Clinical Value and Operational Risks of MRI in ICU patients – A Retrospective Analysis Performed at a University Medical Center

Klinischer Wert und Risiken der Durchführung von MRT bei Patienten der Intensivstation – Eine retrospektive Analyse an einem Universitätsklinikum

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ABSTRACT

Purpose Intensive care unit (ICU) patients have a high risk of developing complications when leaving the ICU for diagnostic procedures or therapeutic interventions. Our study examined the frequency of adverse events associated with magnetic resonance imaging (MRI) of intensive care patients and the extent of changes in therapy due to the MRI scan to weigh the risks associated with the scan against the potential benefits of an MR scan, using a change in therapy as an indicator of benefit.

Materials and Methods 4434 ICU patients (January to December 2015) were identified by Hospital Information System (SAP-R/3 IS-H, Walldorf, Germany), ICU patient data management system Metavision (iMDsoft, Israel), and Radiology Information System (Nexus.medRIS, Version 8.42, Nexus, Germany). All intensive care and medical records (HIS) and MRI reports (RIS) were matched and further evaluated in a retrospective case-to-case analysis for biometric data, mechanical ventilation, ICU requirements, planned postoperative vs. emergency diagnostic requirements, complications and impact on further diagnosis or therapy.

Results Out of 4434 ICU patients, 322 ICU patients (7.3 %) underwent a total of 385 MRI examinations. 167 patients needed a total of 215 emergency scans, while 155 patients underwent 170 planned postoperative MRI exams. 158 (94.6 %) out of 167 emergency scan patients were ventilated under continuous intravenous medication and monitoring. In the planned postoperative group, only 6 (3.9 %) out of 155 were ventilated, but a total of 38 (24.5 %) were under continuous medication. 111 patients were accompanied by nurses only during MRI. Only one severe adverse event (0.3 %) was noted and was attributed to study preparation (n = 385). In 8 MRI examinations (2.1 %), the examination was interrupted or cancelled due to the patients' condition. While all MRI examinations in the planned group were completed (n = 170, 100 %) (e. g., postoperative controls), only 207 out of 215 (96.3 %) could be performed for emergency diagnostic reasons. MRI influenced the clinical course with a change in diagnosis or therapy in 74 (19.2 %) of all 385 MRI examinations performed, and in the emergency diagnostic group it was 31.2 % (n = 67/215).

Conclusion Nearly 20 % of MRI examinations of ICU patients resulted in a change of therapy. With only one potentially life-threatening adverse event (0.3 %) during transport and the

MRI examination, the risk seems to be outweighed by the diagnostic benefit.

Key Points

- The risk of adverse events associated with MRI scans in ICU patients is low.
- The rate of premature termination of ICU patients' MRI scans is low.
- Almost 20 % of ICU patients' MRI scans lead to a change of therapy.

ZUSAMMENFASSUNG

Hintergrund Patienten auf der Intensivstation (ICU) haben ein hohes Risiko, Komplikationen zu entwickeln, wenn sie die Intensivstation für diagnostische Verfahren oder therapeutische Eingriffe verlassen. Unsere Studie untersuchte die Häufigkeit von unerwünschten Ereignissen im Zusammenhang mit der Magnetresonanztomographie (MRT) von Intensivpatienten und das Ausmaß von Änderungen der Therapie aufgrund der MRT-Untersuchung, um die mit der Untersuchung verbundenen Risiken gegen den potenziellen Nutzen einer MR-Untersuchung abzuwägen, wobei eine Änderung der Therapie als Indikator für den Nutzen dient.

Material und Methoden 4434 Intensivpatienten (Januar bis Dezember 2015) wurden über das Krankenhausinformationssystem (SAP-R/ 3 IS-H, Walldorf, Deutschland), das Intensivpatienten-Datenmanagementsystem Metavision (iMDsoft, Israel) und das Radiologie-Informationssystem (Nexus. medRIS, Version 8.42, Nexus, Deutschland) identifiziert. Alle intensivmedizinischen und medizinischen Aufzeichnungen (KIS) und MRT-Berichte (RIS) wurden abgeglichen und in einer retrospektiven Fall-zu-Fall-Analyse hinsichtlich biometrischer Daten, mechanischer Beatmung, ICU-Anforderungen, geplanter postoperativer vs. dringender diagnostischer Anforderungen, Komplikationen und Auswirkungen auf die weitere Diagnose oder Therapie ausgewertet.

Ergebnisse Von 4434 Intensivpatienten hatten 322 Intensivpatienten (7,3 %) insgesamt 385 MRT-Untersuchungen erhalten. 167 Patienten benötigten insgesamt 215 Notfallscans, während 155 Patienten 170 geplante postoperative MR-Untersuchungen erhielten. 158 (94,6 %) der 167 Notfall-Scan-Patienten wurden unter kontinuierlicher intravenöser Medikation und Überwachung beatmet. In der geplanten postoperativen Gruppe wurden nur 6 (3,9 %) von 155 Patienten beatmet, aber insgesamt 38 (24,5 %) unter kontinuierlicher Medikation. 111 Patienten wurden während der MRT ausschließlich durch Krankenschwestern begleitet. Es wurde nur ein schwerwiegendes unerwünschtes Ereignis (0,3 %) festgestellt, das auf die MRT-Vorbereitung zurückgeführt wurde (n = 385). In acht Fällen (2,1 %) aller MRT-Untersuchungen wurde das MRT aufgrund des Zustands der Patienten unterbrochen oder abgebrochen. Während alle MRT-Untersuchungen der geplanten postoperativen Gruppe abgeschlossen wurden (n = 170, 100 %) (z. B. postoperative Kontrollen), konnten nur 207 von 215 (96,3 %) der Notfall-Gruppe durchgeführt werden. Die MRT beeinflusste den klinischen Verlauf mit einer Änderung der Therapie in 74 (19,2 %) von allen durchgeführten 385 MRT-Untersuchungen, in der dringlich diagnostischen Gruppe betrug sie 31,2 % (n = 67/215).

Schlussfolgerungen Nahezu 20 % der MRT-Untersuchungen von Intensivpatienten führten zu einer Änderung der Diagnose oder Therapie. Mit nur einem potenziell lebensbedrohlichen unerwünschten Ereignis (0,3 %) während des Transports und der MRT-Untersuchung scheint der diagnostische Nutzen das Risiko zu überwiegen.

