Diagnostic protocols in oncology: workup and treatment planning. Part 2: Abbreviated MR protocol

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Abstract. – **Magnetic resonance imaging (MRI) is a non-invasive imaging technique (non-ionizing radiation) with superior soft tissue contrasts and potential morphological and functional applications. However, long examination and interpretation times, as well as higher costs, still represent barriers to MRI use in clinical routine. Abbreviated MRI protocols have emerged as an alternative to standard MRI protocols. Abbreviated MRI protocols eliminate redundant sequences that negatively affect cost, acquisition time, patient comfort. However, the diagnostic information is generally not compromised. Abbreviated MRI protocols have already been utilized for hepatocellular carcinoma, for prostate cancer detection, and for nonalcoholic fatty liver disease screening.**

Key Words:
  Oncologic imaging, Magnetic resonance study, Abbreviated protocol, Computed tomography, Radiation exposure.

Introduction

The radiology practice has been focused on the interpretation of images, which was facilitated entirely by human observation and recollection[1-8]. These interpretations are critical for disease and patient management, including diagnosis, prognosis, staging, and assessment of treatment response[9-14]. The spread in expertise in cancer and the opportunity to obtain a tailored treatment by choosing a proper approach, as well as the management of patients within a multidisciplinary team has increased the patient prognosis[13;15-28]. The implicated features are a more suitable surveillance for the patient at risk for cancer development and a progress in the therapies' efficacy due to a better patient selection[29-37]. Moreover, the implicated features and a more strategic approach could give the possibility to identify responders or non-responders to therapies, as soon as possible and the possibility to select different treatments related to genomic data[38-42].

Medical imaging comprises a huge number of techniques, and multiple biomedical techniques are used in different phases of cancer management[43-49]. Computed tomography (CT) is the main diagnostic tool in oncologic setting, and it is usually used for detection, staging and follow-up phases[50-60]. Although only 9% of all radiological

examinations are CT, they contribute to up to 65% of the medically radiation exposure[61]. The patient radiation exposure has been a topic of interest in radiological setting for long[62]. Consequently, the constant reduction, optimization as well as dose inter- and intraindividual consistency are major areas in radiological field[63-70]. The administration of intravenous contrast media (CM) is an integral element of many CT examination protocols. CM administration is also accompanied by a low but proven risk for adverse reactions, in particular allergic reactions and contrast-induced nephropathy[71-72]. Therefore, the need for CM administration should always be scrutinized and the lowest adequate dose should be used[72].

Magnetic resonance imaging (MRI) is a non-invasive imaging technique (non-ionizing radiation) that have superior soft tissue contrasts and potential physiological and functional applications[73-77]. However, long examination and interpretation times, as well as higher costs, still represent barriers to MRI use in clinical practice[79]. Abbreviated MRI protocols eliminate redundant sequences that negatively affect cost, acquisition time, patient comfort. Abbreviated MRI protocols have already been utilyzed successfully for hepatocellular carcinoma screening, for prostate cancer detection, and for nonalcoholic fatty liver disease screening, as well as monitoring patients with this disease[80-85].

The aim of this manuscript is to provide a narrative review reporting an update on the state of the art of the abbreviated protocols in MRI. In addition, we described the latest knowledge in the field of artificial intelligence (AI) in the daily practice of radiology in order to optimize studies protocol.

Abbreviated MRI Liver Protocol

The greatest approval of abbreviated liver MRI protocol has been in screening of patients at risk for hepatocellular carcinoma (HCC)[86-92]. These fast protocols are simplified shorter studies[86-88] comprising a lesser number of sequences that are adapted to the assessment of specific disease. Although the effectiveness of MRI in HCCs, both for detection and staging and for the assessment of treatment is well-established[92-97], its higher cost and longer study time compared with CT might limit its appliance. With regard to the use and the type of contrast medium, three methods have been developed: non-contrast abbreviated protocol (NC-AMRI), dynamic contrast-enhanced abbreviated protocol (Dynamic-AMRI), and hepatobiliary phase contrast-enhanced (HBP) abbreviated protocol[97]. These procedures can be completed in 10 minutes, significantly less to the standard protocol. NC-AMRI shows several advantages. By avoiding gadolinium-based contrast agent (GBCA), it limits costs, is safe, avoiding IV placement, and reduces acquisition time. The main limit is that it is an unenhanced study, diminishing the HCC characterization. The addition of DWI could assist the focal liver nodules assessment. However, several HCCs may not show restricted diffusion[98,99]. Dynamic-AMRI acquires dynamic contrast enhanced sequences using T1-W sequences with fat suppression following administration of an extracellular contrast medium. This protocol allows detecting and characterizing HCCs based on the vascular pattern[98]. This protocol offers the advantages to define major features of HCC according to LI-RADS so that dynamic AMRI alone is sufficient to definitive diagnosis of HCC[99-108]. The disadvantages is related to the lack ancillary features[97]. HBP-AMRI is based on the acquisition of T1-W FS sequences after the administration of the hepatobiliary agent, gadoxetate disodium. HBP-AMRI offers several advantages: high-contrast-to-noise, aiding in lesion detection. The 20-min delay also allows hand injection of contrast while the patient is in the waiting room, which simplifies workflow, reduces the acquisition time, thus reducing the examination cost. However, with this protocol no data on vascular lesion profile is given[97].

Due to the repetitive nature of surveillance imaging, the use of CT results in an unacceptably high cumulative radiation risk, especially in patients with HBV infection and well-compensated cirrhosis[97]. In addition, conventional MRI, due to the large number of imaging sequences and the length and complexity of complete diagnostic protocols, they are not cost- or time-effective for HCC. Consequently, several research have suggested abbreviated approaches in an effort to make MRI a more feasible option for HCC surveillance[86-92]. Marks et al[92] assessed an abbreviated protocol (including only a T2-weighted single-shot fast spin-echo [SSFSE] sequence and a contrast-enhanced T1-weighted hepatobiliary phase sequence) reporting a mean per-patient sensitivity and negative predictive value of 82.6% and 93.2%. They showed that this protocol might be an acceptable lower-cost alternative to the conventional protocol. Besa et[87] showed that an abbreviated protocol, including contrast-enhanced T1-weighted hepatobiliary phase after gadoxetic

acid injection, DWI, T1-weighted in-phase and out-of-phase, and T2-weighted FSE sequences, yielded a per-patient sensitivity of 80.6% and a negative predictive value of 90.0%. Moreover, the estimated cost reduction ranged between 30.7% and 49.0% below the standard MRI cost. A recent meta-analysis[88] showed that surveillance with abbreviated protocol had a good overall diagnostic performance for detecting HCC, with pooled sensitivities for detection of any-stage and early-stage HCC of 86% (95% CI, 80-90%) and 81% (95% CI, 69-89%), respectively. Both HBP-AMRI and NC-AMRI protocols demonstrated acceptable diagnostic performance for HCC surveillance and would therefore be clinically useful for patient surveillance.

In the context of treatment assessment (Figure 1), although the adoption of imaging tools can be subject to patient characteristics and institutional inclination, it is mandatory to maintain consis-

tency in the imaging performed before and after procedures[108-112]. Accurate assessment of ablated area is crucial to guide further management decisions[28,29]. Follow-up imaging of treated HCC patients should assess new lesions, early recurrence and observe for neovascularity that may allow for detection of pathological angiogenesis within the ablated area[97]. The presence of an enhanced area and washout in a treated lesion raises the suspicion for local recurrence. To the best of our knowledge, only Granata et al[97], assessed the role of abbreviated protocol in evaluation of HCC treatment, showing that the abbreviated dynamic protocol had similar diagnostic accuracy to conventional protocol, with a reduction of the acquisition study time of 30%.

In oncological patients, although MRI utility in the detection and characterization of focal liver lesions is well established[113-122], its high cost and longer acquisition time compared with MDCT
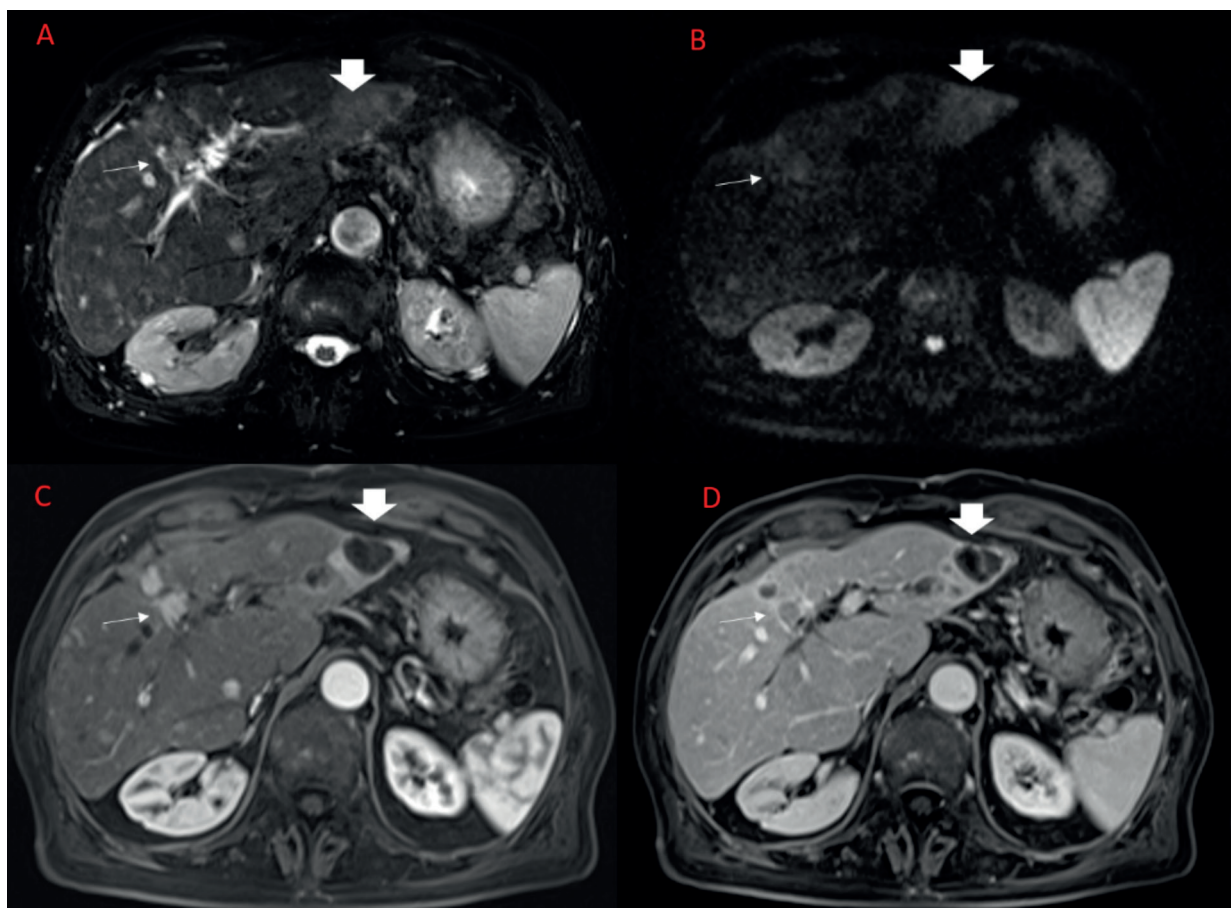

