© Pol J Radiol 2023; 88: e415-e422
DOI: https://doi.org/10.5114/pjr.2023.131213

Received: 31.05.2023
Accepted: 26.07.2023
Published: 11.09.2023

POLISH JOURNAL of RADIOLOGY

http://www.polradiol.com

Review paper

Abbreviated magnetic resonance imaging protocols in oncology: improving accessibility in precise diagnostics

Sylwia Grabowska[B,D,E,F], Anna Hitnarowicz[B,D,E,F], Anna Barczyk-Gutkowska[E], Katarzyna Gruszczyńska[E], Katarzyna Steinhof-Radwańska[D,E], Mateusz Winder[A,D,E]

Department of Radiology and Nuclear Medicine, Medical University of Silesia, Katowice, Poland

Abstract

Cancer, as the second leading cause of death in the world, is one of the major public health concerns today. Accurate diagnosis and prompt initiation of adequate treatment are of key importance for prognosis. Abbreviated magnetic resonance protocols (AMRI) are promising techniques based on magnetic resonance imaging (MRI) protocols that shorten acquisition time without significant loss of examination quality. Faster protocols that focus on detection of suspicious lesions with most precise sequences, can contribute to comparable diagnostic performance of a full MRI protocol. The purpose of this article was to review the current application of AMRI protocols in several oncological diseases.

Key words: magnetic resonance imaging, abbreviated protocol, cancer, oncological radiology, screening.

Introduction

Magnetic resonance imaging (MRI) is one of the basic methods of diagnostic imaging. High contrast resolution of images obtained from MRI examinations, ability to analyze tissue function and metabolism, and high sensitivity of detecting malignant changes, make this method particularly important in oncological diagnostics. However, disadvantages of MRI include long scanning times, limited availability, and high costs. An effective MRI protocol is critical in making an accurate diagnosis and has a direct impact on time of examination. In order to fully exploit the potential of MRI in urgent setting, e.g., neurological imaging, abbreviated protocols have been introduced to facilitate fast and accurate diagnosis without compromising the diagnostic value of examination [1,2]. B422y shortening the acquisition time, more examinations can be performed and thus, the availability of MRI improves. AMRI can possibly complement findings of computed tomography (CT). The use of short protocols may also help to reduce the cost of MRI examinations [3]. This makes AMRI a convincing substitute for standard MRI use, which is particularly important for oncological patients [4]. However, there is an increasing need to standardize diagnostic path in the selection of appropriate AMRI protocols in individual disease entities.

The main objective of this article was to summarize the ongoing achievements in the application of AMRI protocols in selected cancerous diseases. This review concentrated mostly on the research published in the last 5 years. While choosing the studies included in our article, we drew special attention to the type of sequences applied in AMRI, the maximum time of AMRI, and the sensitivity and specificity in cancer detection. Database search consisted of terms, including 'magnetic resonance imaging', 'abbreviated protocol', 'cancer'.

Metastatic liver disease

Detection of liver metastases and their differentiation is a diagnostic challenge due to high incidence of benign liver lesions [5]. Accurate analysis of liver metastases de-

Correspondence address:

Mateusz Winder, Department of Radiology and Nuclear Medicine, Medical University of Silesia, Katowice, Poland, e-mail: mwinder@sum.edu.pl

Authors' contribution:

A Study design · **B** Data collection · **C** Statistical analysis · **D** Data interpretation · **E** Manuscript preparation · **F** Literature search · **G** Funds collection

termines a suitable oncological treatment strategy, and may prevent exposing patients to unnecessary invasive therapeutic measures [6]. Extracting the most suitable sequences from a full MRI protocol and thereby shortening the examination time, may improve effectiveness of liver metastasis detection without sacrificing quality of diagnostic performance.

Several studies evaluated the use of abbreviated MRI protocols in the detection of liver metastases. The authors often included gadoxetate-enhanced T1W, T2W, or diffusion-weighted imaging (DWI) as well as hepatobiliary phase (HBP) sequences. Another components of an abbreviated protocol, which can participate in the reduction of acquisition time, is simultaneous multislice imaging (SMS) or reduced field-of-view (FOV) DWI [7-9]. This subject has been discussed in detail in our previous work [10].

Diffusion-weighted imaging and dynamic contrast-enhanced MRI seem to be able to allow a full assessment of the presence and nature of focal liver lesions [11]. The detection rate of T2W and DWI sequences was described as high [4,11]. Considering disadvantages of DWI, such as low signal-to-noise ratio (SNR) or low spatial resolution, dynamic and unenhanced MRI sequences should be combined together in order to provide an appropriate lesion assessment [12]. A reduced FOV DWI evaluated by Wargo *et al.* provided higher image SNR, which was supported by Chan *et al*. In this study, according to the authors, reducing the acquisition FOV DWI to a smaller area of interest may contribute to improving the scanning time without loss in diagnostic performance [7,8].

The progress in using functional sequences rise a question whether the contrast agents are always necessary. However, contrast-enhanced imaging with an appropriate gadolinium contrast agent improves detection, characterization, and determination of lesion extent [11]. Diffusion-weighted imaging alone can appear beneficial for patients with contrast contraindications, although incorporating both the afore-mentioned sequences into protocol is mostly considered a better option than using each sequence alone [13-16].

