Review article

Updates in postoperative imaging modalities following musculoskeletal surgery

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A R T I C L E   I N F O

A B S T R A C T

Postoperative imaging following orthopaedic surgeries is essential in assessing complications post-surgery and also helps plan further treatment. Combining a high degree of clinical insight with appropriate imaging can guide the treating clinician to the correct diagnosis. Imaging is quite challenging because of surgery-related soft tissue changes, especially in the early postoperative period and the presence of metal implants resulting in image scatter and metal artifacts. Newer modalities and advances in imaging have helped overcome shortcomings and assess better, especially in procedures that involve implants. Collaborative decision-making involving radiologists and clinicians has shown to be beneficial and is the way forward. This narrative review discusses the utility of imaging in evaluating postoperative complications following musculoskeletal surgeries with specific relation to trauma, arthroplasty, and tumour by discussing commonly encountered clinical scenarios.

1. Introduction

Imaging is a vital part of the work-up and follow-up of patients following orthopaedic surgery to assess their progress and monitor any complications.[1,2] Management depends on early and accurate diagnosis, as delayed interventions, especially in complications, have been associated with poorer outcomes. Ideally, decision-making should be achieved without any invasive diagnostic method, if possible, but quickly and reliably. Understanding the respective advantages and disadvantages of each imaging modality is required to deliver optimal patient care. Imaging plays a vital role in i) identifying the exact nature of the complication and ii) helping in formulating an appropriate management plan to address the issue.[3–5] As imaging techniques are always evolving, appropriate knowledge of techniques will guide the treating clinician towards choosing the best modality required for the patient. This narrative review focuses specifically on imaging following musculoskeletal surgeries related to trauma, arthroplasty, and tumour by discussing

commonly encountered clinical scenarios.

Challenges in postoperative imaging: Postoperative patients usually present with vague symptoms, majority being non-specific. Imaging is equally challenging due to surgery related soft-tissue and bone changes.[6]

Soft tissue changes: The major soft issue changes like edema, hematoma or seroma can be expected and will be challenging to distinguish from infection or abscess. Another potential mimic of collection could be a pseudo aneurysm which can be missed without appropriate imaging.[7,8] Flaps and graft may have variable appearances which can be problematic for untrained interpreter. Fibrosis or scarring can give rise to confusing imaging picture especially when there is a question of post-operative tumor recurrence.

Metal artifacts: Presence of metal is another challenge which results in suboptimal images in CT and MRI scan. Presence of metal results in severe attenuation of the X-ray beam resulting in artifact in the reconstructed image. Similarly, loss of magnetic field homogeneity due to presence of metal will result in image distortion, signal loss and misregistration in MRI.[9] Fortunately, there are multiple advances both in CT and MRI to reduce these artifacts to

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Abbreviations	
MRI	Magnetic Resonance Imaging
CT	Computerized Tomography
USG	Ultrasonogram
PET	Positron emission tomography
ALVAL	Aseptic lymphocyte-dominated vasculitis-associated lesion
MARS	Metal artifact reduction sequence

the extent required for adequate information, basic knowledge of which are helpful for both radiologist and referring surgeon in order to collaboratively diagnose most complex complications while being aware of certain limitations. Metal artifact reducing sequences (MARS) are useful advances which assist in clearer evaluation of structures whenever metals or prosthesis are involved (Fig. 1).[10,11]

This review article aims to discuss the utility of imaging in evaluating postoperative complications following musculoskeletal surgeries with specific relation to trauma, arthroplasty, and tumour by discussing commonly encountered clinical scenarios. We also discuss the role of the time-tested MRI and CT scans (Table 1) in postoperative imaging and the newer modalities, including nuclear medicine (Table 2).

1.1. Assessment of fracture union

Radiographs: Conventional radiographs are the workhorse to assess fracture union. The ability to monitor fracture healing to predict which fractures will go onto non-union accurately is of

great value in reducing patient morbidity.[12,13] The gradual appearance of the callus and its progressive ossification, as seen in two plain radiographs in a patient with decreased pain, is an indicator of good healing. Oblique radiographs may be helpful in some cases to visualize for callus. Radiographic union score (RUS) and modified RUS were developed to overcome the subjective nature of visual, radiographic evaluation, and clinical correlation in patients with delayed or non-union.[14] Studies showed good inter-observer agreement in validation studies, even in complex bone defects and in patients with co-morbidities. These are not routinely used in clinical practice and still suffer from the fundamental limitation of being semiquantitative and subjective. The scoring system can be challenging for beginners and in the presence of metal plate.

CT scan: Computed tomography (CT) with the ability for multiplanar reconstruction and metallic artifact reduction is superior to plain radiography in the assessment of union even in the presence of abundant callus or overlaying cast. Krestan et al. compared MDCT and digital radiography in evaluation of the fracture healing in 43 patients in which 19% of digital radiographs underestimated the extent of bone healing, whereas in another 19% they overestimated the degree of fusion.[15] Another study by Bhattacharyya et al. showed that computed tomography has 100% sensitivity for detecting non-union; however, it is limited by a low specificity of 62%, were in there was fibrous union intraoperatively.[16]

Quantitative and qualitative assessment using CT scan: Investigators have compared quantitative and qualitative changes of fracture healing using both computed tomography and conventional radiography. They found that early manifestations of healing, including blurring of fracture margins and formation of external callus, were observed earlier with CT scan. Most of the discrepancies between X-ray and CT scan findings were in periarticular and metaphyseal injuries.[17] Currently, cost and radiation dose of CT
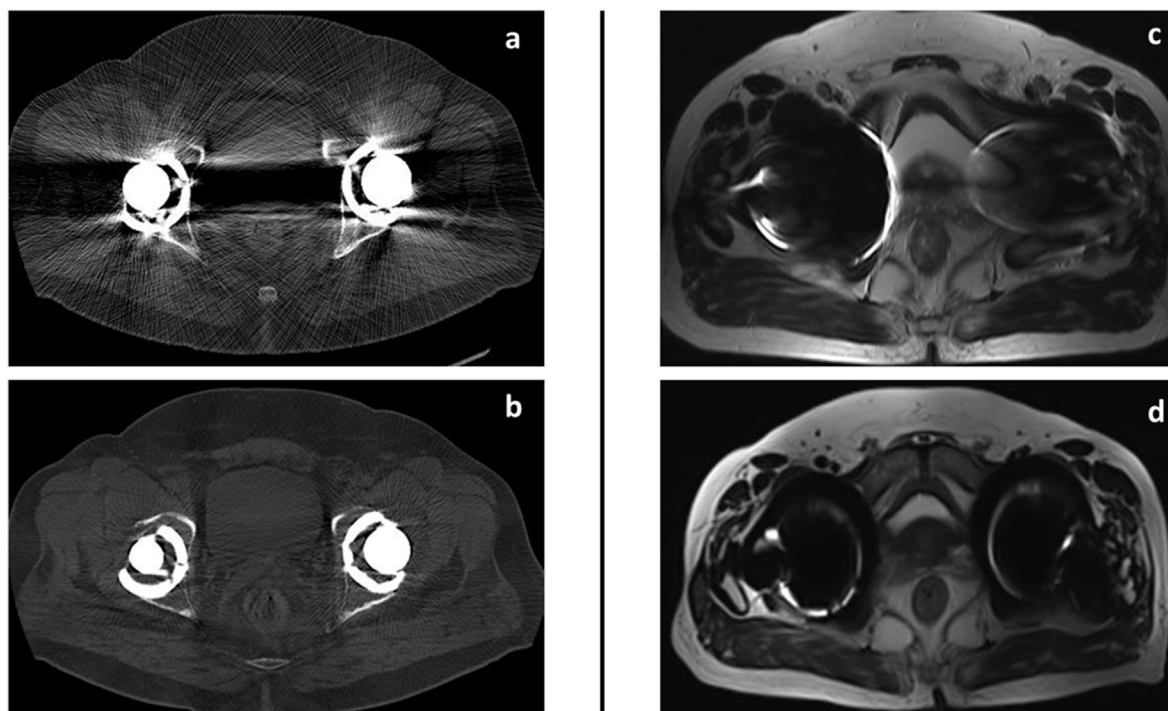

Fig. 1. Role of metal artifact reduction/subtraction techniques: CT scan (a) of both hip axial images following total hip replacement shows significant signal loss due to proton starvation and beam hardening artifacts (arrow) which is drastically reduced by metal artifact reduction techniques as in (b). MRI scan of both hip axial images(c) following total hip replacement shows significant image distortion and loss of signal around the implant(arrow). Substantial improvement of periprosthetic tissue details following artifact reduction techniques as in (d).

