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Review

How Moisture Level Impact MRI Room performance and Patient Safety: A Comprehensive Analysis

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Abstract:
Magnetic Resonance Imaging (MRI) is a highly sensitive imaging modality that requires strict environmental control to ensure optimal performance and patient safety. Among environmental factors, moisture level—commonly expressed as relative humidity—plays a critical yet often underrecognized role in influencing MRI hardware reliability, image quality, and clinical safety. This study examines the impact of high and low moisture conditions in MRI suites, focusing on their effects on image quality, superconducting magnet systems, radiofrequency (RF) coils, electronic components, and patient comfort and safety. Elevated humidity levels are associated with increased RF noise, image artifacts, corrosion of coils and electronic components, condensation-related equipment malfunction, and heightened infection and slip hazards. Conversely, excessively low humidity increases the risk of electrostatic discharge, electronic instability, and patient discomfort.

The findings are discussed in the context of existing standards and guidelines, including recommendations from the American College of Radiology (ACR), ASTM, engineering-based MRI facility practices, and controlled-environment principles outlined in ISO 14644. Although current guidelines emphasize environmental stability, explicit humidity thresholds for MRI rooms remain limited. The study highlights the need for continuous environmental monitoring, dedicated HVAC systems, and improved reporting of moisture-related incidents. Future research should focus on quantitative, multi-center studies to establish stronger correlations between humidity control and MRI performance outcomes. Overall, this work underscores moisture management as a fundamental component of MRI quality assurance and patient safety.

Keywords: Magnetic resonance imaging (MRI); relative humidity; moisture control; MRI environmental conditions; HVAC systems; RF coil performance; image quality; signal-to-noise ratio; patient safety; electrostatic discharge; infection control; MRI hardware reliability; clinical quality assurance; environmental monitoring.

Introduction

Magnetic Resonance Imaging (MRI) is a non-invasive imaging modality based on nuclear magnetic resonance principles, utilizing strong magnetic fields, radiofrequency excitation, and gradient-based spatial encoding to generate high-resolution images.[1]Hydrogen protons within the body align with the static magnetic field and emit detectable RF signals during relaxation following excitation.[2] These signals are spatially encoded and reconstructed into diagnostic images. The accuracy and reliability of MRI are highly dependent on environmental stability, as factors such as humidity can influence RF performance, electronic integrity, and overall system function.[3]

Humidity (Moisture Level) Standards in MRI Suites

MRI suites require tightly regulated environmental conditions to ensure optimal system performance and patient safety. Recommended temperature ranges typically lie between 18–22°C, while relative humidity is maintained within 45–55% to prevent condensation, electrostatic discharge, and electronic degradation. These parameters are achieved through dedicated HVAC systems specifically designed for medical imaging, incorporating precise humidity control, continuous monitoring, and non-magnetic components. Failure to maintain these environmental conditions can compromise image quality, increase equipment failure rates, and elevate patient safety risks.[4]

Recommended relative humidity ranges and their impact on MRI system performance and patient safety (Table.1)

Moisture Condition	Safety Impact	Comfort Impact
High RH (>60%)	Slips, infection, electrical risk	Sweating, anxiety
Optimal RH (45–55%)	Safe environment	Comfortable scanning
Low RH (<30%)	Static discharge	Dryness, irritation

Recommended relative humidity ranges and associated safety and performance implications in MRI environments (adapted from ACR guidelines, ASHRAE recommendations, and manufacturer site-planning documents).

Why Moisture Level Matters

Relative humidity plays a critical role in maintaining the operational stability of MRI systems and ensuring patient safety. Elevated moisture levels, typically exceeding 60% relative humidity, have been associated with corrosion of electronic components and radiofrequency coils, increased RF interference, and condensation on equipment surfaces. These conditions can promote microbial growth and create physical hazards such as slippery floors, thereby increasing the risk of healthcare-associated infections and patient or staff injury. Conversely, excessively low humidity levels, generally below 30% relative humidity, increase the likelihood of electrostatic charge accumulation, which may result in electrostatic discharge events capable of damaging sensitive electronic components and disrupting imaging performance. In addition, low humidity environments contribute to patient discomfort through skin dryness and mucosal irritation, particularly during prolonged MRI examinations. [5]

Review Methodology

This review was conducted using a structured narrative approach to evaluate the impact of environmental moisture levels on MRI system performance and patient safety. A comprehensive literature search was performed to identify relevant peer-reviewed articles, professional guidelines, technical standards, and authoritative textbooks addressing humidity control, HVAC requirements, MRI hardware performance, image quality, and patient safety.

