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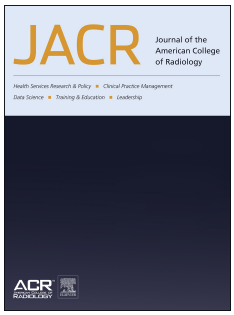

Incidence of Adverse Events Related to Ballistic Fragments in Patients Undergoing MRI at a Large Urban Health System: Implications for MR Safety Screening

Paul M. Armenta, MD, Adam Siegel, MD, Russel R. Fullerton, MD, Renee Segarra, MRI, Technical Director, Judah Burns, MD, FACR, Vice Chair for Education and Director, Diagnostic Radiology Residency Program, Michael L. Lipton, MD PhD FACR

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Paul M Armenta MD
Department of Radiology, Montefiore Medical Center, Bronx, NY
Twitter - @paulmarmenta
Role: acquisition, analysis and interpretation of data; drafting manuscript; final approval of the submitted manuscript; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Adam Siegel MD
Department of Radiology, Weill Cornell Medicine, New York, NY
Role: acquisition, analysis and interpretation of data; drafting manuscript; final approval of the submitted manuscript; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Russel R Fullerton MD
Department of Radiology, Beth Israel Deaconess Hospital, Needham, MA
Role: acquisition, analysis and interpretation of data; drafting manuscript; final approval of the submitted manuscript; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Renee Segarra, MRI Technical Director
Department of Radiology, Montefiore Medical Center, Bronx, NY
Role: acquisition, analysis and interpretation of data; drafting manuscript; final approval of the submitted manuscript; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Judah Burns MD, FACR
Vice Chair for Education and Director, Diagnostic Radiology Residency Program
Department of Radiology, Montefiore Medical Center, Bronx, NY
Twitter - @JudahBurnsMD
Role: interpretation of data; critically revising manuscript; final approval of the submitted manuscript; Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Michael L Lipton MD PhD FACR
Department of Radiology, Columbia University Irving Medical Center
Department of Biomedical Engineering, Columbia University
530 West 166th Street
New York, NY 10032
mll2219@cumc.columbia.edu
718-305-2800
Role: Conceived and designed the study; supervised collection and analysis of data; interpretation of data; critical review and revision of the manuscript; Accountable for all aspects of the work and will ensure questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

The author(s) declare(s) that they had full access to all of the data in this study and the author(s) take(s) complete responsibility for the integrity of the data and the accuracy of the data analysis.

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Incidence of Adverse Events Related to Ballistic Fragments in Patients Undergoing MRI at a Large Urban Health System

Background: Patients with retained ballistic fragments commonly require MRI. Very few studies have reported MRI-related adverse events in patients with retained bullet and/or shrapnel fragments. Current American College of Radiology (ACR) recommendations suggest caution when scanning patients with retained fragments, but offer limited concrete guidance to assist MRI personnel with safety determinations.

Purpose: To assess the incidence of retained bullet/shrapnel fragments undergoing MRI and of associated adverse events, in the context of an existing screening policy.

Material and Methods: The Montage search feature of the PS360 reporting system for radiological examinations was used to identify, for the years 2010-2023, all patients who underwent radiographic examinations demonstrating retained bullet or shrapnel fragments, who underwent a subsequent MRI examination. Medical record review was used to assess the occurrence of adverse events related to the MRI examination.

Results: 220 patients with evidence of a retained bullet or shrapnel fragment who underwent subsequent MRI were identified from 6,143 positive radiographs. 4 of 220 patients (1.8%) reported transient localized burning or discomfort during the MRI examination. In each of the four patients, the retained bullet/shrapnel fragments were in the superficial soft tissues. No medical treatment was required, and no serious adverse events or persistent symptoms were reported.

Conclusion: There is a low incidence of adverse events in patients with known bullet or shrapnel fragments undergoing MRI in the context of the local screening policy. An effective screening paradigm likely plays a role in minimizing adverse events.

