Software-Based Evaluation of Optimization Potential for Clinical MRI Scanners in Radiology

Software-basierte Evaluation des Optimierungspotenzials bei klinischen MRT-Scannern in der Radiologie

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ABSTRACT

Objective The aim of the study was to use a software application to analyze the examination times and changeover times of two clinically highly applied MRI scanners at a university hospital for radiology and to evaluate whether this could result in optimization potential for examination planning in the daily clinical routine of MRI diagnostics.

Materials and Methods Based on the newly developed software application "Teamplay Usage" (Siemens Healthineers, Germany), the examinations carried out on two MRI scanners (1.5 T and 3 T) were investigated within an analysis period of 12 months with regard to the type of examination and its duration. In addition, compliance with the previously defined planning time (30, 45, 60 min.) was checked and deviations were analyzed. In addition, the changeover times between the examinations were determined and a possible influence due to the exchange of MRI coils was investigated for a selection of change combinations.

Results For the total of 7184 (1.5 T: 3740; 3 T: 3444) examinations included in the study, the median examination time was 43:02 minutes (1.5 T: 43:17 min.; 3 T: 42:45 min.). The ten most frequent types of examinations per MRI scanner were completed within the predefined plan time of 54.5 % (1.5 T) and 51.9 % (3 T), taking into account a previously defined preparation and post-processing time of 9 minutes per examination. Overall, more time was spent on examinations with a planned time of 30 minutes, whereas the majority of the examinations planned with 45 minutes were also completed within this time. Examinations with a planned time of 60 minutes usually took less time. A comparison between the planned time and the determined examination duration of the most common types of examinations showed overall a slight potential for optimization. Coil exchanges between two examinations had a small, but statistically not significant effect on the median changeover time ($p = 0.062$).

Conclusion Utilizing a software-based analysis, a detailed overview of the type of examination, examination duration, and changeover times of frequently used clinical MRI scanners could be obtained. In the clinic examined, there was little potential for optimization of examination planning. An exchange of MRI coils necessary for different types of examination only had a small effect on the changeover times.

Key Points:

- The use of the "Teamplay Usage" software application enables a comprehensive overview of the type of examination, examination duration, and changeover times for MRI scanners.
- Adjustments to examination planning for MRI diagnostics show optimization potential, which, however, is to be assessed as low in the clinic examined.
- Necessary replacements of MRI coils only have a small effect on the changeover times.

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ZUSAMMENFASSUNG

Ziel Ziel der Studie war es, unter Verwendung einer Software-Applikation die Untersuchungsdauern und Wechselzeiten von 2 klinisch stark frequentierten MRT-Scannern einer Universitätsklinik für Radiologie zu analysieren und zu evaluieren, ob sich daraus ein Optimierungspotenzial für die Untersuchungsplanung in der täglichen klinischen Routine der MRT-Diagnostik ableiten lässt.

Material und Methoden Anhand einer detaillierten Abfrage mit einer neu entwickelten Software-Applikation („Teamplay Usage", Siemens Healthineers, Deutschland) wurden innerhalb eines Analysezeitraums von 12 Monaten an 2 MRT-Scannern (1,5 T und 3 T) die durchgeführten Untersuchungen im Hinblick auf Untersuchungsart und jeweilige Untersuchungsdauer analysiert. Zudem erfolgte eine Überprüfung der Einhaltung vorab definierter Planzeiten (30, 45, 60 min) und eine Analyse von Planzeitabweichungen. Des Weiteren wurden Wechselzeiten zwischen Untersuchungen ermittelt und bei einer Auswahl von Wechselkombinationen ein möglicher Einfluss durch den Austausch von MRT-Spulen untersucht.

Ergebnisse Bei insgesamt 7184 (1,5 T: 3740; 3 T: 3444) in die Studie einbezogenen Untersuchungen betrug die mediane Untersuchungsdauer 43:02 Minuten (1,5 T: 43:17min; 3 T: 42:45 min). Die 10 häufigsten Untersuchungsarten je MRTScanner wurden unter Berücksichtigung einer Vor- und Nachbereitungszeit von 9 Minuten je Untersuchung zu 54,5 % (1,5 T) bzw. 51,9 % (3 T) innerhalb der vordefinierten Planzeit abgeschlossen. Gesamthaft betrachtet wurde für Untersuchungen mit einer Planzeit von 30 Minuten mehr Zeit aufgewendet, hingegen wurde der größte Anteil der mit 45 Minuten geplanten Untersuchungen auch innerhalb dieser Zeit abgeschlossen. Untersuchungen mit einer Planzeit von 60 Minuten nahmen zumeist weniger Zeit in Anspruch. Ein Vergleich zwischen Planzeit und ermittelter Untersuchungsdauer der häufigsten Untersuchungsarten zeigte insgesamt ein nur geringes Optimierungspotenzial. Spulenaustausche zwischen 2 Untersuchungen hatten einen geringen, jedoch statistisch nicht signifikanten Effekt auf die mediane Wechselzeit ($p = 0{,}062$).

