Appropriate excision time of heterotopic ossification in elbow caused by trauma

Shu-Kun He, Min Yi, Gang Zhong, Shi-Qiang Cen, Jia-Lei Chen, Fu-Guo Huang*
Department of Orthopedics, West China Hospital, Sichuan University, Sichuan, PR China

ARTICLE INFO
Article history:
Received 14 September 2016
Received in revised form 23 November 2017
Accepted 24 November 2017
Available online 28 December 2017

Keywords:
Elbow
Heterotopic ossification
Trauma
Timing of excision

ABSTRACT
Objective: The aim of this study was to investigate the optimal timing for the resection of heterotopic ossification (HO) of the elbow.

Methods: We retrospectively reviewed 42 patients who were treated operatively for heterotopic ossification of the elbow from March 2010 to December 2014 at our institution. The patients were divided into early (before 12 months) and late (after 12 months) excision groups. In the early excision group (17 patients), the average time from the initial injury to HO excision was 7.4 (3–11) months, and in the late excision group (25 patients), the average time was 33.5 (12–240) months. Every patient was evaluated by range of motion (ROM), the Mayo Elbow Performance Score (MEPS), postoperative complications and HO recurrence.

Results: The preoperative mean ROM in the late excision group was greater than that of the early excision group, suggesting that the ROM is expected to increase even without surgery. Both early and late surgery increased ROM and MEPS, but early surgery improved ROM and MEPS more than late surgery did (p < .05).

Conclusions: Early excision of HO can provide better elbow function, as indicated by ROM and MEPS. Considering that there were no notable differences in postoperative ROM and MEPS, HO recurrence, or postoperative complications, we concluded that early excision is safe and that the time from an elbow injury to surgery may be shortened.

Level of Evidence: Level III, therapeutic study.
© 2017 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Compared with other joints, the elbow commonly shows growth of a heterotopic ossification (HO), a generally acknowledged complication following an elbow injury. The specific cause of post-traumatic HO may be multifactorial, but it remains unclear, requiring further study. The development of HO around the elbow may impair the range of motion (ROM) and even lead to complete loss of movement. If non-operative treatment cannot result in a functional ROM, surgery becomes the effective method to restore elbow function. Many authors have reported that the time from initial injury to surgical release is always more than one year until the maturation of HO occurs in order to avoid recurrence. However, as time goes by, the elbow function becomes worse as a result of soft tissue contracture and muscular atrophy. The purpose of this study was to compare the improvements of ROM and the Mayo Elbow Performance Score (MEPS) after surgery between the early excision group and the late excision group. In addition, we investigated whether the time from an elbow injury to surgery might be shortened.

Methods

Patients

After obtaining institutional review board approval, we retrospectively analyzed all patients who were treated with open surgical release at our institution between March 2010 and December 2014. Inclusion criteria: (1) post-traumatic stiff elbow with an ROM

https://doi.org/10.1016/j.aott.2017.11.008
1017-955X/© 2017 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
less than 100°; (2) preoperative X-ray images were observed in HO and were confirmed during surgery; and (3) imaging of bone and joint development in good condition with no deformity. Exclusion criteria: (1) elbow stiffness caused by skin or muscle contracture; (2) HO caused by burns or central nervous system injury; and (3) limited ROM in patients with trauma history before the injury. Fifty-one patients satisfied the inclusion criteria and eight patients were excluded after checking the medical records and plain films. In December 2015, we investigated 43 patients who were treated; we were unable to contact one patient. Overall, 42 patients received telephone interviews with more than 12 months of medical records; the average follow-up time was 37 (12–65) months. To avoid HO recurrence and postoperative complications and to compare the outcome between early surgical excision of HO and late surgical excision, we established a time limit of 12 months to define early (<12 months) and late (>12 months) surgical excision.14 In the early excision group, 17 patients had an average time of 7.4 (3–11) months before surgery; the late excision group, 25 patients had surgery after an average time of 33.5 (12–240) months.

