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Narrative Review

Thermography for Detection of Synovitis in Rheumatoid Arthritis - A Narrative Review

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Received: February 24, 2026; **Published:** March 06, 2026

Abstract

Synovitis is the fundamental pathological process in rheumatoid arthritis (RA), and accurate identification of active inflammation is central to diagnosis, prognostication, and treat-to-target therapeutic strategies. While musculoskeletal ultrasound (US), particularly with power Doppler (PD), and magnetic resonance imaging (MRI) provide sensitive assessment of synovial hypertrophy and vascularity, their cost, limited accessibility, and operator dependence restrict routine multijoint and serial evaluation. Infrared thermography (IRT), a non-contact imaging modality that detects cutaneous temperature variations, has re-emerged as a potential adjunctive tool for detecting inflammatory hyper perfusion associated with synovitis. Advances in sensor technology and portable devices have improved feasibility in both outpatient and remote settings.

Recent clinical studies demonstrate consistent temperature differentials between inflamed and non-inflamed joints, with moderate correlations between thermographic indices and ultrasound-detected synovitis, particularly PD vascularity. Larger superficial joints such as the knee and elbow appear to show stronger concordance compared to smaller joints of the hand, where anatomical complexity and environmental influences may affect accuracy. The integration of automated image processing and machine-learning algorithms, including thermographic joint inflammation scores, has further enhanced reproducibility and enabled potential remote disease activity assessment. However, thermography remains an indirect measure of synovitis and is influenced by ambient conditions, patient-specific factors, and acquisition variability. The absence of standardized imaging protocols and limited multicentre validation currently preclude its use as a standalone diagnostic modality.

Infrared thermography represents a promising, safe, and rapid adjunct for screening, monitoring, and triage in RA. Further large-scale prospective studies, standardized acquisition frameworks, and external validation of automated analytical models are required to establish its definitive clinical role.

***Keywords**: Artificial Intelligence in Detecting Synovitis; Thermography in Rheumatoid Arthritis; Ultrasonography in Synovitis; Power Doppler in Synovitis of Small Joints*

Introduction

Synovitis is the central pathology in Rheumatoid Arthritis (RA) [1]. Identifying active synovitis is fundamental to diagnosis, prognosis and to target management decisions, because subclinical synovitis on imaging predicts relapse and structural damage even when clinical examination suggests remission [1]. Traditionally, musculoskeletal ultrasound (US) with grey-scale (GS) and power Doppler (PD) and magnetic resonance imaging (MRI) are the imaging standards for detecting synovial hypertrophy and vascularity; however, they have drawbacks for serial or community use. US is operator dependent and resource intensive for multijoint surveys, and MRI is costly and is less accessible particularly due to the acquisition time [2-4]. Infrared thermography (IRT; or thermal imaging) measures cutaneous surface temperature in a non-contact manner and has regained interest as a rapid, low-cost adjunct to identify inflammatory hyper perfusion overlying affected joints [5-7]. This review summarizes the underlying principles, technical and methodological considerations, diagnostic and monitoring evidence and research priorities for IRT in detecting synovitis.

Physiological basis and technical principle

Inflammation produces increased local blood flow and metabolic heat; this can raise skin temperature overlying inflamed synovium and yield focal "hotspots" on thermal maps [8]. Modern uncooled microbolometer sensors convert long-wave infrared emission into temperature images. Camera performance (thermal sensitivity/NETD and spatial resolution), emissivity settings (skin ≈ 0.98), distance and viewing angle, ambient conditions, and patient factors all influence measured values [9,10]. Consequently, thermography is an indirect measure as it detects surface thermal effects of inflammation rather than imaging synovium directly as in an US or an MRI [8,11].

Acquisition and processing

Study heterogeneity in acquisition protocols has been a recurrent theme in IRT literature. Key acquisition variables that must be reported and standardized include: a) room temperature and humidity, b)patient acclimatisation time, c) camera model and sensitivity, d) camera-to-skin distance and angle, e) patient posture, f) avoidance of topical agents or recent exercise, emissivity, and ROI (region of interest) definitions [9,12]. Many early and some contemporary studies omitted complete control of one or more of these factors, increasing noise and reducing comparability across cohorts [6,13]. For quantitative analysis, researchers extract ROI measures (maximum, mean, minimum temperature), normalized differentials (joint vs adjacent reference area), heat-distribution indices, or feed raw thermal maps into machine-learning algorithms [5,14]. Dynamic protocols that add provocation (cold challenge or functional tasks) can magnify differences in rewarming behaviour, but add complexity [15]. Figure 1 depicts the workflow of thermography imaging for synovitis detection in rheumatoid arthritis.