Schlussfolgerung Mittels einer Software-basierten Analyse konnte ein detaillierter Überblick in Bezug auf Untersuchungsart, Untersuchungsdauer und Wechselzeiten hochfrequentierter klinischer MRT-Scanner erlangt werden. In der untersuchten Klinik ließ sich ein geringes Optimierungspotenzial für die Untersuchungsplanung ableiten. Ein für unterschiedliche Untersuchungsarten notwendiger Austausch von MRTSpulen hatte einen geringen Effekt auf die Wechselzeiten.

Introduction

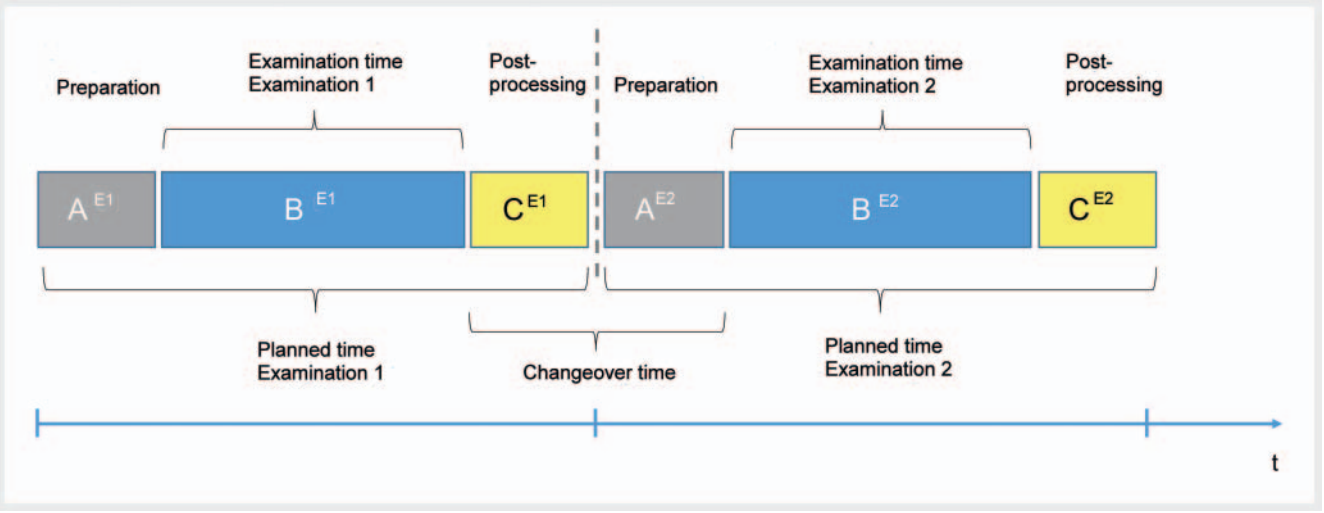
Due to the increasing cost pressure in the health care system, there is likewise a need in radiology to optimize examination and reporting processes while at the same time providing the highest possible quality of examination services [1, 2]. Previous approaches have focused on improving process flows, particularly in sectional imaging procedures such as computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound [3–5]. The intention is to achieve the highest possible utilization of the examination equipment with simultaneously low idle times which are associated with high (opportunity) costs, especially in MRI [6, 7].

However, in large hospitals, the optimal utilization of available MRI equipment continues to be difficult, especially since a large number of sometimes very complex examination procedures have to be offered with different MRI coils, while at the same time precisely coordinating the timely availability of critically ill and mostly immobile patients from different wards. In addition, the duration of even similar examinations can vary widely depending on patient compliance [8]. Until now, planning for the utilization of different MRI scanners has often been carried out by administrative staff in the sense of a "pseudo-optimization", based on previously established empirical values. In retrospect, however, this usually falls short of an achievable optimum [9]. However, modern MRI scanners utilize associated IT applications that make detailed data available on the actual use of the equipment [10, 11].

The aim of the study was to obtain a comprehensive and detailed overview of the use of two clinically-busy MRI scanners with respect to examination type, duration and changeover times using a newly-available software application and to evaluate whether this could be used to derive optimization potential for examination planning in the daily clinical routine of MRI diagnostics.

