Heliyon 10 (2024) e33756

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Case report

Heterotopic ossification of the elbow joint in a child: Successful surgical resection - A case report

Xiaolei Zhao, Hongtao Xu *

Qilu Hospital (Qingdao), Cheeloo College of Medicine, Shandong University, Qingdao, China

A R T I C L E I N F O

Keywords:
Pediatrics
Elbow
Heterotopic ossification
Surgical procedures
Case reports

A B S T R A C T

Background: This case report describes the occurrence of a rare heterotopic ossification of the elbow joint in a child, caused by inappropriate movement after trauma. A successful operation to remove heterotopic ossification was described in the report with satisfactory results.

Case presentation: A 7-year-old boy suffered a supracondylar fracture of the humerus after an accidental fall, and after immobilization with a cast, improper movement resulted in heterotopic ossification of the elbow joint, which severely affected joint function. The heterotopic ossification was surgically removed and a complete recovery was demonstrated at 18 months follow-up. The heterotopic ossification was successfully removed with good elbow function and no recurrence at 18 months follow-up.

Conclusions: The purpose of this report is to show the good results with surgical treatment of heterotopic ossification of the elbow joint in children,when conservative treatment does not work.

1. Background

Heterotopic ossification (HO), first described by the German physician Riedel in 1883, is a common complication in the field of rehabilitation, presenting as lesions similar to benign tumors [1]. It is characterized by ectopic ossification of collagen supporting tissues such as tendons, ligamentum aponeurosis and skeletal muscle. The most commonly affected areas are the hip and elbow joints, and occur mainly in young people, with a lower incidence in children.

HO can be divided into different types and classifications based on its underlying causes and anatomical site. Traumatic HO is commonly seen in people who have suffered severe trauma, such as broken bones or burns. Neurogenic HO may be a complication of central nervous system diseases such as spinal cord injury or traumatic brain injury. Hereditary HO, such as fibrodysplasia ossificans progressiva, is very rare but causes extensive and progressive ossification of fibrous tissues such as muscle, tendons and ligaments throughout the body [2].

The diagnosis of HO usually includes a combination of clinical evaluation, medical imaging (e.g. X-rays, CT scans), and laboratory tests. X-rays is the usual diagnostic pathway for children with HO. Treatment options for HO are limited and often focus on controlling symptoms, reducing inflammation, and preventing further ossification. Depending on the severity, type and location of the HO, treatment options such as non-steroidal anti-inflammatory drugs (NSAIDs), physical therapy, and surgery may be considered [3]. The diagnostic challenge lies in the fact that the interpretation of elbow radiographs in pediatric patients necessitates expertise from both

* Corresponding author.
E-mail address: xht028216@qlyyqd.com (H. Xu).

https://doi.org/10.1016/j.heliyon.2024.e33756
Received 12 March 2024; Received in revised form 10 June 2024; Accepted 26 June 2024
Available online 26 June 2024

imaging departments and clinicians with a comprehensive understanding of elbow development in children.

Although most cases of HO are self-limited, and some cases resolve on their own [4], surgical intervention for HO in children is rare. Widespread HO in the elbow can lead to significant joint deformity and, in rare cases, complete ankylosis. The purpose of this study was to follow up a case of HO caused by inappropriate movement at another hospital after trauma, resulting in decreased elbow function. We provided scientific exercise instructions, however, HO did not naturally absorb, thus hindering joint mobility and requiring surgical removal. The follow-up results were satisfactory. This case shows that elbow HO has a significant effect on the function of children and can be surgically removed to achieve satisfactory results, but prevention should be the first priority. In children after elbow joint trauma need through scientific exercise methods, should not be unprofessional rough methods, so as to prevent the formation of elbow heterotopic ossification.

2. Case presentation

A six-year-old boy accidently fell while playing, injuring his right elbow. He was diagnosed with a supracondylar fracture of the humerus at another hospital, which was not an open fracture, without nerve damage, and given a cast. Three weeks later, the cast was removed, but the boy's elbow was stiff. The patient had normal elbow joint activity before injury, no history of trauma or burns, no