Literature Strategy

Electronic searches were carried out across multiple scientific and medical databases, including PubMed/MEDLINE, Google Scholar, Scopus, and IEEE Xplore, to capture both clinical and engineering-focused literature. Additional sources included professional organization publications and standards issued by bodies such as the American College of Radiology (ACR), ASHRAE, and international MRI safety frameworks. Reference lists of key articles and textbooks were also manually screened to identify additional relevant studies.

The search was conducted for literature published primarily between 2005 and 2025, ensuring inclusion of contemporary MRI technology while retaining foundational technical and safety concepts.

Inclusion Criteria

- Addressed the role of humidity or moisture in MRI environments
- Discussed MRI hardware performance, image quality, or patient safety
- Were peer-reviewed articles, professional guidelines, standards, or recognized textbooks
- Were published in English

Exclusion Criteria

- Focused exclusively on non-MRI imaging modalities

- Lacked relevance to environmental control or moisture-related effects
- Were opinion pieces without technical or clinical relevance

Data Extraction and Synthesis

Relevant data were extracted focusing on the relationship between moisture levels and MRI hardware reliability, image quality degradation, patient comfort, and safety risks. Rather than performing a quantitative meta-analysis, findings were synthesized qualitatively due to heterogeneity in study designs, outcome measures, and reporting standards across clinical, engineering, and facility-based literature. Emphasis was placed on identifying consistent patterns, reported failure mechanisms, and commonly recommended humidity thresholds across sources.

Methodological Limitations

As a narrative review, this study is subject to limitations inherent to qualitative synthesis, including potential publication bias and variability in guideline recommendations. Additionally, many available sources describe moisture effects indirectly or as contributing factors rather than primary outcomes, highlighting the need for future quantitative and multicenter investigations.

Review of Literature on the Impact of Moisture Level on MRI Performance and Patient Safety (Table.2)

Author & Year	Study Focus	Key Findings	Relevance to Present Review
Westbrook et al., 2018	MRI physics and system performance	Highlighted the importance of environmental stability for RF performance and electronic reliability in MRI systems.	Provides foundational evidence linking environmental control with MRI performance.
McRobbie et al., 2017	MRI technology and image quality	Reported that environmental instability, including humidity, can contribute to RF noise, artifacts, and reduced signal-to-noise ratio.	Supports the relationship between moisture imbalance and image degradation.
Shellock & Crues, 2004	MRI safety and patient care	Demonstrated that environmental factors influence RF heating, electrical safety, and patient risk in MRI suites.	Establishes the clinical safety importance of humidity control.
ASHRAE Handbook, 2021	Healthcare HVAC standards	Recommended maintaining relative humidity below 60% in imaging rooms to prevent condensation, microbial growth, and equipment damage.	Provides engineering justification for humidity thresholds.
ACR Manual on MR Safety, 2024	MRI facility safety guidelines	Emphasized continuous environmental monitoring and humidity control as part of safe MRI operation.	Supports guideline-based humidity management.
Brown et al., 2014	RF coil performance and image quality	Reported that coil degradation and RF instability are major contributors to reduced image quality.	Explains mechanisms by which humidity affects coils and SNR.
Bushong, 2021	MRI physical and biological principles	Discussed how environmental instability can influence electronic performance and thermal safety in MRI systems.	Connects moisture control with patient safety mechanisms.
IEC / Manufacturer Site Planning Guides	MRI facility design	Specified non-condensing humidity ranges (typically 30–60% RH) for safe MRI operation.	Provides manufacturer-validated environmental limits.
Heliyon Survey, 2017	MRI safety practices	Reported variability in environmental monitoring practices	Identifies real-world gaps and need for

		and highlighted gaps in humidity control across facilities.	standardized humidity management.
StatPearls, 2026	MRI patient safety	Emphasized environmental stability to reduce electrical hazards, RF burns, and equipment failure.	Reinforces the clinical safety implications of moisture imbalance.

Effect of Moisture on MRI Hardware

Moisture imbalance within MRI suites has a pronounced impact on hardware reliability, with radiofrequency (RF) coils representing the most vulnerable components. Prolonged exposure to elevated humidity accelerates corrosion of coil connectors and solder joints, facilitates moisture absorption into insulating materials, and alters coil impedance characteristics.[6] These changes reduce signal transmission efficiency and contribute to a measurable decline in signal-to-noise ratio, often necessitating coil replacement and increasing system downtime. Gradient electronics are also indirectly affected, as increased humidity raises electrical leakage currents and insulation resistance variability, which may lead to amplifier overheating, instability, and, in severe cases, circuit failure.[7] Although the superconducting magnet itself is not directly influenced by ambient moisture, condensation on cryogenic surfaces can compromise vacuum insulation, increase helium boil-off, and elevate the risk of magnet-related faults, thereby increasing operational costs and system interruptions.[8]