Materials and Methods

The present study was performed in the Department of Radiology of a Swiss university hospital. As part of an internal institute survey, the examination durations and changeover times of MRI examinations on two MRI scanners (1.5 Tesla (T), Siemens Aera and 3 T, Siemens Skyra, both Siemens Healthcare, Erlangen,



▶ **Fig. 1** The different sections of an MRI examination process, divided into preparation (A^{U1}), duration of examination 1 (B^{U1}), and post-processing (C^{U1}) of examination 1. The process sections of subsequent examination 2 are correspondingly designated as A^{U2}, B^{U2}, C^{U2}.

Germany) were subjected to a detailed retrospective analysis. The examination spectrum included all MRI examinations (body regions or subject areas: abdomen, urology, chest, heart, breast and musculoskeletal system) performed in the clinic with the exception of neurological examinations, which were performed by the independent clinic for neuroradiology.

The sequence of an MRI examination was as follows in each case: after referral by a physician and review of the indication by the clinic's own radiology specialists, the planning of all examinations and their sequence was organized by the radiology clinic's scheduling department. Once the patients had arrived and been informed about the examination, and after the administration of intravenous contrast medium (i. v.), if necessary, the radiological staff prepared the patients for the MRI examination (e. g., insertion of a flexure tube) and made the appropriate preparations in the MRI room, such as attaching and adjusting the coils. This was followed by the examination in the MRI scanner according to the pre-established sequence protocol. After completion of the examination, patients were escorted out of the MRI room. Outpatients then left the department, while inpatients were promptly picked up by the transport service organized in advance. Finally, the room was cleaned by radiological staff and the process started again with a subsequent examination. In the radiology clinic, two members of medical-technical staff were basically assigned to each MRI scanner at the same time.

A scheduled time of either 30, 45 or 60 minutes was defined internally at the clinic for all examinations. This planned time contained the expected examination time [B^{E1}] including a preparation and post-processing time [A^{E1} and C^{E1}] (▶ **Fig. 1**). Examination duration [B^{E1}] was defined as the period between the time of acquisition of the first image of an MRI examination and the completion of acquisition of the last image. The changeover time was defined as the period between the end of the examination and the start of the subsequent examination. It thus consisted of the post-processing time for an examination [C^{E1}] and the preparation time for the respective subsequent examination [A^{E2}].

The period analyzed was 12 months from March 1, 2017 to February 28, 2018. The study-specific detailed data were collected by querying the software application "Teamplay Usage" (Siemens Healthineers, Erlangen, Germany), that was available to the radiology clinic for the above-mentioned period as part of this study. The application used data directly from the consoles on the MRI scanners and recorded the examination type, date, start and end time based on the DICOM data from the examinations. The examination duration and changeover time between two examinations were calculated automatically from this. The times were recorded to the second (in hours:minutes:seconds). The application did not make pre-selections. It had to be taken into account that upstream processes such as homogenization of the magnetic field ("shimming") were required before the first DICOM image was created. The application did not record these times separately. These usually vary between 15 to 30 seconds, depending on the body region, patient constitution or field strength of the MRI scanner. In this study upstream processes were considered preparation time. The descriptions of the types of examinations on the MRI consoles was based on the designations stored in the Radiological Information System (RIS). For most examination types, the designations in the RIS corresponded to the sequence protocols performed (e. g., MRI knee). However, descriptions such as "MRI abdomen" encompassed several specific protocols for the liver. "MRI pelvis" contained sequence protocols for the prostate or pelvic tumor staging.

In the first part of the study, the actual performance times of all examinations or types of examinations on both MRI scanners were analyzed. A median examination time was determined for all examinations, including a constant preparation and post-processing time of 9 minutes. This preparation and post-processing time resulted from considering the frequency distribution of all changeover times recorded within the core working hours (weekdays Monday through Friday between 06:45 and 18:45). The adherence to the planned times (30, 45 or 60 minutes) and an analysis of the planned time deviations were checked. In addition,

▶ **Table 1** Number and proportion of examinations performed on both MRI scanners (n = 7184; 1.5 T = 3740, 3 T = 3444) in relation to the planned examination time (planned time) and the median examination duration (mED). In addition, the mED is displayed including preparation and post-processing of 9 minutes. The difference between the planned time and the mUD including preparation and post-processing is also shown. All times are given in hours, minutes and seconds (hh:mm:ss).

MRI scanner and number of examinations	planned time	number of examinations	percentage of examinations	median examination duration (mED)	mED[1]	Δ between planned time and mED[1]
1.5 T MRI n = 3740	0:30:00	905	24.2 %	0:30:58	0:39:58	–0:09:58
	0:45:00	2488	66.5 %	0:34:36	0:43:36	0:01:24
	1:00:00	347	9.3 %	0:40:07	0:49:07	0:10:53
3 T MRI n = 3444	0:30:00	885	25.7 %	0:29:03	0:38:03	–0:08:03
	0:45:00	2481	72.0 %	0:34:32	0:43:32	0:01:28
	1:00:00	78	2.3 %	0:44:00	0:53:00	0:07:00

[1] including preparation and post-processing time of 9 min.

the number and proportion of the total number of analyzed examinations as well as the respective median duration were determined for each examination type. The evaluation focused on the ten most frequently performed types of examination (top 10) of both scanners.

