ORIGINAL ARTICLE

Magnetic resonance whole body imaging at 3 Tesla: feasibility and findings in a cohort of asymptomatic medical doctors

CME

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Objectives To evaluate the feasibility of whole body imaging using a 3 Tesla magnetic resonance scanner without a contrast agent, and to study the prevalence of abnormal findings among a cohort of asymptomatic doctors.

Design Prospective study.

Setting Private hospital, Hong Kong.

Participants A total of 132 asymptomatic medical doctors (111 men, 21 women), with a mean age of 56 (range, 38-82) years, volunteered for the study. They underwent corresponding whole body imaging at our hospital between October 2005 and February 2006. Imaging involved a 3 Tesla magnetic resonance scanner with 32 channels, parallel imaging, Total Imaging Matrix technology, a maximum gradient amplitude of 40 mT/m and a slew rate of 200 mT/m/ms (Magnetom Tim Trio, Siemens Medical Solution, Erlangen, Germany). The use of matrix coils enabled coverage of the whole body. No contrast agent was used.

Main outcome measures Detection of abnormalities in asymptomatic, apparently healthy adults.

Results All examinations were completed successfully. The mean scan time per subject was 33 (standard deviation, 4) minutes. All subjects tolerated the examination well and overall imaging quality was satisfactory. A total of 124 (94%) subjects had positive findings, of whom 24 (18%) had further workup. Five (4%) subjects were found to have tumours, of which two (1.5%) were proven malignant. Our cancer detection rate was comparable to that of other reported whole body screening studies using contrast magnetic resonance imaging and positron emission tomography.

Conclusion We demonstrated the feasibility of performing whole body imaging in 30 minutes, using 32-channel magnetic resonance imaging at 3 Tesla without a contrast agent or any ionising radiation.

Key words
Image interpretation, computed-assisted; Magnetic resonance imaging; Whole body imaging

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Introduction

Magnetic resonance imaging (MRI) could be the ideal tool for non-invasive whole body imaging (WBI), as it offers high spatial resolution, excellent soft tissue contrast, and does not involve ionising radiation. A major limitation of conventional MR scanning is to complete WBI within reasonable scan time, since this involves patient repositioning and coil changes in order to target different body parts. More recently, whole body MRI has become available with new hardware and software developments. The aims of this study were: (1) to evaluate the feasibility of WBI using a 3 Tesla MR scanner, and (2) to study the prevalence of abnormal findings among a cohort of asymptomatic doctors at our hospital, and thereby explore the sensitivity of our scanning protocol. To our knowledge, this is the first reported study of WBI using a 3 Tesla MR scanner.

Methods

The study was carried out with the approval of our institutional human studies review board. Between October 2005 and February 2006 inclusive, MR WBI was performed on

132 asymptomatic medical doctors (111 men and 21 women; mean age, 56 years; age range, 38-82 years) at our hospital. Informed consent was obtained from all subjects who volunteered. All imaging was performed using a 3 Tesla MR scanner with 32 channels, parallel imaging, Total Imaging Matrix technology, a maximum gradient amplitude of 40 mT/m, and a slew rate of 200 mT/m/ms (Magnetom Tim Trio, Siemens Medical Solution, Erlangen, Germany). The use of matrix coils enabled coverage of the whole body. The subjects were scanned in the supine position with a head matrix coil (12 elements), neck matrix coil (4 elements), three body matrix coils (6 x 3 elements), and a spine matrix coil (24 elements) embedded in the patient table.

The imaging protocol consisted of the following sequences: (1) axial T1- and T2-weighted scans of the brain, neck, thorax, abdomen, and pelvis; (2) sagittal STIR scan of the whole spine; (3) coronal T1-weighted scans of the whole body in four stations. No contrast agent was used. The imaging parameters, voxel sizes, and scan times for each sequence are summarised in Table 1.

All subjects were interviewed after the examination and asked whether they had experienced any physical discomfort during the scan, specifically an increased sensation of body warmth due to increased specific absorption rate (SAR) at 3 Tesla compared with 1.5 Tesla. They were also asked whether or not they thought the scan duration was acceptable.

All images were reviewed and reported by five qualified radiologists, each with more than 10 years' experience in MRI interpretation.