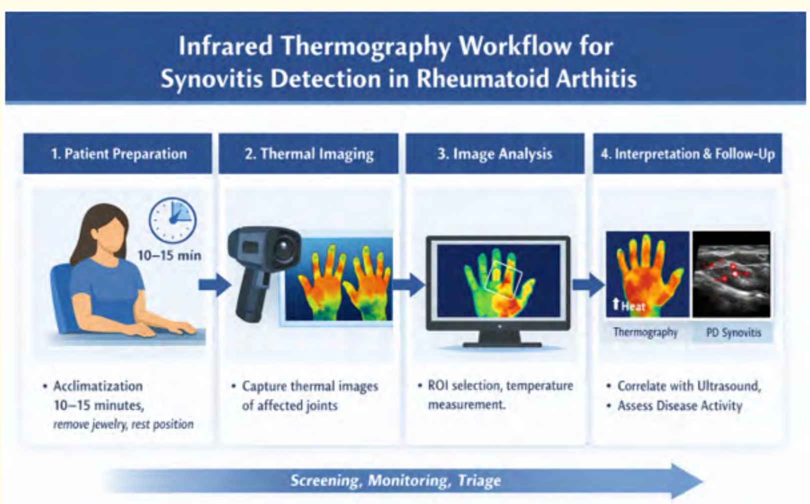

Figure 1: *Workflow of thermography imaging for synovitis detection in rheumatoid arthritis.*

Diagnostic performance and concordance with ultrasound or MRI

Numerous observational studies have compared thermographic indices to ultrasound-detected synovitis and PD signal. Recent pilot studies show consistent temperature differences between inflamed and non-inflamed joints and moderate correlations with US measures, especially PD vascularity (which indicates active synovial perfusion) [6,16]. In a focused machine learning study on hand, Morales-Ivorra and colleagues developed Thermo-JIS (a thermographic joint inflammation score) and composite Thermo-DAI indices; Thermo-DAI correlated moderately with US GS ($\rho \approx 0.52 - 0.58$) and PD ($\rho \approx 0.56 - 0.61$), and correlated strongly with clinical composite scores, highlighting potential for remote assessment [1,15]. Larger cross-sectional work at the metacarpophalangeal joints (810 joints from 81 patients) found summed thermographic temperatures correlated with summed PD and GS ultrasound scores ($\rho \approx 0.45 - 0.52$ and 0.26 - 0.29, respectively) and had good discrimination for PD positivity [16]. Similar concordance has been reported for elbow and knee joints: thermographic indices showed significant associations with PD signals at the elbow and knee in single-centre studies [16].

Despite these encouraging results, diagnostic accuracy varies by joint and by study. Larger, superficial joints (knee, elbow) tend to produce clearer thermal differentials and better agreement with PD than small, complex anatomic areas (MCP, wrist) where skin thickness, local tendon anatomy and proximity to other heat sources complicate interpretation [16]. Heterogeneity of protocols (acclimatisation time, ambient control, camera quality) and thresholds used for positive thermal findings partly explain variable sensitivity and specificity results reported across studies and reviews [6,13]. Table 1 outlines key clinical studies that evaluated IRT for detection of synovitis in RA.

Author / (Year)	Study Design	Sample Size	Joint(s) Assessed	Comparator	Key Findings	Clinical Implication
Devereaux., *et al.* [13] (1985)	Prospective comparative	20 RA patients	Hands	Clinical indices	Thermographic heat distribution correlated with disease activity indices	Early evidence that surface heat reflects inflammatory burden
Brenner., *et al.* [15] (2006)	Observational	Rat Models	Hands	Clinical activity	Distinct "thermal signature" in inflamed joints; reproducible measures	Introduced concept of quantitative thermal mapping
Gatt., *et al.* [8] (2019)	Case-control	31 RA, 51 controls	Hands and wrists	Healthy controls	Higher mean joint temperatures in RA vs controls	Demonstrated discriminatory ability of IRT
Pauk., *et al.* [7] (2019)	Diagnostic pilot	50 severe; 16 Moderate disease activity - RA	Hands	DAS28	Thermal sensor parameters correlated with clinical activity	Validated feasibility of portable sensors
Tan., *et al.* [2] (2020)	Cross-sectional	51 RA	Hands	Ultrasound (GS and PD)	Moderate correlation between thermal measures and PD synovitis	Supports association with synovial vascularity
Vasdev., *et al.* [9] (2023)	Observational	30 RA knees	Knee	Power Doppler US	Significant correlation between thermal differential and PD signal	Better performance in large superficial joints

Tan., *et al*. [3] (2024)	Cross-sectional	81 RA (810 MCP joints)	MCP joints	GS and PD US	Thermographic temperature sums correlated with PD (ρ≈0.45 - 0.52)	Multijoint validation; good discrimination for PD positivity
Tan., *et al*. [4] (2024)	Observational	RA cohort	Elbow	Ultrasound	Thermal indices associated with PD synovitis	Extends validation beyond small joints
Morales-Ivorra., *et al*. [1] (2022)	Development and validation	146 RA	Hands	Ultrasound + DAS28	ThermoJIS/ThermoDAI correlated with GS and PD (ρ≈0.5 - 0.6)	AI-enabled remote disease monitoring
Tan., *et al*. [5] (2025)	Prospective validation	RA knees	Knee	Ultrasound	Heat signatures discriminate PD-positive knees	Confirms role in large joint triage