In some recent studies, the implementation of HBP with DWI and T2W images to the protocol have been portrayed as highly accurate sequences in observation of colorectal cancer (CRC) liver metastases and neuroendocrine tumors' (NET) metastases [1,5,17,18]. The time needed to acquire HBP is usually several minutes. Therefore, performing the acquisition of DWI and T2W sequences after administration of gadoxetic acid can help to use some of wait time [1].

The evaluated scanning time of AMRI implementing ultrafast SE T2W, DWI, and T1W-HBP is approximately less than 10 minutes, which is much shorter than the time of full MRI protocol (35-50 min) [19]. Several studies showed the same or similar diagnostic performance of AMRI and standard MRI protocols in liver metastases detection. An AMRI, including images acquired with T2W half-Fourier acquisition single-shot turbo spin echo (HASTE), DWI, HBP, and second-shot arterial phase (SSAP) imaging, was relevantly shorter in comparison with full protocols [20]. Another AMRI protocol comprising of DWI and SPACE T2W fat-suppressed sequences resulted in approximately 8 minutes of acquisition time [11]. In some studies, the exact time of scanning was not measured or was only estimated, such as the study conducted by Hayoz *et al*., who described 4 diverse MRI protocols for the detection of liver metastases from neuroendocrine tumor (NET). In one of their protocols, the authors used a combination of HBP and DWI sequences, and evaluated scanning time of approximately less than 5 minutes [18].

As specified by Ghorra *et al*., the diagnostic quality of proposed AMRI protocol was similar to that of a full protocol with dynamic sequences. This protocol consisted of T2W, DWI, and HBP images [5]. Torkzad *et al*. demonstrated an AMRI protocol involving DWI, ADC maps, axial and coronal HBP gadoxetate disodium-enhanced T1W, which enabled reducing acquisition time [5,21].

Hepatocellular carcinoma

Hepatocellular carcinoma (HCC), as the most frequent primary cancer of the liver, is related to liver cirrhosis of various origins and infection of hepatitis B virus (HBV) [22]. MRI has a very high accurateness for HCC detection; however, it is not suggested as the first method of choice. Moreover, MRI is inefficient as a screening option as a result of high cost and limited accessibility. Therefore, AMRI techniques could become an effective screening tools in HCC surveillance [23]. AMRI, having high per-lesion and per-patient sensitivities in HCC, has substantially lower sensitivity for the detection of HCCs < 2 cm than those ≥ 2 cm. Nevertheless, it is considerably greater than that of ultrasonography (US) that makes it a possible alternative for HCC screening method in high-risk groups [24,25]. HCC detection has been discussed in detail in our previous work [10].

Based on quantity of sequences used, a standard liver MRI examination can regularly take up to 40 minutes, whereas AMRI can be accomplished in less than 10 minutes [26,27]. AMRI sequences used for HCC screening usually consist of a non-contrast (NC-MRI) DWI and T2W, or in case of dynamic AMRI, gadoxetate-enhanced HBP or extra-cellular gadolinium-based contrast agent with or without DWI and T2W. It is worth emphasizing that NC-MRI without the need for contrast agent can become a superb non-invasive imaging method, with reduced costs and scanning time [24]. Regardless of the origin of the liver disease, various AMRI sequences have proportionate diagnostic performance [4,24]. Several studies take into consideration the combination of DWI and T2W with T1W sequences [2]. Sunyoung Whang *et al*. reported that AMRI with gadoxetate-enhanced HBP and non-contrast MRI have similar diagnostic performance in detection of early stage HCCs [25]. Both, the sensitivity and specificity of AMRI protocols in HCC surveillance reach between 61.5 and 100%, and 77.5 and 100%, respectively [28].

Non-alcoholic fatty liver disease

MRI-based techniques show exact disposition of fat within the liver tissue. It accurately measures fat content with regard to corresponding histological grade. MRI is also able to evaluate liver iron overload in patients with non-alcoholic fatty liver disease (NAFLD). In this way, MRI can assess liver fat as well as iron content in one examination. An AMRI protocol consisting of MR elastography and viscera adipose tissue (VAT) measurements and the amount of iron and liver fat assessments, can be even more feasible, less costly, and more accessible tool for screening and monitoring of patients with obesity, NAFLD, and metabolic syndrome. In a prospective study conducted by Cunha *et al*., a reported scan time of an AMRI protocol was approximately 7 minutes. The fact that the short protocol did not need venous puncture or bowel preparation made the patient's setup much faster and easier to obtain in comparison with a standard MRI protocol [29]. Abbreviated protocol mentioned by Olson *et al*. involved in-phase and opposed-phase T1-weighted images, a parametric map of hepatic proton density fat fraction (PDFF), R2 – a measure of iron content derived from chemical shift-encoded MRI (CSE-MRI) data, and MR elastography (MRE). The described time of these sequences was approximately 2-4 minutes. Consequently, the total in-room time for image acquisition was approximately 10-15 minutes, in comparison with 30-70 minutes for a full liver examination. AMRI protocols are well-suited for evaluating parameters, such as hepatic fibrosis, increased iron content, or hepatic steatosis [4].

