

Remote operation of cross-sectional imaging devices as a new form of teleoperation: Structural, technical, regulatory, and qualification aspects in Germany

Fernsteuerung der radiologischen Schnittbildgebung als neue Form der Gerätesteuerung aus der Ferne: strukturelle, technische, regulatorische und qualifikatorische Aspekte in Deutschland

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ABSTRACT

Background There is a significant shortage of radiographers in Germany and this shortage is expected to increase. Thus, it is becoming increasingly difficult for radiological facilities to adequately provide their services for the required period of

time. Teleradiology has already been established for electronic transmission of diagnostic radiographic imaging examinations between two geographical locations for diagnostic reporting. Recently, the concept of teleoperating radiological devices has become increasingly attractive.

Method We examined the potential of teleoperating magnetic resonance imaging (MRI) in radiological facilities within the German regulatory framework in order to address the shortage of qualified personnel. To this end, we are introducing the concept of remote scanning, the structural foundations, the technical requirements associated with it, as well as the legal and educational qualifications of the relevant professional groups. Furthermore, suggestions regarding nomenclature and necessary standard operating procedures to efficiently integrate teleoperation into a clinical workflow adhering to high patient safety standards are provided.

Results Companies provide technical solutions or even experienced radiographers as a service on demand for teleoperating radiological imaging devices remotely from a distance. There should be a comprehensive on-site strategy to effectively embed remote scanning into clinics. Local information technology and data security institutions should be involved in implementation. In order to guarantee that the remote operation workflow is able to provide health care services in line with regulative and legal standards, it is essential to implement standardized personal and institutional training, certifications, and accreditation procedures. Standard operating procedures (SOPs) and checklists for the involved staff, which are adapted to the local workflow in the participating facilities, are beneficial.

Conclusion Remote MRI scanning is an evolving technology that further expands the concept of teleradiology to include teleoperations and provides flexibility with respect to the staffing of MRI operators. Careful consideration and dedicated expertise of all involved parties are required to ensure patient safety, meet regulations, and successfully integrate teleoperations into clinics.

Key points

- Remote MRI scanning expands the concept of teleradiology.
- Remote scanning provides flexibility regarding the staffing of MRI operators.
- IT and data security institutions should be involved when implementing remote scanning.
- Comprehensible SOPs and checklists should be established for remote MRI scanning.
- Radiation protection legislation does not allow purely remote CT scanning.

ZUSAMMENFASSUNG

Hintergrund In Deutschland herrscht ein erheblicher Mangel an medizinischen Technolog:innen für Radiologie (MT-R), der sich aufgrund der Demografie noch verstärken wird. Damit wird es für radiologische Einrichtungen immer schwieriger, ihre Leistungen über den erforderlichen Zeitraum adäquat zu erbringen. Die Teleradiologie hat sich bereits für die elektronische Übertragung von diagnostischen radiologischen Untersuchungen zwischen zwei Standorten zur Befundung etabliert. In jüngster Zeit hat das Konzept der Steuerung radiologischer Geräte aus der Ferne an Attraktivität gewonnen.

Methode Wir untersuchen das Potenzial des Telebetriebs von Magnetresonanztomografen (MRT) im deutschen Rechtsrahmen, um dem Mangel an qualifiziertem Personal zu begegnen. Dazu werden das Konzept des Telebetriebs, die damit verbundenen technischen Anforderungen sowie die rechtlichen und ausbildungsbezogenen Qualifikationen der relevanten Berufsgruppen vorgestellt. Des Weiteren machen wir Vorschläge zur Nomenklatur und für notwendige Standardarbeitsanweisungen zur effizienten Integration des Telebetriebs in den klinischen Arbeitsablauf unter Berücksichtigung hoher Standards für die Patientensicherheit.

Ergebnisse Unternehmen bieten technische Lösungen oder sogar erfahrene MT-R als Dienstleistung auf Abruf an, um radiologische Bildgebungsgeräte aus der Ferne zu bedienen. Für die effektive Verankerung einer Remote-Scanning-Lösung in der Klinik, sollte eine umfassende Strategie unter Berücksichtigung der lokalen Besonderheiten erstellt werden. Die

lokalen IT- und Datenschutzeinrichtungen sollten für die Implementierung in der Einrichtung einbezogen werden. Um zu gewährleisten, dass die Arbeitsabläufe im Fernbetrieb in der Lage sind, Gesundheitsdienstleistungen im Einklang mit den regulativen und rechtlichen Standards zu erbringen, ist es notwendig, standardisierte persönliche und institutionelle Schulungen, Zertifizierungen und Akkreditierungsverfahren einzuführen. Standardarbeitsanweisungen (SOPs) und Checklisten für das beteiligte Personal, die an die lokalen Arbeitsabläufe in den beteiligten Einrichtungen angepasst sind, sind von Vorteil.

Schlussfolgerungen Die Fernbedienung von Magnetresonanztomographen ist eine sich entwickelnde Technologie, die das Konzept der Teleradiologie durch Telebedienung weiter ausbaut und Flexibilität bei der Personalbesetzung der Bildgebungsgeräte bietet. Um die Sicherheit der Patienten zu gewährleisten, die Vorschriften einzuhalten und die Telebedienung in den klinischen Einrichtungen zu etablieren, bedarf es sorgfältiger Überlegungen und spezieller Kenntnisse aller beteiligten Mitarbeiter:innen.

Kernaussagen

- Der Telebetrieb von MRT-Geräten erweitert das Konzept der Teleradiologie.
- Remote-Scanning bietet Flexibilität bei der Besetzung von MRT-Bedienpersonal.
- IT- und Datensicherheitsabteilungen sollten bei der Implementierung von Remote-Scanning-Lösungen einbezogen werden.
- Für den Telebetrieb von MRT-Geräten sollten verständliche SOPs und Checklisten erstellt werden.
- Das Strahlenschutzgesetz erlaubt keinen reinen Telebetrieb von CT-Untersuchungen.