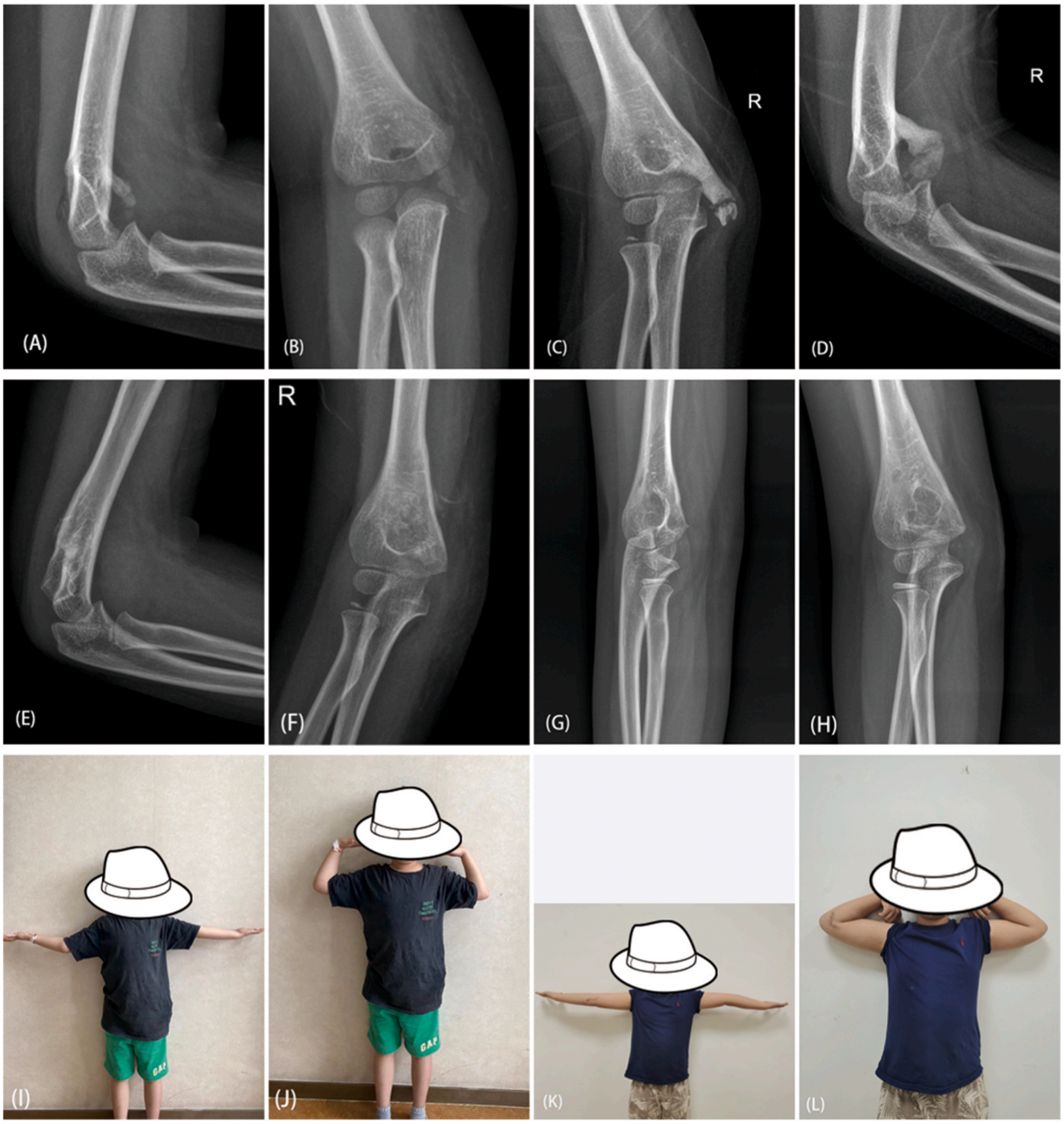

Fig. 1. (A)(B) HO at first visit. (C)(D) Prior to surgery, HO had deteriorated to grade II. (E) (F) Complete surgical removal of the HO. (G)(H) There was no recurrence of HO at last follow-up. (I) (J) Preoperative elbow range of motion: 45° (range 45°–90°). (K)(L) At last visit, elbow range of motion: 140° (range 5°–145°).

central nervous system diseases such as spinal cord injury or traumatic brain injury, and genetic diseases such asfibrodysplasia ossificans progressiva, he underwent passive exercise as part of his rehabilitation. However, improper training caused the function of his elbow joints to gradually deteriorate and caused the child pain, as his parents said. The patient underwent manual passive flexion and extension of the elbow joints by other physicians, resulting in pain and discomfort with each session. This passive exercise was not mechanically assisted, and had to be discontinued each time due to the patient's pain.

