

Reconstruction of coronoid process of the ulna: a literature review

Journal of International Medical Research

49(4) 1–10

© The Author(s) 2021

Article reuse guidelines:

sagepub.com/journals-permissions

DOI: 10.1177/03000605211008323

journals.sagepub.com/home/imr

**Shanwen Zhao^{1,2,3,*}, Canjun Zeng^{1,2,3,*},
Song Yuan⁴ and Runguang Li^{1,2,3,4}** 

Abstract

As a pivotal part of the elbow joint structure, the coronoid process of the ulna plays a vital role in maintaining elbow joint stability. Loss of coronoid process height causes instability of the elbow joint depending on the fracture characteristics and size. The diagnosis and treatment of coronoid process fractures has gained widespread attention from orthopedic surgeons. Nevertheless, few reports have described reconstruction of coronoid process fractures and defects that affect elbow joint stability. Treatment of elbow joint instability induced by coronoid process defects is challenging because most cases are complicated by other elbow joint injuries. Moreover, the clinical efficacy remains unclear. The present narrative review was performed to examine the research progress on reconstruction of the coronoid process. The findings of this review provide evidence for clinical repair and reconstruction of coronoid process defects and contribute to the published literature on this topic.

Keywords

Coronoid process, defect, reconstruction, ulna, elbow stability, fracture, narrative review

Date received: 9 March 2021; accepted: 12 March 2021

¹Department of Foot and Ankle Surgery, Center for Orthopaedic Surgery, the Third Affiliated Hospital of Southern Medical University, Guangzhou, China

²Orthopaedic Hospital of Guangdong Province, Guangzhou, China

³Academy of Orthopaedics, Guangdong Province, Guangzhou, China

⁴Department of Orthopedics, Linzhi People's Hospital, Linzhi, China

*These authors contributed equally to this work.

Corresponding author:

Runguang Li, Department of Foot and Ankle Surgery, Center for Orthopaedic Surgery, the Third Affiliated Hospital of Southern Medical University, 183 Zhongshan Avenue West, Tianhe District, Guangzhou 510610, China. Email: lirunguang79@163.com



Introduction

Coronoid fractures are relatively uncommon injuries occurring in approximately 2% to 15% of patients with dislocation.¹ They can be complicated by fractures of the proximal end of the radius, the olecranon, the distal end of the humerus, injuries of the medial and lateral collateral ligaments of the elbow joint, and the elbow joint capsule, leading to elbow joint instability. The coronoid process of the ulna plays a vital role in elbow joint stability. At present, it is considered that coronoid process fractures should be repaired because such fractures affect the stability of the elbow joint. However, it is difficult to directly repair severe coronoid process fractures or old coronoid process defects, which require reconstruction of the coronoid process to restore elbow joint stability. Few methods of coronoid process reconstruction have been described to date. This article reviews and summarizes coronoid process fractures, characteristics of elbow joint stability, reconstruction indications, surgical approaches, reconstruction materials, fixation approaches, and postoperative efficacy. The purpose of this narrative review is to provide evidence for clinical repair and reconstruction of coronoid process defects.

Literature search methods

This review focuses on reconstruction of the coronoid process of the ulna. The electronic database PubMed was searched using the following terms: “coronoid process” (all fields) AND “defect” (all fields) AND “reconstruction” (all fields) OR “coronoid process” (all fields) AND “fracture” (all fields) AND “reconstruction” (all fields). In total, 160 articles were identified via this PubMed search. An additional 27 articles were identified by screening the reference lists of relevant articles. Articles were

selected by screening the title, abstract, and full text using the following three inclusion criteria: stability of the coronoid process in the elbow joint, repair and reconstruction of coronoid process defects, and morphological and biomechanical study of the coronoid process. Thirty-three articles were included in the review (16 clinical case studies, 13 basic experimental research articles, and 4 reviews). Of these 33 articles, 13 were selected from the PubMed database search and 20 from screening the reference lists of relevant articles.

