Fracture-Separation of the Medial Humeral Epicondyle Caused by Arm Wrestling

A Systematic Review

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Background: Arm wrestling is a popular sport in which various injuries have occurred, even in children.

Purpose: To analyze reported fracture-separation of the medial humeral epicondyle (MHE) caused by arm wrestling to determine its mechanism and provide a current overview.

Study Design: Systematic review; Level of evidence, 4.

Methods: The PubMed and Web of Science databases were searched using the terms "arm wrestling" and "humeral fracture" or "medial humeral epicondyle fracture"; and "sports" and "humeral fracture" or "medial humeral epicondyle fracture," following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The inclusion criteria were English full-text articles on arm wrestling–induced MHE fracture that described patient characteristics and presented appropriate images. Studies with a lack of appropriate images or detailed description of the injury situation were excluded. The patient characteristics were evaluated, and the ratios of treatment selection and outcomes were evaluated using the chi-square test.

Results: Included were 27 studies with a total of 68 patients, all boys with a mean age of 14.6 ± 1.24 years (based on n = 65, with 3 patients excluded from this calculation as no definitive age was provided). Boys aged 14 to 15 years accounted for 72% (49/68) of the cases. Fracture occurred suddenly during arm wrestling in 63 boys, while the other 5 boys experienced antecedent medial elbow pain. The match status at the time of injury, provided for 46 patients, was varied. In 31 boys with known match details, injury occurred when a participant suddenly added more force to change the match status. Eight patients displayed anterior and/or proximal displacement of the MHE fragment. Treatment was nonoperative in 25 patients and operative in 38 patients (n = 63, excluding 5 unknown patients). In 35 patients followed up for ≥3 months (mean, 17.6 ± 12.3 months), outcomes were not significantly different between the operative and nonoperative groups.

Conclusion: MHE fracture-separation caused by arm wrestling occurred mostly in boys aged 14 to 15 years regardless of the match status. The likely direct cause is forceful traction of the attached flexor-pronator muscles. A relative mechanical imbalance during adolescence may be an underlying cause. A sudden change from concentric to eccentric contraction of the flexor-pronator muscles increases the likelihood of fracture occurrence.

Keywords: arm wrestling; adolescence; avulsion fracture; medial humeral epicondyle

Arm wrestling is a sport that consists of a challenge between 2 persons that uses technique and force of the upper limbs to overcome the resistance of the opponent.[50] It is a popular sport and recreational game practiced worldwide by both men and women of all ages, but it is by no means safe. Various bone and soft tissue injuries related to this sport have been reported in various locations from the shoulder to the hand.[4,5,11,17-19,43] The most common injuries are fracture of the humeral shaft in adults and epiphyseal fracture-separation of the medial humeral epicondyle (MHE) in teenagers.[32,37-40] The MHE anatomy is described below because this knowledge is important to understanding physeal injuries to this region.

The distal epiphysis of the humerus develops from 4 separate ossification centers, which appear in the following order: capitulum, medial epicondyle, trochlea, and lateral epicondyle.[49] The ossification center of the MHE is normally observed on radiographs by 4 years of age but develops slowly. The MHE is the last of the distal humeral epiphyses to unite with the shaft, but the reported ages of

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fusion represent a wide time range; Scheuer and Black[49] reported ages of 13 to 16 years for girls and 14 to 16 for boys, while Cardoso[9] reported ages of 13 to 16 years for girls and 16 to 18 for boys. These values are greatly influenced by the observation method, race, and socioeconomic status of the patients.[9] As fusion progresses from inferior to superior, the superior and anterior parts of the epiphysis are the last to unite, leaving a temporary anterosuperior notch.[49] The epiphysis of the MHE is a traction epiphysis (apophysis) located at the site of attachment of major muscle tendons to bone and is subjected primarily to tensile forces.[7] Because this epiphysis contributes to bone shape but not to longitudinal growth, acute or chronic injury to the epiphysis does not disturb longitudinal bone growth.[7] The epiphysis of the MHE is a posterior structure on the distal humerus and faces backward and downward, with a reported median coronal plane angle of the physis of 36° and a median axillar plane angle of 45°.[8]

