Abdominal Radiology

Published online: 1 November 2018

Abdom Radiol (2019) 44:1567–1574
https://doi.org/10.1007/s00261-018-1818-3

Orthopedic metallic hardware in routine abdomino-pelvic CT scans: occurrence and clinical significance

Vinit Baliyan,[1] Hamed Kordbacheh,[1] Amir H. Davarpanah,[2] Amirhossein Mozafarry,[3] Dushyant V. Sahani,[1] and Avinash Kambadakone[1]

[1]Department of Radiology, Massachusetts General Hospital, 55 Fruit Street, White 270, Boston, MA 02114, USA
[2]Department of Radiology and Imaging Sciences, Emory University Hospital, Emory University School of Medicine, Atlanta, GA 30322, USA
[3]Department of Radiology, Northwestern Memorial Hospital, Northwestern University - Feinberg School of Medicine, Chicago, IL 60611, USA

Abstract

Purpose: To study the occurrence of orthopedic metallic hardware in routine abdomen/pelvic computed tomography (CT) scans and their impact on image quality (IQ) and diagnostic evaluation.
Material and methods: In this retrospective single institution study, we analyzed 3500 consecutive abdomen/pelvis CT scans for occurrence of orthopedic metallic hardware. In the cohort of patients with metallic hardware detected on CT scans, subjective and objective IQ analysis was performed to estimate diagnostic acceptability (DA, 4-point scale), subjective noise (SN, 3-point scale), presence of artifacts (PA, 4-point scale) and objective noise. The clinical significance of metallic hardware was determined by evaluating the impact of artifacts on radiological diagnosis according to the clinical indication and disease type.
Results: Orthopedic metallic hardware was encountered in 4.97% of abdomino-pelvic CT scans ($n = 174/3500$), and artifacts related to the hardware in the region of clinical interest were identified in 82% ($n = 144/174$) of scans. The overall mean DA was 2.66 ($n = 174$), and it was severely limited (score < 2) in 32% of cases particularly affecting patients with bilateral hip implants (92.6%, $n = 25/27$). The artifacts due to hardware significantly limited diagnostic evaluation in 58.6% of cases (PA score ≥ 3), and the image noise was unacceptable in 71% of cases (SN score > 2) in the region of clinical interest.
Conclusion: Orthopedic metallic hardware is encountered in nearly 5% of abdomino-pelvic CT scans and causes significant image degradation limiting diagnostic evaluation in the region of clinical interest.

Key words: Computed tomography—Orthopedic metallic hardware—Artifacts

Aging US population has led to rising prevalence of orthopedic metallic hardware, and nearly 2.5 million individuals in the USA have hip implants (0.83% of the population) [1]. The incidence of joint replacement procedures is soaring, with over 1 million total hip and total knee replacement procedures performed each year in the USA, and it is projected that the number of hip replacement procedures will swell to more than double by 2030 [1, 2]. Similarly there has also been a growing use of lumbar spine instrumentation in various clinical settings, including degenerative disk disease, spondylolisthesis, tumors, infection and trauma [3, 4]. Computed tomography (CT) is integral in the management of a wide spectrum of clinical conditions ranging from acute abdomen, trauma, vascular diseases to oncology due to its easy availability, rapid acquisition time and excellent image quality (IQ) [5–11]. Artifacts from metallic orthopedic hardware (specially hip prostheses and spinal implants) are frequently encountered in abdomino-pelvic CT scans performed in the elderly for oncologic indications and vascular abnormalities [12–17]. Metal-related artifacts on CT scans limit IQ and are generally seen in the form of streaks around the implants, their severity being determined by the composition, shape and orientation of the metallic hardware [18–21]. These artifacts occur as a consequence of incomplete projection data

Correspondence to: Avinash Kambadakone; *email:* akambadakone@mgh.harvard.edu

due to beam hardening, partial volume averaging and severe attenuation of the X-ray beam [19]. Dense metal alloys such as cobalt–chrome and stainless steel generate more severe artifacts compared to less dense metals such as titanium. Bulkier hardware such as hip implants with femoral head and stem components produces more severe artifacts than smaller hardware such as plates or screws [18–21]. Furthermore, these patients are not suitable candidates for MRI, given the concerns of image degradation due to artifacts related to magnetic susceptibility caused by the metallic implants [12, 14].

Standard techniques, such as high tube voltage/current and thinner collimation, help partially mitigate the impact of metal artifacts. In addition, several advanced metal artifact reduction (MAR) techniques, such as monoenergetic dual-energy CT (DECT) and sinogram inpainting software, are available on modern multi-detector CT (MDCT) scanners which enable optimal diagnosis in the presence of metal artifacts [22–27]. However, these techniques are not widely available and have not been adequately incorporated into the routine clinical work flow even on scanners capable of MAR [12]. One of the impediments to the successful implementation of MAR remains the lack of literature on the prevalence of clinically significant metallic hardware in routine practice and their real clinical impact on IQ and diagnostic accuracy. Determining the clinical significance of these artifacts is crucial in emphasizing the need for application of these strategies in routine practice. Therefore, we undertook this study to assess the occurrence of orthopedic metallic hardware and their impact on IQ in CT of abdomen/pelvis and therefore understand the magnitude of this problem in routine practice.