Figure 1. Man 74 y with multiple vital HCC lesions *(arrow)* and necrotic ablated lesion *(arrow-head)*. Vital HCC shows hyperitense signal in T2-W sequences **(A)**, restricted diffusion **(B)**, hyperenhancement during arterial phase of contrast study **(C)** and wash-uot appearance in portal phase **(D)**. Ablated lesion shows hyperitense signal in T2-W sequences **(A)**, restricted diffusion (B: b 800s/mm2) and hypointense signal in arterial **(C)** and portal phase **(D)** of contrast study.
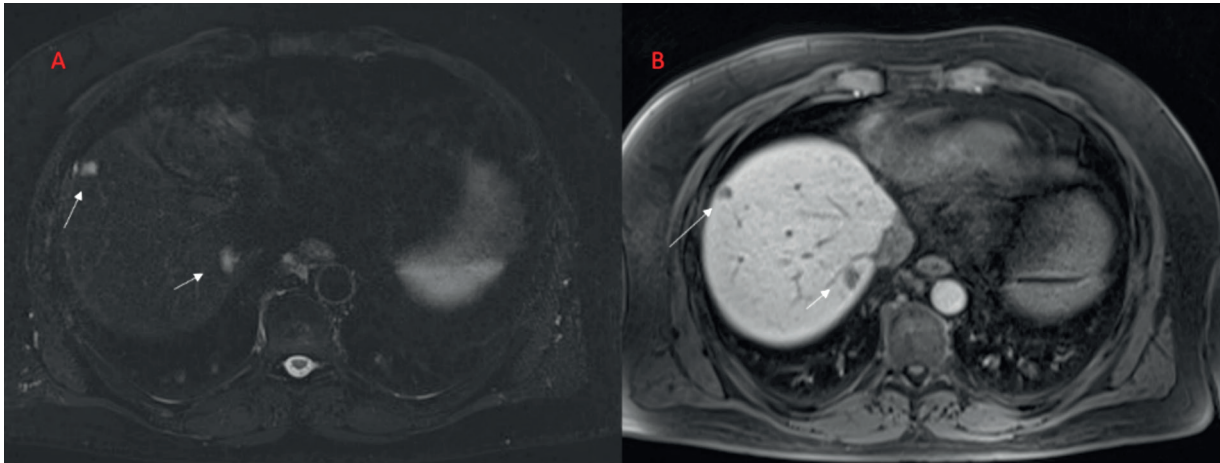
Figure 2. Man 46 y with colorectal liver metastases. The lesions (arrow) show hyperintense signal in T2-W FS sequences **(A)** with hypointense signal in EOB-phase **(B)**.

or ultrasound may limit its widespread use in patients with suspicious liver metastases (figure 2)[123]. However, recent radiological guidelines recommend gadoxetic acid-enhanced MRI for preoperative liver metastasis evaluation because it can detect small metastatic lesions also < 1 cm[119]. It is necessary to shorten the acquisition time of gadoxetic acid-enhanced MRI in patients with cancer for several reasons. First, the number of new patients with cancer is increasing because of the aging population, and the number of cancer survivors is increasing because of advances in early detection and treatment. Therefore, the waiting period for an MRI examination becomes longer, which can delay the more appropriate treatment. Second, a long MRI examination is more likely to be inconvenient for patients with cancer than for healthy individuals[119]. However, although contrast enhanced imaging improved lesion detection, tissue characterization and tumor extent assessment, advances in MR technology, as well as improved of functional sequences as DWI give rise to the question if the administration of contrast agents is actually always needed. In fact, in pre surgical setting after conversion treatment, the radiologist's role is identifying residual metastases in order to assess the resectability. Considering that all lesions in this phase have already been detected and identified, several researches[120-122] showed that MR contrast media administration may not be necessary for pre surgical setting. Granata et al [122] showed that a faster, unenhanced MRI protocol, including DWI and T2-W Fat Suppression sequence, had no significant difference in detection rate of metastases compared to gadolini-

um-enhanced MRI study (Figure 3). According to Granata et al[122], also Barabasch et al[123], in a study of 71 patients who underwent MRI to search for metastases, showed that a nonenhanced protocol (consisting of T2-weighted FSE, diffusion-weighted MRI, and T1-weighted in-phase and opposed-phase sequences) was appropriate to detect and classify liver lesions. Canellas et al[124], in a retrospective study, including 43 patients with pathologically proven liver metastases showed that an abbreviated protocol (including ultrafast spin-echo (SE) T2-weighted, T1-weighted hepatobiliary phase and DWI) had an inter-observer agreement excellent (κ = 0.91), a sensitivity and AUCs for the lesion characterization very high (over 90%) and they found no statistically significant differences in sensitivity and AUCs for lesion characterization compared to conventional protocol. The abbreviated protocol acquisition time was estimated to be less than 10 min.

Abbreviated MRI Pancreatic Protocol

MRI is employed in pancreatic imaging as alternative to or as an adjunct to CT, as a problem-solving tool thanks to its superior soft-tissue resolution[125-128]. Standard pancreatic MRI protocol includes T2 weighted coronal single-shot fast spin-echo (SSFSE), T2-weighted 2D axial fat-suppressed FSE, T1-weighted 2D axial in-phase and opposed-phase gradient echo (GE), axial echo planar diffusion-weighted imaging (DWI) with b values of 50, 500, and 1000, axial unenhanced and contrast-enhanced T1-weighted fat-saturated (arterial, portal, and delayed phases) and coronal contrast-enhanced T1 weighted with fat satura-

tion (delayed phase 3-5 minutes after injection start). Coronal 2D and 3D single-shot MR cholangiopancreatography (MRCP) are recommended for cystic pancreatic lesions or in case of pancreatic duct or main bile duct involvement[5]. Despite the spatial resolution of MRI is lower than CT, gadolinium contrast enhancing T1-weighted sequence is able to assess vascular involvement of pancreatic cancer providing nearly equivalent information to contrast-enhanced CT[5]. Motosugi et al[129] found that contrast-enhanced MRI had greater sensitivity in the detection of liver metastasis than CT. Moreover, many studies[130-139] underlined how DWI is helpful to detect especially small pancreatic NETs and metastasis thanks to its greater image contrast. Therefore, Verde et al[130] proposed an abbreviated MRI protocol for detection and surveillance of pancreatic NETs in patients with multiple endocrine neoplasia type 1 (MEN-1). They found that DWI and T2-weighted images had the highest diagnostic performance in detecting PNETs, suggesting an abbreviated MRI protocol without contrast medium administration in MEN-1 patients undergoing imaging follow-up. For the screening of pancreatic cancer in patients with BReast CAncer susceptibility gene (BRCA) mutation, Corrias et al[138] proposed an abbreviated pancreatic MRI protocol performed in conjunction with breast MRI. They suggested a rapid screening pancreatic MR protocol during

less than 10 minutes and that consisted of: coronal navigator-triggered (NT) T2 SSFSE, axial NT T2 SSFSE, axial DWI (b=0, 20, 50, 80, 250, 500, and 800 s/mm^2), and axial T1 post-contrast fast spoiled gradient echo (with contrast administration during the breast MRI examination). For the surveillance of cystic disease (Figure 4), abbreviated MRI protocols represent a good alternative. In literature, many authors suggested an MRI protocol without administration of a contrast agent. In their retrospective study on 56 patients with pancreatic cysts, Macari et al[132] found that contrast-enhanced images did not lead to different treatment recommendations compared to unenhanced images. Nougaret et al[133] found similar results with their follow-up in 301 patients and 1174 cysts: they reported that the only predictor of malignancy is the size of the cyst at diagnosis and the MRI protocol with administration of contrast agent did not provide any additional information. Pedrosa suggested to reserve the standard contrast-enhanced MRI protocol with MRCP for the initial evaluation of pancreatic cystic lesions while for the follow-up he proposed a 10-min MRI protocol consisting of the following sequences: axial and coronal SSFSE T2-weighted, 2D and 3D single shot MRCP, and 3D T1-weighted spoiled gradient echo[134]. On the utility of DWI in the surveillance of pancreatic cystic lesions, there is a debate in literature. Pozzi-Mucelli et al[135] in their
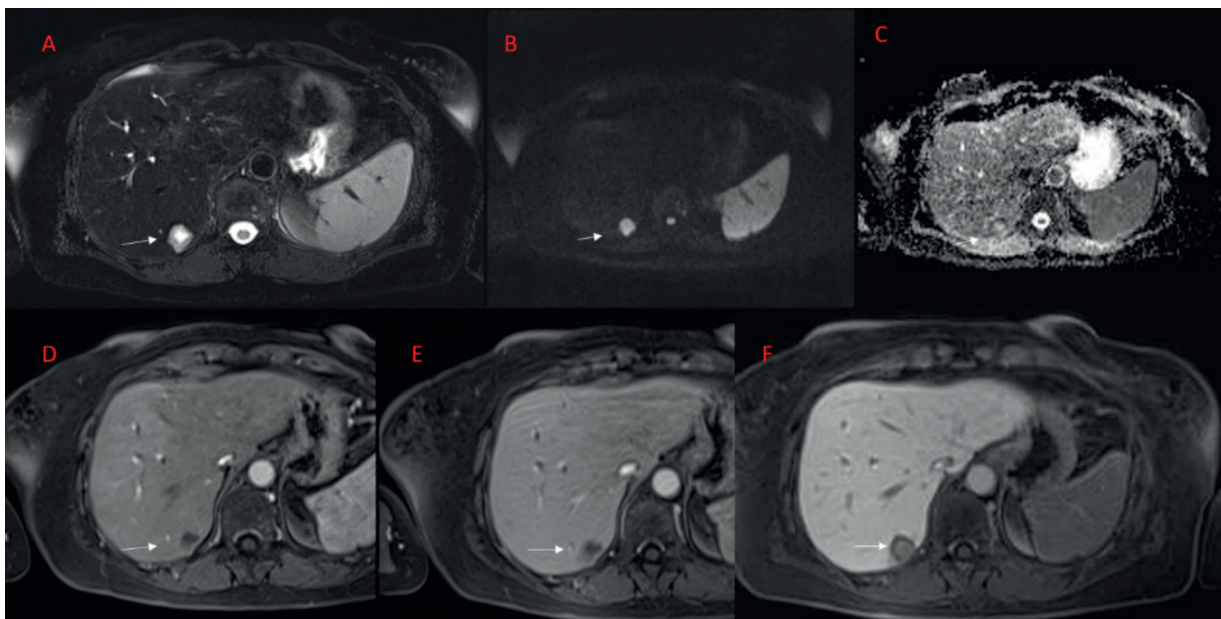