Table 1
Summary of the recent advances, applications and drawbacks of CT Scan and MRI in postoperative imaging in musculoskeletal surgery.

Imaging modality	Advances	Applications in post operative imaging	Drawbacks/Disadvantages
CT Scan: CT is readily available, easy to perform and less expensive modality used in post operative period. It is popular imaging tool used mainly in revision arthroplasty to look for bone loss and complex anatomies before revision surgeries. Although soft tissue details pertaining to collections, infection can also be evaluated by CT scan, MRI is preferred for such details.	1. *Multi detector CT scan (MDCT):* will use wide Xray beam to cover to multiple detector rows, hence multiple sections at same slice can be obtained which can be reconstructed to form single image without increasing the dose.	1. Isotropic volumetric acquisition with multiplanar reformatting capability. 2. Excellent resolution of bony details and implants 3. Faster acquisition time	1. Radiation exposure 2. Limited soft tissue contrast 3. Metal artifacts.
	2. *Advances in metal artifact reduction:* Routine techniques like Image acquisition with higher kilovoltage and increase in mAs to increase the x ray penetration, Decrease in collimation, avoiding the imaging plane parallel to thickest portion of the metal, gantry tilt, reduced pitch can be used to reduce the artifacts Advancement in post processing techniques as below results in great deal of artifact reduction.	1. Routine techniques mentioned here are greatly helpful even with low configuration scanners and reduces the metal artifacts and technicians can easily follow these procedures.	1. These routine techniques to reduce metal artifact may not be feasible in all the situations for example gantry tilt and change in imaging plane may not be possible for hip implants. Increasing the X Ray energy can result in increased dose.
	a) Multiplanar reconstruction b) Reconstruction of images from the acquired raw data with thicker slices.	1. MPR images and using raw data to obtain images with thicker slides is possible with MDCT and is useful in good metal artifact reduction.	1. Although present scanners have inbuilt advanced post processing techniques these are not widely available.
	c) Iterative image reconstruction instead of filtered backprojection d) MAR algorithms (sinogram inpainting techniques). Here corrupt X-ray projections that traversed the metal hardware are removed and replaced with interpolation from adjacent unaffected projections to obtain artifact free image.	2. Combinations of various methods of image reconstruction methods and algorithms reduce the metal artifact without additional radiation dose.	2. In spite of great deal of soft ware advancement, metal artifact reduction is not completely overcome in most of the cases. There is also possibility of image blurring with MAR algorithms.
	e) Combination of MAR and Iterative software	3. Additionally, using soft reconstruction kernel instead of bone kernel which is routinely used for MSK imaging and wider window setting	
	3 *Dual energy CT scan:* also known as **spectral CT**, is a computed tomography technique that uses two separate x-ray photon energy spectra, allowing the interrogation of materials that have different attenuation properties at different energies. Whereas conventional single energy CT produces a single image set, dual energy data (attenuation values at two energy spectra) can be used to reconstruct numerous image types.	1. Knowing how a substance behaves at two different energies can provide information about tissue composition beyond that obtainable with single-energy techniques. 2. Early detection of subtle fractures. 3. DECT provides an additional option for metal artifact reduction, particularly the beam-hardening component, without any radiation dose penalty. Virtual monoenergetic imaging simulates images acquired with a monoenergetic x-ray beam and can decrease beam hardening. This is helpful in reduction of the metallic artifact and optimal visualization of periprosthetic soft tissues.	1. Not widely available, expensive and requires a learning curve to interpret various image sets at different energy settings. 2 Bone marrow edema detection is only suitable for yellow marrow. 3. The Virtual monoenergetic metal artifact reduction techniques unique to DECT may not be applicable for larger and denser metals.
Magnetic resonance imaging (MRI): Due to its superior soft tissue resolution MRI is increasingly used as a problem-solving modality in various complications like soft tissue collections around the implant, adjacent muscle and tendon pathologies, tumor surveillance. It is well known that ferromagnetic materials will be attracted to the main magnetic field of an MR scanner; however, it is safe to scan patients with orthopedic hardware such as intramedullary nails, screws, malleable plates, and joint prostheses, even in the immediate postoperative period.	1 Metal artifact reduction techniques: Generally, artifacts less severe in 1.5T machines as compared to 3T machines. Spin echo and using higher bandwidth radio frequency waves for excitation as well as for receiving the signals will help to reduce incoherence and Signal loss. Spatial misregistration can be overcome by swapping the direction of slice selection and readout gradients.	1. All these parameter changes are inbuilt in to the system as metal artifact reduction sequence in most of the scanners and help in reduction of the artifacts.	1 These are time consuming and result in increase in heat deposition

Table 1 (*continued*)

Imaging modality	Advances	Applications in post operative imaging	Drawbacks/Disadvantages
	2. Short tau inversion recovery (Stir) is preferred technique since its immune to metal induced magnetic field changes.	2. Stir sequences are immune to metal induce magnetic field changes.	2. Stir sequences should be avoided when gadolinium contrast is used. Dixon sequences is preferred when contrast is necessary.
	Advanced techniques for metal artifact reduction: a. **View angle tilting (VAT):** spatial misregistration occurring during slice selection and signal readout is reduced by replaying a gradient with an angle or a tilt to bring back the signals in coherence	a. mainly circumvents in plane image distortions	a. Unless VAT is combined with isotropic three-dimensional fast spin echo sequences (eg: space sequences in Siemens)) there will be a degree of blurring hence of no added value. These sequences can be also challenging in area with large surface area like hip joint where 3D imaging cannot be applied
	b. **Slice encoding metal artifact correction (SEMAC):** this is a two-dimensional (2D) imaging method adds multiple spatial partitions to the (turbo) spin echo pulse sequence to mitigate the through plane artifacts. Simply put every slice is reconstructed by several images from multiple partitions which are reconstructed separately. These are then combined together with summation techniques to form a final composite image.	b. Combining SEMAC with VAT will give additional benefit of reducing in-plane and through plane distortions	
	c. **Multi –acquisition with variable –resonance image combination (MAVRIC):** MAVRIC the resonance frequency or RF pulse is split into multiple frequency bins or spectral bins. These frequencies are capable of exciting different set of protons in inhomogeneous B0. For each frequency bin, a sub image is acquired corresponding to a particular subset of protons which are then added up to form a final image.	c. Like SEMAC, MAVRIC has better resolution with isotropic 3D acquisition.	d. Both SEMAC and MAVRIC are time consuming due to spatial partitions and additional spectral bins respectively. Various acceleration algorithms have been developed and studied. However, these are in research applications.
	2. **Diffusion Weighted Imaging:** Diffusion weighted imaging which is routinely used to study brain perfusion is also available for MSK applications.	2 Helpful tool to detect abscess. Useful tool to differentiate tumor recurrence vs post treatment changes.	2 May be challenging in presence of metal implants. The quantitative values are not standardized.
	3. **Dynamic Contrast Imaging:** here the post contrast images are acquired in arterial, venous and late phases.	3. useful for post tumor excision follow up studies. Helpful in targeted biopsy in tumor recurrence	3. Can be equivocal in some cases due to post-operative soft tissue changes. Contrast cannot not be used in renal failure patients
	4. **US-MR fusion:** These are recent advanced software systems available where MRI image can be fused while performing guided biopsy using USG.	4. helpful in targeted biopsy of the tumour.	4 Limited availability
	5. **MRI wire localization:** MRI comparable wire is used for localising the tumor	5. helpful in selective excision of tumour	5. Limited availability

scans limit their widespread use as the main clinical assessment tool for fracture healing. However, MDCT with 2D reformatted images can be considered the gold standard for evaluating the suspected non-union not clearly evident on radiographs (Figs. 2 and 3).