Coronoid process of the ulna and elbow joint stability

Heim and Bühler² proposed the theory of the elbow joint stability ring, which consists of the medial, lateral, anterior, and posterior columns. The coronoid process is a vital component supporting the anterior and medial columns. Moreover, as the primary osseous structure related to the stability of the posterior elbow joint, the coronoid process can resist the stress of posterior displacement of the ulna during flexion and extension of the biceps brachii, brachialis, and triceps brachii; maintain the axial stability of the elbow joint; retain the stability of posteromedial and posterolateral rotation; and prevent the incidence of elbow joint varus and valgus. Loss of the osseous structure of the coronoid process causes significant elbow joint instability. Closkey et al.³ demonstrated that excision of >50% of the coronoid process can lead to axial instability of the elbow joint. Hull et al.⁴ demonstrated that loss of coronoid process height is negatively correlated with coronoid process stability under the stress of elbow joint varus. With respect to the intact elbow, coronoid osteotomy influences elbow stability at 90° (mean deflection, 11.49 ± 17.39 mm), whereas small differences occur at 30° and 60° because of ligament

constraint.⁵ Besides these important functions related to its osseous structure, the coronoid process also provides an attachment site for multiple soft tissues. The anterior bundle of the medial collateral ligament, the brachialis, and the anterior joint capsule of the elbow joint are attached to the coronoid process from its basal aspect to its tip. Consequently, a fracture of the coronoid process of the ulna causes more severe functional loss than does joint instability induced by a simple fracture. Defects of the coronoid process can be accompanied by soft tissue instability.⁶

Indications for reconstruction of the coronoid process of the ulna

The first step in treating elbow joint instability accompanied by a fracture of the coronoid process of the ulna is to determine whether the elbow joint instability has been induced by the coronoid process fracture. A Regan–Morrey or O’Driscoll type III fracture involving the body or basal parts of the coronoid process is regarded as the primary factor leading to elbow joint instability. It is considered necessary to repair this type of coronoid process fracture in the early stage of injury.⁷ However, it is occasionally difficult to determine whether type I or II coronoid process fractures are the vital factors of elbow joint instability.⁸ Especially during the early stage of injury, patients cannot undergo muscle strength testing because of severe pain and swelling of the elbow, which increases the difficulty of evaluating the incidence and identifying the causes of elbow joint instability. Therefore, if type I or II coronoid process fractures that affect the stability of the elbow joint are left untreated, the patient may develop delayed elbow joint instability. The fractured coronoid process might be absorbed, leading to old coronoid process defects.⁹

Attention has been focused upon the necessity of reconstruction of the coronoid process of the ulna in clinical settings. According to previous literature,^{9–14} the surgical indications for coronoid process reconstruction can be summarized as follows: (1) Regan–Morrey or O’Driscoll type III fresh comminuted fractures, which are ineligible for internal fixation; (2) old coronoid process fractures for which it is impossible to use residual bone tissues to repair the coronoid process structure because of absorption of the fractured bone, leading to elbow joint instability; and (3) poor function of the coronoid process, causing elbow joint instability after surgical or nonsurgical treatment.

Methods of coronoid process reconstruction

Selection of reconstruction materials

Ideal reconstruction materials should possess an articular cartilage surface that matches the elbow joint in size and shape, a favorable or high success rate of healing, and a radius of curvature similar to that of the patient’s native intact coronoid; they should also be easy to obtain and induce only slight injury to the donor site.¹⁵ Previous studies have shown that autologous radial head fragments or the allogeneic radial head, the olecranon tip, iliac crest cortical bone, the costochondral joint ends, an artificial prosthesis, the caput fibulae, allogeneic bone, and navicular bone can be used to reconstruct the coronoid process of the ulna. However, different materials possess diverse advantages and disadvantages or limitations.¹⁶

Ring et al.¹³ and Esser¹⁷ used the discarded capitulum radii for coronoid process reconstruction. They recommended adopting an artificial radial head when a severe capitulum radii fracture could not be reduced or fixed. The capitulum radii and

coronoid process share a similar shape. The capitulum radii possesses an articular cartilage surface, which is an ideal material for coronoid process reconstruction. Nevertheless, it is merely applicable to cases accompanied by radial head fracture, requires capitulum radii fragments of a certain size, and increases the indications for capitulum radii replacement. Van Riet et al.¹⁸ adopted an allogeneic radial head for coronoid process reconstruction in three cases but observed heterotopic ossification, elbow joint instability, and other complications. The authors considered that it was difficult to predict the outcomes of coronoid process reconstruction using allogeneic bone and that relevant techniques remained to be improved. Bellato et al.¹¹ made certain modifications in 2016. The authors tilted the osteotomy to increase the contact area between the bone graft and basal part of the original coronoid process of the ulna. They also fixed the bone graft from different angles using three screws and adjusted the position of bone graft implantation. The three patients in their study obtained significantly better efficacy than did their counterparts in the study by Van Riet et al.¹⁸ Kataoka et al.¹⁹ found that the depression facet of the proximal radial head was the most suitable for defects of the anterior and medial coronoid process.