Numerous muscles, including the flexor carpi radialis, flexor carpi ulnaris (FCU), palmaris longus, flexor digitorum superficialis, and part of the pronator teres, originate from the MHE, forming the flexor-pronator muscle complex (Figure 1). The pronator teres originates from not only the common tendon of the flexor-pronator muscle complex but also from the medial supracondylar ridge just proximal to the MHE, medial intermuscular septum of the arm, antebrachial fascia, and ulna.[3,10] These muscles act as the dynamic stabilizer of the medial elbow.[10] Another important structure attached to the MHE is the anterior bundle of the ulnar collateral ligament complex (ABUCL), which is composed of anterior, posterior, and oblique bundles. The ABUCL attaches to the anteroinferior aspect of the MHE epiphysis.[57] The origin of the ABUCL always remains medial to the cartilaginous interface of the epiphysis, where it is approximately 3 mm medial to the lateral edge of the epiphysis and just posterior to the axis of rotation of the elbow joint.[22,57] The ABUCL has great biomechanical significance, serving as the primary static stabilizer of the medial elbow against valgus stress during functional range of motion when there is elbow flexion between 20° and 120°.[6] The posterior surface of the MHE is smooth and is crossed by the ulnar nerve, which lies in a shallow sulcus as it enters the forearm.[3]

The purpose of this review was to systematically evaluate the available literature to clarify the current concept of fracture-separation of the MHE caused by arm wrestling and propose the possible mechanism based on the biological evidence. We hypothesized that because MHE fracture-separation due to arm wrestling occurs at particular ages, the physiological and developmental characteristics specific to those ages are the basis of this injury.

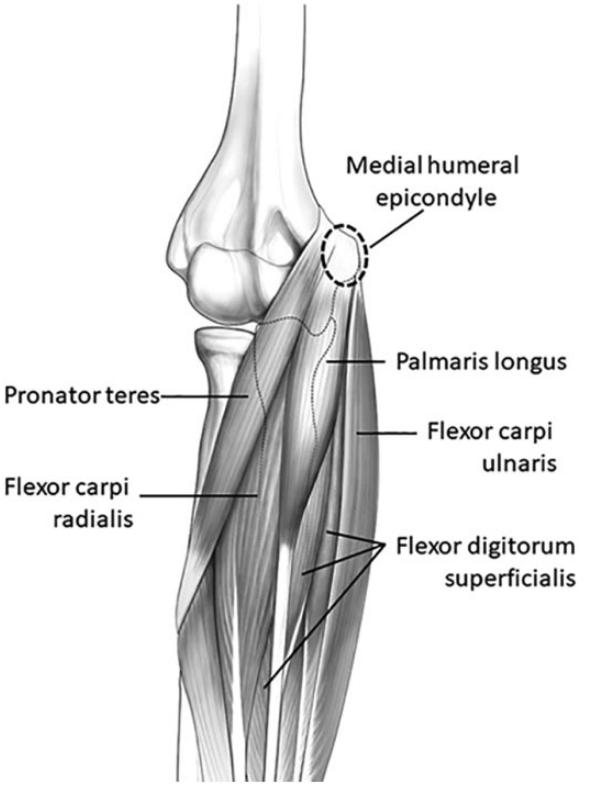

Figure 1. The flexor-pronator muscle complex originates from the medial humeral epicondyle. The anterior bundle of the ulnar collateral ligament complex is present behind these muscles.

METHODS

This systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines using a checklist for systematic reviews.[36] The literature search was performed from January to March 2021, and the publication years of the included articles ranged from 1900 to 2020. The PubMed and Web of Science databases were searched using the terms "arm wrestling" and "humeral fracture" or "medial humeral epicondyle fracture"; and "sports" and "humeral fracture" or "medial humeral epicondyle fracture" to identify relevant studies. Two reviewers (K.O., N.M.) independently conducted the search and review.