MRI: The most promising work comes from the recent development of dynamic contrast-enhanced MRI, which enables the evaluation of the vascularity of a non-union site.[18] Presently it has been used more successfully in scaphoid fractures. Another major utility is for physeal fracture healing, where clinicians can accurately detect bony bridging and area or involvement.

Ultrasound: The use of ultrasound was estimated to have 97% positive predictive value, and 100% sensitivity for fracture union when bridging callus was visualized at approximately two months following fixation. Fracture union was determined by ultrasound at a mean of 6.5 weeks versus 19 weeks on radiographs.[19] However, USG is not popular as a standard clinical modality, mainly due to its operator dependency, lack of depth resolution in obese patients, and penetration through the bone.

Finite element analysis: Using CT scan images, this approach captures bone and callus tissue location, density, and distribution, and virtual loadings can be applied to simulate various biomechanical scenarios. In one recent study with image-based FEA, virtual stress testing of severely comminuted tibial fractures under clinically relevant loading was able to predict which patients would suffer a failure upon hardware removal with a sensitivity and specificity of 100% and 78%, respectively.[20] DEXA and nuclear scans are not used in current practice to evaluate fracture non-union. In addition to clinical examination, we rely on conventional two-plane radiographs to assess union in routine clinical practice. MDCT with 2D reformatted images for suspected non-united fractures or complex anatomy fractures has been beneficial.

Evaluating suspected Prosthesis/Implant malposition: Radiographs are the first-line imaging modality to assess the

Table 2
Role of Nuclear Imaging as a modality following musculoskeletal surgery.

Imaging Modality	Advances	Applications in post operative imaging	Drawbacks/Disadvantages
Bone Scintigraphy Most common radiopharmaceutical are Tc-99 m MDP and Tc-99 m HDP These are bone-seeking agents that undergo adsorption to the hydroxyapatite structure of bone tissue.	1 **SPECT** Visualization of the three dimensional distribution of the radiopharmaceutical in the skeleton.	Allows for better image contrast and precise lesion localization.	SPECT is an added procedure rather than a stand-alone procedure in that whole body images or limited bone scan are performed initially followed by SPECT imaging
Uptake is dependent on blood flow and bone turnover(in osteoblastic areas) Less sensitive for osteolytic lesions Planar whole body images or focal planar images can be acquired.	2 **SPECT/CT** SPECT acquisition combined with CT using an integrated CT scanner	SPECT allows for greater accuracy in the determination of the source of abnormal activity Correlation with CT-morphology allows the exclusion of potentially false positive bone uptake	Increased radiation exposure. Not widely available.
Quantification of uptake- the osseous radioactivity concentration is expressed as standardized uptake values (SUV)	Quantification and Iterative metal artifact reduction techniques	Improves attenuation correction around metal implants	3-phase skeletal scintigraphy is nonspecific and is most useful when study is normal or identifies fracture or other non prosthesis-related cause of symptoms
	4 **Multiphase bone scan (dynamic scan)** First phase- Blood flow to the region of interest Second phase- Degree of hyperemia Delayed phase- Amount of bone formation	Localization to regions of increased bone perfusion and osteoblastic response	
Tracers	1 **Tc-99m MDP** more commonly used	**Normal bone scan has high negative predictive value Rules out infection and loosening**	Patients with implants can show false positive uptake up to 3 years after surgery.
	2 **Labeled leukocyte Scintigraphy**	Localizes to areas of infection and stress fractures with positive three phase uptake	Compacted marrow from procedure also shows increased activity
	Used both in conjunction with bone scans and independent of bone scans for further specificity Tagged WBC scan In-111 or Tc-99 m HMPAO WBCs localize to infection	Differentiation of metabolically active vascular hypertrophic union and oligotrophic/atrophic non union Early detection of heterotrophic ossification	False-positive WBC scan in recently "violated" bone likely fracture due to localization in marrow elements False-negative results occur in chronic infections/aseptic inflammation
	3. **Tc-99m HMPAO WBC scan**	Labeled leukocytes are mostly neutrophils, which are present in infections and not prevalent in aseptically loosened prosthesis	Requires Tc-99 m SC marrow map 24 −72 h later if (+) Radiation exposure to the patient is greater
	4 **Technetium 99m sulphur colloid**	Usually matches 3-phase bone scan distribution in infection	Radiation exposure is a major disadvantage
PET/CT & PET/MRI Three-dimensional images are obtained with a circular array of detectors and a CT scanner in the PET/CT bore.	**F-18 FDG PET CT**	Better imaging characteristics Used to confirm labeled leukocyte scintigraphy results Localizes to normal marrow, hence discordant activity to	Increased uptake around prosthesis
	A glucose analogue, F-18-labeled	leukocyte scintigraphy indicates infection	CT based attenuation correction can falsely elevate radiotracer uptake in presence of implant related artifacts
	fluorodeoxyglucose is taken up by many types of tumour cells in the glycolysis pathway and is trapped after phosphorylation by hexokinase.	Areas of recurrent tumour show increased activity, particularly in patients with implants	Limited in case of metallic artifacts
	PET/MRI is a recent advance which can be used in patients with radiation concern-like pregnancy and young adults	Combined high soft tissue resolution of MRI and metabolic activity with PET increases sensitivity	Not widely available
	F-18 NaF PET Second-line modality after nondiagnostic Tc-99 m bone scans.	During shortages of Tc-99 m, F-18 PET bone scans offer an alternative for skeletal imaging	Shows no uptake in sclerotic acellular/ small tumor volume in areas of tumor recurrence
	The mechanism of uptake is incorporation of fluoride ions into the bone matrix in sites of infection, after trauma/stress, or during inflammation	The resolution and pharmacokinetics are far greater than Tc-99m-based bone agents Fast blood clearance Higher bone uptake High bone to soft tissue uptake ratio	
	Shows uptake in osteolytic and osteoblastic lesions	Total exam time is shorter Improved resolution when compared to planar and SPECT or SPECT/CT	

components and their relationship to the adjacent bone. In certain situations, special radiographic views are used and are comparable to the CT scans; however, when surgery is planned, accurate assessment by CT scan is recommended. For example, in patients with recurrent dislocation post total hip replacement in whom surgery is indicated, obtaining a CT scan can help identify patients who have adequate bone stock which allows surgeons to retain the acetabular shell during revision surgery. Assessment of exact version of native bone is also possible helping plan revision surgeries if indicated.[21] Another study by Keil et al. concluded that although Intraoperative 3D imaging is a valuable adjunct in

assessing reduction and implant placement in acetabular fractures, it lacks accuracy due to metal artifacts, and hence post-operative CT is indicated to avoid impairment of clinical outcome.[22]