The shape of the olecranon tip is identical to the shape of the tip of the ulnar coronoid process. The olecranon tip possesses a cartilage surface. Appropriate removal of the olecranon process exerts only a slight effect on joint stability and does not increase the morbidity of the procedure by accessing a donor site outside of the intended surgical field. Therefore, some scholars regard the olecranon tip as the primary material for coronoid process reconstruction. Kataoka et al.¹⁹ performed three-dimensional computed tomography to compare the articular facet configuration among the olecranon tip, radial head, and

coronoid process. The authors considered that the olecranon tip was the most suitable material for coronoid process reconstruction. Moritomo et al.²⁰ employed the ipsilateral olecranon tip for ulnar coronoid process reconstruction and obtained favorable surgical outcomes. Nevertheless, the maximal incisional area of the olecranon osteotomy, which does not affect elbow joint stability, has gained widespread attention from orthopedic surgeons. An et al.²¹ demonstrated that excision of <50% of the olecranon process does not lead to joint instability. Bell et al.²² performed a biomechanics study using fresh frozen elbow joint specimens to evaluate the effect of the olecranon on elbow joint stability. They found that excision of 50% of the olecranon exerted no significant effect on elbow joint stability, including varus, valgus, and rotation. Alolabi et al.²³ comparatively analyzed the biomechanics among the intact ulna, partial excision of the coronoid process (40%) and partial excision of the coronoid process (40%) combined. Ramirez et al.²⁴ conducted a biomechanics experiment and obtained findings consistent with those of Alolabi et al.²³ However, they made certain modifications, such as complete excision of the coronoid process and use of an identically sized olecranon osteotomy for reconstruction. They also measured the size of the excised olecranon fragment, which accounted for approximately 50% of the olecranon. The results of an experiment by Wegmann et al.²⁵ indicated that the contralateral olecranon tip showed significantly better shape matching to the native coronoid than the ipsilateral olecranon tip graft. Therefore, the contralateral olecranon tip may be a more suitable graft for coronoid process reconstruction. However, donor-site morbidity is a disadvantage of this approach.

The iliac bone is a common site of bone harvesting in clinical practice. In a previous report, tri-cortical iliac crest bone was used

for ulnar coronoid process reconstruction, and relatively favorable clinical efficacy was achieved.²⁴ However, the poor homogeneity between the iliac crest cortical bone and ulnar coronoid process required trimming of the bone fragment, and the lack of a cartilage layer on the surface of the iliac bone increased the incidence of postoperative arthritis.²⁴ The size and shape of the iliac bone after trimming are key intraoperative factors. Chung et al.²⁶ excised and trimmed the ipsilateral tricortical iliac crest bone to $2 \times 1 \times 1$ cm to repair a comminuted fracture of the coronoid process complicated by an olecranon fracture in one patient and obtained high surgical efficacy.

In previous studies, other bones have been also adopted for coronoid process reconstruction. In 2013, Silveira et al.¹² first used costal cartilage as an autograft for ulnar coronoid process reconstruction. The authors considered that the shape consistency between the costal bone and ulnar coronoid process was significantly superior to that of the iliac crest. The osseous substance of costal bone fused with the ulna, and the cartilage substance possessed high plasticity, which contributed to reconstruction of humeroulnar joint surface. In 2017, Erhart et al.²⁷ reported a case of paraplegia complicated by elbow joint trauma. Autologous navicular bone was used as a cartilage graft for coronoid process reconstruction. Postoperatively, the elbow joint was stable and relevant function was restored. Hackl et al.¹⁵ performed an *in silico* analysis of fitting accuracy, and the results suggested that a distal clavicle autograft may be suitable to replace a transverse defect of the coronoid process; however, such an autograft may not fully reconstruct the anteromedial and anterolateral aspects of the coronoid.

Along with the development of prosthetic materials and technologies, certain progress has been made in the application of prostheses for coronoid process reconstruction.

