RADIOLOGIC ARTIFACTS: RECOGNITION, MINIMISATION, AND CLINICAL IMPLICATIONS

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Abstract. Artifacts in radiologic imaging, including CT and MRI, pose significant challenges to diagnostic precision by obscuring or distorting anatomical structures. This review examines major artifact types, such as metal, bone, motion, and beam-hardening artifacts, and discusses the effectiveness of current minimization strategies, including dual-energy CT, iterative reconstruction, and AI-driven models. Key findings suggest that while advanced techniques have improved artifact management, certain artifacts, particularly those caused by metallic implants, continue to compromise image quality. The review underscores the clinical implications of artifacts, which may lead to diagnostic inaccuracies, and calls for ongoing research into advanced correction techniques. By refining artifact reduction technologies, future advancements can help mitigate diagnostic risks, ensuring clearer and more accurate imaging.

Keywords: Radiologic artifacts, Computed tomography (CT), Magnetic resonance imaging (MRI), Artifact minimization, Metal artifacts, Diagnostic accuracy.

Abbreviations

CT - Computed Tomography
MRI - Magnetic Resonance Imaging
MARS - Metal Artifact Reduction Sequence
AI - Artificial Intelligence
CNN - Convolutional Neural Network
SWI - Susceptibility Weighted Imaging
PET - Positron Emission Tomography
SPECT - Single Photon Emission Computed Tomography

INTRODUCTION

Radiologic imaging modalities, including computed tomography (CT), magnetic resonance imaging (MRI), and digital radiography, are fundamental to contemporary diagnostic and therapeutic procedures (Uffmann & Schaefer-Prokop, 2009). However, the quality and interpretive accuracy of these images are frequently compromised by artifacts—unwanted visual features that do not represent true anatomy and may obscure or mimic pathologic findings. Artifacts originate from diverse sources, including patient movement, metallic implants, and inherent limitations of imaging technology, and can significantly impact diagnostic precision if not correctly identified and mitigated (Barrett & Keat, 2004). The clinical implications are substantial, as misinterpretation of artifacts as pathological findings, or failure to recognize relevant anatomic details due to artifacts, can lead to diagnostic inaccuracies, potentially affecting patient outcomes (Dillenseger et al., 2016).

Each imaging modality presents distinct artifact challenges, linked to its technology and clinical applications. For example, metal artifacts—commonly encountered in CT and MRI due to metallic objects like dental fillings, implants, and surgical hardware—arise from complex interactions between the imaging field and dense materials, often producing streaks, signal voids, or geometric distortions (Boas & Fleischmann, 2012). Other prevalent artifacts include beam-hardening effects in CT imaging, where differences in X-ray attenuation between soft tissue and dense structures, such as bone, create dark bands and streaks that can hinder interpretation (Rief et al., 2012). Similarly, MRI is particularly vulnerable to motion artifacts due to patient movement during longer imaging sequences, leading to image blurring and reduced diagnostic accuracy (Kotsenas et al., 2015).

Significant progress has been made in artifact reduction, including the development of advanced algorithms and optimized imaging protocols. Techniques like metal artifact reduction sequences (MARS) for MRI and dual-energy CT algorithms have demonstrated efficacy in minimizing the appearance of metal-induced distortions, while new reconstruction methods continue to enhance image quality by reducing noise and clarifying structures (Hsieh et al., 2004; Schueler et al., 2009). The emergence of artificial intelligence (AI) in radiology has further advanced artifact recognition and reduction. AI-driven models, particularly deep learning algorithms, are showing promise in detecting and mitigating artifacts, potentially allowing radiologists to differentiate artifacts from true pathologies with higher accuracy and efficiency (Zhang et al., 2020).

