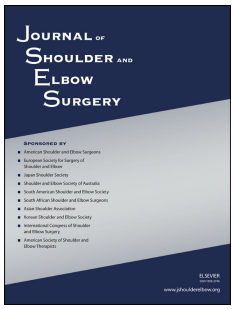
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Proceedings from the 2025 International Consensus Meeting on Orthopedic Infections: the definition of Shoulder Periprosthetic Joint infection

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Proceedings from the 2025 International Consensus Meeting on Orthopedic Infections: the definition of Shoulder Periprosthetic Joint infection

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Abstract

Background: Periprosthetic joint infection (PJI) remains one of the greatest diagnostic and treatment challenges facing shoulder surgeons and their patients. A definition for shoulder PJI was established by the 2018 International Consensus Meeting (ICM) on Orthopedic Infections, but the selection and weighting of its minor criteria relied largely on expert opinion. The purpose of this study was to present an updated, evidence-based definition of shoulder PJI generated by the 2025 ICM Shoulder Group.

Methods: The 2025 ICM Shoulder Group, an international panel of shoulder surgeons and infectious disease specialists, used a modified Delphi process informed by 86 systematic reviews and by a predictive statistical model derived from the American Shoulder and Elbow Surgeons (ASES) Multicenter Revision Arthroplasty and PJI Group dataset to reconsider the 2018 ICM definition of shoulder PJI, including its major criteria, minor criteria, and diagnostic categories.

Results: The delegates voted to eliminate organism virulence from the definition and to retain gross intra-articular purulence and presence of a sinus tract as the two criteria defining Definite PJI. The Minor Criteria were revised to include erythema, unexpected wound drainage, elevated erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP), elevated synovial neutrophil percentage, positive frozen section, radiographic humeral osteolysis, intraoperative humeral loosening, and positive culture, each statistically weighted using the predictive model. Non-definite PJI was categorized by summed minor criteria score as High likelihood (≥13 points), Moderate likelihood (7-12 points), Unknown (1-6 points), or No PJI (0 points). The final definition achieved unanimous delegate consensus (51 of 51 delegates; 100% agreement; super majority, strong consensus).

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Conclusions: The 2025 ICM definition of shoulder PJI represents an evidence-informed evolution of the 2018 definition, combining statistical modeling of prospective multicenter data with structured expert consensus. The definition is expected to continue to evolve as further shoulder-specific data become available.

Keywords: shoulder arthroplasty; periprosthetic shoulder infection; Cutibacterium acnes; diagnostic criteria; PJI definition

Level of Evidence: Level V, Consensus Statement, Voting

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Periprosthetic joint infection (PJI) remains one of the greatest diagnostic and treatment challenges facing shoulder surgeons and their patients. A primary goal of the 2018 International Consensus Meeting (ICM) on Orthopedic Infection Shoulder Group was to establish a definition of shoulder PJI that is specific to, and accounts for, the differences between shoulder PJI and PJI of other large joints. The purpose of that definition was to improve diagnostic consistency and to facilitate standardized research reporting.[4] While the 2018 delegates used available data from the literature, the selection and weighting of its minor criteria, was largely guided by expert opinion rather than statistical evidence. With widespread clinical utilization, the 2018 ICM Shoulder Group anticipated that the definition would evolve as additional data became available.

Subsequent validation work supported the clinical utility of the 2018 definition.[5,9] **In a cohort of 157 cases performed in 144 patients and categorized by infection probability according to the 2018 ICM definition, 46 cases (29%) were classified as definitely or probably infected, 25 (16%) as possibly infected, and 86 (55%) as unlikely to be infected; recurrence rates were 2.3% for unlikely PJI, 12% for possible PJI, and 17.4% for definite or probable PJI**.[5] These findings confirmed that the 2018 categories were predictive of recurrent infection following treatment, but also highlighted the opportunity to refine the underlying criteria using higher-quality, prospectively collected data.

It is important to note that a "universal definition" of PJI was also presented at the 2025 ICM meeting, developed collaboratively by several professional societies (ICM, European Bone and Joint Infection Society, Infectious Diseases Society of America, the Musculoskeletal Infection Society, and the European Society of Clinical Microbiology and Infectious Diseases) and based

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primarily on data from hip and knee arthroplasty.[2] This universal definition was carefully reviewed by the 2025 ICM Shoulder Group, which unanimously agreed that it did not adequately consider the unique challenges of defining shoulder PJI and strongly favored retaining a shoulder-specific definition.