An analysis of the changeover times was carried out in a second part of the study. When considering the changeover times, those examinations were taken into account which were carried out and completed within the above-mentioned core working hours. Number and median changeover times of combinations, i. e., sequences of different types of examinations, were determined together for both MRI scanners. The focus was placed on those combinations that occurred at least 20 times. The changeover time analysis then identified the five most frequent combinations and those with changeovers taking the longest time.

Furthermore, we reviewed whether keeping an MRI coil for two consecutive examinations was associated with lower median changeover times than when replacement was required. In each case, all examinations of the five most frequent combinations were compared in which the MRI coil was retained or replaced. The significance of the difference was tested using a Mood's median test with a significance level of p = 0.05. Excel 2010 for Windows (Microsoft Corporation, Redmond, WA, USA) and R (version 3.6.3, R Foundation for Statistical Computing, Vienna, Austria) were used for all analyses in this study.

Results

Analysis of Examination Time

In the first part of the study analyzing examination time, a total of 7184 MRI examinations were included during the period under consideration, of which 3740 (52.1 %) were performed in the 1.5 Tesla MRI scanner (1.5 T) and another 3444 (47.9 %) examinations were performed in the 3 Tesla MRI scanner (3 T), with a total of 34 different examination types.

The median examination time of the total examination volume was 43:02 minutes (1.5'T: 43:17 min; 3'T: 42:45 min) including a preparation and post-examination time of 9 minutes. The frequency distribution of changeover times within the core working hours showed that the highest proportion of changeover times was between 6 and 9 minutes, at around 27 %. A proportion of 48.2 % (1801/3740) of all examinations in the 1.5 T MRI scanner and 47.4 % (1632/3444) of all examinations in the 3 T MRI scanner were performed within the defined planned time. The number and the respective proportion of examinations with a plan time of 30, 45 and 60 minutes can be found in ▶ **Table 1**. Overall, examinations scheduled for 30 minutes took longer for both MRI scanners (1.5'T: 39:58 min; 3'T: 38:03 min). On the other hand, the highest proportion of examinations with a planned time of 45 minutes could be completed within this time. Less time was spent on the small proportion of examinations planned at 60 minutes (1.5'T: 49:07 min; 3'T: 53:00 min).

Considering both scanners, the ten most frequently performed examination types (top 10) accounted for 81.0 % (3031/3740) of the total examination volume in the 1.5 T MRI scanner and 80.8 % (2783/3444) in the 3 T MRI scanner.

When 9 minutes of preparation and post-processing time was included in each of the median examination times, a proportion of 54.5 % (1652/3031) in the 1.5 T scanner and 51.9 % (1443/2783) in the 3 T scanner were within the defined planned time for the ten most frequently performed examination types. A detailed breakdown per examination type and per MRI scanner is shown in ▶ **Table 2**.

In the 1.5 T scanner, examinations of the cervical soft tissues represented the most common type of examination, accounting for 20.9 % and lasting 43:53 minutes, followed by examinations of the abdomen (18.2 %; 43:09 minutes). In the 3 T scanner, pelvic examinations were performed most frequently at 22.4 %, with an examination duration of 46:02 minutes. Likewise, abdominal examinations accounted for a comparatively high proportion in the 3 T scanner (19.6 %; 43:59 minutes).

▶ **Table 2** The most common types of examination (Top 10: 1.5 T = 3031; 3 T = 2783) for both MRI scanners (1.5 T and 3 T) with the corresponding frequency of performance, proportion of the total volume, planned time, median examination duration (mED), difference between the planned time and the mED including preparation and post-processing of 9 minutes, proportion of examinations including preparation and post-processing of 9 minutes that were started and completed within the planned time. All times are given in hours, minutes, seconds (hh:mm:ss).

