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Assessing the Diagnostic Accuracy of Plain Radiography for Upper Limb Fractures: CT as the Gold Standard

[1]Laraib Sarwar[a], [2]Attia Batool[a]*, [3]Noor Nisha[a], [4]Hina Shaffi[a], [5]Noor Fatima[a], [6]Aqsa Shahzadi[a]

[a]Faculty of Rehabilitation and Allied Health Sciences, Riphah International University, Lahore, Pakistan.

ABSTRACT

Background: Plain radiography is the first-line imaging modality for suspected upper limb fractures; however, its diagnostic performance varies according to fracture location and morphology.

Objective: To assess the diagnostic accuracy of plain radiography compared with computed tomography (CT) for detecting upper limb fractures.

Methods: This cross-sectional study included 138 patients with suspected upper limb fractures at Aznostics Diagnostic Centre, Lahore, Pakistan. All participants underwent plain radiography and CT. Two radiologists independently assessed the images, with discrepancies resolved by consensus. CT was used as the reference standard. Sensitivity, specificity, and diagnostic classifications were evaluated.

Results: Reported sensitivity ranged from 39.3% for scapular body fractures to 100.0% for occult humeral shoulder and radial head fractures. Coracoid process fractures demonstrated 56.3% sensitivity and 100.0% specificity, whereas scapular body fractures showed 39.3% sensitivity and 67.6% specificity. For comminuted ulnar shaft fractures, sensitivity was approximately 89.8%, with 100.0% specificity based on the reported contingency table. Statistically significant p-values were reported for coronoid process (p=0.016) and scapular body fractures (p=0.007).

Conclusion: Fractures are more likely to be detected by CT scans. They are able to demonstrate the things that can be missed by X-rays. Plain radiography demonstrated variable diagnostic performance across fracture types. CT may improve fracture detection when radiographic findings are inconclusive.

Keywords: Bone fractures, Computed Tomography, Diagnostic Accuracy, Radiography, Upper Extremity, X-ray

Correspondence
Attia Batool | attiabatool19@gmail.com

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Introduction

Upper limb fractures constitute a substantial proportion of musculoskeletal injuries encountered in emergency departments and orthopaedic practice worldwide. These injuries commonly result from road traffic accidents, falls, sports-related trauma, occupational incidents, and direct impact, and may considerably impair mobility, functional capacity, and independence. Prompt and accurate diagnosis is essential for determining the appropriate treatment strategy, restoring anatomical alignment, and minimizing complications such as malunion, non-union, persistent pain, joint stiffness, and long-term functional impairment. The clinical presentation of upper limb fractures may vary according to the mechanism of injury, anatomical location, fracture configuration, and extent of associated soft-tissue damage. Consequently, reliable diagnostic imaging plays a central role in the initial evaluation and subsequent management of patients with suspected fractures (1,2).

Plain radiography remains the first-line imaging modality for the assessment of suspected upper limb fractures because of its widespread availability, relatively low cost, rapid acquisition, and comparatively low radiation exposure. Standard anteroposterior, lateral, and additional targeted projections facilitate the identification of cortical discontinuity, fracture displacement, angulation, and gross abnormalities of bone alignment. Radiographs also provide important information for initial treatment planning and follow-up assessment. However, conventional radiography has inherent limitations because it produces two-dimensional projections of complex three-dimensional anatomical structures. Fractures may therefore remain undetected when they are nondisplaced, minimally displaced, anatomically obscured, or associated with complex fracture patterns. These limitations are particularly relevant to injuries involving the scaphoid, carpal bones, hand phalanges, articular surfaces, and proximal humerus, where overlapping anatomical structures or subtle cortical abnormalities may obscure the fracture line (2,3).

Missed or delayed diagnosis of upper limb fractures can have important clinical consequences, particularly when an apparently normal radiograph does not correspond with the patient's symptoms or physical examination findings. Persistent pain, localized tenderness, swelling, and restricted movement may indicate an occult fracture despite initially inconclusive radiographic findings. Failure to recognize such injuries promptly may delay immobilization or definitive treatment and increase the risk of secondary displacement, impaired fracture healing, chronic pain, and functional limitation. In addition to adversely affecting patient outcomes, diagnostic uncertainty may necessitate repeated clinical assessments, additional imaging examinations, and prolonged healthcare utilization. Accurate differentiation between the presence and absence of a fracture is therefore important for reducing diagnostic errors and supporting timely, evidence-based clinical decisions, particularly in busy emergency departments and healthcare settings with limited diagnostic resources (3,4).