Material and methods

Patient selection

This study was approved by the Institution Review Board and Health Insurance Portability and Accountability Act compliant. We performed a search of the radiology database through the hospital picture archiving and communication system (PACS; IMPAX 6.6.1; AGFA Healthcare) to identify consecutive patients who underwent abdomino-pelvic CT scans during a 1-month period between January and February 2016. Our institution has a high-volume busy CT practice with multiple MDCT scanners and this period was considered to provide a representative sample of the overall practice. The inclusion criteria consisted of adults (≥ 18 years old) who underwent routine abdomino-pelvic CT examinations using an institutionally defined protocol. In order to maintain consistency in the type of imaging studies evaluated, we excluded CT scans performed in pediatric patients, intraprocedural CT scans during IR procedures and targeted CT studies such as CT cystogram. The initial application of the inclusion and exclusion criteria resulted in a cohort of 3500 consecutive patients.

An independent observer (HK) then performed a preliminary review of the selected patient cohort (n = 3500 CT scans) on PACS workstation to identify scans with orthopedic metallic hardware (hip prosthesis, spinal implant, femoral screws, proximal femoral nail, bone plates and pelvic external fixator). As this study focused on the investigating the occurrence of orthopedic metal hardware that are likely to cause significant diagnostic limitation and are easily identifiable by technologists on scout images, those CT scans with metallic objects such as surgical clips, endoscopy clips, skin staples and vascular coils were excluded. The preliminary review resulted in 174 CT scans with orthopedic metallic hardware which formed the final cohort for qualitative and quantitative analysis (Fig. 1).

CT imaging technique

Our institution is a quaternary care hospital with multi-vendor CT practice and over 15 MDCT scanners with a wide range of technology including 16-, 64-, 128-slice and DECT scanners. The patients included in the study underwent routine non-contrast or contrast-enhanced abdomino-pelvic CT examinations (single or multiphasic CT scans including angiographic examinations). The routine contrast-enhanced abdomino-pelvic CT examination protocol included single phase (portal venous) or multiphasic (arterial/pancreatic and portal venous) examinations with image acquisition after administration of both oral and intravenous contrast media in accordance with an institutionally defined protocol. Technical parameters included tube voltage of 100–120 kVp, at noise index 17–22, automatic tube current modulation with tube current range between 75 and 450 mA, 5-mm axial slice thickness and 3 mm coronal/sagittal reformatted images. Intravenous iodinated contrast material was injected at a

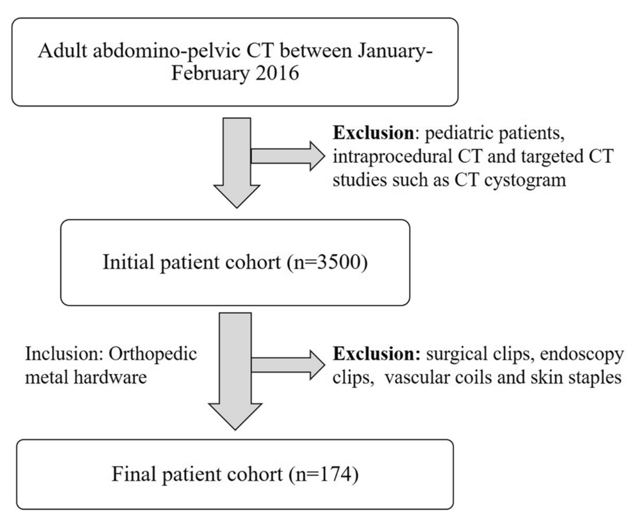

Fig. 1. Flowchart showing patient selection and study population.

rate of 3 mL/s with total volume of contrast based on body weight (80–120 cc). CT angiographic examinations included non-contrast, arterial phase and a 2-min delayed acquisition. Non-gated aortic CT angiography was performed with 120 kVp, pitch of 1–1.5, beam collimation of 0.5–1.0 mm, 1.0 mm axial slice thickness with 0.75 mm inter-slice gap. The contrast was injected at a rate of 3–5 mL/s, and overall contrast volume was proportional to the scan time [injection rate × (scan duration + 5–10 s)]. On the rapid switching DECT scanners, routine abdomino-pelvic CT scans were performed using gemstone imaging mode in the portal venous phase after the administration of oral and intravenous contrast. These examinations were performed at a pitch of 1.375, 64 × 0.625 mm detector collimation and a fixed mA (375 for upto 150 lbs and 630 for 151–250 lbs) with contrast injection rate of 3 mL/s. Monochromatic images at 65 keV generated from the DECT datasets were included for qualitative and quantitative assessment.