Table 1: *Key clinical studies evaluating infrared thermography for detection of synovitis in rheumatoid arthritis.*

Automated analysis and remote monitoring - the AI opportunity

A critical advance has been application of automated image processing and machine-learning to thermographic datasets. Algorithms can segment hands, extract localized thermal features and produce composite scores (Thermo-JIS/Thermo-DAI) that reduce reader variability and generate single-value outputs suitable for remote clinics and telemedicine [1,15]. External validation studies have been promising; internal validation shows good sensitivity for active synovitis and improved performance over patient-reported global assessments when ultrasound is the reference [15,16]. However, the challenge with AI models is to train on the data sets of multiple centres and large cohorts with diverse demography for robust generalization and to avoid algorithmic bias and fairness [13].

Clinical roles: Where thermography may fit today?

Given current evidence, IRT is best viewed as a complementary technology with specific roles such as; a) screening/triage: quick imaging to flag joints for targeted ultrasound when clinical suspicion is uncertain or resources constrained [16]; b) Remote monitoring/telehealth: combined with AI indices (ThermoDAI) to augment remote disease activity evaluation and prioritize in-person review for patients showing thermal increases [1,15]; c) Research/decentralized trials: inexpensive, repeatable measurements that allow frequent, objective outcome assessments across geographically dispersed participants [16].

Crucially, positive thermographic findings should prompt confirmatory US/PD (or clinical review) when therapeutic decisions depend on synovitis detection as thermography does not visualize synovial tissue directly and has known confounders [8,15].

Strengths and Limitations

IRT strengths include safety (non-ionizing), contactless operation (valuable in infection control or part of telemedicine), speed, portability and the emergence of low-cost sensors and smartphone-attached cameras that expand potential deployment beyond tertiary centres [9]. However, IRT has its limitations as it measures surface temperature and can be confounded by ambient environment and certain local conditions like local skin pathology, vascular tone, subcutaneous fat and systemic fever might give a false positive values. Small joints are technically more challenging due to their close proximity and defining ROI is cumbersome [6,13,15]. Finally, while machine-learning shows promise, transparency of algorithms, reproducible reporting and external validation remain necessary before clinical adoption [13].

Standardization and reporting recommendations [Table 2]

To advance the field, studies should adhere to standardized acquisition and reporting. Minimum items to report include camera model and NETD, emissivity setting, lens and spatial resolution, room temperature/humidity, patient acclimatisation time, patient posture and joint positioning, camera distance/angle, ROI definitions, preprocessing steps, and whether dynamic provocation was used. Studies aiming at diagnostic accuracy should prespecify thresholds and use blinded US/PD or MRI reference standards, provide inter- and intra-observer reliability, and follow STARD (Standards for Reporting of Diagnostic accuracy studies) or TRIPOD (for predictive models) guidelines when applicable [13].

Parameter	Recommended Standard
Room temperature	20-24°C controlled environment
Acclimatization time	10 - 15 minutes
Emissivity setting	0.98 (human skin)
Camera-to-skin distance	Fixed (usually 0.5 - 1.0m depending on device)
Camera thermal sensitivity (NETD)	≤ 0.05°C preferred
Patient preparation	No exercise, topical creams, or hot/cold exposure prior
ROI definition	Standardized anatomical landmarks
Comparator imaging	Blinded ultrasound (GS + PD) preferred
Reporting standards	Follow STARD/TRIPOD guidelines

Table 2: *Recommended acquisition parameters for thermographic assessment of synovitis.*

Research priorities

Key priorities are: (1) multicentre prospective diagnostic-accuracy studies using standardized acquisition protocols and blinded US/PD or MRI comparators to quantify sensitivity/specificity by joint and disease state; (2) creation and open sharing of large annotated thermal image datasets to enable robust AI model training and external validation; (3) pragmatic trials testing whether thermography-guided triage reduces imaging burden, shortens time to detection of flares, or improves treat-to-target outcomes; and (4) health-economic analyses comparing thermography-augmented care pathways to standard practice, particularly in low-resource settings [6,13,15].

Conclusion

Infrared thermography is a rapidly evolving adjunctive tool for detecting synovitis in RA. Clinical studies show concordance between thermal measures and ultrasound-detected synovitis - most consistently with power Doppler vascularity and machine-learning approaches (ThermoJIS/ThermoDAI) enable automated, remote assessment [1,15,16]. However, thermography remains an indirect measure of synovitis; methodological heterogeneity, environmental confounders, and limited external validation of AI models mean IRT should currently complement rather than replace ultrasound or MRI. Standardisation of acquisition and reporting, large multicentre validation, and transparent AI development are essential next steps to translate thermography into routine clinical practice.

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Volume 17 Issue 3 March 2026