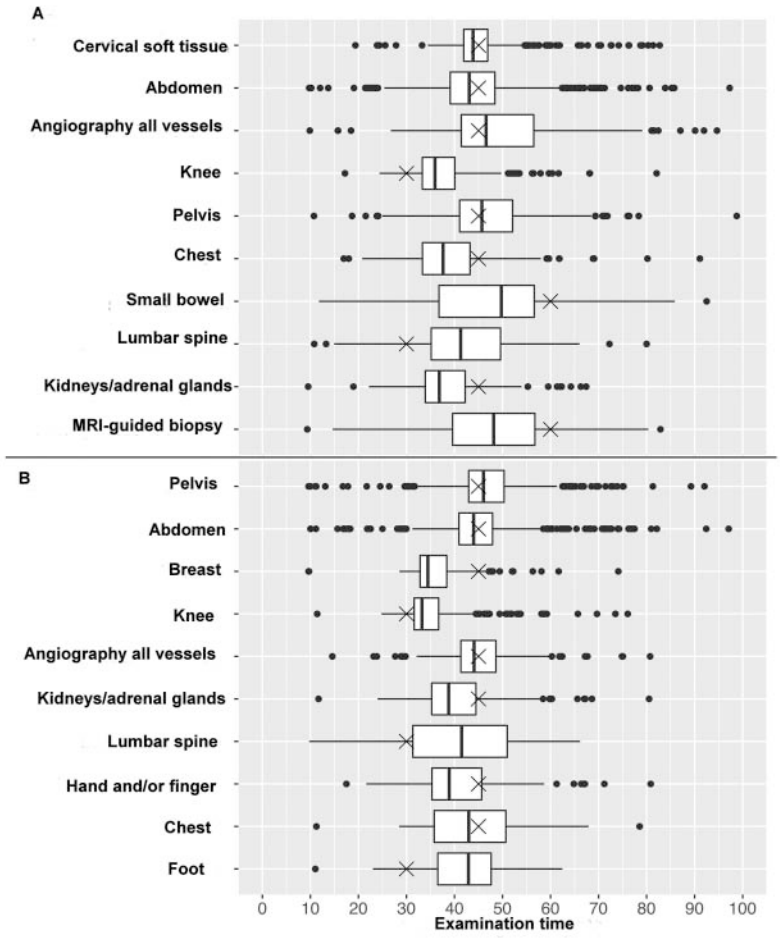
top 10 examination types per MRI scanner	number of examinations	percent of total volume per MRI scanner	planned time	median examination duration (mED)	mED[1]	Δ between planned time and mED[1]	Percent of examinations[1] within planned time
1.5 T MRI scanner							
cervical soft tissue[2]	781	20.9 %	0:45:00	0:34:53	0:43:53	0:01:07	62.0 %
abdomen[3]	679	18.2 %	0:45:00	0:34:09	0:43:09	0:01:51	61.9 %
angiography all vessels	297	7.9 %	0:45:00	0:37:37	0:46:37	−0:01:37	43.1 %
knee	289	7.7 %	0:30:00	0:26:56	0:35:56	−0:05:56	3.1 %
pelvis[4]	278	7.4 %	0:45:00	0:36:44	0:45:44	−0:00:44	47.8 %
thorax	198	5.3 %	0:45:00	0:28:42	0:37:42	0:07:18	77.3 %
small bowel	152	4.1 %	1:00:00	0:40:45	0:49:45	0:10:15	82.9 %
lumbar spine	138	3.7 %	0:30:00	0:32:17	0:41:17	−0:11:17	13.0 %
kidneys/adrenal glands	126	3.4 %	0:45:00	0:27:51	0:36:51	0:08:09	86.5 %
MRI-guided biopsy	93	2.5 %	1:00:00	0:39:20	0:48:20	0:11:40	73.5 %
3 T MRI scanner							
pelvis[4]	772	22.4 %	0:45:00	0:37:02	0:46:02	−0:01:02	42.2 %
abdomen[3]	674	19.6 %	0:45:00	0:34:59	0:43:59	0:01:01	58.8 %
breast	346	10.0 %	0:45:00	0:25:28	0:34:28	0:10:32	94.5 %
knee	282	8.2 %	0:30:00	0:24:15	0:33:15	−0:03:15	8.5 %
angiography all vessels	187	5.4 %	0:45:00	0:35:07	0:44:07	0:00:53	55.6 %
kidneys/adrenal glands	153	4.4 %	0:45:00	0:29:47	0:38:47	0:06:13	75.8 %
lumbar spine	105	3.0 %	0:30:00	0:32:29	0:41:29	−0:11:29	21.0 %
hand and/or finger	97	2.8 %	0:45:00	0:29:54	0:38:54	0:06:06	73.2 %
thorax	85	2.5 %	0:45:00	0:33:58	0:42:58	0:02:02	60.0 %
foot	82	2.4 %	0:30:00	0:33:54	0:42:54	−0:12:54	7.3 %

[1] including preparation and post-processing time of 9 min.
[2] MRI of cervical soft tissue includes the following examination protocols: MRI of neck, parotid gland, facial bones.
[3] MRI of abdomen includes the following examination protocols: MRI of liver, liver after transplantation, liver with hepatocyte-specific contrast.
[4] MRI of pelvis includes the following examination protocols: MRI of prostate, pelvic tumor staging.