Qualitative image analysis

An independent reviewer analyzed the 174 CT datasets to identify the type and location of orthopedic metallic hardware. Qualitative image analysis of the 174 CT datasets was performed by two radiologists (VB and AD each with 3 and 2 years of experience in interpreting abdominal CT scans) on PACS workstation. The readers were aware of the clinical details of the patients, and diagnostic acceptability (DA) assessment was performed after reviewing the clinical indications (Fig. 2). In patients with multiphasic examinations, particular attention was paid to CT series with maximum clinical utility for subjective image analysis, i.e., the portal venous phase or arterial (hepatic/pancreatic) + portal venous phase for routine abdominal CTs (n = 138/174), the arterial + delayed phase for vascular studies (n = 15/174) and non-contrast images (n = 21/174). Qualitative IQ evaluation of CT images for DA, subjective image noise and presence of artifacts (PAs) was performed using European CT quality criteria [28, 29]. A 4-point score was used to grade DA (= fully acceptable, 3 = probably acceptable, 2 = acceptable only under limited conditions, 1 = unacceptable). A 4-point score was used to evaluate presence and clinical impact of artifacts (PA, 4 = artifacts rendering the study diagnostically unacceptable, 3 = major artifacts affecting diagnostic interpretation, 2 = minor artifacts not affecting diagnostic interpretation, 1 = no artifacts). A 3-point score was used for subjective analysis of noise (SN, 3 = excessive noise, 2 = acceptable noise, 1 = too little noise).

Quantitative analysis

An independent observer (HK), who was blinded to the technical scanning parameters performed quantitative evaluation of the image noise by placing circular regions of interest (ROIs) of 25–75 mm^2 area within subcutaneous fat, muscle and within the urinary bladder at the level of metallic objects. These ROIs were placed outside the artifact streaks, to measure the general image noise within the slice at the level of hardware. Similar ROI were placed at the closest adjacent slice that was free from artifacts (control). The standard deviation within the ROI was taken as the image noise for the particular image location. As this study was focused on investigating the impact of orthopedic metallic hardware on IQ and diagnostic evaluation, the radiation dose details of the CT scans in the study cohort were not estimated.

Clinical significance: metallic hardware

In order to assess the clinical significance of metallic hardware, the independent observer recorded any disclaimer made in the original radiology reports regarding

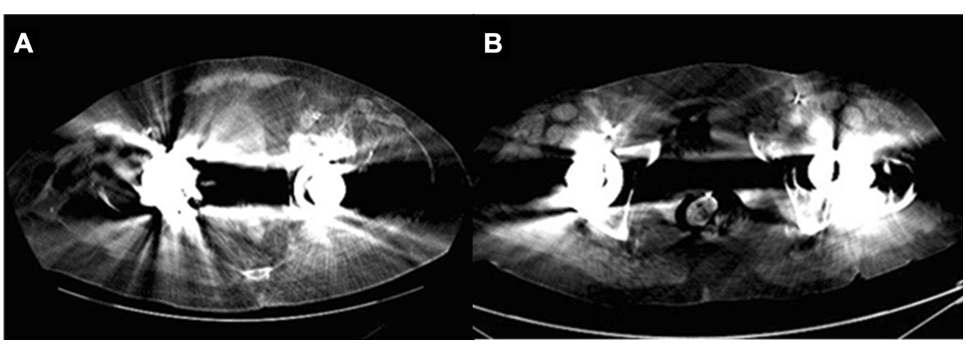

Fig. 2. Image quality degradation due to bilateral metallic hip implants in two different patients. **A** Axial contrast-enhanced CT image in a 82-year-old patient with prostate cancer shows that the artifacts from the B/L hip implants limit evaluation of prostate and internal iliac nodes rendering this study diagnostically unacceptable (DA score 1). **B** Axial contrast-enhanced CT image in a 76-year-old patient with abdominal aortic aneurysm who underwent CT angiogram for evaluation of aorto-iliac vasculature. The artifacts from hip implants limit evaluation of femoral and distal external iliac arteries which are crucial for planning the abdominal aortic aneurysm (AAA) repair (DA score 1).

limitation presented by the hardware in evaluation of sites/disease of clinical interest. During qualitative image analysis by the two readers, the relationship of the metallic artifacts to the critical organs of interest based on clinical indication was reviewed. In patients with vascular and oncologic indications, it was noted whether the artifacts impeded the evaluation of vasculature and primary disease or the sites of potential metastases, respectively. For example, in patients with pelvic malignancies such as bladder or prostate cancer, the evaluation of nodal stations in the pelvis can be extremely important and their assessment can be limited by bilateral hip implants. Similarly, in patients with endovascular repair of aortic aneurysm or with aorto-iliac grafts, the evaluation of aorto-iliac vasculature and femoral vessels is important, and they can be obscured by spinal fixation hardware and hip implants limiting assessment of vascular patency and endoleaks. These factors were taken into account when the readers gave the IQ scores for diagnostic evaluation.