Gray et al.²⁸ and Alolabi et al.^{23,29} established a cadaveric model with coronoid process defects (40%) and elbow joint instability in an *in vitro* biomechanics study. A metal prosthesis with a shape identical to that of the coronoid process was adopted for coronoid process reconstruction. After implantation, the stability of the elbow joint was restored. Collateral ligament injury should be repaired simultaneously during reconstruction surgery. In 2017, Bellato and O'Driscoll¹⁰ first adopted a non-anatomical metal prosthesis for coronoid process reconstruction in three cases. During the long-term follow-up of 10 to 12 years, the patients' elbow joint pain completely resolved, their joint stability was excellent, their joint movement improved to varying degrees, and the position of their coronoid process prosthesis remained fixed without loosening after implantation surgery. The authors considered that coronoid process reconstruction using a prosthesis was a feasible option for coronoid process defects and persistent elbow joint instability. Accurate assessment of the size and geometric characteristics of the coronoid is paramount because it plays the main role in the longevity of the prosthesis. Zhang et al.³⁰ showed that the bilateral coronoid processes share high similarity in terms of their three-dimensional structure and articular surface morphology, suggesting that the osseous architecture of a coronoid process with a comminuted fracture can be predicted by the morphological characteristics of the contralateral side. Although individually designed prostheses properly adapt to the articular surface, they may be too expensive for some surgical facilities.

Selection of fixation methods

Multiple internal fixation approaches can be used for coronoid process fractures, such as steel wire fixation, Kirschner wire fixation, tension screw fixation, micro-steel

plate fixation, anchor fixation, and pallial line technology fixation. Internal fixation methods should be chosen according to the bone graft size, shape of the bone fracture, quality of the osseous substance, and pattern of injury. Because of the lack of biomechanics analyses, hollow screw fixation is mainly adopted for coronoid process reconstruction because the reconstructed "coronoid process" is suitable for screw fixation in terms of the osseous substance and size. Moritomo et al.²⁰ and Chung et al.²⁶ performed coronoid process reconstruction with the olecranon process and iliac bone using a screw for fixation and obtained an excellent fixation effect. Nevertheless, Bellato et al.¹¹ argued that the use of a single screw for fixation lacked sufficient stability. They recommended the use of two to three screws to fix the graft from different angles and stated that the distal end of the screws should be distant from the articular surface. Besides screws, micro-plate fixation and Kirschner wire fixation have been applied in clinical practice. Silveira et al.¹² adopted a T-shaped internal fixation plate with variable angles and screws to fix the bone graft during coronoid process reconstruction using a costochondral graft and obtained high clinical efficacy with early functional exercise depending on the bone graft stability. Okazaki et al.³¹ used three 1.5-mm Kirschner wires for bone graft fixation during coronoid process reconstruction in three cases. No dislocation of the bone graft occurred, and elbow joint stability was obtained during follow-up in all three cases (14, 8, and 6 months, respectively).

Surgical skills and precautions of coronoid process reconstruction

Surgical approaches to the elbow joint can be divided into posterior, medial, lateral, and anterior approaches. Minimally invasive arthroscopic approaches can also be

used for the treatment of fresh fractures by surgeons who are skilled in performing elbow arthroscopy.³² The surgical approach for coronoid process reconstruction should be selected based upon the associated injuries of the elbow joint and adjacent soft tissues, previous surgical approaches, reconstruction material sampling, and the fixation method.^{10,11,13,18,20} Matching between the bone graft and elbow joint and maintaining concentric motion of the humeroulnar joint are widely recognized as keys to successful coronoid process reconstruction. In terms of matching between the bone graft and elbow joint, Van Riet et al.,¹⁸ Ring et al.,¹³ Ring and Jupiter,¹⁴ Esser,¹⁷ Chen and Ring,⁹ Moritomo et al.,²⁰ and Ramirez et al.²⁴ recommended use of the radial head or olecranon process for coronoid process reconstruction because their anatomical structures are similar to those of the coronoid process, allowing for proper matching with the elbow joint after slight repairing and trimming. For materials that differ in shape from the ulnar coronoid process, such as iliac bone and costochondral bone, Chung et al.,²⁶ Kohls-Gatzoulis et al.,³³ Okazaki et al.,³¹ and Silveira et al.¹² considered that the bone grafts should be carefully trimmed into a shape similar to that of the ulnar coronoid process intraoperatively to avert collision between the "coronoid process" and humeral trochlea during flexion and extension of the elbow joint. During coronoid process reconstruction, the scarred soft tissues of the coronoid fossa should be eliminated. The old fractured ends should be trimmed until *errhysis* from the spongy bone appears, which contributes to the healing of the reconstructed bone graft.