The purpose of this study was to describe the evidence-based, consensus-driven process used by the 2025 ICM Shoulder Group to generate an updated, shoulder-specific definition of periprosthetic joint infection, and to report the resulting definition and its supporting rationale.

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Methods

Committee Formation and Goals

The process of generating the 2025 definition of shoulder PJI began with the formation of a panel of shoulder delegates, characterized as an international group of shoulder surgeons and infectious disease specialists with clinical expertise and research interest in the management of shoulder PJI. The committee established four goals to guide its work:

1. Reconsider the 2018 ICM definition of Definite Shoulder PJI (Table 2).
2. Reconsider the 2018 ICM Minor Criteria (Table 2).
3. Reconsider the 2018 categorization of Non-Definite PJI into the categories of Probable, Possible, and Unlikely PJI (Table 2).
4. Use the best available evidence to support a proposed definition of shoulder PJI.

Committee Process

As reported in other publications from the 2025 ICM addressing prevention, evaluation, and management of shoulder PJI, 86 systematic reviews were conducted by shoulder PJI experts to explore questions related to prevention, diagnosis, and management of shoulder PJI. A modified Delphi process was used to generate the questions; the resulting systematic reviews were distributed to delegates prior to the meeting and then discussed and refined during in-person deliberations in Istanbul, Turkey. The delegates then voted on each question and statement. These reports served as a framework for discussions regarding the definition of shoulder PJI, and, together with the expert opinion and experience of the delegates and real-time debate during the meeting, formed the foundation for the generation of the 2025 ICM shoulder PJI definition.

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Subsequent to the 2018 meeting, high-quality prospective data from the American Shoulder and Elbow Surgeons (ASES) Multicenter Revision Arthroplasty and PJI Group became available. This dataset provided updated information that the 2025 ICM Shoulder Group used to formulate a revised definition of shoulder PJI. Prior to the meeting, a subcommittee reviewed the ASES Multicenter Group data and used it to generate a predictive model; the purpose of this model was to present objective data to the delegates to help guide decision-making and consensus generation.

Statistical Modeling and Reconsideration of Diagnostic Criteria

The 2025 ICM Shoulder Group used the 2018 ICM definition as its starting framework. **The committee intentionally used an evidence-informed consensus approach: statistical modeling of the ASES Multicenter Revision Arthroplasty and PJI Group dataset was used to identify candidate variables, estimate their relative importance, and inform weighting of the minor criteria. However, the final definition was not adopted solely on the basis of statistical performance. Through a modified Delphi process, delegates considered the modeling results together with systematic review evidence, clinical applicability, global feasibility, and representative clinical scenarios to determine the final variables, weighting scheme, and diagnostic thresholds.**

For the major criteria, delegates reviewed the three criteria used in the 2018 definition of Definite PJI: (1) gross intra-articular purulence, (2) presence of a sinus tract from the skin surface to the prosthesis, and (3) two positive tissue cultures with phenotypically identical virulent organisms. As part of the systematic review process (Question 35), the group considered whether organism virulence, though traditionally associated with more obvious clinical signs of infection, could be

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reliably and consistently defined; because *Cutibacterium acnes*, despite being considered a low-virulence organism in many cases, remains a common cause of clinically aggressive and apparent shoulder PJI,[10] virulence was evaluated as a candidate criterion for removal.

For the minor criteria, delegates first reviewed whether each 2018 criterion should be retained for the 2025 definition. This review incorporated dedicated systematic review questions, including Question 34 (subjectivity of "cloudy synovial fluid"), Question 41 (evidence supporting synovial alpha defensin), and Question 42 (whether global availability of a diagnostic test should influence its inclusion in the criteria). Variables retained after this initial review were then evaluated using regression modeling of the ASES Multicenter dataset, with the modeled outcome defined as either (1) gross intra-articular purulence or (2) presence of a sinus tract communicating from the skin surface to the prosthesis. **Delegates chose to focus on the hosts' clinical response to presence of infection rather than creating a definition of PJI based on unexpected culture positivity or elevation in serum markers. From a clinical relevance standpoint, the delegates made the consensus agreement that cases with high Minor Criteria scoring (but without purulence or sinus tract) would be at greater risk to develop one of the two Major Criteria if undiagnosed and untreated. This is a critical point and was a consensus decision that drove the selection and weighting of minor criteria.** This analysis considered multiple variables collected as part of the dataset, including erythema, wound drainage, elevated inflammatory markers, synovial laboratory abnormalities, culture data, and histopathologic evidence of acute inflammation (frozen section); the relative importance of each predictor was quantified, and the seven variables with the greatest relative influence were retained in the final multivariable model, which demonstrated excellent discrimination. The calculated relative importance of these variables was used to assign scores for weighting of the minor criteria (Table 1).

