



Review

The application of abbreviated MRI protocols in malignant liver lesions surveillance

Mateusz Winder^{a,*}, Sylwia Grabowska^b, Anna Hitnarowicz^b, Anna Barczyk-Gutkowska^a, Katarzyna Gruszczyńska^a, Katarzyna Steinhof-Radwańska^a

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

^b Students' Scientific Society, Department of Radiology and Nuclear Medicine, Medical University of Silesia, Katowice, Poland

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ABSTRACT

Cancer is one of the leading public health problems globally. Since time is of the essence in oncology, the sooner an accurate diagnosis is made, the better the prognosis for patients. There is a growing need to find a flawless and fast imaging method for cancer detection, but also for its evaluation during treatment. In this respect, the possibilities and novelties of magnetic resonance imaging are particularly promising. Abbreviated magnetic resonance imaging (AMRI) protocols have aroused universal interest as a compromise between scanning time reduction and preservation of image quality. Shorter protocols focused on the detection of suspicious lesions with the most sensitive sequences could provide a diagnostic performance similar to the one of the standard protocol. The purpose of this article is to review the ongoing accomplishments in the use of AMRI protocols in liver metastases and HCC detection.

1. Introduction

Magnetic resonance imaging (MRI) is a continuously expanding technique which provides comprehensive information on organs' anatomy, functioning and metabolism. The clinical indications for MRI application have been broadened in the course of time [1]. Among various imaging methods, MRI has its superiority in e.g. liver metastases detection and their surveillance due to higher soft tissue resolution, multiple scan sequences, innovative MRI techniques, such as improvements in data acquisition, image reconstruction, post-processing denoising, artifact reduction and the use of hepatocyte-specific contrast agents. However, MRI examinations require special attention in patients with heart pacing devices and metal implants and due to long acquisition times along with higher costs of examination, the use of MRI has still limited accessibility. Recently, the speed of MRI scanning and the simplicity of technical operation have significantly improved, however, the acquisition time of numerous standard sequences is still not competitive compared to computed tomography (CT) [2]. An efficient MRI protocol is essential to ensure the accurate diagnosis. In order to minimize the length of MRI examinations an abbreviated MRI (AMRI) protocols have emerged as an alternative to standard protocols [3]. The diagnostic information in AMRI is generally not impaired [4]. Apart

from cost reduction, the use of short protocols can increase the availability of MRI and therefore facilitate a better surveillance of liver lesions, including liver metastases. By decreasing the examination time of the comprehensive protocol, more slots in the daily schedule become available and can substantially increase the workflow in the MRI departments [5]. Moreover, AMRI can potentially complete findings of standard CT examinations. AMRI protocols are not a new topic and have their diagnostic use in neurological imaging, in particular in patients with acute conditions such as ischemic stroke, therefore it is worth considering their use in oncological radiology. A short MRI protocol could be an interesting alternative to a conventional and long MRI protocols [6]. Shortening the scanning time by implementing AMRI may facilitate the diagnostic process and therapeutic decision-making, which is of great importance especially in cancer patients. Many are searching for the appropriate AMRI protocols that could unify the diagnostic path in particular diseases. There is a spectrum of MRI sequences, each with its own unique characteristics which can form AMRI, although one AMRI protocol cannot be applied to all patients and therefore various illnesses require dedicated approach.

* Corresponding author at: Medyków 14, 40-752 Katowice, Poland.

E-mail addresses: mwinder@sum.edu.pl (M. Winder), katarzyna.steinhof@sum.edu.pl (K. Steinhof-Radwańska).

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2. Methods

The aim of this article is to summarize the current knowledge on the use of AMRI protocols in the imaging surveillance of malignant liver lesions such as metastases and hepatocellular cancer (HCC). The literature review focuses primarily on the research published in the last 5 years. In the selection of studies, particular attention was paid to the detailed information on the type of sequences used in the AMRI protocol, the total time of the abbreviated protocol, and its sensitivity and specificity in detecting focal lesions. The database search included i.a. the following terms: 'abbreviated MRI', 'liver metastases', 'HCC', 'surveillance'.