The inclusion criteria were English full-text articles concerning MHE fracture caused by arm wrestling that described patients' characteristics and presented appropriate

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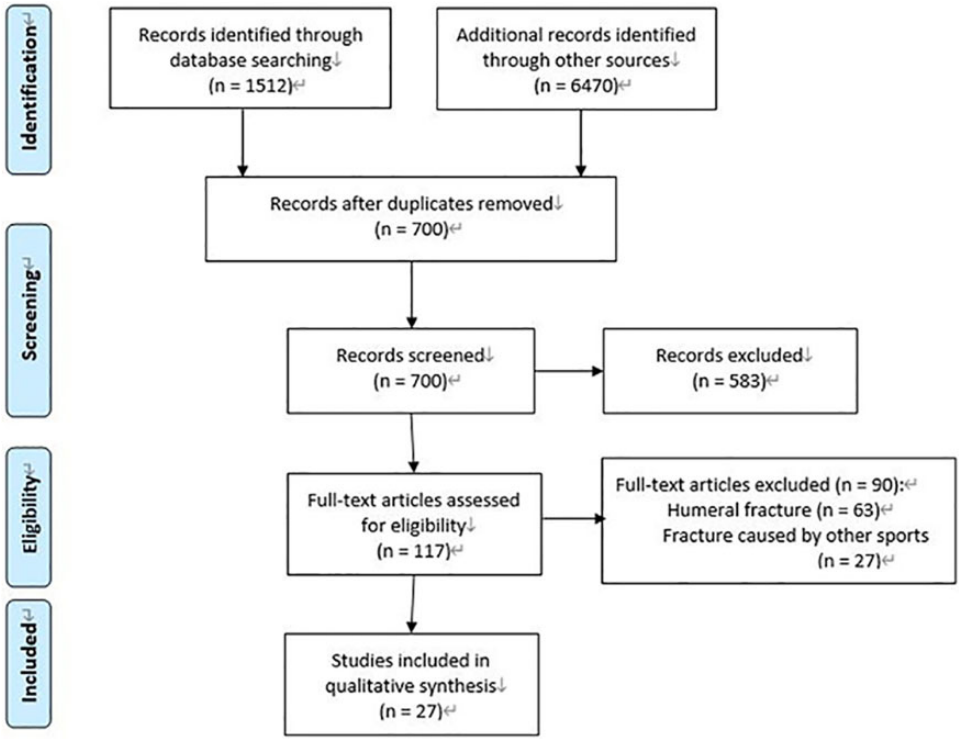

Figure 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of the study selection process.

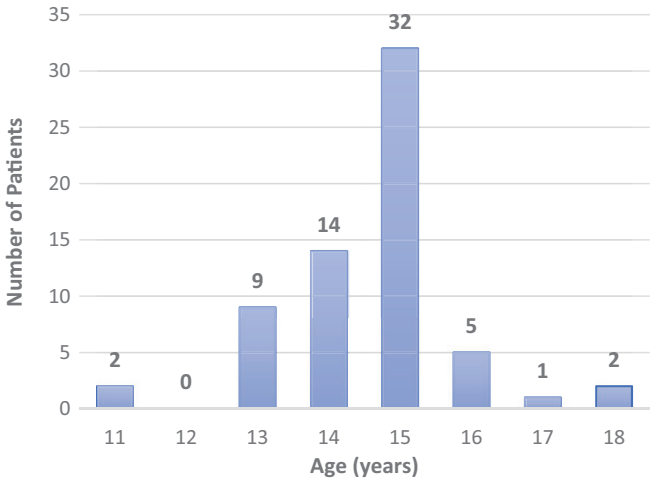

Figure 3. Age distribution of patients with medial humeral epicondylar fracture-separation.

images or descriptions of the injury scenarios using widely accepted classification methods to confirm the details of the MHE fracture. The exclusion criteria were descriptive articles or cases without appropriate images to enable evaluation of the injury details. Citation tracking was carefully conducted to find additional related English articles and notable full-text articles written in other languages, which were selected and added to the qualitative synthesis. The article selection process is shown in Figure 2.

With the exception of 6 case series, all studies were case reports with $\leq$3 patients.[27,32,37-39,56] We evaluated the patients in terms of age, sex, occupation, physical characteristics, injured side, dominant arm, match status/details, number of matches, posture in the match, opponent's physical characteristics, fracture type/displacement, associated injuries, type of treatment, and outcome. A case of a 39-year-old man with an old MHE fracture was excluded because the time when the fracture occurred could not be determined.[32] The 2 reviewers discussed the choice of articles and the patients to be included, and they ultimately reached agreement regarding all papers and cases. Patient data suspected of being duplicated based on the description of demographic characteristics were excluded if the same author had described multiple reports of the same injury.