3 Tesla磁共振全身造影：對一組無症狀醫生研究所得的結果及可行性

目的 評估在無顯影劑的情況下，應用3 Tesla磁共振掃瞄器作全身造影的可行性，以及檢視對一組無症狀醫生測試的結果中有異常發現的普遍程度。

設計 前瞻研究。

安排 香港一家私營醫院。

參與者 共有132位無症狀的醫生（111男，21女）自願參與本研究，他們的平均年齡為56歲（介乎38至82歲）。他們在2005年10月至2006年2月間，分別在本院接受全身造影。造影採用3 Tesla 32通道磁共振掃瞄器、平行造影、全影矩陣造影技術、最大梯度幅度40 mT/m，以及轉換速率200 mT/m/ms。矩陣絲圈覆蓋整個身體範圍。造影沒有使用顯影劑。

主要結果測量 在無症狀、表面上健康的成人身上偵測到的異常情況。

結果 所有檢視順利完成。平均掃瞄時間為33分鐘（標準差：4分鐘），所有接受檢視的對象均能忍受檢視過程，整體造影質量滿意。124位(94%)檢視對象的結果為陽性，當中24人(18%)接受進一步檢查。5人(4%)發現腫瘤，其中兩位 (1.5%) 證實患惡性腫瘤。本研究的癌腫偵測率，與其他已發表的應用顯影劑磁共振掃瞄或正電子斷掃瞄器作全身檢查的研究報告結果相近。

結論 本研究顯示，30分鐘內不使用顯影劑或電子化輻射、應用3 Tesla32通道磁共振掃瞄器作全身造影是可行的。

Results

Scan time

All examinations were completed successfully. The scan times per subject ranged between 30 and 42 minutes, with a mean (standard deviation) of 33 (4) minutes.

TABLE 1. Sequences for the whole body magnetic resonance imaging examination*

Region	Sequence	Repetition time (ms)	Echo time (ms)	Flip angle	Voxel size (pixel size x thickness)	Scan time (min)
Brain	Ax T1 Flash	180	2.57	70°	1.0x0.7x5.0	0:24
	Ax T2 TSE	4800	109	150°	1.0x0.7x5.0	1:04
Neck	Ax T2 FS	5790	94	140°	1.0x0.8x5.0	1:05
Thorax	Ax T1 Flash	188	2.46	70°	2.1x1.5x8.0	0:16
	Ax T2 Haste	1000	95	150°	1.2x1.1x8.0	0:25
Abdomen	Ax T1 Flash	210	2.46	70°	2.0x1.4x8.0	0:18
	Ax T2 Haste	1000	94	150°	1.4x1.1x8.0	0:28
	Ax T1 FS	195	2.46	70°	1.9x1.1x6.0	0:15
Pelvis	Ax T1 Flash	185	2.46	70°	2.0x1.4x8.0	0:16
	Ax T2 Haste	1000	95	90°	1.4x1.1x8.0	0:24
Spine	Sag STIR (2 stations)	2500	52	150°	1.5x1.1x5.0	3:10x2
Whole body	Cor T1 Flash (4 stations)	90	2.72	65°	1.4x1.0x6.0	0:34x4

* Z-direction coverage: 1600 mm

TABLE 2. Subjects with positive magnetic resonance findings (n=124)

Region	Findings	Subjects, No. (%)	
		Not requiring further workup	Requiring further workup
Head and neck	Sinus mucosal thickening	25 (19)	
	Nasopharyngeal cysts	3 (2)	
	Simple thyroid cysts	8 (6)	
	Thyroid nodules		10 (8)
	Borderline-sized lymph nodes	3 (2)	
Thorax	Lung fibrosis/scar	3 (2)	
	Other lung lesions		4 (3)
	Mediastinal lesion		1 (1)
Abdomen	Liver cysts	32 (24)	
	Liver nodules		2 (2)
	Liver cirrhosis	1 (1)	
	Haemochromatosis of liver	1 (1)	
	Cholelithiasis	4 (3)	
Retroperitoneum	Simple renal cysts	24 (18)	
	Renal masses		2 (2)
	Pancreatic lesion		1 (1)
	Retroperitoneal mass		1 (1)
Pelvis	Uterine adenomyosis/fibroids	3 (2)	
	Ovarian cysts	3 (2)	
	Prostatic lesion		1 (1)
Musculoskeletal	Degenerative spine disease	84 (64)	
	Spinal haemangioma	10 (8)	
	Tarlov cysts	2 (2)	
	Osteoma of skull	1 (1)	
	Other bone lesions		2 (2)
	Lipomas	3 (2)	

* US denotes ultrasound, CT computed tomography, and MRI magnetic resonance imaging

Subject tolerance

Eleven (8%) of the subjects reported mild-to-moderate increased sensation of body warmth during the examination. Of these, three (2%) felt warm during the middle part of the examination, and eight (6%) towards the end of the examination. All of them thought the sensation was tolerable. The other 121 (92%) subjects did not report such sensation. There was no other complaint of physical discomfort.