3. MRI in liver imaging

The liver is the most common site of cancer metastases. Cancers that spread to the liver most often originate from colon as well as breast, stomach, pancreas, lung and neuroendocrine tissue. They present as multifocal lesions, sometimes as a solitary mass or confluent masses. Liver metastases do not contain functional hepatocytes or biliary ducts and may be hypovascular or hypervascular, solid or cystic – mainly depending on the tissue components of the primary tumor [7]. Hypovascular metastases are characteristic of colon, lung, and gastric cancer, while hypervascular metastases are secondary to the dissemination of renal cell carcinoma (RCC), melanoma, thyroid carcinoma, and carcinoid tumors. Breast cancer metastases may appear as hypo- or hypervascular lesions. Cystic liver metastases are mainly associated with cystic tumors such as ovarian cancer or mucinous pancreatic cystadenocarcinoma [8]. Imaging plays a pivotal role in the detection, management, and post-treatment surveillance of liver metastases.

When compared to CT, MRI has a higher contrast-to-noise ratio (CNR), lack of ionizing radiation exposure and uses contrast agents with the ability to explore both extracellular and hepatocellular compartments [9]. MRI could offer the radiologist a more comprehensive assessment of the liver characteristics. It is the method of choice when the results of other imaging examinations, such as CT or ultrasonography (US) are inconclusive or in patients with contradictions to the intravenous (i.v.) administration of the iodine contrast agent [10]. A gadolinium-based MRI contrast agent can be applied to acquire a dynamic liver MRI images in order to differentiate between hypo- and hypervascularized focal liver lesions. The use of hepatocyte-specific contrast agents can further increase the diagnostic accuracy of MRI for the detection and characterization of focal liver lesions. It allows the visualization of the delayed hepatocyte uptake and partial excretion of the contrast agent into the biliary system. It is so-called hepatobiliary phase (HBP) of imaging. Hepatic metastases do not enhance in the liver-specific phase and therefore appear hypointense compared to healthy liver parenchyma. Apart from liver-specific contrast, MRI offers other functional parameters that are frequently used in the diagnosis of focal liver disease, e.g. diffusion-weighted imaging (DWI) sequences [7].

Many AMRI protocols consist of DWI sequences whose sensitivity reflects the b-value, where a high b-values mean high sensitivity, and low b-values mean low sensitivity [8]. Malignant lesions provide lower apparent diffusion coefficient (ADC) values because of a combination of higher cellularity and tissue disorganization. In that way, they lead to diffusion restriction. Due to the bright appearance of malignant liver lesions on high b-value DWI images, DWI has a particular value especially in the detection of sub-centimeter liver lesions [7]. It provides the information about solid and cystic or necrotic tumor components, which was previously only accessible with contrast-enhanced sequences [11].

Nonetheless, the use of MRI is limited and MRI cannot be routinely performed in patients with claustrophobia, pacemakers, cardiac defibrillators, cochlear implants and ferromagnetic foreign bodies [12]. Other limitation of MRI is a higher demand for patient cooperation in order to prevent motion artifacts during the liver exams [2]. Movement during image acquisition leads to blurring and ghosting, image

duplicates from misplaced signal that may impede image interpretation [9]. The frequency of motion artifacts can however be reduced by shortening the examination time with AMRI.

4. AMRI protocols in the detection of liver metastases

Liver metastasis is the most prevalent malignant tumor of the liver parenchyma and second most common site of the metastatic involvement after the lymph nodes [13]. One of the main difficulties in liver imaging for metastases is the high prevalence of benign liver lesions that can be misinterpreted as an evidence of metastatic disease. Lesions composed of hepatocytes such as focal nodular hyperplasia (FNH) and hepatocellular adenomas are the main sources of confusion. They usually exhibit hyperenhancement in the arterial phase, which is difficult to visualize without dynamic phases [14].

Selection of appropriate oncological therapy requires careful assessment of the presence, amount and location of liver metastases. If the intraoperative findings in the liver make curative resection of the primary tumor e.g. pancreatic cancer impossible, patients are exposed to an unnecessary invasive procedure. Therefore, efficient detection of liver metastases at an early stage is crucial for improving patient's survival by simplifying the selection of potential patients who will benefit from curable surgery and disqualifying those who are not eligible for it [15]. There is an increasing need to find an ideal and effective MRI liver protocol for the initial work-up and follow-up of patients with suspected liver metastases. Shorter exploration protocol focused on the detection of the liver lesions with the most sensitive sequences could provide a diagnostic performance that is similar to the standard protocol.