Figure 3. Man 76 y with mucinous colorectal liver metastasis. The lesion shows targetoid appearance in T2-W FS sequences **(A)**, in ADC map **(C)** and EOB phase **(F)**, with restricted diffusion **(B)** b 800 s/mm^2) and hypointense signal during arterial **(D)** and portal **(E)** phase of contrast study.
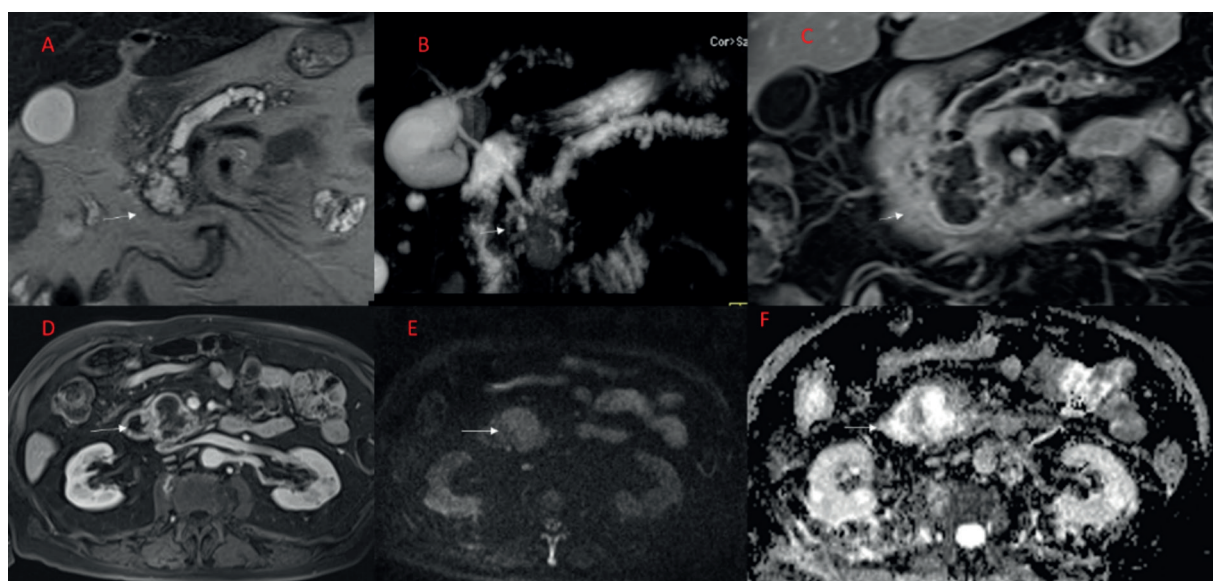
Figure 4. Man 81 y with malignant pancreatic intraductal papillary mucinous neoplasms. The lesion (arrow) shows hyperintense signal in T2 (A) (coronal plane) and cholangiography sequences (B), with contrast ehancement of internal septa (C and D) coronal and axial plane in portal phase) and restricted diffusion (E: b 800 s/mm²). In F ADC map.

retrospective study on 154 patients with pancreatic cystic neoplasms concluded that a short protocol MRI with T2-weighted and unenhanced 3D T1-weighted (total examination time 7-8 min) is more economical and provides equivalent clinical information for patient surveillance compared to a standard protocol.

Abbreviated Breast Magnetic Resonance Imaging

Breast MRI represents the breast imaging technique with the highest diagnostic accuracy, superior to morphological imaging, i.e., mammography, ultrasound and Tomosynthesis[140-144]. The most important indications of contrast-enhanced breast MRI (ce-MRI) are preoperative staging of breast cancer, evaluation during neoadjuvant chemotherapy, screening of high-risk patients and research of the primary tumor in case of Carcinoma of Unknown Primary origin[145-148].

The standard breast MRI protocol includes non-contrast-enhanced acquisitions: T2-weighted and diffusion-weighted imaging (DWI), native T1-weighted acquisition and subsequently the contrast-enhanced series: ultrafast imaging and regular T1-weighted imaging. The acquisition time is about 30 minutes[145].

Among the most important limitations of ce-MRI we find the limited availability, the long duration time and the high costs; elements that make ce-MRI not accessible to all patients who could

benefit from it. The idea of developing abbreviated breast ce-MRI protocol was first presented by Kuhl et al[149] in 2014. The authors compared standard ce-MRI protocol and abbreviated protocol (AP) consisting of one pre- and one post-contrast acquisition and their derived images (first postcontrast subtracted and maximum-intensity projection images) in a prospective reader study in 443 women at intermediate risk for breast cancer. The AP had a duration of only 3 minutes, an image reading time of less than 30 seconds and a diagnostic accuracy equivalent to the standard (Figure 5). Many other studies on the subject were subsequently conducted, evaluating different typologies of APs, such as that of Mango et al[150] composed of one fat-saturated T1-weighted precontrast, early postcontrast T1 and subtraction MIP sequences. The AP was performed in 10-15 minutes compared to the 30-40 minutes of the standard and the sensitivity for each sequence was 96% for the first post-contrast sequence, 96% for the first post-contrast subtraction sequence and 93% for the subtraction MIP sequence. Thus confirming the feasibility of the new APs[150]. Moschetta et al[151] evaluated an AP consisting of a STIR, T2-weighted sequences, a precontrast and single postcontrast T1-weighted sequence and this AP result with a diagnostic accuracy equivalent to the standard. Some other studies have been conducted on AP containing T2-weighted or STIR sequences, such as those of Dogan et al[152]

and of Choi et al[153] while others solely relied on dynamic contrast-enhanced MRI[154,155]. In all the mentioned studies, the diagnostic accuracy of APs was similar to the full MRI protocol.

Over the years, some types of APs have been evaluated to understand which were the most important sequences for a confident breast cancer detection. Strahle et al[156] conclude that T2-weighted, T1-weighted precontrast, first and late postcontrast images are necessary to facilitate detection of suspicious lesions with a reduction of more than 50% of the scan time. Heacock et al found that T2-weighted imaging increased lesion conspicuity without altering cancer detection rate evaluating three different protocols in 107 tumors[157]. The high diagnostic performance of APs was also confirmed

by a review of 21 studies published in 2018, including more than 4500 patients worldwide.