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Description of the Problem

Patients reporting prior gunshot or shrapnel injury at the time of MR safety screening present a particular challenge due to uncertainty regarding foreign body composition, location, and lack of guidance on whether MRI can proceed safely in a specific scenario. Fragment composition is typically not known at the time of MRI screening. However, any metallic object may undergo heating on exposure to the time-varying radiofrequency magnetic fields that are active during scanning, with potential for thermal injury. Ferromagnetic components of a retained fragment, if present, could lead to mechanical injury if significantly displaced by the main MRI magnetic field. The 2023 ACR MR safety guidelines cover general safety concepts regarding fragment size, time from injury, and anatomic location without offering specific recommendations on how to proceed in individual cases. [1,2]

Common practice in the United States is to ascertain the location of any retained fragments by performing screening radiography of patients with potential retained bullet or shrapnel fragments. [2,3] Safety is then determined based on the proximity of fragments to "sensitive tissues". [1] However, specific criteria for determination of safety based on fragment location have not been defined by a clinical study.

What We Did

We implemented a standardized policy across a tertiary urban health system comprising multiple hospitals and outpatient imaging facilities. Patients who report prior bullet or shrapnel injury or who have evidence of a bullet or shrapnel fragment on review of prior imaging studies at the time of MRI safety screening are assessed to determine if a fragment is located within a solid organ or within 5 mm of a 3rd order or more proximal branch/tributary of the aorta/vena cava. (see Figure S1 in the Supplemental Material online) These criteria were chosen to minimize potential thermal injury or mechanical force harm to critical structures. The purpose of this retrospective study is to report the incidence of adverse events during MRI that are attributable to a retained bullet or shrapnel fragments in patients subject to this screening policy over a thirteen-year period.

This study was performed with the approval of the Albert Einstein College of Medicine Institutional Review Board (IRB), which also approved a waiver of informed consent. The study complied fully with HIPAA.

The Montage search feature of the PS360 reporting system (Nuance Communications, Inc.; Burlington, MA) for radiological examinations was used to identify, for years 2010-2023, all patients who underwent radiographic examinations demonstrating retained bullet or shrapnel fragments, who underwent MRI after the radiographic examination. All radiograph reports for 7/1/2010 through 6/28/2023 containing the terms "bullet" or "shrapnel" were retrieved, excluding reports with "no bullet" or "no shrapnel". A second search was performed to identify MRI reports within the same date range. Using a sequential query function, a sequential search was performed which included patients who had a radiograph report with the term "bullet" or "shrapnel" who underwent MRI after the radiograph demonstrating the fragment.

Once the study group was identified, each radiographs was visually inspected by a board-certified radiologist (MLL, RF) to confirm the presence of at least one retained bullet or shrapnel fragment. The location of the bullet or shrapnel fragment, the body part imaged during MRI, field strength, scanner manufacturer, and whether subsequent MRI examinations were performed were recorded. The medical record and hospital event reporting system were reviewed for indication of an adverse event during MRI. Adverse events were defined as localized pain or abnormal sensation reported by the patient at the time of the exam.

Outcomes

A total of 6,143 radiograph reports contained the terms "bullet" or "shrapnel". During the same period, 415,364 MRI examinations were performed. The sequential search identified 284 patients who underwent MRI following the finding of a bullet or shrapnel fragment by radiography. Visual inspection of the radiographs determined that 64 patients captured by the search did not in fact have a visible bullet or shrapnel fragment. These individuals were excluded, leaving 220 patients with a radiographically confirmed bullet or shrapnel fragment who underwent subsequent MRI.

187 of 220 patients were men (85%). The average age was 58.3 years (range 19-90 years). The number and location of fragments and the MRI field strength for each exam is shown in Table 1. The MRI examinations were performed on GE (3.0T). Phillips (1.0T, 1.5T or 3.0T) or Siemens (3.0T) scanners. In 22 cases, the fragment was included within the MRI field of view.

Table 1: Sample Characteristics

Characteristic	**Frequency (n = 220)**
Sex	
Men	85.0% (187)
Women	15.0% (33)
Race	
Black	50.0% (110)
White	9.1% (20)
Asian	0.9% (2)
Mixed Race	0.9% (2)
Other	33.2% (73)
Decline to Respond	4.1% (9)
No Response Recorded	1.8% (4)
Ethnicity	
Non-Hispanic	55.0% (121)
Hispanic	36.8% (81)
Decline to Respond	4.1% (9)
No Response Recorded	4.1% (9)
Location of Fragments	
Extremities	53.6% (118)
Chest wall	20.0% (44)