At present, neither of AMRI protocols are officially recommended for the detection of liver metastases, thus suitable choice of MRI sequences is necessary. DWI (so as dynamic contrast-enhanced MRI) allows both proper detection and characterization of focal liver lesions [11]. According to Michael C. Olson et al. lesion characterization would additionally require T2W and DWI to differentiate between metastasis and benign lesions [6]. Several studies evaluated that the detection rate with these sequences alone or in combination was high, particularly for small-sized liver lesions [6,11]. However, according to Coenegrachts et al. DWI alone has been shown to be more sensitive than single T2-weighted MRI in detecting colorectal liver metastases [16].

Nonetheless, DWI sequences are not flawless. Crucial disadvantages of DWI are the low signal-to-noise ratio (SNR), low spatial resolution and the susceptibility for artifacts. Lesion characterization should therefore be performed with combined unenhanced and dynamic MRI sequences [8]. In order to increase image SNR a reduced field-of-view (FOV) DWI has been evaluated. FOV DWI reduced to a smaller area not only may provide better image quality but also faster scanning time [17,18].

The improvement of functional sequences, like DWI, gives consideration to the necessity for the i.v. administration of contrast agents. Contrast enhanced imaging improves lesion detection, tissue characterization, and determination of the extent of the infiltration [11]. Combining both is generally accepted to be better than each sequence alone [19,20]. Choosing the adequate gadolinium contrast agent (extracellular contrast agent or Eovist) is also important. According to Vilgrain et al. DWI and gadoxetate-enhanced T1weighted imaging (T1W) in HBP provide high sensitivity for detection of liver metastasis [20]. Nevertheless, in case of patients with renal failure who have contraindications for gadolinium contrast agent, DWI can be used as stand-alone imaging method [21,22].

Recently, AMRI protocols which consisted of HBP images together with DWI and T2W images have shown high accuracy for the detection and characterization of liver metastases from colorectal cancer (CRC) and neuroendocrine tumors (NET) [3,14,23,24]. According to Roschan Hayoz et al. gadoxetic acid should be considered the contrast agent of choice for liver MRI in NET patients (23,24). In addition, the acquisition of DWI and T2W sequences can be performed after the administration of gadoxetic acid, to use the time needed to obtain the HBP (usually ~20

min) [3]. The use of gadoteric acid-enhanced MRI enables the acquisition of HBP images that has shown to be effective in detecting liver metastases in patients with pancreatic ductal adenocarcinomas (PDAC) with higher sensitivity than that of contrast-enhanced CT (CECT) [23,25,26].

Another interesting technique is simultaneous multislice imaging (SMS), also known as multiband imaging, which allows to acquire multiple slices simultaneously and therefore enabling the reduction in scanning time [17,27]. According to Taron et al. the scanning time of the liver was reduced by 70% when comparing SMS-accelerated DWI with conventional DWI [27]. Obele et al. compared image quality between multiband diffusion acquisition (mb2-DWI) and conventional free-breathing DWI (c-DWI) in patients undergoing clinically indicated liver MRI. The maintained or improved overall quality and comparable lesion detectability in comparison to c-DWI was achieved in time reduced by 41%. Given results suggest that mb2-DWI may possibly take over the standard diffusion-weighted sequence in the liver imaging [28]. Nonetheless, in both aforementioned studies, the lower liver ADC values in SMS-DWI might be related to the lower repetition time. As a consequence, the signal measured at high b-values may be falsely too high, due to biased noise contribution and, therefore, the ADC values calculated could be falsely too low [17]. Possible lower ADC values measured in SMS sequences should be kept in mind when interpreting ADC values obtained in different DWI studies. The best compromise between reduction in scan time, image quality and ADC quantification accuracy is adding an acceleration factor of 2. In 2016, Andreas Boss et al. evaluated the feasibility of SMS-DWI with blipped Controlled Aliasing in Parallel Imaging Results in Higher Acceleration (blipped CAIPIRINHA) unaliasing technique for liver and pancreas assessment. They focused on the optimal acceleration factor (AF), the achievable SNR and the effective SNR/time. The study demonstrated that SMS-DWI of the liver and especially the pancreas is feasible, while reducing the scan time by up to 45% with an AF of 2 compared to a standard DWI sequence. It was without significant reduction in SNR, with only minimally reduced image quality at the liver dome and thus overall liver image quality and no detectable deviation of ADC values. By applying the acceleration factor of 3 made an acquisition time similar to conventional DWI acquisitions using a standard sequence. SMS-DWI of the liver and pancreas provides substantially higher SNR/time, which either may be used for shorter scan time, higher slice resolution or intravoxel incoherent motion (IVIM) measurements. IVIM analysis provides additional information on tissue perfusion. It may provide important information regarding the assessment of the degree of liver steatosis and fibrosis, for characterization of hepatocellular carcinoma, and treatment response in liver metastases [29].