The ratios of the treatment selection and outcomes were evaluated using the chi-square test. The level of significance was set at $P < .05$.

RESULTS

Ultimately, 27 studies were included in the analysis. These studies included 68 reported cases of an isolated MHE fracture-separation. All patients were boys, with a mean age of 14.6 ± 1.24 years (range, 11-18 years) (n = 65, excluding 3 patients whose ages were described as 14-15 years). Patients aged 14 and 15 years comprised 71% (46/65) of the total (Figure 3). With the inclusion of the 3 patients aged 14 to 15 years, this rate increased to 72%

(49/68). Patients aged 13 to 16 years accounted for 93% (63/68) of all patients.

An MHE fracture suddenly occurred during arm wrestling without any antecedent symptoms in 63 boys.[‖] In the other 5 boys, 4 reported having experienced mild pain of the medial elbow when arm wrestling from 1 to 6 months before the injury.[39,48] A 14-year-old boy who practiced judo had experienced elbow pain during judo for 7 months. In this patient, it was considered that arm wrestling had resulted in fracture that was apparently secondary to microinjuries to the physeal cartilage that had repeatedly occurred during judo.[35] The injured arm was the right arm in 48 boys and the left in 8 boys (n = 56). Injuries occurred in the dominant side in 30 boys and nondominant side in 6 boys (n = 36).

The status of match at the time of injury varied; 21 boys had been winning, 13 had been even, and 12 had been losing (n = 46). In 31 of these 46 cases in which the match status was known, the details of the match situation at the time of injury were described. They all suffered the injury when 1 of the pair suddenly added more force to attempt to force an end to the match or to change the match status. The status of these boys' matches also varied: winning in 13 boys, even in 9 boys, and losing in 9 boys. The mean number of matches on the day of the injury was 2.4 ± 1.5 (range, 1-6; n = 17). The posture during the match was sitting in 8 boys and standing and leaning over in 6 boys (n = 14). Compared with boys of the same generation, physical characteristics such as weight, height, and degree of muscle development of the injured boys varied and did not have any clear tendency (n = 8). The opponent's physique was larger or stronger than the patient in 6 cases and similar in 7 cases (n = 13).

The type of fracture-separation was Salter-Harris type 1 in 3 cases and type 2 in 4 cases (n = 7). The degree and/or direction of displacement of MHE fragments were described in 31 cases. MHE fragment displacement was type 1 in 18 boys and type 2 in 9 boys in accordance with the Watson-Jones classification.[45] In 4 boys among 18 cases with a Watson-Jones type 1 fracture, the MHE fragments demonstrably displaced toward the anterior.[16,54,55] In the other 4 cases for whom the Watson-Jones classification was not used, the MHE fragment was displaced proximally in 1 case, medioproximally in 2 cases, and medioanteroproximally in 1 case.[34,38] The only concurrent injury was ulnar nerve paresis, which was recognized in 2 patients, although 1 of these 2 spontaneously recovered after nonoperative treatment.[38]

Treatment methods were nonoperative in 25 cases and open reduction and internal fixation in 38 cases (n = 63). The fixation device in the operative cases was Kirschner wire in 25 cases, screw in 8 cases, tension band in 3 cases, and unknown in 2 cases (n = 38). Investigation of the tendency of treatment selection and the age of patients in the patient groups aged 13 to 15 years showed that nonoperative treatment accounted for 33% to 38% and surgery accounted for 59% to 71% at any age, and there was no significant difference in treatment selection ($P = .798$). In 8 of 9 cases with a Watson-Jones type 2 fracture, surgery was performed.

Thirty-five patients (17 nonoperative cases and 18 operative cases) were followed up for at least 3 months after injury (mean, 17.6 ± 12.3 months). Even though no study used any of the widely accepted evaluation methods—such as Disability of the Arm, Shoulder and Hand Scale; Patient-Rated Elbow Evaluation; or American Shoulder and Elbow Surgeons–Elbow Questionnaire—the treatment outcome was excellent in 27 cases. An excellent outcome was defined as the absence of any residual symptoms, limitation of range of motion, or instability of the elbow that impaired daily or sports activities. The other 8 patients had a good outcome, defined as the presence of $\leq 30^\circ$ of extension loss of the elbow and very mild neuropathy that did not impair daily or sports activities. Seven cases had $\leq 30^\circ$ of extension loss of the elbow.[33,38,52,53] Another patient who had ulnar nerve paresis at the time of injury still complained of slight discomfort in the ulnar nerve area 8 years postoperatively, although the muscle strength and sensation were normal.[39] There was no significant difference in outcomes (excellent-good ratio) between the nonoperative and operative groups ($P = .370$). Except for 1 abovementioned case, there were no reports of intraoperative, postoperative, or late complications, including growth retardation and elbow instability.

