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Abstract

Background: Heterotopic ossification (HO) involves abnormal bone formation in soft tissues near joints, commonly occurring after elbow trauma or surgery, leading to pain and functional limitations. Previous studies have primarily characterized HO distribution based on bony landmarks, lacking a detailed investigation into the characteristics of its distribution in periarticular soft tissue in post-traumatic elbows. This study aimed to (1) develop a muscle-guided classification system using computed tomography (CT) to map HO relative to elbow muscle-tendon units and (2) investigate correlations between HO location and severity.

Methods: In a retrospective study, 56 patients with HO and elbow stiffness following trauma were analyzed. CT imaging was used to classify HO into seven categories: Posterior - olecranon tip - triceps brachii (P-O-T); Posteromedial - medial gutter - flexor carpi ulnaris (PM-MG-FCU); Posterolateral - lateral gutter – anconeus (PL-LG-AN); Medial - medial epicondylar – flexor muscles (M-ME-FLEX); Lateral - lateral epicondylar – extensor muscles (L-LE-EXT); Anterior - humeroulnar joint – brachialis (A-HU-B); and Anterior - humeroradial – supinator (A-HR-SP). HO severity was graded (1-3) based on CT morphology, and correlations between HO location and severity were assessed.

Results: PM-MG-FCU was the most common HO location (67.9%). Significant correlations were found between HO severity and location, with higher rates of HO in grades 2 and 3, characterized by extensive mature bone formation and bone bridge development occurring in the PL-LG-AN, P-O-T, and PM-MG-FCU.

Conclusion: The muscle-guided classification system effectively delineated HO distribution near elbow muscle-tendon units. HO locations surrounding the anconeus, triceps brachii, and FCU (flexor carpi ulnaris) correlate with higher radiographic severity, providing valuable insights for treatment strategies.

Keywords: Elbow trauma; heterotopic ossification; elbow stiffness; radiographic severity; muscle-guided; classification; distribution prevalence

Level of evidence: Level IV; Case Series; Development of Classification System

Heterotopic ossification (HO) is a dynamic, complex pathologic process of ectopic bone formation in periarticular soft tissues.[8] It often occurs after trauma, burns, brain injuries, or surgical procedures, frequently affecting the hip, knee, and elbow joints.[7] Although the exact pathogenesis of HO formation remains unclear, it is commonly considered that musculoskeletal injuries and postsurgical changes induce aberrant differentiation of mesenchymal stem cells.[17] This results in the pathological formation of cartilage and bone growth within soft tissues such as tendons, ligaments, and muscles, outside the native skeleton.[8, 17] The process may be influenced by the products of torn muscle, torn soft tissue, and bleeding following trauma.[6]

The formation of HO in the elbow joint can cause pain and functional impairment, significantly affecting the quality of life of patients. Direct trauma is the most common cause of HO in the elbow.[14] The prevalence of HO with functional limitation after elbow trauma is 20%.[12] Foruria et al proposed that HO in the post-traumatic elbow is preferentially located at the origin of soft-tissue structures near fracture sites, and it is particularly more frequent in areas where the soft tissue is damaged.[12] This suggests that the formation and growth of HO likely occur at specific locations within the soft tissue. Nevertheless, the authors did not indicate a specific location.

A recent animal study revealed that an injured Achilles tendon can be affected by HO, which presents specific spatiotemporal characteristics during the tendon healing process. A small HO initially deposits in the stump close to the bone, then near the muscle, and then extends in the direction of the tendon's main axes. These characteristics of HO formation in a healing Achilles tendon are also commonly observed in humans.[29]

However, few studies have investigated the characteristics of HO distribution in relation to the surrounding periarticular soft tissues in the post-traumatic elbow. To our knowledge, the distribution of HO in the post-traumatic elbow has previously been described only based on plain radiographic studies using two-dimensional bony landmarks.[4, 15, 22, 33] However, a classification that illustrates the relationship between HO characteristics and the soft tissue involved is lacking. Muscle-tendon units, which are directly involved in joint movement and stabilization with clear tendinous insertions on the bone, can serve as the main pathologic landmarks to classify elbow HO.[3, 13, 20,

[25, 26, 28]

This study aimed to achieve two primary purposes: (1) to develop a novel muscle-guided classification system based on computed tomography (CT) images that precisely describes the positional relationship between HO and periarticular muscle-tendon units, and (2) to investigate the distribution characteristics of HO near muscle-tendon units in a post-traumatic stiff elbow and the correlation between HO location and radiographic severity. This knowledge may enhance the understanding of HO location in soft tissue and provide new treatment strategies such as optimizing the preoperative surgical plan, guiding surgical approaches for HO removal, and assisting the decision between arthroscopic and open procedures considering the available operational area.

Methods

Participants

The present retrospective investigation obtained ethical commission approval from the institutional review board of Asan Medical Centre (no. 2024-1302). An informed consent form was signed by the subjects.

The institutional case database was queried to identify all patients who underwent surgical treatment for symptomatic post-traumatic stiff elbow concurrent with HO from December 2010 to May 2024 at our hospital. The inclusion criteria were the following: (1) post-traumatic elbow stiffness resulting in functional debilitation, defined as a flexion contracture of ≥30° or further flexion limitation of ≤130°; (2) elbow HO diagnosed based on radiographic workup; (3) complete clinical record and CT data; and

(4) aged 18 years or older. Elbows that fulfilled the above inclusion criteria with intra-articular injuries were included if radiographic assessments confirmed a congruent articular surface and an intact joint space, indicating that fracture healing did not adversely affect ulnohumeral motion. The exclusion criteria were the following: (1) immature bone; (2) insufficient clinical or radiographic data; (3) association with burns or central nervous system injuries; (4) other factors that might manifest as the primary features of elbow stiffness, such as scarred skin, incongruent joint surfaces, trauma-associated non-union, or malunion of the elbow; (5) other potential factors blocking elbow motion, such as loose bodies in the olecranon fossa; and (6) severe articular deformity with indistinct articular anatomy.