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Abdomen/Pelvis	16.4% (36)
Head and Neck	5.0% (11)
Spine	4.5% (10)
Thorax	0.5% (1)
MRI Field Strength (Tesla)	
1.0	6.4% (14)
1.5	60.9% (134)
3.0	32.7% (72)
Body Region Examined	
Brain	25.9% (57)
Spine	25.0% (55)
Extremities	25.0% (55)
Abdomen	14.5% (32)
Pelvis	8.2% (18)
Heart	0.9% (2)
Neck	0.5% (1)

Four of 220 patients (1.8%) experienced symptoms during the MRI examination. Three had bullet fragments within the superficial soft tissues of the upper torso and one within the thigh. None of the symptomatic exams included the bullet within the MRI field of view. Two of four patients experiencing symptoms underwent MRI at 1.5 T and two at 3.0 T. Each MRI examination was terminated early due to with symptoms of, burning in 3 patients and discomfort in 1 patient (Figures 1 and 2). Repeated MRI at the same field strength in two patients was not associated with adverse symptoms (Figure 3). No serious injury occurred, and no follow-up care was required for MRI-related symptoms. The adverse event rate for patients undergoing MRI with a retained bullet fragment was 1.8% over 13 years. All adverse events occurred in patients with bullet fragments within the superficial soft tissues. The events comprised mild symptoms and none led to adverse effects that persisted after the time of scanning or required additional medical care.

Only a single report on MRI safety in a patient cohort with retained shrapnel fragments has been published. Eshed, et al. (2013) reported a retrospective study of 17 patients with shrapnel fragments from combat and terrorist explosion-related injuries, out of 10,322 who underwent 1.5 Tesla MRI.[4] Each patient who reported retained metal fragments and underwent MRI was contacted regarding adverse effects related to MRI. In one patient, a subcutaneous fragment migrated during MRI, without further injury. Risk associated with 3.0 Tesla MRI might be higher but remains unreported.

Time-varying magnetic fields disproportionately induce current and resistive heating in conductive materials, ferromagnetic or not. [5] However, ex vivo testing up to 7T has demonstrated minimal heating of bullets, and the ACR Manual on MRI Safety states: “If the metallic object is less than 2cm heating should not be an issue.”[1] In vitro testing shows torque of ferromagnetic bullets in MRI, which remains untested in human tissue. Ex-vivo testing of common projectiles predicted ferromagnetism based on CT and radiography, which has not been examined in a clinical study. [6]

Fragments within extremities, located distant from isocenter where gradient magnetic field amplitude and rate of change are greatest, may be more susceptible to adverse sensations.[7] We expected more adverse events at higher field strength because radiofrequency power increases with field strength, and the proportion at 3.0T (2/72) was greater than 1.5T (2/134), but the small number precludes conclusions regarding field strength. Notably, all scanners are required to operate within the same Food and Drug Administration RF power limits.

Institutional screening protocol required screening radiographs, or prior radiographic studies, for any patient who reported a prior gunshot or shrapnel wound. Subsequently, a radiologist reviewed the images that showed the fragment(s) to identify fragments embedded within a solid organ or within 5 mm of a tertiary or more proximal branch/tributary of the aorta/vena cava. Patients with fragments in these locations were excluded from MRI. In cases where the reviewing radiologist cannot confirm fragment position from prior radiographs, additional radiographs in oblique projections or non-contrast CT would be obtained. Prior to this protocol, radiologists at our institution would refer to the ACR MR Safe Practice Guidelines for guidance. Our screening protocol is more specific than ACR guidelines and is rooted in the anatomic position of the ballistic fragments. The protocol remains compatible with thermal and magnetic characteristics that have been described in ex-vivo safety testing. Although we encountered adverse events only related to superficially located fragments, this does not indicate that deeper locations would not cause adverse events, as fragments in these locations were excluded from MRI.

Although this study reports the largest sample to date of patients with embedded bullet and shrapnel fragments undergoing MRI, the main limitation of our work remains its relatively small sample size, and low frequency of adverse events. Due to the rigorous MR safety screening process in use, patients with bullets in high-risk locations such as solid organs would be excluded from MRI, lowering the adverse event rate. Determining the contribution to patient safety achieved by our protocol would require replication at additional centers. Additional limitations include the retrospective determination of adverse events based on the medical record and institutional safety reporting systems. This may have led to false negatives. However, institutionally mandated reporting of thermal injury events during the study period makes this less likely.