DISCUSSION

The findings of this systematic review revealed that MHE fractures caused by arm wrestling occurred mostly in boys aged 14 to 15 years, accounting for 72% (49/68) of all patients. In 93% (63/68) of the injured boys, fracture suddenly occurred without any antecedent symptom regardless of the match status. The analyzed items and the mechanism of fracture occurrence are considered and discussed below.

The age- and sex-adjusted incidence for the first physeal fracture is 249.5/100,000 per year, of which 63% to 66% are in boys.[46] The estimated incidence rates are greatest for boys aged 14 years, with a relatively high rate in the range 12 to 15 years.[12,46] They occur in the upper extremity in 71% of all cases and in the distal humerus in 3.9%.[46] Fractures involving the MHE constitute approximately 14% of fractures involving the distal humerus and 12% of all fractures in the elbow region.[2,44] Most fractures involving the MHE occur between the ages of 9 and 14 years, with the peak incidence at ages 11 to 12 years. Fractures of the MHE more frequently affect boys, constituting 79% of the patients.[2] The reported incidence of association with elbow dislocation is approximately 50% of such injuries.[2,23] No epidemiologic data of isolated MHE fracture exist. The incidence of acute physeal injuries due to sports activity reportedly ranges from 1% to 12% of all sports injuries, depending on the sport.[7] However, no data regarding the incidence of MHE injuries among all sports-related (and, specifically, arm wrestling–related) physeal injuries are available.

To the best of our knowledge, the first publication of a case of MHE fracture-separation owing to arm wrestling

[‖]References 16, 27, 32–34, 37–39, 48, 52–56.

TABLE 1
Number of Studies and Patients Reporting Medial Humeral Epicondylar Fracture-Separation by Country

Country	No. of Studies	No. of Patients
India	1	1
Israel	2	12
Italy	3	3
Japan	14	34
South Korea	5	13
Singapore	1	2
Taiwan	1	3
Total	27	68

was by Crainz.[13] By the time Masaki[34] presented a report with images in 1952, there were already reports of 4 cases without images. This injury has been reported with images from Italy, Japan, South Korea, Israel, Singapore, Taiwan, and India (Table 1).¶ Considering that humeral shaft fractures due to arm wrestling have been reported from many more countries, and that arm wrestling has been practiced for many years,[40] numerous cases of MHE fracture-separation may go unreported.

In arm wrestling, an internal rotational force is applied to the proximal humerus by the internal rotators of the shoulder, such as the pectoralis major muscle, subscapularis, teres major, latissimus dorsi, and deltoid.[24,40,50] By contrast, the force applied to the hand from the opponent acts as an external rotational force via the forearm in the distal humerus.[24,50] Sufficient power of the flexor muscles of the wrist and fingers is needed to resist the external rotation force from the opponent and to transmit the player's own internal rotation force to the opponent's hand.[24,26,50] That is, the power of these flexor muscles is indispensable to fully exert the internal rotational force generated to the proximal humerus. Some experimental studies have demonstrated that the muscle activity during arm wrestling as a percentage of the maximum muscular contraction was approximately 100% or 74% to 78% for the FCU regardless of the status of the match.[24,50] A significant increase in electric activity of the pectoralis major, pronator teres, and FCU has been observed with an increasing load.[50] The FCU may play a key role in gaining a positional advantage in arm wrestling matches.[26] In summary, during arm wrestling, the MHE is constantly subjected to strong traction of the attached muscles including the FCU, regardless of the status of the match.