A total of 95 hospitalized patients who underwent surgical excision of HO for post-traumatic elbow stiffness were identified from the case system. Of these, 54 underwent open arthrolysis and 41 underwent arthroscopic arthrolysis. After applying our inclusion and exclusion criteria, 56 patients remained for analysis. Of the 95 patients, 39 were disqualified based on the following reasons: age younger than 18 years(n = 4), unavailable preoperative CT performed at another hospital (n = 1), controversial diagnosis of immature HO with small hazy display (n = 5), low-quality CT images with dark and bright streaks from metal implants masking the majority of anatomical structures (n = 14), association with traumatic brain injury (n = 2), elbow joint malunion or nonunion (n = 5), severe joint surface damage (n = 4), severe deformity with indistinct articular anatomy (n = 1), and presence of loose bodies or fragment debris immediately after trauma (n = 3). Thus, the remaining 56 patients were deemed eligible and included in the study. A flowchart of enrollment and exclusion is shown in **Figure 1**.

The study group included 37 men (66.1%) and 19 women (33.9%) with elbow stiffness and defined HO after trauma. The mean age was 41 years (range, 19–74 years), and stiffness in the dominant arm was present in 31 patients (55.3%). The mean injury duration was 19 months (range, 3–144 months), and the most common original injury type was simple elbow dislocation (20 of 56, 35.7%), followed by injuries associated with distal humerus fractures (12 of 56, 21.4%) (**Table 1**).

CT-based radiographic analysis of HO

The most recent CT scans before stiff elbow surgery were evaluated by two independent observers: an upper extremity fellowship-trained surgeon and a research fellow with clinical experience in HO treatment. Each observer studied the CT scans combined with three-dimensional CT (3D CT) of the participants independently and blindly following the same research protocol to identify, evaluate, and categorize the HO. One observer reviewed the images first, and then the second observer conducted two separate evaluations of the images with a time interval of one month to minimize potential bias. HO was defined as new bone formation that was not visible on radiographs taken immediately after the trauma, explicitly excluding any correspondence with fracture fragments.[12] The presence of HO in the elbow joint was documented using anatomical regions and bony landmarks as references in each respective region.[12, 21, 22, 32, 33] The observers evaluated the anatomical positions of the detected HO on the 3D CT images and CT scans set to a bone window (level: 800 Hounsfield units [HU]; width: 2000

HU). The following categories were used as a primary assessment of HO location: (1) Posterior - olecranon tip; (2) Posteromedial - medial gutter; (3) Posterolateral - lateral gutter; (4) Medial - medial epicondyle; (5) Lateral - lateral epicondyle; (6) Anterior - humeroulnar joint; (7) Anterior - humeroradial joint (**Table 2**).

The sublime tubercle on the medial aspect of the coronoid process, where the ulnar footprint of the ulnar collateral ligament (UCL) inserts, was used as a prominent bony landmark to separate the medial and posteromedial aspects of the elbow joint.[1] Thus, the medial gutter was defined as the bony region within the posteromedial compartment, posteriorly from the anterior band of the UCL as the border. Similarly, the supinator tubercle on the lateral surface of the ulna, where the lateral ulnar collateral ligament (LUCL) attaches, was used as the bony landmark to separate the lateral and posterolateral aspects of the elbow.[5, 10] The lateral gutter was defined as the bony region within the posterolateral compartment lying posterior to the LUCL. A subsequent analysis was conducted to analyze the positional relationship between the HO and the periarticular muscle-tendon units. The same review procedure was applied to 2D CT imaging, with the window settings adjusted to a soft-tissue window (level: 60 HU; width: 360 HU) to enhance the visualization of periarticular muscles and tendons in relation to the identified HO in the categorized anatomical regions.

The periarticular muscles, with tendinous insertions at specific bone landmarks within the elbow joint, were used as references (**Table 2**). The following muscles were included:

(1) The distal triceps brachii, which has its tendinous insertion on the olecranon.[31]

(2) The flexor carpi ulnaris (FCU), originating from the medial epicondyle and the medial aspect of the olecranon.[13]

(3) The anconeus muscle, which arises from the dorsal side of the lateral epicondyle of the humerus to the posterolateral aspect of the ulna.[16]

(4) The other flexor-pronator muscles, which form common tendons attached to the medial epicondyle. This group includes the pronator teres (PT), flexor carpi radialis (FCR), palmaris longus (PL), and flexor digitorum superficialis (FDS) muscles.[13]

(5) The extensor muscles, which develop common extensor tendons attached to the lateral epicondyle of the distal humerus.[5]

(6) The brachialis muscle, which originates from the anterior aspect of the distal humerus and inserts into the tuberosity on the ulnar.[30]

(7) The supinator muscle, with its superficial head arising from the lateral epicondyle and inserting on the lateral, posterior, and anterior surfaces of the proximal radius.[11]

The margins of muscles or tendons, where HO is distributed and extended, were traced. Three slices of the CT images were documented to illustrate the positional relationship between the distribution of HO and the related muscle-tendon units. A muscle-guided classification was then defined with the following categories:

(1) Posterior - olecranon tip - triceps brachii (P-O-T)

At the posterior aspect, the distal triceps brachii served as the reference muscle. The average distance from the most proximal edge of the tendon insertion to the tip of the olecranon is 14.8 mm.[18, 19] HO formed in the region between the triceps and olecranon was categorized and recorded as "Posterior - olecranon tip - triceps brachii (P-O-T)" (**Figure 2**).