Computed tomography (CT) provides detailed cross-sectional images of the skeletal structures and enables multiplanar and, when appropriate, three-dimensional reconstruction. These capabilities improve the visualization of cortical disruption, subtle fracture lines, comminution, articular involvement, and complex anatomical relationships that may not be adequately demonstrated by conventional radiography. CT is particularly valuable when radiographic findings are equivocal, when complex fractures require detailed characterization, or when precise delineation of fracture morphology is necessary for treatment planning. In the assessment of selected complex and occult upper limb fractures, CT may therefore provide additional diagnostic information and help resolve discrepancies between clinical findings and initial radiographs. Nevertheless, its use must be balanced against considerations including greater radiation exposure than conventional radiography, higher costs, equipment availability, and the need for appropriate clinical justification. These considerations are especially important in resource-constrained healthcare environments, including Pakistan, where the availability and affordability of advanced imaging may influence diagnostic pathways (4–6).

Although the diagnostic advantages of CT have been described for several individual anatomical sites, the performance of plain radiography may vary substantially according to fracture location, morphology, and the complexity of the injury. Fractures involving the wrist and hand may be difficult to identify because of overlapping bones and subtle cortical abnormalities, whereas injuries around the shoulder, elbow, and other periarticular regions may be challenging because of complex anatomy and superimposed structures. Evaluating diagnostic performance across multiple upper limb regions may therefore provide a more comprehensive understanding of the limitations of plain radiography and the circumstances in which CT offers clinically meaningful additional information. A systematic comparison of the two imaging modalities may also help distinguish fractures correctly identified on radiographs from those that are missed or incorrectly classified, thereby supporting more appropriate imaging selection and clinical decision-making (5–7).

In this context, the present study was conducted at Aznostics Diagnostic Centre, Lahore, Pakistan, to assess the diagnostic accuracy of plain radiography in detecting upper limb fractures using CT as the reference standard. The study evaluated suspected fractures involving the hand, wrist, humerus, elbow, forearm, clavicle, and scapular regions among 138 patients who underwent both

imaging examinations. The principal objective was to determine the ability of plain radiography to identify fractures in comparison with CT, with particular emphasis on sensitivity, specificity, positive predictive value, and negative predictive value. By examining diagnostic performance across different anatomical sites and fracture patterns, the study aimed to identify potential limitations of conventional radiography and clarify the contribution of CT to the evaluation of suspected upper limb fractures. The findings were intended to inform clinical imaging decisions and contribute to the optimization of diagnostic assessment in routine trauma and orthopaedic practice (7).

Material and Methods

A cross-sectional observational study was conducted at Aznostics Diagnostic Centre, Lahore, Pakistan, over the study period reported as 14 February to 20 June. A total of 138 patients with clinically suspected upper limb fractures were recruited using a non-probability convenience sampling technique. Eligible participants were those who underwent both plain radiography and computed tomography (CT) for the evaluation of a suspected fracture involving the upper limb. Patients were excluded if they did not provide informed consent, were unable to cooperate adequately with the imaging procedures, had a history of previous surgery involving the affected bone that could interfere with image interpretation, or had metallic implants or foreign objects that were considered likely to compromise the diagnostic assessment. The study population included patients undergoing imaging for suspected fractures of the hand, wrist, humerus, elbow, forearm, clavicle, and scapula. The exact age range and other demographic eligibility criteria were not specified in the available study records and should be confirmed before finalization of the manuscript.

After eligibility had been established, relevant demographic and clinical information was collected using a standardized data collection proforma. The recorded information included patient characteristics, the anatomical site of suspected injury, and the findings of the imaging examinations. Where available, the mechanism of injury, clinical presentation, and relevant medical or surgical history were also documented to facilitate the interpretation of imaging findings. Each participant underwent plain radiography followed by CT examination of the affected anatomical region. Radiographic examinations were performed using a Simon X-ray system, with anteroposterior and lateral projections and additional oblique views obtained when clinically indicated. The projections were selected according to the anatomical site and the suspected fracture pattern to optimize visualization of the affected bone and minimize the effects of anatomical overlap. Particular attention was given to identifying cortical discontinuity, fracture lines, displacement, angulation, comminution, and articular involvement.

