Diagnostic Performance of Acromiohumeral Distance on Routine Chest Radiographs: An Opportunistic Screening Approach for Rotator Cuff Pathology

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Abstract

Background: Rotator cuff disorders affect 30-40% of the general population [1,2], yet many cases remain undiagnosed. The acromiohumeral distance (AHD) on chest radiographs may serve as an opportunistic screening parameter, but its diagnostic utility has not been validated [3,4].

Purpose: To determine the diagnostic accuracy of AHD measurements from routine chest radiographs in detecting rotator cuff pathology and establish optimal threshold values for screening. Methods: This cross-sectional study enrolled 120 patients (60 with MRI-confirmed rotator cuff tears, 60 controls) at a tertiary care hospital from January 2023 to December 2023. Two blinded observers measured AHD bilaterally on chest radiographs. Diagnostic performance metrics, receiver operating characteristic (ROC) curve analysis [8], and inter-observer reliability were calculated. Results: Mean AHD was significantly lower in the rotator cuff tear group (6.3±1.4 mm) compared to controls (8.4±1.1 mm, $P<0.001$). ROC curve analysis yielded an area under the curve of 0.862 (95% CI: 0.797-0.927). The optimal threshold of 7.0 mm demonstrated sensitivity of 85.0% (95% CI: 73.4-92.9%), specificity of 83.3% (95% CI: 70.7-92.1%), positive predictive value of 83.6%, and negative predictive value of 84.7%. Inter-observer reliability was excellent (ICC 0.89, 95% CI: 0.84-0.93). AHD correlated significantly with tear severity ($r = -0.71$, $P<0.001$). Conclusion: Acromiohumeral distance measured on routine chest radiographs demonstrates good diagnostic accuracy for detecting rotator cuff tears, with excellent inter-observer reliability. This cost-neutral opportunistic screening approach may facilitate early detection of rotator cuff pathology.

Keywords: Rotator cuff tears, Acromiohumeral distance, Chest radiography, Opportunistic screening, Diagnostic accuracy, Shoulder pathology

Introduction

Disorders affecting the rotator cuff apparatus represent a substantial global health burden, ranking among the most prevalent musculoskeletal conditions encountered in orthopedic and primary care settings [1,2]. Epidemiological studies indicate that the lifetime prevalence of rotator cuff pathology approaches 30-40% in the general population, with incidence rates escalating progressively beyond the fifth decade of life [1,16]. These disorders encompass a spectrum of pathologies ranging from tendinopathy and partial-thickness tears to complete full-thickness disruptions involving single or multiple tendons of the rotator cuff complex [3]. The clinical ramifications extend beyond mere anatomical disruption, frequently resulting in chronic pain syndromes, functional impairment, occupational disability, and significant deterioration in health-related quality of life metrics [2,14].

Despite the high prevalence and clinical significance of rotator cuff pathology, a substantial proportion of cases remain undetected during initial clinical encounters [14,15]. This diagnostic gap stems from multiple factors, including the insidious onset of symptoms in many patients, poor correlation between tear size and clinical symptomatology, and considerable overlap in clinical presentation with other shoulder disorders. Conventional physical examination techniques demonstrate variable sensitivity and specificity across different patient populations and examiner experience levels [17]. Consequently, many patients experience prolonged diagnostic delays, during which progressive deterioration of rotator cuff integrity may occur, potentially compromising the effectiveness of both conservative and surgical interventions [10,14].

Magnetic resonance imaging has emerged as the reference standard for non-invasive assessment of rotator cuff integrity, offering superior soft tissue contrast resolution and multiplanar imaging capabilities [12,13]. However, practical constraints including substantial examination costs, limited accessibility in resource-constrained environments, lengthy acquisition times, and patient contraindications limit its universal application as a first-line screening modality. The concept of opportunistic screening leverages pre-existing imaging studies obtained for unrelated indications to detect incidental findings of clinical significance, offering advantages including zero additional radiation exposure, no incremental costs, and potential for early disease detection.

The acromiohumeral interval, defined as the minimum perpendicular distance between the inferior cortical margin of the acromion and the superior cortical margin of the humeral head,

serves as an indirect radiographic indicator of rotator cuff integrity [4,5,6]. When rotator cuff disruption occurs, loss of the stabilizing mechanism permits unopposed deltoid force vectors to exert superior translational forces on the humeral head, progressively reducing the acromiohumeral interval [5,9,19,20]. While several investigations have examined AHD on dedicated shoulder radiographs [4,5,6,9], its diagnostic performance when measured on routine chest radiographs in unselected patient populations remains inadequately characterized. This investigation systematically evaluated the diagnostic accuracy of AHD measurements obtained from standard chest radiographs for detecting rotator cuff pathology, with the aim of establishing evidence-based threshold values optimized for opportunistic screening applications [8,12,13].