(2) Posteromedial - medial gutter - FCU (PM-MG-FCU)

At the medial aspect of the distal humerus, the flexor-pronator muscles (FPMs) develop a common flexor insertion at the medial epicondyle of the humerus. However, their tendinous attachments on the proximal ulna are distinctly different. Specifically, the FCU exhibits a distinct tendinous insertion posterior to the sublime tubercle, with muscle fibers extending posteriorly along the oblique bundle of the UCL and distributing near the medial gutter of the posteromedial compartment.[9, 13] Thus, the FCU was used as the reference muscle in the posteromedial region. HO located within the posteromedial region near the medial gutter and FCU was categorized and recorded as "Posteromedial - medial gutter - FCU (PM-MG-FCU)" (**Figure 3**).

(3) Posterolateral - lateral gutter – anconeus (PL-LG-AN)

The anconeus muscle, originating at the posterosuperior aspect of the lateral epicondyle and inserting on the posterolateral surface of the proximal ulna, was used as the reference muscle in the posterolateral region (**Figure 4**).

(4) Medial - medial epicondylar – flexor muscles (M-ME-FLEX)

Compared to the FCU, other flexor muscles are positioned more anteriorly at the medial aspect of the elbow. The deep layers of the FPMs, including the FDS and pronator teres, develop attachments to the ulna just medial to the ulnar ridge, with fibers extending along the anterior bundle of the UCL.[13] Therefore, other muscles within the flexor-pronator mass, in addition to the FCU, served as reference muscles at the medial aspect of the elbow. HO formed between these flexors and medial epicondyle was categorized and documented as "Medial - medial epicondylar – flexor muscles (M-ME-FLEX)" (**Figure 5**).

(5) Lateral - lateral epicondylar – extensor muscles (L-LE-EXT)

To the lateral side of the elbow joint, the extensor muscles, featuring a typical tendinous structure attached to the lateral epicondyle, served as the reference muscles.[5] HO found between the extensor muscles and the lateral epicondyle was categorized and documented as "Lateral - lateral epicondylar – extensor muscles (L-LE-EXT)" (**Figure 6**).

(6) Anterior - humeroulnar joint – brachialis (A-HU-B)

To the anteromedial aspect of the elbow, the brachialis muscle, spanning along the humeroulnar joint, served as the reference muscle (**Figure 7**).

(7) Anterior - humeroradial – supinator (A-HR-SP)

To the anterolateral aspect of the elbow, the supinator was used as the reference muscle, which spans the humeroradial joint (**Figure 8**).

The severity of the HO was assessed using a radiographic classification system recently developed by Foruria et al that describes the relation between HO severity on CT images.[12] Severity was graded as follows in this study: 1 (hazy or scattered HO, with small to moderate size), 2 (extensive mature HO nearly bridging two separate bones), and 3 (complete bone bridge formation)[12] (**Figure 9**).

The time interval from the trauma to the recorded time of the most recent CT examination was considered the injury duration for cases of stiff elbow with HO.

Statistical analysis

Descriptive statistics were performed using absolute and relative frequencies to depict the characteristics of HO distribution and radiographic severity within each category of the muscle-guided classification system.

Cohen's Kappa coefficient (κ) was used to assess intra- and interobserver reliability regarding HO severity and localization.[24] According to Landis and Koch's criteria, values were categorized as follows: ≤0 (no agreement), 0.01–0.20 (none to slight), 0.21–0.40 (fair), 0.41–0.60 (moderate), 0.61–0.80 (substantial), and 0.81–1.00 (almost perfect agreement).[23]

To examine the correlation between radiographic severity, classified into three degrees, and the seven categories of the muscle-guided classification for elbow HO, a 3×7 contingency table was used to present the association frequencies. Fisher's exact test was performed to evaluate the frequencies and calculate the corresponding significance. Spearman regression analysis was performed to investigate the relationship between injury duration and the radiographic severity of HO located within the categorized muscle-guided regions. A significance level of $p < .05$ was defined.

Statistical analysis of the collected data was performed using the statistical software SPSS Statistics (version 25; IBM, Armonk, NY, USA). A significance level of $p < .05$ was defined for the above statistical analysis.

Results

The most common HO localization was at PM-MG-FCU in 38 patients (67.9%) according to the muscle-guided classification. The next most common localization was at P-O-T in 32 patients (57.1%), M-ME-FLEX in 27 (48.2%), A-HU-B in 24 (42.9%), L-LE-EXT in 21 (37.5%), PL-LG-AN in 17 (30.4%), and A-HR-SP in 8 (14.3%) (**Figure 10**).

Table 3 summarizes the occurrence of HO at various locations across different original injury types. According to Fisher's exact test, no significant difference was observed in the distribution of locations categorized based on the muscle-guided classification across different injury types ($\chi^2 = 41.581$, $p = .811$).

A 3×7 contingency table was created to display the constituent ratio of three radiographic severity grades in seven categories of the muscle-guided classification.