Surgery

The indication of surgical excision was at least three months after injury and continual loss of elbow flexion of the upper limb in daily activities. All surgeries were performed with the patient in the supine position and under general anesthesia with a tourniquet. While protecting and preserving important structures, surgical approaches were individualized considering the location of the HO, previous incisions, and skin condition. In the early excision group, medial and lateral approaches were utilized in 14 patients, a medial approach in two, and a lateral approach in one. In the late excision group, medial and lateral approaches were utilized in 13 patients, a medial approach in four, a lateral approach in five, an anterior approach in one, and a posterior approach in two. With the release of contracted capsular structures, HO excision, and ligament re-constructions, we achieved our goal in all patients (i.e., obtaining >130° of flexion and <10° of flexion contracture by passive motion intraoperatively).14 Intraoperative ROM measured with a sterile goniometer in the flexion–extension arc of all patients was recorded. In addition, the ulnar nerve was released in 37 patients with ulnar nerve symptoms and transferred anteriorly into the subcutaneous layer.

Aftercare

A unilateral hinged external fixator was applied for protection on all patients for as long as four weeks (4–6 weeks) post-operatively. Physical therapy consisted of active assisted and mild passive flexion and extension exercises and was initiated on the second postoperative day continuing until the ROM was no longer changed by the flexion and extension exercises. The exercise was tailored to each patient’s individual conditions and usually continued for 4–6 months. All of the patients received indomethacin for 4 weeks at a dose of 25 mg three times a day to prevent HO recurrence. No radiotherapy was used for any patient.

Data measures and evaluation

Data from all patients regarding sex, age, involvement of dominant elbow, type of injury, surgical approach, and initial treatment were collected. Preoperative biplanar radiographs were obtained to assess the location of heterotopic ossification as medial, lateral, anterior, or posterior. Computed tomography (CT) with 3-dimensional reconstruction was not routinely utilized to evaluate HO; quantitative analysis of HO was not done. The elbow flexion and flexion contracture arc was measured with a goniometer, and the MEPS was evaluated before the surgical excision of HO. In addition, ulnar nerve palsy was assessed by electrophysiological studies only when ulnar nerve dysfunction was suspected prior to surgery. The final ROM and MEPS were assessed at the final follow-up. Medical records covering more than 12 months were available for 13 patients. Twenty-nine patients who did not visit after one year postoperatively were interviewed by telephone; these patients stated that the final ROM was essentially unchanged from the time of discharge. Therefore, we defined the final ROM of those patients as the joint activity measured at the last visit. Postoperative complications and recurrence of HO were also reviewed.

Statistical analysis

All independent variables were coded as continuous or categorical data. The ROM and MEPS were assessed by the independent sample T test. Fisher’s exact test was used to assess categorical variables. The level of significance was predetermined at P < .05. Statistical analysis was performed using SPSS 22 software (IBM, Armonk, NY, USA).

Results

Comparison of ROM and MEPS after surgery between the early excision group and the late excision group

The comparison of clinical characteristics of patients showed no significant difference between the two groups regarding sex, age, involvement of dominant elbow, type of injury, location of HO, surgical approach, initial treatment, follow-up time, postoperative complications, or recurrence of HO (Table 1). The ROM and MEPS of the two groups before surgery and at the final follow-up were summarized in Table II. In the early excision group, the average postoperative flexion was 114° (50°–135°), which had improved from 63° (10°–100°) preoperatively with an average improvement of 51° (–5° to 105°). The average flexion contracture decreased from 47° (5°–90°) preoperatively to 16° (0°–50°) postoperatively with an average improvement of –31° (–70° to 0°). The average total arc of motion increased from 16° (0°–70°) preoperatively to 98° (20°–125°) postoperatively, with an average improvement of 82° (15°–120°). In the control group, the average postoperative flexion was 112° (80°–135°), which had improved from 81° (5°–120°) preoperatively with an average improvement of 31° (0°–105°). The average flexion contracture decreased from 45° (0°–95°) preoperatively to 19° (0°–70°) postoperatively with an average improvement of –26° (–80° to 10°). The average total arc of motion increased from 35° (0°–90°) preoperatively to 93° (50°–130°) postoperatively, with an average improvement of 57° (0°–120°). The average MEPS increased from 37 (20–55) preoperatively to 91 (60–100) postoperatively with an average improvement of 54 (5–80) in the early excision group, and the average MEPS increased from 47 (20–70) preoperatively to 85 (55–100) postoperatively with an average improvement of 38 (15–80) in the late excision group. In all clinical variables, the preoperative flexion (P = 0.045), total arc of motion (P = 0.013) and MEPS (P = 0.027) had significant differences between the two groups (Table 2). Additionally, the preoperative mean ROM in the late excision group is greater than that of the early excision group; thus, it can be concluded that as time passes, the ROM increases even if no procedure is done. In addition, differences of improvement in flexion (P = 0.042), total arc of motion (P = 0.024) and MEPS (P = 0.001) between the two groups were significant (Table 2), suggesting that early or late surgery both increased ROM.
and MEPS, but early surgery statistically improved ROM and MEPS more than late surgery.

