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Original article

Predictive value of valgus head-shaft angle in identifying Neer 4-part proximal humerus fractures. A radiographic and CT-scan analysis of 120 cases

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Summary. *Background and aim of the work:* Understanding the fracture morphology and its relation to the expected outcome and risk of complications is fundamental for proximal humerus fractures (PHFs) management. Most Neer 3- and 4-part fractures may deserve surgical treatment. Unfortunately, plain x-rays may not be able to differentiate between a 3- or 4-part fractures unless an axillary or analogue projection is carried out. Aim of the present study is to evaluate whether a high valgus head-shaft angle degree is predictive of a Neer 4-part rather than a 3-part fracture. *Methods:* The study included 120 3-(75 cases) and 4-(45 cases) part PHFs (valgus displaced in 98 cases), M:F ratio = 1:2.6, mean age 65.7 years, classified on CT scan images. The humeral head shaft angle was calculated on AP x-rays and statistically correlated with 3 and 4-part fractures to identify values predictive of 4-part fracture. *Results:* Valgus head/shaft angle was significantly higher in 4-part fractures, especially in the valgus displaced group ($p < 0.001$). A cutoff value of 168.5° was identified as predictive of a 4-part fracture with a sensibility of 74% and specificity of 78%. Increasing by 1 degree the humeral head-shaft angle, the chance to have a 4-part fracture increases of 3% in the whole population and of 11% in the valgus sub-group. *Conclusion:* The severity of PHF can be predicted analysing valgus head shaft angle on AP x-rays with a sensibility of 74% and specificity of 78% in identifying a 4-part fracture with a cutoff value of 168.5°.

Key words: proximal humerus fractures, 4-part fracture, predictive value, valgus displacement, humeral head-shaft angle

Background and aim of the work

Proximal humerus fractures (PHFs) are the third most common fragility fractures after proximal femur and distal radius fractures. Incidence varies between 82 and 105 per 100.000 person/year (1,2). Proper treatment for these fractures is currently matter of debate in the literature. Several indications and treatment options have been described without a clear evidence about outcome (3). About 80% of PHFs have a stable configuration, with absent or minimal displacement. In these cases, mostly 2-part fractures according to Neer classification, excellent results may be achieved with conservative treatment. Displaced or comminuted PHFs may also be better treated conservatively in patients over 85 years old affected by severe osteoporosis, cognitive impairment or significant comorbidities (4-7). In rare cases, below 1%, surgical indication for PHFs is considered absolute. The remaining about 20% may benefit from surgical intervention. Most

Neer 3- and 4-part fractures, that represent about 13-16% of all PHFs, belong to this group. Nonetheless, whether reduction and fixation or primary arthroplasty may be better indicated in these cases is still matter of debate (4). Correct indication should consider the expected outcome, functional demand, compliance of the patient and surgeon experience (8). Ideally, fracture reduction and fixation should be preferred to arthroplasty because of the better clinical results achieved in uncomplicated cases with anatomic reconstruction (9,10). On the other hand, especially in fragility osteoporotic fractures, osteosynthesis is frequently related to complications mostly deriving from the surgeons insufficient understanding of risk factors for humeral head avascular necrosis (AVN) and failure of fixation (11,12). Thus, "understanding" the fracture morphology and its relation to the expected outcome and risk of complications is fundamental. The key elements to detect are severity of tuberosities displacement and comminution, valgus or varus humeral head impaction/displacement, fracture of the humeral head (true or false head split), associated gleno-humeral dislocation, metaphyseal comminution, humeral head fragment thickness and quality of cortical and trabecular bone (8,9). To reach this goal radiographic analysis is necessary. Unfortunately, plain x-rays may not be easy to interpret or may not be able to differentiate between a 3- or 4-part fractures unless an axillary or analogue projection is carried out. For all the above reasons CT scans with 3D reconstruction are typically used to better evaluate PHFs and are considered essential in pre-op planning. Nonetheless, plain x-rays might give substantial information about the severity of PHF if correctly interpreted, especially in distinguishing between Neer 3- and 4-part fractures. Indeed, detecting a displaced lesser tuberosity fracture is needed to distinguish between Neer 3- and 4-part PHFs, which may significantly influence fracture management. However, data show that most patients prefer not to undergo a traditional axillary projection (13), and that even when explicitly requested by the orthopedic surgeon in a complete trauma series, this projection is often not performed (14). Nonetheless, severe valgus displacement has been classically associated to Neer 4-part fractures (10), whereas valgus impacted fractures may present as 2, 3 or 4-part fractures, without clear association with the severity of valgus displacement according to the literature (2,6,15). Aim of the present study is to analyze whether severity of PHF can be predicted on AP shoulder plain x-rays based on the valgus humeral head-shaft angle. The null hypothesis is that a high valgus head-shaft angle degree is predictive of a Neer 4-part rather than a 3-part fracture.