Zitierweise

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ABBREVIATIONS & TRANSLATIONS

knowledge of radiation protection	Kenntnisse im Strahlenschutz
expertise in radiation protection	Fachkunde im Strahlenschutz
radiographer	Medizinische(r)-Technologe(in) Radiologie (MT-R)
qualified medical employee	medizinische(r) Fachangestellte(r) (MFA)
Radiation Protection Act	Strahlenschutzgesetz

Radiation Protection Ordinance	Strahlenschutzverordnung
StrSchG	Strahlenschutzgesetz
StrSchV	Strahlenschutzverordnung

Introduction

In Germany, patients may have to endure rather long wait times for radiological cross-sectional imaging exams. Thus, it is not uncommon for patients to wait up to 3 months for certain MRI exams, depending on medical conditions and the severity of the disease/issue. One of the reasons for this is, among other things,

a shortage of skilled technicians to operate imaging devices. Similar to other clinical areas, medical imaging is affected by a shortage of physicians as well as skilled radiographers. According to an expert report from the German Hospital Institute published in 2019, 52% of radiographers are younger than 44 years, 22.4% are between 45 and 54 years old, and 25.5% are 55 years or older [1]. There is also a high fluctuation in the number of radiographers. In 2017, 59% of German hospitals with radiographers had radiographers (excluding students) leave, mostly due to retirement, temporary job abandonment, and transfer to other hospitals [1]. While in 2011, 23% of the hospitals in Germany experienced staffing problems with radiographers, the figure substantially increased to 46% in 2019 with 840 full-time radiographer vacancies in German hospitals [1]. This shortage of radiographers is expected to increase further due to the age structure of the population [2].

This shortage of qualified radiographers is often overlooked due to an underestimation of the future demand, the need for non-specialists to fill radiographer positions, and other non-clinical staffing issues. As a result, this imbalance between the supply and demand of radiographers becomes an economic issue, and higher salaries alone are not anticipated to address current and future shortages. These issues lead to operational inefficiencies, starting within the 24/7 around-the-clock imaging service. While the majority of facilities experience staffing shortages during their second, third, or weekend shifts, many facilities are urged to block at least part of their daily schedules due to the inability to staff their MRI units [3].

In this scenario, the increase in teleworking solutions, in particular due to the COVID-19 pandemic, may offer more flexibility with respect to staffing radiology departments. So far, the use of teleradiology in the sense of tele-reporting and tele-consulting has become well established in many radiology departments and practices [4]. Teleradiology functions include remote access to the radiology information system (RIS), picture archiving and communication system (PACS), and the hospital information system (HIS) to provide access to clinical history and prior imaging studies, and reporting capabilities to radiologists. Contact with clinicians on-site to solve specific questions regarding radiological exams and reports is achieved using telecommunication solutions. The next logical step would be to perform at least parts of the radiological scanning procedure (teleoperation) remotely as well. Technical solutions for remote scanning have been developed by scanner manufacturers as a more modern approach that allows personnel to manage multiple scanners directly without being on the scanner's location site. Remote scanning access can either allow for monitoring of scanning activities or for the taking over of device control to remotely perform scanning. This approach, initially marketed as a means for imaging teams to provide remote support, is no longer just a tool for service engineer's or application support but is growing into a problem solution of its own.

Today, there are a variety of companies that provide technical solutions, in some cases additionally with experienced radiographers, for teleoperating radiological devices remotely. In radiology departments, remote operation of magnetic resonance imaging devices is very attractive as the scanning procedure takes