**Evaluation of potentially shortening the time from elbow injury to surgery**

Ten patients showed radiographic recurrence of HO; clinical recurrence associated with dissatisfied ROM was observed only in three patients after comprehensive rehabilitation exercises (Table 3). In one patient, repeat excision of HO was performed 17 months after the first surgery. After the second excision, HO did not recur and the final follow-up ROM was increased. The other two patients accepted the result (i.e., recurring HO) but refused a second surgery (Table 3). One patient had persistent ulnar nerve palsy during the final follow-up (Table 3). However, no patient showed worsening ulnar nerve palsy after the surgery. Two patients developed infections immediately after the surgery; both patients were cured by irrigation and debridement with systemic administration of antibiotics (Table 3). However, the infection still affected the final ROM in one patient. One patient had elbow instability and underwent a secondary surgery to reconstruct elbow stability by medial and lateral collateral ligament reconstruction (Table 3). There was no notable difference concerning postoperative complications (P = 0.888) or recurrence of HO (P = 0.972) between the early and late excision groups (Table 1).

**Discussion**

The existence of HO of the elbow can impede patients’ personal lives, especially when the dominant extremity is affected. The surgical release of elbow stiffness caused by HO after trauma allows patients to regain satisfactory elbow ROM. The purpose of our study was to compare improvements of ROM and MEPS after surgery between the early excision group and the late excision group. In addition, we wished to know whether the time from elbow injury to surgery might be shortened. The formation of HO around the elbow can manifest from two to 12 weeks after trauma, traumatic brain injury, or burn.15 The maturation of bone is indicated by smooth, well-demarcated cortical margins and defined trabecular markings, generally about three to six months after HO onset.16 In previous studies of patients with post-traumatic HO, surgical excision of HO was usually delayed from the time of injury to surgery for 12–24 months.5–10,18 Hastings et al.19 delayed surgery to reduce recurrence of HO until the HO appeared mature in the plain film as well as a bone scan and serum alkaline phosphatase.

### Table 1
Comparison of patient clinical characteristics.

| Variable                               | Early excision group (n = 17) | Late excision group (n = 25) | P value |
|----------------------------------------|------------------------------|-----------------------------|---------|
| Gender, n                              |                              |                             |         |
| Male                                   | 13                           | 17                          | .731    |
| Female                                 | 4                            | 8                           |         |
| Age, average (range), y                | 37 (20–63)                   | 36 (17–62)                  | .800    |
| Involvement of dominant elbow, n       |                              |                             | .531    |
| Yes                                    | 8                            | 15                          |         |
| No                                     | 9                            | 10                          |         |
| Type of injury, n                      |                              |                             | .146    |
| Distal humeral fracture                | 4                            | 12                          |         |
| Proximal radial or ulnar fracture      | 7                            | 10                          |         |
| Elbow dislocation/fracture-dislocation | 6                            | 3                           |         |
| Location of heterotopic ossification, n|                              |                             | .951    |
| Medial                                 | 3                            | 3                           |         |
| Lateral                                | 2                            | 4                           |         |
| Anterior                               | 13                           | 18                          |         |
| Posterior                              | 14                           | 19                          |         |
| Surgical approach, n                   |                              |                             |         |
| Medial and lateral approaches          | 14                           | 13                          | .329    |
| Medial approach                        | 2                            | 4                           |         |
| Lateral approach                       | 1                            | 5                           |         |
| Anterior approach                      | 0                            | 1                           |         |
| Posterior approach                     | 0                            | 2                           |         |
| Initial treatment, n                   |                              |                             | .374    |
| Nonoperative                           | 1                            | 5                           |         |
| Operative                              | 16                           | 20                          |         |
| Time to index surgery, average (range), mo | 7.4 (3–11)                  | 33.5 (12–240)               | .010    |
| Follow-up time, average (range), mo    | 42 (16–63)                   | 33 (12–65)                  | .067    |
| Postoperative complications            | 3                            | 4                           | .888    |
| Recurrence of heterotopic ossification | 4                            | 6                           | .972    |