At our hospital, X-rays showed HO at the elbow, which was grade I of the Brooker classification (Fig. 1A and B). The Brooker classification of HO was initially used to describe the degree of HO around the hip joint, but now it is often used as a clinical classification for all cases of HO based on X-ray display. This condition results in limited flexion and extension of the elbow, which is measured by computer aided measurements of approximately 80° (range 30°–110°). Mayo Elbow Performance Score (MEPS) is one of the most commonly used instruments for the functional assessment of elbow joint, and MEPS of the patient is 80, the patient feels pain, and the affected area can reach a mass. The doctor instructs the patient to exercise the elbow properly and conducts regular follow-up visits. The patient was followed up seven times. At the last visit, the patient reported persistent elbow pain and significantly limited flexion and extension with a flexion range of approximately 45° (range 45°–90°) (Fig. 1I and J). According to research on the biomechanics of the elbow joint, a range of flexion and extension motion of 100° (30–130°) and a range of forearm rotation motion of 100° (50° forward rotation and 50° backward rotation) are sufficient to meet daily activity needs. The MEPS score is 60 points. The HO of the elbow joint worsened to grade II (Fig. 1C and D).

During preoperative testing, Gc protein and RBP4 were not detected, and hemoglobin results were normal. Under general anesthesia, two experienced pediatric orthopedic surgeons operated on the child to remove the HO. During the operation, the ulnar nerve was initially exposed for protection to prevent damage during the procedure. Subsequently, the base of HO was exposed, and the entire HO was exposed using an electrosurgical unit along its surface, avoiding excessive exposure of growth plates, muscles and tendons. The HO base was completely excised with an osteotome, hemostasis was achieved on the bony surfaces using bone wax, and thorough hemostasis was ensured at muscular bleeding points with an electrosurgical unit. The joint capsule was repaired, and the HO was completely resected (Fig. 1E and F). The surgical procedure was uneventful with no complications. The excised HO was sent for pathology, and the pathological report showed dense connective tissue, with focal cartilage ossification. The patient began active elbow movement 24 hours after surgery, including full range of flexion and extension, ensuring that the movements did not induce local pain, for 20 minutes each session, twice daily. This was increased to thrice daily after 2 weeks and lasted for 6 months. Patients are encouraged to use the operated arm in their daily routines, and took Ibuprofen for 3 weeks, 5ml each time, 3 times a day.

After 18 months of follow-up in the outpatient department, the patient had significantly improved elbow function, with a flexion and extension Angle of approximately 140° (range 5°–145°) and a MEPS score of 100 (Fig. 1K and L). X-rays showed no recurrence of HO (Fig. 1G and H). There were no adverse and unanticipated events throughout the process.

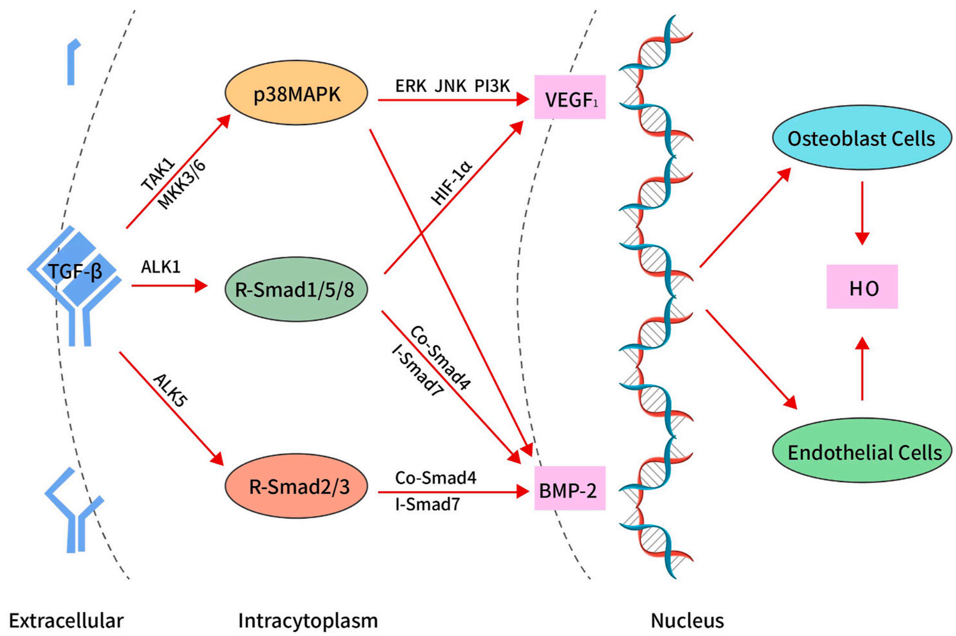

Fig. 2. Schematic diagram of the relationship between TGF-β and HO.