In conclusion, bullet fragments located within soft tissues, at least 5 mm from major neurovascular structures or solid organs are unlikely to lead to a clinically significant adverse event. In the case of an adverse event, if the examination is terminated when symptoms are first reported, significant or persistent symptoms or injury are unlikely. In addition to excluding potentially high-risk patients from MRI, identifying all patients with embedded bullet or shrapnel fragments offers the opportunity to focus patient monitoring during MRI, to detect symptoms early and terminate scanning to minimize chance of injury. In our practice, having a specific institutional screening protocol in place for ballistic fragments has been effective in maintaining and monitoring a safe and consistent MRI service.

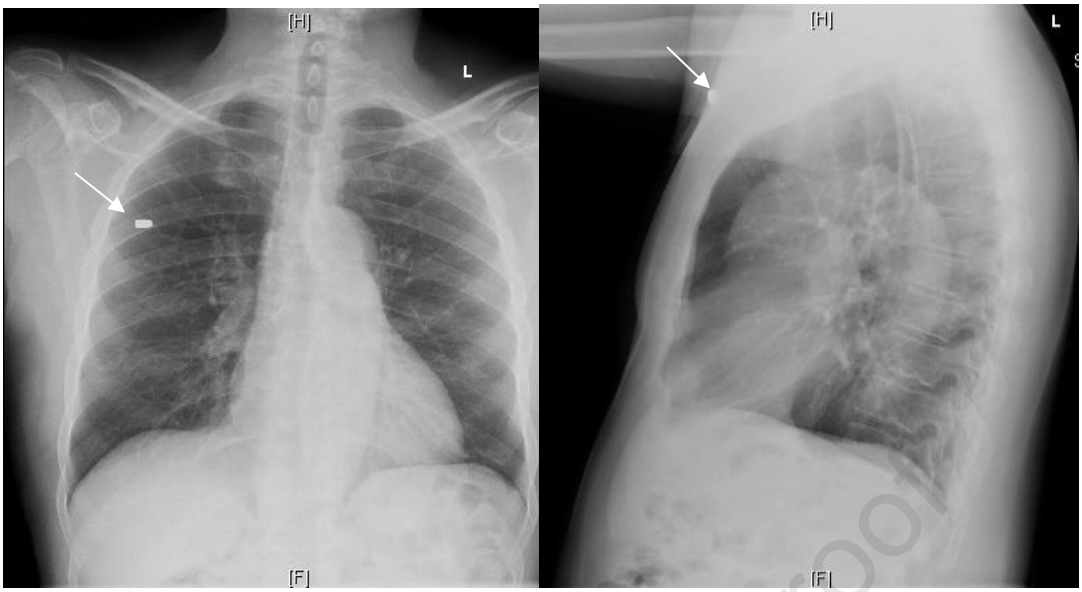

Figure 1: 72-year-old man referred for prostate MRI. Frontal and lateral chest radiographs were obtained due to history of gunshot wound to the thorax. A bullet fragment was identified in the anterior subcutaneous tissue of the chest wall on the right (white arrows). Prostate MR was initiated at field strength of 3.0 T, but was terminated when the patient reported localized burning over the site of the bullet fragment during the acquisition of localizer images. No persistent adverse effect occurred.