Prostate cancer

Magnetic resonance imaging as a screening method for prostate cancer has a potential to avoid unnecessary biopsies and reduce overdiagnosis that can occur in screening programs. AMRI protocols with higher thresholds for denoting a positive MRI could refine specificity of MRI screening program. Additionally, it could minimize acquisition cost and time [30,31]. Standard examination protocols include T2W sequences, DWI, and dynamic contrast-enhanced MRI after intravenous injection of contrast agent, which gives approximately 30 minutes of scan time (i.e., multiparametric approach or mpMRI). Abbreviated protocols have been proposed using an axial T2W and DWI sequences (with readout-segmented and selective-excitation DWI techniques). They demonstrated to reduce scan time from 30 to approximately 10 minutes without sacrificing diagnostic performance [31-33]. Strategies that allow to save time involve the use of external coils as a substitute for endorectal ones, or the evaluation of only prostate gland and not the whole pelvis [26]. AMRI could also play an important role in case of MRI-guided radiotherapy treatment planning for prostate cancer. Sequences, such as T2W TSE, DWI-echo planar imaging (DWI-EPI), and read-out segmented echo planar imaging (RS-EPI) with field mapping corrections, could improve proper assessment of lesions [34,35].

Cystic pancreatic lesions and intraductal papillary mucinous neoplasm

Magnetic resonance imaging is considered the favored imaging modality for initial characterization and follow-up of cystic pancreatic lesions (CPLs). It avoids exposure to ionizing radiation, and provides greater contrast resolution and assessment of cyst communication with main pancreatic duct (MPD), as compared with CT. A standard pancreatic protocol MRI (PP-MRI) typically includes T2W sequences, unenhanced and dynamic contrast-enhanced T1W sequences, magnetic resonance cholangiopancreatography (MRCP) sequences, and DWI. The acquisition time can typically take 30-35 minutes and up to 50 minutes, considering patient's preparation time, safety procedures, and venous cannulation. Since imaging techniques for T2W sequences and MRCP have improved, the necessity of contrast-enhanced sequences and DWI for routine MRI follow-up of CPLs has been questioned. AMRI protocol for CPL surveillance that excludes contrast-enhanced sequences and DWI, and includes axial T1W, axial and coronal T2W sequences with half-Fourier acquisition single-shot turbo spin-echo, and fat-suppressed MRCP, was described as an alternative. It could decrease the scanning time and avoid additional procedures, such as cannulation for intravenous injections and thus save time. The estimated reduction in acquisition time ranges 10-27 minutes. AMRI can have an ability to reliably identify suspicious features and become a valuable tool in imaging surveillance of CPLs than standard PP-MRI [3,36-38].

Cystic pancreatic lesions, such as pancreatic intraductal papillary mucinous neoplasms (IPMNs), carry a malignant transformation risk; therefore, an intensive surveillance is needed [39-42].

In a retrospective study by Yoo *et at*., AMRI with breath-hold 3D-MRCP (AMRI-BH) showed promising results concerning detection of a potential malignant transformation of IPMNs. AMRI-BH consisted of single-shot fast spin-echo, T1W fat-suppressed gradient-echo sequence, and BH-3D-MRCP (breath-hold three-dimensional MRCP). Compressed sensing techniques of gradient-echo and spin-echo sequence (GRASE) used in this study enabled to obtain 3D-MRCP images within a single BH, which resulted in shortening the acquisition time. The full acquisition time of AMRI-BH was 5 minutes compared with 35 minutes of full-sequence MRI. The full protocol consisted of the following sequences: T2W, 2D-MRCP with single-shot turbo spin-echo, conventional RT-3D-MRCP (respiratory-triggered three-dimensional MRCP), BH-3D-MRCP, T1W in-phase and opposed-phase spoiled 3D gradient-echo sequences, DWI, and T1W fat-suppressed gradient-echo sequence [41]. Johansson *et al*. evaluated an ultrashort (USP) MRI and compared it to two longer protocols. The results showed that USP MRI might be suitable for IPMN surveillance without losing any essential information within shorter time. Long protocol (LP) consisted of the following sequences: axial T2W HASTE, coronal T2W HASTE (fs), axial T2W HASTE fs, axial T1W fast low angle shot (FLASH) ffs, T1W in-phase and out-of-phase, T2W 3D-MRCP sampling perfection with application-optimized contrasts using different flip angle evolution (SPACE) and maximum intensity projection (MIP), thick coronal T2W HASTE fs, DWI and apparent diffusion coefficient maps (ADC), and pre- and post-contrast administration T1W fs volumetric interpolated breath-hold (VIBE). Short protocol (SP) consisted of axial T2W HASTE, thin coronal T2W HASTE fs, axial T1W FLASH fs, thick coronal T2W HASTE fs, 3D-MRCP SPACE, and MIP. Ultrashort MRI included only axial T2W HASTE and 3D-MRCP SPACE sequences. The full acquisition time for LP, SP, and USP was 23, 13, and 7 minutes, respectively [43].