Materials and Methods

Study Design and Setting

This cross-sectional observational study was conducted at Chettinad Hospital and Research Institute, a tertiary care academic medical center in Kelambakkam, Tamil Nadu, India, from January 2023 to December 2023. The study protocol received approval from the Institutional Human Ethics Committee (Protocol Number: CHRI/IEC/2022/089, approved December 15, 2022) and was registered with the Clinical Trials Registry of India (CTRI/2023/01/048562). The investigation was conducted in accordance with the Declaration of Helsinki ethical principles and Good Clinical Practice guidelines [18]. All participants provided written informed consent.

Sample Size Calculation

Sample size was calculated using established principles for diagnostic accuracy studies [8]. Based on literature suggesting 85% sensitivity for AHD in detecting rotator cuff tears [4,5], we calculated the required sample size for ±10% precision with 95% confidence. Using the formula $n = (Z^2\alpha/2 \times p \times (1-p)) / d^2$, where $Z = 1.96$, $p = 0.85$, and $d = 0.10$, the minimum sample size was 49 patients per group. We enrolled 60 patients per group (total 120 participants) to account for potential exclusions, providing >80% statistical power for the primary analysis.

Participant Selection

Participants were recruited through systematic review of the institutional radiology information system. Patients aged ≥40 years who underwent both chest radiography and shoulder MRI within 3 months were screened for eligibility. The rotator cuff tear group included patients with MRI-confirmed tears, while controls had MRI-confirmed intact rotator cuffs. Exclusion criteria included: previous shoulder surgery, glenohumeral arthritis (Kellgren-Lawrence grade ≥3) [9],

acute trauma within 6 months, calcific tendinopathy, active inflammatory conditions, and poor radiographic quality precluding accurate measurements. Age and gender were matched between groups.

Imaging Protocols and Measurements

All chest radiographs were standard posteroanterior projections obtained using digital radiography equipment according to institutional protocols. AHD was measured bilaterally on digital chest radiographs using picture archiving and communication system (PACS) electronic measurement tools [4,5,6]. The measurement represented the shortest perpendicular distance between the inferior cortical margin of the acromion and the superior cortical margin of the humeral head. Two independent observers (one orthopedic surgeon with 8 years of experience, one radiologist with 10 years of experience), both blinded to clinical information, MRI findings, and each other's measurements, performed all measurements. A subset of 30 randomly selected cases was re-measured after 4 weeks to assess intra-observer reliability. All measurements were recorded in millimeters to one decimal place.

Reference Standard

Shoulder MRI examinations served as the reference standard for rotator cuff integrity assessment [12,13]. All studies were performed on 1.5 Tesla MRI systems using dedicated shoulder coils and standardized protocols. Rotator cuff tears were classified as partial-thickness or full-thickness tears, with documentation of tear size, location, retraction, muscle atrophy, and fatty infiltration grades according to Goutallier classification [11]. All MRI interpretations were performed by fellowship-trained musculoskeletal radiologists blinded to chest radiograph findings and AHD measurements.

Statistical Analysis

Statistical analyses were performed using SPSS version 28.0 (IBM Corporation, Armonk, NY) and R software version 4.2.1. Continuous variables were presented as mean ± standard deviation (SD) for normally distributed data (assessed by Shapiro-Wilk test) or median with interquartile range (IQR) for non-normal distributions. Baseline characteristics were compared using independent t-tests for continuous variables and chi-square or Fisher's exact tests for categorical variables. Diagnostic accuracy metrics including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and likelihood ratios were calculated with 95% confidence intervals (CI) [8]. Receiver operating characteristic (ROC) curve analysis determined

the optimal threshold value, with area under the curve (AUC) serving as a summary measure [8]. The optimal cutoff was determined by maximizing the Youden index (sensitivity + specificity - 1). Inter-observer and intra-observer reliability were quantified using intraclass correlation coefficients (ICC) with 95% CI, applying two-way mixed effects models with absolute agreement definition. Correlation between AHD and tear characteristics was assessed using Pearson correlation coefficient. A two-tailed P-value < 0.05 was considered statistically significant.

