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ORIGINAL ARTICLE • ELBOW - FRACTURES

Analysis of radial head and coronoid process fractures in terrible triad of elbow

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Abstract

Purpose To describe the morphological characteristics of radial head and coronoid fractures and evaluate the relationship of two fracture patterns in terrible triad.

Methods Distributions of all types of radial head and coronoid fractures according to the Mason, Regan–Morrey, and O'Driscoll classifications were firstly described by reviewing radiographs and computed tomography scans in 92 consecutive terrible triads. Then, distributions of all combinations of radial head and coronoid fractures were reported. Correlation analysis between severity of radial head and coronoid fractures was finally performed.

Results In radial head fractures, Mason 2 accounted for 68%, Mason 3 accounted for 32%, and no Mason 1 was found. In coronoid fractures, there were 29 type 1, 44 type 2, and 19 type 3 in Regan–Morrey classification and 72 type 1, one type 2, and 19 type 3 in O'Driscoll classification. There were 28 M2R2, 23 M2R1, 16 M3R2, 12 M2R3, seven M3R3, and six M3R1 in combined Mason and Regan–Morrey type. There were 53 M2O1, 19 M3O1, 10 M3O3, nine M2O3, and one M2O2 in combined Mason and O'Driscoll type. A weak correlation was found between radial head and coronoid fractures.

Conclusions In terrible triad injuries, the most common type of radial head fracture is Mason 2, while the most common type of coronoid fracture is Regan–Morrey type 2 or O'Driscoll type 1. In combinations of two fracture patterns, M2R2 or M2O1 is the most common. Severity of radial head fractures is weakly correlated with coronoid fractures.

Keywords Terrible triad · Coronoid · Radial head · Fractures

Introduction

Terrible triad of elbow is one of the most challenging injuries of elbow joint due to its complex injury pattern and compromised clinical results. In 1997, Hochkiss first described terrible triad of elbow as a posterior dislocation of elbow with fractures of radial head and coronoid [1].

Josefsson [2] and Ring [3] published clinical reports which showed that the final results of terrible triad were not ideal, and the complications include elbow instability, arthritis, and stiffness. Therefore, fundamental studies such as the mechanism and fracture morphology are essential to improve the understanding and treatment of terrible triad. In recent years, there were some studies focused on the morphology and classifications of coronoid process fractures [4–6]. Jonas [4] described the anatomy of coronoid process, with specific focus on the coronoid height and width, olecranon–coronoid angle in detail. Adams [5] tried to use CT scans to describe coronoid process fracture morphology. Manidakis [6] performed a meta-analysis which suggested that early recognition of specific coronoid process fracture patterns and use of appropriate classification systems were critical to achieve favorable outcomes. Unfortunately, no previous study evaluated the relationship between radial head and coronoid process fractures in terrible triad. Because the two fracture patterns are associated in a particular injury, we believe it is necessary to analyze the relationship between radial head and coronoid process fractures. In this study, we reviewed plain films and two-dimensional computed scans of 92 terrible triad injuries, the primary goal is to evaluate the morphology character of radial head and coronoid process fracture pattern in terrible triad and analyze the relationship of these two fractures in this special elbow injury.

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Methods

Patients and materials

From January 2013 to January 2015, a consecutive cohort of 102 patients with terrible triad of elbow was admitted in our hospital for operative treatment. Patients with complete radiographic information, including AP and lateral X-ray of elbow, preoperative two-dimensional CT scans, were included. Ten patients were excluded due to incomplete radiographic records, and thus 92 patients were included finally. There were 63 males and 29 females with average age of 41 years old (range 16–73 years old), 77 patients (83%) sustained terrible triads through fallings, 8 (9%) through traffic accidents, 7 (8%) through sport injuries.

Analysis of radial head fracture

Radial head fracture was described by Mason classification [7].

In this system, type-1 fractures are defined as nondisplaced or minimally displaced fractures (displacement, < 2 mm); type-2 fractures are defined as displaced fractures (displacement, > 2 mm) of the radial head or neck with less than 3 fragments; and type-3 fractures as displaced fractures that are not amenable to reconstruction.

Proportions of each type of radial head fracture were reported. Proportions of radial neck fractures in male and female patient groups were also reported.