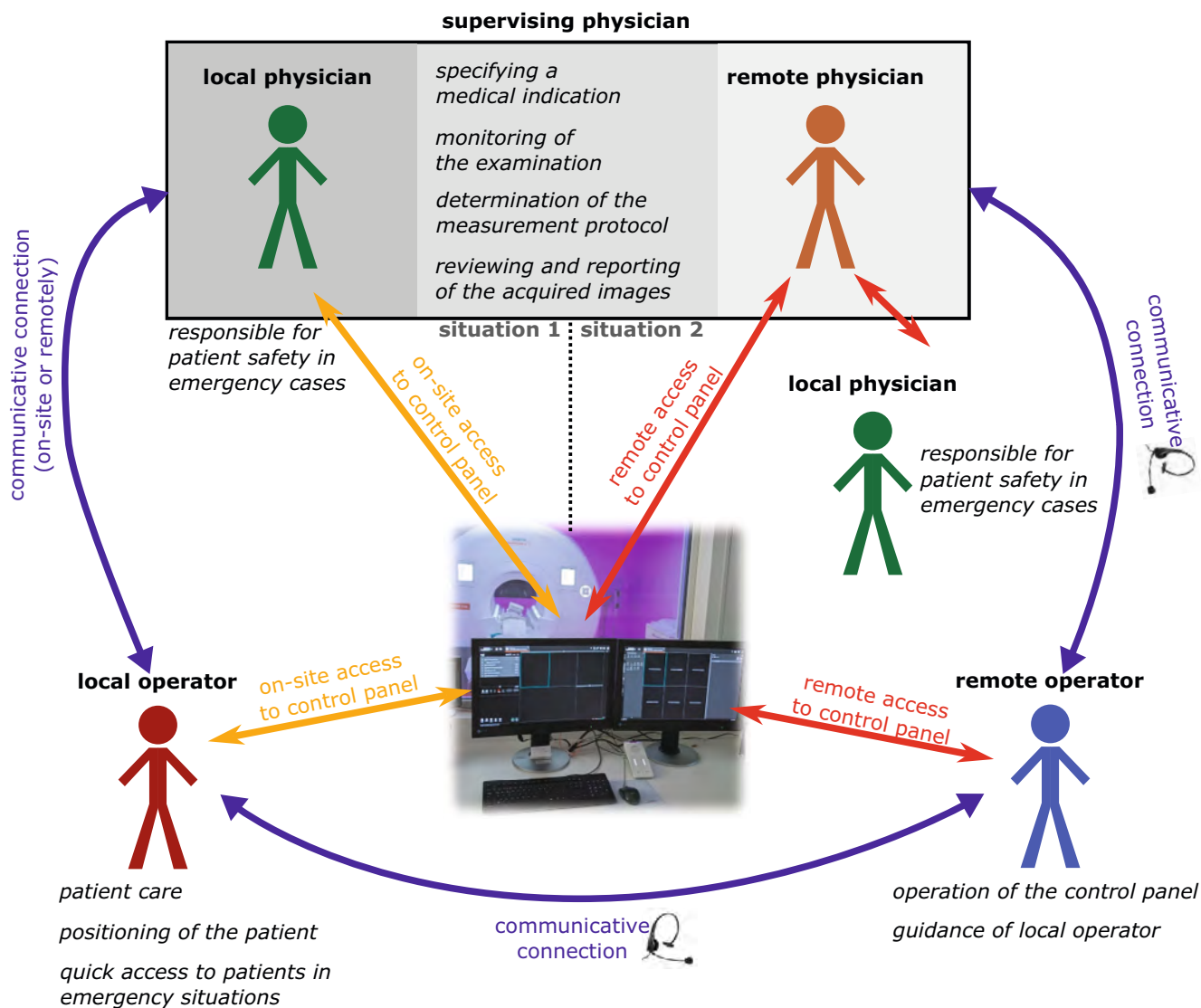
rather long (usually 15–50 minutes) in comparison to the patient positioning (approx. 5 minutes, provided that the patient is cooperative and not restricted) and the level of necessary technical knowledge to provide adequate images is high. Currently, remote MRI scanning is used in hospitals in a number of countries around the world, including the United States of America, Australia, Germany, Denmark, Belgium, and China [5]. The adoption of remote MRI scanning in the United Kingdom has been the subject of recent research, with 8/11 respondents viewing remote scanning as a “friend” that has potential [6]. Very recently, the radiology department of the University of Essen summarized its experience with remote MRI scanning and its findings [5].

We systematically reviewed the concept of remote MRI scanning in the German legal and economic framework including practical and educational questions and definitions of nomenclature in order to address the increasing shortage of qualified personnel. Since we provide detailed suggestions for standard operating procedures (SOPs) and checklists as well as qualification issues for integrating remote scanning into the clinical workflow while ensuring patient safety high standards, the present review substantially expands upon the ideas in other studies published very recently [5, 6]. Finally, the legal restrictions relating to the remote operation of CT systems are briefly explained.

Remote Scanning

In remote scanning, at least parts of the technical execution of the radiological examination are not carried out at the location of the imaging device, but rather by a spatially remote, appropriately qualified person using telemedicine (teleoperation). As schematically illustrated in ► Fig. 1, the scenario is that a potentially lower qualified medical professional (e.g., qualified medical employee; MFA) at the site of the medical imaging device (local operator; LO) is supported by a qualified radiographer teleoperating the scanner from a distance (remote operator; RO). The remote operator could teleoperate from inside (e.g., in a separate control center) or outside the hospital or imaging center (e.g., home office, referred by another company, in a central office of a hospital group). The remote operator performs the examination from a distance, so that an examination result is produced according to the specifications of a qualified radiologist (who can be on-site or off-site). While the technical execution is divided between two persons (LO and RO), an advantage of such a scenario, beside a potentially lower qualification level of the local operator, is that the person directly at the imaging device (local operator) can take care of other things during the scanning process (e.g., preparing the next patient for the same scanner or even for a second scanner). If the supervising physician is working remotely, a second physician is required to be in the vicinity of the imaging device to provide patient education and emergency safety. The relevant definitions, our proposed terminology and nomenclature, and the occupational and qualification groups involved in the remote scanning scenario are provided in ► Table 1.

Direct communication with a synchronous optical and acoustic connection between the personnel directly at the imaging device, the patient on the scanner, and the remote operator during the



► **Fig. 1** Duties and responsibilities of staff during a remote MRI scan. Situation 1 illustrates the case when the local physician is responsible as the supervising physician. In situation 2, the supervising physician is working remotely via the framework of telemedicine, whereas the local physician (not necessarily a radiologist) is in the vicinity of the radiological unit for emergency situations.

► **Table 1** Overview of occupational and qualification groups involved in the remote MR scanning process.

Terms	Abbreviation	Definition
Local operator	LO	Specially trained person who has completed specific medical training involving working locally at the scanner (e. g., qualified medical employee)
Local physician	LP	Physician on-site (near the examination room) to directly respond to emergencies (e. g., contrast medium intolerance) <ul style="list-style-type: none"> ▪ Mandatory: if the remote supervising physician is responsible for the examination ▪ Not applicable: if the supervising physician on-site takes on this role
Remote operator	RO	Qualified radiographer who operates the scanner remotely
(Remote) supervising physician	(R)SP	Physician working on-site or via telemedicine (remote) who is responsible for the examination

► **Table 2** Overview of MRI remote scanning solutions available in Germany¹.