Despite these technological advances, artifacts remain a challenging issue in radiologic imaging, often requiring a combination of technical solutions and interpretive expertise to manage effectively. Radiologists must remain adept at recognizing artifact types and deploying appropriate reduction strategies to maintain diagnostic integrity (Uffmann & Schaefer-Prokop, 2009). Recent developments in deep learning have expanded the potential for artifact correction, with convolutional neural networks (CNNs) demonstrating effectiveness in reducing artifacts in CT images without sacrificing diagnostic detail (Shan et al., 2019). Moreover, novel metal artifact reduction (MAR) techniques, such as dual-layer detector CT, offer promising results in minimizing artifact interference in scans of patients with implants, enhancing the clarity of soft tissue visualization around metallic objects (Bauer et al., 2021). Recent investigations into the nature and mitigation of radiologic artifacts underscore the importance of modality-specific approaches in artifact management, particularly in complex clinical environments (Gjesteby et al., 2016). For example, advancements in iterative reconstruction algorithms in CT have been shown to decrease the intensity of artifacts arising from high-density materials, thereby improving the diagnostic utility of scans involving metal implants (Matsubara et al., 2020). MRI innovations, such as susceptibility-weighted imaging (SWI), have proven effective in minimizing susceptibility artifacts, especially in regions affected by blood products or air-tissue interfaces, enhancing lesion detectability (Reichenbach & Haacke, 2001). Digital radiography also faces its own unique challenges, with scatter radiation artifacts often being addressed through the integration of anti-scatter grids and digital post-processing techniques (Boone, 2010).

Emerging techniques in ultrasound, although less prone to traditional artifacts associated with CT and MRI, are improving artifact reduction by applying harmonic imaging to decrease reverberation and shadowing artifacts, especially useful in abdominal and vascular imaging (Tranquart et al., 1999). In nuclear medicine, motion correction algorithms have become crucial for addressing motion artifacts, particularly in PET and SPECT scans, where patient movement can drastically alter quantitative measurements (Rahmim & Tang, 2009). Hybrid imaging technologies, such as PET-CT and PET-MRI, benefit from fusion techniques that not only integrate anatomical and functional data but also enhance artifact reduction capabilities through synchronized acquisition protocols (Beyer et al., 2008).

Furthermore, photon-counting CT (PCCT), a novel approach, demonstrates significant reductions in beam-hardening and noise artifacts, showing potential for improved visualization of subtle lesions near high-contrast structures (Rajendran et al., 2021).

This modality-specific refinement in artifact handling highlights the continuous innovation within radiologic imaging, ensuring that artifacts are minimized while enhancing diagnostic accuracy and patient outcomes. This review synthesizes current research on the mechanisms, identification, and clinical implications of radiologic artifacts, with an emphasis on contemporary techniques for their minimization and the interpretive skills essential for clinical practice.

Materials and Methods

This review aims to provide a comprehensive synthesis of current knowledge on radiologic artifacts, with a particular focus on artifact recognition, reduction techniques, and the clinical implications of metal and bone artifacts. The following systematic methodology was applied to ensure a thorough and balanced examination of the existing literature.

Literature Search Strategy

A systematic literature search was performed using three major academic databases: PubMed, IEEE Xplore, and ScienceDirect. Relevant terms were carefully selected, including *radiologic artifacts*, *artifact minimization*, *CT artifacts*, *MRI artifacts*, *metal artifact reduction*, *image quality*, and *diagnostic accuracy*. The search was restricted to studies published between 2000 and 2024 to encompass both recent advancements and seminal work in the field of radiologic artifacts.

Inclusion and Exclusion Criteria

To ensure clinical relevance, only peer-reviewed studies were considered, specifically those focusing on:

1. Types and etiologies of artifacts in CT, MRI, and digital radiography.
2. Clinical strategies and technological solutions for artifact reduction.
3. The impact of artifacts on diagnostic accuracy and patient outcomes.

Studies lacking a primary clinical focus, those published in non-peer-reviewed formats (e.g., editorials, letters to the editor), and those exploring artifacts in non-human or experimental models not aligned with standard clinical practice were excluded from this review.