Kernaussagen

- Das Risiko unerwünschter Ereignisse bei ICU Patienten durch MRT Untersuchungen ist extrem gering.
- Die Rate vorzeitiger Untersuchungsabbrüche bei ICU Patienten ist gering.
- Abhängig von der Indikationsstellung kann bei bis zu 20 % der ICU Patienten eine Änderung der Therapie erreicht werden.

Zitierweise

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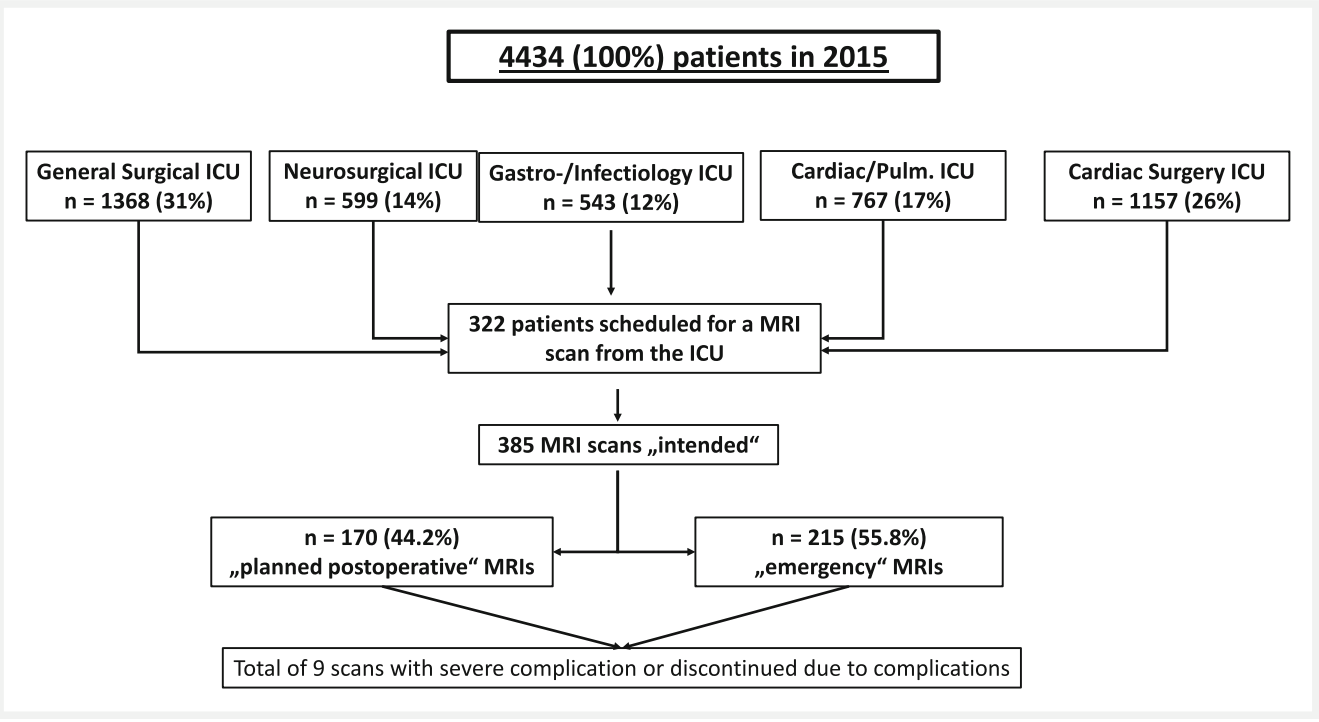
Introduction

In recent years, the number of intensive care unit (ICU) patients examined by means of cross-sectional diagnostic imaging methods such as computed tomography (CT) or magnetic resonance imaging (MRI) has been steadily increasing in our institution and generally in emergency situations [1, 2]. However, ICU patients who require such examinations need to be transported to radiology departments, which can be located far away from the ICU. Despite the attendance of a physician and a critical care nurse during transport and MRI scanning, in-house transportation bears significant risks for ICU patients who are often in a critical condition and require constant monitoring and ventilation [3–8].

The transport between the ICU and the radiology department as well as monitoring and ventilation during the MRI study represent organizational and medical challenges to ICU and radiology staff [3, 7, 9–11]. Beside ultrasound (US), computed tomography (CT) is frequently used for ICU patients. However, its use is limited in several indications such as neurologic ischemia, contusion of the spinal cord, and ligamentous tears of the spinal ligamentous apparatus. MRI has at the same time significant limitations for patients on ventilation and monitoring and those requiring continuous i. v. medications (e. g., sedatives, analgesics, catecholamines, antiarrhythmics, and cardiac inotropes).

Either special MR-compatible in-room equipment for monitoring and ventilation is used or extended ventilation tubes and intravenous lines are applied from the outside of the radiofrequency



▶ **Fig. 1** Patient data acquisition.

▶ **Abb. 1** Datenerfassung der Patienten.

(RF) shielded MR suite. Patients need to be monitored and ventilated in the very confined space of a scanner within a strong magnetic field for a relatively long examination time [12].

In 2015, a study showed that MRI scans – in contrast to CT scans – yield additional results in up to 95 % of ICU patients with neurological deficits [13]. From a radiologist's point of view, it is indisputable that MRI is a more sensitive method than CT, particularly in the case of complex neurological disorders [14]. In clinical practice, however, physicians have to consider the clinical relevance of any additional diagnoses that are obtained at great effort and expense. The particular superiority of MRI is mainly in the area of unclear, neurological deficits like ischemia as already mentioned above.

In other words, physicians must question whether such additional diagnoses would result in a change of diagnosis and consequently in a different intensive care therapy. In 2018, one retrospective study assessed the feasibility and pitfalls of cardiothoracic MRI in ICU patients [15]. However, until now, no study has evaluated the associated risks and the added value of MRI examinations in ICU patients in general.

For this reason, we examined the associated risk and the diagnostic benefit of MRI scans in ICU patients treated at a tertiary university medical center over a period of 1 year (January to December 2015). The patient population was analyzed regarding the occurrence of complications during in-house transportation and MRI examination. We evaluated the possible benefits of the performed MRI scans regarding changes of diagnosis and finally clinical therapy and investigated possible further correlations with the indication for the MRI assessment, the requesting ICU specialty, and the examined body region.

Materials and Methods

Patient selection

This retrospective study was approved by the institutional ethics committee (File Number: 21–2524–104).