Product name	Provider	Multi-vendor support	Restriction of functions	Properties
Expert-i	Siemens Healthineers (Erlangen, Germany)	No	No	<ul style="list-style-type: none"> Works without additional connection device Serves as additional feature to the specific MRI device
Digital Expert Access	General Electric (Milwaukee, WI, USA)	No	Yes ²	<ul style="list-style-type: none"> Works without additional connection device Serves as additional feature to the specific MRI device
Cockpit	Philips (Best, Netherlands)	No	No	<ul style="list-style-type: none"> Works without additional connection device Serves as additional feature to the specific MRI device
Syngo Virtual Cockpit	Siemens Healthineers (Erlangen, Germany)	Yes	No	<ul style="list-style-type: none"> Siemens devices do not need an additional connection device. A connection device is used to connect imaging devices from other vendors Supports on-site and cloud-based solutions The provider offers radiographer service on demand as an additional service
Radiology Operations Command Center (ROCC)	Philips (Best, Netherlands)	Yes	No	<ul style="list-style-type: none"> Philips devices do not need an additional connection device. A connection device is used to connect imaging devices from other vendors Supports only on-site solutions The provider offers radiographer service on demand as an additional service
All rocStars	roclub GmbH (Berlin, Germany)	Yes	No	<ul style="list-style-type: none"> A connection device is used to connect imaging devices Supports only cloud-based solutions The provider offers access to a marketplace to order radiographer service on demand
Tele-MTRA	3H-Vision GmbH (Pfullingen, Germany)	Yes	No	<ul style="list-style-type: none"> A connection device is used to connect imaging devices Supports on-site and cloud-based solutions The provider offers radiographer service on demand as an additional service
Telehealth Interactive Service (TIS)	VEPRO AG (Pfungstadt, Germany)	Yes	No	<ul style="list-style-type: none"> A connection device is used to connect imaging devices Supports on-site and cloud-based solutions The provider offers radiographer service on demand as an additional service

¹ The overview was compiled in November 2023 and should not be considered comprehensive.

² The scan has to be started on-site by the local operator.

scanning procedure as well as remote access of the remote operator to the user interface of the imaging device are crucial. Nowadays, this can be implemented with modern, technically secure, data-protected IT solutions (e. g., screen sharing, video telephony). Vendors of medical imaging devices or smaller medium-sized specialized companies offer suitable technical solutions to remotely operate medical imaging devices, some of them are even vendor-independent (► **Table 2**).

A medically qualified employee must always be present on-site at the medical imaging device to support the remote examination (local operator: LO). This qualification may be lower than that of a standard radiographer (medical technologist for radiology: MT-R). The local operator is responsible for local patient care (e. g., organizes patient education, ensures compliance with hygiene requirements, answers or passes along questions, performs positioning on the scanner table, connects coils, and guides the patient out of the imaging device area) and also recognizes and masters the necessary basic procedures in emergency situations.

Before entering the scanner room, the local operator checks the patient's clothes and reminds them to remove any material or device contraindicated for MRI (e. g., metallic personal belongings, jewelry, dental prosthesis). The local operator also supports the patient in case they suffer from pain, claustrophobia, restlessness, or shortness of breath. Positioning on the table, connection of intravenous lines for contrast media application, and adapting the required coils to the region of interest need special qualification programs.

An on-site physician (local physician: LP) must also be in the vicinity of the imaging unit to ensure patient safety in the case of an emergency, to provide an intravenous line if needed, and to obtain the patient's informed consent. In the course of the latter, the local physician has to verify possible contraindications of the patient for the MRI examination, clarify the MR suitability of possible implants, and inform the patient about possible risks. These activities do not necessarily have to be carried out by a radiologist.

In order to conduct an MRI examination, a specific medical indication has to be posed by the supervising physician (SP; typically, a radiologist). The supervising physician involved in the individual diagnostic examination checks the medical indication before imaging is performed, specifies the examination protocol precisely (e. g., sequence protocol), and bears the overall responsibility for the diagnostic quality of the examination. The supervising physician may be present in the clinical institution or is involved via teleradiology. The supervising physician must be able to directly join communication between the local and remote operators and should have access to the control panel of the imaging device directly or remotely to clarify questions quickly and easily during the examination. The supervising physician is authorized to give instructions to the remote operator. If the supervising physician is locally available, they may take over the role of the local physician (LP) as well.

Legal Considerations and Qualification Aspects

Remote scanning falls within the scope of telemedicine or remote treatment. There is already a legal framework for teleradiology as specified by the Radiation Protection Act (Strahlenschutzgesetz [StrSchG]) covering the imaging process of X-ray-based devices, electronic transmission of radiological images between different geographic locations, and diagnostic radiological reporting. Therefore, the use of teleradiology must meet several requirements including the existence of a comprehensive concept that takes into account the local situation, the assurance of image transmission, and image quality (through consistency tests of the transmission route, the monitor, etc.) [7], failure concepts as well as approval from the responsible authority (§ 14(2) StrSchG). Further details on teleradiology regarding its potential, implementation, regulations, and workflows are summarized in [8]. The legal framework for teleradiology does not apply to images that were not created using X-ray technology such as MRI. However, the teleradiology infrastructure is commonly used for diagnostic reporting of MR images as well.

Remote scanning has not been explicitly regulated yet. There is a first-right conclusion in article 7 paragraph 4 of the (model) professional code for doctors working in Germany ((Muster-) Berufssordnung für die in Deutschland tätigen Ärztinnen und Ärzte, MBO-Ä) that allows physicians to provide highly personal, non-delegable treatment via communication media by way of telemedicine, provided that necessary care is taken. Thus, it can be concluded by analogy that activities that are less dangerous and do not require the medical expertise of a physician can also be performed by means of telemedicine and the delegated medical service may also be provided remotely.

The Federal Master Agreement for Physicians (Bundesmantelvertrag Ärzte, BMV-Ä) regulates outpatient medical and psychotherapeutic care in Germany. In Annex 24, the delegation of medical services to non-medical staff in outpatient medical care is described. According to that, the performing of MRI exams can be delegated to persons with the minimum qualification of a qualified medical employee (medizinische(r) Fachangestellte(r) [MFA]), while X-ray and CT examinations can only be delegated

to specially qualified, certified persons with expertise or knowledge of radiation protection as specified by the Radiation Protection Act.