For both MRI scanners, the median examination time, including preparation and post-processing time of 9 minutes, was within the initial planned time for six of the ten examination types (▶ **Fig. 2**). For example, in the 1.5 T MRI scanner, 61.9 % of the abdominal examinations mentioned above (3 T: 58.8 %) required less time than the planned time of 45 minutes. In addition, even complex examinations performed exclusively in the 1.5 T MRI scanner were sometimes significantly below the planned time. This was the case, for example, with small bowel examinations (MR enteroclysis) and MRI-guided biopsies, for each of which 60 minutes had been planned, but only 49:45 minutes (MRI small bowel) and 48:20 minutes (MRI-guided biopsy) were required. Further typical examples of examinations lasting less than the planned time can be found in ▶ **Table 2**. In contrast, however, various types of examinations were also found to have longer examination times compared with the scheduled time. For example, lumbar spine examinations took longer than the scheduled plan time of 30 minutes (1.5 T: 41:17 min; 3 T: 41:29 min).

Changeover Time Analysis

In the second part of the study, with an analysis of changeover times, the focus was on those combinations of examination sequences that were recorded within the defined core working hours and occurred at least 20 times (n = 3037). First, the five most frequent examination sequences and their median changeover times were analyzed (n = 862, ▶ **Table 3**). The most frequent combinations showed that the same types of frequently performed examinations, such as abdominal, pelvic and cervical



▶ **Fig. 2** Box plots of the examination durations (in minutes) of the 10 most common types of MRI examination (A: 1.5 T MRI scanner, B: 3 T MRI scanner). Cross = defined planned time.

examinations, also often followed each other. In these cases, the MRI coil used in the previous examination could be retained. For the five most common combinations, median changeover times ranged from 07:44 to 09:42 minutes (▶ **Table 3**). The five combinations with the longest median changeover times were considered in more detail (n = 158). Among these, the longest median changeover time documented was 16:47 minutes with a sequence of two small bowel examinations in succession. In the other combinations with the longest exchange times, different examination types followed each other in each case, which was basically also accompanied by an exchange of the MRI coil (▶ **Table 3**).

A final comparison of the five most common combinations of examination type sequences in which the MRI coil was retained (n = 691) with the five most common combinations in which coil replacement (n = 639) was required showed a small and statistically non-significant time difference of 33 seconds (median changeover time with coil retained: 09:08 min versus need for coil replacement: 09:41 min; p = 0.062). Replacement of the MRI coil required for different types of examinations had no significant effect on the changeover time for the combinations analyzed.

Discussion

Process analyses in radiology have been carried out for decades and have demonstrated a positive effect on the improvement of process organization as well as added value for patient treatment [12–15]. Previous analyses were often based on small samples with corresponding limitations on the informative value with regard to the potential for improvement to be derived for the organization of processes in everyday clinical practice [16].

The analysis software used in this study provided a comprehensive overview of the use of two clinically-busy MRI scanners in relation to the evaluated factors of examination type, examination duration and changeover time. About half the median examination times of the total examination volume including preparation and post-processing time were within the corresponding planned time (1.5 T: 48.2 %; 3 T: 47.4 %). Of the ten most common

▶ **Table 3** Examination sequences of both MR scanners showing the five most frequent (n = 862; 28.4 %; upper part of the table) and the five longest (n = 158; 5.2 %; lower part of the table) median changeover times, taking into account all examination sequences that occurred at least 20 times and were within core working hours (n = 3037). All times are given in hours, minutes and seconds (hh:mm:ss).

examination	subsequent examination	median change-over time	combination frequency	percent
cervical soft tissue	cervical soft tissue	0:07:44	162	5.3 %
pelvis	pelvis	0:08:42	170	5.6 %
abdomen	cervical soft tissue	0:08:45	135	4.4 %
abdomen	abdomen	0:08:57	240	7.9 %
abdomen	pelvis	0:09:42	155	5.1 %
cervical soft tissue	small bowel	0:13:56	21	0.7 %
abdomen	kidneys/adrenal glands	0:14:24	34	1.1 %
lumbar spine	abdomen	0:14:46	30	1.0 %
angiography all vessels	knee	0:14:55	25	0.8 %
small bowel	small bowel	0:16:47	48	1.6 %

exam types per MRI scanner, slightly more than half of the examinations were completed within the scheduled time (1.5 T: 54.5 %; 3 T: 51.9 %). The respective planned times for MRI examinations thus corresponded on average to the actual examination durations including their preparation and post-processing times.

Depending on the type of examination, however, the examination times deviated to varying degrees from the respective planned time, which is why it can be considered how much optimization potential could be realized by adjusting individual planned times. Thus, for example, in the case of frequently-performed abdominal examinations, based on the measured examination times (1.5 T: 43:09 min; 3 T: 43:49 min), the original planned time of 45 minutes could be reduced by one minute. Despite the high number of this type of examination performed, any potential for optimization in this case would still be low. Other types of examinations, however, with initially higher planned times allow for more optimization. For example, 50 minutes could be scheduled for small bowel sub-examinations (1.5 T: 49:45 min) instead of 60 minutes. Likewise, the planned time for breast examinations would be reduced from 45 minutes to 35 minutes (3 T: 34:28 min).