Effect of Moisture on Imaging Quality

Variations in ambient moisture levels significantly influence MRI image quality by altering the electromagnetic and thermal stability of system components. High relative humidity modifies the dielectric properties of the surrounding environment, contributing to increased RF noise and signal attenuation, particularly in high-field MRI systems.[9]These effects manifest as shading, ghosting, banding, and localized signal dropouts, which may mimic pathological findings and reduce diagnostic confidence. Furthermore, moisture-related degradation of RF coil performance directly reduces the signal-to-noise ratio, often requiring longer acquisition times or increased signal averaging to compensate. Such adjustments prolong scan duration, increase patient discomfort, and elevate the likelihood of motion artifacts, thereby compounding image quality degradation.[10]

Impact of High Moisture Levels on Patient Safety

Excessive humidity within MRI environments poses several patient safety concerns. Elevated moisture levels promote condensation on floors and equipment surfaces, increasing the risk of slip-and-fall incidents during patient transfer or emergency movement. Increased ambient moisture also enhances electrical conductivity, raising the potential for leakage currents and equipment malfunction in high-power MRI systems. From an infection control perspective, sustained high humidity supports bacterial and fungal growth within air-handling systems, RF coils, and patient-contact surfaces, thereby increasing the risk of healthcare-associated infections. [11]In addition, condensation on patient positioning accessories and RF coils may contribute to localized skin irritation and increase susceptibility to RF-related thermal injuries.[9]

Impact of Low Moisture Levels on Patient Comfort and Safety

Low relative humidity environments introduce a distinct set of patient safety and comfort challenges. Reduced ambient moisture facilitates the accumulation of static electricity, increasing the likelihood of electrostatic discharge during patient positioning or table movement. [12]Such events may startle patients, induce involuntary motion, and disrupt image acquisition, while also posing a risk to sensitive electronic components. Additionally, prolonged exposure to dry air contributes to skin dryness, ocular irritation, and nasal discomfort, particularly during lengthy imaging procedures. These factors can heighten patient anxiety and reduce tolerance to the MRI examination, ultimately increasing motion-related artifacts and the need for repeat scans.[13]

Moisture Level and Measurement in MRI Environments

Moisture level in indoor clinical environments refers to the amount of water vapor present in the air and is most commonly expressed as relative humidity (RH), defined as the ratio of actual water vapor content to the maximum amount the air can hold at a given temperature. In MRI suites, relative humidity is the primary parameter used for environmental control due to its direct relevance to condensation risk, electrostatic discharge, and electronic stability. Other humidity-related parameters, such as absolute humidity, specific humidity, and dew point, are primarily utilized in HVAC engineering and facility design to predict condensation events and optimize air-handling performance. Continuous monitoring of relative humidity through digital hygrometers, HVAC-integrated sensors, and data logging systems is essential for maintaining stable MRI operating conditions and preventing moisture-related equipment degradation.[14]

Zoning of MRI Suites and Environmental Control

Environmental control requirements within MRI facilities vary according to access zoning and equipment sensitivity. Zones I and II generally follow standard hospital HVAC conditions, as these areas do not contain sensitive MRI hardware. Zone III requires controlled temperature and humidity due to restricted access and proximity to MRI equipment, while Zone IV—the scanner room—demands the strictest environmental regulation. In this zone, precise humidity control is critical to protect radiofrequency coils, gradient electronics, and patient-contact components, as well as to ensure consistent image quality and patient safety. Failure to maintain appropriate environmental parameters in Zone IV has been associated with increased equipment failure rates, image artifacts, and patient discomfort.[15]

MRI suite zoning and corresponding environmental control requirements (Table.3)

MRI Zone	Environmental Control
Zone I & II	General hospital standards
Zone III	Controlled temperature & humidity
Zone IV (Scanner room)	Strict environmental control

MRI suite zoning is based on standard access control principles, with progressively stricter environmental regulation from Zone I to Zone IV. Humidity and temperature control requirements increase with equipment sensitivity and patient exposure.