The authors conclude that although there is a need to large-scale prospective studies, abbreviated MRI seems feasible in particular in order to make ce-MRI accessible to a greater patient's number[158]. The subgroup of patients in which the APs have been most studied, as well as in patients with known breast cancer, are intermediate risk patients, i.e., patients with high breast density, with personal history of breast cancer and a history of high-risk lesions at biopsy (specifically, atypical ductal hyperplasia, atypical lobular hyperplasia and lobular carcinoma *in situ*)[159,160]. In the study by Comstock et al[161], the ce-MRI with abbreviated protocol was compared to digital
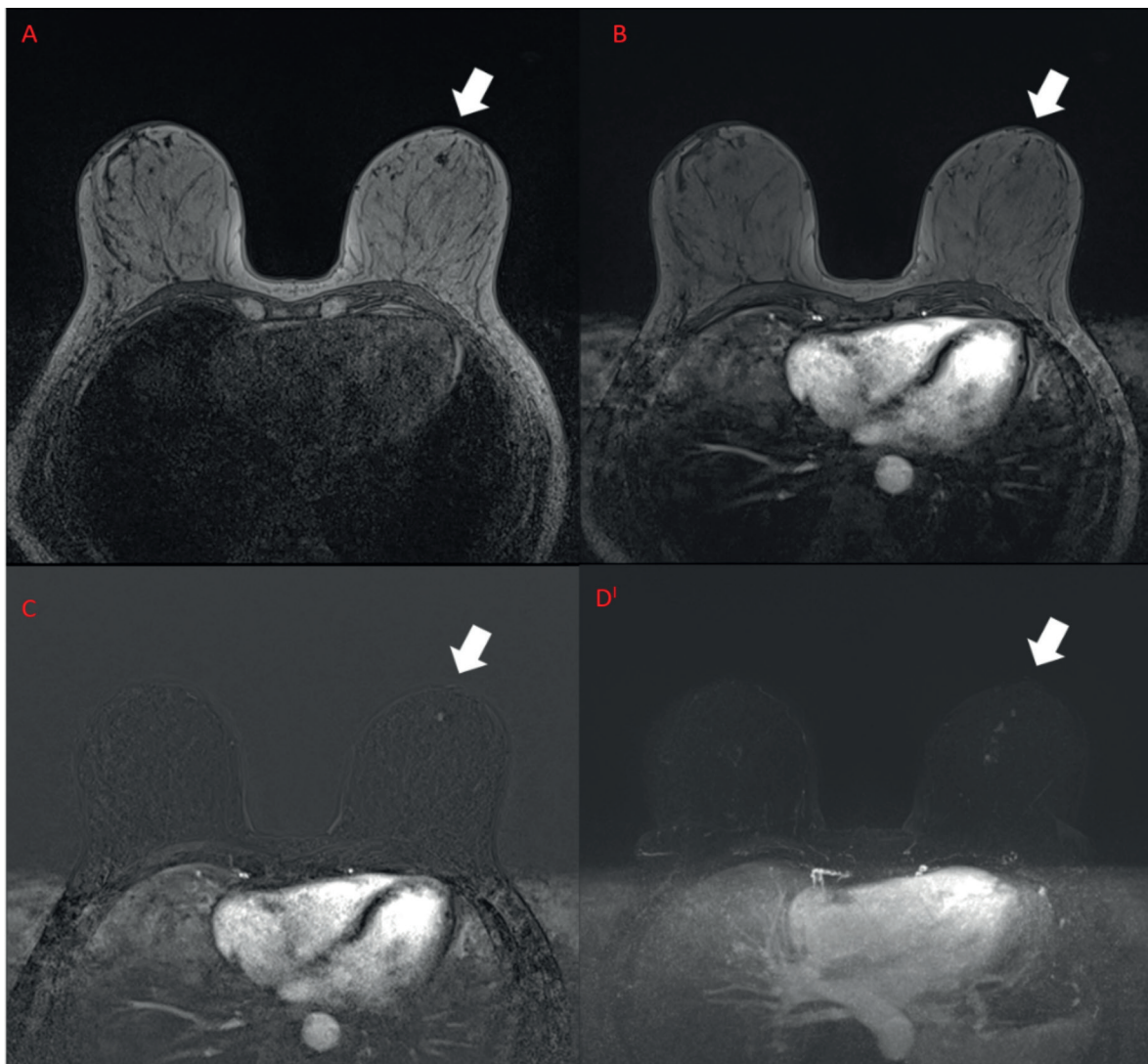

Figure 5. Abbreviated breast MRI protocol shows left lesion **(A** and **B)** with ce in early postcontrast T1 **(C)** and subtraction MIP sequences **(D)**.
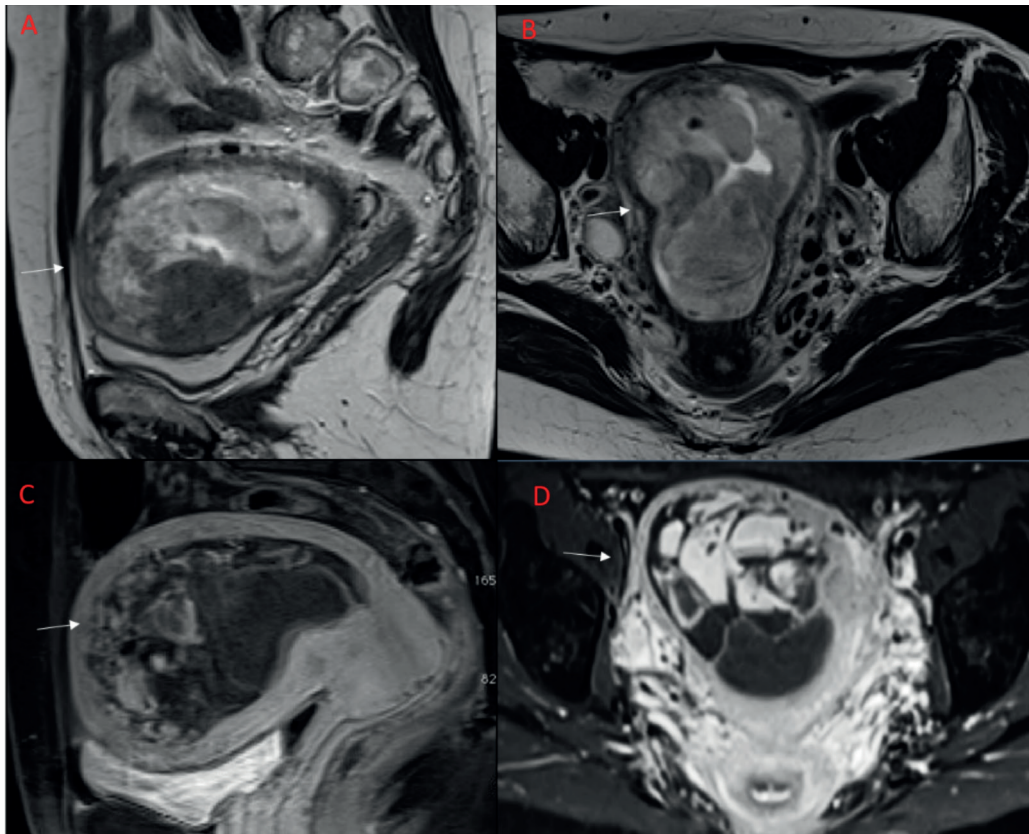
Figure 6. Endometrial Cancer. The lesion shows inhomogeneous signal in T2-W sequences **(A)** sagittal plane; **(B)** axial plane, with progressive contrast enhancement during arterial phase **(C)** and late phase **(D)**.

breast tomosynthesis (DBT) in the screening of patients with dense breasts. In 1444 patients who performed both examinations, abbreviated MRI demonstrated a higher rate of invasive breast cancer detection than DBT. The fundamental finding that emerged from all screening studies conducted with abbreviated MRI is that the cancers identified are early-stage invasive cancers in an extremely relevant percentage (64-97%). In addition, the ductal carcinomas *in situ* identified were also predominantly of intermediate or high grade[161-166]. We could say that screening with abbreviated MRI could identify biologically relevant tumors, abbreviated MRI in general could reduce the costs and times of ce-MRI and thus making it accessible to an increasing number of patients. Further prospective multicentric studies will be needed to further confirm these evidence available to date and to better understand which patients could benefit most from abbreviated MRI.

Endometrial Cancer

Endometrial carcinoma (EC) is the most frequent gynecological malignancy. Diagnosis is made by hysteroscopy with biopsy, which also provides cancer grade and histological type[167]. Disease staging is surgical, based on the International Federation of Gynecology and Obstetrics (FIGO) classification. However, in daily clinical practice several imaging techniques have been used for preoperative staging[168]. Staging Keypoint is myometrial invasion, which correlates with tumor grade, lymph node metastasis and overall survival (OS)[168]. In particular, during preoperative assessment is necessary to discriminate between stages FIGO IB and IC [respectively myometrial invasion <50% (IB) and > 50% myometrial invasion (IC)] with high risk of lymph node metastasis with subsequent lymphadenectomy[167]. International guidelines largely recognize MRI as the modality of choice to evaluate disease extent in patients with newly diagnosed EC (Figure 6)[169]. T2-weighted imaging (T2-W) is mandatory for MRI of the female pelvis. At least two Fast Spin Echo (FSE) T2-w sequences should be performed in sagittal and axial oblique perpendicular to the endometrial cavity to detect tumor and assess myometrial depth[168-169]. Tsuboyama et al[170] in a

preliminar study explored the use of Half-Fourier acquisition single-shot turbo spin echo (HASTE) in female pelvis. They improved the sharpness and contrast of HASTE images without decreasing of SNR (signal-to-noise ratio) with multiple excitations (multi-NEX mHASTE), increasing image contrast for junctional zone, without ghosting artifacts compared to TSE T2WI. Further evidence[170] is necessary, but HASTE with short acquisition time (one third of that of TSE) could be a powerful tool in female pelvis investigations. DWI is particularly useful to detect malignant lesions in case of polypoid masses, leyomiomas, adenomiosis or others anatomical distortion. The ESUR panel recommends including DWI to confirm tumor depth. Minimum acquisition shall comprise an axial oblique plane[168] with the same orientation as axial oblique T2-W and minimum of two b values with an optimal high b value of 800 to 1000 s/mm^2.

Chen et al[171] confirmed what was observed in a previous prospective study rFOV (reduced field-of-view) DW imaging provided significantly better mean accuracy, specificity, and positive predictive values compared to fFOV (full field-of-view) with faster acquisition and less distortion. rFOV improves diagnostic performance for deep myometrial invasion in EC, without loss image quality[172]. Deng et al[173] observed higher diagnostic performance of DWI in association with T2WI compared to DCE-MRI for evaluation of myometrial invasion. DCE-MRI could be employed only in patients of child-bearing age who desire fertility preservation and have grade 1 EC to confirm endometrium-confined disease[168]. Considering previous data, a rapid and effective approach in EC assessment should include at least two scans in T2W on endometrial plane and an axial oblique rFOV DWI relegating the use of contrast agent only in selected cases with savings of resources and workflow reduction.

Ovarian Cancer

Several score systems have been developed to evaluate adnexal lesions based on sonographycal, clinical and biochemical data (cancer antigen 125 and human epididymis protein-4 levels)[174]. Nevertheless, between 18% and 31% of adnexal masses are still indeterminate following ultrasonography. In the last few years a risk stratification system based on MRI study has been proposed (Ovarian-Adnexal Reporting and Data System Magnetic Resonance Imaging O-RADS MRI), whose efficacy has been tested in a large multicenter clinical study. MRI demonstrated high power of discrim-

ination between benign and malignant lesions, moreover, it showed the possibility of tracing exact origin of the tumor mass with relevant consequences on treatment and patient's prognosis[175]. First MRI screening of adnexal formations should include at least axial FSE T1-W images and T2-W FSE images with a small field of view to allow high-resolution visualization in the axial, sagittal, and coronal planes (at least two). Furthermore, axial fat-suppressed (FS) T1-W imaging is essential to quickly and effectively distinguish hemorrhagic or proteinaceous cysts that require further investigation especially in postmenopausal women[176]. T2 dark solid components require functional DWI studies using high b value usually between 800-1000 s/mm^2 to cancel bladder contents signal. Masses with low signal even on DWI are certainly benign, whereas lesions indeterminate or bright must be assess with dynamic contrast enhanced MRI. DWI is not helpful in T1 bright masses, which can be confused with others restricted diffusion entities like teratoma, endometrium and tubo-ovarian abscesses[177,178]. In ovarian cancer, MRI's target would be to distinguish with certainty different histopathologic entities whose early diagnosis affects patient's outcome.