### Table 2
Comparison of preoperative and postoperative ROM and MEPS.

| Variable                      | Early excision group | Late excision group | P value |
|-------------------------------|----------------------|---------------------|---------|
| Preoperative                  |                      |                     |         |
| Flexion, º                    | 63 (10–100)          | 81 (5–120)          | .045    |
| Flexion contracture, º        | 47 (5–90)            | 45 (0–65)           | .818    |
| Total arc of motion, º        | 16 (0–70)            | 35 (0–90)           | .013    |
| Postoperative                 |                      |                     |         |
| Flexion, º                    | 114 (50–135)         | 112 (80–135)        | .682    |
| Flexion contracture, º        | 16 (0–50)            | 19 (0–70)           | .587    |
| Total arc of motion, º        | 98 (20–125)          | 93 (50–130)         | .556    |
| Improvement, º                |                      |                     |         |
| Flexion, º                    | 51 (–5–105)          | 31 (0–105)          | .042    |
| Flexion contracture, º        | –31 (–70 to 0)       | –26 (–80 to 10)     | .576    |
| Total arc of motion, º        | 82 (15–120)          | 57 (0–120)          | .024    |
| MEPS                          |                      |                     |         |
| Preoperative                  | 37 (20–55)           | 47 (20–70)          | .027    |
| Postoperative                 | 91 (60–100)          | 85 (55–100)         | .187    |
| Improvement                   | 54 (15–80)           | 38 (15–80)          | .001    |

a ROM, range of motion.

b MEPS, Mayo elbow Performance Score.

c All measurements are presented as average (range).

d Improvement of Flexion contracture needs to have the “+” sign convention consistent with comments in the Abstract, Methods, and Results sections.

and MEPS, but early surgery statistically improved ROM and MEPS more than late surgery.

**Discussion**

The existence of HO of the elbow can impede patients’ personal lives, especially when the dominant extremity is affected. The surgical release of elbow stiffness caused by HO after trauma allows patients to regain satisfactory elbow ROM. The purpose of our study was to compare improvements of ROM and MEPS after surgery between the early excision group and the late excision group. In addition, we wished to know whether the time from elbow injury to surgery might be shortened. The formation of HO around the elbow can manifest from two to 12 weeks after trauma, traumatic brain injury, or burn.15 The maturation of bone is indicated by smooth, well-demarcated cortical margins and defined trabecular markings, generally about three to six months after HO onset.16 In previous studies of patients with post-traumatic HO, surgical excision of HO was usually delayed from the time of injury to surgery for 12–24 months.5–10,18 Hastings et al.19 delayed surgery to reduce recurrence of HO until the HO appeared mature in the plain film as well as a bone scan and serum alkaline phosphatase.
and the late excision group in the notable difference was observed between the early excision group caused by soft tissue contracture and muscular atrophy. Currently, there is no clear evidence that late excision of HO can decrease recurrence and result in better ROM and MEPS. Koh et al22 concluded that the time from the initial injury to the index surgical release was the only independent variable affecting the final ROM and delayed surgery (>19 months), adversely affecting the final ROM. Baldwin et al23 also suggested that waiting longer than 12 months decreases the probability of achieving functional ROM. In addition, some authors have reported that early excision can achieve satisfactory outcomes, and they believe that surgical delay of HO is unnecessary.4,16,18,24

In our study, surgical excision of HO was performed an average of 7.4 (3–11) months after the injury in the early excision group. Both groups showed considerable improvements in ROM and MEPS. Although there was no significant difference in the final follow-up ROM and MEPS between the two groups, early surgery statistically improved ROM and MEPS more than late surgery. Patients with HO after elbow trauma are often limited in flexion and extension function, and the functional ROM required for normal daily activities is 30°–130°, suggesting that it is more important to restore flexion. Compared with the late excision group, the flexion arc of the elbow joint was worse in the early excision group preoperatively and the improvement of flexion was better postsurgically.