A retrospective study by Canellas R. et al. assessed the performance of AMRI protocol in the detection of colorectal liver metastases. It consisted of ultrafast SE T2W, DWI and T1W-HBP. The estimated acquisition time of AMRI was to be less than 10 min whereas the time of standard MRI protocol required approximately 35–50 min. The full MRI protocol included the aforementioned sequences as well as balanced gradient echo-T2W, fast spin-echo with fat saturation T2W, gradient echo-T1W in-phase and out-of-phase and 3D T1W with fat saturation. According to the authors such AMRI protocol has high lesion detection performance and can be used as a fast alternative to the full MRI protocol [30].

An abbreviated gadoteric acid-enhanced MRI protocol proposed by Kim J.W. et al. assessed the feasibility for liver metastasis evaluation. The simulated AMRI consisted of images obtained with T2W half-Fourier acquisition single-shot turbo spin echo (HASTE), DWI, HBP and second-shot arterial phase (SSAP) imaging. SSAP imaging was collected after a second injection of 4 ml of contrast agent. This retrospective study demonstrated comparable diagnostic performance of AMRI and full MRI protocols. Preserved similarity of sensitivity and specificity on a per-patient and per-lesion basis suggested that the simulated AMRI could serve as an alternative tool for liver metastasis

evaluation. The mean imaging time saved was approximately 12.4 min, from 18.6 to 6.2 min in favor of AMRI [31].

A study by Torkzad M.R. et al. analyzed an AMRI protocol comprising of DWI, ADC maps, axial and coronal HBP gadoteric acid-enhanced T1W. Its results were compared to a full MRI protocol regarding postchemotherapy follow-up of colorectal liver metastases. The full MRI included axial: T1W, T2W and DWI (b values = 0–750 s/mm²), multiphase contrast-enhanced T1W, and axial and coronal HBP T1W sequences. AMRI showed high agreement with a full MRI without losing any information which would affect diagnostic performance. The mentioned AMRI protocol reduced scanning time, however, the exact time was not measured [32].

Ghorra C. et al. compared standard and simulated short gadoteric acid-enhanced MRI protocols for the detection of colorectal liver metastases. Abbreviated protocol consisted of T2W, DWI and HBP images. The time was not measured. The authors concluded that the diagnostic accuracy of fast MRI protocol was comparable to that of a standard long protocol with dynamic phase sequences [14].

Yamaguchi T. et al. evaluated an abbreviated MRI protocol with gadoteric acid contrast for the detection of liver metastases in patients with PDAC. The results of AMRI protocol (sequences: T2W, DWI and HBP) were comparable with those of the standard one. The standard protocol included: gradient dual-echo T1W, fat-suppressed fast spin-echo T2W, single-shot echo-planar DWI, 3D fat-suppressed T1W gradient-echo dynamic contrast-enhanced and HBP sequences. The estimated time necessary for AMRI was said to be less than one-third of the time required for the standard MRI protocol [23].

There are also studies suggesting that non-contrast liver MRI may replace gadoteric acid-enhanced MRI, in patients with relatively high risk of liver metastasis who previously underwent multidetector CT (MDCT) [33]. Noncontrast liver MRI could be beneficial especially in the case of lesions that are already documented as benign but require additional follow-up and in pre surgical setting after conversion treatment, where the main role of the diagnostic imaging is identifying residual metastases in order to assess the resectability. In this case, when all lesions have already been detected, Vincenza Granata et al. conclude that MR contrast media administration may not be necessary for pre surgical setting. This also corresponds with results of the survey performed by Osamu Tokuda et al. that suggest contrast enhancement is not always needed [11,33,34].

Barabasch A. et al. evaluated a non-contrast enhanced AMRI protocol including T2W, DWI and T1W in-phase and out-of-phase imaging extracted from full contrast-enhanced MRI protocol. The authors reported high sensitivity for liver metastases detection as well as high positive predictive value for lesion characterization. This simulated AMRI protocol could be achieved in 10 min with recorded reading times between 42 and 72 s. The measured acquisition time of the AMRI and the full MRI protocol was 10.3 min and 39.8 min respectively [35].