Acute pancreatitis

Acute pancreatitis is one of the most common gastrointestinal causes of hospitalization. Necrotizing pancreatitis is its less common type and complication, and is associated with a worst prognosis, especially in case of its infection. Compared with CT, MRI is superior in detecting non-liquid material in pancreatic and peripancreatic collections. It has a higher sensitivity and specificity in the identification of areas of hypoperfusion compatible with pancreatic necrosis, and enables the evaluation of pancreatic duct integrity [44-46]. A study by Bansal *et al*. that compared a standard, contrast-enhanced MRI protocol with AMRI protocol consisting of a single transverse T2W HASTE sequence in patients with acute necrotizing pancreatitis, showed no significant differences in the detection of pancreatic necrosis [47]. These results indicate that a simple AMRI protocol could become a fast and contrast-free alternative to a full MRI or even CT examination in acute pancreatitis patients.

Breast cancer

The use of AMRI protocol in detection of breast cancer was analyzed in many studies. In 2014, Kuhl and colleagues first put forward early efforts to establish an abbreviated screening MRI protocol for breast cancer [48]. They described AMRI protocol in women at mildly to moderately increased risk of breast cancer. According to this landmark study, the diagnostic accuracy of fast MRI protocol was equivalent to full MRI protocol, with reduced scan time from 17 to 3 minutes. The interpretation time lasted only seconds. The afore-mentioned fast protocol consisted of one unenhanced and one contrast-enhanced T1W sequences and their derived images (first post-contrast-subtracted and maximum intensity projection images). The effectiveness of AMRI protocol evaluated by Kuhl et al. was supported by Mango *et al*. [49]. In this study, scanning time of AMRI and full protocol was 10-15 minutes and 30-40 minutes, respectively. Moschetta *et al*. developed an AMRI protocol using STIR TSE sequence, TSE T2W, pre-contrast THRIVE (three-dimensional dynamic, contrast-enhanced T1W high resolution isotropic volume sequences), and post-contrast THRIVE sequence acquired 3 minutes after injection. The standard protocol included STIR, TSE T2W, pre-contrast THRIVE, and 5 post-contrast THRIVE sequences. The acquisition time of abbreviated MRI protocol was reduced to 10 minutes, and was 6 minutes less than the time required for full MRI protocol. There was no difference in sensitivity, specificity, or accuracy between standard and abbreviated protocols [50].

The utilization of DWI was proposed in order to obtain an unenhanced MRI protocol for characterizing breast lesions [50]. There are results suggesting that standalone DWI may not be ready to serve as screening technique, because its sensitivity for cancer detection is lower than the one of contrast-enhanced MRI [51,52]. However, different findings have shown that non-contrast MRI protocol consisting of DWI with ADC and T1W or T2W sequences has comparable sensitivities and specificities compared with dynamic contrast-enhanced MRI [51,53].

Lung cancer

Lung cancer is the leading cause of cancer death for both men and women worldwide. Early diagnosis is the most effective way to receive optimal therapy and reduce lung cancer mortality. MRI substitutes traditional lung imaging techniques or plays a complementary role in the management of patients with various chest diseases, especially in the detection of pulmonary nodules [54]. Lung MRI provides morphological, functional, and molecular information, and has the potential to reduce high false positive rates associated with low-dose CT (LDCT). Undoubtedly, CT is more sensitive than MRI in detecting lung nodules, and remains the method of choice in lung cancer imaging. However, inevitable ionizing radiation exposure and its potential carcinogenic risks are major drawbacks of CT examinations. Avoiding side effects is especially important when lung cancer screening involves the general population and is not just targeted at the high-risk population [55]. Different MRI sequences seem to be able to differentiate malignant as well as calcified and sub-solid nodules. High signal intensity on T2W images, diffusion restriction, and intense enhancement are indicatives of lung cancer [56]. Nevertheless, well-known limitations of lung MRI remain, particularly low proton density, long scan durations, and its sensitivity to effects of respiratory and cardiac motions.

New techniques of MRI, such as spiral three-dimensional (3D) ultrashort echo time (UTE) may enable the clinical application of lung MRI, and may have potential in nodule detection and evaluation of nodule type in nodule screening, lung metastasis surveillance as well as follow-up [57]. High sensitivity, shorter scan duration, and satisfactory image quality of free-breathing spiral 3D UTE may improve detection of pulmonary nodules [55]. It has smaller voxel sizes and shorter time to echo, which allows for less magnetic susceptibility artifact for the air soft tissue interfaces [58].

In 2015, Dournes *et al.* presented pointwise encoding time reduction with radial acquisition (PETRA) sequence as an attractive field of investigation for radiation-free imaging of the lung with high spatial resolution [59]. Moreover, recent studies on a combination of UTE and a radial acquisition technique, such as PETRA sequence, have proven the feasibility of lung MRI for the evaluation of various pathologies, including pulmonary masses or nodules, cystic fibrosis, and pulmonary embolisms [59-61]. According to the results of a survey conducted by Ohno *et al.*, the efficacy of pulmonary MRI with UTE for diagnosing all radiological findings, except for emphysema or bullae, bronchiectasis, and reticular opacity, was not significantly different from that of standard and low-dose CT examinations. Nevertheless, pulmonary MRI with UTE still needs to be improved by means of further reduction of echo time (TE), data interpolation for apparent resolution, implementation of motion artifact reduction techniques, including navigator or external markers, and advanced image reconstruction, such as parallel imaging and compressed sensing, which potentially may reduce acquisition time [62].