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Following statistical weighting of the minor criteria, a sensitivity analysis was performed to guide delineation of risk categories for non-definite PJI. For every possible cut point c of the total score, patients with a score > c were classified as test-positive and compared with the actual diagnosis of PJI (criteria). Sensitivity, specificity, positive predictive value, and negative predictive value were calculated at each cut point as simple proportions. Delegates then reviewed multiple clinical case scenarios and voted to achieve consensus agreement on the final scoring thresholds for each category.

Consensus Process and Voting

Consistent with the methodology used across the 2025 ICM Shoulder Group proceedings, a modified Delphi process was used, consisting of question development, evidence synthesis, premeeting review, in-person presentation and discussion, live revision of proposed recommendations, and voting. Delegates participated in a single round of open, non-anonymous voting using three options: agree, disagree, or abstain. Agreement was calculated as the number of "agree" votes divided by the total number of delegates who voted or abstained. Consensus thresholds were defined a priori as follows: <50%, no consensus; 50%-64%, weak consensus; 65%-80%, moderate consensus; >80%, strong consensus; and 100%, unanimous consensus, with agreement ≥80% additionally characterized as a super majority.

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Results

Major Criteria: Definite Periprosthetic Joint Infection

The delegates voted to eliminate organism virulence from the definition of shoulder PJI, given the lack of a standardized definition of virulence and the observation that low-virulence organisms such as *Cutibacterium acnes* commonly produce clinically aggressive infection.[10,11] The criteria for Definite PJI were accordingly restricted to either of the following:

- Presence of a sinus tract communicating from the skin surface to the prosthesis
- Gross intra-articular purulence

Meeting either of these criteria is diagnostic of Definite PJI.

Minor Criteria and Evaluation Scoring for Non-Definite PJI

Following review of the systematic reviews addressing Questions 34, 41, and 42, delegates agreed that "cloudy synovial fluid" should not be included in the updated minor criteria, as this descriptor was found to be highly subjective and inconsistently applied by surgeons. Synovial alpha defensin was judged a promising marker of shoulder PJI but with limited supporting data for routine use,[13,20] and, because globally applicable diagnostic criteria should be limited to testing readily available across all countries, hospitals, and health systems, alpha defensin was removed from the minor criteria. Consistent with the elimination of virulence from the major criteria, culture results were no longer scored according to perceived organism virulence.

Based on the predictive model derived from the ASES Multicenter dataset and on systematic review evidence, delegates voted to include erythema and unexpected wound drainage as clinical signs suspicious for PJI, and elevated erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) as serum markers. **Given variability between institutions it is expected that physicians**

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utilize their laboratory's values for normal and abnormal results. Elevated synovial neutrophil polymorphonuclear (PMN) leukocyte percentage and positive frozen section **(≥ 5 PMNs/HPF**) were retained as markers of intra-articular host inflammatory response, despite acknowledged limitations related to frequent dry or low-volume aspirations and institutional variability in frozen section procurement. To prevent misclassification bias, delegates agreed that a score should still be assigned when synovial PMN percentage or frozen section is not obtained, rather than assuming a negative result for unmeasured variables. **Synovial white blood cell (WBC) count was removed from the minor criteria: it demonstrated strong concordance with PMN percentage, risking collinearity and distortion of the weighted scoring system, and the systematic review addressing synovial testing (Question 39) concluded that no absolute neutrophil count threshold for shoulder PJI has yet been established. A study from the ASES multicenter group published after the 2025 ICM meeting subsequently supported this decision, finding that synovial cell count had poor discriminatory utility for Definite PJI (AUC 0.448-0.584) compared with synovial neutrophil percentage (AUC 0.707-0.714).[1]**

Radiographic humeral osteolysis and intraoperative humeral loosening were found to be associated with high suspicion for PJI and were included in the minor criteria. Positive cultures, particularly of *Cutibacterium acnes*, were retained but weighted less heavily, reflecting their limited association with clinical signs of PJI in the predictive model and their high rate of positivity in negative control specimens (15-20%)[7,8] and in primary arthroplasty cases (up to 70%).[3,7,11–13] **Erythema received a comparatively higher weight, reflecting its strong association with the pre-specified model endpoint of definite PJI (purulence or sinus tract) rather than its diagnostic specificity in isolation; because erythema was closely associated with more advanced findings such as wound drainage and frank purulence in the ASES dataset, a**

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moderate-category score driven substantially by erythema is intended to prompt closer clinical scrutiny rather than be discounted, and clinical judgment remains essential in interpreting such cases.