Materials and Methods

All the 279 patients undergoing surgical treatment for PHF at the Cattinara Hospital Orthopedic and Traumatology Unit between January 1st 2016 and May 31st 2019 were considered for the present study. Patients with Neer 3- and 4-part fractures, documented with both pre-operative x-rays and CT scans, were selected for radiographic retrospective evaluation by one of the authors (B.M.). Exclusion criteria were the following: Neer 2 parts fractures; fractures extending to the humeral shaft; low quality pre-op x-rays that did not enable proper radiographic evaluation. The included cases AP x-rays were evaluated by two of the authors (R.N., M.G.) in order to calculate the head-shaft angle. This angle is formed by the intersection of two axis: the humeral shaft axis *(the neck-shaft line)* and the humeral head axis (the *anatomical neck line or inclination line)* (Figure 1). The *neck-shaft line* is obtained drawing a line parallel to the cortical shaft whilst the *inclination line* is obtained drawing a line between the great tuberosity apex and the highest point of the inferior articular surface (10). The angle formed by the intersection of these lines is known as the inclination angle: 90° are added to the inclination angle to obtain the humeral head-shaft angle. This angle is defined as the angle created by the intersection of the neck-shaft line and the perpendicular line to the articular inclination line. Physiologically this angle lies between 135° and 150°. A subgroup including only the valgus head-shaft angle patients (>150°) was identified and data evaluation was carried out on the whole population and on the valgus head-shaft angle group, comparing 3- and 4-part fractures subgroups.

Statistical analysis was performed on all the population and on the subgroup. The variables were analyzed descriptively through the mean, standard deviation,

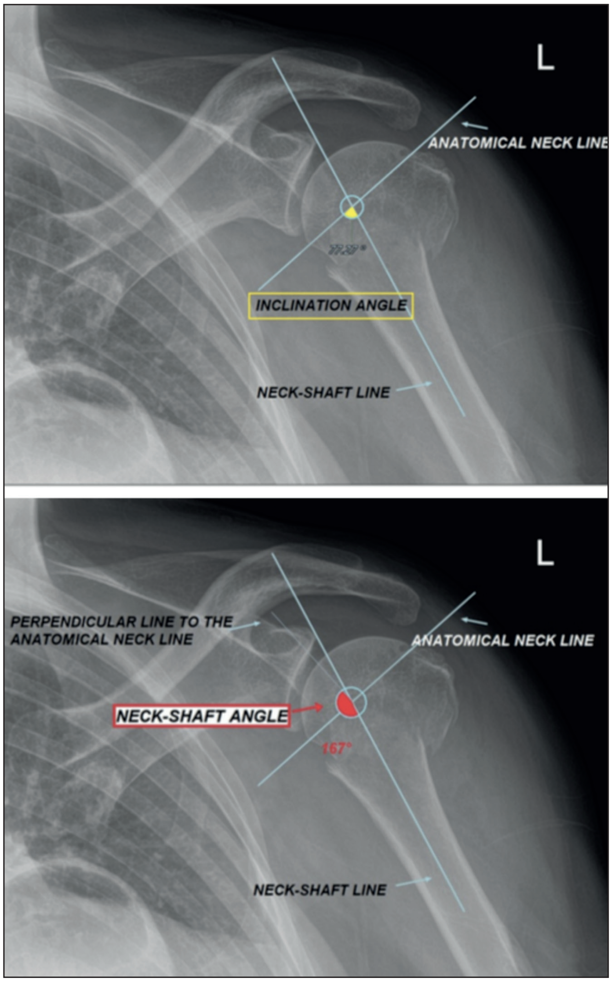


Figure 1. (A) Inclination angle, (B) neck-shaft angle of a valgus 3-part fracture

minimum and maximum values, and 95% confidence intervals. ANOVA test was used to compare the humeral head-shaft angle means of both groups. A ROC curve was created to evaluate the humeral head-shaft angle discrimination capacity to identify 3- or 4-part fractures in both groups. To further discriminate between 3- and 4-part fractures the optimal cutoff with *Youden's Index* (*j = sensibility + sensitivity -1*) was calculated. Finally, a univariate logistic regression was carried out to calculate OR to estimate the probability of increasing valgus humeral head-shaft angle to predict a 4-part fracture compared to a 3-part fracture. Statistical significance was considered with p-value < 0.05.