When projecting an MRI-based lung cancer screening trial, it should be considered to use a multiparametric approach, combining at least 2 or 3 sequences to minimize false positive results [63]. Half-Fourier FSE and 3D-GRE images are considered promising sequences for a screening protocol [58,64]. STIR is also useful for detection and clinical stage assessment in non-small cell lung cancer (NSCLC) and other malignancies as well as for screening of malignant tumors, when compared with T1W and T2W imaging [65,66].

In 2011, Wu *al et*. demonstrated how a lung MRI study can be completed in less than 10 minutes. In this study, the implementation of parallel imaging technique was applied that improved the image quality of HASTE in axial and sagittal views. Volumetric interpolated breath-hold sequence was acquired in axial, coronal, and sagittal planes by reduction of echo time with integrated parallel acquisition techniques (iPAT). This allowed to cover the entire lung volume within a single breath-hold, and to reduce the pulsation artifact from the heart and large vessels [64].

Adrenal incidentalomas

Regular imaging examinations are essential for patients with adrenal incidentalomas. For follow-up of adrenal incidentalomas, AMRI protocols could serve as a radiation-free CT substitute or even standard contrast-enhanced MRI protocol. Therefore, in some indications, AMRI protocol including T1W in-phase and out-of-phase, SSFSE T2W, and DWI sequences, could possibly play a sufficient role in characterization of lesions. These sequences are important elements of the abbreviated protocol considering the fact that they allow to detect lipid, proteinaceous or hemorrhagic, cystic and hypercellular components of adrenal lesions [1,4].

Small renal masses

During surveillance of a small renal masses (SRM), one of the main concerns is to regularly evaluate their growth rate. In order to do so, there is a need for active observation. AMRI, similar to a protocol for adrenal incidentalomas (T1W in-phase and out-of-phase, SSFSE T2W, and DWI), could represent an alternative to the standard contrast-enhanced MRI protocol and help to facilitate the whole process [1,4].

According to a study by Olson *et al.*, the total kidney volume can be measured using T2W in the coronal plane, enabling a fast AMRI kidney protocol without the need for a contrast. This could be useful as an indicator for autosomal dominant polycystic kidney (ADPK) disease progression and for the evaluation of response to therapy. The authors also showed that non-contrast protocol including T2W, DWI, and T1W in-phase and out-of-phase could possibly be an adequate tool for controlling SRM growth rate without the use of gadolinium contrast [4].

Female pelvis neoplasms

Functional MRI is becoming increasingly important in the evaluation of female pelvis. DCE-MRI and DWI-MRI enable morphological as well as functional assessment of the female reproductive system diseases [67]. The sequences that can prove useful in the abbreviated protocol for MRI in cervical and uterine cancers are T2W FSE in axial and sagittal planes, axial oblique high spatial resolution T2W FSE perpendicular to the cervix and/or uterus, and DWI in the axial and axial oblique planes for correlation with T2W planes [68]. Diffusion-weighted imaging has the potential to allow early monitoring of the cervical cancer's response to chemo/radiotherapy. The fact that median ADC in cervix carcinoma is low in comparison with normal cervix may be helpful in defining tumor boundaries for treatment purposes and qualifying to surgical resection [69,70]. For ovaries, an abbreviated protocol may consist of axial and coronal SSFSE T2W, axial non-contrast T1W, and axial DWI in order to assess septa and to identify proteinaceous or hemorrhagic as well as solid component of lesions. For post-menopausal ovarian cyst surveillance, AMRI may include axial 3D FSE T2W, axial non-contrast T1W, and axial DWI [26].

Conclusions

Abbreviated magnetic resonance protocols may become a faster and cheaper alternative to the standard MRI protocol for cancer monitoring without compromising diagnostic quality. AMRI could help expand patient's access by meeting rapidly increasing clinical demands. Non-contrast T1W (in- and out-of-phase), T2W, or T2W FSE in several planes, and DWI are the most commonly implemented sequences in AMRI protocols. The process of evaluating and potentially including AMRI in early liver metastasis and other cancer screening pathways requires further studies.

Conflict of interest

The authors report no conflict of interest.

