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Classification of proximal humerus fractures according to pattern recognition is associated with high intraobserver and interobserver agreement

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A R T I C L E I N F O

Keywords:
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Fracture pattern

Level of evidence: Basic Science Study; Validation of Classification System

Background: The Mayo-Fundación Jiménez Díaz (FJD) classification for proximal humerus fractures aims to identify specific fracture patterns and apply displacement criteria to each pattern. The classification includes 7 common fracture patterns: isolated fractures of the greater or lesser tuberosity, fractures of the surgical neck, impacted fractures involving head rotation in a varus and posteromedial direction or in valgus, and fractures where the humeral head is dislocated (head dislocation), split (head splitting), or depressed (head impaction). The purpose of this study was to evaluate the intraobserver and interobserver agreement of the Mayo-FJD classification system using plain radiographs (xR) and computed tomography (CT).
Methods: Three fellowship-trained shoulder surgeons blindly and independently evaluated the xR and CT of 103 consecutive proximal humerus fractures treated at a Level I trauma center. Each surgeon classified all fractures according to the Mayo-FJD classification system on 4 separate sessions at least 6 weeks apart. K values were calculated for intraobserver and interobserver reliability.
Results: The average intraobserver agreement was 0.9 (almost perfect) for xR and 0.9 (almost perfect) for CT scans. The average interobserver agreement was 0.69 (substantial) for xR and 0.81 (almost perfect) for CT scans at the first round, and 0.66 (substantial) for xR and 0.75 (substantial) for CT scans at the second round.
Conclusion: The pattern-based Mayo-FJD classification scheme for proximal humerus fractures was associated with adequate intraobserver and interobserver agreement using both xR and CT scan. Interobserver agreement was best when fractures were classified using CT scans.

Development of a useful classification system for proximal humerus fractures has remained elusive. Until now, the classification proposed by Neer remains the most widely accepted system.[16,17] It was developed in the 1970s based on radiographic analysis and the concept of fracture segments first described by Codman.[4] Neer disclosed in a 2002 review of his own classification that “the limits of 1.0-cm displacement or 45° angulation were arbitrarily set” at the request of Brown, the editor of Neer's original article. Furthermore, Neer wrote that his classification scheme was “not intended to dictate treatment. As displacement is a continuum, there will always be some borderline lesions.”[17]

Multiple studies have failed to demonstrate adequate levels of agreement or a definitive prognostic value of the Neer classification. Siebenrock and Gerber reported mean kappa coefficients for interobserver and intraobserver reliability of 0.40 and 0.60, respectively.[21] Similar results, with poor-to-fair reliability, have been found by other authors when assessing the Neer classification.[3,7,11,14,20,22] Other classification systems developed later, such as the Arbeitsgemeinschaft für Osteosynthesefragen - Association for the Study of Internal Fixation, Eldelson's, or Hertel's, have not demonstrated adequate reproducibility[10,14,22] or prognostic value[1,5,6] although recent modifications of the Arbeitsgemeinschaft für Osteosynthesefragen - Association for the Study of Internal Fixation published in 2018 improved its performance.[15] In

This study was performed after obtaining Mayo Clinic Institutional Review Board approval (IRB number 18-000463).

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contrast with classification systems for fractures of other bones, most proximal humerus fracture classifications mix fracture displacement and fracture parts or segments when defining the various categories. When using a morphologic classification system, the reproducibility is improved.[19]

During a research project between Mayo Clinic and Fundación Jiménez Díaz (FJD), 2 of the authors of this study realized that the majority of proximal humerus fracture (PHF) followed specific patterns best identified in 3-dimensional renderings of computed tomography.[2,8] A new classification scheme based on pattern recognition was developed to first identify the fracture pattern and only then apply displacement criteria to each pattern, thus separating fracture pattern from fracture displacement. This pattern-based Mayo-FJD classification system includes 7 common patterns described in the material and methods section.

Although the authors have used this classification system in their practice for years, a formal attempt to assess its intraobserver and interobserver agreement has not been completed to date. As such, the purpose of this study was to evaluate the intraobserver and interobserver agreement of the pattern-based Mayo-FJD classification system of proximal humerus fractures on both using plain radiographs (xR) and computed tomography (CT).