CT examinations were performed using a Toshiba Aquilion 64-slice scanner. The affected region was scanned using appropriate acquisition parameters and reconstruction protocols according to the anatomical site and clinical indication. Cross-sectional images and multiplanar reconstructions were reviewed to identify fractures that were subtle, occult, displaced, or complex in configuration. CT findings were used as the reference standard for the assessment of the diagnostic performance of plain radiography. The presence or absence of a fracture, its anatomical location, and its morphological characteristics were documented for each imaging modality. The interpretation of the imaging examinations was performed by two radiologists independently, with each reader blinded to the interpretation of the other reader. Discrepancies between the readers were resolved through consensus review. The available study documentation did not establish whether the radiologists interpreting the plain radiographs were blinded to the CT findings; this aspect should therefore be verified and reported accurately to clarify the potential for interpretation bias.

Diagnostic findings obtained through plain radiography were compared with the corresponding CT findings. For the diagnostic classification of plain radiography, a true-positive result was defined as a fracture identified on radiography and confirmed on CT, whereas a true-negative result was defined as the absence of a fracture on both examinations. A false-positive result was recorded when radiography indicated a fracture that was not identified on CT, and a false-negative result was recorded when radiography failed to demonstrate a fracture subsequently identified on CT. These classifications were used to construct two-by-two contingency tables for the overall study population and, where the available data permitted, for individual anatomical sites and fracture patterns. Diagnostic performance was assessed by calculating sensitivity, specificity, positive predictive value, and negative predictive value. Sensitivity was calculated as the proportion of CT-confirmed fractures correctly identified by radiography, whereas specificity represented the proportion of CT-negative cases correctly classified as negative on radiography. Positive and negative predictive values were calculated to determine the proportions of radiographic positive and negative results, respectively, that agreed with the CT reference classification. Overall diagnostic accuracy and 95% confidence intervals were also to be calculated where the underlying data were available and sufficiently complete.

The collected data were entered, coded, checked for completeness, and analyzed using IBM SPSS Statistics for Windows, version 25.0. Descriptive statistics were used to summarize the study population and imaging findings. Categorical variables, including fracture presence, anatomical location, and fracture classification, were expressed as frequencies and percentages. Continuous

variables, where applicable, were summarized using means and standard deviations for approximately normally distributed data or medians and interquartile ranges for non-normally distributed data. The diagnostic performance of plain radiography was evaluated against CT using two-by-two contingency tables, with sensitivity, specificity, positive predictive value, negative predictive value, overall accuracy, and corresponding 95% confidence intervals calculated where appropriate. For paired comparisons of binary diagnostic outcomes, McNemar's test could be applied when the relevant paired data were available and its assumptions were satisfied. All statistical tests were two-sided, and a p-value of less than 0.05 was considered statistically significant. The final statistical analysis was to be based on the actual recorded observations, and no missing diagnostic classifications or patient-level data were to be imputed without a justified and documented procedure.

Ethical principles governing research involving human participants were observed throughout the study. Ethical approval was reported as having been obtained from Riphah International University; however, the formal name of the approving committee, approval reference number, and date of approval were not available in the supplied documentation and should be inserted after verification. The study was conducted in accordance with the ethical principles, subject to confirmation that the approved study protocol complied with the applicable version and institutional requirements. Written informed consent was obtained from participants before their inclusion in the study and the use of their clinical and imaging information for research purposes. Participation was voluntary, and participants were informed of their right to withdraw without affecting their clinical care. Patient confidentiality was maintained by using coded study identifiers and restricting access to study data to authorized research personnel. Imaging examinations were performed in accordance with routine clinical protocols and applicable radiation-safety principles, with exposure limited to that considered clinically justified. The study findings were reported in aggregate form to protect participant identity.

Results

The diagnostic performance of plain radiography was evaluated against computed tomography (CT), which was considered the reference standard, for the detection of different upper limb fractures. The analysis included fractures involving the shoulder, humerus, elbow, forearm, and scapular region. Sensitivity, specificity, and p-values were reported for each fracture type, and the corresponding true-positive (TP), true-negative (TN), false-positive (FP), and false-negative (FN) classifications were used to characterize agreement between the two imaging modalities.