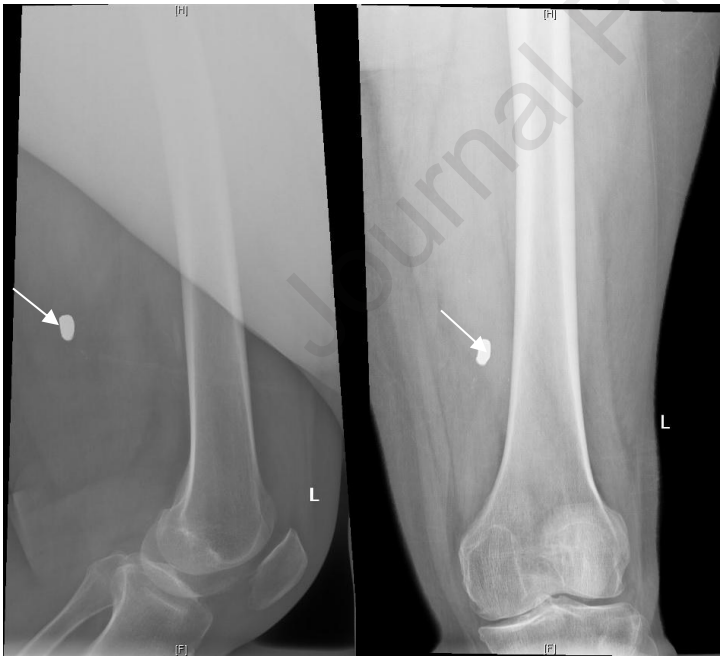

Figure 2: 56-year-old man referred for spine MRI. Frontal and lateral radiographs of the left femur were obtained due to history of gunshot wound to the left leg. A bullet fragment was identified in the soft tissue of the left thigh (white arrows). Spine MRI was performed at field strength of 3.0 T and terminated early due to the patient's report of warming in the region of the bullet. The later underwent spine MRI at 3.0 T without any adverse sensation.

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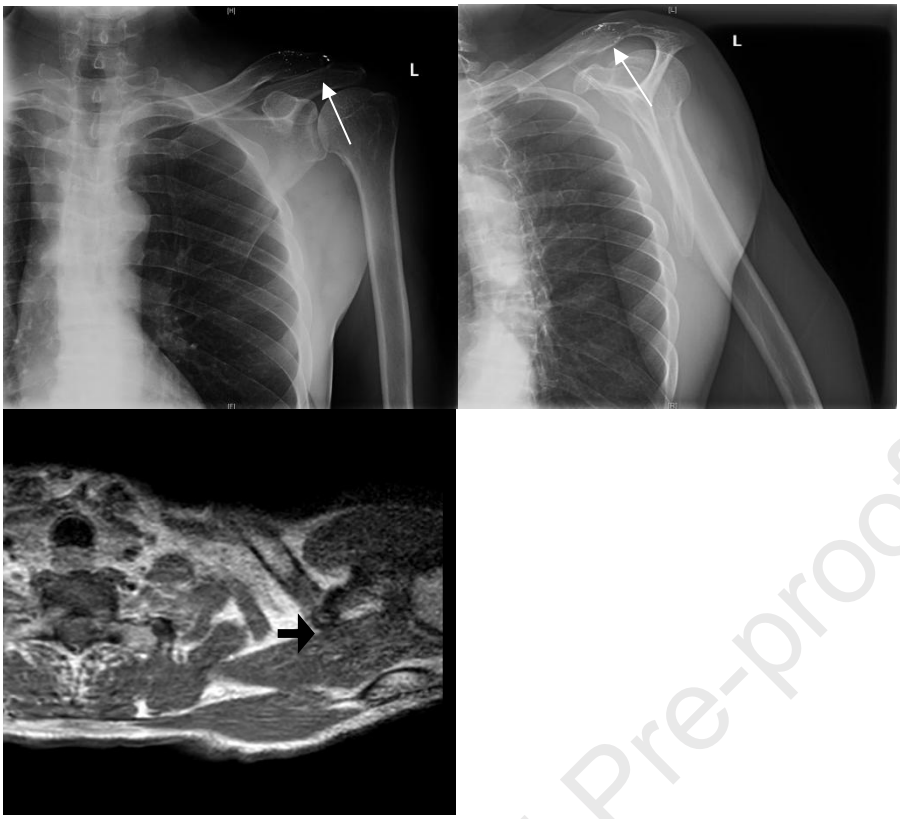

Figure 3: 59-year-old man referred for lumbar spine MRI. Frontal and oblique radiographs of the left clavicle were obtained due to a history of a gunshot wound. Multiple tiny metallic fragments project over the distal end of the left clavicle (white arrows). Lumbar spine MRI was initiated at 1.5 T. The examination was terminated early when the patient reported localized burning superficial to the site of the bullet fragments. This patient underwent subsequent cervical spine MR at 1.5 T without adverse event. Minimal magnetic susceptibility-related signal loss and distortion is present on the T1-weighted image in the region of the chronic left clavicular fracture (black arrow).

