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

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Key words
health policy and practice, scheduling, optimization, MR imaging

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.

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, 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 were 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 [BE1] including a preparation and post-processing time [AE1 and CE1] (Fig. 1). Examination duration [BE1] 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 [CE1] and the preparation time for the respective subsequent examination [AE2].

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, 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

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examinations accounted for a comparatively high proportion in the 3 T scanner (19.6 %; 43:59 minutes).

For both MRI scanners, the median examination time, including preparation and post-processing 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 time were analyzed (n = 862, ▶ Table 3). The most frequent

<table>
<thead>
<tr>
<th>Table 2</th>
<th>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).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>top 10 examination types per MRI scanner</td>
</tr>
<tr>
<td>1.5 T MRI scanner</td>
<td></td>
</tr>
<tr>
<td>cervical soft tissue2</td>
<td>781</td>
</tr>
<tr>
<td>abdomen1</td>
<td>679</td>
</tr>
<tr>
<td>angiography all vessels</td>
<td>297</td>
</tr>
<tr>
<td>knee</td>
<td>289</td>
</tr>
<tr>
<td>pelvis4</td>
<td>278</td>
</tr>
<tr>
<td>thorax</td>
<td>198</td>
</tr>
<tr>
<td>small bowel</td>
<td>152</td>
</tr>
<tr>
<td>lumbar spine</td>
<td>138</td>
</tr>
<tr>
<td>kidneys/adrenal glands</td>
<td>126</td>
</tr>
<tr>
<td>MRI-guided biopsy</td>
<td>93</td>
</tr>
<tr>
<td>3 T MRI scanner</td>
<td></td>
</tr>
<tr>
<td>pelvis4</td>
<td>772</td>
</tr>
<tr>
<td>abdomen1</td>
<td>674</td>
</tr>
<tr>
<td>breast</td>
<td>346</td>
</tr>
<tr>
<td>knee</td>
<td>282</td>
</tr>
<tr>
<td>angiography all vessels</td>
<td>187</td>
</tr>
<tr>
<td>kidneys/adrenal glands</td>
<td>153</td>
</tr>
<tr>
<td>lumbar spine</td>
<td>105</td>
</tr>
<tr>
<td>hand and/or finger</td>
<td>97</td>
</tr>
<tr>
<td>thorax</td>
<td>85</td>
</tr>
<tr>
<td>foot</td>
<td>82</td>
</tr>
</tbody>
</table>

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.
combinations showed that the same types of frequently performed examinations, such as abdominal, pelvic and cervical 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 prepara-
tion and post-processing time were within the corresponding planned time (1.5 T: 48.2%; 3 T: 47.4%). Of the ten most common 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 Bekel et al. [16] who found that in about one-third of the time there was no generation

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

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).
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.

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