As shown in Table 1, the reported sensitivity of plain radiography varied considerably according to fracture type, ranging from 39.3% for scapular body fractures to 100.0% for occult humeral shoulder and radial head fractures. High sensitivity was also reported for supracondylar fractures (97.2%), coronoid process fractures (94.1%), intercondylar fractures (93.4%), and olecranon fractures (93.1%). Sensitivity was lower for comminuted ulnar shaft fractures (89.7%) and coracoid process fractures (56.3%). Specificity was reported as 100.0% for seven of the nine fracture categories, whereas lower specificity was observed for scapular body fractures (67.6%). Statistically significant p-values were reported for coronoid process fractures (\(p=0.016\)) and scapular body fractures (\(p=0.007\)); the remaining comparisons were not statistically significant at the 0.05 level.

Table 1. Diagnostic performance of plain radiography compared with CT for different upper limb fractures

Fracture type	TP	TN	FP	FN	Sensitivity (%)	Specificity (%)	p-value
Occult humeral shoulder fracture	72	66	0	0	100.0	100.0	0.210
Radial head fracture (Mason I–III)	26	112	0	0	100.0	100.0	0.072
Comminuted ulnar shaft fracture	44	89	0	5	89.7	100.0	0.191
Olecranon fracture	41	94	0	3	93.1	100.0	0.251
Coronoid process fracture	32	104	0	2	94.1	100.0	0.016*
Supracondylar fracture	36	101	0	1	97.2	100.0	1.000
Intercondylar fracture	43	92	0	3	93.4	100.0	0.135
Coracoid process fracture	31	83	0	24	56.3	100.0	1.000
Scapular body fracture	13	71	34	20	39.3	67.6	0.007*

*TP: true positive; TN: true negative; FP: false positive; FN: false negative. CT: computed tomography

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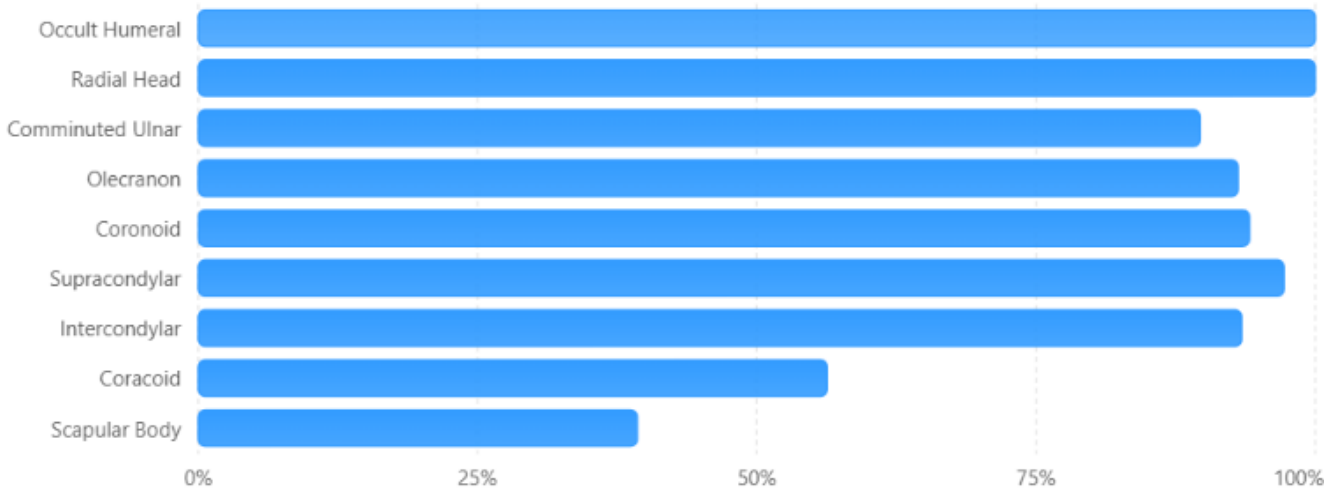


Figure 1. Sensitivity of X-ray Detection by Fracture Type

Plain radiography showed the highest sensitivity for occult humeral and radial head fractures (100%), followed by supracondylar (97.2%) and other elbow fractures (93.1–94.1%). Sensitivity was lowest for coracoid process (56.3%) and scapular body fractures (39.3%), highlighting the potential need for CT when these fractures are suspected.