In our own experience, MDCT with multiplanar reconstruction better depicts the implant status, especially with relation to pelvis and is routinely used when radiographs are equivocal. It also helps to assess the bone quality accurately if revision is planned and gives a 3D view of the anatomy, and related soft tissue and osseous changes (Fig. 4).
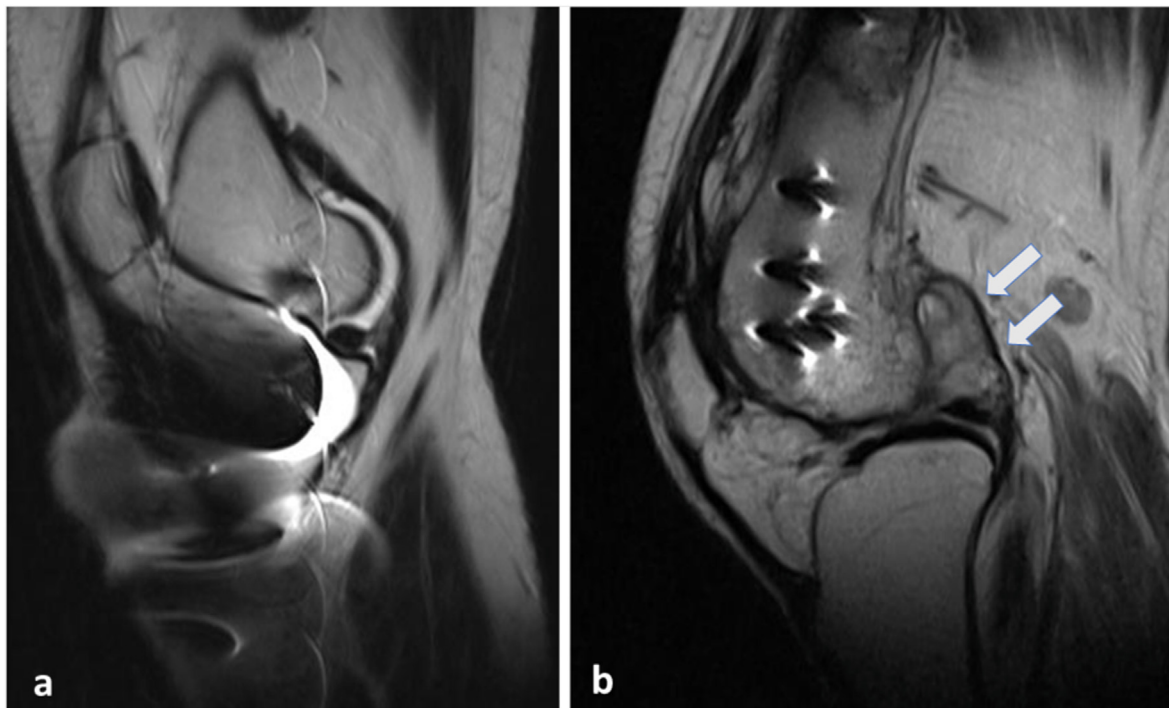
Fig. 2. Metal artifact reduction sequence (MARS): Postoperative case of proximal tibial fracture with implants obscuring the images on routine T2 sequence, rendering it difficult for the radiologist to assess the underlying pathology (a). Another case with implant in the distal femur imaged using MARS sequence, depicting synovial thickening and intra-articular fluid collection in the knee joint (b).
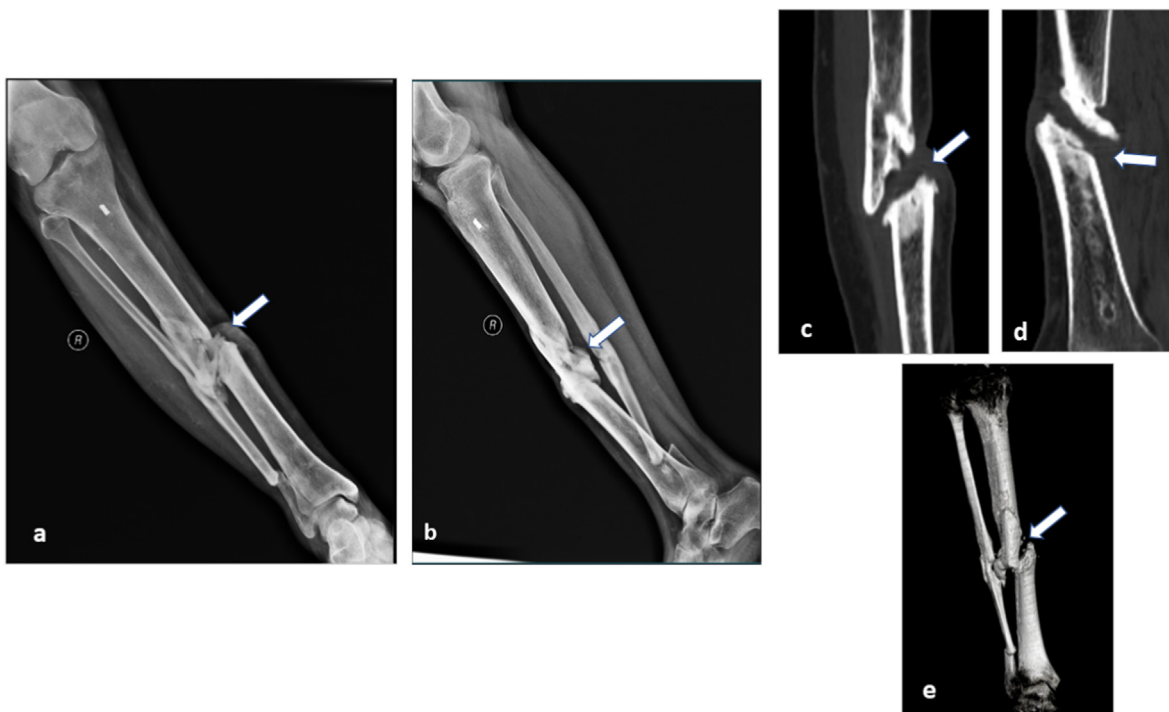

Fig. 3. Assessment of fracture union: Follow up case of open fracture of tibia managed with external fixator. On follow-up at 6 months, AP (a) and lateral radiographs (b)of the leg showed doubtful union of tibia (arrow in a, b) and fibula. CT scan was done to assess bony union. Sagittal and coronal formats (c and d) and three dimensional volumetric re-constructions (e) showed complete non-union at the tibia (arrow in c, d, e).
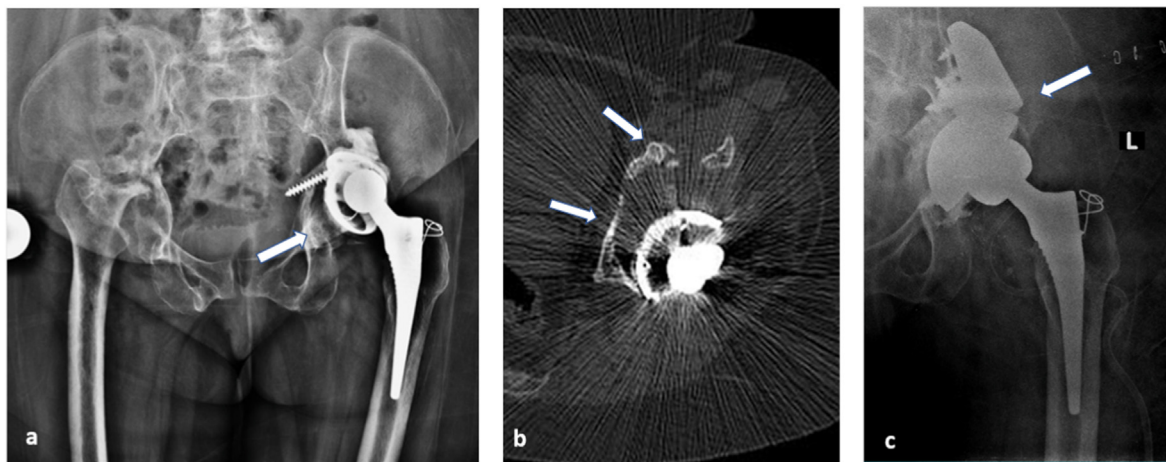
Fig. 4. Evaluating suspected implant malposition: This 48 year old female with rheumatoid arthritis, who has undergone left total hip replacement one and half years back presented with dull aching left hip pain. Anteroposterior radiograph of pelvis with both hips (a)revealed loosening of the acetabular component and superior migration (arrow in a) with periarticular osteopenia. CT scan (b) confirmed the findings and additionally helped assess the extent of acetabular bone loss in specific regions (arrows in b). Post-surgical radiography showing acetabular cup with augmentation using a posterior column buttress (arrows in c) based on planning done on CT scan images.

1.2. Differentiating between aseptic and septic loosening in joint replacement — which imaging modality is preferable?

In failed prosthetic joint replacements, delineating the mechanism of failure is critical for planning ongoing clinical management.[3,23] Clinical evaluation comprises clinical assessment in conjunction with imaging; in the form of plain radiographs, cross-sectional imaging, or nuclear medicine studies.[24] Component loosening, whereby the bone-implant interface becomes loosened, is a commonly reported mechanism of implant failure.[25] The cause of loosening is broadly divided into either septic or aseptic loosening, with differentiating between these causes a major diagnostic challenge.[3] Distinguishing between these causes is clinically relevant; component failure due to aseptic loosening can be managed in a single-stage operation, whereas components loosened by established infection require multi-disciplinary input and more extensive staged operative intervention.