Statistical analysis

The data were recorded using Microsoft Excel 2013 (Microsoft Corporation), and statistical analyses were carried out using the *MedCalc* software version 17.6 (Ostend, Belgium). The average subjective IQ values for DA, PA and SN were estimated from the scores assigned by the two readers. Inter-observer agreement between the two readers was calculated using kappa values (k-value). Inter-observer agreement based on k-values can be interpreted as follows: poor (< 0.20), fair (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80) and very good (0.81–1.00). T-test was used for comparison of objective image noise recorded at different locations. χ^2 Test was used for comparison of qualitative IQ scores for different hardware types. For all comparisons, $p < 0.05$ was considered to indicate a statistically significant difference.

Results

Out of the total 3500 CT scans, orthopedic metallic hardware was encountered in 4.97% (174/3500) CT scans in 174 patients (M:F 99:75, mean age 71 ± 32 years, range 27–89 years, Table 1). The most common metallic hardware encountered was hip prosthesis (unilateral or bilateral) seen in 56.3% (n = 98/174) of scans. The most common clinical indication was oncological (51.7%, n = 90/174) followed by acute abdomen/abdominal pain (31.6%, n = 55/174) and vascular evaluation (8.6%, 15/174). Single or multiphasic contrast-enhanced CT scans accounted for the most common abdomino-pelvic CT examination (79.3%, n = 138/174).

Table 1. Patient demographics and CT details

Patients with metallic hardware	174 (4.97%)
Male/female	99:75
Mean age (years)	71 ± 32
Age range (years)	27–89
CT scan type (n = 174)	
Non-contrast	21 (12.1%)
Single or multiphasic	138 (79.3%)
CT angiograms	15 (8.6%)
Metallic hardware encountered (n = 174)	
Hip prosthesis	98 (56.3%)
(a) Unilateral	71 (40.8%)
(b) Bilateral	27 (15.5%)
Spinal hardware	37 (21.3%)
Femoral screws	36 (20.7%)
Others (iliac plate and pelvic external fixator)	3 (1.7%)
Clinical indications (n = 174)	
Oncologic	90 (51.7%)
Acute abdomen/abdominal pain	55 (31.6%)
Vascular	15 (8.6%)
Trauma	10 (5.7%)
Others	4 (2.2%)

Qualitative image analysis

The mean DA score was 2.66 (k 0.45) and was rated ≤ 2 in 32% of scans (56/174, Table 2). The mean artifact score was 2.89 (range 1.5–4; k 0.63) and was rated ≥ 3 in 58.6% of scans (102/174 patients) with artifacts causing diagnostic unacceptable IQ in 18% of scans (31/174). Mean subjective noise (SN) was 2.56 (range 1.5–3; k 0.44), and it was rated $>$ 2 in 71% of scans (n = 123/174) with a score of 3 in 44% (n = 76/174).

The DA scores were lower for bilateral hip implants (mean DA score 1.37) followed by unilateral hip implants (mean DA score 2.45), spinal hardware (mean DA score 3.54), hip screws with nail (mean DA score 3.6, Table 1; Fig. 3, $p < 0.001$). The mean DA was ≤ 2 (significantly limited or unacceptable) in 92.5% (25/27) of bilateral hip implants, 35.2% (25/71) of unilateral hip implants and 10.8% (4/37) of spinal implants. Scans with hip screws alone did not show any incidence of DA ≤ 2. There was only one case with hip screw with femoral nail where DA was ≤ 2; and it was probably related to the orientation of hardware as the limb was flexed at the hip joint with the nail lying in horizontal plane at the level of pelvis (Table 1). Mean PA score was 3.07 for U/L hip implants, 3.87 for B/L hip implants, 2.58 for spinal implants, 2.11 for hip screws and 2.21 for hip screws with nails ($p < 0.001$, Table 1). The mean subjective analysis of noise score was 2.78 for U/L hip implants, 2.94 for B/L hip implants, 2.33 for spinal implant, 2.02 for hip screws and 2.1 hip screw with nails ($p < 0.001$). Mean image noise was significantly ($p < 0.05$) higher patients with spinal prostheses (27.79 ± 13.4) followed by bilateral hip implants (26.1 ± 10.73) and unilateral implants (23.28 ± 7.06).