Analysis of coronoid process fractures

Analysis of coronoid process fractures was performed by two classification systems: Regan–Morrey classification and O'Driscoll classification. The fractures were firstly classified by the Regan and Morrey classification [8], which was modified by biomechanical studies that suggested that more than 30% loss of coronoid height was associated with increased elbow instability in the setting of a terrible triad injury pattern [9].

In this study, a fracture from tip to 30% of total height of coronoid process is regarded as type 1, a fracture involving 30–50% of total coronoid height is type 2; a fracture involving more than 50% of total coronoid height is type 3.

Secondly, the fractures were classified by O'Driscoll classification, and type-1 injury is a fracture line in the coronal plane that involves the tip. Type 2 is an anteromedial coronoid fracture located between the tip of coronoid process and sublime tubercle. The fracture line assumes an oblique orientation, whose orientation is intermediate between the coronal and sagittal planes. Type 3 is a basal fracture, involving at least 50% of the height of the coronoid process [10].

Three observers (one senior attending surgeon of orthopedic trauma and two orthopedic residents) performed all classifications of radial head and coronoid process fractures on two occasions with an interval of 3 months. The final result was adopted when consensus was achieved among the three observers. If there is any dispute, the final classification type was determined by the senior attending surgeon. The inter- and intra-observer reliability was calculated using the Kappa statistic. A score of 0.81 or more was considered excellent, 0.61–0.80 as good, 0.41–0.60 as moderate, and if less than 0.40 as poor to fair.

Analysis of combined fractures of radial head and coronoid process

To analyze the correlation between severity of radial head and coronoid process fractures, Mason classification, Regan–Morrey classification, and O'Driscoll classification were used to illustrate the severity of each fracture.

Combination of radial head and coronoid process fractures in a terrible triad was originally named by us as MnRn, Mn means Mason type *n*, Rn means Regan–Morrey type *n*. For example, in a terrible triad, radial head fracture was Mason type 2, coronoid process fracture was Regan–Morrey type 1, and then the injury was illustrated as M2R1.

Similarly, the combination of Mason type and O'Driscoll type in a terrible triad was named as MnOn.

Proportions of all combinations of fractures in this cohort were reported.

Correlation analysis between the classifications of radial head fracture and coronoid process fracture in terrible triad was performed at last.

Statistical analysis

Correlation analysis between the classifications of radial head fracture and coronoid fracture in a terrible triad injury was performed by Kendall Tau–*b* test. Values of Tau–*b* range from − 1 (100% negative association, or perfect inversion) to + 1 (100% positive association, or perfect agreement). A value of zero indicates the absence of association. Chi-square test was performed to compare proportions between two groups, when $N \geq 40$, $1 \leq T < 5$, calculation by Yates's correction for continuity was used. Independent T test was used to compare means. $P \leq 0.05$ was considered meaningful in Chi-square test and T test. Statistical analysis was performed using statistical software (SPSS statistical package, version 19.0; SPSS Inc., Chicago, IL).

Table 1 The relation of Regan–Morrey type in coronoid fractures with Mason type in radial head fractures

Coronoid (Regan–Morrey)/radial head (Mason)	Mason-I radial head fracture	Mason-II radial head fracture	Mason-III radial head fracture	Total
Type-I coronoid fracture	0	23	6	29
Type-II coronoid fracture	0	28	16	44
Type-III coronoid fracture	0	12	7	19
Total	0	63	29	92

Table 2 The relation of O'Driscoll type in coronoid fractures with Mason type in radial head fractures

Coronoid (O'Driscoll)/radial head (Mason)	Mason-I radial head fracture	Mason-II radial head fracture	Mason-III radial head fracture	Total
Type-I coronoid fracture	0	53	19	72
Type-II coronoid fracture	0	1	0	1
Type-III coronoid fracture	0	9	10	19
Total	0	63	29	92

Results

Analysis of radial head fracture

There were 63 Mason 2 (68%) and 29 Mason 3 fractures (32%) in this cohort. It is noteworthy that we did not find any Mason-1 fracture.