Differentiating between septic and aseptic loosening is not possible on plain radiograph analysis alone, with lysis at the bone-implant interface appearing identical in both aseptic and septic loosening.[25,26] The use of additional imaging modalities is required to evaluate the cause of loosening, in conjunction with blood test monitoring and clinical assessment. The work of Cyteval et al. theorises that radiological identification of soft tissue reaction and inflammatory synovium around a loosened implant can point towards infection as the precipitating cause, as opposed to aseptic loosening.[27] Intravenous contrast used with computerised tomography (CT) has proved to be an adequate and accessible imaging modality in this instance, with an adequate radiological evaluation of both bone and soft tissue.[28] Ultrasound has limited utility in diagnosing deep tissue collection due to the shallow field of imaging afforded by the modality, however, it is a valuable diagnostic tool in evaluating superficial collection without being obscured by metal artifact.[1,28] In the event of equivocal findings from either modality described, more sophisticated techniques can be pursued to evaluate the underlying cause of component loosening.

Within the radiology community, debate exists regarding the modality of choice for differentiating between component loosening due to infectious and non-infectious causes.[29] Leukocyte-marrow scintigraphy is currently favoured, with imaging quality not impeded by implant artifact.[30] Leukocyte labeled imaging stains neutrophils. Hence the procedure is a robust method of detecting neutrophil-mediated bacterial infection. The literature's reported accuracy rates are quoted at 90% in differentiating between aseptic and septic loosening with this technique.[27] This modality is often available in select centers and is both a labour and cost-intensive technique.[31]

An emerging technique, Fluoride-FDG Positron emission tomography/CT, has been shown to provide less radiation exposure and lower cost than the aforementioned radiolabelling leukocyte labelling techniques, with related studies corroborating robust results findings.[32,33] Initial study findings are positive, but current data lacks validation from the broader community. Broadly speaking however, if diagnosis from this modality is inconclusive, leukocyte marrow scintigraphy is often sought to solidify the diagnosis.

MRI has greatest advantage to show soft tissue abnormality, and also in differentiating suspected infection (Fig. 5). Recent study by Galley et al. showed that the presence of periosteal reaction, capsule edema, and intramuscular edema after total hip arthroplasty by MRI had a high accuracy in evaluation of periprosthetic infection.[34] Aliprandi et al. were able to use MRI to identify and characterize fluid collections as being serous, purulent, or bloody and to detect soft-tissue edema and fistulous tracts.[35] Similarly, for knee arthroplasty, MRI has been shown to be highly sensitive (92%) and specific (99%) to detect infection.[36] Clinical examination, patient symptoms, and blood investigations are vital points that help the clinician narrow the diagnosis of infection before imaging in most cases.

Metallosis/aseptic lymphocyte-dominated vasculitis-associated lesion (ALVAL): Radiographs and CT scans are less specific than MRI in the detection and quantification of the ALVAL lesions.[37] MRI can demonstrate ALVAL lesions following metal-on-metal prostheses even in asymptomatic patients. The hallmark appearance of metallosis at MR imaging is a lobulated mass adjacent to the capsule of the joint or bone that shows homogeneous low signal intensity on T2-weighted images and is surrounded by a rim with low T2 signal intensity. On T1-weighted images, the mass shows intermediate-to-high signal intensity, with focal areas of low T1 signal intensity typically at the periphery (Fig. 6).

Williams et al. recommended that USG surveillance be performed in all asymptomatic patients to detect ALVAL lesions.[38] Nishii et al. found USG to be 74% sensitive and 92% specific in detecting adverse local tissue reaction compared to the gold
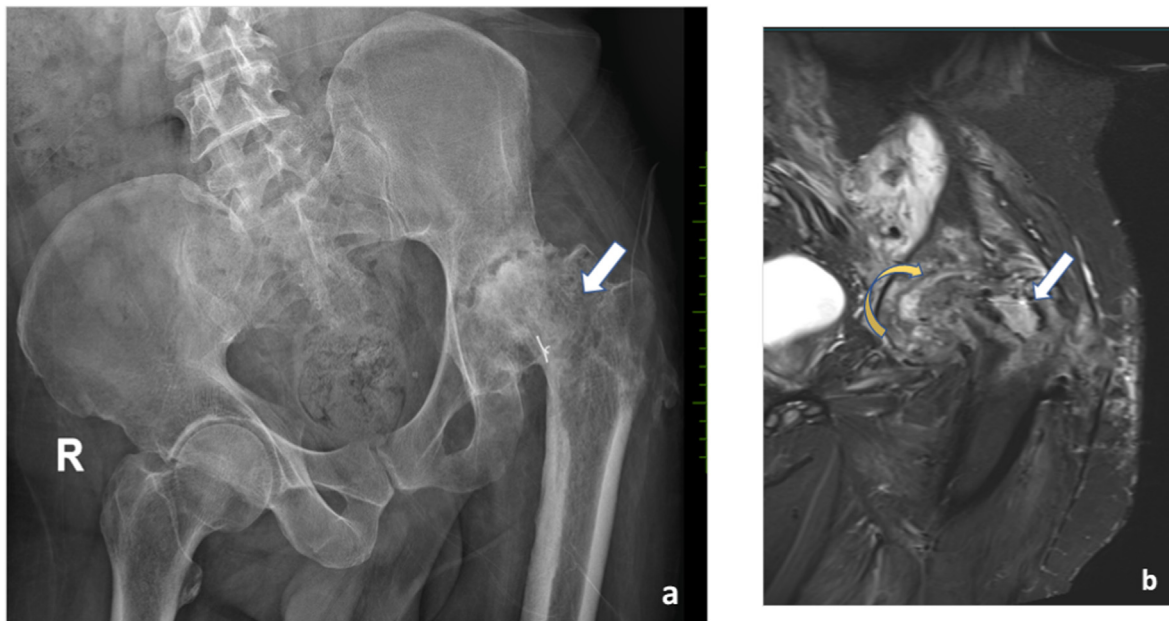
Fig. 5. To rule out infection: Post implant removal - patient presented with complaints of pain in left hip. Anteroposterior radiograph (a) shows screw tracts (arrows in a) in the left neck of femur with severe arthritic changes (flattening of the left femoral head, articular surface irregularity, joint space reduction and deformity). Elevated inflammatory markers raised suspicion of possible infection. MRI demonstrated - T2 axial (b) and coronal STIR (c) images show significant subarticular marrow edema (curved arrow in b), soft tissue edema (blue arrow in b) and screw tract abscess (white arrow in b), suggestive of infection.
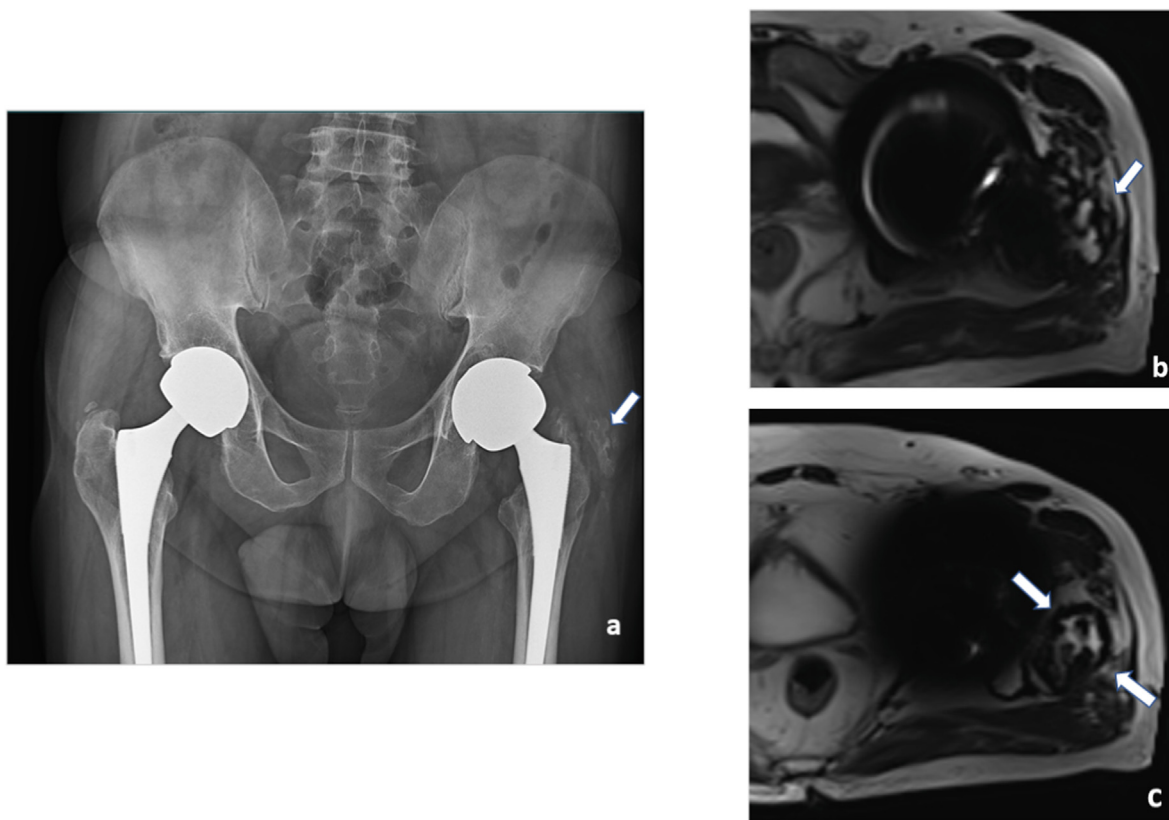