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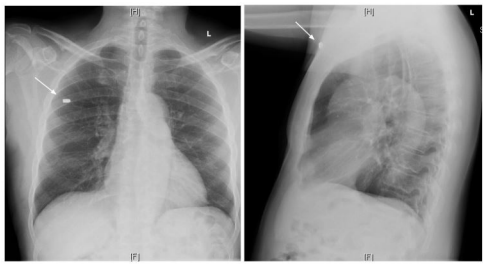

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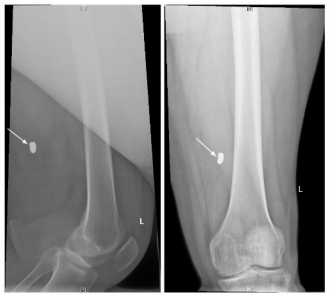

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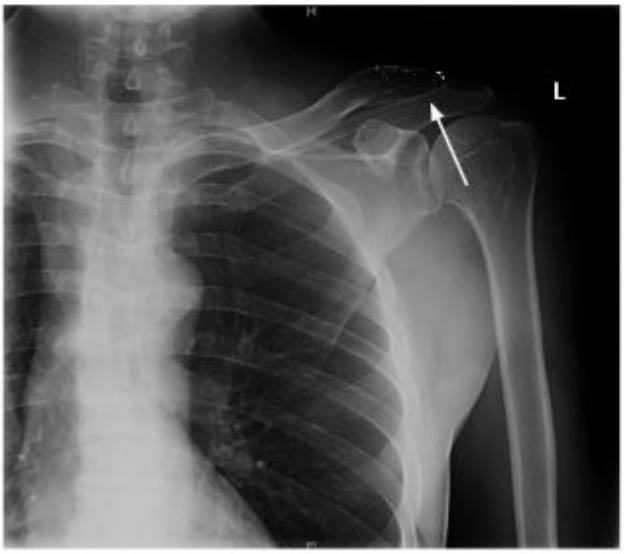
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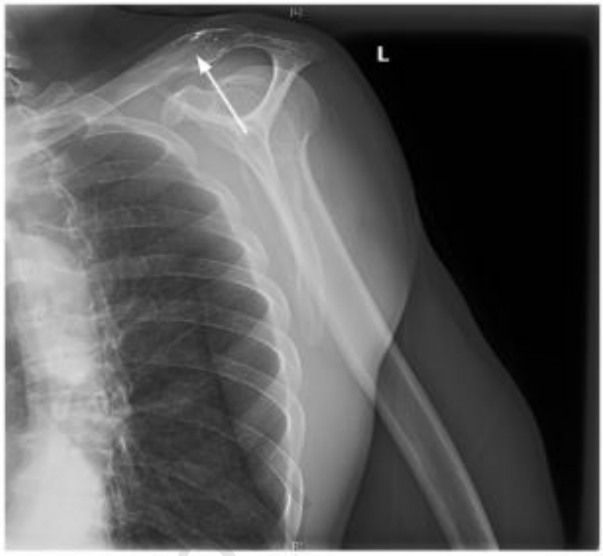
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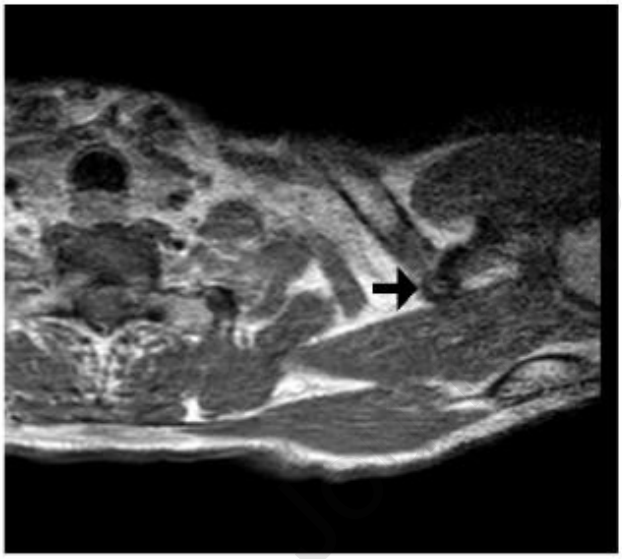

Bullet fragments located at least 5 mm from major neurovascular structures or solid organs, are unlikely to lead to a clinically significant adverse event.

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1. Use of a screening algorithm incorporating explicit actionable criteria facilitates assessment of patients with embedded bullet or shrapnel fragments who require MRI.
2. Fragments at least 5mm from major neurovascular structures or solid organs are not likely to lead to adverse events.
3. Screening based on the criteria presented can mitigate uncertainty and delays in obtaining MRI while maintaining patient safety.

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