No subject reported psychological distress such as claustrophobia or panic attacks during the scan. Sedation was not administered to any subject, nor did anyone complain that the scan duration was unacceptable or beyond their tolerance level.

Image quality

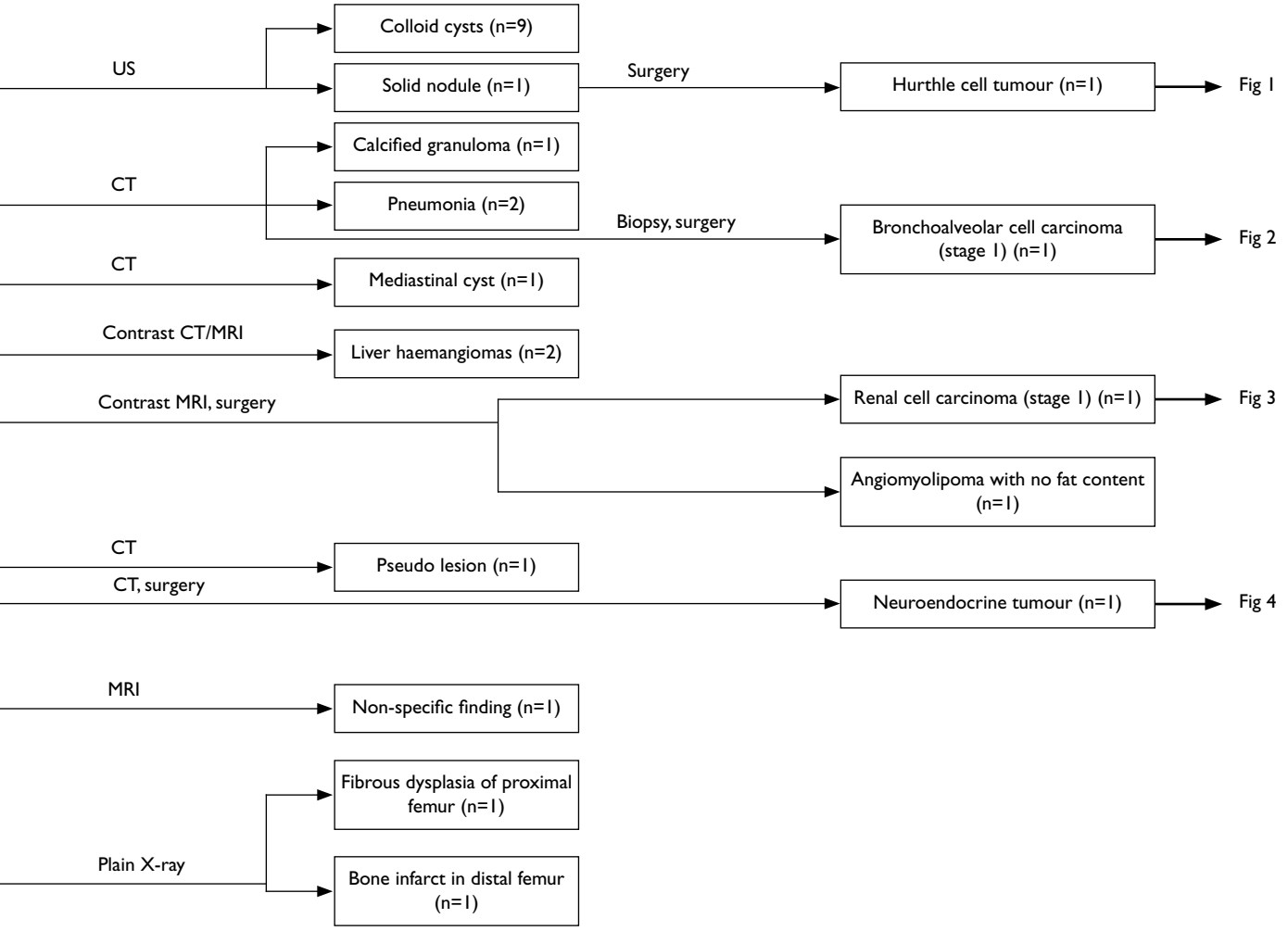
All images were reviewed and the severity of B1-field intensity inhomogeneity was assessed. Significant inhomogeneity was only seen in five (4%) of the cases.