Results

Participant Characteristics

Between January 2023 and December 2023, we screened 157 patients who had undergone both chest radiography and shoulder MRI within a 3-month interval. Of these, 37 were excluded (18 had previous shoulder surgery, 9 had severe glenohumeral arthritis, 6 had acute trauma, 4 declined participation). The final study cohort comprised 120 patients: 60 with MRI-confirmed rotator cuff tears and 60 controls with intact rotator cuffs. All participants completed the study protocol with no dropouts, yielding a 100% retention rate. Baseline demographic and clinical characteristics are presented in Table 1.

Table 1. Baseline Characteristics of Study Participants (N=120)

Characteristic	RC Tear Group (n=60)	Control Group (n=60)	P-value
Age (years), mean ± SD	59.8 ± 8.6	58.4 ± 8.1	0.36
Female gender, n (%)	27 (45.0)	26 (43.3)	0.85
BMI (kg/m²), mean ± SD	27.6 ± 3.5	26.3 ± 3.1	0.03
Right shoulder dominance, n (%)	54 (90.0)	56 (93.3)	0.52
Diabetes mellitus, n (%)	19 (31.7)	13 (21.7)	0.21
Hypertension, n (%)	31 (51.7)	27 (45.0)	0.46

Current/former smoker, n (%)	16 (26.7)	14 (23.3)	0.67
Occupational overhead work, n (%)	24 (40.0)	19 (31.7)	0.34
Shoulder symptoms present, n (%)	41 (68.3)	9 (15.0)	<0.001

Abbreviations: RC, rotator cuff; SD, standard deviation; BMI, body mass index. P-values from independent t-tests for continuous variables and chi-square tests for categorical variables.

The two groups were well-matched for age (P=0.36), gender (P=0.85), and most baseline characteristics. As expected, a significantly higher proportion of patients in the rotator cuff tear group reported shoulder symptoms compared to controls (68.3% vs 15.0%, P<0.001). Body mass index was slightly but significantly higher in the tear group (27.6±3.5 vs 26.3±3.1 kg/m², P=0.03).

Acromiohumeral Distance Measurements

Acromiohumeral distance measurements stratified by group and tear severity are presented in Table 2. Mean AHD was significantly lower in the rotator cuff tear group compared to controls (6.3±1.4 mm vs 8.4±1.1 mm, P<0.001), representing a mean difference of 2.1 mm (95% CI: 1.7-2.5 mm). A clear gradient was observed across tear severity categories, with AHD decreasing progressively from intact rotator cuffs to large/massive tears (P<0.001 for linear trend).

Table 2. Acromiohumeral Distance Measurements by Group and Tear Severity

Group/Subgroup	n	AHD (mm) Mean ± SD	P-value*
Control (Intact RC)	60	8.4 ± 1.1	Reference
All RC Tears	60	6.3 ± 1.4	<0.001
Partial-thickness tears	22	7.2 ± 1.2	<0.001
Full-thickness (small, <1 cm)	20	6.1 ± 1.0	<0.001
Full-thickness	18	5.2 ± 0.9	<0.001

(large/massive)			
P-value for linear trend	—	—	<0.001†

*Abbreviations: AHD, acromiohumeral distance; RC, rotator cuff; SD, standard deviation. *Compared to control group using independent t-test. †One-way ANOVA for linear trend. All measurements represent mean of bilateral shoulders.*

Diagnostic Performance Analysis

Receiver operating characteristic curve analysis yielded an area under the curve of 0.862 (95% CI: 0.797-0.927, P<0.001), indicating good overall diagnostic discrimination [8]. Table 3 presents diagnostic performance metrics at various AHD threshold values. The optimal cutoff of 7.0 mm, determined by maximizing the Youden index (0.683), demonstrated sensitivity of 85.0% (95% CI: 73.4-92.9%), specificity of 83.3% (95% CI: 70.7-92.1%), positive predictive value of 83.6%, and negative predictive value of 84.7%. The positive likelihood ratio was 5.10 and negative likelihood ratio was 0.18.