Results

Applying exclusion and inclusion criteria, a population of 120 PHF cases were selected for the present study. In detail, excluded patients did not undergo preoperative CT scans in 69 cases, presented with a 2-part fracture in 72 cases or with fractures extending to the humeral shaft in 3 cases and in 15 cases the low pre-op x-rays quality hindered proper angles measurement. Of the 120 included patients 34 were male (28.3%) and 86 were female (71.7%), with a M:F ratio = 1:2.6 and a mean age of 65.7 years (*SD 12.15*). A 3-part fracture was present in 75 patients (62.5%) while a 4-part fracture in 45 patients (37.5%). Mean head-shaft angle in the whole population was 160.75° (*SD 17.68, CI 157.56-163.94, range 110°-219°*). In detail, 3-part fractures humeral head-shaft angle had a mean value of 158.01° (*SD 14.04, CI 154.78°-161.24°, range 110°-186°*), while the 4-part fracture humeral head-shaft angle had a mean value of 165.31° (*SD 21.9, CI 158.73°-171.89°, range 117°-219°*). The difference between the two groups resulted to be statistically significant ($p = 0.028$). (Table 1a)

A subgroup of 98 patients displaying a valgus humeral head-shaft angle was identified (Figure 2). The remaining 22 patients displayed a normal angle in 12 cases and a varus humeral head-shaft angle (< 135°) in 10 cases, equally distributed in 3 and 4-part fractures. The mean head-shaft angle in the valgus head-shaft angle subgroup had a mean value of 166.74° (*SD 12.5, CI 164.24-169.25, range 150°-219°*). A 3-part fracture was present in 64 patients (65.3%), with a mean head-shaft angle value of 162.50° (*SD 8.42, CI 160.40°-164.60°, range 152°-186°*), while a 4-part fracture was present in 34 patients (34.7%). With a mean head-shaft angle of 173.74° (*SD 14.94, CI 169.52°-179.95°, range 150°-219°*). The difference between the two groups resulted to be statistically significant ($p < 0.001$). (Table 1b)

The calculation of ROC curve to evaluate the discriminatory power of the humeral head-shaft angle between 3 and 4-part fractures demonstrated an AUC for the total population of 0.64 (*CI 0.53-0.76*) and for the valgus humeral shaft angle sub-group of 0.79 (*CI 0.69-0.89*). (Table 2)

The optimal cutoff to discriminate between a 3- and a 4-part fracture in the total population was

