patients is not enough to consider the outcomes found after our qualitative analysis as univocal. Finally, the lack of uniformity in reporting type of fracture, classification of scapular notching, and clinical and functional outcomes not allowed us to perform a statistical analysis considering all these parameters.

Further studies conducted in a more strict scientific fashion are necessary to understand the prognostic factors, as well as strength and limits, of the use of RTSA for the management of fractures of the proximal humerus.

Conclusions

Following encouraging results of RTSA [69], its use has been enlarged to trauma. RTSA can be considered a useful solution for the management of fractures of the proximal humerus in patients with RC dysfunction and/or severe osteoporosis. Nevertheless, there is a lack of uniformity in the studies in reporting type of fracture, classification of scapular notching, and clinical and functional outcomes. Moreover, no randomized prospective control trials are available in the literature about the topic, limiting the real understanding of the issue.

Compliance with ethical standards

Conflict of interest None.

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