Positive findings

A total of 124 (94%) of the individuals had positive findings. These findings were first categorised into two groups: (1) those considered not to require further imaging workup (most were minor or insignificant lesions), and (2) those that required further imaging workup. The latter consisted of 24 subjects (19% of those with positive findings), who underwent plain radiography, ultrasound, computed tomography (CT), or contrast-enhanced MRI. These various options are summarised in Table 2.

Of the 10 indeterminate thyroid nodules that required ultrasound evaluation, nine were confidently diagnosed as colloid cysts. One was solid and removed surgically, and pathology revealed it was a Hurthle cell tumour (Fig 1).

Four subjects with indeterminate lung lesions underwent CT evaluation. One lesion was a calcified granuloma; two were consistent with pneumonia, which resolved on follow-up. One suspicious lesion



on CT was also scanned with positron emission tomography–CT but was fluorodeoxyglucose-negative. Due to its suspicious CT characteristics, it was percutaneously biopsied; subsequently it was surgically removed and pathology revealed it was a stage 1 bronchoalveolar cell carcinoma (Fig 2).

Two suspicious renal masses were found and both were surgically removed. One was an angiomyolipoma that had no fat content, and thus difficult to differentiate from renal cell carcinoma by MRI. The other was a Bosniak classification type III cystic lesion, which turned out to be a renal cell carcinoma (stage 1) (Fig 3).

One large retroperitoneal mass was found and removed surgically. Pathology revealed it was a benign neuroendocrine tumour (Fig 4).

A focal pancreatic lesion was suspected on MRI, but a dedicated CT of the pancreas revealed no abnormality. Likewise, a focal prostatic lesion was suspected, but dedicated MRI of the prostate showed no definite lesion, and the subject's serum prostate-specific antigen level was also normal.

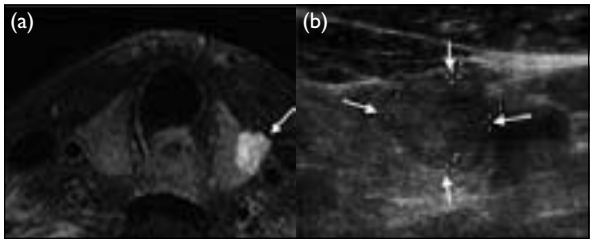


FIG 1. (a) Axial T2-weighted image of the thyroid gland showing a well-defined hyperintense focal lesion in left lobe. (b) Corresponding axial ultrasound scan at the same level reveals a slightly hypoechoic mass in the left thyroid lobe
Surgical diagnosis: Hurthle cell tumour

Discussion

Whole body imaging can be performed in two

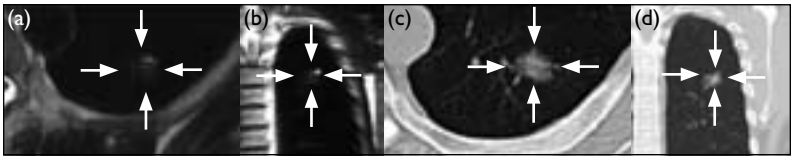


FIG 2. (a) Axial T1-weighted image shows an irregular focal lesion with increased signal in upper lobe of the left lung. (b) Coronal T1-weighted image again shows the left upper lobe lesion with a tiny hyperintense focus. (c, d) Corresponding axial and coronal computed tomographic scans (lung window) demonstrate the patchy lesion with a spiculated outline
Surgical diagnosis: bronchoalveolar cell carcinoma

different subject groups: normal subjects to screen for a range of benign and malignant diseases, and patients with known or suspected malignancy or other disease to evaluate disease extent (staging study). A major deterrent to WBI is the long scanning time. Repositioning the patient in the magnet bore with different receiver coils is highly time-consuming. One approach is to use a sliding table platform that enables data acquisition from different anatomical regions in rapid succession.[1] This has been successfully employed for the detection of bone, hepatic, cerebral, and lung metastases[2-5] and whole body MR angiography.[6-8]

Most MR screening examinations are targeted at organs such as the brain, the cardiovascular system, and the colon. We tried to examine the whole body in asymptomatic subjects, using a simple protocol comprising of T1- and T2-weighted sequences, without a contrast agent. The scan covered the brain, neck, thorax, abdomen and pelvis, and spine. Our subjects were informed that further imaging might be required for lesion characterisation and diagnosis. We did not target specific organs, although we did pay particular attention to malignancies that have a high prevalence locally, including lung, nasopharynx, and liver.