Materials and methods

Study protocol

Three trained shoulder surgeons blindly and independently assessed the xR and CT obtained during the evaluation of 103 consecutive PHFs treated at a Level I trauma center between June 2019 and June 2020. To be included in this study, anteroposterior and axillary xR and a CT scan had to be available for assessment.

xR Were cleared of patient identifying data by an independent research assistant and provided to each of the surgeons. Regarding CT assessment, each surgeon was provided access to all DICOM files so that the surgeons could visualize 2-dimensional images as well as 3-dimensional renderings at their discretion.

Before initiating the study, the 3 surgeons met for a 1-hour training session to discuss all details of the pattern-based Mayo-FJD classification. Pictorial representations of the various fracture patterns were available to use by surgeons during their respective classification sessions. There were 4 separate readings: 2 using only xR and 2 using only CT scans. The observers first evaluated xR, followed by CT scans, then xR again, and last CT scans a second time. Each reading was separated by at least 6 weeks, and the order of images was randomized for each reading to minimize any recall bias.

The pattern-based Mayo-FJD classification

This classification scheme divides fractures into 3 main groups: (1) those where only the tuberosities are fractured; (2) those where the humeral head is severely compromised due to fracture-dislocation, severe impaction, or a division (split) of the head itself; and (3) those where the head is largely intact and not dislocated but fractured at the anatomic or surgical neck (SN) level. These groups encompass a total of 7 patterns (Table I and Fig. 1). Any of the fracture patterns in groups 2 or 3 can have either the tuberosities intact, 1 tuberosity fractured, or both tuberosities fractured.

Table I
Categories of the pattern-based Mayo-FJD classification system

Surgical neck (SN)	Isolated (SN)
	With fractured tuberosities (SN-GT, SN-LT, SN-GT-LT)
Tuberosity fractures	
Greater tuberosity (GT)	Isolated (GT)
	In the setting of anterior dislocation (GT-Dl)
Lesser tuberosity (LT)	Isolated (LT)
	In the setting of posterior dislocation (LT-Dl)
Varus posteromedial (VPM)	Intact tuberosities (VPM)
	Fractured tuberosities (VPM-GT, VPM-LT, VPM-GT-LT)
Valgus (VL)	Intact tuberosities (VL)
	Fractured tuberosities (VL-GT, VL-LT, VL-GT-LT)
Head fracture or dislocation	Head splitting (HS)
	Head impaction (HI)
	Head dislocation (HD)

Fractures of the greater tuberosity or lesser tuberosity

Greater tuberosity (GT) fractures can occur in the setting of an anterior dislocation or as an isolated injury. Similarly, isolated fracture of the lesser tuberosity (LT) may occur with or without an associated posterior dislocation. For the purposes of this classification scheme, when a fracture of either tuberosity occurs in the setting of a shoulder dislocation without any other fracture lines, the pattern is considered a GT pattern or LT pattern, and displacement is only assessed after reduction of the dislocation. The main potential adverse outcome with nonoperative treatment of these fractures when displaced is impingement of the tuberosities on the glenoid rim or subacromial space or dysfunction of the rotator cuff secondary to changes in length and line of pull.[8]

Fractures with severe head compromise: head dislocation, head splitting, and head impaction fractures

In these 3 patterns, if the head is fractured from the shaft and dislocated, the fracture is classified as head dislocation (HD). Other fractures in this group include those where there is severe head impaction (HI) (eg, impaction of the head by the posterior glenoid rim in locked fracture dislocations), or the head itself is fractured into 2 or more pieces (head split [HS]). Any of these 3 fracture patterns may or may not present with fractures of 1 or more tuberosities or the shaft. For example, a fracture dislocation with fracture of both tuberosities would be further subclassified as HD-GT-LT. Persistent instability, maltracking, and/or osteoarthritis are the main anticipated complications with nonoperative treatment of these injuries, and consequently surgery is usually recommended.