While in the above examples the determined duration of the examination was shorter than the planned time, there were also those that took longer than planned; in such cases, the planned time should be increased. Regarding knee examinations in the 3 T MRI scanner, the planned time could be adjusted from 30 minutes to 35 minutes, since examinations in this case took a median of 33:15 minutes.

In the course of the analysis, the planning times were adjusted for the ten most frequent examination types of both MRI scanners based on the results (▶ **Table 2**) in order to determine examples of possible optimization potential. For this purpose, those examination times were rounded up to whole minutes and set as “optimized” planning time. For the examination spectrum of one year, approximately 35 hours were determined in the 1.5 T MRI scanner and 13 hours in the 3 T MRI scanner. In this way minor optimization potential could be derived by adjusting the planning times for the clinic studied. In this context, however, it is necessary to discuss and critically question the extent to which minute-by-minute planning is actually practicable in reality. Even if such precise planning is theoretically possible, it is likely to be rather difficult to implement in practice from an organizational point of view. It is advisable to plan in at least 5-minute intervals to have a certain time margin (buffer) for those examinations that take more time than originally planned. A 5-minute stagger in scheduling, e. g., rounding up to 45 minutes for lumbar spine examinations (1.5 T: 41:17 min; 3 T: 41:29 min), would correspondingly reduce potential for optimization compared with minute-by-minute scheduling. It should be taken into account that the scheduling of examinations and their upstream and downstream process steps should be organized so that MRI capacities are used in the best possible way and idle times are kept correspondingly low. Consideration should be given to the types of examinations for which it is practical to adjust the planned time to avoid a significant discrepancy between actual examination time and scheduled time.

Optimization potential could be realized through changes in the process flow if times for preparation and post-processing were less than the 9 minutes used in this study. With regard to the possibilities of shortening MRI exchange times, Recht et al. [17] reviewed the influence of improved layout of MRI examination units also using mobile examination tables that can be freely coupled to the various MRI scanners. Both measures significantly reduced median changeover times per patient from 481 to 141 seconds per patient. This reduction was primarily due to improved patient preparation, attachment of the coils in a separate preparation room and application of venous flexures outside the examination room. The significance of time lost in MRI diagnostic examination procedures was investigated by Beker et al. [16] who found that in about one-third of the time there was no generation of direct patient benefit (“non-value-added time”). Especially common causes for this included problems with the placement

of venous access and the availability of patients optimally prepared for the examination.

Other studies recommended a number of measures for immediate improvement of process flows, such as a high degree of process standardization, clear definition of responsibilities for different groups of personnel, and improvement of examination protocols [15, 18]. In this regard, O'Brien et al. [19] demonstrated that consistent application of such patient scheduling improvement measures and content optimization of MRI examination protocols resulted in a significant reduction in room utilization time from an average of 46.3 to 43.6 minutes ($p = 0.009$). The cost savings thus enabled were up to $3 million annually.

The extent to which a reduction in preparation and post-processing time could be achieved by deploying more staff should be taken into account, although higher personnel costs directly counteract the potential savings from short changeover times. In our clinic, two members of medical-technical staff were basically assigned to each MRI scanner at the same time. This comfortable staffing level compared to other hospitals and radiology practices is due in part to the availability of trainees. The four staffers at two MRI scanners included one trainee at most. As shown in the study, replacement of MRI coils in successive examinations had no significant effect on the length of changeover times, at least with respect to frequently occurring combinations. This could also be due to staffing levels. Thus, if two medical-technical assistants are available at all times, it is possible for one person to undertake the preparation and post-processing of patients during a change of examination, while another carries out any coil exchange that may be necessary and prepares the examination table.

The main limitation of our study is that it was conducted at a large university hospital with a maximum care objective. The spectrum of examinations was very diverse and examinations that were not offered in the outpatient sector were also included. The resulting changeover times are thus presumably higher than in outpatient practices, as well as due to the examination of often immobile inpatients, and are applicable to the latter only to a limited extent. However, the finding on particularly time-intensive changing between types of examinations should also apply in the outpatient sector. In addition, clinics and practices of different sizes can determine their own average changeover time with little effort and estimate the results on their own optimization potential based on the effects of schedule time variations. The software used did not allow querying certain characteristics of the examinations. For example, it was not possible to access the level of patient mobility (mobile or immobile), the type of classification (outpatient or inpatient), or the percentage of interrupted examinations. Also, no distinction could be made between examinations performed with or without intravenously administered contrast. The level of detail of the results depends on the predefined examination definitions in the RIS. In our clinic, for example, different sequencing protocols of the liver are grouped under the name "MRI abdomen", which have slightly different durations. Ultimately, this should have had only a minor impact on the results. In principle, the software allows the analysis of large quantities of examinations. For users, however, it should be noted that query results remain manageable and allow derivation of recommendations for action in clinical practice.