Interesting approach is based on the now widely recognized assumption of inverse correlation between apparent diffusion coefficient (ADC) value and tumor mass cellularity[178]. Ono et al[179] evaluated ADC values in epithelial ovarian cancer, which are the most frequent histological types in this site. They observed ADC values of clear cell carcinoma (CCC) were significantly higher than those of serous carcinoma (SC) and endometrium adenocarcinoma (EC), as a reflection of the pathological features of CCC with low cellularity and high extracellular space volume. Even in first adnexal studies, it could be possible to avoid contrast agent injection, whereas there is a close clinical collaboration and radiologist supervision.

Cervical Cancer

Cervical cancer remains the fourth-most common cancer in women globally. The initial assessment is determined by the International Federation of Gynaecology and Obstetrics (FIGO) classification, which was revised in 2018[180]. Tumour size, regional lymph nodes status and parametria invasion affect treatment decisions and have prognostic implications, whereas histological tumor type does not impact to patient outcome (Figure 7)[180].

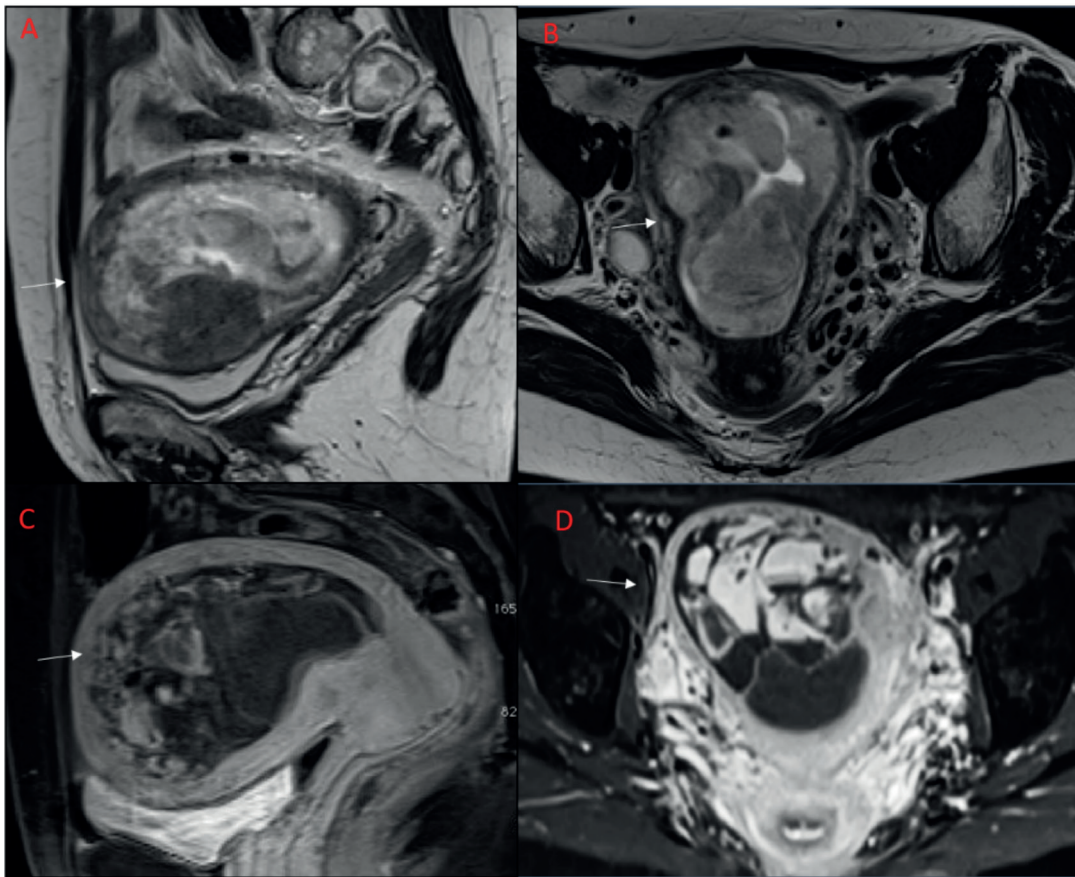MRI is useful to delineate disease extent and to guide decisions regarding fertility-sparing[181,182].

Figure 7. Woman 43 y with cervical bulky lesion in sagittal **(A)**, coronal **(B)** and axial plane **(C)**.

Small field of view, high-resolution T2 weighted sequences are the mainstay. T2WI in sagittal plane best detect tumor extent even in uterus and vagina; T2-WI in Axial oblique plane perpendicular to the long axis of the cervix certainly evaluate fibromuscolar stroma and parametria[183]. Cervical cancer usually appears as an exophytic, infiltrating, or barrel shaped hyperintense T2 mass compared to the background hypointense T2 signal of the cervical stroma. Even peritumoral edema and fibrous changes exhibits high signal intensity in T2-W images so it is possible a lesion overstaging. DWI with high b-values (50, 400, 800, 1000 s/mm²) could be helpful in this case improving tumor size discrimination. Moreover, DWI shows higher sensitivity values than T2W MRI in parametrial invasion assessment and it could be crucial for differentiating between metastatic and non-metastatic lymph nodes[184,185]. Lower ADC values are observed in more aggressive cancers with high stage, grade and local invasion, as well paradoxically with a better treatment response[186]; whereas, lesions with high ADC values are associated with lower disease-free survival[186].

Moreover, ADC values show relevant increasing during treatment response, so it could be possible to evaluate treatment efficacy before dimensional mass changing[186]. Combining T2WI and DWI imaging exhibits similar accuracy in cervical and uterine cancer staging as with adding contrast-enhanced sequences, so it could be an alternative in patients with allergy or renal failure, decreasing risk of nephrogenic systemic fibrosis[187,188].

Abbreviated MR imaging protocols are trending to streamline workflow, decrease costs, and cater to increasing clinical demands. The added advantages of abbreviated protocols are shorter scan times that can reduce motion artefact and improve image quality. An abbreviated protocol for MR imaging of the female pelvis may include coronal and sagittal single shot fast spin echo T2WI, axial fast spin echo T1WI without and with fat saturation (for hemorrhagic/proteinaceous content and fat), and axial DWI. For cervical and uterine cancers, an abbreviated protocol may include fast spin echo T2WI in axial and sagittal planes, axial oblique high spatial resolution fast

spin echo T2WI perpendicular to the cervix and/or uterus to assess stromal and parametrial invasion, and DWI in the axial and axial oblique planes for correlation with T2WI planes. Combining T2WI and DWI imaging has similar accuracy in cervical and uterine cancer staging as with adding contrast-enhanced sequences[79,167-172,181-188].

For Ovaries/Adnexa an abbreviated protocol may include axial and coronal SSFSE T2W (to detect and evaluate septa), axial non-contrast T1W (to detect proteinaceous or hemorrhagic components) and axial DWI (to assess solid component). For postmenopausal ovarian cyst surveillance axial 3D FSE T2W, axial non-contrast T1W and axial DWI (to assess solid component)[79,174-179].

Rectal Cancer

More than 1.9 million new colorectal cancers (including anus) cases and 935,000 deaths were estimated to occur in 2020, representing about one in 10 cancer cases and deaths. Overall, colorectal ranks third in terms of incidence, but second in terms of mortality[20]. The prognosis of rectal cancer is correlated to the mesorectum involvement and the capacity to surgically realize negative circumferential resection margins (CRMs). The mesorectal excision (TME) is the standard of care and the introduction of neoadjuvant chemo-radiotherapy (n-CRT) has led to improvements in local disease control[34]. However, according to European Society for Medical Oncology (ESMO) Clinical Practice Guidelines, in the intermediate/more locally advanced rectal cancers (LARCs) (cT3a/b or cT3a/b), the use of preoperative RT, either CRT or short-course preoperative radiotherapy remains controversial. Conversely, for LARC (>cT3b, and EMVI), treatment decisions regarding neoadjuvant therapy should be based on preoperative MRI, in relation to prediction of CRM involvement (≤ 1 mm), EMVI and more advanced T3 substages[34]. MRI is the most accurate noninvasive imaging tool for primary staging and treatment reastaging[189]. During staging phase, MRI allows the identification of patients with locally advanced rectal cancer, suitable for n-CRT, and the identification of several features, which could affect the patient prognosis. Post-treatment evaluation ('the restaging phase') is crucial for assessing tumor regression in the personalized therapy planning (emerging conservative strategies, wait and see strategy or local excision), follow-up, and local recurrence early detection[190-198].

The European Society of Gastrointestinal and Abdominal Radiology (ESGAR) has updated the MRI guidelines for RC management. New recommendations have been provided regarding the acquisition protocol and image interpretation[199]; structured report templates in MRI for primary staging and restaging were also released[199-201].

MRI for RC staging should be performed with an external surface coil on a 1.5 T, or 3.0 T. A standard protocol should (at least) include 2D T2-W sequences in three planes and a DWI[199]. Although DWI should be included during staging phase, in order to facilitate better identification of tumor and lymph node elements, is not routinely used and is instead generally recommended during restaging phase[199]. Non-enhanced and contrast-enhanced fat-suppressed (FS) T1-W sequences, during dynamic contrast administration (DCE-MRI) or post contrast administration (CE) are not routinely recommended. Slice thickness should be ≤ 3 mm (high-resolution protocol). Transverse and coronal sequences should be angulated perpendicular and parallel to the rectal tumor axis, respectively. In distal tumors, a coronal sequence angulated parallel to the anal canal should be included to assess the relationship between tumor and anal sphincter[199]. An FSE T2W sequence in the axial plane, with a wide field of view (FOV), may finally be helpful for correct visualization of extra-mesorectal lymph nodes[199]. During staging phase, MR should assess as location, morphology (polypoid, semi-annular, annular) and craniocaudal and circumferential extension (clock method) of the lesion, as well as T and N stage. In addition, it is necessary to evaluate the presence of EMVI, the relationship with surrounding structures, including the sphincter complex as well as the involvement of the mesorectal fascia[199].