3. Discussion and conclusions

3.1. Risk factors for HO of the elbow joint

This article describes a case of elbow joint HO caused by improper movement after trauma. It has been hypothesized that trauma and improper exercise are associated with the development of elbow HO [5,6]. Studies have found that HO is related to TGF-β and exhibits high levels of activity of TGF - β in the HO microenvironment [5]. We drew a figure to explain this mechanism (Fig. 2). Trauma and excessive exercise cause muscle damage, leading to local increases in TGF-β(6). Due to the wide variation in muscle strength and severity of HO in children of different ages, it is very difficult to control the application of force during artificial passive movement. Excessive force can exacerbate local soft tissue damage [6]. To reduce this risk, continuous passive exercise machines are recommended [7]. The case reported in this paper were given passive activities in other hospitals, and each passive activity caused elbow joint pain in the patient. Pain means nerve stimulation and is a warning of tissue damage. Therefore, the degree of passive activities could not be controlled, and should be individualized, so as not to cause pain and avoid aggravating soft tissue damage.

Ectopic bone formation requires the presence of osteoblasts, a suitable environment, and stimulating factors [8]. Chemical or mechanical stimuli can serve as stimulating factors, such as alcohol, silver nitrate, and trauma. Osteoblasts are thought to be derived from stroma and nerve cells [9]. Risk factors for elbow HO often include trauma, nerve damage, and burns. After trauma, local factors such as hypoxia, pH, micronutrient supply, and mechanical stimulation induce progenitor cells to differentiate into preosteoblasts, leading to HO [10]. Studies have shown that open fractures and delayed surgery may increase the likelihood of elbow HO [11]. Compared to patients who had surgery within one day, patients who had surgery eight or more days after injury had a 12 times higher chance of developing HO [12]. Open fractures predict extensive soft tissue damage and the release of inflammatory factors, which increases the incidence of HO [13].

Passive movement after fracture also increases the risk of developing HO [6,14]. Therefore, active movement is recommended after fracture, while inappropriate movement should be avoided. Inappropriate passive exercise exacerbates secondary soft tissue injury, thereby increasing the likelihood of HO [6]. In addition, studies have shown that among patients with fractures, there is a higher incidence of HO among men, patients with open fractures, and patients not using NSAIDs [11]. In the case of nerve injury, bone tissue may form in the soft tissues adjacent to the peripheral joint below the injury plane. This condition usually occurs within one to three months of nerve injury, with an average incidence of 10 %–20 % [15]. Animal studies have shown a significant increase in HO at the joint site after nerve injury [16]. However, the exact pathogenic mechanism remains unclear. Low expression levels of Gc protein, RBP4 and hemoglobin may be closely related to HO after TBI [17]. In the case reported here, the fractures were non-open fractures with no neurological damage. Gc protein and RBP4 were not detected, and hemoglobin results were normal. Male gender, non-use of NSaids, and excessive passive exercise are considered risk factors for HO, especially in patients with significant excessive passive exercise.

For burn patients, studies have shown that the incidence of HO after severe burns is about 4.0 %. In addition to identified risk factors such as length of stay in the burn intensive care unit, the extent and depth of the burn, and the presence of lung and skin infections [18]. In addition, HO was experienced by more than 60 % of military personnel with explosion-related amputations, suggesting that explosive effects are a risk factor for HO development [19]. Genetic factors, including but not limited to progressive osteofibroplasia, Albers-Schonberg ossification, and progressive osteodystrophy, may also contribute to HO [20]. None of these risk factors were present in the case reported in this paper.

3.2. Treatment of elbow HO in children

Elbow HO is rare in children [21], which presents a challenge for pediatric orthopedic surgeons to diagnose and treat. Improper treatment can lead to elbow bone malformation and affect elbow function in children. Effective treatment is essential to stop the progression of the disease and restore normal elbow function in children. At present, there are two main treatment methods for elbow HO: conservative treatment and surgical treatment.

Conservative treatment focuses on controlling the progression of the disease through non-surgical means such as physical therapy and medication. Traditional treatments include non-steroidal anti-inflammatory drugs (NSAIDs) and radiation therapy, but these have had limited use in children due to drug toxicity and potential radiation damage. Several treatments have recently emerged, including bisphosphonates, BMP inhibitors, and RARγ agonists, but there is a lack of research specifically in children [22].

Surgical treatment is appropriate for severe cases where conservative treatment cannot control the progression of the disease. According to Morrey's study of the biomechanics of the elbow joint [23], the flexion range of 100° (30–130°) and the forearm rotation range of 100° (50°–50°) (forward 50°, back 50°) are sufficient to meet the needs of daily activities. Therefore, surgical intervention should only be considered in severely limited cases, as most cases can be effectively controlled with conservative treatment [24]. Surgical treatment mainly included ectopic osteotomy and joint capsulotomy. If the flexion range of motion does not improve, further removal of the contractuated capsule may be necessary. Active activity under the guidance of an experienced therapist is recommended after surgery. Although passive movement has been reported to be possible in post-operative care, active movement with pain control is advocated to minimize the risk of exacerbating local soft tissue injury and HO recurrence [7].