An abbreviated MRI evaluated by Granata V. et al. showed the same detection rate in the detection of liver metastases as a conventional MRI protocol. The AMRI included DWI and SPACE T2W fat suppressed sequences and the acquisition time was approximately 8 min [11].

Hayoz R. et al. studied 4 diverse MRI protocols for the detection of liver metastases from neuroendocrine tumor (NET). These were as follows: 1) DWI and ADC map, 2) T2W and dynamic contrast-enhanced images (including unenhanced, arterial, and portal phases), 3) T2W and HBP, 4) DWI and HBP. Sensitivity as well as specificity were lower with the protocols without contrast agent (unenhanced T1W, T2W, and DWI). The combination of HBP and DWI sequences appeared to have the highest sensitivity and could play significant role in detection of liver metastases from neuroendocrine tumor. Although no scanning time was measured, the authors assessed that DWI and HBP sequences would last less than 5 min [24]. Above mentioned AMRI protocols with their characteristics are presented in Table 1.

In all, regardless of the location of primary malignancy, the presence of liver metastases is of significant importance in choosing treatment

Table 1

Characteristics of several proposed AMRI protocols for detection of liver metastases, including acquisition time.

No.	Reference	Contrast enhancement (CE) / Non-contrast enhancement (NC)	Sequences used in protocol	Acquisition time	Sensitivity (Sen) / specificity (Spe)	Malignancy
1.	Canellas R. et al.	CE	Ultrafast SE T2W, DWI, T1W-HBP	<10 min	Sen > 90%	CRC
2.	Barabasch A. et al.	NC	(Axial) T2W-TSE, DWI, pre-contrast T1w-GRE in- and opposed phase	10 min	Sen for lesion detection 98.2% and 100% (depending on the reader) and high positive predictive value for lesion characterization (92% and 88%)	–
3.	Kim J.W. et al.	CE	T2-w, DWI, HBP, and SSAP images	6,2 min	The per-patient Sen and Spe (reader 1: 98.04% vs 98.04%, $P > 0.99$ and 100.0% vs 95.71%, $P = 0.250$; reader 2: 98.04% vs 98.04%, $P > 0.99$ and 100.0% vs 98.57%, $P > 0.99$) and the per-lesion Sen and Spe (reader 1: 95.97% vs 93.29%, $P = 0.288$ and 100.0% vs 97.22%, $P = 0.125$; reader 2: 95.30% vs 93.29%, $P = 0.561$ and 100.0% vs 99.07%, $P = 0.500$) were not significantly different between image sets 1 and 2 for the two readers. *Set 1 = original MRI protocol **Set2 = AMRI protocol	–
4.	Granata V. et al.	NC	DWI, SPACE T2W FS	–	In terms of per-lesion detection rate, all three readers had similar diagnostic detection rate with Gd-EOB MRI and with abbreviated protocol (96.8% [732 of 756] vs. 96.5% [730 of 756] for reader 1; 95.8% [725 of 756] vs. 95.2% [720 of 756] for reader 2; 96.5% [730 of 756] vs. 96.5% [730 of 756] for reader 3). Inter-reader agreement of lesions detection rate between the three radiologists was excellent (k range, 0.86–0.98) both for Gd-EOB MRI and for Fast protocol (k range, 0.89–0.99). Conventional MRI showed similar diagnostic performance compared to abbreviated protocol in per-patient detection rate, (97.2% [105 of 108] vs. 96.3% [104 of 108] for reader 1, 94.4% [102 of 108] vs. 95.4% [103 of 108] for reader 2, and 95.4% [103 of 108] vs. 94.4% [102 of 108] for reader 3). Nothing differences statistically was relieved between abbreviated Protocol and Conventional Protocol detection rate for each reader and for the radiological consensus obtained by three readers (p value = 0.70, 0.31, 0.31 and 0.45 at Chi square test, respectively). Inter-reader agreement in per patient detection rate between the three radiologists was excellent both for Gd-EOB MRI (k range, 0.89–0.98) and for abbreviated protocol (k range, 0.90–0.99).	CRC
5.	Torkzad M.R. et al.	CE	HBP gadoxetate disodium-enhanced T1W, DWI	–	In terms of the impact of identifying metastases in liver segments for potential surgical treatment planning, no difference in surgical approach would have resulted from reading SMRI versus AMRI. Using the combined readers' results, the total number of metastases showed high agreement between SMRI and AMRI with an ICC of 0.97. Although there seemed to be a relationship between the number of metastases and underdetection on AMRI, this difference was not statistically significant (p = 0.69). In patients with few metastases (≤ 6), only 3.45% of metastases were missed on AMRI compared with SMIR. By contrast, 9.80% of metastases were missed on AMRI in patients with a large number of metastases (≥ 7), which could be because of radiologist fatigue and because of irrelevancy of finding more metastases after the point of inoperability.	CRC
6.	Hayoz R. et al.	CE/NC	Set 1: DWI Set 2: T2WI + dynamic contrast-enhanced images Set 3: T2WI + HBP Set 4: DWI + HBP	< 5 min (DWI + HBP)	Sen 86% (95% CI 0.845–0.878), Spe 94% (95% CI 0.901–0.961) (DWI + HBP)	NET
7.	Ghorra C. et al.	CE	Fat saturated T2W, DWI, HBP	–	The metastasis detection rate was 86.1% (95% CI 82–89.4)–86.7% (82.6–90) and 85.8% (81.6–89.2)–87% (82.9–90.2) with the short and long protocols,	CRC