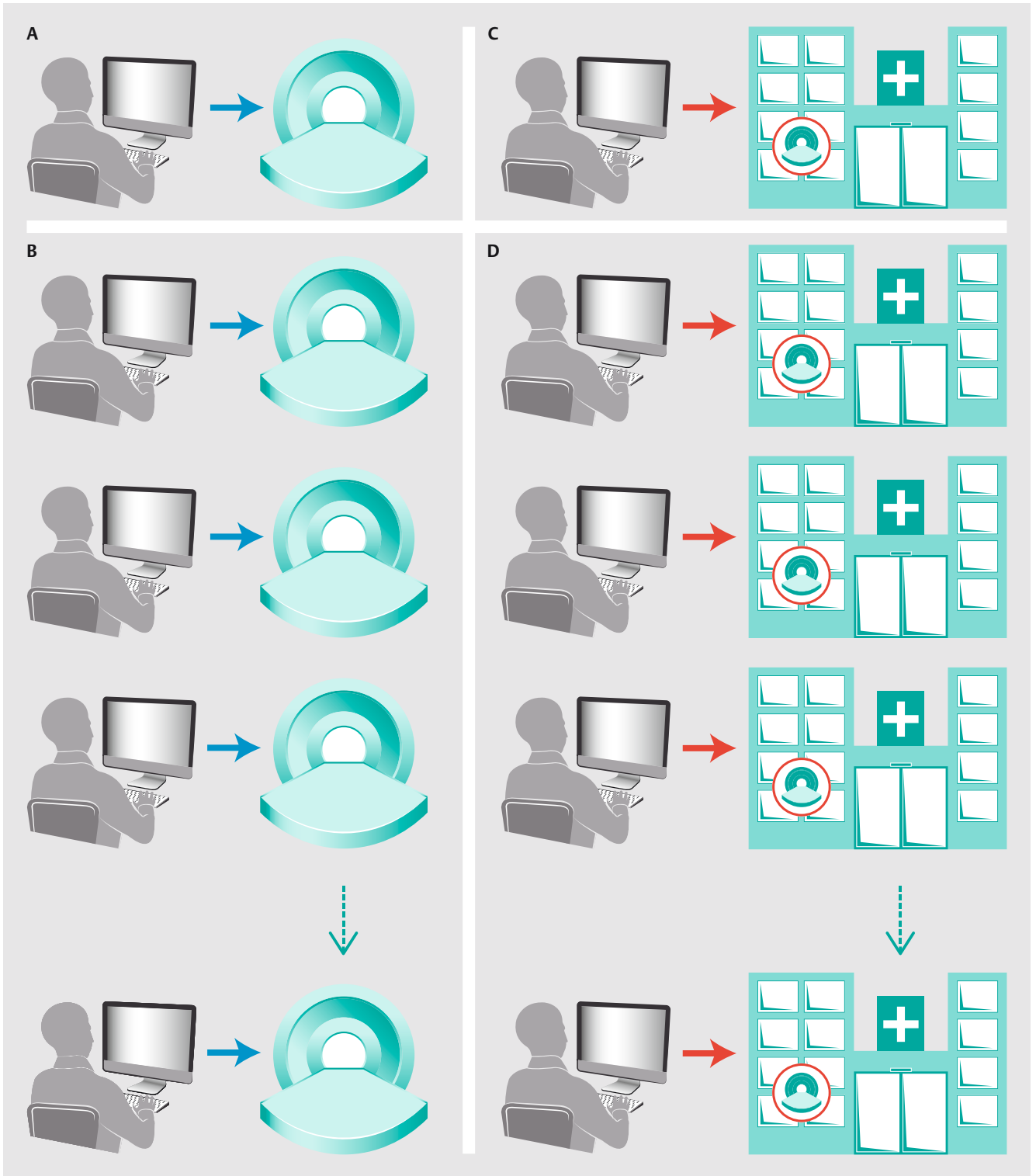
The prerequisite for delegating the technical performance of a radiological examination is that the supervising physician can directly issue technical instructions to the remote operator and that the remote operator is obliged to follow these instructions. In each case, however, the supervising physician has to check whether the patient is suitable for the technical performance of the examination with the involvement of the remote operator. Since there is no strict quantitative restriction to telemedicine (i. e., telemedicine is only applied in individual cases, whereas telemedicine-based examinations do not comprise the majority of activities), but only a qualitative restriction (only possible after individual decision by the physician regarding the suitability of the individual patient for telemedical treatment/diagnostics), the remote scanning activities are in line with the statements of the 121st German Medical Congress 2018 [9].

MRI

According to the previously stated facts, the local operator can be supported by the remote operator and the activities of the local operator on-site can be carried out by persons who are not qualified as a radiographer (e. g., medical technical assistants, qualified medical employees, nurses). The requirements for the qualifications of the local operator depend largely on their tasks. If qualified medical employees or nurses are used as part of the remote MR scanning solution, it must be ensured in advance and documented that they are fully proficient in safety aspects and patient positioning as well as technical aspects of coils and their placement. In addition, they must also be essentially able to operate the MRI scanner on-site, e. g., in the case of a connection loss. If these requirements are fulfilled, qualified medical employees and nurses can also be used as local operators on-site due to their qualifications. However, it is important in this context that the respective local operator is carefully selected, regularly checked, appropriately instructed, and supervised. This has to be properly documented. If qualified medical employees or nurses are used as local operators, the supervising physician has to ensure that these persons have the skills and knowledge for their task. In this case, the supervising physician has to check when the local operator starts working and whether the corresponding local operator is suitable for carrying out the required activities on the basis of their general skills. This may be checked with certain certificates regarding specific knowledge, which may be provided by specialized institutions. The frequency of supervision and instruction can be reduced over time as the local operator's qualifications become more established with routine.