Varus posteromedial fractures

The plane that separates the humeral head from the diaphysis is located at the anatomic level medially and through the metaphysis laterally. The medial and posterior upper edge of the shaft (the so-called "calcar") suffers comminution and collapse at the posteromedial neck-head junction. As a result, the humeral head articular cartilage typically faces posteriorly (increased head retroversion) and inferiorly (varus), and the shaft is in extension. In these fractures, both tuberosities may be intact, 1 may be fractured, or both may be fractured; the acronyms of the tuberosities may be added to further subclassify varus posteromedial (VPM) fractures as VPM-GT, VPM-LT, or VPM-GT-LT. VPM fractures are very frequent.[8] As these fractures are typically stable due to bony impaction, nonunion is seldom a problem. The main potential adverse outcome with nonoperative treatment is malunion, resulting in decreased range of motion and loss of function.[8]

Valgus fractures

Similar to the VPM fracture, the plane that separates the humeral head from the diaphysis is also located at the head-neck junction medially and at the metaphysis laterally, but the head

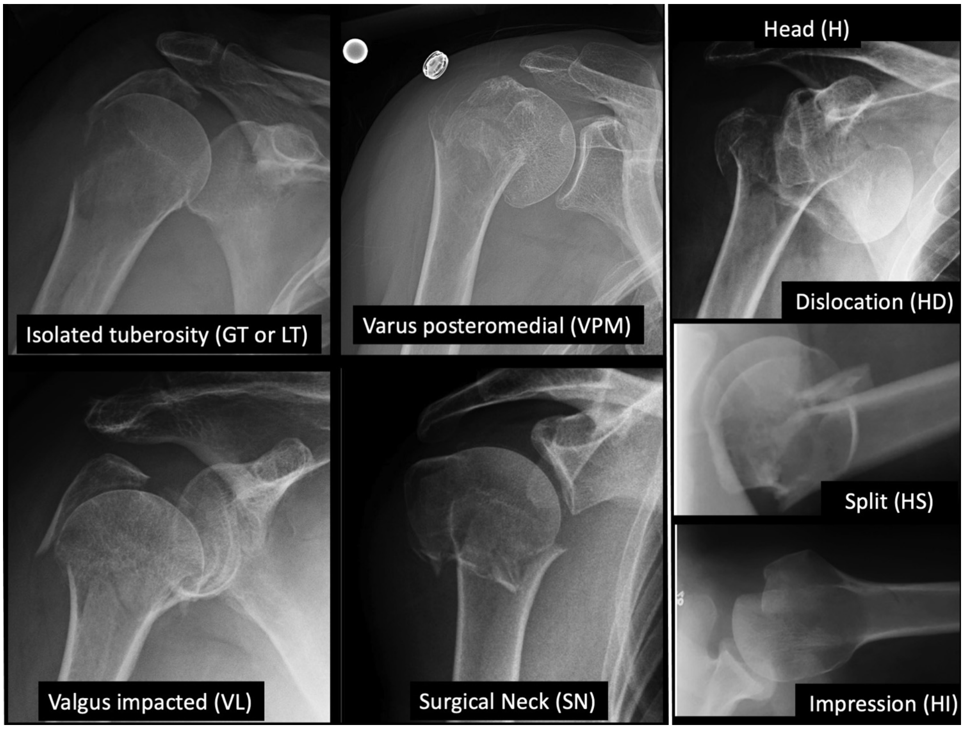

Figure 1 Radiographic examples of the 7 major patterns of proximal humerus fractures for the Mayo-FJD classification.

Table II
Intraobserver Kappa statistics

	X-ray	CT
Observer 1	1.00 (1.00, 1.00)	0.81 (0.71, 0.91)
Observer 2	0.84 (0.76, 0.92)	0.87 (0.79, 0.95)
Observer 3	0.87 (0.80, 0.93)	0.90 (0.85, 0.95)
Average	0.9	0.9

CT, computed tomography.

is displaced in *valgus* (VL) in reference to the shaft, and *comminution occurs laterally* as opposed to posteromedially. As such, the head faces superiorly or superolaterally. Due to this VL displacement, the lateral aspect of the articular surface is inferior compared to its anatomic position. In this fracture pattern, the grater tuberosity is almost always fractured (VL-GT) and pushed laterally by the displaced humeral head. The LT may be intact or also fractured (VL-GT-LT). The main potential adverse outcome with nonoperative treatment of VL fractures is malunion. The medial periosteal hinge can be preserved or disrupted; when disrupted, there is an additional level of instability, which may increase the chances of malunion or even nonunion. Avascular necrosis is also seen more frequently in this fracture pattern when treated nonsurgically[8] or after open reduction and internal fixation.[9]

SN fractures

In these fractures, the plane that separates the diaphysis from the rest of the proximal humerus is at the level of the SN (metaphyso-diaphyseal junction). This fracture plane separates the head and both tuberosities from the diaphysis, and in many SN fractures, the tuberosities are not fractured.