References

1. Canellas R, Rosenkrantz AB, Taouli B, et al. Abbreviated MRI protocols for the abdomen. Radiographics 2019; 39: 744-758.
2. Carbonell G, Taouli B. Abbreviated MR protocols for chronic liver disease and liver cancer. Magn Reson Imaging Clin N Am 2021; 29: 321-327.
3. Pozzi-Mucelli RM, Rinta-Kiikka I, Wünsche K, et al. Pancreatic MRI for the surveillance of cystic neoplasms: comparison of a short with a comprehensive imaging protocol. Eur Radiol 2017; 27: 41-50.
4. Olson MC, Vietti Violi N, Taouli B, et al. Abbreviated magnetic resonance imaging protocols in the abdomen and pelvis. Magn Reson Imaging Clin N Am 2020; 28: 381-394.
5. Ghorra C, Pommier R, Piveteau A, et al. The diagnostic performance of a simulated "short" gadoxetic acid-enhanced MRI protocol is similar to that of a conventional protocol for the detection of colorectal liver metastases. Eur Radiol 2021; 31: 2451-2460.
6. Mao Y, Chen B, Wang H, et al. Diagnostic performance of magnetic resonance imaging for colorectal liver metastasis: a systematic review and meta-analysis. Sci Rep 2020; 10: 1969.
7. Chan WY, Hartono S, Thng CH, et al. New advances in magnetic resonance techniques in abdomen and pelvis. Magn Reson Imaging Clin N Am 2020; 28: 433-445.
8. Wargo CJ, Moore J, Gore JC. A comparison and evaluation of reduced-FOV methods for multi-slice 7T human imaging. Magn Reson Imaging 2013; 31: 1349-1359.
9. Taron J, Martirosian P, Erb M, et al. Simultaneous multislice diffusion-weighted MRI of the liver: analysis of different breathing schemes in comparison to standard sequences. J Magn Reson Imaging 2016; 44: 865-879.
10. Winder M, Grabowska S, Hitnarowicz A, et al. The application of abbreviated MRI protocols in malignant liver lesions surveillance. Eur J Radiol 2023; 164: 110840.
11. Granata V, Fusco R, Avallone A, et al. Abbreviated MRI protocol for colorectal liver metastases: how the radiologist could work in pre surgical setting. PLoS One 2020; 15: e0241431.
12. Lincke T, Zech CJ. Liver metastases: detection and staging. Eur J Radiol 2017; 97: 76-82.
13. Kim HJ, Lee SS, Byun JH, et al. Incremental value of liver MR imaging in patients with potentially curable colorectal hepatic metastasis detected at CT: a prospective comparison of diffusion-weighted imaging, gadoxetic acid-enhanced MR imaging, and a combination of both MR techniques. Radiology 2015; 274: 712-722.
14. Vilgrain V, Esvan M, Ronot M, et al. A meta-analysis of diffusion-weighted and gadoxetic acid-enhanced MR imaging for the detection of liver metastases. Eur Radiol 2016; 26: 4595-4615.
15. Kenis C, Deckers F, De Foer B, et al. Diagnosis of liver metastases: can diffusion-weighted imaging (DWI) be used as a stand alone sequence? Eur J Radiol 2012; 81: 1016-1023.
16. Baghdadi A, Mirpour S, Ghadimi M, et al. Imaging of colorectal liver metastasis. J Gastrointest Surg 2022; 26: 245-257.
17. Yamaguchi T, Sofue K, Ueshima E, et al. Abbreviated gadoxetic acid-enhanced MRI for the detection of liver metastases in patients with potentially resectable pancreatic ductal adenocarcinoma. J Magn Reson Imaging 2022; 56: 725-736.
18. Hayoz R, Vietti-Violi N, Duran R, et al. The combination of hepatobiliary phase with Gd-EOB-DTPA and DWI is highly accurate for the detection and characterization of liver metastases from neuroendocrine tumor. Eur Radiol 2020; 30: 6593-6602.
19. Canellas R, Patel MJ, Agarwal S, et al. Lesion detection performance of an abbreviated gadoxetic acid-enhanced MRI protocol for colorectal liver metastasis surveillance. Eur Radiol 2019; 29: 5852-5860.
20. Kim JW, Lee CH, Park YS, et al. Abbreviated gadoxetic acid-enhanced MRI with second-shot arterial phase imaging for liver metastasis evaluation. Radiol Imaging Cancer 2019; 1: e190006.
21. Torkzad MR, Riddell AM, Chau I, et al. Clinical performance of abbreviated liver MRI for the follow-up of patients with colorectal liver metastases. AJR Am J Roentgenol 2021; 216: 669-676.
22. Marrero JA, Kulik LM, Sirlin CB, et al. Diagnosis, staging, and management of hepatocellular carcinoma: 2018 practice guidance by the American Association for the Study of Liver Diseases. Hepatology 2018; 68: 723-750.
23. Vernuccio F, Cannella R, Bartolotta TV, et al. Advances in liver US, CT, and MRI: moving toward the future. Eur Radiol Exp 2021; 5: 52.
24. Gupta P, Soundararajan R, Patel A, et al. Abbreviated MRI for hepatocellular carcinoma screening: a systematic review and meta-analysis. J Hepatol 2021; 75: 108-119.