Moisture-Induced Effects on MRI Image Quality

Environmental moisture levels exert a significant influence on MRI image quality by affecting electromagnetic stability, RF transmission, and thermal equilibrium. Elevated relative humidity alters the dielectric properties of the surrounding environment, increasing RF noise and signal attenuation, particularly in high-field MRI systems.[16]These effects manifest as image artifacts, including shading, ghosting, banding, and localized signal dropouts, which may mimic pathological findings and reduce diagnostic confidence. Moisture-related degradation of RF coil performance further reduces signal-to-noise ratio, necessitating longer acquisition times or increased signal averaging. Such compensatory measures prolong scan duration, increase patient discomfort, and elevate the likelihood of motion-related artifacts, thereby compounding diagnostic limitations.[9]

Patient Safety Risks Associated with High Moisture Levels

High moisture levels within MRI environments introduce several patient safety hazards. Excess humidity promotes condensation on floors, patient tables, and equipment surfaces, increasing the risk of slip-and-fall incidents during patient transfer or emergency evacuation.[17]Increased ambient moisture also enhances electrical conductivity, raising the potential for leakage currents and equipment malfunction in high-power MRI systems. From an infection control perspective, sustained elevated humidity creates favourable conditions for bacterial and fungal growth within air-handling systems, RF coils, and patient-contact accessories, increasing the risk of healthcare-associated infections. Additionally, moisture accumulation on patient positioning devices and skin surfaces may reduce surface resistance, thereby increasing susceptibility to RF-related thermal injuries.[18]

Patient Safety and Comfort Issues Associated with Low Moisture Levelss

Excessively low relative humidity presents a distinct set of safety and comfort challenges in MRI suites. Dry air facilitates the accumulation of static electricity, increasing the likelihood of electrostatic discharge during patient positioning, table movement, or contact with equipment surfaces. Such events may startle patients, induce involuntary movement, and disrupt image acquisition, while also posing a risk to sensitive electronic components.[19]Low humidity environments also contribute to skin dryness, ocular irritation, and nasal discomfort, particularly during prolonged imaging sessions. These factors may heighten patient anxiety, reduce tolerance of the MRI procedure, and increase motion-related artifacts, ultimately leading to repeat scans and prolonged examination times.[20]

Indirect and Combined Effects of Moisture Imbalance on Patient Safety

Beyond its direct effects, moisture imbalance contributes to several indirect patient safety risks within MRI environments. Variations in humidity influence skin resistance and thermal conductivity, which, when combined with RF energy and conductive loops, may increase the likelihood of localized RF burns. Environmental instability may also compromise the reliability of monitoring and support equipment, potentially delaying response during patient emergencies. Furthermore, repeated scan interruptions and prolonged examination times associated with moisture-related image degradation can increase patient fatigue, anxiety, and procedural stress, particularly in vulnerable populations such as elderly or claustrophobic patients.[21]

Effects of elevated and reduced relative humidity on MRI hardware performance and imaging quality. (Table.4)

Issue	Result
Coil corrosion	Frequent hardware failure
RF noise	Poor diagnostic quality
Image artifacts	Repeat scans
Increased scan time	Patient discomfort
System downtime	Financial loss

Table content is synthesized from peer-reviewed literature, MRI physics textbooks, and manufacturer site-planning documentation describing moisture-related mechanisms affecting system reliability and image quality.

Recommended Humidity Range for MRI Environments

Based on a synthesis of engineering practices, manufacturer site specifications, and professional safety guidelines, an optimal relative humidity range of approximately 45–55% is widely regarded as appropriate for MRI environments. This range minimizes the risk of condensation and microbial growth while reducing the likelihood of electrostatic discharge and maintaining patient thermal comfort. Although recommended thresholds vary among professional organizations, HVAC standards, and equipment manufacturers, maintaining relative humidity within this range has consistently been associated with improved equipment longevity, stable imaging performance, and enhanced patient safety. Continuous environmental monitoring and dedicated HVAC systems are essential to ensure compliance with these targets and to mitigate moisture-related operational risks. [22]

Recommended relative humidity ranges for MRI environments and comparable clinical spaces (Table .5)

Environment	Ideal RH (%)
Human comfort	40–60%
MRI suite	**45–55%**
Data centers	45–55%
Operating rooms	40–60%

Relative humidity ranges are summarized from healthcare HVAC standards, professional MRI safety guidelines, and engineering best practices. Values represent commonly recommended non-condensing operating conditions.