Contrast Agent Administration

Often, MRI examinations require the intravenous injection of contrast agents. As the application of contrast agent is part of the technical performance of the examination, the minimum qualifications of the local operator required for conducting MRI have to be fulfilled (see above). In addition, Annex 24 of the Federal Master Agreement for Physicians (Bundesmantelvertrag-Ärzte, BMV-Ä) regulates



► **Fig. 2** Application fields of remote operation of radiological devices. A: Decentralized remote scanning. B: Remote operations via in-house control centers. C: Remote operation of individuals outside the clinical facility. D: Remote operation centers controlling radiological devices in multiple clinical centers. Blue arrows indicate a remote connection to the image device within the network of the hospital. Red arrows highlight remote control from locations outside the hospital hosting the image device.

that intravenous injections and the setting up of infusions can be carried out by staff with the lowest qualification level such as a qualified medical employee, nurse, or occupational health nurse. It can

be deduced from this that the injection of contrast media in the case of MRI examinations can be performed by the local operator,

whereas only the presence (not the constant supervision) of a physician near the MRI scanner is required for emergencies.

Computed Tomography

While remote scanning is highly attractive for MRI, there might also be efforts to expand remote scanning to computed tomography (CT). In contrast to MRI, the Radiation Protection Act (StrSchG) must be observed when performing CT examinations on patients. The concept of teleoperation (as outlined in ► Fig. 1) is contrary to the objectives of radiation protection, as the remote operator is no longer able to provide direct patient care in the event of abnormal occurrences (e. g., restless patients, contrast media allergy, sudden onset of intense pain). Within the 4th Amendment to the Radiation Protection Ordinance (Strahlenschutzverordnung [StrSchV]) passed by the German Bundestag in October 2023 [10], the statement in § 145(2) (StrSchV) has been revised, thereby limiting technical performance to dedicated persons that are on-site. Therefore, it is not feasible to legally conduct independent teleoperation of X-ray-based devices, like CT systems, in Germany.

The technical possibilities available today for remote operations, however, may be used for remote assistance for technical or special application support of the local qualified radiographer, which manages the technical performance on-site [11]. Here, the application and triggering of radiation are the responsibility of the local operator, who fulfills the qualification level as described in § 145(2) (StrSchV). While this setting does not permit the remote operator to perform the activities of a local radiographer, it does provide an opportunity for subsidiaries to perform highly demanding CT examinations (e. g., cardiac CT and cerebral perfusion) or to conduct application training and refresher courses.

Working Scenarios

Integrating remote scanning into the radiological environment reveals several scenarios providing additional flexibility to cover work shifts, in particular in secondary- or tertiary-care hospitals with maximum supply that have to provide MRI exams 24/7. These remote scanning centers may also supply primary- and secondary-care centers with emergency imaging services during times of low volume, but a demand for high urgency imaging. Specific scenarios utilizing remote operations are summarized in ► Fig. 2 and described in more detail in the following subsections.

Teleoperation can also be used by application specialists to instruct the local staff on new radiological devices, with the potential to provide specific education services with more flexibility (e. g., short time windows and short-term appointments) at lower costs. However, it should be noted that during application training or support for CT, the responsibility of radiation application lies with the local operator, who must meet the necessary qualification level outlined in § 145(2) StrSchV.

Decentralized in-house remote scanning (A)

In many clinical centers, the radiological devices may not be locally concentrated in one location, but rather distributed throughout the building or campus. In these situations, remote MRI scanning

from a teleworking location within the hospital would be an elegant solution to increase flexibility when deploying staff within the hospital. Other use cases are associated with application support in specialized MRI or CT examinations (e. g., spectroscopy, cardiac imaging, functional imaging, perfusion CT, or perfusion MRI), education, or supervision of less experienced radiographers and colleagues to provide tips and tricks. Here, highly qualified and specialized radiographers could technically support their colleagues at other locations remotely while they carry out routine examinations themselves on another scanner, thereby learning from each other. The emergency department equipped with a CT scanner is often separate from the central radiology department, but qualified radiographers have to be on-site for CT examinations. There are often situations when the emergency CT scanner is not used. In these periods, the employee in the emergency department may provide MRI scanning or technical support for CT exams remotely in the same hospital.

In-house control centers (B)

If a radiology department runs multiple scanners distributed over a large area, it can be beneficial to establish a dedicated control center within the institution for conducting MRI scans or providing application support for CT remotely. The advantage of establishing control centers is that the radiographers can directly focus on the planning, performing, or supporting of examinations without being distracted, e. g., by administrative or organizational tasks (planning appointments, controlling, communicating results, etc.). In such a scenario, the remote operator could, in principle, monitor or supervise multiple MRI systems in parallel. This is further supported by the availability of pre-planned scanning protocols and standardized post-processing methods with minimal user interaction and by the fact that the qualified remote operator is not burdened with repetitive tasks such as patient positioning. Based on our calculations and depending on the local conditions, the setting up of an in-house control center could already be useful and efficient for the handling of a minimum of 4 individual MRI systems (starting with 3 scanners when they are locally distributed throughout the campus).

Remote operations distant from the imaging center (C, D)

The opportunity for remote operations to be performed by personnel outside the hospital or imaging center offers an elegant solution to the lack of qualified personnel and even has the possibility to increase the quality of scanning as well as radiographer job satisfaction.