A study by Eric K. Lee [25] of 384 surgically treated patients with elbow HO showed that the average flexion and extension of the elbow before surgery was 53°/83°. After surgery, the patient's range of motion improved significantly, with elbow flexion/extension increasing to 75°/123°. After surgical removal of elbow HO, the patient's functional range of motion improved significantly. Arthroscopic HO of the elbow can reduce surgical trauma and the complication rate is comparable to that of traditional open surgery. A study consisting of 213 elbow surgeries and 213 elbow surgeries in 211 patients found no statistically significant difference in complications between open surgery and arthroscopic surgery [26].

In conclusion, the treatment of elbow HO in children should be based on the specific condition, considering the severity and limitations of symptoms. Conservative treatment should be taken first, and surgical treatment should only be performed if conservative treatment has failed. Careful postoperative management and active exercise are essential to optimize treatment outcomes and reduce the risk of complications.

3.3. When to surgically remove HO of elbow joints

The traditional surgical treatment for elbow HO is to intervene one year after the injury. However, recent studies have shown that early removal of ossified tissue has similar effects in terms of function and complications compared to delayed removal. For example, a study by Shuai Chen [27] found that HO recurred in 30 (26.8 %) of 112 patients who underwent delayed surgery, compared with 15 (28.9 %) of 52 patients who underwent earlier surgery. There were no significant differences in HO recurrence, range of motion (ROM), Mayo Elbow Function score (MEPS), or postoperative complications between the two groups. In another retrospective analysis by Koh [28], researchers studied 77 patients with post-traumatic elbow stiffness due to HO. The final results were assessed according to elbow range of motion and MEPS. Through univariate and multivariate analyses, it was determined that delaying surgery for more than 19 months was an independent risk factor for HO recurrence. He Shukun [29] investigated 42 patients with elbow joint HO and divided them into early operation group and late operation group with 12 months as the cut-off point. The study found that the average preoperative ROM was higher in the late resection surgery group, suggesting that ROM could be improved even without surgery. Both early and late surgery resulted in increased ROM and MEPS, but early surgery showed greater improvements in ROM and MEPS compared to late surgery, suggesting that early HO ectomy provides better elbow function. In addition, a study of eight patients who underwent HO surgical removal of elbow joints showed satisfactory follow-up results. The surgery was performed between 3 and 10 months (average 7 months) after the injury, and all patients received postoperative radiation therapy. Therefore, the study concludes that the timing of elbow HO ectomy is not strictly limited to the traditionally recommended 12–18 months after injury [30].

3.4. How to prevent HO of elbow joints in children

At present, there are few studies on the prevention of elbow HO in children. Among adults who eventually develop HO, 86 % of cases have imaging evidence within two weeks of surgery, underscoring the importance of early postoperative imaging [31]. Yangbai Sun's study showed that 200 mg of celecoxib taken daily for 28 days after elbow joint surgery significantly enhanced elbow flexion and extension function [32]. The use of celecoxib immediately after elbow surgery can effectively inhibit HO formation. However, celecoxib has limited efficacy in reducing the development of HO once it has become apparent on imaging [33]. Unfortunately, no studies have investigated the efficacy and safety of celecoxib in children under the age of 18.

Studies have also shown that prophylactic single-dose radiotherapy combined with NSAIDs is a safe and effective measure to prevent HO after elbow joint surgery [34]. Radiation can inhibit the osteogenic differentiation of mesenchymal stem cells [35]. Nevertheless, a review of the literature showed that routine HO prevention after elbow replacement surgery in adults lacks existing literature support, and the effectiveness of preventive measures in high-risk patients remains uncertain [36]. In a study involving children with neurogenic hip dislocation, preventive radiation therapy was found to be ineffective in preventing post-operative HO formation in any patient with neurogenic hip dislocation. Therefore, radiation prevention methods used in adults cannot be used in children [37]. In addition, exposure to radiation can lead to radiation-induced cancer many years after treatment [38], and side effects on the gastrointestinal tract, kidneys, and cardiovascular system [20]. Therefore, the risks and benefits of radiotherapy for elbow HO in children need to be carefully considered. In the case reported in this paper, the authors concluded that radiation therapy would do more harm than good in pediatric patients, so the patients were not treated with radiation therapy. Further research is needed to develop prevention strategies for elbow HO after elbow surgery in children.