Fig. 6. Evaluation of HO: Patient with post traumatic left hip arthritis presented with stiffness and foot drop, AP radiograph of pelvis and both hips (a) shows trans articular screws in situ with deformation of femoral head. severe degenerative changes and periarticular heterotrophic soft tissue ossification. Axial sections of CT scan (b) shows heterotrophic ossification in the posterior aspect of left hip (b)with reduced intermuscular fat plane along course of left sciatic nerve. Post operative radiograph (c)shows-myositis mass excision and implant removal with total hip replacement.

standard of MRI of metal-on-metal prostheses. [39]

Localized areas of bone resorption around joint prothesis occur due to the release of small particles of cement, polyethylene, or metal. This may lead to osteolysis and subsequent arthroplasty implant failure. The condition may be clinically silent, emphasizing the need for imaging even on slight suspicion. Radiographs are typically the first method of identifying these areas of bone resorption. Special views can be used to supplement the AP radiograph for this assessment. However, considerable bone loss is necessary before lesions are identified with certainty on radiographs. Puri et al. found the sensitivity of radiographs for identifying osteolytic acetabular lesions to be 62% and the specificity 100% in comparison to a CT standard. [40] MRI has been reported to be the most accurate method for detecting and quantifying osteolysis and wear-induced synovitis after hip arthroplasty. A study on cadaver models involving hip replacements showed MRI to be the most sensitive test (95.4%) for detecting periacetabular lesions, although CT was the most accurate for determining lesion volume. [41] On imaging, hallmark features of particle disease include T2-weighted MR imaging demonstrating fluid collections or effusions with intermediate-to-high signal intensity, with specific segmental foci at periphery representing disorganized, irregular synovitis.

1.3. Evaluation of heterotopic ossification (HO)

Radiographs are the standard investigation pf choice for evaluating HO. In many cases, they are incidentally discovered during routine radiographs. CT scans are used to identify and determine the volume of heterotopic bone, the extent of bridging across the joint, and assess the maturity and relationship to neurovascular structures. [42] MRI is not the primary modality for diagnosing HO; rather its main use is to differentiate heterotopic ossification from infection.

A three-phase bone scan has shown to be the most sensitive test for detecting heterotopic ossification in patients. [43] Flow studies and blood-pool images can detect heterotopic bone approximately 2.5 weeks after injury. However in practice, the performance of bone scanning for determination of the maturity of hetero-topic ossification for surgical resection is not routinely done. In our institute, we prefer to use CT scan with contrast before surgical resection (Fig. 7) as it also acts a useful aid in surgical planning.

Evaluation of suspected tendon, muscle, bursal pathologies and nerve injury: Superficial tendon, muscles as well as neurovascular injuries and bursal pathologies can be easily detected by ultrasound (Fig. 8); however, deeper structures require MRI. [44]

1.4. Evaluation of suspected tumour recurrence post-surgery

Evaluation starts from proper history-taking and physical examination during every follow-up visit. Tumour characteristics including location and grade have a substantial impact on the local recurrence and imply the need for follow-up imaging. [45]

Routine follow-up of these patients, especially involving bone tumour, is mainly by serial radiographs. In the immediate postoperative period, the baseline radiograph is extremely important since it shows the osseous and soft tissue changes following surgery. USG is helpful to detect soft tissue mass, especially in superficial regions, and useful in biopsies. [46] MRI is the modality of choice to differentiate residual or recurrent tumors from post-surgical scars in the post-operative period. Many tumour mimics can complicate the imaging. Fortunately, there are many advancements in MR imaging that can be problem-solving along with routine sequences. The details of imaging appearances of recurrence and mimics are shown in Table 3.

PET(Positron emission tomography) -CT can be used as a problem-solving tool when MRI is equivocal for tumour recurrence, shows extensive artifacts, or is contraindicated. Tumour residue or recurrence appears as hypermetabolic tissue with increased standardized uptake values (SUV). Patients with implants, however can show false positive uptake scans. [47] Discussion of suspected cases of recurrence will benefit from MDT (multi-disciplinary team) discussion, and allows better judgement making in complex cases. [48]

Biopsy of suspicious areas might be necessary in equivocal cases to confirm the presence of recurrence and initiate appropriate treatment. DCE-MRI (Fig. 9) and PET-CT can target highly perfused and metabolically active tissue, which will increase the chances of a positive diagnostic yield of the planned biopsy. US-MR fusion and MRI-guided wire localization are other options that have been tried for targeting tumour tissue. [49–51]

Advanced imaging techniques including MR elastography, MR spectroscopy, and recent advances in artificial intelligence like machine learning and feature extraction in radionics have shown promising results for evaluating post-treatment soft tissue tumour recurrence. However, these are still in research areas. Depending on the tumour characteristics and available sources, clinicians can tailor the follow-up strategies in these patients as illustrated in the flow chart (Fig. 10).
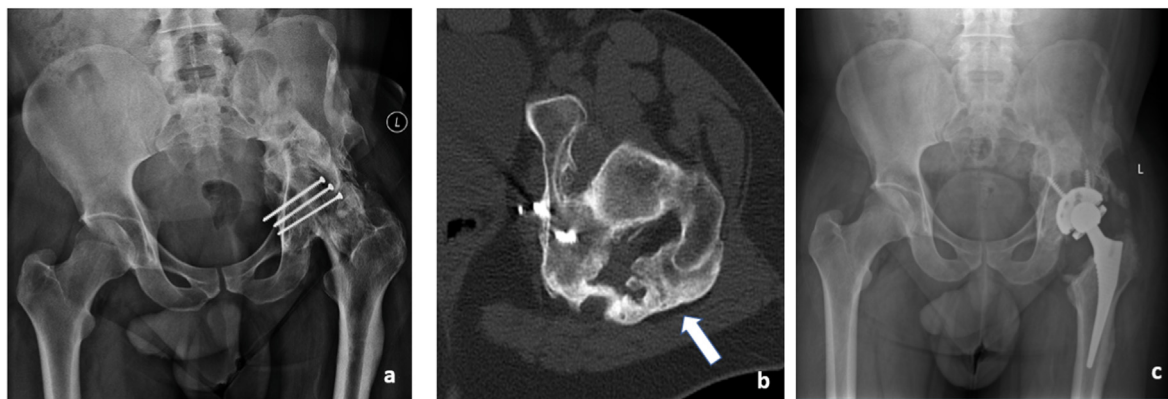