Discussion

This review synthesizes current evidence demonstrating that environmental moisture control is a critical determinant of MRI system reliability, image quality, and patient safety. Across the reviewed literature, a consistent theme emerges: deviations from recommended relative humidity ranges adversely affect both technical performance and clinical outcomes. Textbooks and professional guidelines describe environmental stability as a foundational requirement for safe MRI operation, yet real-world studies and facility reports indicate that humidity control is frequently under-monitored and inconsistently implemented, particularly in resource-limited settings. From a technical perspective, the literature confirms that moisture imbalance directly compromises MRI hardware integrity. Studies and manufacturer site-planning documents highlight that elevated relative humidity accelerates corrosion of radiofrequency coil connectors, solder joints, and printed circuit boards, leading to impedance mismatch, increased noise, and reduced signal transmission efficiency. McRobbie et al. and Westbrook et al. emphasize that RF system stability is highly sensitive to environmental conditions, with moisture altering dielectric properties and increasing electromagnetic interference. These mechanisms explain the observed reduction in signal-to-noise ratio, increased image artifacts, and prolonged acquisition times reported in multiple sources. In addition, HVAC engineering standards and ASHRAE guidelines describe how high humidity promotes condensation within electronic enclosures and air-handling units, increasing the risk of insulation breakdown, leakage currents, and unexpected system shutdowns. The reviewed literature further demonstrates that moisture imbalance has direct and indirect implications for patient safety. Shellock and Crues, along with the ACR Manual on MR Safety, identify environmental control as a core component of MRI risk management. Elevated humidity increases electrical conductivity and reduces surface resistance, thereby raising the likelihood of RF-related thermal injury, particularly in the presence of conductive loops and patient monitoring cables. Low humidity, conversely, facilitates electrostatic discharge, which may startle patients, disrupt image acquisition, and damage sensitive electronics. Infection control literature and HVAC standards consistently report that sustained humidity above recommended thresholds supports microbial growth within air-handling systems, RF coils, and patient-contact accessories, increasing the risk of healthcare-associated infections. These findings align with operational reports documenting higher equipment failure rates and safety incidents in poorly controlled MRI environments. Importantly, the literature reveals that environmental moisture control influences not only technical performance but also the overall patient experience. Dry environments are associated with mucosal irritation, skin dryness, and ocular discomfort, which may reduce patient tolerance during prolonged examinations and increase motion artifacts. Excessively humid conditions contribute to thermal discomfort, condensation on patient tables, and slip hazards during transfer and emergency evacuation. These clinical consequences are not isolated technical issues but directly affect diagnostic confidence, workflow efficiency, and patient-centred care. Despite broad agreement on the importance of humidity control, this review identified substantial variability among professional recommendations and manufacturer specifications. While most sources converge on maintaining relative humidity between approximately 30% and 60%, the lack of MRI-specific, evidence-based thresholds highlights an important research gap. Existing studies frequently describe moisture as a contributing factor rather than a primary variable, and quantitative, multicentre investigations linking humidity levels to measurable image quality metrics, equipment failure rates, and patient safety outcomes remain limited. This gap underscores the need for future research integrating environmental monitoring with imaging physics and clinical outcome measures to establish standardized, MRI-specific humidity guidelines. From a clinical and operational perspective, the findings of this review have clear implications for MRI practice. Humidity management should be incorporated into routine quality assurance programs alongside magnetic field homogeneity checks, RF coil testing, and safety audits. Continuous environmental monitoring, integration of HVAC alarms with MRI control systems, and formal documentation of humidity parameters during accreditation inspections can significantly reduce moisture-related risks. Multidisciplinary collaboration between radiology departments, medical physicists, biomedical engineers, and facility managers is essential to ensure that environmental control is treated as a core component of MRI safety culture rather than a secondary facility concern.

Overall, this review demonstrates that moisture level is a modifiable environmental factor with substantial technical and clinical impact. Effective humidity control protects equipment integrity, preserves image quality, enhances patient comfort, and reduces safety risks. Recognizing and addressing this factor through evidence-based guidelines, continuous monitoring, and targeted research represents an important opportunity to improve MRI reliability and patient-centred care.

Conclusion

Environmental moisture control is a critical yet frequently underestimated factor influencing MRI system performance, image quality, and patient safety. This review demonstrates that deviations from recommended relative humidity ranges can compromise hardware reliability through corrosion and electronic instability, degrade image quality by increasing RF noise and reducing signal-to-noise ratio, and negatively affect patient safety and comfort by promoting condensation, infection risks, electrostatic discharge, and procedural intolerance. These technical and clinical consequences increase the likelihood of repeat examinations, extended scan times, and unplanned system downtime. Collectively, the findings underscore that humidity management should be regarded as an essential component of MRI quality assurance and patient-centred care rather than a purely facility-maintenance concern. Although existing guidelines and manufacturer specifications provide general environmental targets, inconsistencies among recommendations highlight the need for clearer, evidence-based standards tailored specifically to MRI environments. Continued quantitative and multicentre research is therefore required to refine optimal humidity thresholds and support safer, more reliable MRI practice.

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