Chung et al.²⁶ and Okazaki et al.³¹ suggested that repairing injuries of ligaments, insertional tendons, and the anterior joint capsule establish and maintain elbow joint stability. After intraoperative fixation of

the bone graft, exploration of the soft tissues surrounding the elbow joint should be performed. An elbow joint stress test can be performed when necessary to identify any medial collateral ligament injuries (patients usually refuse to undergo this test preoperatively because of pain). The equipment and duration of external fixation and brace application after surgery are controversial. In clinical practice, hinged plaster or a brace is mainly adopted for elbow joint fixation. Bellato et al.¹¹ used a cast to fix the affected limb for 3 weeks in three patients who underwent coronoid process reconstruction using the allogeneic radial head. Ring et al.¹³ used a hinged external fixator for 36 days in a patient who had undergone coronoid process reconstruction, and postoperative follow-up revealed that the function of the elbow joint was well restored. How to avert the incidence of ankylosis and accelerate restoration of elbow joint function has gained increasingly more attention over time. The duration of fixation has been shortened from 4 to 5 weeks to 2 to 3 weeks. Patients wearing a hinged brace can perform passive functional exercises under a physician's guidance. The range of flexion and extension can be gradually increased by 5° to 10° daily. Nevertheless, premature removal of the fixator affects bone healing and soft tissue repair, thereby influencing elbow joint stability.

Clinical efficacy of coronoid process reconstruction

Ulnar coronoid process reconstruction has been seldom reported. All such studies have had small sample sizes, and the reported curative effects are quite different. Clinical efficacy is influenced by multiple factors; in particular, the severity of injury and surgical methods affect the surgical efficacy of coronoid process reconstruction. Ring

et al.¹³ performed coronoid process reconstruction using autologous radial head fragments in eight patients with capitulum radii fractures complicated by coronoid process fractures. Excellent clinical efficacy was obtained in four patients, good clinical efficacy in one, and moderate clinical efficacy in three. The Mayo score ranged from 65 to 100 (average, 83). The clinical efficacy in four patients with terrible triad injury of the elbow was higher than that in four patients with olecranon fracture and dislocation.

Van Riet et al.¹⁸ performed coronoid process reconstruction using the allogeneic capitulum radii in three patients. Poor clinical efficacy was obtained in two patients, one of whom required total elbow replacement. Bellato et al.¹¹ reported that three patients obtained high clinical efficacy with restoration of normal function. The authors made certain modifications based on the findings of Van Riet et al.¹⁸ They tilted the osteotomy to increase the contact area between the bone graft and basal part of the original coronoid process of the ulna. They also fixed the bone graft from different angles using three screws and adjusted the position of bone graft implantation. Kohls-Gatzoulis et al.³³ and Chung et al.²⁶ obtained high clinical efficacy after coronoid process reconstruction using iliac bone, although the sample size was quite small. Kohls-Gatzoulis et al.³³ reported that the postoperative range of elbow joint flexion and extension was 45° to 120° and that rotation function was completely normal. The Morrey score was 94. Chung et al.²⁶ reported that the postoperative range of elbow joint flexion and extension was 0° to 140° and that rotation function was fully restored. The Mayo score was 100.

Moritomo et al.²⁰ used the olecranon process for coronoid process reconstruction in two patients. The elbow joint pain and stability were significantly improved, and the range of flexion and extension was

enhanced to varying degrees postoperatively (the range of motion increased from 35°–80° to 20°–135° in one patient and from 5° to 30°–120° in the other patient). No resorption of the reconstructed bone was observed during follow-up. The authors considered that excision of the olecranon process exerted no effect upon elbow joint stability.²⁰ Silveira et al.¹² successfully performed ulnar coronoid process reconstruction using costal bone as an autograft. During the 3-month postoperative follow-up, the elbow joint stability improved, the range of flexion and extension increased from 80°–100° to 10°–100° and from 10° to 70° for backward rotation, the Mayo score improved from 35 to 70, and the Oxford elbow score improved from 16 to 42. Bellato and O'Driscoll¹⁰ first adopted a metal prosthesis for coronoid process reconstruction in three patients with a >10-year follow-up. The visual analog scale score was <3 in all three patients, elbow joint stability was satisfactory, and no loosening of the prosthesis occurred. However, the range of elbow joint flexion and extension was poor because of severe injury, multiple operations, and simultaneous replacement of the coronoid process and capitulum radii.