According to the results of Fisher's exact test, there was a significant correlation between the radiographic severity and the location categorized by the muscle-guided classification ($\chi2$ = 32.039, $p<.001$). Pairwise comparisons following the Kruskal-Wallis test further showed that the formation rate of extensive mature HO, characterized by almost complete or complete bridging of two separate bones in the radiographic images (grades 2 and 3 of radiographic severity), was significantly higher in regions categorized as Pl-LG-AN (41.2%), P-O-T (40.6%), and PM-MG-FCU (39.5%) compared to M-ME-FLEX (0%). The p-values, adjusted by the Bonferroni correction, were.047,.007, and.007, respectively. Furthermore, the formation rate of extensive mature HO in the regions categorized as P-O-T (40.6%) and PM-MG-FCU (39.5%) was significantly higher than in the L-LE-EXT (0%) (adjusted p-values of.019 and.018, respectively). However, the HO formation rates in the anterior compartment of the elbow joint involving A-HU-B (16.7%) and A-HR-SP (37.5%) were moderate and did not show a significant difference compared to the other five categories. There was no significant relationship between injury duration and radiographic severity ($p =.109$)

The interobserver reliability for the HO location was substantial, with a kappa (κ) value of 0.739 ($p <.001$). For HO severity, it was also substantial, with a κ value of 0.651 ($p <.001$). Additionally, the intraobserver reliability for the HO location was almost perfect, with a κ value of 0.890 ($p <.001$). For HO severity, it is almost perfect as well, with a κ value of 0.848 ($p <.001$).

Discussion

Previous radiographic studies on post-traumatic elbow HO were based on anatomical regions or specific bony landmarks in plain radiographs.[22] Foruria et al classified the locations of HO in the post-traumatic elbow based on the relative position to bony components such as the humerus, radius, and ulna.[12] Zhang et al categorized the HO locations in the elbow as lateral/medial supracondylar areas, lateral/medial aspects of the capsule, and proximal radius/ulna.[33] While these studies described the information based on general location, the authors did not specify the localization relative to the periarticular soft tissue, which is the main pathology of post-traumatic HO.[8]

Although HO is currently defined as new bone formed within extra-skeletal soft tissues, no further investigation of the positional relationship between soft tissue and HO has been described.[8, 17] A recent study demonstrated that injured Achilles tendons in animal models can develop HO that exhibits specific spatiotemporal patterns during healing.[29] Microtomography revealed that a small HO initially forms at the stump of the torn tendon near the bone site and subsequently extends along the muscle following the direction of the tendon's main axes. The study also identified similarities in HO deposits between rats and humans through a review of clinical CT images from 38 patients with Achilles tendon injuries. In a clinical study on HO in post-traumatic elbows, Foruria et al proposed that HO location is likely correlated with the injury pattern, often developing at the origins of torn soft-tissue structures or near fracture sites. Their results are consistent with HO being more prevalent in areas with extensive soft-tissue injury. Therefore, to contribute new insights into the mechanisms of HO formation and effectively treat and prevent HO after elbow trauma, further investigation is necessary to achieve a more precise mapping of HO localization and determine its position near soft tissue in post-traumatic elbows with greater precision.

In the present study, we introduced a novel muscle-guided classification system to precisely determine the positional relationship between HO and the periarticular muscle-tendon units in the elbow joint. This classification system provided a detailed depiction of HO detected in the CT images using anatomical references such as muscle-tendon units and bony landmarks. The system identified seven categories based on prominent reference muscles distributed near the elbow joint: triceps, FCU, FDS along with other flexor muscles, extensor muscles, anconeus, brachialis, and supinator. This approach allowed a more accurate localization and mapping of HO relative to the soft tissue in the elbow joint. CT was effective for determining the precise location of HO in a stiff elbow, including small, hazy HO categorized as grade 1 in radiographic severity classifications. CT also provided a detailed view of the complex architecture of articular surfaces, offering advantages over plain radiographs. We found that CT scans efficiently displayed HO location in soft tissue when using reference muscles with satisfactory observer reliability. Although MRI is useful for evaluating soft tissues near the elbow, it is less effective than CT in visualizing the bony details of structures such as HO and joint architecture. Additionally, using reference muscles to describe HO location provides three-dimensional spatial information about HO distribution based on muscle distribution and insertion in the elbow.

Among patients with symptomatic post-traumatic elbow stiffness from HO, 38 out of 56 (67.9%) elbows developed HO in the posteromedial aspect of the elbow, specifically in the area between the FCU and the medial gutter, categorized as PM-MG-FCU. This category exhibited the highest frequency among all categories in the muscle-guided classification, which is consistent with previous reports. Park et al reported that HO most commonly developed in the posterior aspect such as the posteromedial aspect of the capsule, occurring in 36 out of 40 (90%) individuals with elbow stiffness following trauma.[27] Foruria et al reported that HO was primarily distributed in the posterior aspect of the ulna following surgery for proximal radius and ulna fractures, with or without associated distal humeral fractures, occurring in 15 out of 48 elbows (31.3%).[12] Zhang et al reported a high HO prevalence in the posterior region of the ulna, in 31 out of 56 patients (55%), whereas the highest frequency of postoperative HO was observed in the medial aspect in 52 out of 56 patients. This may be because the authors divided the elbow region primarily based on bony landmarks in the coronal two-dimensional plane without clearly defining the posteromedial and medial regions. In the present study, the sublime tubercle, where the anterior band of the UCL inserts and separates the FDS and FCU, was used as a prominent landmark to demarcate the region between the posteromedial and medial areas.