Patients who underwent an MRI scan during their treatment in one of the five ICUs of a tertiary university medical center between January and December 2015 were identified by means of a database search of the radiological information system (RIS; Nexus.medRIS, Version 8.42, Nexus, Villingen, Germany). Further data evaluation was based on the digital patient records and ICU discharge letter. All data were obtained from the in-house hospital information system (HIS; IS-H; i.s.h.med; SAP, Walldorf, Germany). In addition, both the patient data management system (PDMS) Metavision (*iMDsoft,* Tel Aviv, Israel) and written anesthesia documentation for potential complications during in-house transport were screened. 322 ICU patients with 385 MRI exams, with 167 requiring a total of 215 emergency scans, and 155 patients undergoing 170 planned postoperative MRI exams (▶ **Fig. 1**). Out of the 167 patients with emergency scans, 158 (94.6 %) were ventilated under continuous intravenous medication and monitoring. In the planned postoperative group, only 6 (3.9 %) out of 155 were ventilated, but a total of 38 (24.5 %) were under continuous medication. Only 111 patients were accompanied by nurses during MRI.

MR imaging

All MRI scans were carried out with a 1.5 Tesla MRI scanner (MAGNETOM Avanto, Siemens Healthcare, Erlangen, Germany). The final MRI reports were available for evaluation in the radiological information system as well as the MRI images, which were not evaluated by the study investigators again. All final medical reports were assessed by a board-certified radiologist. Patients were connected to MRI-compatible monitoring (Expression MR 200, Philips Medical Systems, Germany) and, if necessary, to an MRI-compatible ventilator (Fabius MRI, Dräger, Germany) in the preparation room and then transferred to MRI.

Data acquisition

All data were entered into a spreadsheet (Microsoft Office Excel 2010, Microsoft, Redmond, Washington, USA). Data consisted of patient characteristics and clinical data based on the patient records obtained from the radiological information system and the PDMS. Patients were classified into one of the five classes established by the American Society of Anesthesiologists (ASA I to ASA V) according to the anesthesiological documentation.

The medical specialty of the respective ICU (conservative gastroenterology/infectiology, conservative cardiology/pulmonology, general surgery, cardiothoracic surgery and neurosurgery) was documented. In a retrospective case-to-case analysis, the patient's primary clinical diagnosis, the clinical indications for the MRI scan, and the scanned body region were recorded and analyzed for any complications associated with the ICU MRI examinations. Furthermore, the clinical impact of the MRI examinations on diagnosis and therapy and the correlation between the requesting ICU specialty and a change of diagnosis or therapy following MRI were analyzed. Additionally, correlations between body region and change of diagnostic or therapeutic measures after MRI were analyzed. The MRI requests were grouped into the two large groups: emergency diagnostic and planned postoperative. The radiology reports were evaluated regarding the diagnostic findings and diagnoses and their further clinical impact on the individual patient. Using the data obtained from the ICU PDMS, we evaluated in a non-blinded consensus-based decision by an experienced (> 30 years) anesthesiologist (MTP) and experienced (> 25 years) radiologist (AGS) the extent to which MRI results led to a change of diagnosis or therapy and documented any actual changes of therapy after the MRI examination. Medical procedures performed prior to the MRI scan were noted. Furthermore, the underlying reasons for complications or interruption during the MRI examination and in-house transport were analyzed and documented.

Statistics

IBM SPSS Statistics 24 (IBM SPSS Armonk, New York, USA) was used for statistical analysis. Data were analyzed using descriptive statistics only and presented as mean ± standard deviation (SD) or as median (range) and percentage, unless otherwise described.

▶ **Table 1** Patient characteristics of all 322 patients in absolute numbers and percentages.

▶ **Tab. 1** Patientenmerkmale aller 322 Patienten in absoluten Zahlen und Prozent.

	Absolute number	Percentages
Sex (male)	199	61.8 %
Sex (female)	123	38.2 %
Age, mean in years ± SD	56 ± 16	
ASA I	9	2.8 %
ASA II	62	19.2 %
ASA III	142	44.1 %
ASA IV	102	31.7 %
ASA V	7	2.2 %

Results

In 2015, 4434 patients were treated in five separate ICU units at a university medical center, resulting in 24 510 treatment days (general surgical ICU: 7435; conservative cardiac and pulmonary ICU: 5032; cardiothoracic surgery ICU: 4534; conservative gastroenterological/infectiology ICU: 4127; and neurosurgical ICU: 3382) (▶ **Fig. 1**). 322 (7.3 %) of all ICU patients underwent 385 MRI scans, resulting in 1 MRI scan per 63.7 treatment days. 164 of these 322 patients were mechanically ventilated**.** Patient characteristics such as age, sex, and ASA status are shown in ▶ **Table 1**. The majority of patients undergoing MRI (142 patients (44.1 %)) were category ASA III, followed by ASA IV (102 patients (31.7 %)).

Most of the MRI scans were requested for neurosurgical ICU patients (n = 198, 51.4 %). Out of these neurosurgical MRI scans, 142 (71.7 %) were performed as planned postoperative examinations. In general, the majority of MRI scans were emergency diagnostic scans (n = 215, 55.8 %) compared to 170 planned postoperative scans (44.2 %) (▶ **Table 2**).

Out of the 385 MRI scans, 279 (72.5 %) were of the brain. ▶ **Table 2** gives a complete overview of the examined body regions. Most MRI scans were of one body region (n = 278; 86.3 %). A minority of patients (n = 37, 11.4 %) had scans of two different body regions (▶ **Table 3**), mostly a combination of the head and carotid arteries (n = 11), and only a few (n = 7; 2.2 %) had scans of three (head, cervical, and thoracic spine) or more regions. The underlying diagnosis of a brain tumor was by far the most common diagnosis in all patients (n = 122, 31.7 %). Further diagnoses are shown in ▶ **Fig. 2**.

The most common indications for MRI scans were the exclusion of hypoxic brain damage or ischemia (23.7 %), exclusion of stroke/hemorrhage (16.3 %), exclusion of spondylodiscitis/meningitis (14.4 %), and exclusion of spine fractures or of disco-ligamentous injuries (9.8 %). Cardiac MRI assessment (6.5 %) was of further diagnostic importance. Assessment regarding further

▶ **Table 2** Frequency of MRI requests and overview of the different body regions scanned by MRI in absolute numbers (n = 385) and percentages.