According to ESGAR guidelines[199] the protocol for Rectal Cancer staging, that includes T2-W sequences in three planes and a DWI, allows an adequate evaluation of the disease in about 10/15 minutes, representing in fact an abbreviated protocol.

Regarding restaging phase, it is known that the accuracy of MRI is lower than pre-CRT evaluation[202,203]. Therefore, a multidisciplinary approach integrating MRI, clinical, and endoscopy is essential for adequately assessing treatment response. MRI restaging is usually performed at approximately 8 to 10 weeks after CRT, although sometimes-incomplete responders turn into complete responders after this period[204]. During "restaging phase" the radiologist should assess residual tumor (Figure 8 and Figure 9), clinical tumor stage after CRT (ycTstage), lymph node status, so as EMVI and the relationship with surrounding structures[34]. To date there is no uniformity of thought on the protocol to be used during the restaging phase, nor on the usefulness of the DCE
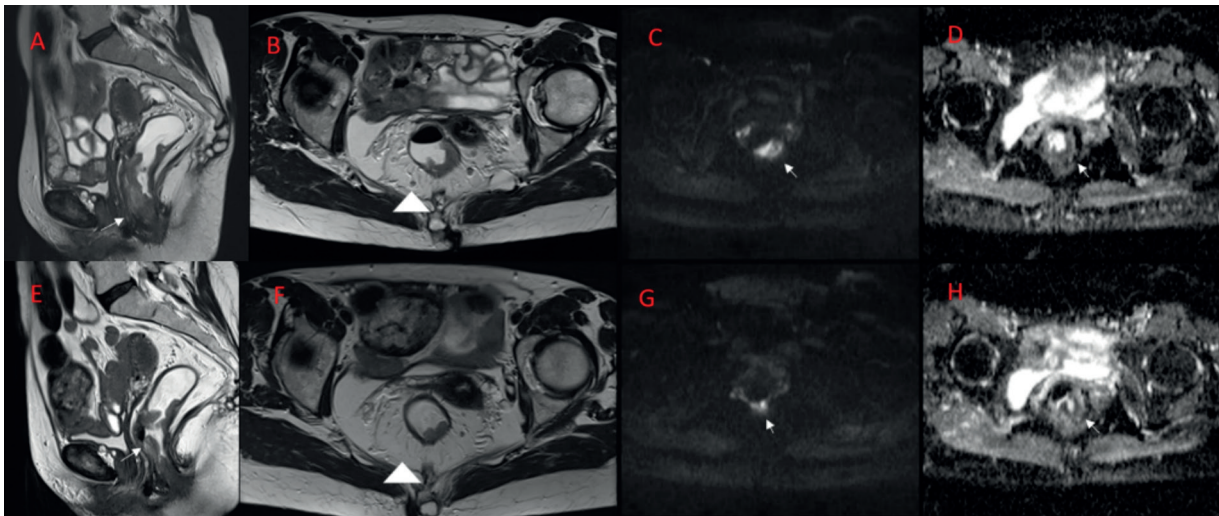
Figure 8. Rectal cancer **(A** and **B)** T2-W in sagittal and axial plane with partial response after nCRT treatment **(E** and **F)** (T2-W in sagittal and axial plane). Restricet Diffusion in pretreatment **(C)** b 800 s/mm^2) and post treatment sequence **(G**: b800s/mm^2). In D (pretreatment) and **H** (post treatment) ADC map.
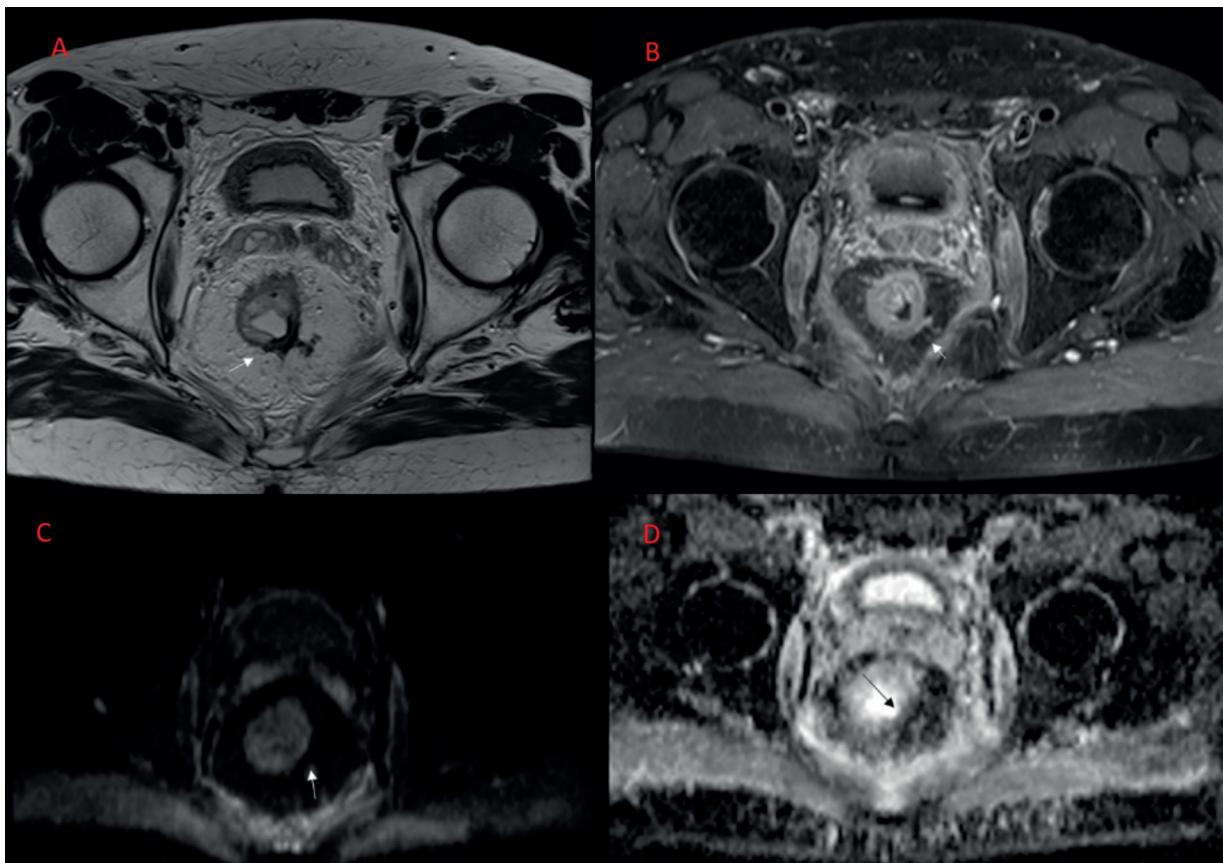

Figure 9. Post treatment rectal cancer: complete response with fibrotic residual tissue that shows hypointense signal in T2-W sequence **(A)**, no contrast enhancement **(B)** (ce MRI), no restricted signal in diffusion **(C**: b 800 s/mm2). In D ADC map.

and DWI. However, it is advisable that the assessment of tumor response should be performed with the same protocol that was used in the initial staging phase, in order to optimize the compar-
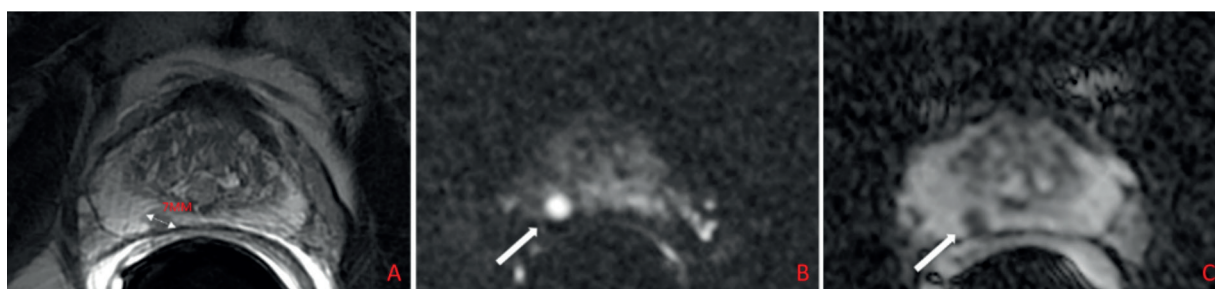
Figure 10. A 7 mm rounded lesion (arrow) in dorsally peripheral zone of the mid-portion of the prostate on the right **(A)**. This lesion was assigned to PI-RADS category 4, based on a 7 mm lesion (<1.5 cm), markedly hyperintense on DWI **(B)** (b300 s/mm^2) and hypointense on ADC **(C)** (score 4 - dominant sequence), correlated to moderately hypointense on T2WI **(A)**.

ison between pre- and post treatment study, so as it would be preferable that the examination be performed with the same scanner and by the same radiologist[34,199]. In this context, it is therefore difficult to consider the abbreviated protocols. In fact, a morphological and functional evaluation, combining T2-W sequence with DWI and DCE-MRI sequences, is useful[191-193]. Finally, regarding future directions, new techniques are being developed to overcome MRI limitations and, particular interest is given to radiomics and texture analysis studies[206-209]. However, although these techniques are showing promise for RC management, further research is needed to provide standardized technical parameters and their use in clinical practice.

Abbreviated MRI Prostate Protocol

Imaging-based approach plays a pivotal role in work-up of Prostate Cancer (PCa). Notably, some studies[210-213] suggest a prominent role of MRI as also recommended by the recently updated international guidelines. Standard MRI approach include T2, DWI and DCE sequences (i.e., multiparametric approach or mpMRI) as proposed by the current recommendations of the European Society of Urogenital Radiology (ESUR), which provide an accurate imaging-derived probability of lesion malignancy useful in patient management[214].