Table 2. Image quality scores in CT scans with metallic hardware

Hardware types	Diagnostic acceptability score			Presence of artifacts score			Subjective noise score		
	R1	R2	Mean	R1	R2	Mean	R1	R2	Mean
U/L hip implants (n = 71)	2.36 (1–4) [≤ 2 in 38/71]	2.54 (1–4) [≤ 2 in 32/71]	2.45 (1–3.5) [≤ 2 in 25/71]	2.98 (2–4)	3.15 (2–4)	3.07 (2–4)	2.61 (2–3)	2.94 (2–3)	2.78 (2–3)
B/L hip implants (n = 27)	1.51 (1–2) [≤ 2 in 27/27]	1.22 (1–4) [≤ 2 in 25/27]	1.37 (1–3) [≤ 2 in 25/27]	3.85 (3–4)	3.88 (2–4)	3.87 (2–4)	2.92 (2–3)	2.96 (2–3)	2.94 (2–3)
Spinal implant (n = 37)	2.83 (1–4) [≤ 2 in 7/37]	3.4 (2–4) [≤ 2 in 4/37]	3.12 (1.5–4) [≤ 2 in 4/37]	2.72 (2–4)	2.43 (2–4)	2.58 (2–4)	2.35 (2–3)	2.32 (2–3)	2.33 (2–3)
Hip screws (n = 22)	3.22 (2–4) [≤ 2 in 1/22]	3.86 (3–4) [≤ 2 in 0/22]	3.54 (3–4) [≤ 2 in 0/22]	2.13 (2–3)	2.09 (1–3)	2.11 (1–3)	2 (1–3)	2.04 (1–3)	2.02 (1–3)
Hip screws with nails (n = 14)	3.5 (2–4) [≤ 2 in 1/14]	3.71 (1–4) [≤ 2 in 1/14]	3.6 (1.5–4) [≤ 2 in 1/14]	2.28 (2–3)	2.14 (1–4)	2.21 (1–4)	2.07 (1–3)	2.14 (1–3)	2.1 (1–3)

The values within parenthesis () represent mean of IQ scores for two readers. The values within square brackets [] represent the diagnostic acceptability scores ≤ 2, which represents limited IQ for diagnostic evaluation
R1, reader 1; R2, reader 2; U/L, unilateral; B/L, bilateral; DA, diagnostic acceptability

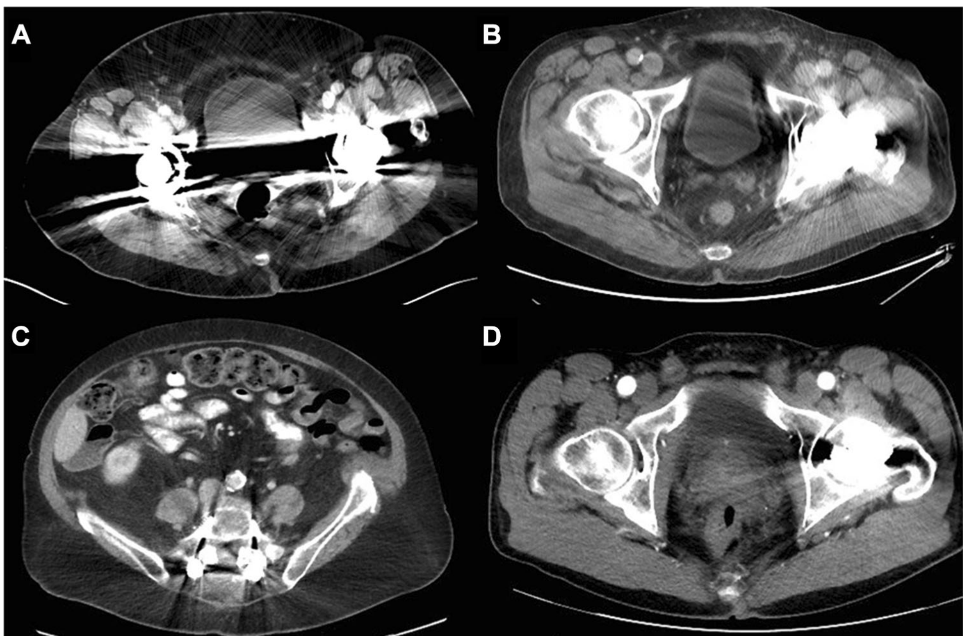

Fig. 3. Orthopedic metallic hardware in abdomen and pelvis CT and the degree of artifacts. **A** Axial contrast-enhanced CT images shows bilateral hip implants producing most marked artifacts causing severe image degradation followed by unilateral hip implant (**B**), spinal prosthesis (**C**) and femoral screws (**D**).

Quantitative image analysis

Mean image noise was significantly higher at the level of metal artifacts within the urinary bladder (22.44 ± 9.7 vs. 12.9 ± 4.1, $p < 0.001$), within muscle (25.58 ± 12.24 vs. 16.06 ± 6.53, $p < 0.001$) and within subcutaneous fat (20.16 ± 10.44 vs. 14.9 ± 5.4, $p < 0.001$) compared to outside the site of metallic artifacts.

Clinical significance: metallic hardware

On analysis of radiological reports, a disclaimer regarding the limited nature of CT examination due to the presence of metallic hardware was seen in 24.7% (n = 43/174) of cases (bilateral hip prosthesis: n = 14, unilateral hip prosthesis: n = 18, spinal implants: n = 6, hip screws: n = 3 and others: n = 2). In 82.7% of scans (144/174), metallic hardware produced artifacts in the anatomic location corresponding to the site of clinical relevance (Table 3). In patients with metallic hardware undergoing CT for oncological evaluation (n = 90), hardware-related artifacts were identified at the site of primary disease in 23.3% (n = 21/90) of scans limiting evaluation. Hardware-related artifacts at the site of primary tumor were mostly seen in pelvic malignancies (n = 18, bladder, cervical, endometrial, ovarian, prostate cancer) which could be explained by the increased occurrence of hip prosthesis. In three patients with upper