The present study also assessed the radiographic severity of HO by referencing the classification system for elbow HO proposed by Foruria et al in 2013.[12] In contrast to the existing functional classification by Hastings and Graham,[32] assessment of HO severity in the present study predominantly focused on radiographic morphological characteristics.

Our results revealed a significant correlation between radiographic severity and HO location. The overall posterior compartment of the elbow presented a significantly higher risk of developing extensive mature HO and bridging two separate bones (grade 2 and 3 in radiographic severity) (Figure 3), specifically in the PL-LG-AN (41.2%), P-O-T (40.6%), and PM-MG-FCU (39.5%) categories. However, no grade 2 or 3 radiographic severity of HO was observed in the medial or lateral aspects of the elbow involving the M-ME-FLEX and L-LE-EXT categories. These results suggest a varying susceptibility to develop severe, massive HO in different areas of the elbow.

Based on the positional relationships observed between HO and surrounding muscle-tendon units on CT images, HO was mostly located at tendinous insertion points and extended directionally along the respective muscles. Interestingly, images obtained from several patients revealed small, limited HO formations in tendons near their bony insertions (Figure 6). These observations suggested that HO development in the elbow may exhibit a specific spatial pattern, similar to findings by Pierantoni et al regarding the Achilles tendon.[29]

The present study demonstrated substantial to almost perfect inter- and intraobserver reliability for both HO location and severity. This reliability underscores the validity of the muscle-guided classification system in clinical practice and research settings.

Understanding the precise location where HO forms and extends in the elbow joint could significantly advance research on the mechanisms of HO formation and improve treatment strategies. For instance, this knowledge could aid in localizing HO during surgery[4] and identifying specific muscles affected by HO for targeted botulinum toxin injections as part of HO treatment and prevention strategies.[2] Furthermore, the use of a standardized nomenclature can improve the determination of HO location on CT scans and refine preoperative surgical planning.

This study has several limitations. First, there was a selection bias as it included only patients with elbow stiffness who underwent surgical treatment. Additionally, because of the nature of the study, few cases had both available MRI images and CT scans from the same time point. Future studies will benefit from image registration or fusion techniques for CT and MR images to better illustrate the correlation between HO location and soft tissue involvement.

Conclusion

A novel muscle-guided classification system was developed to effectively characterize HO distribution near muscle-tendon units in post-traumatic elbows. The HO in the PM-MG-FCU category was the most prevalent, occurring in 38 patients (67.9%), the highest frequency among all classifications. HO located in the posterior compartment, particularly involving specific muscle-tendon units such as the anconeus, triceps brachii, and FCU, was associated with a higher risk of greater radiographic severity. These findings improve our understanding of HO distribution near soft tissue in post-traumatic elbow stiffness and may potentially inform more targeted therapeutic strategies.

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Figure Legends

Figure 1. Flowchart of enrollment and exclusion. HO, heterotopic ossification; CT, computed tomography.

Figure 2. The Posterior - olecranon tip - triceps brachii (P-O-T) category in the muscle-guided classification system. The Posterior - olecranon tip - triceps brachii (P-O-T) category in the muscle-guided classification system. The HO in the posterior region is marked in green in the 3D CT image. The extended large HO in the sagittal 2D scan is marked with red asterisks and the small HO is indicated by a red arrowhead. The tendinous insertion of the triceps brachii muscle is indicated by a yellow single arrow, and the belly of the triceps brachii muscle is indicated by blue triple arrows.

Figure 3. The Posteromedial - medial gutter - flexor carpi ulnaris (PM-MG-FCU) category in the muscle-guided classification system. The HO in the posteromedial region is marked in green in the 3D CT image. The extended large HO in the axial 2D scan is marked with red asterisks and the small HO is indicated by a red arrowhead.

The tendinous insertion of the flexor carpi ulnaris (FCU) on the ulna is indicated by a yellow single arrow, and the belly of the FCU muscle is indicated by blue triple arrows.

Figure 4. The Posterolateral - lateral gutter – anconeus (PL-LG-AN) category in the muscle-guided classification system. The HO in the posterolateral region is marked in green in the 3D CT image. The extended large HO in the axial 2D scan is marked with red asterisks. The tendinous insertion of the anconeus on the ulna is indicated by a yellow single arrow, and the belly of the anconeus muscle is indicated by blue triple arrows.

Figure 5. The Medial - medial epicondylar – flexor muscles (M-ME-FLEX) category in the muscle-guided classification system. The HO located at the medial aspect is marked in green in the 3D CT image. The small, limited HO in the coronal 2D scan is marked with red arrowheads. The common tendinous insertion of the flexor muscles on the medial epicondylar of the humerus is indicated by a yellow single arrow.

Figure 6. The Lateral - lateral epicondylar – extensor muscles (L-LE-EXT) category in the muscle-guided classification system. The HO located at the lateral aspect is marked in green in the 3D CT image. The small, limited HO in the coronal 2D scan is marked with red arrowheads. The common tendinous insertion of the extensor muscles on the lateral epicondylar of the humerus is indicated by a yellow single arrow, and the belly of the extensor muscles is indicated by blue triple arrows.

Figure 7. The Anterior - humeroulnar joint – brachialis (A-HU-B) category in the muscle-guided classification system. The HO in the anteromedial aspect is marked in green in the 3D CT image. The HO in the sagittal 2D scan is marked with red asterisks. The insertion of the brachialis muscle on the anterior ulna is indicated by a yellow single arrow, and the belly of the brachialis muscle is indicated by blue triple arrows.