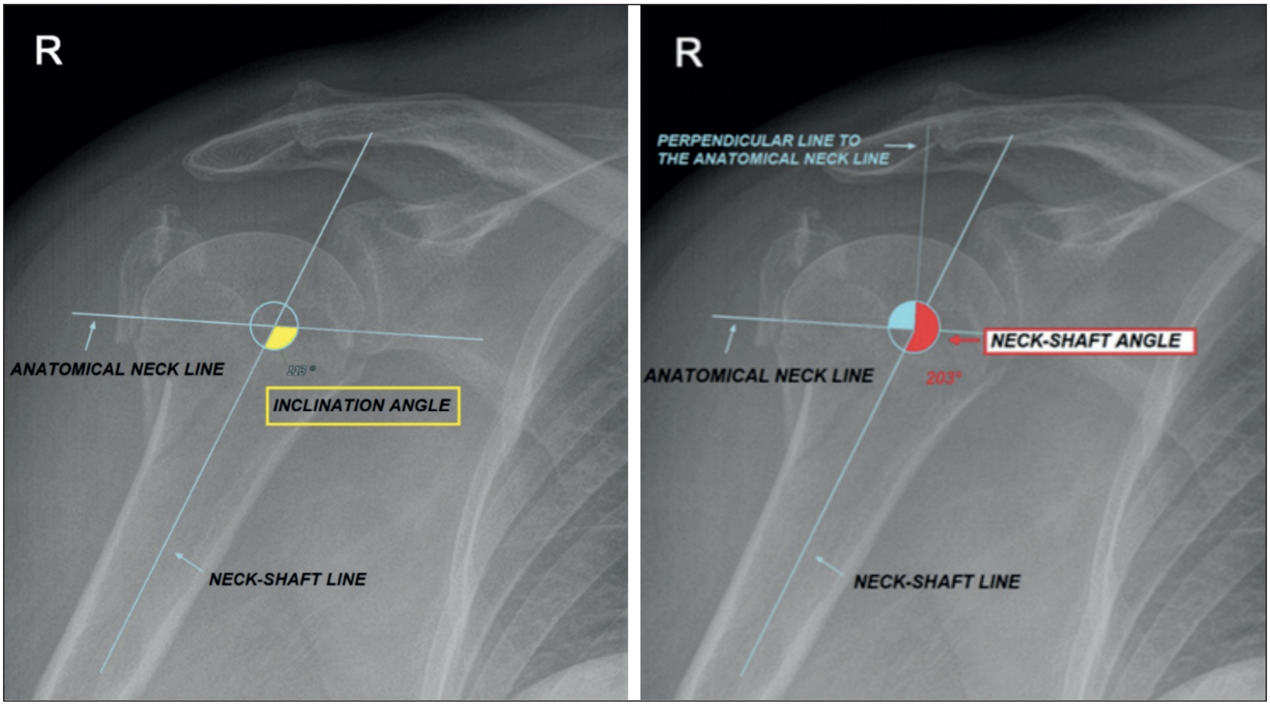


Figure 2. (A) Inclination angle, (B) neck-shaft angle of a valgus 4-part fracture

Table 1. Humeral head-shaft angle in 3- and 4-part PHFs: a) Total population; b) valgus humeral head-shaft angle sub-group

a)

Total population				
	3 parts (n = 75)	4 parts (n = 45)	Tot (n = 120)	p value
Mean and Standard Deviation of the head-shaft angle	158.01 ± 14.04	165.31 ± 21.9	160.75 ± 17.68	0.028
Min value	110	112	110	
Max value	186	219	219	

b)

Valgus humeral head-shaft angle subgroup				
	3 parts (n = 64)	4 parts (n = 34)	Tot (n = 98)	*P value*
Mean and Standard Deviation of the head-shaft angle	162.5 ± 8.42	174.74 ± 14.94	166.74 ± 12.50	< 0.001
Min value	152	150	150	
Max value	186	219	219	

168.5° (sensibility 56%, specificity 81%, Younden's Index = 0.52). The optimal cutoff to discriminate between a 3- and a 4-part fracture in valgus sub-group was 168.5° (sensibility 74%, specificity 78%, Younden's Index = 0.52). Compared with the *Boxplot* of the whole population, the *Boxplot* of the valgus subgroup showed many outliers for severe valgus angles (Table 3). The *Odds Ratio* for the whole population was *1.03* (*C.I. 1.00-1.05)* and for the valgus sub-group was *1.11 (C.I. 1.06-1.175)*. Hence, increasing by 1 degree the humeral head-shaft angle, the chance to have a 4-part fracture increases of 3% in the whole population and of 11% in the valgus sub-group.