Table 3. Clinical impact of metallic hardware and its artifacts for oncological and vascular indications

CT indication	% (n)
Oncological evaluation (n = 90)	
– Artifacts limiting evaluation of primary disease site (n = 21)	23.3% (21/90)
Pelvic malignancies (n = 18)	85.7% (18/21)
(Bladder, n = 2; cervical, n = 2; endometrial, n = 1; ovarian, n = 2; colon, n = 7; prostatic, n = 2; pelvic sarcoma, n = 2)	
Primary upper abdominal malignancies (n = 3)	14.3% (3/21)
(HCC, n = 1; sarcoma, n = 1; RCC, n = 1)	
– Artifacts limiting evaluation of secondary metastatic site (n = 69)	
(Unknown primary, n = 11; breast cancer, n = 1; cholangiocarcinoma, n = 2; GIST, n = 2; esophagus cancer = 1, GB cancer = 2, HCC = 6, lung cancer = 13, lymphoma = 2, melanoma = 5, ovarian cancer = 2, NHL = 8, osteosarcoma = 1, prostate cancer = 3, RCC = 4, thyroid cancer = 2, neuroendocrine tumor = 1, chondrosarcoma = 2, chordoma = 1)	76.7% (69/90)
Vascular evaluation (n = 19)	
(Abdominal aortic aneurysm, n = 14; aortic dissection, n = 1; IVC thrombosis, n = 1; limb ischemia, n = 2; value implantation, n = 1)	
– Artifacts limiting evaluation of aorto-iliac vasculature	0% (0/19)
– Artifacts limiting evaluation of iliac and femoral arteries	100% (19/19)

abdominal malignancies, streak artifacts from spinal fixation hardware limited evaluation of primary tumor. In 76.7% of cases, evaluation of potential secondary disease sites of malignancy was limited at the site of artifacts. In patients undergoing CT angiographic studies for vascular evaluation, metallic hardware in the hip limited visualization of external iliac and common femoral arteries in all patients, while the evaluation of the aorto-iliac artery region was always acceptable and did not impede diagnosis.

Discussion

Artifacts from metallic orthopedic hardware such as hip prostheses and spinal implants are increasingly encountered on abdominal CT and negatively impact the visualization and interpretation of the abnormalities within the abdomen and pelvis. In our single institutional cohort, we found that nearly 5% of the abdominal CT examinations were found to have orthopedic metallic hardware and clinically significant limitation of IQ was seen in 32% of these CT scans. Bilateral hip implants had the maximum impact with deterioration of IQ at the site of the implants in 92% of scans followed by unilateral hip and spinal implants. The findings of our study show that occurrence metallic artifacts on routine abdomen and pelvic CT scans can deteriorate IQ and limit diagnostic performance at the site of clinical interest in nearly a third of the patients with metallic hardware which adversely impacts patient care and is concerning given the rising use of metallic hardware in various orthopedic procedures.

Hip implants are more often encountered in older individuals and can have a significant impact on the interpretation of cross-sectional imaging techniques in patients with pelvic malignancies as the organs of interest lie within the artifact zone [1]. Metallic artifacts also impede detection of pelvic lymph nodal metastases in pelvic malignancies such as prostate cancer which is common in elderly males [30]. Additionally, malignant manifestations of non-pelvic primary cancers are also affected by hip and spinal implants as the pelvic bones and vertebrae are a frequent site for metastases [31, 32]. Elderly individuals often undergo CT angiography for the evaluation of aortic aneurysms or as a pre-procedure work-up for transcatheter aortic valve replacement (TAVR/TAVI) [8, 9, 33]. Patency of femoral and iliac vessels is crucial for determining the suitability of vascular access for percutaneous intervention [8, 9, 33]. We found that evaluation of ilio-femoral vasculature is limited in patients with hip implants which considerably limits diagnostic evaluation. The problem of clinically significant metal-related artifacts is expected to increase, as routine use of lower kVp is becoming increasingly popular due to its radiation dose benefits. This has clinical relevance as minor artifacts at 120 kVp are likely to become clinically significant at scans performed at 100 kVp and lower [19, 34].

Metallic CT artifacts can be reduced using standard techniques, such as using high kVp and tube current, narrow collimation and thinner slices [12]. However, the impact of these techniques on additional radiation risk has not been fully evaluated. Several advanced techniques, such as monoenergetic DECT and sinogram inpainting methods can also be used to decrease the artifacts [12, 22–24, 26, 27]. Metal implants create image artifacts due to a combination of beam hardening and photon starvation. Beam hardening is a consequence of the poly-energetic nature of the X-ray beam and would not occur with monoenergetic or monochromatic beams, as the photon energy would remain the same before and after passing through the metallic objects. In patients scanned with DECT, post-processed high energy VMC images are less prone to metal artifacts [12, 26, 27]. In particular, VMC images reconstructed at energies between 95 and 150 keV can be used to reduce the artifacts resulting from metal hardware depending on the composition and size of metal implants [35]. However, use of high keV images leads to a certain degree of loss of soft tissue contrast information. Several new sinogram inpainting methods are emerging that reduce metal artifacts by removing the corrupted data and replacing with the interpolated data using various algorithms. Different vender-specific commercially available software implemented includes MARS (GE Medical Systems, Milwaukee, WI), MAR in image space (Siemens Healthcare, Forchheim, Germany), single energy MAR (Toshiba Medical Systems, Otawara, Japan) and O-MAR (MAR for orthopedic implants) (Philips Healthcare System, Cleveland, OH) [12].