Conclusion

This review of biomechanically and clinically based publications suggests that for elbow joint instability caused by a fresh coronoid process comminuted fracture or old fracture with coronoid process absorption, coronoid process reconstruction should be performed to restore elbow joint stability if the instability has been induced by coronoid process defects. There are diverse patterns of coronoid process injury complicated by other injuries. Multiple methods of coronoid process reconstruction are currently being adopted, and a unified standard has not been established. Various non-uniform methods are in use given the

unique qualities of this type of injury, other possible accompanying injured structures, and the short-term follow-up from which firm conclusions can be drawn, making this a complicated injury scenario.

Ethics

The study protocol was not approved by an ethics committee because it did not involve human trials and ethical approval was not applicable.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Funding

This work was supported by the Natural Science Foundation of Guangdong Province (Nos. 2018A030313640 and 2019A1515012176) and the National Natural Science Foundation of China (No. 81101366).

Author contributions

Study design: Runguang Li.

Literature search: Shanwen Zhao, Canjun Zeng, and Runguang Li.

Manuscript preparation: Shanwen Zhao, Canjun Zeng, Song Yuan, and Runguang Li.

All authors read and approved the final manuscript.

ORCID iD

Runguang Li  <https://orcid.org/0000-0002-4703-7180>

References

1. Wells J and Ablove RH. Coronoid fractures of the elbow. *Clin Med Res* 2008; 6: 40–44.
2. Heim U and Bühler M. Kombinierte verletzungen von radius und ulna im proximalen unterarmsegment. In: Holz U and Rehm KE (eds) *57. Jahrestagung der Deutschen Gesellschaft für Unfallchirurgie e.V.* Springer-Verlag Berlin Heidelberg GmbH, 1994, pp.61–79.
3. Closkey RF, Goode JR, Kirschenbaum D, et al. The role of the coronoid process in