Figure 8. The Anterior - humeroradial – supinator (A-HR-SP) category in the muscle-guided classification system. The HO in the anterolateral aspect is marked in green in the 3D CT image. The HO in the 2D scan is marked with red asterisks. The distribution of the supinator muscle is indicated by blue triple arrows.

Figure 9. The sagittal 2D CT scan of HO in the Posterior - olecranon tip - triceps brachii (P-O-T) category illustrates the three levels of HO severity: Grade 1, hazy or scattered

HO, with small to moderate size; Grade 2, extensive mature HO nearly bridging two separate bones; Grade 3, complete bone bridge formation.

Figure 10. A frequency distribution shows the exact number of HO cases grouped by muscle-guided classification, as well as the count of each of the three levels of radiographic severity within the different HO categories. PM-MG-FCU, Posteromedial - medial gutter - flexor carpi ulnaris; P-O-T, Posterior - olecranon tip - triceps brachii; M-ME-FLEX, Medial - medial epicondylar – flexor muscles; A-HU-B Anterior - humeroulnar joint – brachialis; L-LE-EXT, Lateral - lateral epicondylar – extensor muscles; PL-LG-AN, Posterolateral - lateral gutter – anconeus; A-HR-SP, Anterior - humeroradial – supinator.

Table Legends

Table 1. Demographics and injury characteristics of patients

Table 2. Anatomic regions and bony landmarks for primary assessment of HO location

Table 3. Distribution of locations of heterotopic ossification among original injury patterns

TABLE 1

Demographics and injury characteristics of the patients

Characteristics	Values or proportions
Number of patients, n	56
Male, n	37 (66.1)
Age, mean (range), years	41, 19-74
Dominant arm, n	31 (55.3)
Injury duration* mean (range), months	19, 3-44
Original injury treatment, n	
Surgical treatment	39 (69.6)
Nonoperative management	17 (30.4)
Original injury types, n	
Simple elbow dislocation	20 (35.7)
Injuries with associated distal humeral fracture	12 (21.4)
Isolated radial head/neck fracture	8 (14.3)
Terrible triad injury	6 (10.7)
Isolated olecranon fracture	3 (5.4)
coronoid fracture associated with elbow dislocation	3 (5.4)
Transolecranon fracture-dislocation	2 (3.6)
Monteggia fracture-dislocation	1 (1.8)
olecranon with concomitant radial head fracture	1 (1.8)
Surgical approach for elbow arthrolysis, n	
Open arthrolysis	30 (53.6)
Arthroscopic arthrolysis	26 (46.4)

* The time interval between the occurrence of the traumatic injury and the most recent recorded CT examination

TABLE 2

Anatomic Regions and Bony Landmarks for Primary Assessment of HO Location[1]

	Anatomical regions	Bony Landmarks	Muscle-Tendon Units
1	Posterior	Olecranon tip	Triceps
2	Posteromedial	Medial gutter	FCU
3	Posterolateral	Lateral gutter	Anconeus
4	Medial	Medial humeral epicondyle	Flexor Muscles (FCR, FDS, pronator)
5	Lateral	Lateral humeral epicondyle	Extensor muscles
6	Anteromedial	Humeroulnar joint line	Brachialis
7	Anterolateral	Humeroradial joint line	Supinator

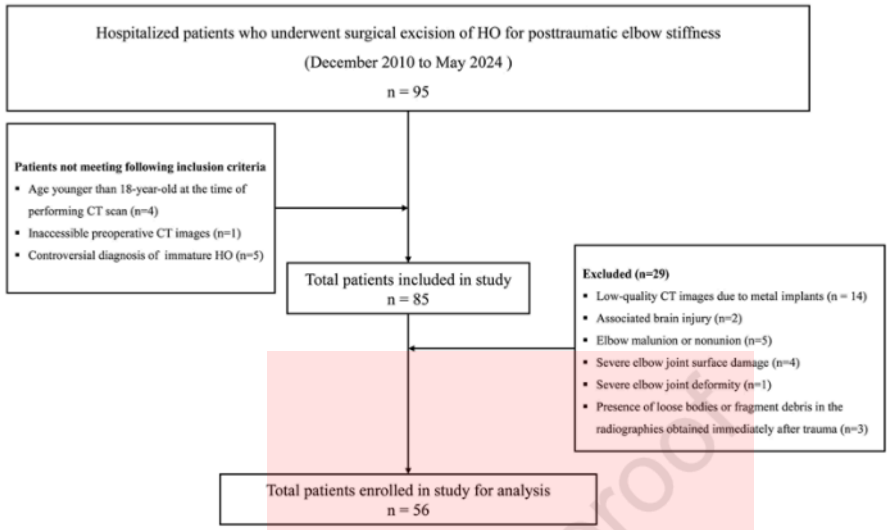
[1]FCU, flexor carpi ulnaris; FDS, flexor digitorum superficialis

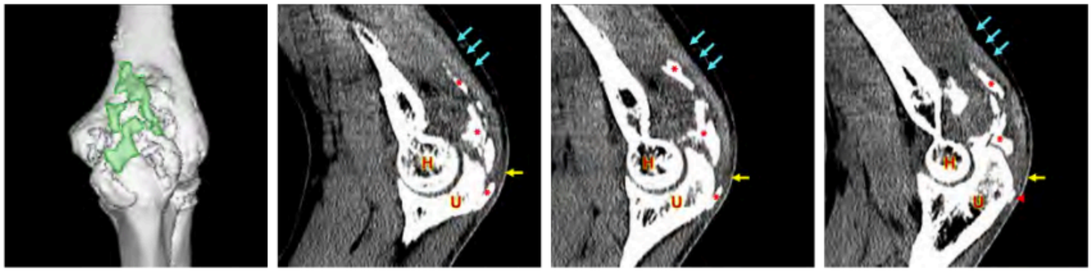
TABLE 3

Distribution of Locations of Heterotopic Ossification Among Original Injury Patterns