Fig. 7. Case of bilateral total hip replacement with complaints of hip pain for 2 months.
AP radiographs of pelvis and both hips (a) shows suspected heterotopic ossification (arrows in a) along the greater trochanter. MRI axial T2 weighted images (b) periprosthetic fluid collection with central hypointense foci and capsule (arrows in b and c), suggestive of metallosis.
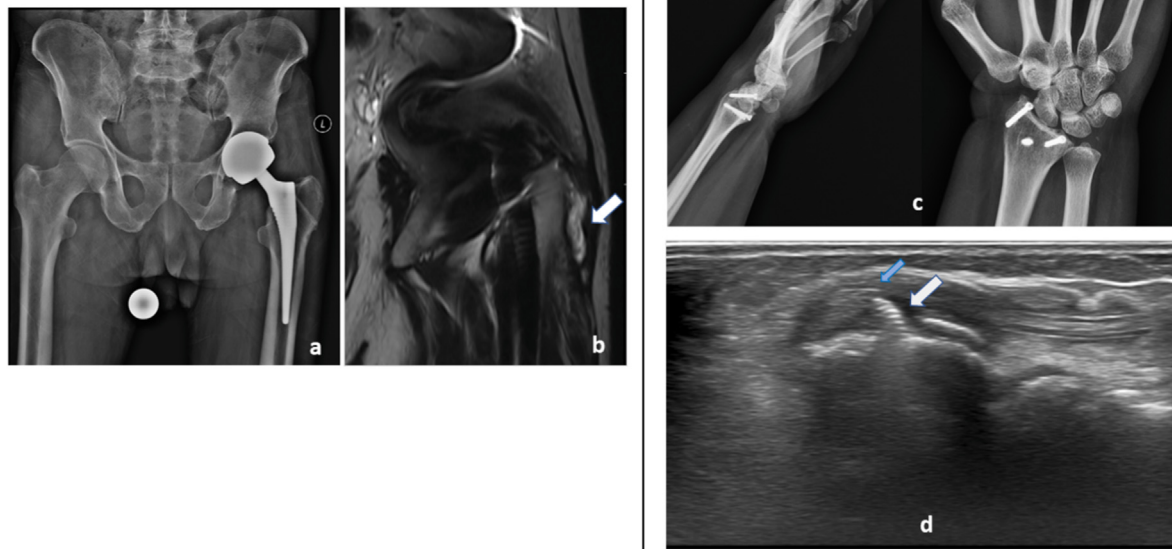
Fig. 8. Evaluating implant related muscle, tendon and bursal pathologies: Patient with left hip implant 8 year post surgery with left hip pain AP radiograph (a) shows no significant abnormality. MRI T2 coronal image (b) shows left greater trochanteric bursitis (arrows in b). Patient with history of injury to the wrist 6 years back, post-surgical status, presented with complaints of pain in the wrist for past 2 years. AP and Lateral radiographs of wrist showed no significant abnormality. Ultrasound image the tip of implant (white arrows in c) at the level of listers tubercle impinging on the extensor digitorum tendon (blue arrow in d), which is thickened with fluid accumulation within the tendon sheath.

Table 3
Common postoperative complications and their respective imaging modalities.

Complication	MRI Findings	Role of advanced Imaging	Pitfalls and precautions
Hematoma/ Seroma	Signal intensity varies with age of hematoma	**Gradient-echo imaging** shows areas of blooming in the region of hematoma. These areas will not show any post contrast enhancement.	When haemorrhage occurs within the tumour it may not be possible to differentiate.
	Seroma is well defined, Homogeneous area with T1 hypointense and T2 hyperintense with low-intensity rim caused by deposition of hemosiderin	**DWI:** ADC is significantly higher compared to recurrent tumour	Recurrent myxomas are T2 hyperintense-show post contrast enhancement and mimic seroma
Post-surgical hypertrophic scar/ Pseudotumor	Can be bulky mass- like progressively enlarging, irregular shape T1: Hypointense T2: Hypointense Little/no post contrast enhancement	**DWI:** Increased ADC values **DCE:** Almost never shows arterial phase enhancement	Early inflammatory pseudotumors with granulation tissue might show T2 hyper intensity and enhancement pattern mimicking tumour
Pseudo-progression	Post radiation/post chemotherapy Heterogeneous signal intensity Enlargement of central non-enhancing component with reduced solid enhancing areas	The residual tumour will show persistent enhancement and diffusion restriction. The pseudo-progression will show blooming in gradient sequences with non-enhancement and no diffusion restriction.	Avoid imaging for 4–6weeks following therapy to allow differentiation form recurrence.
Post radiation reactive changes in soft tissue, flaps and bone	**Soft tissue:** Diffuse edema with preserved architecture ("muscle texture sign or feathering sign" on T1 weighted images) limited to the radiation field is seen within the muscles and the flap.	**DWI:** Low signal on DWI and high signal on ADC	Follow up imaging muscle atrophy with fat overgrowth. The overall flap size will decrease.
	Radiation osteitis: T2/STIR hyperintense areas in the marrow Radiation osteonecrosis: New heterogeneous area within irradiated area T1 hyperintense T2 intermediate signal intensity	**DCE:** Delayed enhancement	New mass or bone destruction within radiation field, Heterogenous signal intensity lesion with matrix calcification can be sarcoma and should not be mistaken for osteonecrosis.
Tumour recurrence Bone/soft tissue	Focal progressively enlarging mass with heterogeneous signal intensity	Shows Post contrast enhancement with increase diffusion restriction and decreased ADC values.	Certain Densely ossified tumors and fibrous tumors may remain T2 hypointese.
	Replacement of normal muscle texture	Diffusion quantification also known as tumor ADC histograms represent the distribution of ADC values within the tumor. Malignant tumor components generally show ADC values less than 1.0 x 10-3 mm2/s	No optimal cut off value between different vendors for ADC parameters.
	T1 hypointensity T2 hyperintensity Similar in signal intensity to primary tumor	**DCE:** Early arterial phase enhancement with washout or plateau in highly vascular recurrent tumor as seen in time intensity curves.	Time consuming for routine clinical use and may not be available in all centers

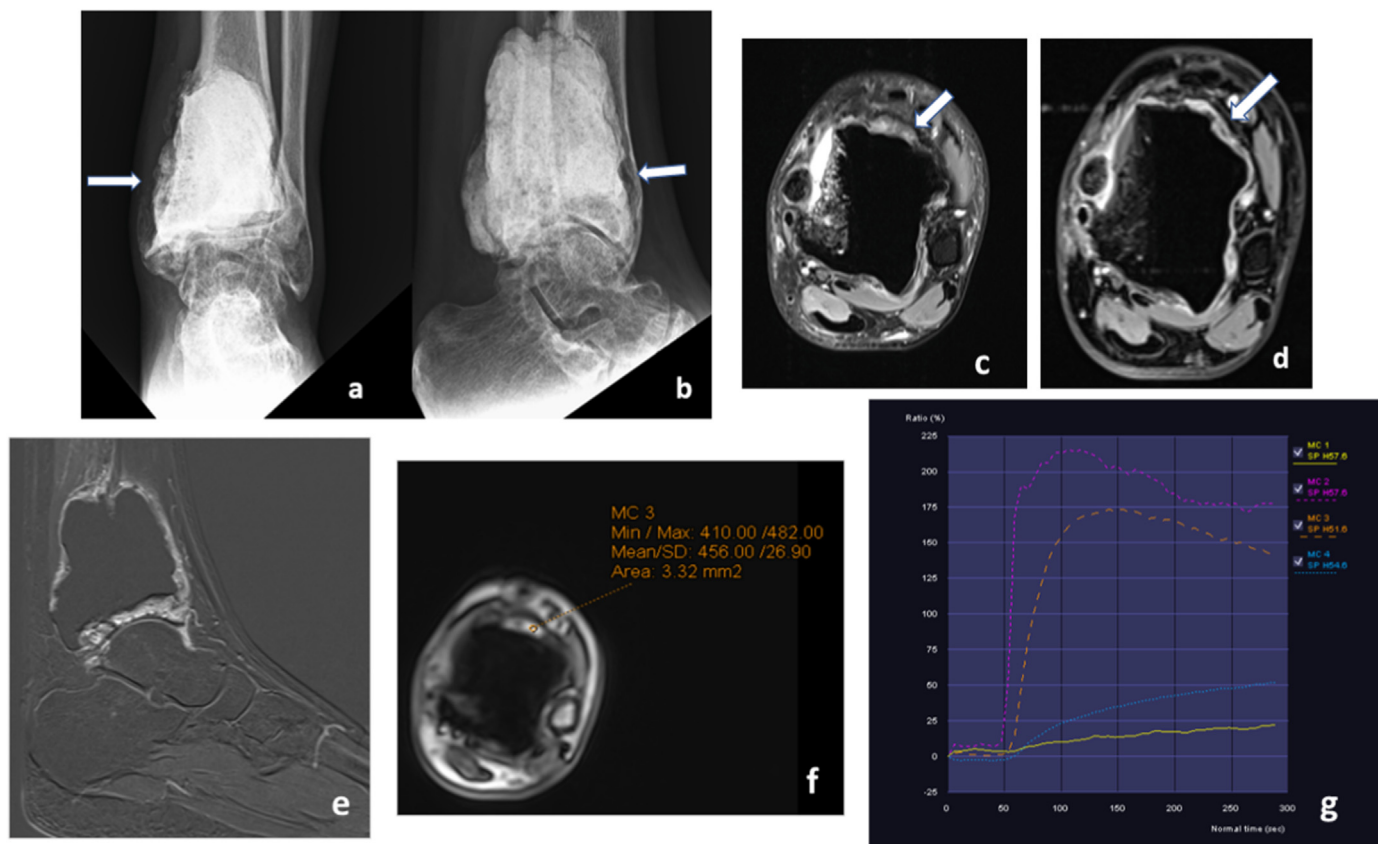**DCE** – Dynamic contrast enhancement; **DWI** – Diffusion weighted image.