▶ **Tab. 2** Häufigkeit der MRT-Anfragen und Überblick über die verschiedenen Körperregionen, die mit MRT untersucht wurden in absoluten Zahlen (n = 385) und Prozent.

	All MRI scans	Emergency diagnostic MRI scans	Planned postoperative MRI
General Surgery ICU	96 (25 %)	83 (38.6 %)	13 (7.6 %)
Neurosurgery ICU	198 (51.4 %)	56 (26.0 %)	142 (83.5 %)
Cardiothoracic Surgery ICU	20 (5.2 %)	16 (7.4 %)	4 (2.4 %)
Gastroenterology/Infectiology ICU	33 (8.6 %)	29 (13.5 %)	4 (2.4 %)
Cardiology/Pulmonology ICU	38 (9.9 %)	31 (14.5 %)	7 (4.1 %)
Total	**385 (100 %)**	**215 (100 %)**	**170 (100 %)**
Brain	279 (72.5)		
cerebral vessels	10 (2.6)		
carotid arteries	15 (3.9)		
cervical spine	17 (4.4)		
thoracic spine	12 (3.1)		
lumbar spine	9 (2.3)		
Entire spine	5 (1.3)		
neck	5 (1.3)		
thoracic	3 (0.8)		
heart	13 (3.4)		
pancreas	4 (1.0)		
liver	7 (1.8)		
intestine	2 (0.5)		
pelvis	3 (0.8)		
knee	1 (0.3)		
Total	**385 (100)**		

▶ **Table 3** MRI examinations including two body regions (n = 37).

▶ **Tab. 3** MRT-Untersuchungen mit zwei Körperregionen (n = 37).

Body regions	Patients
Head and carotid arteries	11 (30.0 %)
Head and brain vessels	7 (19.0 %)
Thoracic and lumbar spine	4 (11.0 %)
Head and cervical spine	4 (11.0 %)
Head and neck	3 (8.0 %)
Cervical and thoracic spine	3 (8.0 %)
Head and entire spine	2 (5.2 %)
Cervical spine and carotid arteries	1 (2.6 %)
Head and lumbar spine	1 (2.6 %)
Head and heart	1 (2.6 %)
Total	**37 (100 %)**

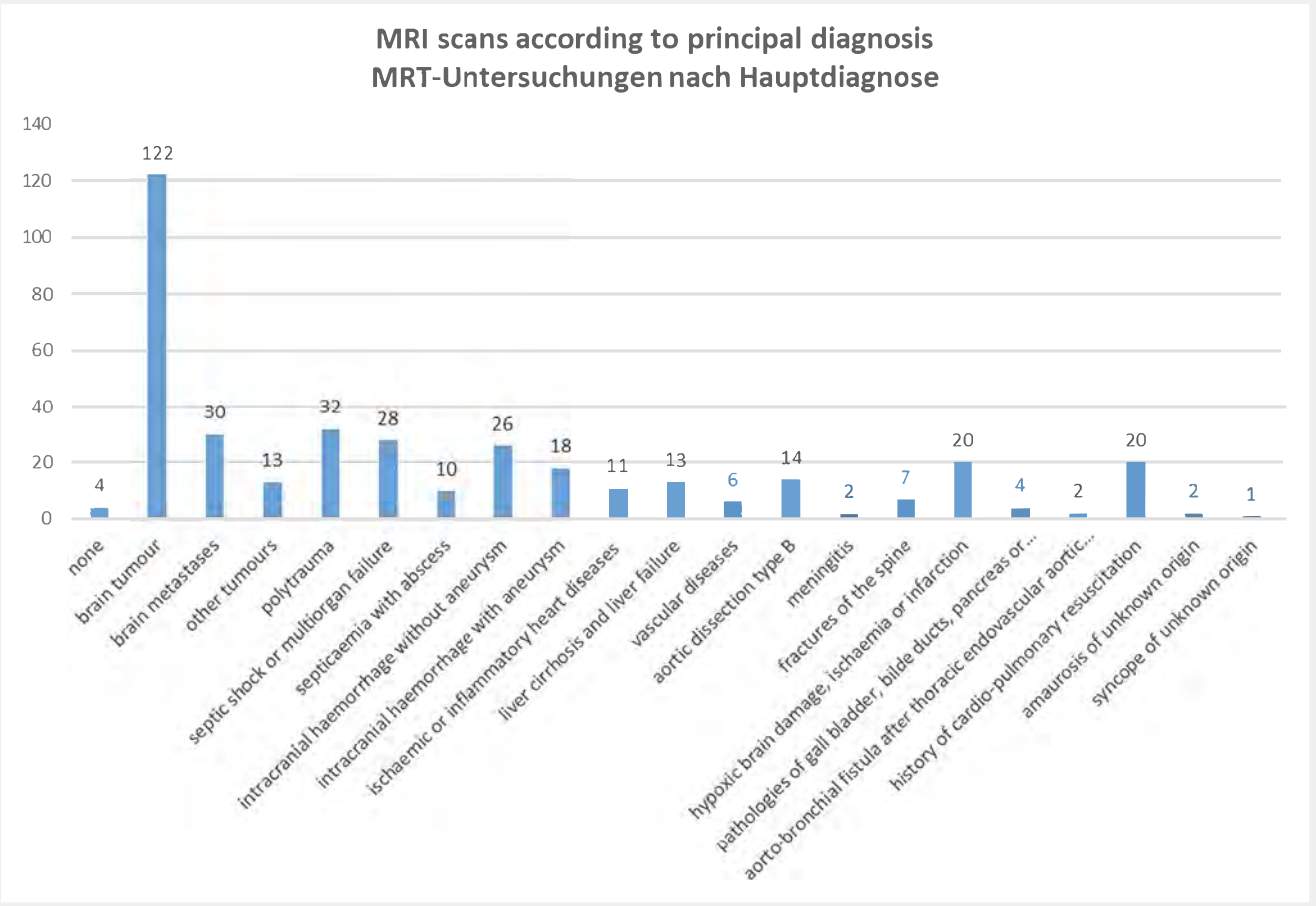
diagnoses like possible spinal hematoma or imaging of the bile ducts or the pancreas was seldomly requested.

In 50.6 % (n = 195) of 385 MRI examinations, patients underwent a CT scan of the affected body region prior to the MRI examination. After subtracting 103 CT scans (4 aborted MRI examinations + 99 postinterventional MRI examinations), 22/92 = 23.9 % resulted in a change in diagnosis or therapy in patients in the emergency group, who were diagnosed by CT scan prior to MRI examination.