We optimised the scan protocol to limit the total examination time to within 30 minutes. This was made possible with a new technology that allows application of multiple phased–array surface coils and receiver channels, enabling complete head-to-toe coverage without the need for applying different surface coils to various body parts. A similar approach on a 1.5 Tesla system has proved successful in initial feasibility studies for the assessment of metastatic and vascular diseases.[9-11] The added benefit of high signal-to-noise resolution of the 3 Tesla system allows use of a fast imaging sequence without compromising image quality. The aims of our study were to evaluate the feasibility of WBI using this technology on a 3 Tesla system, and to explore the sensitivity of our scanning protocol.

The WBI protocols adopted by most centres included the use of gadolinium contrast, either for parenchymal organ assessment[3] or MR angiography.[6] Although gadolinium has a good safety profile and is not nephrotoxic if administered as standard doses in the presence of normal renal function patient, a totally non-invasive procedure is more appealing. Using contrast also prolongs the imaging time of the study. Thus, we decided to forego intravenous contrast. To our knowledge, this screening study is the first WBI depending on MR scanning that uses no contrast. We were aware that detection of parenchymal lesions in organs such as the liver, pancreas, and kidneys might be compromised. To circumvent this problem, we added a fat-saturated T1-weighted sequence for the abdomen, so as to enhance lesion detection in organs such as the pancreas. We did not aim to characterise and diagnose every lesion. Once an indeterminate lesion was identified, separate imaging workup was performed as required. In the future, new hardware and software development may allow us to include more sequences without prolonging the examination time.

Our current protocol was not tailored to examine the breasts, gastro-intestinal tract, and prostate gland. Also, MRI may not be sensitive enough to pick out small gallstones or renal stones.

Our initial experience clearly demonstrates that WBI by MR is technically feasible. All examinations were well tolerated and completed in about 30 minutes without the need to reposition the subjects. Increased body warmth due to the SAR effect did not seem to be a significant problem,

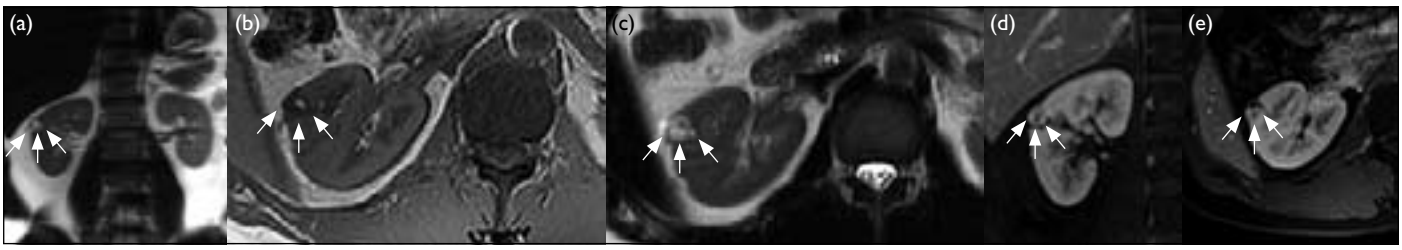


FIG 3. (a) Coronal T2-weighted image of right kidney shows a hyperintense multi-septated cystic lesion in the cortex of mid-pole of the right kidney. (b) Axial T1-weighted image shows a small hyperintense focus within the lesion. (c) Axial T2-weighted image of the lesion. (d, e) Subsequent post-contrast scans demonstrate heterogeneous contrast enhancement in the lesion, rendering it a Bosniak classification type III cystic lesion
Surgical diagnosis: renal cell carcinoma