Based on the sensitivity analysis of the weighted minor criteria (Figure 1) and on delegate review of representative clinical scenarios, non-definite PJI is categorized by the summed minor criteria score (Table 1) as follows:

- ≥13: High likelihood of PJI
- 7-12: Moderate likelihood of PJI
- 1-6: Unknown PJI
- 0: No PJI

Final Consensus Recommendation

The final definition achieved unanimous delegate agreement:

Question: *What are the diagnostic criteria of shoulder periprosthetic joint infection?*

Recommendation: *See the International Consensus Meeting definition of shoulder periprosthetic joint infection above (Major Criteria and Minor Criteria).*

Level of evidence: *Consensus.*

Delegate vote: *agree 51, 100%; disagree 0, 0%; abstain 0, 0% (super majority, strong consensus).*

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Discussion

The updated 2025 ICM definition represents an important step toward improving diagnostic consistency in shoulder PJI. Its principal strength is the use of prospectively collected, multicenter clinical data from the ASES Multicenter Revision Arthroplasty and PJI Group to statistically inform the selection and weighting of minor criteria, addressing a key limitation of the 2018 definition, which relied primarily on expert opinion. The process also removed criteria — cloudy synovial fluid and organism-virulence-based scoring — that were identified as subjective, inconsistently applied, or lacking a standardized definition, and it removed synovial WBC count and synovial alpha defensin based on evidence of limited discriminatory value or limited global availability, respectively. By combining statistical modeling with a modified Delphi consensus process, the 2025 definition integrates objective predictive performance with the clinical judgment, global feasibility, and practical experience of an international panel of experts, and achieved unanimous, strong consensus (100% agreement).

Limitations

Most importantly, the decision to build a predictive model for the minor criteria using an endpoint of definite PJI biases the results toward clinically apparent cases of infection. This may leave patients with a less clinically obvious presentation relatively under-accounted for and potentially unidentified by either the major criteria or the sum of the weighted minor criteria. Additionally, the model assumes that the minor criteria contribute additively on the log-odds scale. Although this specification produces super-additive increases in absolute risk when multiple criteria are present, it does not permit synergistic effects beyond those implied by the logistic link. Pairwise interactions among the minor criteria were tested and none were

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statistically significant, but the sample size afforded limited power to detect such effects, and the corresponding confidence intervals did not exclude clinically relevant departures from additivity. If true synergy exists — for example, if positive cultures carry greater diagnostic weight in the presence of elevated neutrophils than in their absence — the nomogram may underestimate risk in patients with multiple concurrent minor criteria.

Future Work

External validation of the 2025 definition in a larger, independent cohort would allow the additivity assumption and overall model performance to be assessed more definitively. As large-scale data regarding the diagnosis, and more importantly the treatment, of shoulder PJI continue to be collected by the ASES Multicenter PJI Group, the Société Européenne de Chirurgie de l'Epaule et du Coude (SECEC) PJI Group, and other international institutions and societies, the definition should be iteratively refined and re-validated. Future work should also explore whether specific combinations of minor criteria carry synergistic diagnostic weight not captured by the current additive model, and should continue to reconcile the shoulder-specific definition with the universal PJI definition as shoulder-specific evidence accumulates.

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Conclusion

The 2025 ICM Shoulder Group generated an updated, evidence-informed definition of shoulder PJI. Definite PJI continues to be defined by either gross intra-articular purulence or presence of a sinus tract communicating from the skin surface to the prosthesis, with organism virulence removed from consideration. Non-definite PJI is categorized using a statistically weighted sum of eight minor criteria — erythema, unexpected wound drainage, elevated ESR and CRP, elevated synovial PMN percentage, positive frozen section, radiographic humeral osteolysis, intraoperative humeral loosening, and positive culture — into High likelihood, Moderate likelihood, Unknown, or No PJI categories. This definition was adopted with unanimous delegate consensus (100% agreement, super majority, strong consensus).