There were 6 (7%) radial neck fractures, including 4 female (14%, 4/29) and 2 male patients (3%, 2/63). We did not find any significant difference between the proportions of radial neck fractures in female patients and male patients ($P=0.144$). The mean age of 4 female patients was 50 years old, and the mean age of 2 male patients was 41 years old. We did not find any significant difference between the mean ages of patients with radial head and radial neck fractures (40 vs. 47 years old, $P=0.266$).

Analysis of coronoid process fractures

According to Regan and Morrey classification, there were 29 type 1 (31%), 44 type 2 (48%), 19 type 3 (21%) coronoid process fractures.

According to O'Driscoll classification, there were 72 type 1 (78%), 1 type 2 (1%) and 19 type 3 (21%) coronoid process fractures (21%).

Correlation between radial head and coronoid process fractures

The relationship between Mason type in radial head fractures and Regan–Morrey type in coronoid fractures is illustrated in Table 1.

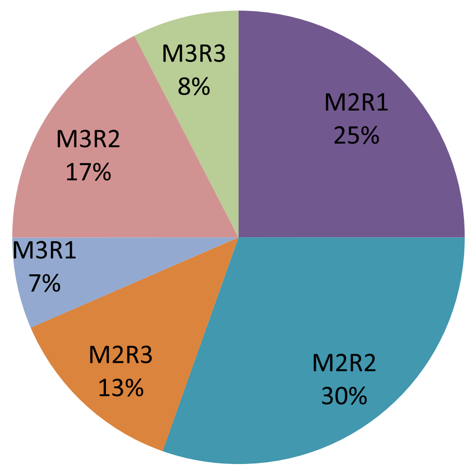

Fig. 1 The distribution of each combination of Mason type and Regan–Morrey type

The relationship between Mason type in radial head fractures and O'Driscoll type in coronoid fractures is illustrated in Table 2.

In combinations of Mason and Regan–Morrey type, M2R2, M2R1, M3R2, M2R3, M3R3, M3R1 are listed in the order of occurrence (Fig. 1).

In combinations of Mason and O'Driscoll type, M2O1, M3O1, M3O3, M2O3, M2O2 are listed in the order of occurrence (Fig. 2). Each pattern of injury was illustrated (Figs. 3, 4, 5, 6, 7).

In Kendall correlation analysis of Mason type in radial head fractures with Regan–Morrey type in coronoid process fractures, the tau–b value was 0.133 ($P=0.182$), which means a weak correlation between the patterns of the two fractures.

In Kendall correlation analysis of Mason type in radial head fractures with O'Driscoll type in coronoid process

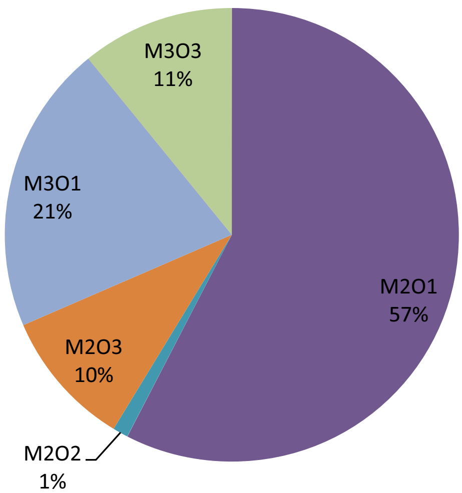

Fig. 2 The distribution of each combination of Mason type and O'Driscoll type

fractures, the tau–b value was 0.214 ($P = 0.04$), meaning a weak correlation between the two fractures.

The inter-observer and intra-observer reliability in this study is presented in Table 3.

Discussion

Terrible triad of elbow remains to be an extremely difficult injury to treat nowadays. It is partly due to lack of anatomical or pathological understandings of the injury. Until now, only one small sample-sized study focused on the anatomical character of coronoid process fractures in terrible triad of elbow [11]. There is no large sample study about the anatomical characters of combined radial head fractures with coronoid fractures in terrible triad. In our study, not only the character and distribution of each type of fracture was delineated, but the combinations of radial head and coronoid fractures were originally named and analyzed.

In radial head fractures, no Mason-1 fracture was found. The first reason we believed is relative high-energy mechanism required in terrible triad; the second may be that mechanisms of terrible triads are different with that of isolated radial head fractures. Specifically, terrible triad is usually caused by combined valgus, rotation and depression forces in a severe posterolateral rotator injury [12, 13], and then radial head would be more likely to collide with capitellum during posterior dislocating process of elbow joint, which would lead to a more severe fracture of radial head rather than Mason type-1 fracture.