Only 6.5 % (n = 23) of all MRI examinations had been preceded by an MRI scan of the same body region (▶ **Table 4**).

Complications associated with the ICU MRI scans

In 376 (97.7 %) of all MRI examinations, no complications occurred during in-house transport, and the acquisition of the MRI scan and the exam were completed successfully. One serious complication occurred in the ICU prior to MRI when the change of a tracheostomy tube for an MRI-suitable one resulted in a small tear



▶ **Fig. 2** Overview of the MRI scans according to the principal diagnosis (n = 385).

▶ **Abb. 2** Überblick über die MRT-Untersuchungen nach Hauptdiagnosen (n = 385).

▶ **Table 4** Diagnostic procedures performed prior to the MRI scan (n = 385).

▶ **Tab. 4** Vor der MRT-Untersuchung durchgeführte diagnostische Verfahren (n = 385).

	Number	Percentage
Missing values	5	1.3
No previous diagnostic procedure	143	37.1
Computed tomography	195	50.6
Preceding magnetic resonance imaging	23	6.0
Sonography	13	3.4
Angiography	4	1.0
Electrophysiological examination	1	0.3
Electroencephalography	1	0.3
Total	**385**	**100**

in the frontal wall of the trachea. After bronchoscopic examination of the trachea by thoracic surgeons, the MR-suitable tracheal cannula was placed correctly. Antibiotic therapy was administered, and surgical measures were not performed due to the minimal tear of trachea wall.

Only a total of 8 (2.1 %) MRI examinations out of all 385 MRI studies were not feasible or had to be terminated prematurely (▶ **Fig. 1**). All of those examinations were in the emergency group and the reasons were as follows: patient non-compliance (n = 2), breathing artifacts (n = 2), metallic object in the eye (n = 1), claustrophobia (n = 1), technical failure of vital monitoring during ventilation (n = 1), and morbid obesity (n = 1).

Short optimized MRI sequences for uncooperative patients were available and used for MRI scans of the brain and the spine. Despite the utilization of these sequences in the 2 non-compliant patients, the image quality was not considered to be diagnostic.

Clinical impact of the MRI examinations

The largest group of MRI examinations was postinterventional (including planned postoperative) MRI scans that showed the expected post-surgery findings (n = 162, 42.1 %), with 146 of

▶ **Table 5** Consequences of the MRI scan (n = 385) according to different groups in absolute numbers and percentages.

▶ **Tab. 5** Konsequenzen aus der MRT-Untersuchung (n = 385) nach verschiedenen Gruppen in absoluten Zahlen und Prozentsätzen.

	Emergency diagnostic MRI	Planned postoperative MRI	Total
	n (%)	n (%)	n (%)
Termination of MRI examination	8 (3.7)	0 (0.0)	8 (2.1)
Changes based on patient files could not to be determined	9 (4.2)	0 (0.0)	9 (2.3)
Postinterventional control without pathological findings	16 (7.4)	146 (85.9)	162 (42.1)
Confirmation of suspected diagnosis (no changes)	26 (12.1)	4 (2.4)	30 (7.8)
No change of therapy	78 (36.3)	11 (6.4)	89 (23.1)
Further clarification required following the MRI scans	11 (5.1)	2 (1.2)	13 (3.4)
Σ "No change of therapy"	*148 (68.9)*	*163 (95.9)*	*311 (80.8)*
"Change of therapy"	*67 (31.2)*	*7 (4.1)*	*74 (19.2)*
Total	**215 (100.0)**	**170 (100.0)**	**385 (100.0)**

these MRI scans being performed as planned postoperative scans and 16 as emergency scans (▶ **Table 5**). A further 30 (7.8 %) scans were conducted with the aim of confirming a precise clinically suspected diagnosis by means of MRI, with a vast majority being performed as emergency MRI scans (n = 26).

A total of 89 scans (23.1 %) did not lead to changes in therapy, 78 from the emergency group and 11 from the planned postoperative group. In 74 cases (19.2 %) the ICU MRI scan resulted in a change of diagnosis or therapy with most cases being conducted on an emergency basis for further clarification (n = 67 in the emergency diagnostic group). In 13 cases patients underwent surgery as an immediate therapeutic consequence of the MRI examination, e. g., trauma (11 in the emergency group and 2 in the planned postoperative group) (▶ **Fig. 3a, b**). One patient (from the emergency group) underwent a CT-controlled puncture following the MRI result to further assess a fluid collection. In 42 patients, MRI led to a change of conservative therapy (n = 39 in the emergency group and n = 3 in the planned postoperative group), e. g., commencement of antibiotic therapy. In 18 cases, MRI resulted in the termination of life-sustaining therapy (▶ **Fig. 4**), especially in the emergency group (n = 16).

Correlation between requesting ICU specialty and change of diagnosis or therapy following MRI

30 (40.5 %) of the 74 MRI examinations (both planned postoperative and emergency MRI scans) leading to a change in therapy had been requested by the surgical ICU and the neurosurgical ICU, respectively. In 6 patients of the cardiac ICU (8.1 %) and 4 patients of the cardiothoracic ICU (5.4 %), MRI led to a change of therapy. In 4 (5.4 %) patients of the gastroenterological/infectiology ICU, the MRI result changed the further treatment, e. g., one patient with known colitis received extended antibiotic treatment due to the diagnosis of the extensiveness of the penetrating disease.

Correlation between body region and change of diagnosis or therapy after MRI

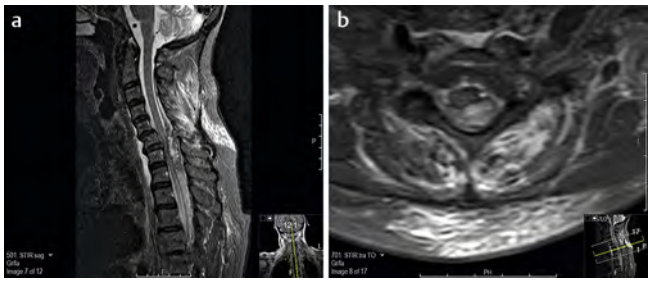
All 74 MRI examinations resulting in a change of therapy were analyzed regarding their correlation with the scanned body region. 56 (75.7 %) MRI scans resulting in a change of diagnosis or therapeutic management were of the brain (▶ **Fig. 5a, b**), 4 (5.4 %) of the carotid arteries, and 2 (2.7 %) of the neck region. 4 (5.4 %) MRI scans of the cervical and lumbar spine each and 2 (2.7 %) of the thoracic spine altered patient management. Only one (1.4 %) liver MRI and one (1.4 %) pancreatic MRI incl. an MRCP led to a change in diagnosis or therapy. In the case of pancreatic MRI with MRCP, previously undetected prepapillary choledocholithiasis leading to cholestasis was diagnosed. None of the requested cardiac MRI scans led to a change in therapy. The 10 MRI scans leading to a change of therapy requested by either the conservative cardiac ICU or the cardiothoracic ICU were of the head (n = 5), the thoracic or lumbar spine (n = 4), or the carotid arteries (n = 1).