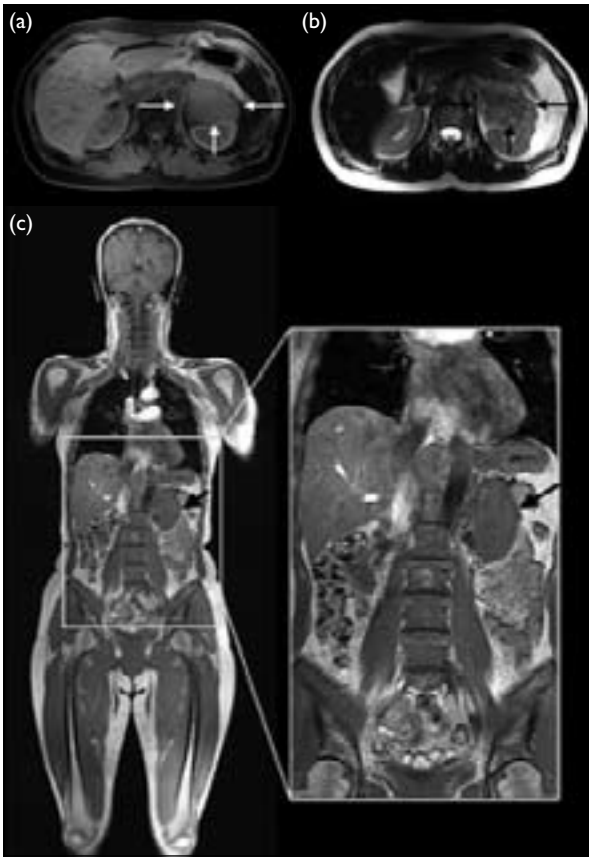


FIG 4. (a) Axial T1-weighted image with fat suppression shows a left retroperitoneal mass anterior to the left kidney and posterior to the pancreatic tail. (b) The mass is mildly hypointense on axial T2-weighted image. (c) Coronal T1-weighted image demonstrates cranio-caudal extent of the mass
Surgical diagnosis: benign neuroendocrine tumour

as only about 8% of subjects experienced such a sensation during the examination and none felt it was intolerable.

We were generally satisfied with the image quality of the non-contrast scans. Significant B1-field intensity inhomogeneity was only seen in 4% of cases, which mainly affected images of the spine. This may be improved by readjusting the transmitter voltage. Future hardware and software improvements may also help to overcome these problems.

Our current scanning protocol detected a wide range of lesions. There was a high prevalence of positive findings (94%), although most abnormalities were minor and did not require further follow-up; only 18% of our subjects needed further imaging. This rate appears higher than the 11.5% workup rate reported in a similar WBI study from Taiwan.[12] However, that study included ultrasound of the thyroid gland as part of the protocol. If we exclude the thyroid cysts diagnosed by ultrasound from our data, our workup rate becomes 11%, which compares favourably with the Taiwanese study. Moreover, unlike our MRI protocol, theirs included the use of intravenous contrast.

We detected tumours in five (4%) of our subjects, all of whom underwent surgery, Three turned out to have benign, namely a Hurthle cell thyroid tumour, a large retroperitoneal neuroendocrine tumour, and a fat-free renal angiomyolipoma. Being fat free, it was not possible to differentiate the latter from renal cell carcinoma by MRI. All three subjects preferred surgical excision without prior percutaneous biopsy. Taking into account the clinical circumstances and the imaging appearance of these lesions, we considered this operative rate to be acceptable.

Two malignant tumours were found on surgery (a bronchoalveolar cell carcinoma and a renal cell carcinoma, both stage 1 disease). The cancer pick-up rate of our study was 1.5%, which is comparable to that of the Taiwanese WBI study (1.8%)[12] and another Japanese WBI study using positron emission tomography scans (1.2%).[13]

A particular issue to consider is the clinical value of MRI in the detection of pulmonary lesions. Computed tomography is generally accepted as the imaging modality of choice for the lungs, as it provides the highest resolution. However, the latter also involves considerable ionising radiation, unless low-dose screening (unsuitable for visualisation of the mediastinum) is used. A previous study using T2-weighted HASTE (half-Fourier acquired single-shot turbo spin-echo) demonstrated a sensitivity of 93% in detecting pulmonary lesions of 5 mm or larger in size.[14] Arguably, pulmonary lesions smaller than 5 mm do not require intervention other than follow-up. However, for identifying patients with pulmonary nodules a more recent study[9] reported that MRI had a false negative rate of 14% compared to CT. In our study, pulmonary lesions (including fibrosis, scar, nodules, and infiltrates) were found in 5% of the subjects, the smallest being 5 mm in diameter. Since CT correlation was not available in all subjects, we could not evaluate the true sensitivity of MRI. Further studies to validate the sensitivity of 3 Tesla MRI in detecting pulmonary lesions are indicated.

In conclusion, this preliminary study demonstrates that WBI by MRI is technically feasible in less than 35 minutes, without the need to reposition subjects. In our cohort of 132 medical doctors, this method was able to detect two malignant tumours in asymptomatic individuals. While the long-term cost-effectiveness of screening is yet to be determined, the value of such imaging to individuals who can seek early treatment appears immeasurable.

Declaration

No conflicts of interest were declared by the authors.

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