There were 6 (7%) radial neck and 86 (93%) fractures. Radial neck fractures were frequently low-energy fragility fractures associated with osteoporosis [14, 15]. Radial head fractures were more commonly associated with more complex injuries and reported to be almost twice as common as radial neck fractures, compatible with limited data stating that radial head fractures account for 56% and radial neck fractures 20% of all proximal forearm fractures [16, 17].

In this study, most injuries of proximal radius in terrible triad were radial head fractures, which were almost ten times as common as radial neck fractures. The results are consistent with the conclusion mentioned above that radial head fractures were more commonly associated with complex injuries such as terrible triads. However, in terrible triad injuries, radial neck fractures were not necessarily caused by osteoporosis, because the mean age of female patients and male patients with radial neck fractures was only 50 and 40 years old, respectively. Secondly, we did not find any significant difference between the mean ages of patients with radial head fractures and patients with radial neck fractures.

Although there is no significant statistical difference, female patients were more likely to develop radial neck fractures in terrible triads than male patients.

In coronoid process fractures, according to O'Driscoll classification, most were type-1 fractures (78%), followed by type 3 (21%), type 2 were the least (1%).

The results suggested that 99% coronoid process fractures in terrible triads were in coronal plane, in which 78% involved the tip with variable height, 21% involved the base of coronoid.

In corporation with Regan–Morrey classification, only 31% fractures involved less than 30% height of coronoid process, the others involved more than 30% height. A biomechanical study suggested that more than 30% loss of coronoid height was associated with increased elbow instability in the setting of a terrible triad injury pattern [9].

Identification of the type and morphology of the coronoid fracture is vital for identifying the overall pattern of injury. Job [18] studied coronoid fracture patterns by reviewing 67 coronoid fractures as part of a fracture–dislocation of the elbow. He found that 32 patients with terrible triad injuries had small (50%) coronoid fractures with 1 of these being a fracture of the anteromedial facet of the coronoid. The author speculated that fractures of the coronoid associated with terrible triad injuries with rare exception are transverse fractures [10, 18]. Now this speculation is strongly supported by the results of our large sample-sized study. Through overall analysis of two classifications, it is natural to point out that most coronoid process fractures in terrible triads are tip fractures involving different heights of coronoid process; the possible mechanism is axial compression of the trochlea on the coronoid process in valgus posterolateral rotator force [6].

The degree of elbow flexion during dislocation may play a key role in the height of coronoid process fractures because previous biomechanical study indicated elbow instability in extension, and all pretest elbow dislocations

Fig. 3 A 58-year-old female presents with an injury to her right elbow following a fall. Plain films reveal a terrible triad injury of elbow (**a**, **b**). In the CT scans, a Mason type-2 radial head fracture (**c**) and an O'Driscoll type-1 coronoid fracture (**d**) are clearly illustrated. So the injury is classified as M2O1, which is the most common type of terrible triad in this study

occurred at 30° and 45° of elbow flexion. As elbow flexion angle increases, the line of action of muscles crossing the elbow joint changes, resulting in a shift of the resultant joint force vector from the most distal portion of the coronoid process to a more central position in the sigmoid fossa [19]. Theoretically, the base of coronoid process could serve as a buttress against the dislocating ulna only in a flexed elbow. But, flexed elbow is assumed to be relatively stable and not easily dislocated. That may explain less basal coronoid process fractures in terrible triad. After all, in this study, basal coronoid fractures accounted for 21%, in contrast to 0 case reported in Job's study; the difference is probably due to selection bias caused by different sample sizes. The bias may also contribute to different proportions of Regan–Morrey type-1 fracture between our study (31%) and Job's report (0%). On the other hand, modified Regan–Morrey classification was used in our study instead of original Regan–Morrey classification with ambiguous distinguishes of type-1 and type-2 fracture used by Job.

Similar to Job's report, there was only one type-2 fracture (1%) in this study. Although anteromedial facet fracture of coronoid is extremely rare in terrible triad injury, its existence means that posteromedial rotation could also result in a terrible triad. This kind of terrible triad may be different from the terrible triad that we normally refer to.