- elbow stability. A biomechanical analysis of axial loading. *J Bone Joint Surg Am* 2000; 82-A: 1749–1753.
4. Hull JR, Owen JR, Fern SE, et al. Role of the coronoid process in varus osteoarticular stability of the elbow. *J Shoulder Elbow Surg* 2005; 14: 441–446.
5. Panero E, Gastaldi L, Terzini M, et al. Biomechanical role and motion contribution of ligaments and bony constraints in the elbow stability: a preliminary study. *Bioengineering (Basel)* 2019; 6: 68.
6. Ablove RH, Moy OJ, Howard C, et al. Ulnar coronoid process anatomy: possible implications for elbow instability. *Clin Orthop Relat Res* 2006; 449: 259–261.
7. Rausch V, Hackl M, Seybold D, et al. [Plate osteosynthesis of the coronoid process of the ulna]. *Oper Orthop Traumatol* 2020; 32: 35–46.
8. Papatheodorou LK, Rubright JH, Heim KA, et al. Terrible triad injuries of the elbow: does the coronoid always need to be fixed? *Clin Orthop Relat Res* 2014; 472: 2084–2091.
9. Chen NC and Ring D. Terrible triad injuries of the elbow. *J Hand Surg Am* 2015; 40: 2297–2303.
10. Bellato E and O'Driscoll SW. Prosthetic replacement for coronoid deficiency: report of three cases. *J Shoulder Elbow Surg* 2017; 26: 382–388.
11. Bellato E, Rotini R, Marinelli A, et al. Coronoid reconstruction with an osteochondral radial head graft. *J Shoulder Elbow Surg* 2016; 25: 2071–2077.
12. Silveira GH, Bain GI and Eng K. Reconstruction of coronoid process using costochondral graft in a case of chronic posteromedial rotatory instability of the elbow. *J Shoulder Elbow Surg* 2013; 22: e14–e18.
13. Ring D, Guss D and Jupiter JB. Reconstruction of the coronoid process using a fragment of discarded radial head. *J Hand Surg Am* 2012; 37: 570–574.
14. Ring D and Jupiter JB. Reconstruction of posttraumatic elbow instability. *Clin Orthop Relat Res* 2000; 44–56.
15. Hackl M, Knowles NK, Wegmann K, et al. Coronoid process reconstruction with a distal clavicle autograft: an in silico analysis of fitting accuracy. *J Shoulder Elbow Surg* 2020; S1058-2746(20)30775-8.
16. Bellato E and O'Driscoll SW. Management of the posttraumatic coronoid-deficient elbow. *J Hand Surg Am* 2019; 44: 400–410.
17. Esser RD. Reconstruction of the coronoid process with a radial head fragment. *Orthopedics* 1997; 20: 169.
18. Van Riet RP, Morrey BF and O'Driscoll SW. Use of osteochondral bone graft in coronoid fractures. *J Shoulder Elbow Surg* 2005; 14: 519–523.
19. Kataoka T, Moritomo H, Miyake J, et al. Three-dimensional suitability assessment of three types of osteochondral autograft for ulnar coronoid process reconstruction. *J Shoulder Elbow Surg* 2014; 23: 143–150.
20. Moritomo H, Tada K, Yoshida T, et al. Reconstruction of the coronoid for chronic dislocation of the elbow. Use of a graft from the olecranon in two cases. *J Bone Joint Surg Br* 1998; 80: 490–492.
21. An KN, Morrey BF and Chao EY. The effect of partial removal of proximal ulna on elbow constraint. *Clin Orthop Relat Res* 1986; 270–279.
22. Bell TH, Ferreira LM, McDonald CP, et al. Contribution of the olecranon to elbow stability: an in vitro biomechanical study. *J Bone Joint Surg Am* 2010; 92: 949–957.
23. Alolabi B, Gray A, Ferreira LM, et al. Reconstruction of the coronoid process using the tip of the ipsilateral olecranon. *J Bone Joint Surg Am* 2014; 96: 590–596.
24. Ramirez MA, Ramirez JM, Parks BG, et al. Olecranon tip osteoarticular autograft transfer for irreparable coronoid process fracture: a biomechanical study. *Hand (N Y)* 2015; 10: 695–700.
25. Wegmann K, Knowles NK, Lalone EE, et al. The shape match of the olecranon tip for reconstruction of the coronoid process: influence of side and osteotomy angle. *J Shoulder Elbow Surg* 2019; 28: e117–e124.
26. Chung CH, Wang SJ, Chang YC, et al. Reconstruction of the coronoid process with iliac crest bone graft in complex fracture-dislocation of elbow. *Arch Orthop Trauma Surg* 2007; 127: 33.

27. Erhart S, Lutz M, Deml C, et al. Restoring independency with an osteochondral graft of the navicular for coronoid process reconstruction. *Arch Orthop Trauma Surg* 2017; 137: 225–232.
28. Gray AB, Alolabi B, Ferreira LM, et al. The effect of a coronoid prosthesis on restoring stability to the coronoid-deficient elbow: a biomechanical study. *J Hand Surg Am* 2013; 38: 1753–1761.
29. Alolabi B, Gray A, Ferreira LM, et al. Reconstruction of the coronoid using an extended prosthesis: an in vitro biomechanical study. *J Shoulder Elbow Surg* 2012; 21: 969–976.
30. Zhang HL, Lin KJ and Lu Y. Prediction of the size of the fragment in comminuted coronoid fracture using the contralateral side: an analysis of similarity of bilateral ulnar coronoid morphology. *Orthop Surg* 2020; 12: 1495–1502.
31. Okazaki M, Takayama S, Seki A, et al. Posterolateral rotatory instability of the elbow with insufficient coronoid process of the ulna: a report of 3 patients. *J Hand Surg Am* 2007; 32: 236–239.
32. Oh WT, Do WS, Oh JC, et al. Comparison of arthroscopy-assisted versus open reduction and fixation of coronoid fractures of the ulna. *J Shoulder Elbow Surg* 2020.
33. Kohls-Gatzoulis J, Tsiridis E and Schizas C. Reconstruction of the coronoid process with iliac crest bone graft. *J Shoulder Elbow Surg* 2004; 13: 217–220.