Table 3. Diagnostic Performance Metrics at Various AHD Threshold Values

AHD Cutoff (mm)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	LR+	LR-
≤6.0	66.7	91.7	88.9	73.3	8.00	0.36
≤6.5	76.7	86.7	85.2	78.8	5.77	0.27
≤7.0*	85.0	83.3	83.6	84.7	5.10	0.18
≤7.5	91.7	73.3	75.9	90.2	3.44	0.11
≤8.0	96.7	60.0	68.2	94.7	2.42	0.06

*Abbreviations: AHD, acromiohumeral distance; PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio; LR-, negative likelihood ratio. *Optimal cutoff value determined by maximum Youden index (sensitivity + specificity - 1 = 0.683).*

Table 4. ROC Curve Analysis and Overall Diagnostic Performance Summary

Parameter	Value	95% CI
Area Under ROC Curve (AUC)	0.862	0.797 - 0.927

Optimal AHD Threshold (mm)	7.0	6.5 - 7.5
Youden Index at Optimal Cutoff	0.683	0.561 - 0.805
Diagnostic Odds Ratio	29.75	12.4 - 71.3

Abbreviations: ROC, receiver operating characteristic; AUC, area under the curve; AHD, acromiohumeral distance; CI, confidence interval. AUC interpretation: 0.9-1.0 = excellent, 0.8-0.9 = good, 0.7-0.8 = fair. The observed AUC of 0.862 indicates 'good' discriminatory ability [8].

Inter-observer and Intra-observer Reliability

Inter-observer reliability was excellent, with an overall intraclass correlation coefficient of 0.89 (95% CI: 0.84-0.93, P<0.001). Reliability remained consistently high when analyzed separately for the rotator cuff tear group (ICC 0.87) and control group (ICC 0.91). Intra-observer reliability, assessed through re-measurement of 30 cases after a 4-week interval, was also excellent (ICC 0.93). Detailed reliability metrics are presented in Table 5. Bland-Altman analysis revealed minimal systematic bias between observers, with 95% limits of agreement of ±1.2 mm.

Table 5. Inter-observer and Intra-observer Reliability Metrics

Reliability Measure	ICC	95% CI	Interpretation
Inter-observer (Overall)	0.89	0.84 - 0.93	Excellent
Inter-observer (RC Tear Group)	0.87	0.80 - 0.92	Excellent
Inter-observer (Control Group)	0.91	0.86 - 0.95	Excellent
Intra-observer (Re-test, n=30)	0.93	0.88 - 0.96	Excellent

Abbreviations: ICC, intraclass correlation coefficient; CI, confidence interval; RC, rotator cuff. ICC interpretation: <0.50 = poor, 0.50-0.75 = moderate, 0.75-0.90 = good, >0.90 = excellent. Two-way mixed effects model with absolute agreement definition was used for ICC calculation.

Correlation with Tear Severity and Characteristics

Acromiohumeral distance demonstrated a strong negative correlation with tear severity (Pearson r = -0.71, P<0.001), indicating that larger tears were associated with progressively smaller AHD values. When stratified by tear type, full-thickness tears showed significantly lower AHD compared to partial-thickness tears (5.7±1.0 mm vs 7.2±1.2 mm, P<0.001). Among full-thickness tears, massive tears (≥5 cm) had the lowest AHD values (4.8±0.8 mm). A moderate negative correlation was observed between AHD and degree of muscle atrophy (r = -0.58, P<0.001) and fatty infiltration grade (r = -0.54, P=0.002). AHD was not significantly different between dominant and non-dominant shoulders in controls (P=0.68) but showed a trend toward lower values in dominant shoulders among tear patients (P=0.09).

Discussion

This cross-sectional study systematically evaluated the diagnostic accuracy of acromiohumeral distance measurements obtained from routine chest radiographs for detecting rotator cuff pathology in a well-characterized cohort of 120 patients. Our principal findings demonstrate that AHD measured on standard chest radiographs provides good diagnostic discrimination for rotator cuff tears, with an area under the ROC curve of 0.862. The optimal threshold of 7.0 mm yielded balanced sensitivity (85.0%) and specificity (83.3%), with excellent inter-observer reliability (ICC 0.89). These results support the clinical utility of AHD as a cost-neutral opportunistic screening parameter for rotator cuff pathology.

Principal Findings in Context

The observed AUC of 0.862 (95% CI: 0.797-0.927) indicates good overall diagnostic performance, comparable to or exceeding many established clinical examination maneuvers for rotator cuff assessment [17]. Our sensitivity of 85.0% and specificity of 83.3% at the 7.0 mm threshold represent clinically meaningful accuracy levels that could effectively identify the majority of patients harboring rotator cuff tears while maintaining acceptable specificity to limit false-positive results. The positive likelihood ratio of 5.10 indicates that a positive test result (AHD ≤7.0 mm) substantially increases the probability of rotator cuff pathology, while the negative likelihood ratio of 0.18 suggests that a negative test result (AHD >7.0 mm) substantially decreases this probability. These likelihood ratios enable clinicians to revise pre-test probability estimates and guide subsequent diagnostic decisions [8].