Data Extraction and Synthesis

Key information from each selected study was extracted systematically, including study objectives, methodologies, findings, and conclusions. Emphasis was placed on:

- The classification and origin of artifacts specific to each imaging modality.

- Techniques employed for artifact reduction, particularly in clinical applications.
- Clinical relevance of artifacts, with specific attention to their potential impact on diagnostic accuracy and subsequent patient management.

Extracted data were then organized and synthesized thematically, allowing for a cohesive narrative on current practices, challenges, and technological advancements in the management of radiologic artifacts (Table 1).

Quality Assessment

To ensure the reliability of this review's findings, each study was evaluated for methodological rigor, sample size, and clinical applicability. Studies demonstrating high methodological quality and direct relevance to clinical radiology were prioritized, reinforcing the credibility and depth of the synthesized findings.

Types of Radiologic Artifacts

Radiologic artifacts encompass various unintended features that can obscure, distort, or mimic anatomical structures, potentially impacting diagnostic accuracy. These artifacts arise from diverse sources and are specific to imaging modalities such as CT, MRI, and digital radiography.

Metal Artifacts

Metal artifacts are among the most prevalent and challenging artifacts encountered in CT and MRI. These artifacts often result from metallic objects like implants, dental fillings, or surgical hardware, which interact with the imaging field to produce streaks, signal voids, or geometric distortions. In CT, metal artifacts arise from beam hardening and photon starvation effects due to high-density metals absorbing and scattering X-rays unevenly, leading to image distortion (Kalra et al., 2012). In MRI, they occur due to magnetic susceptibility differences between metal and surrounding tissues, often creating voids or distortions (Lu et al., 2019). Techniques such as metal artifact reduction sequences (MARS) and dual-energy CT are commonly applied to mitigate these effects, although challenges persist, especially with larger metal implants (Sureshbabu & Mawlawi, 2005), (Fig.1.A).

Bone Artifacts

Bone artifacts are notably significant in CT imaging, where dense structures like bone lead to beam hardening, which causes selective absorption of low-energy X-ray photons. This process results in dark bands or streaks near dense bony regions, which can complicate diagnostic interpretation by obscuring adjacent soft tissue structures (Alessio et al., 2010). Beam hardening correction algorithms and iterative reconstruction techniques are employed to manage these artifacts by balancing the attenuation profile across the scanned region, thus improving soft tissue visibility around dense bones (Wu et al., 2021), (Fig.1.D).

Motion Artifacts

Motion artifacts present a considerable challenge in both CT and MRI imaging, especially in cases where patients have difficulty remaining still due to discomfort or extended scan times. These artifacts appear as blurring or ghosting of structures and are particularly problematic in MRI due to the long acquisition times required (King et al., 2013). In CT, rapid imaging sequences reduce motion artifacts; however, involuntary movements, such as those caused by respiratory or cardiac motions, can still introduce artifacts. Motion correction methods, including faster acquisition sequences and motion detection algorithms, are used to address this issue, with navigator echo-based methods showing promise in reducing artifact prevalence (Budde et al., 2020), (Fig.1.E).

Beam Hardening Artifacts

Beam hardening is a common artifact in CT imaging, where dense materials such as bone selectively absorb lower-energy photons. This selective absorption results in an imbalance in the X-ray beam, causing dark streaks or “cupping” effects, especially around dense structures like the skull base and spine (Kachelrieß et al., 2006). Techniques to minimize beam hardening include filtration to “harden” the X-ray beam before passing through dense objects, as well as advanced iterative reconstruction algorithms that account for differential attenuation (Gu et al., 2019), (Fig.1.B).

Partial Volume Artifacts

Partial volume artifacts occur when a single voxel contains multiple tissue types, causing an averaging effect that can obscure or distort small structures. This artifact is particularly common in CT, where low-resolution settings exacerbate the blurring of fine anatomical features (Feng et al., 2013). Strategies to minimize partial volume effects include using thinner slice thickness and high-resolution imaging protocols, which improve detail but may increase noise and require longer scan times (Qin et al., 2019), (Fig.1.C).