Among the patients for whom details of the situation at the time of injury are known, all 31 suffered injury when 1 of the pair suddenly added more force to attempt to change the status of the match, regardless of the status of the match at the time. The players were readily able to move their trunk, because the known posture in the matches in the present review was sitting or standing while leaning over. One experimental study showed that an inclination or tilting of the attacker's trunk occurred while adding more force.[24] Such movement of the trunk will change concentric contraction of the internal rotators in the proximal humerus to eccentric contraction. We believe eccentric contraction of the flexor muscles of the wrist joint and finger must occur in response to the force generated by the eccentric contraction of its own internal rotator group and the force of the "counterattack" from the opponent that is inevitably applied to the attacker's hand. Research has demonstrated that isokinetic eccentric strength is generally 20% to 60% greater than isokinetic concentric strength,[14,25] although no data are available on the muscle groups involved in arm wrestling. On the basis of the abovementioned experimental studies, we think a large nonphysiological force owing to eccentric muscle contraction of the wrist joints and finger flexors will cause MHE fracture.

All of the patients in the present review who suffered an MHE fracture-separation were boys, of whom 72% were aged 14 to 15 years, coinciding with the age range (12-15 years) in which most physeal fractures occur in boys.[46] The age at peak height velocity is mid–13 years for boys and at the end of 11 years for girls.[21,47] The age of peak velocity of lean body mass, which strongly reflects the skeletal muscle in the extremities, is 0.3 years and 0.4 years later in boys and girls, respectively, than the age of the peak height velocity, with an upper extremity velocity of 1100 g/y in boys and 500 g/y in girls.[47] Similarly, a study that estimated the muscle cross-sectional area of the mid–upper arm demonstrated a rapid increase in boys aged 13 to 15 years and girls aged 11 to 13 years, with an increase of just over 12 cm^2 in boys and approximately 5 cm^2 in girls during this period.[1] The upper limb skeletal muscle index, which represents the upper limb muscle mass/height^2 (kg/m^2), increased dramatically until 14 years and increased slowly again thereafter.[31] Therefore, muscle mass of the upper extremity increases rapidly just before the age of 14 years in boys. We speculate that this rapid increase may have contributed to fracture-separation of the MHE in boys aged 14 to 15 years because this increase can be considered as an increase in muscle strength.[47]

In boys aged 14 to 15 years, which corresponds to the age immediately before the start of physeal closure of the MHE, the quality of physeal cartilage, in terms of its ultimate tensile strength, was found to be physiologically reduced because of the effect of hormonal changes.[41] Therefore, boys aged 14 to 15 years are characterized by a rapid increase in muscle strength, physiological reduction of tensile strength of the physeal cartilage, and resultant relative mechanical imbalance.[39] Five patients reported antecedent elbow pain before an obvious fracture, which may have resulted from a chronic repetitive epiphyseal injury, such as a microcrack.[35,39,41,48]

Fractures of the MHE that occurred in arm wrestling were a physeal separation in all cases, whereas fracture types by the Salter-Harris classification were described in only 7 cases. This fact will lead to difficulty in accurately determining the fracture type because the fractured fragment is small and rotates. The degree of displacement according to the Watson-Jones classification is described in only 27 cases, but it is noteworthy that the fragment of 8 patients displayed displacement in the anterior or

¶References 16, 27, 32–35, 37–39, 48, 52–56.

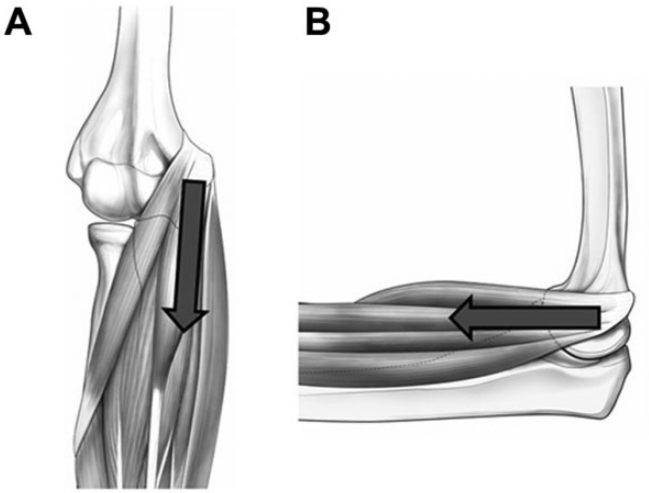

Figure 4. Displacement of the medial humeral epicondylar (MHE) fracture fragment (arrows indicate direction of traction by the attached muscles). (A) When the elbow is in the extended position at the time of injury, the MHE fragment displaces toward the distal and slightly toward the anterior. (B) When the elbow is in the flexed position, the posteriorly located MHE fragment displaces anteriorly after going around the anterior edge of the metaphysis.