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316 **Figure Legend**

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318 Figure 1: **Sensitivity analysis of minor criteria scoring that the delegates used to guide**
319 **consensus agreement on thresholds. Highlighted bars reflect the total scores that would**
320 **optimize certain diagnostic test performance metrics. ppv = positive predictive value; npv =**
321 **negative predictive value.**

322 **Table Legend**

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324 Table 1: Minor Criteria Used for Categorization of Non-Definite PJI

325 Table 2: 2018 Definition for Shoulder PJI

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Table 1: 2025 Minor Criteria Used for Categorization of Non-Definite PJI (Maximum Score: 31)

Minor Criteria	Weight
Erythema	**10**
Elevated ESR or CRP	**5**
Unexpected drainage	**4**
Radiographic humeral osteolysis	**3**
Synovial neutrophil ≥ 70% **OR** **Frozen section ≥ 5 PMNs/HPF**	**4 if either positive** **2 if neither tested** **0 if both negative (or one negative and other untested)**
Intra-operative humeral loosening	**2**
≥2 positive cultures with the same bacteria	**3**
• ≥13 High likelihood of PJI • 7-12 Moderate likelihood of PJI • 1-6 Unknown PJI • 0 No PJI	

ESR (Erythrocyte sedimentation rate)

CRP (C-reactive protein)

PMNs (Polymorphonuclear leukocytes)

HPF (high power fields)

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Table 2: 2018 Definition for Shoulder PJI

A. Criteria Diagnostic of Definite PJI

Meeting any one of the following:

- Sinus tract communicating from skin surface to the prosthesis
- Gross intra-articular pus
- Two positive tissue cultures with phenotypically identical virulent organisms

B. Minor Criteria (Weighted Scoring System)

Minor Criterion	**Weight**
Unexpected wound drainage	4
Single positive tissue culture with virulent organism	3
Single positive tissue culture with low-virulence organism	1
Second positive tissue culture (identical low-virulence organism)	3
Humeral loosening	3
Positive frozen section (≥5 PMNs in ≥5 high-power fields)	3
Positive preoperative aspirate culture (low- or high-virulence organism)	3
Elevated synovial neutrophil percentage (>80%)*	2
Elevated synovial WBC count (>3000 cells/μL)*	2
Elevated ESR (>30 mm/h)*	2
Elevated CRP (>10 mg/L)*	2
Elevated synovial α-defensin level	2
Cloudy synovial fluid	2

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* Laboratory thresholds apply beyond 6 weeks from index surgery.

C. Interpretation of Minor Criteria Score

Total Score	**Microbiology**	**Interpretation**
≥6	Identified organism	Probable PJI
≥6	No identified organism	Possible PJI
<6	Single positive culture with virulent organism	Possible PJI
<6	Two positive cultures with identical low-virulence organism	Possible PJI
<6	Negative cultures OR single positive culture with low-virulence organism	PJI Unlikely

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	Total points	sensitivity	ppv	specificity	npv
	> 0	1	0.14	0.22	1
	> 2	0.98	0.16	0.36	0.99
	> 3	0.97	0.19	0.47	0.99
	> 4	0.96	0.2	0.53	0.99
	> 5	0.9	0.27	0.69	0.98
	> 6	0.9	0.28	0.72	0.98
	> 7	0.83	0.34	0.8	0.97
	> 8	0.82	0.39	0.84	0.97
Maximize sensitivity, PPV	> 9	0.79	0.43	0.87	0.97
	> 10	0.72	0.49	0.91	0.96
	> 11	0.72	0.51	0.91	0.96
	> 12	0.66	0.56	0.94	0.96
	> 13	0.65	0.6	0.95	0.96
Maximize sensitivity, specificity	> 14	0.63	0.66	0.96	0.95
	> 15	0.53	0.69	0.97	0.94
	> 16	0.53	0.73	0.98	0.94
	> 17	0.47	0.81	0.99	0.94
	> 18	0.43	0.82	0.99	0.93
	> 19	0.37	0.85	0.99	0.93
	> 20	0.35	0.86	0.99	0.92
	> 21	0.3	0.88	0.99	0.92
	> 22	0.22	0.87	1	0.91
	> 23	0.2	0.9	1	0.91
	> 24	0.14	0.93	1	0.9
	> 25	0.11	0.91	1	0.9
	> 26	0.08	0.88	1	0.9
	> 27	0.04	1	1	0.89
	> 29	0.01	1	1	0.89
	> 31	0	-	1	0.89

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Ethics declaration

Informed consent and patient details

The authors have NOT obtained informed consent from participants or their legal representatives. This study is a consensus statement and does not include patient data.

Studies in Human

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place.

Ethics committee approval was not required under relevant laws and institutional guidelines. This is a concensus statement so relevant laws, regulatory frameworks, and institutional guidelines is not required

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