In addition to steroidal anti-inflammatory drugs and radiation therapy, bisphosphonates have also been studied for the prevention of elbow pain, with results showing a significant reduction in the occurrence of post-traumatic elbow pain [39]. Exercise also plays a crucial role in preventing elbow HO. Postoperative elbow activities can prevent joint adhesion and reduce the likelihood of HO. However, care should be taken to avoid aggressive passive movements that aggravate the injury and increase the risk of developing HO. Functional exercises can begin 24–72 hours after surgery, including active and gentle passive movements [40]. In the case reported here, after surgical removal of HO, progressive painless active movement should be performed while ensuring that wound healing is not affected. Excessive activity should be avoided to prevent wound cracking and soft tissue damage. In addition, excessive activity before the wound heals may increase the tension of the incision, creating a risk of scar formation.

In conclusion, prevention of elbow joint HO in children should be done from two aspects. First, identifying and controlling risk factors is essential to reduce the occurrence of HO. Second, the use of drugs and/or radiation therapy should be carefully evaluated, taking into account the associated benefits and risks. Non-steroidal anti-inflammatory drugs and radiation therapy are not commonly used in pediatric patients, so it is necessary to develop and evaluate a personalized prevention strategy for elbow HO based on the risk-benefit ratio. In addition, in pediatric patients with multiple elbow fractures and severe soft tissue injuries, careful hemostasis and minimization of soft tissue stripping during surgery are also important measures to prevent HO.

The significance of this study lies in its presentation of an exceptional case of the disease and demonstration of a successful surgical procedure for excising heterotopic ossification from the elbow joint, resulting in satisfactory restoration of elbow function. These findings provide valuable insights into the treatment of heterotopic ossification in pediatric patients; however, it is important to note that personalized treatment approaches may be necessary due to variations in each child's condition.

4. Patient perspective

In my personal experience, my kid underwent a crucial elbow joint heterotopic ossification resection surgery, which significantly improved the functionality of his elbow joint. Notably, He is now pain-free and the X-ray examination revealed complete realignment of the heterotopic bone. This outcome has brought immense joy and satisfaction to my family. Throughout this process, I have witnessed the selfless dedication and professional expertise of healthcare professionals who not only demonstrated exceptional surgical skills but also provided my kid with attentive care and guidance during postoperative follow-up. I am deeply grateful for the hard work and professional treatment delivered by the entire medical team.

Ethics approval and consent to participate

The consent of the patient's legal guardian has been obtained and the informed consent has been signed.

This article does not contain any studies with human or animal subjects performed by any of the authors, has been granted an exemption from requiring ethics approval by ethics committee of Qilu Hospital (Qingdao).

All methods were performed in accordance with the ethical standards as laid down in the Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent for publication

The consent of the legal guardian has been obtained for the publication of case data.

Data availability statement

Has data associated with your study been deposited into a publicly available repository?
NO.
Has data associated with your study been deposited into a publicly available repository?
Data included in article/supp. material/referenced in article.

Funding

Key Laboratory of Qingdao in Medicine and Engineering.

CRediT authorship contribution statement

Xiaolei Zhao: Writing – original draft. **Hongtao Xu:** Writing – review & editing.

Declaration of competing interest

All authors disclosed no relevant relationships.

Acknowledgements

Not applicable.

List of abbreviations

HO Heterotopic Ossification
ROM Range of Motion
MEPS Mayo Elbow Performance Score
NSAIDs Non-Steroidal Anti-Inflammatory Drugs

References

[1] E. Sun, A.A. Hanyu-Deutmeyer, Heterotopic ossification, in: StatPearls, StatPearls Publishing, Treasure Island (FL), 2023. Available from: http://www.ncbi.nlm.nih.gov/books/NBK519029/. (Accessed 21 April 2023).
[2] G. Cao, F. Pei, [Research progress of traumatic heterotopic ossification], Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi 36 (3) (2022 Mar 15) 386–394.