In our scenario, two distinct types of remote operators can be distinguished: i) those that are affiliated with the clinical institution, and ii) those that are not affiliated with the clinical institution like freelancers or workers supplied by an external company. In the first case, decentralized remote operations by own staff from outside the hospital or imaging center could be an opportunity to better reconcile the radiography profession with family life, especially if employees still have children or dependent relatives to care for. In particular, night shifts or weekend shifts when the scanning workload is typically lower compared to the regular

shifts could be carried out from a home office without the need to drive to or sleep at the hospital provided that the employee is equipped with the required IT and communication systems. Another advantage of that scenario relates to the place of residence when it comes to recruiting specialist staff, as the commuting area is no longer limited to a few kilometers around the workplace, because qualified and trained remote operators can provide their service throughout Germany or even the world (e. g., Thailand, India).

With the help of control centers (e. g., at larger hospitals), radiological facilities can be supported by teleoperating of MRI devices or application assistance for CT exams. These control centers could support the acquisition of MR images for other partners or cooperating institutions within radiology networks and, thus, provide adequate diagnostic care for emergencies, especially in rural regions, or in case of emergencies on weekends or at night. Since remote scanning services allow radiographers to travel to fewer locations, improve their efficiency, and better distribute resources across the system in comparison to local demand fluctuations, the number of specialized examinations for one operator is increased, in parallel to the skills and quality of service. Centralized, specialized centers may provide temporary help with respect to short-term, temporary staff shortages. If data acquisition is performed by remote operators outside the organization, it must be ensured that the supervising physician fulfills their selection and monitoring obligation (e. g., by joining the video conference between the local operator and remote operator during the examination). Additionally, the supervising physician must be convinced that the remote operator has the necessary qualifications, e. g., documented by a specialized, certified training at an appropriate institution. Thus, such short-term collaboration needs to be planned ahead of time and should not constitute an emergency measure, and the necessary contracts and legal documents must be in place. Additionally, the prerequisite for remote scanning in such situations is that the supervising physician can issue technical instructions to the remote operator and that the remote operator is obligated to follow these instructions. It should also be possible for the supervising physician to refuse an external remote operator if they is not convinced of their qualifications. These mutual obligations should be components of the respective contract concluded with the companies or external staff beforehand (not belonging to the hospital hosting the specific imaging device).

Technical Requirements

Typically, vendors provide dedicated solutions for remotely controlling their specific MRI equipment (► **Table 2**). However, this kind of approach is restricted to the vendors' devices and, thus, is not suited for clinical institutions with imaging devices of different vendors in a clinical setting. Common solutions for remotely operating the control panel independent of the vendor utilize dedicated connection devices, typically keyboard-video-mouse [KVM] switches, in conjunction with a hardware video splitter. The video splitter multiplies the video signal from the scanner workstation identically to several outputs, to which several monitors can be connected to display the same picture. In teleopera-

tion, the video splitter is placed between the scanner workstation and the scanner workstation monitor. The duplicated video stream from the scanner workstation is forwarded to the connection device. The connection device is also connected directly to the scanner workstation typically via Universal Serial Bus (USB) and via the local area network (LAN) to a communication server that provides the software features for video conferencing, control panel screen sharing, and potentially in-room monitoring and is remotely controlling the scanner via keyboard and mouse events as secondary inputs. The connection device and the video splitter are standard IT equipment that should not affect the purpose of the MRI or CT scanner as a medical device. Nevertheless, the provider of the remote scanning solution has to guarantee (e. g., via certificates) that the specific configuration does not impact the approval of the specific imaging device as a medical product. The communication server does not have to be specifically located within the hospital, depending on the solution. The features provided by the communication server could also be arranged as a cloud service. Provided that the data protection issues of cloud solutions are solved on a local basis (data protection regulations may vary regionally in Germany), setting up a cloud-based remote operation service may be attractive for imaging centers to gain initial experience without having to set up a dedicated hardware server on-site or to adjust local practices to the remote operation provider. Implementing a cloud-based platform for remote scanning offers numerous benefits. For example, the online digital remote scanning platform could be utilized as a model to provide global access to MRI scanners and, thus, could potentially address the current issues associated with the lack of radiographers in certain countries [5]. An overview of MRI remote scanning solutions offered in Germany is presented in ► **Table 2**.

In order to effectively conduct remote operations, it is essential to have a reliable network structure that allows for rapid and consistent data transmission within a broadband range while safeguarding the privacy of patient information. This requirement is usually easily fulfilled when remote operations are carried out in-house, thus relying on the local network architecture available in modern hospitals. If remote operations are performed by staff from outside the hospital, a stable broadband internet connection (we suggest min. 40 Mbit/s download; min. 15 Mbit/s upload) between the radiological center and location of the remote operator is a prerequisite. For external staff and cloud-based solutions, a virtual private network (VPN) or https connections are appropriate solutions to provide remote access to the network of the imaging device as they also ensure the necessary security for the cyber environment [12, 13].

In order to ensure that the remote operator can appropriately control the imaging device, the screen on which a radiological examination is conducted (in-house or remotely accessed) must meet the recommended requirements. Monitors produced with LCD or OLED technology and screen sizes with at least 24 inches (aspect ratio: 16:9) are recommended in order to mirror the workstation monitor. Since no clinical reporting is conducted by the remote operator, there is no need for a medically graded display as required in teleradiology. A second monitor, which could be smaller, for video conferencing and patient monitoring is highly recommended in our view. The latter could be achieved by installing

a camera with audio capabilities in the scanning room and operating room and live forwarding the signal to the remote operator. To guarantee direct, synchronous contact with the local operator and the supervising physician, a video conference system with headphones (wireless headphones are recommended) should be set up at the imaging device on-site as well.

Demands

In order to guarantee that the implemented remote operation workflow is able to provide health care services that meet the necessary regulatory and legal standards, it is essential to implement standardized personal and institutional training, certifications, ac-

creditation procedures, and documents. Remote operation services must be conducted by radiographers who have been trained in the specifics of the field, the legal framework, and who have substantial experience with the specific imaging device in question.