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Table 1 (continued)

No.	Reference	Contrast enhancement (CE) / Non-contrast enhancement (NC)	Sequences used in protocol	Acquisition time	Sensitivity (Sen) / specificity (Spe)	Malignancy
8.	Yamaguchi T. et al.	CE	Fat suppressed T2W, DWI, HBP	Estimated examination time < 10 min	respectively ($p > 0.99$). Among detected lesions, 92.1% (89.1–94.4)–94.8% (92.2–96.6) and 84.6% (80.8–87.7)–88.8% (85.4–91.5) were correctly classified with the short and long protocols, respectively ($p = 0.13$ and $p = 0.10$). Set 1: CECT-alone; set 2: CECT and abbreviated MRI comprising fat-suppressed T2-weighted, diffusion-weighted, and hepatobiliary phase images; and set 3: CECT and standard gadoxetic acid-enhanced MRI. Reader-averaged FOM to detect liver metastases were significantly higher for sets 2 (0.884) and 3 (0.886) than for set 1 (0.609), while they were comparable between sets 2 and 3 ($P = 0.96$). The mean per-patient sensitivities, negative predictive values, and accuracies were significantly higher for sets 2 and 3 than for set 1, while those between sets 2 and 3 were not significantly different (not applicable, $P > 0.99$, and $P > 0.99$, respectively). Gadoxetic acid-enhanced MRI combined with CECT had higher diagnostic performance than CECT alone for the detection of liver metastases in patients with PDAC. The incremental values were comparable for the abbreviated MRI and standard MRI.	PDAC

AMRI – abbreviated magnetic resonance imaging; CECT – contrast-enhanced computed tomography; CRC – colorectal cancer; DWI – diffusion-weighted imaging; FOM – figure of merit; FS – Fat suppression; GRE – gradient echo; HASTE – Half fourier Single-shot Turbo Spin-Echo; HBP – hepatobiliary phase; MRI – magnetic resonance imaging; NET – neuroendocrine tumors; PDAC – pancreatic ductal adenocarcinoma; SE – spin-echo; SMRI – standard magnetic resonance imaging; SPAIR – Spectral adiabatic inversion recovery; SPACE – sampling perfection with application-optimized contrasts using different flip angle evolution; SSAP – the simulated abbreviated protocol; T1/T2W – T1 and T2-weighted imaging.

strategy. Therefore, the accurate diagnosis and follow-up of liver metastases is an unmet medical need in such patients [36]. AMRI protocols constitute an alternative to conventional MRI scans and can help to expand patient access and meet the rapidly growing clinical demands [3].

5. AMRI protocols in the detection of hepatocellular carcinoma (HCC)

HCC is the most common primary liver cancer. The occurrence of HCC is associated with liver cirrhosis of various etiologies and hepatitis B virus (HBV) infection [37]. These patient groups require periodic follow-up which include blood alpha-fetoprotein (AFP) testing and imaging studies. US is a dedicated imaging method in HCC screening. However, it has its limitations resulting from the obesity of patients, the presence of fatty liver or simply the subjective nature of the examination. MRI is very accurate for the detection of HCC, but a full MRI protocol is not practical as a screening procedure due to the high cost and limited availability, and therefore it is not recommended as a method of choice. AMRI protocols could however prove useful as a screening tool [38]. AMRI has a high per-patient and per-lesion sensitivity for HCC. Although the sensitivity for the detection of HCC < 2 cm is considerably lower than for HCC $\geq$ 2 cm, it is substantially higher than that of US, making it a potential alternative for HCC screening in high-risk populations [39,40].