Original Injury Types	HO Cases	Categories of HO Location*						
		P-O-T	PM-MG-FCU	PL-LG-AN	M-ME-FLEX	L-LE-EXT	A-HU-B	A-HR-SP
Simple elbow dislocation	20 (35.7%)	14	14	5	13	9	8	4
Injuries with associated distal humeral fracture	12 (21.4%)	8	7	4	4	0	6	1
Isolated radial head/neck fracture	8 (14.3%)	4	5	2	5	6	3	0
Terrible triad injury	6 (10.7%)	4	4	4	2	5	5	3
Isolated olecranon fracture	3 (5.4%)	1	3	1	0	0	0	0
Coronoid fracture associated with elbow dislocation	3 (5.4%)	1	2	1	2	1	2	0
Transolecranon fracture-dislocation	2 (3.6%)	0	1	0	1	0	0	0
Monteggia fracture-dislocation	1 (1.8%)	0	1	0	0	0	0	0
Olecranon with concomitant radial head fracture	1 (1.8%)	0	1	0	0	0	0	0

* Categories of HO location are based on the muscle-guided classification as follows: Posterior - Olecranon tip - Triceps brachii (P-O-T); Posteromedial - Medial gutter - Flexor carpi ulnaris (PM-MG-FCU); Posterolateral - Lateral gutter – Anconeus (PL-LG-AN); Medial - Medial epicondylar – Flexor muscles (M-ME-FLEX); Lateral - Lateral epicondylar – Extensor muscles (L-LE-EXT); Anterior - Humeroulnar joint – Brachialis (A-HU-B); Anterior - Humeroradial – Supinator (A-HR-SP).