No significant difference was observed regarding the rate of postoperative complications including symptomatic recurrence of HO, ulnar nerve, infection, and elbow instability, between the early excision group (n = 3) and the late excision group (n = 4). No notable difference was observed between the early excision group and the late excision group in the final follow-up of ROM (P = 0.556) and MEPS (P = 0.187). In addition, because of more improvements of ROM (P = 0.024) and MEPS (P = 0.001), we believe that early surgical treatment of elbow stiffness caused by post-traumatic HO can result in good clinical scores and increased elbow movement.

HO recurrence is a serious complication, often compromising the long-term result. HO recurrence is a serious complication, often compromising the long-term result. Although some patients can be asymptomatic or minimally symptomatic after rehabilitation exercises, others may still experience restriction in elbow motion; in this situation, re-excision of the HO may be the most effective way to increase the ROM. In our study, of the 10 patients with recurrence of HO, only three patients had severe limitations in elbow function. Two of the three patients refused to undergo another operation; the remaining one patient chose to undergo a second surgical resection of HO, and the postoperative elbow function improved well.

Previous studies reported that periaricular HO may lead to cubital tunnel syndrome. Although there were 37 patients with ulnar nerve symptoms resulting from compression in our study, only a small number of patients had severe ulnar nerve palsy symptoms, and most of the rest were mild symptoms before surgery. Most of the patients recovered full ulnar nerve function attributed to thorough operative resection of HO and submuscular ulnar nerve transfer. Only one patient had persistent ulnar nerve palsy without deterioration after surgery; the elbow activity was not affected.

The incidence of joint infection is very low, and the risk factors include diabetes mellitus, immune suppression, joint surgery or injection, and infection of overlying skin. Once the joint infection is diagnosed, surgical intervention and antibiotic therapy may need to start as soon as possible to avoid permanent damage to the joint cartilage. In our study, two patients had an elbow joint infection after surgery. Unfortunately, the elbow function of one patient was still affected after early debridement and appropriate antibiotic treatment.

Following capsular structure release and excision of the HO to regain motion in a stiff elbow, the joint with ligament reconstructions may still be unstable. External hinged fixation can be used in this situation to provide sufficient stability to allow for soft tissue healing without limiting early postoperative motion. Thus, we recommend the routine use of external fixation after HO resection of the elbow. However, we still performed a second surgical reconstruction of elbow joint stability in a patient after excision of HO. Fortunately, the patient’s elbow function was partially restored without elbow instability.

Several authors support the use of single-dose radiotherapy to prevent HO of the elbow because radiotherapy is a safe and efficacious treatment and leads to excellent function of the vast majority of patients. A meta-analysis showed that low-dose (<2500 cGy) radiotherapy was an effective way to prevent HO development, and multi-fraction radiation was superior to single fraction radiotherapy, whether postoperative or preoperative. However, several authors disagree with the use of prophylactic radiotherapy because using radiotherapy to prevent HO after elbow injury may increase the incidence of nonunion in the fracture site and the risk of causing a malignancy. When considering the costs and risks of radiotherapy, we did not use it as prophylaxis for recurrence of HO in our study. Moreover, additional studies are encouraged to determine the safety and efficiency of radiotherapy prophylaxis.