Fig. 9. Evaluating suspected tumour recurrence: Follow up case of giant cell tumour of tibia-post excision and augmentation with bone cement- AP and lateral radiographs (a and b) reveal mild cortical irregularities with lucency in the medial and anterior aspect of tibia. MRI was done to rule out recurrence. Proton density fat saturated axial images (c) showed suspicious areas of T2 hypointensity with postcontrast enhancement (d) along the anterior aspect of bone cement(arrows), better seen in subtraction image (e). Time-signal intensity curves of dynamic contrast enhanced images with region of interest on suspicious area (orange curve in g) shows type I enhancement (rapid wash in and wash out of contrast) which is similar to the arterial washout pattern (Pink curve in g). Compare with normal soft tissue and scar (blue and yellow curves in g).
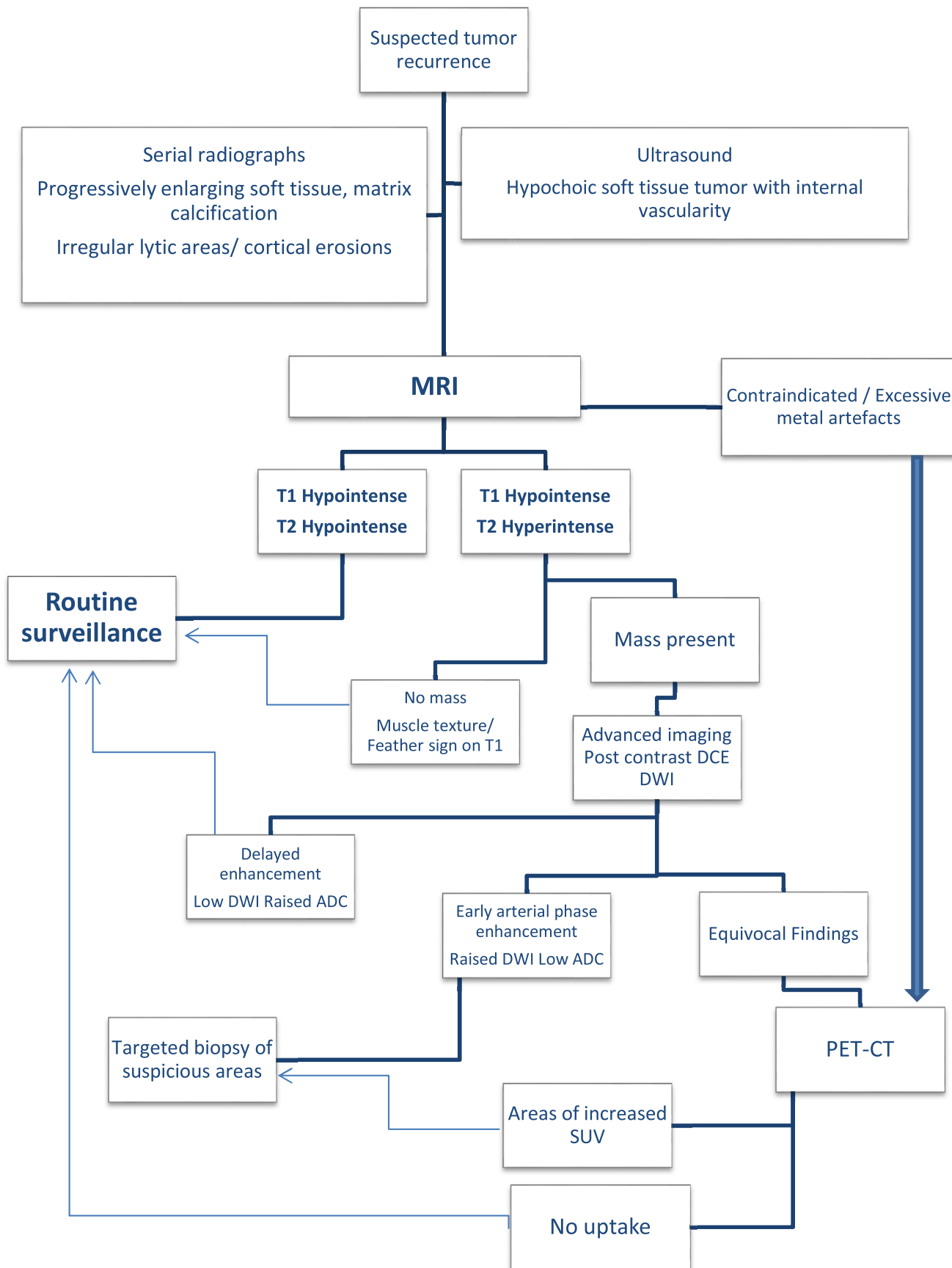
Fig. 10. Flowchart depicting the imaging modalities for a patient with suspected tumour recurrence post-surgery.

2. Limitations & future directions

Despite recent advances in imaging, there remains no proven 'gold standard' imaging modality following musculoskeletal surgery to detect complications. The investigations of choice are also based on availability and affordability, especially in the developing world. Standardization of protocols of imaging would go a long way in making clinicians diagnose better. Improving image quality, especially by reducing implant artifacts, would be a fertile ground for future research. Nuclear medicine has shown promise in the early detection of tumour recurrence and differentiating inflammatory changes from sinister features. This modality could increasingly be employed if resources are available. However, irrespective of the investigation modality, clinical examination is of utmost importance and can help clinch the exact diagnosis in most cases. Formulation of multi-disciplinary clinics in institutions, co-ordinated discussion of findings, and combined clinics involving orthopaedic surgeons and radiologists could benefit all involved.

Imaging in post operative period following musculoskeletal surgeries can be challenging due to soft tissue changes and the presence of graft and implants. Although radiographs play a primary role in post-operative imaging, cross-sectional imaging and nuclear medicine imaging with a plethora of recent advances are valuable and vital problem-solving modalities. Ultrasound (US) has a limited role in the assessment of most complications. Still, it is a simple helpful modality to identify post-surgery hematoma, periprosthetic fluid collections, the presence of soft tissue sinus tracts, and also tendon and ligament status. Plain radiographs are still the first-line investigation of choice to assess early complications related to bone and implants. CT scan is simple to perform and readily available, making it an excellent tool to supplement radiographs when evaluating bone status, periprosthetic soft tissue ossifications, and implant positioning. MRI with evolved metal artifact reduction techniques (MARS) has become an essential diagnostic tool for assessing soft tissue abnormalities and is particularly useful in identifying adverse local tissue reactions in metal on metal implants. CT and MRI are accurate in determining most causes of the complications except infection, for which leukocyte-marrow scintigraphy is considered the modality of choice. Single-photon emission computed tomography with CT (SPECT-CT) is an emerging modality that has been shown to combine the sensitivity that bone scintigraphy offers with the high specificity of CT and has the advantage of showing the bone's metabolic activity. Based on the clinical scenarios, clinicians can choose imaging modalities depending on choice and availability in the local site. Knowledge of the advantages and limitations of advanced imaging is crucial for both radiologists and surgeons for collaborative diagnosis, ultimately benefitting patient care.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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