The main feature that distinguishes SN fractures from VMP and VL fractures is that comminution does not determine any orientation or translation of the humeral head due to lack of impaction or bony engagement. Some amount of bony contact at the fractured metaphysis is common. SN fractures may exhibit various degrees of translation or comminution. In many cases, when displacement occurs, the proximal humeral shaft exhibits anteromedial displacement. The humeral head typically remains anatomically oriented in reference to the glenoid since the rotator cuff, tuberosities, and capsule remain intact. In rare cases, an associated tuberosity fracture can lead to humeral head rotation as determined by the pull of the rotator cuff attached to the other intact tuberosity. There are also SN fractures with severe medial diaphyseal displacement leading to bony contact between the shaft calcar and the inferior glenoid rim, with potential mechanical interference with shoulder rotation.[18]

The main potential adverse outcome with nonoperative treatment of these fractures is nonunion at the SN, which is more likely to happen in the presence of substantial fracture displacement (with limited or no contact between the shaft and the proximal humerus), gross fracture instability, or severely compromised healing potential (pathologic fractures, severe malnutrition, smoking).

Statistical analysis

The intraobserver reliability was determined by comparison of the classification of each case by the observers for both the xR and CT scans. Pairwise comparisons between each observer were also performed to determine interobserver reliability. The κ values were calculated for both intraobserver and interobserver reliability. The κ value adjusts for the proportion of agreement among observers that could have occurred by chance. Landis and Koch[13] previously categorized κ values of 0.00 to 0.20 as slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, substantial agreement; and 0.81 or greater, almost perfect agreement. A value of 0.00 indicates agreement no better than chance, and 1.00 indicates perfect agreement. An additional

Table III
Interobserver Kappa statistics

	X-ray		CT	
	Time 1	Time 2	Time 1	Time 2
Observer 1 vs observer 2	0.71 (0.60, 0.82)	0.66 (0.54, 0.78)	0.85 (0.77, 0.94)	0.71 (0.58, 0.83)
Observer 2 vs observer 3	0.65 (0.53, 0.76)	0.63 (0.52, 0.75)	0.76 (0.67, 0.86)	0.71 (0.60, 0.83)
Observer 3 vs observer 3	0.72 (0.63, 0.82)	0.70 (0.60, 0.80)	0.81 (0.73, 0.90)	0.84 (0.77, 0.91)
Average	0.69	0.66	0.81	0.75

CT, computed tomography.

Table IV
Radiograph and CT scan assessments for each reader 1

Reader 1									
		CT scans							
		SN	VPM	VL	GT/LT	HD	HS	HI	
xR	SN	20	11	2	0	1	0	0	34
	VPM	2	21	0	0	0	0	0	23
	VL	0	4	9	0	1	0	0	14
	GT/LT	0	0	0	20	0	0	0	20
	HD	0	0	1	0	5	0	0	6
	HS	0	1	0	0	0	1	0	2
	HI	0	1	0	2	0	0	1	4
		22	38	12	22	7	1	1	103

CT, computed tomography; *SN*, surgical neck; *VPM*, varus posteromedial; *VL*, valgus; *GT*, greater tuberosity; *LT*, lesser tuberosity; *HD*, head dislocation; *HS*, head splitting; *HI*, head impaction; *xR*, radiograph.

Table V
Radiograph and CT scan assessments for reader 2

Reader 2									
		CT scans							
		SN	VPM	VL	GT/LT	HD	HS	HI	
xR	SN	14	4	0	1	0	0	0	19
	VPM	2	38	4	0	0	0	0	44
	VL	0	1	6	0	0	0	0	7
	GT/LT	0	0	0	20	0	0	0	20
	HD	0	0	0	0	7	0	0	7
	HS	0	0	0	1	1	2	0	6
	HI	0	0	0	0	2	0	0	2
		16	43	10	22	10	2	0	103

CT, computed tomography; *SN*, surgical neck; *VPM*, varus posteromedial; *VL*, valgus; *GT*, greater tuberosity; *LT*, lesser tuberosity; *HD*, head dislocation; *HS*, head splitting; *HI*, head impaction; *xR*, radiograph.

analysis was performed to compare the initial reading of xR and CT scans of each observer.

Results

The first reading on xR by the most senior surgeon was arbitrarily defined as the "gold standard" to define the sample analyzed. On the 103 shoulders in this reading, the most senior observer classified 34 as SN (33%), 23 as VPM (22%), 14 as VL (14%), 20 as isolated GT or LT (19%), 6 as HD (6%), 2 as HS (2%), and 4 as HI (4%).