There were three limitations in this study. First, our research was a retrospective type of study with inherent deficiencies that could lead to confusion or observer bias. Second, our preoperative evaluation of HO was based only on X-ray plain films without quantification of HO by using computed tomography scans. Third, we were unable to measure the final ROM of 29 patients; they said in a telephone interview that the final ROM basically did not change from the discharge time. As the ROM reaches a plateau over time, we define the ROM measured at the time of discharge as the final ROM.
Conclusions
Early excision of HO can result in better elbow function, as indicated by the ROM and MEPS. Considering no notable difference in postoperative ROM and MEPS, recurrence of HO and post-operative complications, early excision is safe, and the time from the elbow injury to surgery may be shortened.

Acknowledgements
We thank Jin-Hai Guo MD, Shi-Zhou Wu MD, Department of Orthopedics, West China Hospital, Sichuan University for help with data collection and their extraordinary commitment to this project.

References
1. Cohen RB, Hahn CV, Tabas JA, et al. The natural history of heterotopic ossification in patients who have fibroblastos of ossification. A study of forty-four patients. J Bone Joint Surg 1993;75(2):215–219.
2. Gardner RJ, Yun K, Craw SM. Familial ectopic ossification. J Med Genet. 1988;25(2):113–117.
3. Ellerin BE, Helfet D, Parikh S, et al. Current therapy in the management of heterotopic ossification of the elbow: a review with case studies. Am J Phys Med Rehabil. 1999;78(2):259–271.
4. McAliffe JA, Wolfson AH. Early excision of heterotopic ossification about the elbow following radiation therapy. J Bone Joint Surg Am. 1997;80(3):453–454.
5. Abrams RA, Simmons BP, Brown RA, Botte MJ. Treatment of posttraumatic radioulnar synostosis with excision and low-dose radiation. J Hand Surg. 1993;18(4):703–707.
6. Beessensner DM, Patterson SD, King GJ. Early excision of heterotopic bone in the forearm. J Hand Surg. 2000;25(3):483–488.
7. Garland DE. A clinical perspective on common forms of acquired heterotopic ossification. Clin Orthop Relat Res. 1991;263(263):13–29.
8. Garland DE, Hanscom DA, Keenan MA, Smith C, Moore T. Resection of heterotopic ossification in the adult with head trauma. J Bone Joint Surg Am. 1985;67(8):1261–1269.
9. Roberts JB, Pankrazis DG. The surgical treatment of heterotopic ossification at the elbow following long-term coma. J Bone Joint Surg 1979;61(5):760–763.
10. Summerfield SL, Diovigiani C, Weiss AP. Heterotopic ossification of the elbow. J Shoulder Elb Surg. 1997;6(3):321–332.
11. Tisonio I, Leclercq C, Rochet JM. Heterotopic ossification of the elbow in patients with burns. Results after early excision. J Bone Jt Surg 2004;86(3):396–403.
12. Morrey BF, Adams RA. Semiconstrained arthroplasty for the treatment of rheumatoid arthritis of the elbow. J Bone Joint Surg Am. 1992;74(4):479–490.
13. Elgazzar AH, Collier BD. Heterotopic ossification. J Nucl Med. 2002;43(1):346–353.
14. Park MJ, Chang MJ, Lee YB, Kang HJ. Surgical release for posttraumatic loss of elbow flexion. J Bone Joint Surg Am. 2010;92(2):2692–2699.
15. Orzel JA, Rudd TG. Heterotopic bone formation: clinical, laboratory, and imaging correlation. J Nucl Med. 1985;26(2):125–132.
16. Viola RW, Hanel DP. Early “simple” release of posttraumatic elbow contracture associated with heterotopic ossification. J Hand Surg. 1999;24(2):370–380.
17. Viola RW, Hastings H 2nd. Treatment of ectopic ossification about the elbow. Clin Orthop Relat Res. 2000;370(370):65–86.
18. Morimoto H, Tada K, Yoshida T. Early, wide excision of heterotopic ossification in the medial elbow. J Shoulder Elb Surg. 2001;10(2):164–168.