[3] S.M. Hinck, Heterotopic ossification: a review of symptoms and treatment, Rehabil. Nurs. 19 (3) (1994) 169–173.
[4] S.L. Summerfield, C. DiGiovanni, A.P. Weiss, Heterotopic ossification of the elbow, J. Shoulder Elbow Surg. 6 (3) (1997) 321–332.
[5] X. Wang, F. Li, L. Xie, J. Crane, G. Zhen, Y. Mishina, et al., Inhibition of overactive TGF-β attenuates progression of heterotopic ossification in mice, Nat. Commun. 9 (2018 Feb 7) 551.
[6] T. Wang, P. Chen, L. Chen, Y. Zhou, A. Wang, Q. Zheng, et al., Reduction of mechanical loading in tendons induces heterotopic ossification and activation of the β-catenin signaling pathway, J Orthop Translat 29 (2021 Jul) 42–50.
[7] D. Salazar, A. Golz, H. Israel, G. Marra, Heterotopic ossification of the elbow treated with surgical resection: risk factors, bony ankylosis, and complications, Clin. Orthop. Relat. Res. 472 (7) (2014 Jul) 2269–2275.
[8] J. Chalmers, D.H. Gray, J. Rush, Observations on the induction of bone in soft tissues, J Bone Joint Surg Br 57 (1) (1975 Feb) 36–45.
[9] J. Anthonissen, C.T. Steffen, A. Hofmann, J. Victor, The pathogenesis of heterotopic ossification after traumatic brain injury. A review of current literature, Acta Orthop. Belg. 86 (3) (2020 Sep) 369–377.
[10] K. Ranganathan, S. Loder, S. Agarwal, V.W. Wong, J. Forsberg, T.A. Davis, et al., Heterotopic ossification: Basic-science principles and clinical correlates, JBJS 97 (13) (2015 Jul 1) 1101.
[11] Z. Sun, W. Liu, H. Liu, J. Li, Y. Hu, B. Tu, et al., A new prognostic nomogram for heterotopic ossification formation after elbow trauma : the Shanghai post-Traumatic Elbow Heterotopic Ossification Prediction (STEHOP) model, Bone Joint Lett. J 104-B (8) (2022 Aug) 963–971.
[12] A.S. Bauer, B.K. Lawson, R.L. Bliss, G.S.M. Dyer, Risk factors for posttraumatic heterotopic ossification of the elbow: case-control study, J Hand Surg Am 37 (7) (2012 Jul) 1422–1429.e1-6.
[13] J.F. Dickens, K.W. Wilson, S.M. Tintle, R. Heckert, W.T. Gordon, J.C.G. D'Alleyrand, et al., Risk factors for decreased range of motion and poor outcomes in open periarticular elbow fractures, Injury 46 (4) (2015 Apr) 676–681.
[14] G.I. Vasileiadis, D.N. Varvarousis, I. Manolis, A. Ploumis, The impact of continuous passive motion on heterotopic ossification maturation, Am. J. Phys. Med. Rehabil. 100 (12) (2021 Dec 1) e194–e197.
[15] A.D. Valbuena Valecillos, D.R. Gater, G. Alvarez, Concomitant brain injury and spinal cord injury management strategies: a narrative review, J Pers Med 12 (7) (2022 Jul 6) 1108.
[16] R.D. Brady, M.Z. Zhao, K.R. Wong, P.M. Casilla-Espinosa, G.R. Yamakawa, R.C. Wortman, et al., A novel rat model of heterotopic ossification after polytrauma with traumatic brain injury, Bone 133 (2020 Apr 1) 115263.
[17] M. Hongwei, Q. Tiebing, L. Zhiguo, L. Kemin, Proteomics study on biomarkers for heterotopic ossification secondary to traumatic brain injuries, J. Rehabil. Med. 52 (1) (2020 Jan 2) jrm00001.
[18] X. Hu, Z. Sun, F. Li, C. Jiang, W. Yan, Y. Sun, Burn-induced heterotopic ossification from incidence to therapy: key signaling pathways underlying ectopic bone formation, Cell. Mol. Biol. Lett. 26 (2021 Jul 27) 34.
[19] Z. Kazezian, A.M.J. Bull, A review of the biomarkers and in vivo models for the diagnosis and treatment of heterotopic ossification following blast and trauma-induced injuries, Bone 143 (2021 Feb) 115765.
[20] C.D. Hwang, C.A. Pagani, J.H. Nunez, M. Cherief, Q. Qin, M. Gomez-Salazar, et al., Contemporary Perspectives on Heterotopic Ossification, American Society for Clinical Investigation, 2022. https://insight.jci.org/articles/view/158996/pdf. (Accessed 27 April 2023).
[21] A.R. Markes, N. Venishetty, A. Gatto, I. Swarup, Pediatric heterotopic ossification: a comprehensive review, Curr Rev Musculoskelet Med 16 (11) (2023 Aug 17) 514–520.