Agreement for each observer can be found in Table II. The average intraobserver agreement was 0.9 (almost perfect; 1.00, 0.84, and 0.87) for x-rays and 0.86 (almost perfect; 0.81, 0.87, and 0.90) for CT scans.

The interobserver agreement between each physician for both xR and CT scans is shown in Table III. The average interobserver agreement was 0.69 (substantial; 0.71, 0.65, and 0.72) for xR and 0.81 (almost perfect; 0.85, 0.76, and 0.81) for CT scans for the first round of readings and 0.66 (substantial; 0.66, 0.63, and 0.70) for xR and 0.75 (substantial; 0.71, 0.71, and 0.84) for CT scans for the second round.

Tables IV–VI show the first CT scan and xR readings of each of the 3 observers. The diagonal from top left to bottom right indicates the agreement between CT scans and xR. Agreement when considering SN versus VPM fractures was inferior, but for the most part, classification based on x-rays and CT scans coincided for the majority of fractures for all 3 observers.

Discussion

Prior attempts to classify PHF have been reported to provide inadequate agreement and poor prognostic value.[1,3,5-7,10-12,14,20,22] The results of our study seem to indicate that Mayo-FJD classification scheme showed adequate intraobserver and interobserver agreement when PHFs were independently classified by 3 separate shoulder experts using either xR or CT.

Even through our pattern-based classification provided almost perfect intraobserver agreement and substantial interobserver agreement, most of the disagreement involved fractures in which there was some degree of varus or VL orientation of the articular surface along with severe displacement of the head in reference to the diaphysis, sometimes to the extreme of complete lack of head-to-shaft contact. For example, in some cases, the articular surface is

Table VI
Radiograph and CT scan assessments for reader 3

Reader 3									
		CT scans							
		SN	VPM	VL	GT/LT	HD	HS	HI	
xR	SN	4	1	0	0	0	0	0	5
	VPM	0	47	2	0	0	0	0	49
	VL	0	8	9	2	1	0	0	20
	GT/LT	0	0	0	18	0	0	0	18
	HD	0	0	0	0	7	0	0	7
	HS	0	0	0	0	1	0	0	1
	HI	0	0	0	2	1	0	0	3
		4	56	11	22	10	0	0	103

CT, computed tomography; *SN*, surgical neck; *VPM*, varus posteromedial; *VL*, valgus; *GT*, greater tuberosity; *LT*, lesser tuberosity; *HD*, head dislocation; *HS*, head splitting; *HI*, head impaction; xR, radiograph.