19. Hastings H 2nd, Graham TJ. The classification and treatment of heterotopic ossification about the elbow and forearm. Hand Clin. 1994;10(3):417–437.
20. Lundborg G. Surgical treatment for ulnar nerve entrapment at the elbow. J Hand Surg Br Eur Volume. 1992;17(3):245–247.
21. Veltman ES, Lindenhouvis AL, Kloon P. Improvements in elbow motion after resection of heterotopic bone: a systematic review. Strateg Trauma Limb Reconstr. 2014;9(2):65–71.
22. Koh KH, Lim TK, Lee HJ, Park MJ. Surgical treatment of elbow stiffness caused by post-traumatic heterotopic ossification. J Shoulder Elb Surg. 2013;22(8):1128–1134.
23. Baldwin K, Hosalkar HS, Donegan DJ, Rendon N, Ramsey S, Keenan MAE. Surgical resection of heterotopic bone about the elbow: an institutional experience with traumatic and neurologic etiologies. J Hand Surg. 2011;36(5):796–803.
24. Chen S, Yu SY, Yan H, et al. The time point in surgical excision of heterotopic ossification of post-traumatic stiff elbow: recommendation for early excision followed by early exercise. J Shoulder Elb Surg. 2015;24(8):1165–1171.
25. Morrey BF, Askew IJ, Chao EY. A biomechanical study of normal functional elbow motion. J Bone Jt Surg Am. 1981;63(6):872–877.
26. Almangour W, Schnitzler A, Salga M, Deubau C, Denormalie P, Genet F. Recurrence of heterotopic ossification after removal in patients with traumatic brain injury: a systematic review. Ann Phys Rehabil Med. 2016;59(4):263–269.
27. Cipriano CA, Pill SG, Keenan MAE. Heterotopic ossification following traumatic brain injury and spinal cord injury. J Am Acad Orthop Surg. 2009;17(11):690–697.
28. Wainapel SF, Rao PU, Scheppis AA. Ulnar nerve compression by heterotopic ossification in a head-injured patient. Arch Phys Med Rehabil. 1983;66(8):512–514.
29. Garland DE, Blum CE, Waters RL. Periarticular heterotopic ossification in head-injured patients. Incidence and Location. J Bone Joint Surg Am. 1980;62:1143–1146.
30. Mcgowan AJ. The results of transposition of the ulnar nerve for traumatic ulnar neuritis. Bone Jt J. 1992;74(3):293–301.
31. Chi C. Infectious Arthritis of Native Joints: Mandell, Douglas and Bennett’s Principles of Infectious Diseases. 2010:1443–1460.
32. Tan V, Dalunski A, Capo J. Hotchkiss R. Ringing elbow external fixators: indications and uses. J Am Acad Orthop Surg. 2005;13(8):503–514.
33. Heyd R, Strassmann G, Schopohl B, Zamboglu N. Radiation therapy for the prevention of heterotopic ossification at the elbow. J Bone Joint Surg Br. 2001;83(3):332–334.
34. Milakovic M, Popovic M, Ramas S, Tsao M, Lam H, Chow E. Radiotherapy for the prophylaxis of heterotrophic ossification: a systematic review and meta-analysis of randomized controlled trials. Radiother Oncol. 2015;116(1):4–9.
35. Lindenhouvis A, Linzler D, Jn Ring D, Jupiter J. Comparison of elbow contracture release in elbows with and without heterotrophic ossification restricting motion. J Shoulder Elb Surg. 2007;16(5):621–625.
36. Brady LW. Radiation-induced sarcomas of bone. Skelet Radiol. 1979;4(2):72–78.
37. Kim JH, Chu FC, Woodard HQ, Melamed MR, Huyos A, Cantin J. Radiation-induced soft-tissue and bone sarcoma. Radiology. 1978;129(2):501–508.
38. Park MJ, Kim HG, Lee JY. Surgical treatment of post-traumatic stiffness of the elbow. J Bone Jt Surg Br. 2004;86(3):1158–1162.
39. Sharma S, Rymaszewski LA. Open arthrolysis for post-traumatic stiffness of the elbow: results are durable over the medium term. J Bone Joint Surg Br. 2007 Jun;89(6):778–781.
40. Stans JA, Maritz NG, O’Driscoll SW, Morrey BF. Operative treatment of elbow contracture in patients twenty-one years of age or younger. J Bone Jt Surg Am. 2002;84-A(3):382–387.