Since the proved utility of MRI in PCa management led to an increased demand for MRI-examination and consequent doubt on the availability to this modality, a wide debate has risen on the advantages of abbreviated MRI protocol (Figure 10)[215,216]. The role of DCE has remained uncertain among different sequences. Latest PIRADS 2.1 limited DCE to a dichotomous evaluation, with T2 (dominant sequence for the transition zone) and DWI sequences (dominant sequence for the peripheral zone) (both zone accounting for about

80% of the gland) are generally adequate for PCa assessment (biparametric protocol or bpM-RI)[216-220]. Moreover, bpMRI approach eliminates the risks related to the contrast medium administration, and shortens the time of each examination, thus suggesting a more concrete role of bpMRI as a potential screening tool. However, specific exceptions must be considered, and caution is recommended for a definitive bpMRI approach over the multiparametric one[221].

MRI Approach to Naïve Men with Suspected PCa andAabbreviated bpMRI

mpMRI approach is generally time-consuming, with acquisition-time ranging between 30 to 45 minutes[222]. Time-sparing strategies include the use of external coils rather than endorectal ones, or the evaluation of prostate-gland-only rather than the whole-pelvis. However, the greatest advantages in time-sparing strategies derived from the abbreviated bp protocol. Optimized "fast" protocol showed a sensitivity comparable to the standard protocol, as highlighted by Van der Leest et al[223]. In this regard, T2-W sequences are often the most time-consuming component; moreover, ESUR recommends the acquisition of at least one other plane other than the axial views, for a comparative evaluation of imaging findings. Use of single-planar axial acquisitions or 3d-fast sequences has been proposed as potential strategies in time-preserving protocols. Further time-reduction may result from the use of DW-EPI$_{SMS}$ sequences (rather than standard DWI) which allow the fastest bp protocol (i.e., 5-minute protocol) without involving the diagnostic accuracy when additional to single-planar T2-WI, as demonstrated in the study by Weiss et al[224]. However, necessary clarifications must be highlighted on the use of bp protocols. In fact, different studies often highlighted a lower specificity of bp

protocols, therefore increasing equivocal cases and risk of unnecessary biopsies. In this regard, the use of single-plane axial T2 sequences may not allow for adequate differentiation with partial volume finding, while 3d T2W sequences suffers for lower in-plane resolution and soft-tissue contrast[5]. Similarly, DW-EPI$_{SMS}$ sequences may be limited in the evaluation of extracapsular lesion extension. Therefore, faster protocols should be reserved for a screening intention[224]. Moreover, other studies showed similar evidence. Recently, the PROMIS study (one of the few multicenter trials performed for the comparative evaluation of mpMRI and bpMRI, which showed similar negative predictive value and sensitivity between the bp and mpMRI protocols) faced with a sensitive increase of equivocal lesions[226]. These findings confirm the need for: high image quality in bp protocol; greater experience of the reader, who seems to be discriminating for an overlapping reading of both protocols[227-229].

Going back to these premises, the PIRADS Committee also edited a narrative review including the current position on bpMRI. In particular, abbreviated bp protocol should be used in naive patients with suspected PCa on the base of a risk-model and pre-test probability of malignancy[230].

MRI Approach in Post-Treatment Evaluation and Abbreviated mpMRI

Radiant and surgical treatments, or recurrence of small lesion, might represent a limit for bpMRI. Treatment-derived morphological or fibrotic alterations could affect bp accuracy; fibrotic tissue can mimic a gland lesion with hypointense T2W appearance, as well as marked artifacts can impair the evaluability of DWI sequences[224]. Although matter of debate as shown by the results of Abd-Alazeez et al[231], and Lotte et al[232], DCE is expected to increase the sensitivity of MRI in identifying disease recurrence. Some studies[233,234] have in fact proven a comparative efficacy of mpMRI to other technique in assessing disease recurrence, highlighting an even greater efficacy of mpMRI rather than PET/CT as found in the study of Panebianco et al[233,234].

Besides, angiogenesis is known to be a predictor of lesion malignancy and aggressiveness. Lesion with early enhancement due to neo-angiogenesis are suspected of disease recurrence unlike fibrosis which shows a more gradual enhancement. The adoption of sequences for the evaluation of early enhancement only can spare the 30% of the acquisition time compared to a whole-acquired mpMRI[235]. However, significance of angiogenesis in PCa remains controversial, thus reducing the sensitivity of DCE and early-DCE evaluation[235].

Musculoskeletal Tumors

Despite the technological advances of sectional imaging methods, namely MRI, the clinical-radiological management of musculoskeletal tumors cannot disregard a multimodal approach, where radiographic examination still today remains a milestone[236-242]. In fact, plain films performed in orthogonal projections are fundamental in bone and soft tissue tumors to characterize basic semeiological features, such as the type of osteolysis, bone interface, periosteal reaction, and ossification/calcification patterns[240]. Multidetector CT examination is essential to integrate the radiographic findings in cases of lesions in complex anatomical areas, for matrix characterization, and to identify minor alterations in soft tissue tumors. Isotropic acquisition with multiplanar reconstructions is also fundamental for biopsy and pre-surgical planning[243-245]. Providing multiparametric information, thanks to advanced functional and metabolic sequences, MR imaging is the primary modality for characterization, staging, and follow-up in MSK oncology. Tumor imaging protocol optimization, it is crucial to tailor sequences and acquisition planes according to the clinical setting of the given case[243-248]. The examination should always be conducted with a field strength of at least 1.5-3T. Considering the variability of possible anatomical locations, the field of view should be sufficiently focused but include the entire lesion and perilesional anatomical landmarks. It is essential always to ensure-compatibly with the scanning times- high in-plane spatial resolution and high signal-to-noise ratio (matrix 384-512, slice thickness 3-4 mm). The lesion should be studied on the three spatial planes, but the axial sequences are fundamental to define the tumor margins and the compartmental extension[245-249]. Morphological imaging should include SE T1-weighted and SE T2-weighted sequences, which guarantee the best visualization of the medullary extension and some tissue characteristics (adipose, myxoid, fibrous, etc.). Fluid-sensitive sequences (STIR or fat-suppressed T2-weighted) performed in two scan planes depict perilesional edema and soft tissues extension[244-251]. Gradient-echo sequences may be added to evaluate hemosiderin deposits (e.g., in PVNS or GCT), while chemical shift imaging may be helpful in some cases of differential diagnosis of bone marrow replacement[240-244]. DWI sequences provide useful functional information for both

characterization (e.g., solid/cystic) and follow-up. In particular, the quantitative evaluation of ADC values is a good indicator in the evaluation of cellularity in response to therapy. Single or multishot EPI sequences are used, with at least two b-values (usually, 50, 400, and 1000s/mm^2). For quantitative evaluation, there is no standardization on the number and size of the ROI to be placed, nor on the evaluation of the mean, minimum or maximum ADC. Some authors[252,253] suggest that the evaluation of the minimum ADC may be more accurate, as it would represent the area of the greatest cellularity of the lesion (Figure 11). Contrast-enhanced imaging is useful both in characterization -though with sensitivity between 72-83% and specificity 77-89%, for a substantial overlap in highly vascularized benign lesions- and especially in the follow-up,

for the assessment of the degree of tumoral necrosis (responders/non-responders) and the differentiation of residual/recurrent disease from fibrosis and granulation tissue[254-256]. DCE-MRI is usually performed using multislice, volumetric, gradient echo sequences acquired after gadolinium bolus (0.1 mmol/ kg). A delayed fat-suppressed T1-weighted sequence after 3-5 minutes is also acquired to provide contrast-enhanced anatomic information, possibly accompanied by subtraction images. The most cost-effective perfusion analysis currently includes the semiquantitative postprocessing of time-intensity curves providing a graphic representation of contrast perfusion (time to enhancement, wash in, peak enhancement, and washout)[254-256] (Figure 12).

To date, not a single thought has been reported about the usefulness of abbreviated protocols in
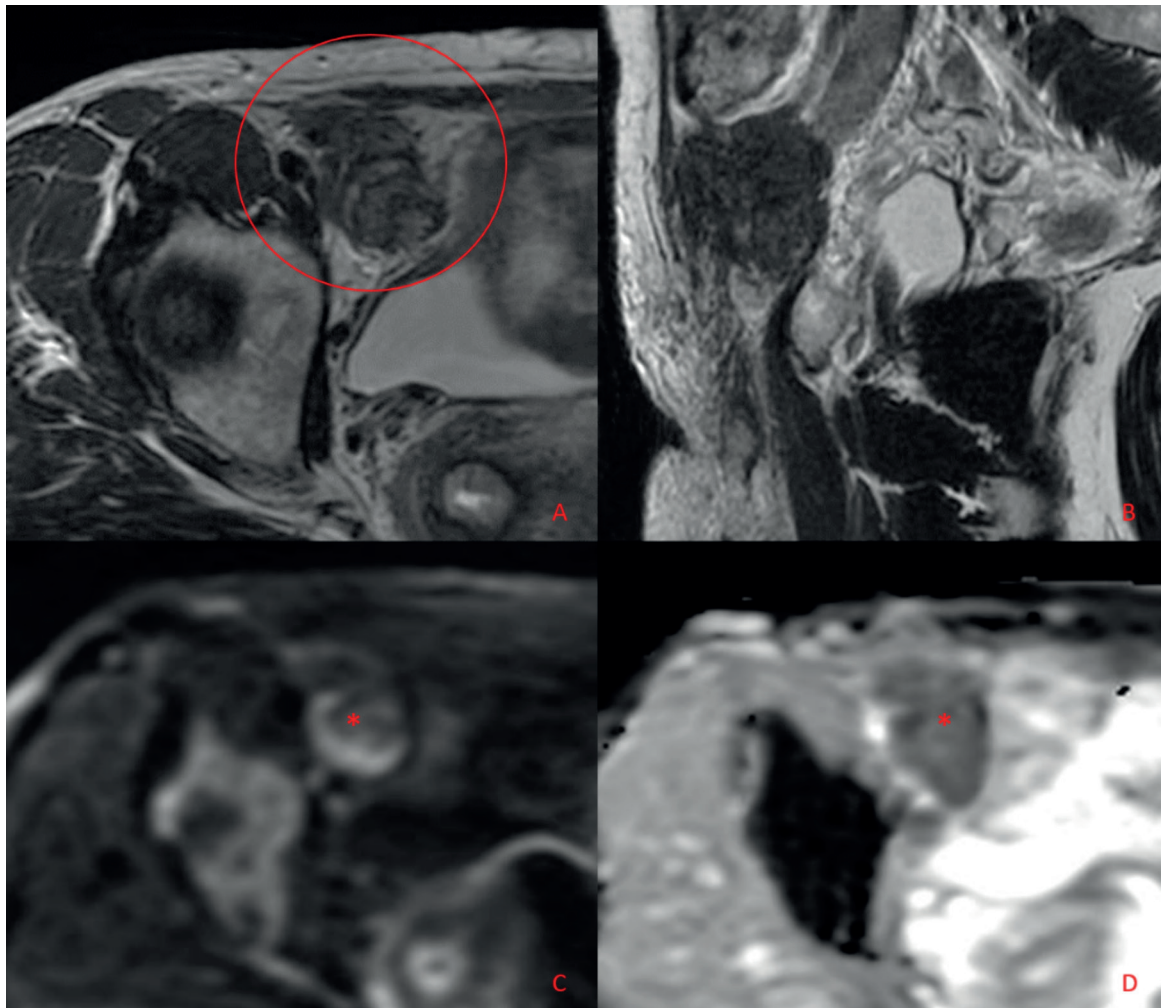