Discussion

MRI scans of ICU patients are time-consuming and complex examinations in the everyday hospital routine. Critical care physicians have to carefully weigh the indication for an MRI examination because of the complexity, cost [16], and potential risks [7] posed to ICU patients during in-house transport.

The majority of our ICU patients were middle-aged men, which is consistent with the average characteristics described for ICU patients in the literature [17].

Most of the MRI scans were requested by the neurosurgical ICU with a total of 198 scans (51.4 %). Consequently, the brain was the most examined body region (n = 279; 72.5 %). Out of the 198 scans, 142 were performed as planned postoperative exams. This can be explained by the fact that MRI examinations are considered superior in patients with neuropathological disorders such as cranio-



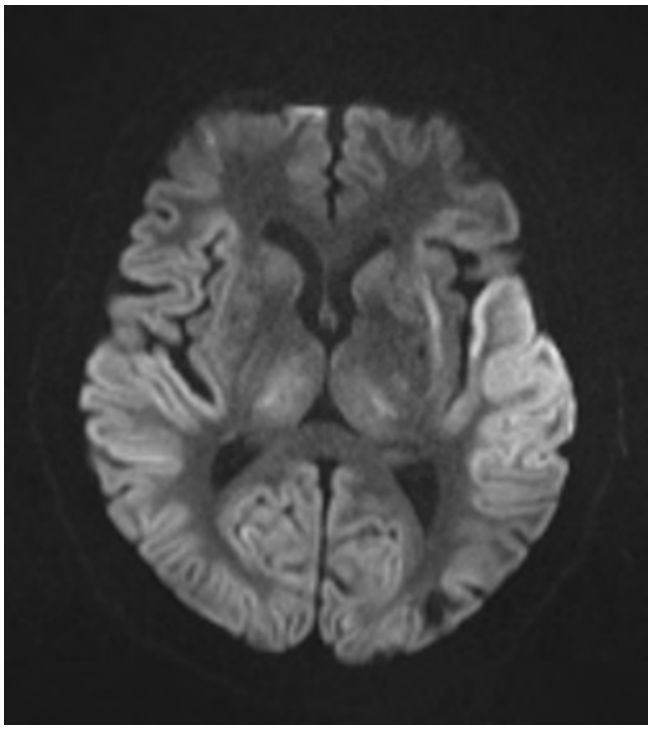
▶ **Fig. 3 a, b** Female, 78-yo, condition after a traffic accident, out-of-town CT shows suspicion of an unstable C6/7 fracture, deteriorating neurology. MRI of intensive care patient: laceration fracture cervical spine 6/7 with extended distance C6/7 with laceration of interspinous ligament. Extensive epidural hematoma extending from cervical vertebra 2 to thoracic vertebral body 4 – punctum maximum cervical vertebra body 5/6–7/thoracic 1 to 11 mm hem width with left leading myelon displacement and compression without myelopathy signal forwarded to surgical intervention. Sagittal T2 (STIR) (▶ **Fig. 3**). Axial T2 (STIR) at height C6/7 (▶ **Fig. 3b**).

▶ **Abb. 3 a, b** weiblich, 78 Jahre, Z. n. Verkehrsunfall im auswärtigem CT wird V. a. instabile C6/7 Fraktur geäußert, zunehmende Neurologie. MRT von Intensiv: Zerreißungsfraktur HWK 6/7 mit erweiterter Distanz C6/7 mit Zerreißung des interspinösen Ligaments. Ausgedehntes epidurales Hämatom von HWK 2 bis BWK 4 reichend – punctum maximum C5/6–C7/Th 1 bis 11 mm Saumbreite mit linksführender Myelonverlagerung und -kompression ohne Myelopathiesignal weitergeleitet zur operativen Intervention. Sagittale T2 (STIR) (▶ **Abb. 3**). Axiale T2 (STIR) in der Höhe HWK 6/7 (▶ **Abb. 3b**).

cerebral trauma, tumors, or intracranial hemorrhage [13] and thus are considered the gold standard following neurosurgery.

When evaluating the risk of MRI scans in ICU patients, our study showed one case of a potentially life-threatening complication: a tear in the frontal wall of the trachea following the replacement of a tracheostomy tube with an MRI-compatible system. Such pre-exam preparations are only required for MRI examinations but not for CT scans, which stresses the importance of a very strict indication for MRI scans in this group. Since the MRI environment can be potentially dangerous to patients and staff due to the strong magnetic field, specific guidance has been recommended and published by the American College of Radiology [18]. Beside patient-specific risks that need to be ruled out like ferromagnetic objects in the orbita, spine, or brain, MRI staff must carefully check patients as well as all inexperienced medical staff for magnetic objects (e. g., ferromagnetic oxygen tanks or regular lung ventilators that are not MRI-compliant) prior to them entering MRI zones.

The long duration of MRI examinations presents a great challenge for both ICU patients and physicians, mainly regarding patient cooperation and breathing control, particularly in awake and spontaneously breathing patients. Still, 98.0 % of all MRI examinations in our study were completed successfully. Kumarasamy et al. studied cardiothoracic MRI imaging in the ICU patient cohort over a period of 10 years and showed an MRI completion rate of 52.0 % in cardiothoracic MRI imaging and 62.0 % in brain MRI imaging [15]. However, cardiac MRI imaging is very challenging and needs a high level of cooperation from the patient, and



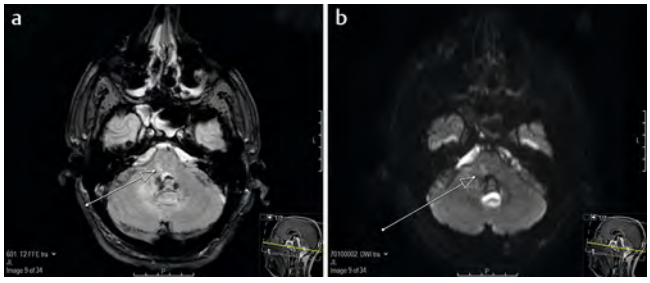
▶ **Fig. 4** MRI scan of the brain performed in a 75-year-old male patient from the neurosurgical ICU in suspected cerebral hypoxia following prolonged cardiopulmonary resuscitation due to cardiac arrest. Diffusion-weighted imaging (DWI) (Fig. 4) incl. the apparent diffusion coefficient (ADC) map (Fig. 4) shows extensive cerebral hypoxic-ischemic injury of the cerebral cortex of both temporal lobes (hyperintense cortex grey matter on DWI with corresponding hypointensity on the ADC, not shown). The diagnosis of diffuse hypoxic-ischemic brain injury was confirmed by electroencephalography (EEG).