Table 2. Crosstabulation between X-ray and CT Findings for Comminuted Ulnar Shaft and Acromion Fractures

Fracture type	X-ray finding	CT negative, n	CT positive, n	Total, n
Comminuted ulnar shaft	Negative	89	5	94
	Positive	0	44	44
	Total	89	49	138
Acromion	Negative	95	0	95
	Positive	0	43	43
	Total	95	43	138

Discussion

The present study evaluated the diagnostic performance of plain radiography in comparison with computed tomography (CT) for detecting upper limb fractures among 138 patients examined at Aznostics Diagnostic Centre, Lahore, Pakistan. The findings demonstrated considerable variation in radiographic sensitivity according to fracture type and anatomical location. Plain radiography showed high reported sensitivity for several humeral and elbow fractures, whereas lower sensitivity was observed for coracoid process and scapular body fractures. These findings highlighted the importance of interpreting radiographic findings alongside the mechanism of injury, physical examination, and persistence of symptoms, particularly when initial imaging findings did not adequately explain the clinical presentation.

The high reported sensitivity for several fractures involving the humerus and elbow suggested that plain radiography could provide useful diagnostic information when appropriate projections and technically adequate images were obtained. However, fracture detection may vary according to anatomical location, displacement, complexity, and visibility on the acquired projections. Bahrs et al. investigated the diagnostic contribution of CT in proximal humeral fractures and reported that CT provided additional information regarding fracture morphology and anatomical involvement that could be inadequately characterized by conventional radiography (10). Their findings supported the use of CT when radiographs did not adequately demonstrate fracture configuration or provide sufficient information for treatment planning. In the present study, the reported sensitivity of 100.0% for occult humeral shoulder fractures should be interpreted cautiously because the term occult fracture generally refers to a fracture that is not readily identified on initial conventional radiographs. This apparent discrepancy requires clarification of the original case definitions and data classification before a definitive interpretation can be made.

For fractures involving the elbow and forearm, the present study reported sensitivities of 89.7% for comminuted ulnar shaft fractures, 93.1% for olecranon fractures, 94.1% for coronoid process fractures, 97.2% for supracondylar fractures, and 93.4% for intercondylar fractures. These findings suggested that plain radiography identified most fractures in these categories, although some CT-positive

fractures were not detected radiographically. The crosstabulation for comminuted ulnar shaft fractures showed 44 true-positive, 89 true-negative, no false-positive, and five false-negative classifications. Based on these counts, sensitivity was approximately 89.8%, with a specificity of 100.0%. The missed fractures demonstrated that negative radiographic findings could not invariably exclude an underlying fracture when clinical suspicion remained high. Üstün et al. also compared conventional radiography with CT in patients presenting with extremity trauma and reported differences in diagnostic performance across injury types, supporting the additional diagnostic contribution of CT in selected cases (12). These findings supported the selective use of CT when fracture morphology remained uncertain or when a missed fracture could affect clinical management.

The results should also be considered alongside evidence concerning wrist and hand fractures, where conventional radiography may fail to demonstrate subtle or nondisplaced injuries. Etli et al. compared the diagnostic performance of radiography and CT in patients with wrist injuries and highlighted the value of CT in identifying fractures and defining fracture characteristics that may not be adequately demonstrated on conventional radiographs (8). Similarly, Bäcker et al. reviewed imaging approaches for clinically suspected scaphoid fractures, examining the diagnostic challenges associated with fractures that remain undetected on initial radiographs and the role of advanced imaging in resolving diagnostic uncertainty (9). These studies supported the broader clinical principle that negative radiographic findings do not invariably exclude a fracture when symptoms and examination findings remain suggestive. However, direct comparisons with the present study were limited by differences in study populations, anatomical distributions, fracture definitions, and diagnostic protocols.