Figure 11. MRI study of a soft tissue lesion adjacent to the anterior abdominal wall in the inguinal region. The lesion is studied using morphological T2 sequences in axial **(A)** and sagittal **(B)** planes. DWI sequences **(C)** included in the imaging protocol show restricted diffusion confirmed at the ADC map **(D)**. Histology: desmoid tumor.
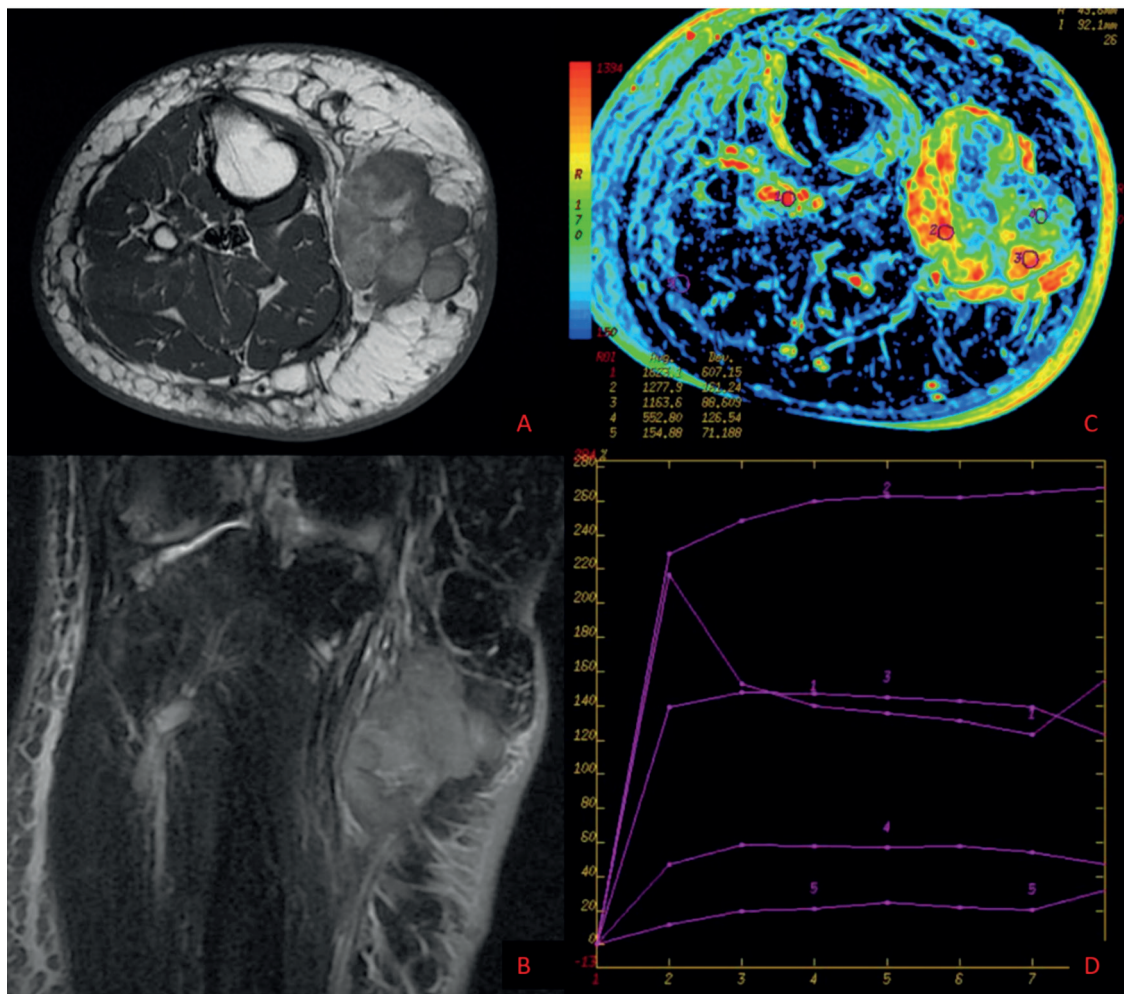
Figure 12. Multiparametric MRI study of a subcutaneous lesion of the leg. Internal morphology and signal are studied using T2 and fluid sensitive sequences in axial and coronal planes **(A, B)**. The imaging protocol is completed with dynamic contrast-enhanced (DCE) sequences and time-intensity curve analysis, showing a rapid early enhancement in the most vascularized portions of the lesion. Histology: myxoid liposarcoma.

musculoskeletal tumors. Tokuda et al[257] reported comparable results for differentiation of benign from malignant tumors in soft tissue masses and even better results for differentiation of benign from malignant bone tumors by using abbreviated protocol, suggesting that contrast enhancement is not always needed[258].

Artificial Intelligence and Imaging

In recent years, through its ability to assemble and quickly analyse enormous volumes of data generated by imaging studies, artificial intelligence (AI) has been transforming radiology. Throughout the field, applications leveraging AI are being used to improve diagnostic accuracy, imaging consistency, workflow efficiency, and patient care by automating many formerly te-

dious, time-consuming, and manually performed tasks[259-262].

AI traditional methods have relied primarily on machine-learning algorithms based on expert programming of predefined rules. However, more recent advances, have given rise to superior algorithms that learn through direct navigation of data to "identify" potentially suspicious findings. These "deep learning" algorithms are advantageous because they operate with minimal human expert intervention, and instead collect and process data in raw form using artificial neural networks.

Current and future clinical applications of AI in radiology range from improving image recognition and suspicious lesion identification to streamlining reporting through predictive analytics[263,264].

AI algorithms have been used for several challenging tasks, such as pulmonary embolism segmentation on computed tomography (CT) angiography, polyp detection by virtual colonoscopy or CT, in the setting of colon cancer detection, breast cancer detection and diagnosis with mammography or magnetic resonance (MR), brain tumor segmentation with MR imaging, hepatic primitive and secondary lesion segmentation on CT or MRI, detection of the cognitive state of the brain with functional MR imaging to diagnose neurologic disease (eg, Alzheimer disease)[265-267].

Blazie et al[264] studied the effect of different reconstruction parameter settings on the performance of a commercially available deep learning based pulmonary nodule CAD system. In addition to optimize and to segment images, AI techniques were investigated by several researcher in order to manage radiation and to improve contrast image reducing imaging doses in different district and with different imaging modality[266-267].

Kitamura et al[263] explored whether machine learning models can accurately label lumbar spine views/positions, detect hardware, and rotate the lateral views to straighten the image. They observed that machine learning techniques can be successfully implemented to optimize lumbar spine x-ray hanging protocols by accounting for views, hardware, dynamic position, and rotation correction.

In CT, AI holds the ability of enabling further reductions in patient radiation dose through automation and optimisation of data acquisition processes, including patient positioning and acquisition parameter settings. Moreover, the image reconstruction parameters optimisation of, advanced reconstruction and post processing algorithmsimprove image quality, especially to reduce image noise and enabling lower radiation doses use for data acquisition[268,269]. A proprietary deep learning image reconstruction (DLIR) method was proposed against an existing advanced adaptive statistical iterative reconstruction method (ASIR-V) and filtered back projection (FBP) in order to optimize CT protocol and increase quality images. The results by Szczykutowicz et al[267] reported that ASIR-V and DLIR were associated with improved contrast-to-noise ratio over FBP for all doses and slice thicknesses. DLIR slice thickness noise scaling differed from FBP, exhibiting less noise penalty with decreasing slice thickness.

Therefore, the holistic integration of AI tools can further enhance clinical workflow consistency, safety, and efficiency, ultimately providing patients with better care and treatment experiences. For example, software that controls and monitors contrast and radiation dose and seamlessly connects to RIS, PACS, and EMR systems at the enterprise level, gives radiology practices easy access to data, standardized reporting formats, and improved performance capabilities[270-272].

Conclusions

Abbreviated MRI protocols have emerged as an alternative to standard MRI protocols. These protocols seek to reduce longer standard protocols by eliminating unnecessary sequences that negatively affect cost, examination time, patient comfort, and image interpretation time. Abbreviated protocols have already been used successfully for hepatocellular carcinoma screening, for prostate cancer detection, and for screening for nonalcoholic fatty liver disease. Of recent and promising use are the pre-surgical evaluation of hepatic metastases, the staging of rectal cancer, the surveillance of cystic lesions of the pancreas and ovaries, as well as of women at risk of breast cancer.

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