MR imaging techniques, such as scanning on lower-field-strength systems and using fast spin echo and short tau inversion recovery sequences with high bandwidth parameters, may be an alternative for the patients with metallic implants. Other advanced imaging techniques, such as slice encoding for metal artifact correction, multi-acquisition variable-resonance image combination and view angle tilting, can also be used [12]. However, despite the implementation of these techniques, MR IQ may be limited due to the presence of susceptibility artifacts.

Anecdotally we have noticed that despite the availability of MAR software and a high prevalence of clinically significant image degradation by metal artifacts, the application of MAR technique has been very low in our clinical practice. The limited utilization is mainly because they are time-consuming and performed only at the request of radiologist retrospectively. A potential solution to improved utilization of MAR techniques is education and training of CT technologists to perform them on patients identified to have metal hardware on CT scout images. The findings of our study will likely automate the implementation of this process which would include steps such as targeted patient scheduling and training of technologists. In radiology departments with multi-vendor practice, it is important to ensure that MAR software is installed across all vendor MDCT scanners or scanning of these patients must be restricted to MAR capable scanners.

Our study has few limitations. Firstly, being a single institution study, the findings of this study are specific to the scanner technology and patient population and therefore might raise concerns for generalizability of data. However, being a multi-vendor, multi-scanner practice in a high-volume quaternary care hospital, our data could be potentially generalized to other academic centers. Secondly, the diagnostic accuracy of CT was not assessed in the patients with metallic artifacts. Thirdly, in patients with malignancies the impact of the diagnostic quality may be overestimated as the presence of a known metastatic lesion elsewhere was not taken into consideration. Finally, our study did not employ and assess the efficacy of MAR strategies for artifact reduction. However, the current study highlights the need for further prospective studies to overcome the problem of clinically relevant metal artifacts.

Conclusion

Orthopedic metallic hardware is encountered in nearly 5% of abdomino-pelvic CT examinations and presents clinically significant limitation of IQ in nearly a third of these studies. Most adverse effect on IQ occurs in patients with bilateral hip implants. Routine integration of metallic artifact reduction strategy into clinical practice needs understanding of the occurrence of the artifacts to improve efficiency and justify cost related to the MAR software.

Compliance with ethical standards

Funding There is no source of funding for this original article.

Conflict of interest Vinit Baliyan, Hamed Kordbacheh, Amir H. Davarpanah, Amirhossein Mozafarry and Avinash Kambadakone declare that they have no conflict of interest. Dushyant V. Sahani received grant support for research activities from GE Healthcare, Advisory Board of Allena Pharmaceuticals, Royalties from Elsevier.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Maradit Kremers H, Larson DR, Crowson CS, et al. (2015) Prevalence of total hip and knee replacement in the United States. J Bone Jt Surg Am 97(17):1386–1397
2. Kurtz S, Ong K, Lau E, Mowat F, Halpern M (2007) Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Jt Surg Am 89(4):780–785
3. Ha AS, Petscavage-Thomas JM (2014) Imaging of current spinal hardware: lumbar spine. Am J Roentgenol 203(3):573–581
4. Rutherford EE, Tarplett LJ, Davies EM, Harley JM, King LJ (2007) Lumbar spine fusion and stabilization: hardware, techniques, and imaging appearances. RadioGraphics 27(6):1737–1749
5. Eberhardt SC, Johnson JA, Parsons RB (2013) Oncology imaging in the abdomen and pelvis: where cancer hides. Abdom Imaging 38(4):647–671
6. Genovese EA, Fonio P, Floridi C, et al. (2013 Jul 15) Abdominal vascular emergencies: US and CT assessment. Crit Ultrasound J 5(Suppl 1):S10
7. Gore RM, Miller FH, Pereles FS, Yaghmai V, Berlin JW (2000) Helical CT in the evaluation of the acute abdomen. Am J Roentgenol 174(4):901–913
8. Rubin GD, Dake MD, Napel SA, McDonnell CH, Jeffrey RB (1993) Three-dimensional spiral CT angiography of the abdomen: initial clinical experience. Radiology 186(1):147–152
9. Rubin GD, Shiau MC, Schmidt AJ, et al. (1999) Computed tomographic angiography: historical perspective and new state-of-the-art using multi detector-row helical computed tomography. J Comput Assist Tomogr 23(Suppl 1):S83–S90
10. Stoker J, van Randen A, Laméris W, Boermeester MA (2009) Imaging patients with acute abdominal pain. Radiology 253(1):31–46
11. Soto JA, Anderson SW (2012) Multidetector CT of blunt abdominal trauma. Radiology 265(3):678–693
12. Gupta A, Subhas N, Primak AN, Nittka M, Liu K (2015) Metal artifact reduction: standard and advanced magnetic resonance and computed tomography techniques. Radiol Clin N Am 53(3):531–547
13. Lee M-J, Kim S, Lee S-A, et al. (2007) Overcoming artifacts from metallic orthopedic implants at high-field-strength MR imaging and multi-detector CT. RadioGraphics 27(3):791–803