Table 2. ROC curve

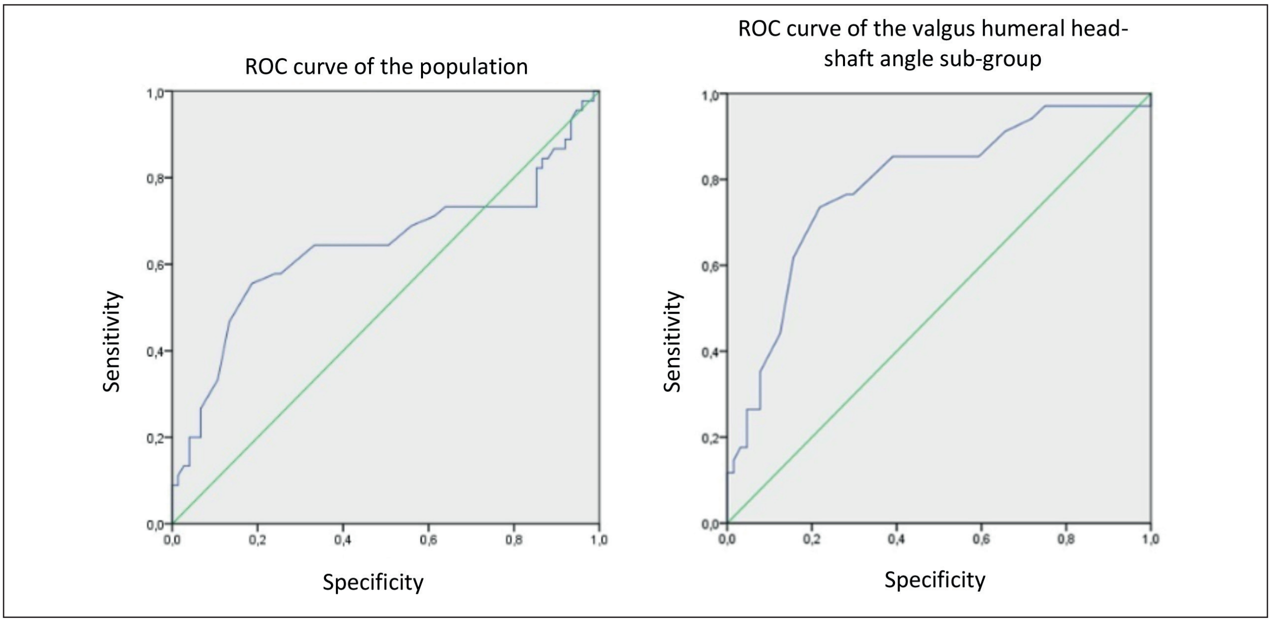
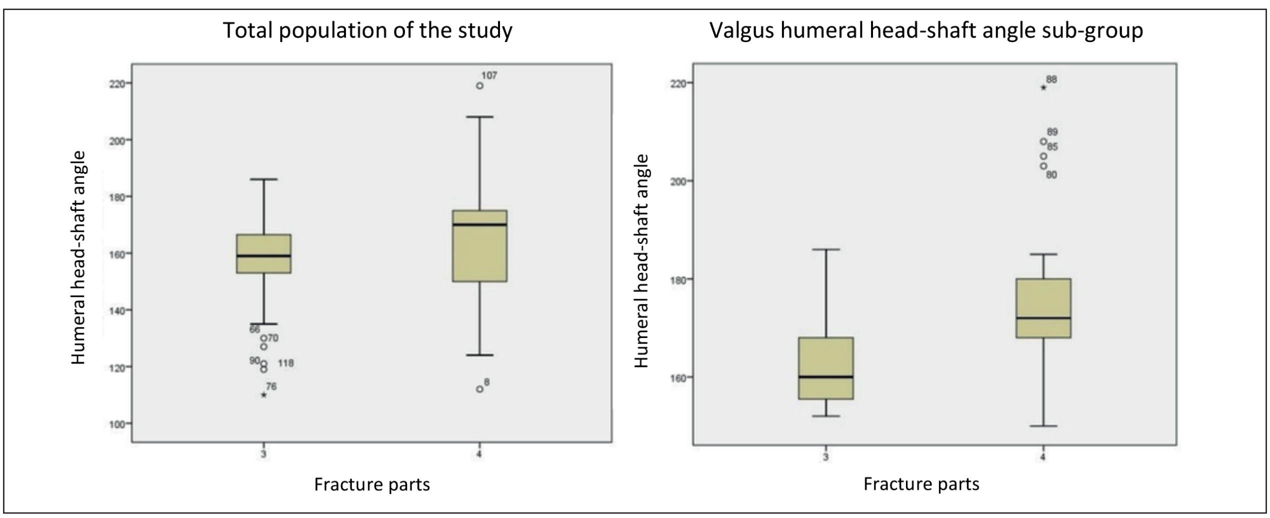