When we combined Mason type with Regan–Morrey type, M2R2 accounted for the most, which was 30%. When we combined Mason type with O'Driscoll type, M2O1 was most often encountered and accounted for 57%. The results verify that most terrible triads represent a posterolateral rotator mechanism [10]. It is created when a combination of axial and valgus directed forces is applied to the extended

Fig. 4 A 55-year-old male presents with an injury to his left elbow following a fall. Plain films reveal a terrible triad injury (**a**, **b**). In the CT scans, a Mason type-3 radial head fracture (**c**) and an O'Driscoll type 1 (**d**) are demonstrated. So the injury is classified as M3O1, which is the second most common type in this study

elbow with the forearm in supination. There is a staged disruption of elbow constraints in a lateral to medial direction referred to as the Horii circle. The disruption starts at the lateral ulnar collateral ligament (LUCL) and progresses anteriorly and posteriorly. In terrible triads, radial head impacts and is forced under the capitellum. Progressive valgus drives the coronoid under the trochlea shearing off its tip in a transverse fashion [6]. What is more, relative high-energy force is necessary in the mechanism based on absence of Mason-1 fracture. All of these could explain why the most common combination is M2O1 in terrible triads.

Initially, we hypothesized that the severity of radial head fractures would be correlated with coronoid process fractures to some extend in a terrible triad. The basis of the hypothesis is that a severe radial head fracture means a high-energy injury, which may also lead to a severe coronoid process fracture. But, statistical analysis does not support our hypothesis. The results only show weak correlation between the severity of radial head and coronoid process fractures. It is partly due to inherent limitations of each individual classification. Such as the Regan–Morrey classification, it does not consider the morphology of coronoid process fracture, only depends on the fracture size. O'Driscoll classification is much better because it focuses not only on the size of fracture but location. Obviously, it is inconvenient to describe fractures in terrible triads using different classifications as we did. As a result, it is meaningful to propose a new classification system for fractures in terrible triad injuries, which would simplify and benefit the evaluation and treatment of terrible triad injuries.

In conclusion, we summarized morphological characters of fractures in terrible triads, originally delineated the overall distribution of combinations of fractures, and analyzed the relationship of the two fractures in terrible triad. This fundamental study would improve the investigation and understanding of terrible triad.

Limitation

1. It is a retrospective study in only one trauma center and has inherent selection and spectrum bias;
2. Further, correlation analysis was not performed for each type of fracture due to limited cases;

Fig. 5 A 27-year-old male presents with an injury to his right elbow following a fall. Plain films reveal a terrible triad injury (**a**, **b**). In the CT scans, a Mason type-3 radial head fracture (**c**) and an O'Driscoll type 3 (**d**, **e**) are demonstrated. So the injury is classified as M3O3, which is the third most common type in this study

Fig. 6 An 18-year-old male presents with an injury to his right elbow following a fall. Plain films reveal a terrible triad injury (**a**, **b**). In the CT scans, a Mason type-2 radial head fracture (**c**) and an O'Driscoll type 3 (**d**, **e**) are demonstrated. So the injury is classified as M2O3, which is the fourth common type in this study