[22] M.M. Ampadiotaki, D.S. Evangelopoulos, D. Pallis, C. Vlachos, J. Vlamis, M.E. Evangelopoulos, New strategies in neurogenic heterotopic ossification, Cureus 13 (4) (2021 Apr 27) e14709.
[23] B.F. Morrey, L.J. Askew, E.Y. Chao, A biomechanical study of normal functional elbow motion, JBJS 63 (6) (1981 Jul) 872.
[24] Z. Yuan, H.W. Xu, Y.Z. Liu, Y.Q. Li, J.C. Li, F. Canavese, The use of external fixation for the management of acute and chronic Monteggia fractures in children, J Child Orthop 13 (6) (2019 Dec 1) 551–559.
[25] E.K. Lee, S. Namdari, H.S. Hosalkar, M.A. Keenan, K.D. Baldwin, Clinical results of the excision of heterotopic bone around the elbow: a systematic review, J. Shoulder Elbow Surg. 22 (5) (2013 May) 716–722.
[26] D.R. Bachman, J.S. Fitzsimmons, S.W. O'Driscoll, Safety of arthroscopic versus open or combined heterotopic ossification removal around the elbow, Arthroscopy 36 (2) (2020 Feb) 422–430.
[27] S. Chen, Yu S. yang, H. Yan, Cai J. yu, Y. Ouyang, H jiang Ruan, 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 Elbow Surg. 24 (8) (2015 Aug) 1165–1171.
[28] K.H. Koh, T.K. Lim, H.I. Lee, M.J. Park, Surgical treatment of elbow stiffness caused by post-traumatic heterotopic ossification, J. Shoulder Elbow Surg. 22 (8) (2013 Aug 1) 1128–1134.
[29] S.K. He, M. Yi, G. Zhong, S.Q. Cen, J.L. Chen, F.G. Huang, Appropriate excision time of heterotopic ossification in elbow caused by trauma, Acta Orthop Traumatol Turc 52 (1) (2018 Jan) 27–31.
[30] J.A. McAULIFFE, A.H. Wolfson, Early excision of heterotopic ossification about the elbow followed by radiation therapy, JBJS 79 (5) (1997 May) 749.
[31] G.D. Abrams, M.J. Bellino, E.V. Cheung, Risk factors for development of heterotopic ossification of the elbow after fracture fixation, J. Shoulder Elbow Surg. 21 (11) (2012 Nov) 1550–1554.
[32] Y. Sun, J. Cai, F. Li, S. Liu, H. Ruan, C. Fan, The efficacy of celecoxib in preventing heterotopic ossification recurrence after open arthrolysis for post-traumatic elbow stiffness in adults, J. Shoulder Elbow Surg. 24 (11) (2015 Nov) 1735–1740.
[33] F. Li, D. Mao, X. Pan, X. Zhang, J. Mi, Y. Rui, Celecoxib cannot inhibit the progression of initiated traumatic heterotopic ossification, J. Shoulder Elbow Surg. 28 (12) (2019 Dec) 2379–2385.
[34] J.B. Strauss, R.W. Wysocki, A. Shah, S.S. Chen, A.P. Shah, R.A. Abrams, et al., Radiation therapy for heterotopic ossification prophylaxis afer high-risk elbow surgery, Am J Orthop (Belle Mead NJ) 40 (8) (2011 Aug) 400–405.
[35] P.L. Craven, M.R. Urist, Osteogenesis by radioisotope labelled cell populations in implants of bone matrix under the influence of ionizing radiation, Clin. Orthop. Relat. Res. 76 (1971 May) 231–243.
[36] E.Y. Liu, A. Hildebrand, N.S. Horner, G.S. Athwal, M. Khan, B. Alolabi, Heterotopic ossification after total elbow arthroplasty: a systematic review, J. Shoulder Elbow Surg. 28 (3) (2019 Mar) 587–595.
[37] C.B. Hess, R. Stein-Wexler, L. Qi, J.R. Davids, R.C. Fragoso, Outcomes of pre-operative vs. Post-operative radiation for heterotopic ossification prevention in children with neuromuscular hip dysplasia undergoing proximal femoral resection, J. Pediatr. Orthop. 39 (2) (2019 Feb) e102–e107.
[38] S.R. McKeown, P. Hatfield, R.J. Prestwich, R.E. Shaffer, R.E. Taylor, Radiotherapy for benign disease; assessing the risk of radiation-induced cancer following exposure to intermediate dose radiation, Br. J. Radiol. 88 (1056) (2015 Dec) 20150405.
[39] S. Agarwal, S. Loder, B. Levi, Heterotopic ossification following upper extremity injury, Hand Clin. 33 (2) (2017 May) 363–373.
[40] S.C. Yang, A.C.Y. Chen, E.K. Chao, L.J. Yuan, M.S.S. Lee, S.W.N. Ueng, Early surgical management for heterotopic ossification about the elbow presenting as limited range of motion associated with ulnar neuropathy, Chang Gung Med. J. 25 (4) (2002 Apr) 245–252.