14. Stradiotti P, Curti A, Castellazzi G, Zerbi A (2009) Metal-related artifacts in instrumented spine. Techniques for reducing artifacts in CT and MRI: state of the art. Eur Spine J 18(Suppl 1):102–108
15. O'Brien J, Baerlocher MO, Asch M, Myers A (2009) Role of radiology in geriatric care. Can Fam Physician 55(1):32–37
16. Kalva SP, Mueller PR (2008) Vascular imaging in the elderly. Radiol Clin 46(4):663–683
17. Hopper KD, Singapuri K, Finkel A (2000) Body CT and oncologic imaging. Radiology 215(1):27–40
18. Buckwalter KA, Parr JA, Choplin RH, Capello WN (2006) Multichannel CT imaging of orthopedic hardware and implants. Semin Musculoskelet Radiol 10(01):086–097
19. Kataoka ML, Hochman MG, Rodriguez EK, et al. (2010) A review of factors that affect artifact from metallic hardware on multi-row detector computed tomography. Curr Probl Diagn Radiol 39(4):125–136
20. Vande Berg B, Malghem J, Maldague B, Lecouvet F (2006) Multidetector CT imaging in the postoperative orthopedic patient with metal hardware. Eur J Radiol 60(3):470–479
21. Roth TD, Maertz NA, Parr JA, Buckwalter KA, Choplin RH (2012) CT of the hip prosthesis: appearance of components, fixation, and complications. RadioGraphics 32(4):1089–1107
22. Brook OR, Gourtsoyianni S, Brook A, et al. (2012) Spectral CT with metal artifacts reduction software for improvement of tumor visibility in the vicinity of gold fiducial markers. Radiology 263(3):696–705
23. Han SC, Chung YE, Lee YH, et al. (2014) Metal artifact reduction software used with abdominopelvic dual-energy CT of patients with metal hip prostheses: assessment of image quality and clinical feasibility. Am J Roentgenol 203(4):788–795
24. Jeong S, Kim SH, Hwang EJ, et al. (2015) Usefulness of a metal artifact reduction algorithm for orthopedic implants in abdominal CT: phantom and clinical study results. Am J Roentgenol 204(2):307–317
25. Kidoh M, Utsunomiya D, Ikeda O, et al. (2016) Reduction of metallic coil artefacts in computed tomography body imaging: effects of a new single-energy metal artefact reduction algorithm. Eur Radiol 26(5):1378–1386
26. Kuchenbecker S, Faby S, Sawall S, Lell M, Kachelrieß M (2015) Dual energy CT: how well can pseudo-monochromatic imaging reduce metal artifacts? Med Phys 42(2):1023–1036
27. Pessis E, Campagna R, Sverzut J-M, et al. (2013) Virtual monochromatic spectral imaging with fast kilovoltage switching: reduction of metal artifacts at CT. RadioGraphics 33(2):573–583
28. European guidelines on quality criteria for computed tomography (Internet). http://www.drs.dk/guidelines/ct/quality/htmlindex.htm. Cited 10 Oct 2018
29. Deetjen A, Möllmann S, Conradi G, et al. (2007) Use of automatic exposure control in multislice computed tomography of the coronaries: comparison of 16-slice and 64-slice scanner data with conventional coronary angiography. Heart 93(9):1040
30. Nguyen-Nielsen M, Borre M (2016) Diagnostic and therapeutic strategies for prostate cancer. Semin Nucl Med 46(6):484–490
31. Haidukewych GJ (2012) Metastatic disease around the hip: maintaining quality of life. J Bone Jt Surg Br 94(11 Suppl A):22–25
32. Constans JP, de Divitiis E, Donzelli R, et al. (1983) Spinal metastases with neurological manifestations. Review of 600 cases. J Neurosurg 59(1):111–118
33. Achenbach S, Delgado V, Hausleiter J, et al. (2012) SCCT expert consensus document on computed tomography imaging before transcatheter aortic valve implantation (TAVI)/transcatheter aortic valve replacement (TAVR). J Cardiovasc Comput Tomogr 6(6):366–380
34. Kaza RK, Platt JF, Goodsitt MM, et al. (2014) Emerging techniques for dose optimization in abdominal CT. RadioGraphics 34(1):4–17
35. Bamberg F, Dierks A, Nikolaou K, et al. (2011) Metal artifact reduction by dual energy computed tomography using monoenergetic extrapolation. Eur Radiol 21(7):1424–1429