25. Whang S, Choi MH, Choi JI, et al. Comparison of diagnostic performance of non-contrast MRI and abbreviated MRI using gadoxetic acid in initially diagnosed hepatocellular carcinoma patients: a simulation study of surveillance for hepatocellular carcinomas. Eur Radiol 2020; 30: 4150-4163.
26. Granata V, Bicchierai G, Fusco R, et al. Diagnostic protocols in oncology: workup and treatment planning. Part 2: Abbreviated MR protocol. Eur Rev Med Pharmacol Sci 2021; 25: 6499-6528.
27. Tillman BG, Gorman JD, Hru JM, et al. Diagnostic per-lesion performance of a simulated gadoxetate disodium-enhanced abbreviated MRI protocol for hepatocellular carcinoma screening. Clin Radiol 2018; 73: 485-493.
28. Altinmakas E, Taouli B. Abbreviated liver magnetic resonance imaging protocols and applications. Radiol Clin North Am 2022; 60: 695-703.
29. Cunha GM, Villela-Nogueira CA, Bergman A, et al. Abbreviated mpMRI protocol for diffuse liver disease: a practical approach for evaluation and follow-up of NAFLD. Abdom Radiol 2018; 43: 2340-2350.
30. Eldred-Evans D, Tam H, Sokhi H, et al. Rethinking prostate cancer screening: could MRI be an alternative screening test? Nat Rev Urol 2020; 17: 526-539.
31. Weiss J, Martirosian P, Notohamiprodjo M, et al. Implementation of a 5-minute magnetic resonance imaging screening protocol for prostate cancer in men with elevated prostate-specific antigen before biopsy. Invest Radiol 2018; 53: 186-190.
32. Rais-Bahrami S, Siddiqui MM, Vourganti S, et al. Diagnostic value of biparametric magnetic resonance imaging (MRI) as an adjunct to prostate-specific antigen (PSA)-based detection of prostate cancer in men without prior biopsies. BJU Int 2015; 115: 381-388.
33. Stanzione A, Imbriaco M, Cocozza S, et al. Biparametric 3T magnetic resonance imaging for prostatic cancer detection in a biopsy-naïve patient population: a further improvement of PI-RADS v2? Eur J Radiol 2016; 85: 2269-2274.
34. Bergen RV, Ryner L, Essig M. Field-map correction in read-out segmented echo planar imaging for reduced spatial distortion in prostate DWI for MRI-guided radiotherapy applications. Magn Reson Imaging 2020; 67: 43-49.
35. Foltz WD, Porter DA, Simeonov A, et al. Readout-segmented echo-planar diffusion-weighted imaging improves geometric performance for image-guided radiation therapy of pelvic tumors. Radiother Oncol 2015; 117: 525-531.
36. Delaney FT, Fenlon HM, Cronin CG. An abbreviated MRI protocol for surveillance of cystic pancreatic lesions. Abdom Radiol 2021; 46: 3253-3259.
37. Kang HJ, Lee DH, Lee JM, et al. Clinical feasibility of abbreviated magnetic resonance with breath-hold 3-dimensional magnetic resonance cholangiopancreatography for surveillance of pancreatic intraductal papillary mucinous neoplasm. Invest Radiol 2020; 55: 262-269.
38. Nougaret S, Reinhold C, Chong J, et al. Incidental pancreatic cysts: natural history and diagnostic accuracy of a limited serial pancreatic cyst MRI protocol. Eur Radiol 2014; 24: 1020-1029.
39. Tanaka M, Fernández-del Castillo C, Kamisawa T, et al. Revisions of international consensus Fukuoka guidelines for the management of IPMN of the pancreas. Pancreatology 2017; 17: 738-753.
40. Del Chiaro M, Besselink MG, Scholten L, et al. European evidence-based guidelines on pancreatic cystic neoplasms. Gut 2018; 67: 789-804.
41. Yoo J, Min JH, Lee DH, et al. Abbreviated magnetic resonance imaging with breath-hold three-dimensional magnetic resonance cholangiopancreatography: assessment of malignant risk of pancreatic intraductal papillary mucinous neoplasm. J Magn Reson Imaging 2021; 54: 1177-1186.
42. Delaney FT, Cronin CG. Growing evidence for the use of an abbreviated magnetic resonance imaging protocol in the surveillance of pancreatic intraductal papillary mucinous neoplasms. J Magn Reson Imaging 2021; 54: 1365-1366.
43. Johansson K, Mustonen H, Nieminen H, et al. MRI follow-up for pancreatic intraductal papillary mucinous neoplasm: an ultrashort versus long protocol. Abdom Radiol 2022; 47: 727-737.
44. Arvanitakis M, Delhaye M, De Maertelaere V, et al. Computed tomography and magnetic resonance imaging in the assessment of acute pancreatitis. Gastroenterology 2004; 126: 715-723.
45. Bugiantella W, Rondelli F, Boni M, et al. Necrotizing pancreatitis: a review of the interventions. Int J Surg 2016; 28 Suppl 1: S163-S171.
46. Zhao K, Adam SZ, Keswani RN, et al. Acute pancreatitis: revised atlanta classification and the role of cross-sectional imaging. AJR Am J Roentgenol 2015; 205: W32-W41.
47. Bansal A, Ramegowda R, Gupta P, et al. Abbreviated non-enhanced magnetic resonance imaging in patients with acute necrotizing pancreatitis. Abdom Radiol (NY) 2022; 47: 2381-2389.
48. Kuhl CK, Schrading S, Strobel K, et al. Abbreviated breast magnetic resonance imaging (MRI): first postcontrast subtracted images and maximum-intensity projection – a novel approach to breast cancer screening with MRI. J Clin Oncol 2014; 32: 2304-2310.
49. Mango VL, Morris EA, David Dershaw D, et al. Abbreviated protocol for breast MRI: are multiple sequences needed for cancer detection? Eur J Radiol 2015; 84: 65-70.
50. Moschetta M, Telegrafo M, Rella L, et al. Abbreviated combined MR protocol: a new faster strategy for characterizing breast lesions. Clin Breast Cancer 2016; 16: 207-211.
51. McDonald ES, Hammersley JA, Chou SHS, et al. Performance of DWI as a rapid unenhanced technique for detecting mammographically occult breast cancer in elevated-risk women with dense breasts. Am J Roentgenol 2016; 207: 205-216.
52. Trimboli RM, Verardi N, Cartia F, et al. Breast cancer detection using double reading of unenhanced MRI including Tl-weighted, T2-weighted STIR, and diffusion-weighted imaging: a proof of concept study. Am J Roentgenol 2014; 203: 674-681.
53. Baltzer PAT, Benndorf M, Dietzel M, et al. Sensitivity and specificity of unenhanced MR mammography (DWI combined with T2-weighted TSE imaging, ueMRM) for the differentiation of mass lesions. Eur Radiol 2010; 20: 1101-1110.
54. Ohno Y, Kauczor HU, Hatabu H, et al. MRI for solitary pulmonary nodule and mass assessment: current state of the art. J Magn Reson Imaging 2018; 47: 1437-1458.
55. Huang YS, Niisato E, Su MYM, et al. Detecting small pulmonary nodules with spiral ultrashort echo time sequences in 1.5 T MRI. MAGMA 2021; 34: 399-409.
56. Meier-Schroers M, Homsi R, Schild HH, et al. Lung cancer screening with MRI: characterization of nodules with different non-enhanced MRI sequences. Acta Radiol 2019; 60: 168-176.
57. Cha MJ, Park HJ, Paek MY, et al. Free-breathing ultrashort echo time lung magnetic resonance imaging using stack-of-spirals acquisition:

a feasibility study in oncology patients. Magn Reson Imaging 2018; 51: 137-143.

58. Biederer J, Ohno Y, Hatabu H, et al. Screening for lung cancer: does MRI have a role? Eur J Radiol 2017; 86: 353-360.
59. Dournes G, Grodzki D, Macey J, et al. Quiet submillimeter MR imaging of the lung is feasible with a PETRA sequence at 1.5 T. Radiology 2015; 276: 258-265.
60. Ohno Y, Koyama H, Yoshikawa T, et al. Standard-, reduced-, and nodose thin-section radiologic examinations: comparison of capability for nodule detection and nodule type assessment in patients suspected of having pulmonary nodules. Radiology 2017; 284: 562-573.
61. Bannas P, Bell LC, Johnson KM, et al. Pulmonary embolism detection with three-dimensional ultrashort echo time MR imaging: experimental study in canines. Radiology 2016; 278: 413-421.
62. Ohno Y, Koyama H, Yoshikawa T, et al. Pulmonary high-resolution ultrashort TE MR imaging: comparison with thin-section standard- and low-dose computed tomography for the assessment of pulmonary parenchyma diseases. J Magn Reson Imaging 2016; 43: 512-532.
63. Heye T, Ley S, Heussel CP, et al. Detection and size of pulmonary lesions: how accurate is MRI? A prospective comparison of CT and MRI. Acta Radiol 2012; 53: 153-160.
64. Wu NY, Cheng HC, Ko JS, et al. Magnetic resonance imaging for lung cancer detection: experience in a population of more than 10,000 healthy individuals. BMC Cancer 2011; 11: 242.
65. Koyama H, Ohno Y, Kono A, et al. Quantitative and qualitative assessment of non-contrast-enhanced pulmonary MR imaging for management of pulmonary nodules in 161 subjects. Eur Radiol 2008; 18: 2120-2131.
66. Koyama H, Ohno Y, Aoyama N, et al. Comparison of STIR turbo SE imaging and diffusion-weighted imaging of the lung: capability for detection and subtype classification of pulmonary adenocarcinomas. Eur Radiol 2010; 20: 790-800.
67. Sala E, Rockall A, Rangarajan D, et al. The role of dynamic contrast-enhanced and diffusion weighted magnetic resonance imaging in the female pelvis. Eur J Radiol 2010; 76: 367-385.
68. Sakala MD, Shampain KL, Wasnik AP. Advances in MR imaging of the female pelvis. Magn Reson Imaging Clin N Am 2020; 28: 415-431.
69. McVeigh PZ, Syed AM, Milosevic M, et al. Diffusion-weighted MRI in cervical cancer. Eur Radiol 2008; 18: 1058-1064.
70. Nougaret S, Tirumani SH, Addley H, et al. Pearls and pitfalls in MRI of gynecologic malignancy with diffusion-weighted technique. AJR Am J Roentgenol 2013; 200: 261-276.