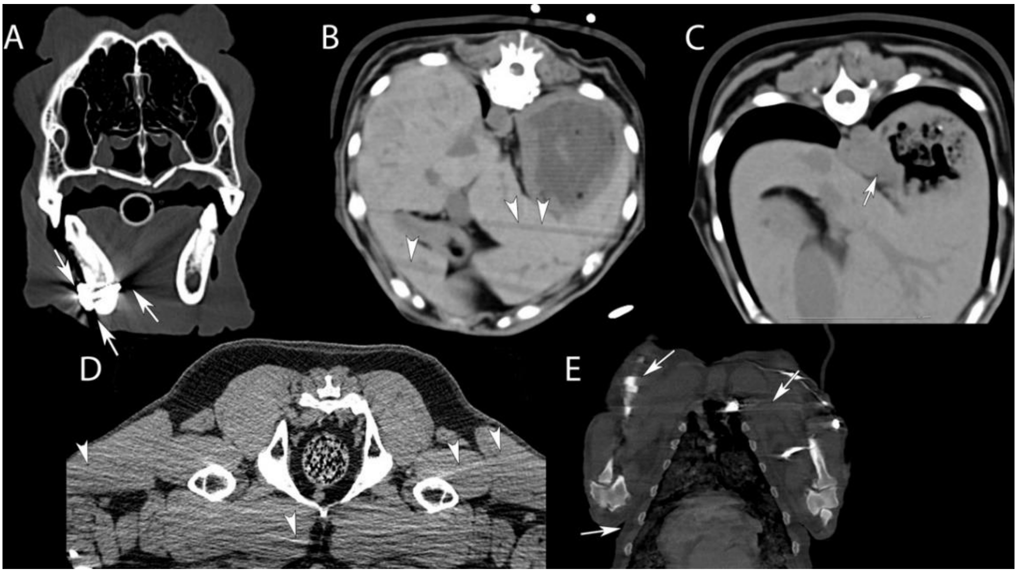

Figure 1. Common artifacts observed in CT images, original images (from the database of the radiology discipline, Faculty of Veterinary Medicine, USAMV Cluj). A - Metallic artifact caused by a bone screw blurring and distortion the adjacent structures (whitre arrows), B – Beam hardening artifact seen as dark bands caused by iodinated contrast (arrowheads), C - Volume portion artifact showing a less defined gastric wall (white arrow), D - Bone artifact causing beam hardening artifact (arrowheads) and E - Motion artifact showing blurred and less sharp structures in the direction of the motion (white arrows)

Table 1. Summary of Radiologic Artifacts, Causes, and Minimization Techniques

Artifact Type	Causes	Imaging Modalities Affected	Appearance	Common Minimization Techniques
Metal Artifacts	Interaction of dense metals with imaging fields	CT, MRI	Streaks, signal voids, geometric distortions	Dual-energy CT, MARS, iterative reconstruction
Bone Artifacts	Beam hardening due to high X-ray absorption by dense bone	CT	Dark bands or streaks around bony structures	Beam-hardening correction algorithms, iterative reconstruction
Motion Artifacts	Patient movement, physiological motion (e.g., heartbeats)	MRI, CT	Blurring, ghosting of structures	Faster acquisition sequences, motion correction algorithms
Beam Hardening Artifacts	Selective absorption of low-energy photons by dense materials	CT	Dark streaks, “cupping” effects	Filtration, dual-energy CT, iterative reconstruction
Partial Volume Artifacts	Multiple tissue types within a single voxel	CT, MRI	Blurring, averaging of tissues	Reduced slice thickness, high-resolution protocols