Table 3. Boxplot of both groups



Discussion

Management of Neer 3- and 4-part fractures is often complex and there is no consensus on best treatment option (11). In the literature, nearly 70% of these fractures affect patients >60 years of age, data consistent with the average age of the present study (65.7yrs). Analysis of the relation between age and fracture patterns shows that the most complex patterns occur in older patients (2). Fracture pattern is often the first factor taken into account when defining treatment strategy (4). PHF are mostly minimally displaced and usually involve the surgical neck and greater tuberosity, in these cases treatment through immobilization alone is a well consolidated practice with acceptable clinical outcomes (16-18). Nonetheless, more complex fracture patterns are not uncommon. Incidence of 3- and 4-part PHF is considered to be around 13-16%. The prevalence rises considerably when taking into account population studies that consider inpatients as well as outpatients data. A study conducted in Finland by Launonen et al. found that whilst 2-part PHF may be the most frequent type of fracture pattern, 3- and 4-part PHFs account for more than a quarter of all PHFs, respectively 19% and 7% (1). The difference in incidence rates can be explained by poor intra- and interobserver sensitivity in assessing and properly classifying PHFs found in all proximal humeral classifications, Stig Brorson found this to be particularly true when assessing 4-part PHFs (19).

Fracture patterns with valgus displacement of the humeral head have been thoroughly described in the literature. The "classical" fracture pattern is characterized by a 4-part fracture with a lateral displacement and rotation of the humeral head (19), the humeral head collapses due to traumatic forces which lead to shortening of the humerus and displacement of the tuberosities. Another specific fracture pattern known as "valgus impacted" is characterized by impaction of humeral head into the humeral shaft with variable displacement of the tuberosities. Integrity of the medial hinge and calcar and the presence of continuity between head and lesser tuberosity are important pro- tective factors in avoiding avascular necrosis of the humeral head (6). Most studies in literature attribute to this fracture pattern an average valgus angle > 160° and a greater tuberosity displacement > 1 cm (15,20-22). Jakob et al. were the first to describe this fracture pattern reporting its prevalence and prognosis. The AO classification describes sub-groups in which impaction of the humeral head into the proximal humeral metaphysis is the principle deformity (15). Court Brown et al. found that fractures with humeral head impaction (classified as B1.1 according to the AO classification) can manifest with variable levels of displacement: minimally displaced, 2- part fractures, 3- part fractures and 4-part fractures (2). There is a lack of literature reports that associate the valgus angle of PHFs with 3- or 4-part fractures, the only data available focus on prosthetic design or functional outcome after treatment (10,23-25). Given the difficulty of obtaining an axillary view to detect a lesser tuberosity fracture in the emergency department and the previous description of severe valgus displacement association with 4-part fractures, recognizing a predictive value of a given valgus angle to be associated with 3 or 4-part fractures might be useful for clinical practice. The present study included 120 PHFs in 120 patients, 75 patients with a 3-part fracture and 45 with a 4-part fracture. The average humeral head-shaft angle was 160°, with 36 patients presenting a severe valgus humeral head-shaft angle (>170°). Notably, patients with a 4-part fracture averaged a humeral head-shaft angle of 174.74°, data aligned with previous literature reports (14). However, the present study data show a direct correlation of valgus humeral head-shaft angle and 3- and 4-part fractures, which was not previously reported at our knowledge. When the valgus humeral head-shaft angle is superior to the cutoff value of 168.5° it is possible to determine whether the fracture is a 3-part fracture or a 4-part fracture with a sensibility of 74% and specificity of 78%. When compared to sensibility and specificity values obtained in the total population, respectively 56% and 81%, the valgus subgroup values become more relevant. Nonetheless, the AUC of 0.79 of the humeral head-shaft angle in the valgus sub-group is significant in discriminating between 3- and 4-part PHF, especially when compared to the whole population AUC of 0.64. Furthermore, it was particularly interesting to find that the chance of finding a 4-part fracture compared to a 3-part fracture increased only by 3% per 1° increase of humeral head-shaft angle in the whole population, while in the valgus sub-group this chance increased by 11%. Taken into account these data it is correct to assume that a fracture with a severe valgus angle (>170°) has a very high chance to be a 4-part fracture.

Conclusions

The severity of a PHF with valgus head displacement can be predicted by analyzing the humeral head-shaft angle, which is easily obtainable from simple AP X-rays, with a sensibility of 74% and specificity of 78% in detecting a 4-part fracture when a cut-off of 165.8° is considered. This simple measurement might be a clinically useful tool to suspect a more complex fracture pattern and thus to guide treatment planning, especially when CT scan is not available.

Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

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