The additional diagnostic value of CT should be interpreted in relation to the clinical question rather than as justification for replacing plain radiography in all cases. Üstün et al. demonstrated the continued usefulness of conventional radiography in the initial evaluation of extremity trauma while highlighting the additional diagnostic information that CT may provide in selected patients (12). In the present study, the acromion fracture crosstabulation showed complete agreement between radiography and CT, with 43 positive and 95 negative cases and no false-positive or false-negative classifications. The corresponding sensitivity and specificity were both 100.0% within the observed sample. Nevertheless, this result did not establish that plain radiography would achieve perfect diagnostic performance in other populations. The absence of misclassified cases may have reflected the characteristics of the included fractures, image quality, case selection, or sample size. Overall, the findings supported a selective approach to CT, with plain radiography remaining the initial imaging modality and CT considered when radiographic findings were inconclusive, clinical suspicion persisted, or additional anatomical detail was required for treatment planning.

An important strength of the present study was the inclusion of 138 patients who underwent both plain radiography and CT, allowing paired assessment of imaging findings against a common reference standard. The study also evaluated multiple upper limb anatomical regions rather than restricting the analysis to a single fracture site. The use of two independent radiologists, with consensus review of discrepant interpretations, provided an additional measure of consistency in image assessment. Furthermore, the inclusion of true-positive, true-negative, false-positive, and false-negative classifications facilitated a clinically relevant evaluation of diagnostic performance and helped identify fracture categories in which radiography appeared less reliable.

Several limitations should be considered when interpreting the findings. First, the study was conducted at a single diagnostic centre using convenience sampling, which may have introduced selection bias and limited generalizability. Second, the sample size was relatively modest for evaluating diagnostic performance separately across multiple fracture categories, potentially affecting the stability of sensitivity and specificity estimates. Third, although CT was used as the reference standard, the study did not establish whether the radiologists interpreting plain radiographs were blinded to CT findings, leaving the possibility of interpretation bias unresolved. In addition, some reported diagnostic metrics were inconsistent with the corresponding contingency-table counts. For example, five false-negative cases among 49 CT-positive comminuted ulnar shaft fractures yielded a sensitivity of approximately 89.8%, rather than the reported 89.7%. The reported 100% sensitivity for occult humeral shoulder fractures also requires clarification because the designation of an occult fracture appears inconsistent with perfect radiographic detection. These discrepancies should be verified against the original dataset before the findings are considered definitive. Finally, the study did not establish whether diagnostic performance varied according to patient age, injury mechanism, time from injury to imaging, radiographic projection, or reader experience.

Future research should involve larger, preferably multicentre prospective studies using consecutive patient recruitment and clearly defined fracture categories. Standardized imaging protocols, documented reader blinding, explicit diagnostic criteria, and independent review of discrepant cases would improve methodological rigour. Diagnostic accuracy estimates should be recalculated from verified patient-level data, with 95% confidence intervals and appropriate statistical tests for

paired diagnostic outcomes. Further studies could also examine interobserver agreement and the clinical consequences of fractures missed on initial radiographs, including delays in treatment, additional imaging requirements, and patient outcomes.

In clinical practice, plain radiography should remain the initial imaging modality for most suspected upper limb fractures because of its accessibility, speed, and comparatively low radiation exposure. However, CT should be considered when radiographic findings are inconclusive, clinical suspicion remains high despite negative radiographs, or complex fracture morphology must be defined to guide treatment. This approach may improve diagnostic confidence while supporting the appropriate use of advanced imaging, particularly in healthcare settings where cost and availability remain important considerations.

Conclusion

The study demonstrated that the diagnostic performance of plain radiography varied across upper limb fracture types, with lower reported sensitivity for coracoid process and scapular body fractures and high agreement with CT for several other fracture categories. These findings supported the continued use of radiography as the initial imaging modality, with CT serving as an important complementary investigation when clinical suspicion persisted or fracture characterization remained inadequate. In healthcare practice, this selective approach could facilitate timely diagnosis, appropriate treatment planning, and reduced risk of complications associated with missed fractures, provided that the reported diagnostic metrics were verified against the original dataset.

Authors' Contributions

ICMJE authorship criteria	Detailed contributions	Authors
Substantial Contributions	Conception or Design of the work	1,2,4,5
	Data acquisition	1,3,6
	Data analysis or interpretation	2,3,5
Drafting or Reviewing	Draft the work	2
	Review critically	1,2,3,4,5,6
Final approval	Final approval of the version to be published.	1,2,3,4,5,6
Accountable	Agreement to be accountable for all aspects of the work.	1,2,3,4,5,6

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