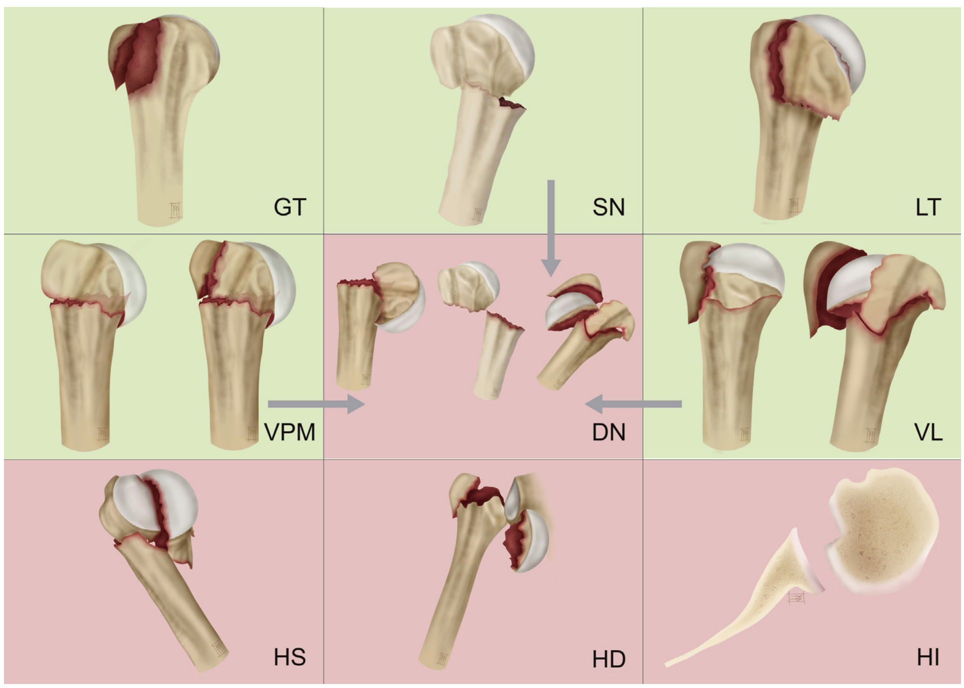

Figure 2 Illustrations representing the categories of the Mayo Classification System. *GT*, isolated greater tuberosity fracture; *SN*, surgical neck fracture; *LT*, lesser tuberosity fracture; *VPM*, varus posteromedial fracture pattern; *DN*, disengaged neck; *VL*, valgus impacted fracture; *HS*, head split; *HD*, head dislocation; *HI*, head impression. Surgery should be considered for cases in categories with red background. Displacement will determine treatment indication in cases included in categories with green background.

facing posteroinferiorly (varus), but there is lack of contact between the humeral shaft and the proximal humerus on all radiographic projections. Conceptually, this could be interpreted as an end-stage displacement of a VPM fracture in which the humeral head and the diaphysis are no longer in contact and the shaft is displaced proximal and laterally toward the deltoid, but it could also be interpreted as a completely displaced SN fracture resulting in such deformity by periarticular muscular pulls. The same occurred with severely displaced VL in which there was no contact between the humeral head and the humeral shaft along with VL displacement of the articular surface.

After discussion, the authors agreed that when xR show absolute loss of contact between the head segment and the diaphysis, it can be very difficult for the observer to determine whether the fracture pattern initiated as VPM, VL, or SN because any of these 3 displacement patterns may lead to complete loss of contact between the head and shaft, and with such severe displacement, nonunion becomes more likely.

As such, because of this study, we have added a new category to our classification scheme (Fig. 2), to reflect those fractures where there is absolutely no contact between the head segment and the diaphysis, regardless of the conditions of the tuberosities: the disengaged neck (DN) fracture.

Another source of disagreement was related to changes in arm position when xR were obtained. This particularly increased confusion when trying to classify a fracture as either VPM or VL. xR Obtained with the arm in internal rotation (which is commonly the case when the arm is in a sling) do not allow adequate assessment of the varus-VL position of the humeral head. This is accentuated when xR are not obtained in the plane of the scapula. In these circumstances, head retroversion in a VPM fracture may project as if the head was in VL, which may lead to classifying a VPM pattern as a VL pattern. Assessment of these fractures using the 3-dimensional rendering of the fracture CT becomes essential in these circumstances.

A previous study published when this classification scheme was developed showed that fracture patterns correlate with outcome when PHFs are treated nonoperatively.[8] Furthermore, within each pattern, fracture displacement was correlated with loss of motion and function, the severity of which may be predicted to some extent with mathematical models. The authors use the pattern-based classification for decision-making on a routine basis. For fractures with severe head involvement (HD, HS, or HI), surgery is almost always recommended. DN fractures are also considered for surgery most of the times. For tuberosity fractures as well as VPM and VL fractures, the indication for surgery depends on the severity of displacement and other patient features. In our prior study, conservative treatment led to a satisfactory outcome in 85%, 70%, and 45% of GT, VPM, and VL fractures, respectively. Measurement of fracture displacement will identify fractures at risk for poor motion and function.

Our study is not without limitations. All imaging studies were evaluated by surgeons that have been exposed to the details of this classification for years, and as such, the results of this study may not be generalized to all orthopedic surgeons; further studies are needed to test the agreement between surgeons not previously exposed to this system. Some of the anteroposterior xR analyzed had been obtained in internal rotation and not in the scapular plane. The main strengths of this study include assessment of many fractures (over 100), availability of CT scans for all fractures, and use of randomization and washout periods between reading sessions to minimize recall bias.

Conclusion

The pattern-based Mayo-FJD classification scheme for PHF was associated with adequate intraobserver and interobserver agreement using both xR and CT scan. Interobserver agreement was best when fractures were classified using CT scans. Distinguishing VPM and VL fractures from SN fractures may be particularly challenging when head-to-diaphysis displacement is severe. As such, it may be better to consider a separate category of DN fractures for those with complete loss of contact between the head and the diaphysis.

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