proximal direction.[16,34,38,54,55] The most common cause of MHE fracture is falling on an outstretched hand, resulting in an outward valgus stress on the elbow and causing an avulsion fracture of the MHE.[2,23] In this scenario, the MHE fragment is mainly displaced anterodistally by the traction of the attached flexor-pronator muscles. However, because the elbow is theoretically in the flexed position in arm wrestling, the traction force of the flexor-pronator muscles is directed anteriorly, causing an anterior displacement of the MHE fragment (Figure 4).

When the intact intermuscular septum of the arm, being the origin of a part of the pronator teres, is attached to the MHE fragment, the fragment can be suspended by this septum and consequently displaced anteroproximally.[38] Both the amount of displacement necessitating surgical intervention and how to measure the displacement are strongly debated.[23] Several studies demonstrated that standard radiographic views of the elbow were unable to accurately portray the true displacement.[8,42] In particular, because the anterior displacement is significantly underestimated,[15] an internal oblique radiograph,[23] an axial view of the distal humerus,[51] and 3-dimensional computed tomography[15] are recommended to measure the true displacement of the fragment. Consequently, application of the Watson-Jones classification to the MHE fracture caused by arm wrestling, which determines the degree of displacement of the MHE fragment in the anteroposterior view, is not appropriate.[16,54]

As a complication of MHE fractures, ulnar nerve dysfunction has been observed in 10% to 15% of patients, including the cases associated with elbow dislocation and other injuries.[29,44] To the best of our knowledge, there is no report concerning association rate of ulnar nerve injury with the isolated MHE fracture. In our review, 3% (2/68) of the isolated MHE fractures were complicated with such an injury. One paper indicated that the clinician should be alert to the possibility of combined acute MHE fractures and ABUCL rupture.[44] However, because the ABUCL is frequently stronger than the physis before physeal closure, an injury that would result in ligamentous disruption in an adult may injure only the physis of the MHE in a child.[7,41] Therefore, the ABUCL attached to the fractured fragment must remain intact. In the present review, there was no case with a rupture of the ABUCL or residual elbow instability at the time of follow-up.

Appropriate management of MHE fractures in the pediatric population is strongly debated.[20,28,29,44] Although the established indications for operative intervention include open fractures, gross elbow instability, intra-articular incarceration of the fracture fragment, and ulnar nerve symptoms,[44] no consensus exists in the literature as to the amount of fracture displacement that warrants surgical intervention.[23,45,58] Treatment decisions based on the fracture displacement are further complicated by the ability to accurately measure the displacement.[58] The nonunion of the epicondylar fragment that was present in most patients who had been treated with a cast did not adversely affect the functional results.[20,29,30] In the present review, operative treatment was performed in 38 cases, despite the fact that their indication for surgical intervention was unclear. Almost 50% of the reported patients were followed for 3 months or longer, and outcomes were generally satisfactory. Although extension loss of the elbow joint ranging from 5° to 30° remained in some patients, no patient complained of difficulty in daily or sports activities or of instability during such activities regardless of the treatment method.

Limitations

The present review had several limitations. First, the number of cases that met the inclusion criteria was small. Second, most studies were case reports or retrospective case series with small numbers of patients. Third, because some studies did not report the patients' characteristics, medical history, or treatment method, the number of cases that could be analyzed differed for each analyzed item. Fourth, the variability in the reported outcome evaluation methods made it extremely difficult to perform meaningful comparisons between the outcomes of the different treatment methods. Finally, because the patients were adolescents, the follow-up period was generally short and the occurrence of late complications could not be confirmed.

CONCLUSION

MHE fracture-separation caused by arm wrestling occurred mostly in boys aged 14 to 15 years (72%) regardless of the status of the match. A rapid increase in muscle strength and physiological reduction of tensile strength of the physeal cartilage resulted in relative mechanical

imbalance in boys during adolescence. These changes are thought to be the main cause of this fracture. Furthermore, it is highly likely that a sudden change from a concentric contraction to an eccentric contraction of the flexor-pronator muscles increases the probability of fracture occurrence.

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