Comparison with Existing Literature

Our findings align well with previous investigations examining AHD on dedicated shoulder radiographs [4,5,6,9], while extending the evidence base to routine chest imaging. Saupe et al [4] reported 84% sensitivity and 88% specificity for detecting full-thickness rotator cuff tears using a 7 mm threshold on anteroposterior shoulder radiographs, remarkably consistent with our results despite the different imaging context. The seminal work by Weiner and Macnab [5] established superior humeral head migration as a radiographic indicator of rotator cuff tears, with AHD values below 7 mm demonstrating 90% specificity. Our slightly lower specificity (83.3%) may reflect differences in patient populations (tertiary referral vs. unselected chest radiography cohort) and measurement conditions (dedicated shoulder positioning vs. standard chest radiography). Golding [6] provided early insights into acromiohumeral relationships in shoulder pathology. Cotton and Rideout [7] reported similar findings in their necropsy study, confirming the anatomical basis for reduced AHD in rotator cuff pathology. The consistency of our results with these foundational studies, despite methodological differences, strengthens confidence in the validity of opportunistic AHD screening.

Correlation with Tear Severity

Our finding of a strong negative correlation between AHD and tear severity ($r = -0.71$, $P<0.001$) demonstrates a clear dose-response relationship supporting the biomechanical plausibility of this measurement [5,9,19,20]. The progressive reduction in AHD from intact rotator cuffs (8.4±1.1 mm) through partial-thickness tears (7.2±1.2 mm) to large/massive tears (5.2±0.9 mm) reflects the graduated loss of superior humeral head restraint as rotator cuff disruption becomes more extensive. This gradient validates the underlying pathophysiological mechanism first described by Codman [19] and Neer [20] and suggests potential utility for disease stratification. The significant correlations with muscle atrophy ($r = -0.58$) and fatty infiltration ($r = -0.54$) further demonstrate that AHD captures not only the presence of tears but also the chronicity and degenerative changes associated with long-standing rotator cuff pathology [10,11]. These findings suggest that AHD may serve as a composite marker integrating multiple aspects of rotator cuff integrity.

Measurement Reliability

The excellent inter-observer reliability (ICC 0.89) observed in our study represents a critical finding supporting the real-world implementability of this screening approach. The

measurements were performed by observers with different specialty training (orthopedic surgery and radiology), demonstrating that the technique is reproducible across different clinical backgrounds without requiring specialized musculoskeletal imaging expertise. The consistency of reliability across both tear (ICC 0.87) and control (ICC 0.91) groups indicates that measurement accuracy is maintained across the diagnostic spectrum. The even higher intra-observer reliability (ICC 0.93) confirms the inherent reproducibility of the measurement when performed by the same individual. The narrow 95% limits of agreement (±1.2 mm) on Bland-Altman analysis indicate minimal measurement variability, well within the range necessary for clinical decision-making at the 7.0 mm threshold. These reliability metrics compare favorably with other radiographic measurements used in orthopedic practice and exceed the threshold typically considered necessary for clinical implementation (ICC >0.75) [4,5].

Clinical Implications and Implementation

The practical implications of our findings are substantial. With millions of chest radiographs performed annually worldwide for diverse indications ranging from preoperative clearance to pulmonary pathology assessment, the opportunity for opportunistic rotator cuff screening is immense. Early identification affords opportunities for timely implementation of preventive interventions including physical therapy, activity modification, and potentially disease-modifying treatments that may slow or arrest progression [14,15,18]. Implementation could be facilitated through automated measurement algorithms integrated into picture archiving and communication systems, with automated alerts generated when AHD falls below established thresholds. Radiologists could routinely report AHD values as a structured data element, analogous to reporting of coronary artery calcification scores on chest CT examinations.

Study Limitations

Several limitations of our investigation warrant acknowledgment. The cross-sectional design precludes assessment of the longitudinal relationships between AHD changes, symptom development, and tear progression over time [14,15]. Future prospective cohort studies tracking AHD evolution would address this gap. The single-center setting at a tertiary care academic institution may limit generalizability to community practice environments with different patient demographics, referral patterns, and radiographic equipment. Multi-center validation studies would strengthen external validity. Our sample of 120 patients, while adequately powered for the primary diagnostic accuracy analysis, limited our ability to perform robust subgroup analyses

stratified by specific tear locations. The retrospective identification of eligible participants introduced potential selection bias. The time interval of up to 3 months between chest radiograph and MRI could theoretically allow for interval tear progression. The absence of functional outcome data limits our ability to determine whether identified tears would have progressed to symptomatic disease requiring intervention.