▶ **Abb. 4** MRT-Aufnahme des Gehirns eines 75-jährigen männlichen Patienten aus der neurochirurgischen Intensivstation mit Verdacht auf zerebrale Hypoxie nach länger andauernder kardiopulmonaler Reanimation aufgrund eines Herzstillstands. Die diffusionsgewichtete Bildgebung (DWI) (Abb. 4) zeigt eine ausgedehnte zerebrale hypoxisch-ischämische Schädigung der Großhirnrinde beider Schläfenlappen (hyperintense graue Rindensubstanz im DWI mit entsprechender Hypointensität im ADC, nicht dargestellt). Die Diagnose einer diffusen hypoxisch-ischämischen Hirnschädigung wurde durch eine Elektroenzephalographie (EEG) bestätigt.

the number of cardiac MRI examinations in our study was relatively small (n = 13; 3.4 % of all MRI scans).

Almost 20 % of all MRI scans requested by the ICU departments led to a change in diagnosis or therapy and can thus be considered highly important for further patient management. If only the MRI examinations of the emergency diagnostic group are included, the percentage increases to 30 % of the MRI scans resulting in a change of intensive care treatment. This fact stresses the importance of MRI imaging in this ICU patient group.

The rate of change of therapy in the planned postoperative MRI group is low (n = 7, 4.2 %), which is strongly related to the high number of postinterventional control MRI examinations in this group without pathological findings (n = 146, 85.9 %). However, these MRI examinations are considered state-of the art



▶ **Fig. 5 a, b** Patient with ventilation (ICU) (male, 41-yo) after a traffic accident with suspicion of incomplete paraplegia; radiological findings: craniocerebral trauma with condylar fracture (findings from trauma CT); intracranial hemorrhage at the right cerebellum- new finding in MRI spot-shaped flat signal elevation (6 mm) in the course of the pons/crus cerebelli on the right matching contusion edema (finding only visible on MRI). **a** Transverse T2-weighted MRI of the head (signal hyperintensity in T2 sequence – findings marked with arrow). **b** Identical patient with DWI (diffusion weighted imaging) shows diffusion restriction matching the contusion oedema.

▶ **Abb. 5 a, b** Patient mit Beatmung (ICU) (männlich, 41 Jahre) nach Verkehrsunfall mit V. a. inkompletten Querschnitt; Radiologischer Befund: Schädel-Hirntrauma mit Kondylenfraktur (Befund aus dem Trauma CT); intrakranielle Blutung am Kleinhirn rechts – neuer Befund im MRT fleckförmige flaue Signalanhebung (6 mm) im Verlauf der Pons/Crus cerebelli rechts passend zu Kontusions-Ödem (Befund nur in MRT sichtbar). **a** Transversale T2-gewichtete MRT des Kopfes (Signalhyperintensität in T2-Sequenz - Befund mit Pfeil markiert). **b** Identischer Patient mit DWI (Diffusion weighted imaging) zeigt eine Diffussionsrestriktion passend zum dem Kontusionsödem.

post-surgery imaging to confirm complete removal of a tumor and to obtain baseline studies for follow-up scans. Therefore, there is no alternative. In our study cohort, these planned postoperative MRI scans can be considered to be rather safe for patients. Moreover, most patients were experienced as a result of having undergone preoperative MRI scans, thus resulting in less anxiety. Additionally, they are in a more stable condition requiring less monitoring, which may explain why all examinations could be performed in this group.

Considering the high number of brain MRI examinations necessary for ICU patients and the associated effort and expenditure for the ICU team and hospital, the availability of mobile MRI scanners for brain imaging could facilitate management of these patients in the future. In a prospective single-center cohort study with 50 patients, a mobile open MRI scanner weighing less than 100 kg allowed diagnosis of brain diseases such as stroke or trauma inside the ICU. 29 of 30 patients with coronavirus disease 2019 (COVID-19) were examined by means of this mobile MRI scanner, thus avoiding in-house transport of highly infectious patients while simultaneously enabling a high-end examination without exposing patients and staff to radiation [19].

Interestingly, more than half of the patient cohort had undergone a CT scan prior to the MRI examination, which is likely because CT scans are more easily accessible, especially outside of regular duty hours, quicker to use, and less cost-intensive. After all, 23.9 % of these patients still had a change in diagnosis or therapy after an MRI examination, which underlines the importance of MRI even after a previous CT examination.

Most of the ICU MRI scans leading to a change in diagnosis or therapy were requested by either the surgical or the neurosurgical ICU department. The high rate of patient management-altering MRI scans being requested by the surgical ICU in our study cohort is likely due to major trauma patients (except for predominant major head traumas) being mainly treated in this ICU at our tertiary care hospital. In addition, the likelihood of changing diagnosis or treatment following MRI scans of major trauma patients in the acute setting is high. Moreover, the rate of altered patient management following an MRI scan was especially high for examinations of the brain, followed by MRI scans of the carotid arteries, the cervical and lumbar spine, and the neck region. This is due in part to these body regions being scanned most frequently in our cohort. The high rate of altered patient management in patients with brain MRI scans may also depend on the superiority of MRI imaging in the context of neurological disorders and might help ICU physicians in their considerations regarding ICU MRI scans of these body regions and the associated risks. Performing an MRI on ICU patients requires not only qualified personnel but also special equipment [20]. Due to the high magnetic field of the MRI scanner, suitable equipment must be used for monitoring and ventilation, which is more expensive to purchase than conventional equipment [21]. This equipment has a higher susceptibility to interference during monitoring than stationary monitoring in the ICU, which presents a special challenge for the ICU team. Not every MRI institution has such equipment and can therefore care for intensive care patients under MRI conditions. Patients must not be too unstable for the MRI examination, which takes much longer than CT scans. Otherwise patients could be put at risk outside the safety of the ICU.