RESULTS AND DISCUSSIONS

Overview of Artifact Types and Their Characteristics

Radiologic artifacts present a substantial challenge across imaging modalities, each type uniquely impacting image quality and diagnostic interpretation. Metal artifacts, primarily associated with CT and MRI, lead to severe image distortions that obscure critical anatomical details, often requiring advanced techniques like dual-energy CT and metal artifact reduction sequences to mitigate (Kalra et al., 2012; Lu et al., 2019). Bone artifacts, frequently resulting from beam hardening, create dark bands that obscure surrounding soft tissue, particularly in CT imaging (Alessio et al., 2010). Meanwhile, motion artifacts continue to impact MRI and CT, where patient or physiological movement causes blurring, emphasizing the need for faster acquisition techniques and motion correction algorithms (King et al., 2013).

Effectiveness of Artifact Minimization Techniques

Over the past decade, significant advancements have been made in artifact reduction techniques, enhancing diagnostic accuracy. Dual-energy CT and iterative reconstruction algorithms are particularly effective in reducing beam-hardening and metal artifacts, as they provide greater flexibility in adjusting attenuation for dense structures (Gu et al., 2019). Studies on motion artifacts have demonstrated that using navigator echo sequences and prospective motion correction can improve image clarity and reduce diagnostic errors caused by blurring in MRI scans (Budde et al., 2020). Despite these advancements, the complete elimination of artifacts, especially with larger or highly dense metallic implants, remains challenging (Sureshbabu & Mawlawi, 2005).

Clinical Implications of Artifacts

Artifacts can significantly compromise clinical outcomes by obscuring pathologies or creating false-positive findings. In CT, metal artifacts may mask critical areas around orthopedic implants, potentially leading to missed diagnoses of infections or fractures (Kachelrieß et al., 2006). Motion artifacts in MRI, particularly in neuroimaging, may impair the assessment of neurological conditions, which can delay timely interventions (Liang, 2024). Thus, understanding the types and impacts of artifacts allows clinicians to better evaluate image reliability and adjust diagnostic protocols as necessary.

Advances in Technology and Future Directions

The rise of artificial intelligence (AI) and machine learning has opened new avenues for artifact recognition and minimization. Deep learning models are proving capable of identifying and correcting artifacts in real-time, offering a potential solution for rapid artifact reduction during imaging procedures (Feng et al., 2013). In particular, convolutional neural networks (CNNs) have shown promise in reducing metal artifacts in CT by using pre-trained models to correct distortion patterns, yielding clearer images for radiologic interpretation (Zhang et al., 2023).

Future research should focus on refining AI-driven artifact correction models and expanding their application across diverse clinical scenarios. Additionally, advancements in hardware, such as MRI coils designed to reduce susceptibility differences, could further enhance artifact reduction in challenging cases, particularly for patients with metallic implants (O’Reilly, 2024). Continued innovation in this field will likely reduce diagnostic uncertainties and improve patient outcomes by providing clearer, artifact-free imaging.

Limitations in Current Artifact Management

Despite technological progress, artifact management still faces limitations, particularly in imaging patients with large or numerous metallic implants. Existing techniques such as MARS and dual-energy CT often cannot fully eliminate metal artifacts and may require further refinement to improve consistency across different imaging environments (Wu et al., 2021). Additionally, AI models, while promising, need to be rigorously tested across diverse patient populations to ensure accuracy and reliability before widespread clinical application (Kalra et al., 2012).

CONCLUSIONS

Radiologic artifacts remain a significant challenge in medical imaging, impacting diagnostic accuracy and patient care. This review has outlined key artifact types, including metal, bone, motion, and beam-hardening artifacts, and evaluated current methods for artifact minimization, such as dual-energy CT and iterative reconstruction. Although these techniques have advanced artifact management, complete elimination remains challenging, particularly in cases involving dense or numerous metallic implants. Ongoing research and technological improvements are essential to optimize artifact reduction strategies. Enhanced solutions will support more reliable imaging and better diagnostic outcomes in diverse clinical settings.

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