Avery et al. analyzed whether predicting actual examination times is possible [20]. They investigated significant factors influencing the variation of examination duration in an identical MRI examination protocol of the neck. They found that examination times depended primarily on the medical technician performing the examination, and that examinations took significantly longer for inpatients and for emergency examinations.

As a conclusion of the study, it can be stated that the analysis software used enabled a detailed overview of the actual use of highly used clinical MRI scanners. In the radiological clinic in which the study was carried out, there was little potential for optimization in the scheduling of examinations in MRI diagnostics.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Swensen SJ, Johnson CD. Radiologic quality and safety: mapping value into radiology. Journal of the American College of Radiology: JACR 2005; 2: 992–1000

[2] Rubin GD. Costing in Radiology and Health Care: Rationale, Relativity, Rudiments, and Realities. Radiology 2017; 282: 333–347

[3] Rawson JV, Kannan A, Furman M. Use of Process Improvement Tools in Radiology. Current problems in diagnostic radiology 2016; 45: 94–100

[4] Qiu H, Wang D, Wang Y et al. MRI appointment scheduling with uncertain examination time. Journal of Combinatorial Optimization 2019; 37: 62–82

[5] Maurer MH, Hamm B, Teichgräber U. ServiceBlueprinting as a service management tool in radiology. European journal of radiology 2011; 79: 333–336

[6] Wessman BV, Moriarity AK, Ametlli V et al. Reducing barriers to timely MR imaging scheduling. Radiographics: a review publication of the Radiological Society of North America, Inc 2014; 34: 2064–2070

[7] Roth CJ, Boll DT, Wall LK et al. Evaluation of MRI acquisition workflow with lean six sigma method: case study of liver and knee examinations. Am J Roentgenol American journal of roentgenology 2010; 195: W150–W156

[8] Talati IA, Krishnan P, Filice RW. Developing Deeper Radiology Exam Insight to Optimize MRI Workflow and Patient Experience. Journal of digital imaging 2019; 32: 865–869

[9] Tokur S, Lederle K, Terris DD et al. Process analysis to reduce MRI access time at a German University Hospital. International journal for quality in health care: journal of the International Society for Quality in Health Care 2012; 24: 95–99

[10] Siemens Healthineers: Teamplay performance management applications. Erlangen, Germany, 2020.

[11] Jones S, Cournane S, Sheehy N et al. A Business Analytics Software Tool for Monitoring and Predicting Radiology Throughput Performance. Journal of digital imaging 2016; 29: 645–653

[12] Revesz G, Shea FJ, Ziskin MC. Patient flow and utilization of resources in a diagnostic radiology department. Radiology 1972; 104: 21–26

[13] Janower ML. Radiology department management system: technologists' costs. Radiology 1986; 159: 566

[14] Recht M, Macari M, Lawson K et al. Impacting key performance indicators in an academic MR imaging department through process improvement. Journal of the American College of Radiology: JACR 2013; 10: 202–206

[15] Rosenkrantz AB, Lawson K, Ally R et al. Focused process improvement events: sustainability of impact on process and performance in an academic radiology department. Journal of the American College of Radiology: JACR 2015; 12: 75–81

[16] Beker K, Garces-Descovich A, Mangosing J et al. Optimizing MRI Logistics: Prospective Analysis of Performance, Efficiency, and Patient Throughput. Am J Roentgenol American journal of roentgenology 2017; 209: 836–844

[17] Recht MP, Block KT, Chandarana H et al. Optimization of MRI Turnaround Times Through the Use of Dockable Tables and Innovative Architectural Design Strategies. Am J Roentgenol American journal of roentgenology 2019; 212: 855–858

[18] Kruskal JB, Reedy A, Pascal L et al. Quality initiatives: lean approach to improving performance and efficiency in a radiology department. Radiographics: a review publication of the Radiological Society of North America, Inc 2012; 32: 573–587

[19] O'Brien JJ, Stormann J, Roche K et al. Optimizing MRI Logistics: Focused Process Improvements Can Increase Throughput in an Academic Radiology Department. Am J Roentgenol American journal of roentgenology 2017; 208: W38–W44

[20] Avey GD, Belden DS, Zea RD et al. Factors predicting the time-length variability of identically protocoled MRI exams. Journal of magnetic resonance imaging: JMRI 2019; 49: e265–e270