One essential limitation of the present study is its retrospective design. Minor incidents occurring during transport may not have been sufficiently documented in the available anesthesia protocols, so the reported incidence of adverse events during transport may be too low. In addition, our single-center study took into account a larger number of MRI scans that were scheduled, i. e., the examined patient group probably consisted of the more stable ICU patients which poses a selection bias. It is also important to mention that our hospital with a large number of ICU beds uses a small, dedicated group of highly experienced intensive care nursing specialists who accompany ICU patients along with physicians during transport from every ICU, resulting in very high-quality monitoring during transport and MRI examination. This may have led to the low number of incidents and incomplete MRI examinations in our study. Further prospective multicenter studies should be conducted to confirm the importance of our observations.

Conclusion

Overall, our study is the first that supports the importance of MRI scanning in ICU patients, especially if emergency diagnostic MRI imaging is required. In the hands of an experienced intensive care team consisting of physicians and nurses accompanying the patients to the MRI scanner and monitoring them during the examination, the method is associated with a low risk of complications.

CLINICAL RELEVANCE

- In a university hospital with dedicated highly trained accompanying ICU physicians and nurses, the rate of severe adverse events during transport and MRI examination is very low (1 in 385 cases).
- A change of diagnosis and therapy was achieved in nearly 20 % overall and up to 31.2 % in emergency diagnostic (non-elective) MRI examinations.
- MRI scans performed after a CT scan may result in a change of diagnosis or therapy in 23.9 % of cases.
- Based on our data from a university hospital with experienced ICU staff, MRI can have significant clinical value with a low rate of severe adverse events.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Smith-Bindman R, Miglioretti DL, Larson EB. Rising use of diagnostic medical imaging in a large integrated health system. Health Aff (Millwood) 2008; 27: 1491–1502. doi:10.1377/hlthaff.27.6.1491

[2] Hu SY, Hsieh MS, Lin MY et al. Trends of CT utilisation in an emergency department in Taiwan: a 5-year retrospective study. BMJ Open 2016; 6: e010973. doi:10.1136/bmjopen-2015-010973

[3] Braman SS, Dunn SM, Amico CA et al. Complications of intrahospital transport in critically ill patients. Ann Intern Med 1987; 107: 469–473

[4] Doring BL, Kerr ME, Lovasik DA et al. Factors that contribute to complications during intrahospital transport of the critically ill. J Neurosci Nurs 1999; 31: 80–86

[5] Knight PH, Maheshwari N, Hussain J et al. Complications during intrahospital transport of critically ill patients: Focus on risk identification and prevention. Int J Crit Illn Inj Sci 2015; 5: 256–264. doi:10.4103/2229-5151.170840

[6] Link J, Krause H, Wagner W et al. Intrahospital transport of critically ill patients. Crit Care Med 1990; 18: 1427–1429

[7] Szem JW, Hydo LJ, Fischer E et al. High-risk intrahospital transport of critically ill patients: safety and outcome of the necessary “road trip”. Crit Care Med 1995; 23: 1660–1666

[8] Wright I, Rogers PN, Ridley S. Risks in intrahospital transport. Ann Intern Med 1988; 108: 638. doi:10.7326/0003-4819-108-4-638_1

[9] Papson JP, Russell KL, Taylor DM. Unexpected events during the intrahospital transport of critically ill patients. Acad Emerg Med 2007; 14: 574–577. doi:10.1197/j.aem.2007.02.034

[10] Parmentier-Decrucq E, Poissy J, Favory R et al. Adverse events during intrahospital transport of critically ill patients: incidence and risk factors. Ann Intensive Care 2013; 3: 10. doi:10.1186/2110-5820-3-10

[11] Voigt LP, Pastores SM, Raoof ND et al. Review of a large clinical series: intrahospital transport of critically ill patients: outcomes, timing, and patterns. J Intensive Care Med 2009; 24: 108–115. doi:10.1177/0885066608329946

[12] Hrishi AP, Lionel KR, Prathapadas U et al. Magnetic resonance imaging (MRI) induced 'hypoxia artifacts' on pulse oximetry: how reliable are MRI compatible monitoring devices? J Clin Monit Comput 2018; 32: 1155–1156. doi:10.1007/s10877-018-0117-4

[13] Algethamy HM, Alzawahmah M, Young GB et al. Added Value of MRI over CT of the Brain in Intensive Care Unit Patients. Can J Neurol Sci 2015; 42: 324–332. doi:10.1017/cjn.2015.52

[14] Chalela JA, Kidwell CS, Nentwich LM et al. Magnetic resonance imaging and computed tomography in emergency assessment of patients with suspected acute stroke: a prospective comparison. Lancet 2007; 369: 293–298. doi:10.1016/S0140-6736(07)60151-2

[15] Kumarasamy N, Tishbi N, Mukundan S et al. Cardiothoracic MRI in the ICU: A 10-Year Experience. Acad Radiol 2018; 25: 359–364. doi:10.1016/j.acra.2017.09.017

[16] Schreyer AG, Friedrich C, Mrosek S et al. Cost analysis of contrast-enhanced cranial MRI at a German university hospital. Rofo 2010; 182: 891–899. doi:10.1055/s-0029-1245511

[17] Jakob SM, Rothen HU. Intensive care 1980-1995: change in patient characteristics, nursing workload and outcome. Intensive Care Med 1997; 23: 1165–1170. doi:10.1007/s001340050474

[18] Kanal E, Barkovich AJ. Expert Panel on MRS et al. ACR guidance document on MR safe practices: 2013. J Magn Reson Imaging 2013; 37: 501–530. doi:10.1002/jmri.24011

[19] Abbasi J. Portable MRI-Coming to the ICU? JAMA 2020; 324: 1386. doi:10.1001/jama.2020.19612

[20] Chikata Y, Okuda N, Izawa M et al. Performance of ventilators compatible with magnetic resonance imaging: a bench study. Respir Care 2015; 60: 341–346. doi:10.4187/respcare.03528

[21] Oster J, Clifford GD. Acquisition of electrocardiogram signals during magnetic resonance imaging. Physiol Meas 2017; 38: R119–R142. doi:10.1088/1361-6579/aa6e8c