Combinations of sequences, which are considered useful for the screening of HCC usually compose of a non-contrast protocol (NC-MRI) with T2W imaging and DWI, dynamic AMRI with an extracellular gadolinium-based contrast agent or gadoxetate-enhanced HBP imaging with or without T2W and DWI. The fact that NC-MRI does not require contrast injection, makes it a suitable and non-invasive tool while reducing costs as well as scanning time. It removes the potential risks of gadolinium-based contrast agents, namely NSF and gadolinium tissue deposition. This makes it even more beneficial considering the fact that HCC surveillance requires periodic repetitive examinations [39].

Different AMRI protocols have comparable diagnostic performance regardless of the presence of cirrhosis and etiology of chronic liver disease [6,39]. Some studies also explored the combination of T2W and DWI with T1W sequences [4]. Sunyoung Whang et al. showed that non-contrast MRI and AMRI with gadoxetate-enhanced HBP have comparable diagnostic performance for detecting patients with the early stage HCCs [40]. The sensitivity and specificity of AMRI protocols in the HCC surveillance ranges between 61.5 and 100% and 77.5 – 100%, respectively [41]. Recent study by Yokoo et al. correlated the histopathological results and radiological findings in patients with liver cirrhosis investigated for early HCC [42]. The authors estimated the sensitivity and specificity of AMRI, composed of coronal T2W and axial 3D fat-suppressed T1W (in pre-contrast, arterial, venous and delayed phases) at 88.2% and 89.1%, respectively. The values were higher in patients with compensated cirrhosis.

In the case of positive findings, there is a need to characterize and specify the observations applying the Liver Imaging Reporting and Data System (LI-RADS) criteria, which were made in order to standardize imaging analysis for HCC screening, diagnosis and response to treatment. For this reason, a recall study using multiphase CT or MRI is needed. Dynamic AMRI protocol, based on dynamic T1W sequences after the i.v. administration of a contrast may be an exception. Major LI-RADS criteria can be applied to multiphase imaging so dynamic AMRI alone is sufficient for definitive diagnosis of HCC. Additionally, it offers cost benefits, since the contrast agents used in dynamic protocol are less expensive than the contrast agent (gadoxetate disodium) required for HBP [4]. Most HCCs, including early HCCs, are hypointense to the liver parenchyma in the abbreviated HBP after gadoxetic acid administration and therefore potentially detectable even in the absence of dynamic images. The T2W acquisition in the abbreviated examination helps differentiate HCC from benign cysts and hemangioma on the basis of their signal intensity. The DWI acquisition is included in the protocol to potentially detect HCCs that are not perceived or underreported on the other sequences [43]. Conventional liver MRI examinations can take 20–40 min depending on the number of sequences while AMRI can be

performed in less than 10 min [44,45].

6. Conclusions

AMRI can help to expand patient access meeting the rapidly growing clinical demands and have the potential to become an acceptable and cheaper alternative to the standard gadoteric acid-enhanced MRI protocol for cancer surveillance. Moreover, it can provide faster image acquisition without compromising the diagnostic impact of MRI for liver metastasis evaluation. Even though the AMRI protocols are highly sensitive and accurate for the characterization of liver lesions, making exact diagnosis can be challenging even in the standard MRI protocol. The process of evaluating and potentially incorporating AMRI into the early hepatic metastases and other cancers screening pathway will require further research.

7. Statements, Declarations and Conceptualization

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All authors contributed to the study conception and design. All authors read and approved the final manuscript.

The research did not involve human participants and/or animals therefore informed consent is not applicable.

CRediT authorship contribution statement

Mateusz Winder: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Sylwia Grabowska:** Formal analysis, Investigation, Writing – original draft. **Anna Hitnarowicz:** Formal analysis, Investigation, Writing – original draft. **Anna Barczyk-Gutkowska:** Writing – review & editing. **Katarzyna Gruszczyńska:** Writing – review & editing. **Katarzyna Steinhof-Radwańska:** Conceptualization, Writing – review & editing, Supervision.

Declaration of Competing Interest

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

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