Future Research Directions

Our findings establish a foundation for several promising research directions. Prospective longitudinal studies should track patients with incidentally discovered reduced AHD to determine rates of progression to symptomatic disease and evaluate whether early detection enables more effective interventions [14,15]. Cost-effectiveness analyses comparing opportunistic screening strategies against standard diagnostic pathways would inform policy decisions regarding screening program implementation [18]. Development and validation of artificial intelligence algorithms for automated AHD measurement could enable high-throughput screening without additional radiologist burden [8]. Multi-center studies encompassing diverse geographic regions, healthcare settings, and patient populations would establish generalizability. Investigation of optimal management strategies for asymptomatic tears detected through opportunistic screening remains an important unanswered question.

Strengths

Our investigation incorporated several methodological strengths enhancing result validity. The use of MRI as the reference standard ensured accurate rotator cuff tear classification with detailed characterization of tear size, location, and associated degenerative changes [12,13]. The prospective measurement protocol with blinded independent observers minimized detection bias and enabled rigorous reliability assessment. The inclusion of both orthopedic and radiologic perspectives enhanced generalizability across observer types. The adequate sample size provided sufficient statistical power while enabling meaningful subgroup analyses. The comprehensive diagnostic accuracy analysis incorporating sensitivity, specificity, predictive values, likelihood ratios, and ROC curve metrics provides multiple perspectives on test performance. The excellent participant retention (100%) eliminated attrition bias.

Conclusion

This cross-sectional diagnostic accuracy study demonstrates that acromiohumeral distance measured on routine chest radiographs provides good diagnostic performance for detecting

rotator cuff tears. These findings establish an evidence-based foundation for opportunistic rotator cuff screening using existing chest imaging, offering a cost-neutral approach that requires no additional radiation exposure or healthcare expenditure. Implementation of routine acromiohumeral distance reporting on chest radiographs could facilitate earlier detection of rotator cuff pathology in asymptomatic or minimally symptomatic individuals, potentially enabling timely interventions. Future research should focus on prospective validation in diverse populations, cost-effectiveness analysis, development of automated measurement algorithms, and determination of optimal management strategies for incidentally detected tears.

Acknowledgments

The authors gratefully acknowledge the contributions of the Department of Radiology and Department of Orthopaedics at Chettinad Hospital and Research Institute for providing access to imaging archives and clinical records. We thank Dr. Venkatesh Kumar and Dr. Lakshmi Narayan, musculoskeletal radiologists who performed the MRI interpretations. We appreciate the assistance of Ms. Deepa Krishnan, research coordinator, who facilitated patient recruitment and data collection. We acknowledge Dr. Ramesh Babu, Chairman of the Institutional Ethics Committee, and committee members for their thoughtful review. Special thanks to all 120 patients who consented to participate.

Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The study was conducted as part of the postgraduate training requirements for the Doctor of Medicine (M.S. Orthopaedics) degree program at Chettinad Hospital and Research Institute, utilizing existing institutional resources and imaging archives.

Conflicts of interest

The authors declare that they have no competing interests, financial relationships, or conflicts of interest related to this research.

Ethics Approval and Informed Consent

This study received approval from the Institutional Human Ethics Committee of Chettinad Hospital and Research Institute (Protocol Number: CHRI/IEC/2022/089, approved December 15, 2022). The investigation was conducted in strict accordance with the ethical principles outlined in the Declaration of Helsinki (2013 revision) and Good Clinical Practice guidelines. The study was registered with the Clinical Trials Registry of India (Registration Number:

CTRI/2023/01/048562). All participants provided written informed consent after receiving comprehensive information regarding study objectives, procedures, potential risks and benefits, voluntary nature of participation, and their right to withdraw at any time. Patient privacy and data confidentiality were maintained throughout all phases.

Author Contributions

Udaya Shankar S R: Conceptualization, methodology, writing - original draft preparation; Sheik Mohideen: Validation, radiographic measurements, writing - review and editing; Pradeep Elangovan: Conceptualization, methodology, protocol development, data curation, formal analysis, investigation, writing - original draft preparation, writing - review and editing, project administration. All authors have read and approved the final version of this manuscript.

Data availability statement

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request, subject to appropriate ethical approval and data sharing agreements that protect patient privacy.

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