Hospitalized patients who underwent surgical excision of HO for posttraumatic elbow stiffness
(December 2010 to May 2024)
n = 95
Patients not meeting following inclusion criteria
Age younger than 18-year-old at the time of performing CT scan (n=4)
Inaccessible preoperative CT images (n=1)
Controversial diagnosis of immature HO (n=5)
Total patients included in study
n = 85
Excluded (n=29)
Low-quality CT images due to metal implants (n = 14)
Associated brain injury (n=2)
Elbow malunion or nonunion (n=5)
Severe elbow joint surface damage (n=4)
Severe elbow joint deformity (n=1)
Presence of loose bodies or fragment debris in the radiographies obtained immediately after trauma (n=3)
Total patients enrolled in study for analysis
n = 56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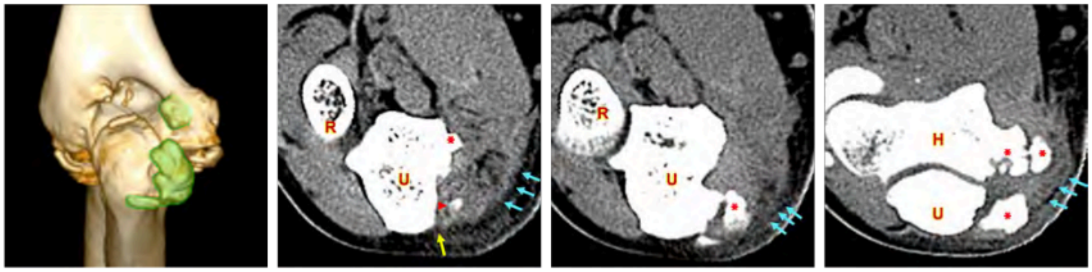
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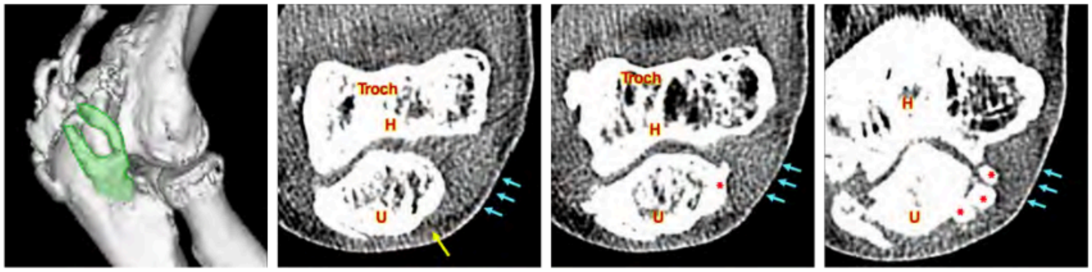
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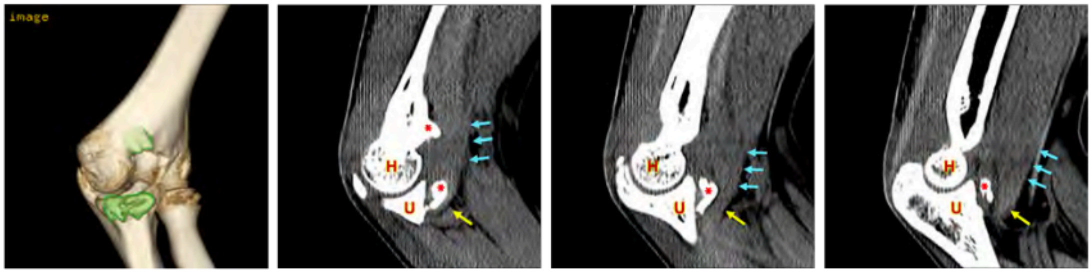
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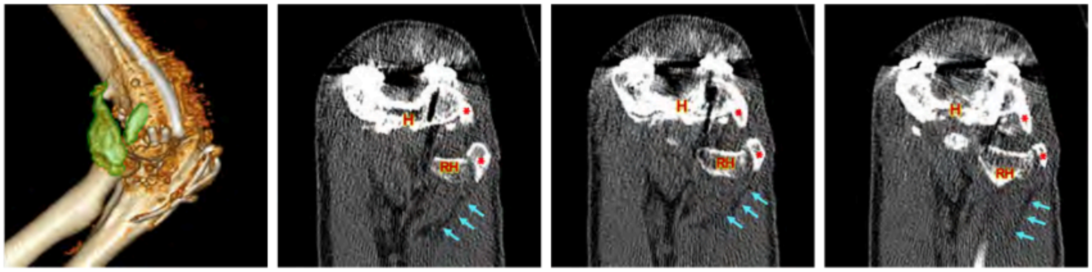
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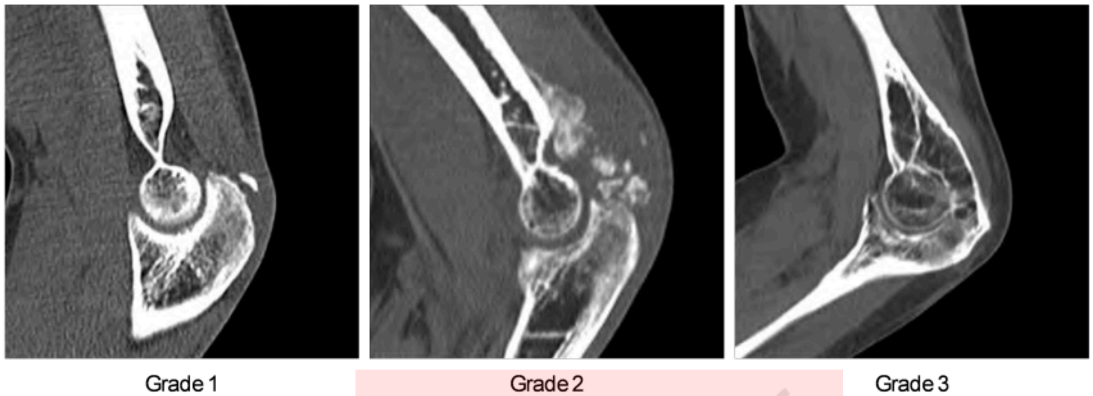
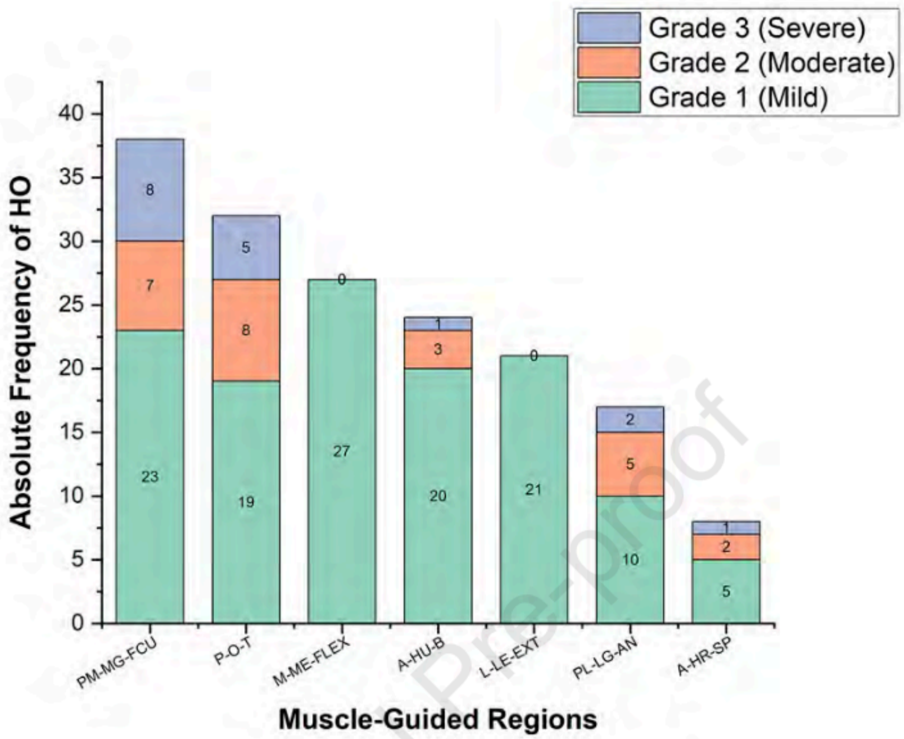

Grade 1
Grade 2
Grade 3


Grade 3 (Severe)
Grade 2 (Moderate)
Grade 1 (Mild)
Absolute Frequency of HO
0
5
10
15
20
25
30
35
40
8
7
23
5
8
19
0
27
1
3
20
0
21
2
5
10
1
2
5
PM-MG-FCU
P-O-T
M-ME-FLEX
A-HU-B
L-LE-EXT
PL-LG-AN
A-HR-SP
Muscle-Guided Regions

11. Hasil uji similaritas Muscle-Guided Mapping

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