This training should include knowledge of the technical requirements of remote scanning (and its failures and troubleshooting), the rights and perspectives of patients, legal regulations regarding the protection of personal data, the specific roles and obligations of involved personal, ethical guidelines, and an understanding of the potential consequences of incorrect practices. It is also essential to ensure that there is an adequate number of personnel to cover the necessary demands on-site. All of this has to be adequately documented and updated in a regular manner. Contracts have to be agreed on. To ensure adequate standards,

► **Table 3** Proposed standard operating procedures (SOPs) and checklists for implementing remote scanning in the clinical workflow.

Type	Description	Groups
SOP	Description of the locally implemented remote scanning workflow, definition of qualifications and roles, managerial authorities, and areas of responsibility for the staff involved. Consider whether remote scanning is carried out by in-house staff or by external partners.	RO, LO, LSP, RSP, LP
SOP	Workflow for preparing the MRI scan (medical indication, informed consent, and patient information on remote operation, safety issues, contrast media, and intravenous line placement, imaging protocol, positioning, coil selection, etc.)	RO, LO, LSP, RSP
SOP	Vendor-specific instructions for the remotely controlled imaging device (instructions regarding the imaging device on-site for the RO and LO by the vendor or a first instructed person and its documentation)	RO, LO
SOP	Behavior in patient emergency situations (guidelines and responsibilities in the case of patient emergencies, e. g., due to claustrophobia or contrast agent intolerance. What to do when the patient hits the alarm button?)	LO, LP, RO
SOP	Guidelines in the case of technical interruptions of the remote connection and/or telecommunication (setting up a backup solution to deal with disconnections from the remote operator during the patient examination)	LO, LP, RO, SP
SOP	Definition of response times (definition of response times for the different groups involved depending on the specific subtask for the remote examination)	RO, LO, LSP, RSP, LP
SOP	Scheduling, registration, and reporting of examinations within local information systems (guidelines for patient scheduling, patient registration, verifying the clinical indication, data collection in the radiological information system and, if necessary, in the hospital information system)	RO, LO, SP
Checklist	Safety and consent check for patients before entering the imaging device (e. g., informed consent, safety questionnaire, check for pacemaker, implants, metal, positioning problems, pain, claustrophobia, restlessness, shortness of breath, allergies, etc.)	LO, RO, SP, LP
Checklist	Intravenous line and contrast media handling (e. g., establishing, connecting, and handling of intravenous lines, handling and connecting of the contrast injector, monitoring of injection, disconnection, and intravenous line removal/protection)	LO, RO, LP, SP
Checklist	Patient positioning on MRI scanner (guidelines for common examinations including patient positioning and selection and connection of MRI coils)	LO, RO
Checklist	Acquisition protocols according to the clinical question (guidelines for acquisition and data post-processing protocols for common clinical questions as this may vary in different imaging centers)	RO, LO, SP
Checklist	Patient care after scanning (tasks after finishing the scanning procedure including removing the patient from the scanner table, detaching the intravenous line, and if necessary, detaching the needle, informing the patient about the next steps, organizing transport)	LO, RO

RO – remote operator; LO – local operator; SP – supervising physician; LSP – local supervising physician; RSP – remote supervising physician; LP – local physician.

we propose specialized institutions and curricula to provide necessary certificates.

To integrate remote scanning into clinics while establishing efficient and consistent workflows, it is highly recommended to establish SOPs and checklists for the staff involved that are adapted to the local workflow in the involved institutions. In particular, the description of the remote scanning workflow as implemented on-site, the definition of qualifications and roles, managerial authorities, and areas of responsibility for the staff involved should be explicitly specified according to the local environment. It should also be ensured that both the remote operator and the local operator are instructed on the specific imaging device they are using. The remote operator should also have access to the RIS and if required to the HIS to directly see at least the patient information, scheduling, and clinical questions. The access to previous imaging data via PACS queries can help to tailor the current acquisition protocol in line with prerecorded images (e. g., follow-up oncological staging). Access to clinic-wide information systems, however, should be coordinated with the departments for information technology and data security, in particular, when remote operators are freelancers or from external companies. Further suggestions for necessary SOPs and checklists are specified in ► **Table 3**.

Conclusion

In conclusion, remote MRI scanning is an evolving technology that further expands the concept of teleradiology to include teleoperations and provides flexibility with respect to the staffing of MRI device operators. It provides radiographers with the ability to work either remotely or locally in-person, thus alleviating local staff shortages and opening up new training and educational opportunities and at the same time potentially increasing quality and job satisfaction. The radiology and IT departments should work hand-in-hand with the remote operation solution provider to efficiently integrate the remote scanning solution into the local clinical workflow while satisfying the highest standards for data security. Providing comprehensible SOPs and checklists to both local and remote staff is essential to maintain the necessary quality and to satisfy legal regulations in the technical performance of the scans. Standardized and dedicated qualification programs adapted to the needs of the different roles involved, resulting in quality-controlled certificates documenting the necessary qualifications by dedicated institutions, have to be established. With the implementation of the 4th Amendment to the Radiation Protection Ordinance, teleoperating CT systems without a qualified radiographer (according to § 145(2) StrSchV) on-site is not legal in Germany. However, remote technical support for CT examinations may still be provided and beneficial to assist the local operator, for instance, in the case of demanding, specialized, or uncommon examinations. Finally, remote scanning has the potential to make the job of the radiographer more attractive and satisfying. In summary, remote MRI scanning offers great potential to ad-

dress the current issues in radiology. However, careful consideration and dedicated knowledge of all involved parties is required to ensure patient safety, to meet the regulations, and to successfully integrate teleoperations into the field.

Conflict of Interest

The authors declare that they have no conflict of interest.

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