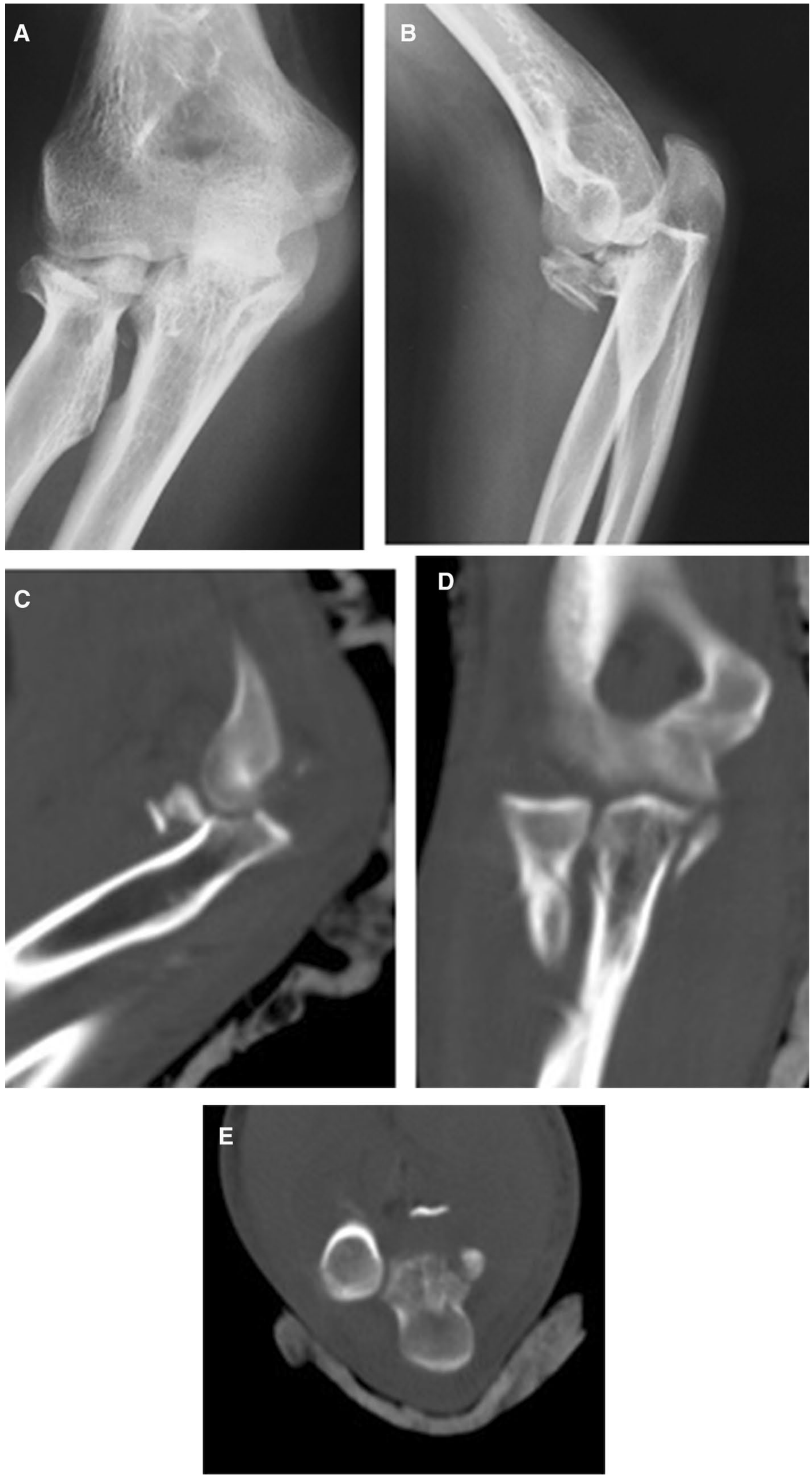

Fig. 7 A 22-year-old male presents with an injury to his right elbow following a fall. Plain films reveal a terrible triad injury (**a**, **b**). In the CT scans, a Mason type-2 radial head fracture (**c**) and an O'Driscoll type 2 (**d**, **e**) are demonstrated. So the injury is classified as M2O2, which is the least common type in this study

Table 3 The inter-observer and intra-observer reliability in this study

	Mason classification	Regan–Morrey classification	O'Driscoll classification
Inter-observer	0.81–0.92	0.68–0.81	0.72–0.85
Intra-observer	0.86–0.95	0.72–0.83	0.75–0.87

3. Only conventional radiographic data were analyzed, and more vital findings may be revealed by studies using advanced morphological technology.

Conclusions

In terrible triad injuries, the most common type of radial head fracture is Mason 2. Radial neck fractures are less, but more easily found in female patients. The most common type of coronoid process fracture is Regan–Morrey type 2 or O'Driscoll type 1. In combinations of Mason and Regan–Morrey type, M2R2 is the most. In combinations of Mason and O'Driscoll type, M2O1 is the most. The severity of radial head fractures is weakly correlated with coronoid process fractures.

Compliance with ethical standards

Conflict of interest Authors Shaoliang Li, Xu Li, and Yi Lu declare that they have no conflict of interest.

Ethical approval The study complies with the current laws of the country.

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