Process analysis to reduce MRI access time at a German University Hospital

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Abstract

Quality problem or issue. Long access times for magnetic resonance imaging (MRI) can negatively impact the quality of care provided to patients. We investigated improving access by reducing MRI processing time.

Initial assessment. Data were collected for scans (n = 360) performed over 3 weeks (April–May 2008) at the University Hospital of Mannheim, Germany. Average access time, excluding emergencies, was 44 (±44) days for outpatients and 3 (±5) days for inpatients. Factors influencing total MRI processing time were identified using multivariate linear regression. In addition to region scanned, the total MRI processing time was significantly related to performing multiple scans (β = 33.57, P < 0.01), using oral contrast media (β = 13.58, P < 0.01), placing an intravenous (IV) catheter (β = 5.00, P = 0.04) and scanning patients ≤8 years old (β = 0.41, P = 0.03). Contrary to prior perceptions, emergency cases (5.6%) and late arrivals (12.8% >5 min late) were less than expected.

Choice of solution. Increasing scheduling flexibility to address non-modifiable process variation and completing preparatory activities outside the scanner room were identified as process improvement targets.

Implementation. Scheduling was adapted to utilize three expected total MRI processing times and IV placement was moved outside the scanner room.

Evaluation. Planned hardware and software upgrades were completed concurrent to the process improvements. As a result, it was not possible to accurately measure the effect of implementing the scheduling and preparatory activity changes.

Lessons learned. Clinical study team members’ prior perceptions of workflow obstacles did not match the study findings. Utilizing insiders and outsiders during process analysis may limit bias in identification of process improvement opportunities.

Keywords: radiology, magnetic resonance imaging, quality of health care, health services accessibility

Introduction

Average access time for magnetic resonance imaging (MRI) is a key performance indicator for radiology departments [1]. Longer access times may result in diagnosis delays [2] or decreased likelihood that patients follow-through with recommended imaging [3]. Shorter access times can also be a competitive advantage [4, 5].

To shorten access time, the Institute for Healthcare Improvement recommends matching supply to demand by shaping demand (e.g. reducing over-use) and increasing supply (e.g. through system redesign) [6]. Internal department staff may hold a common belief as to the causes for access delays. However, subjective perception of processes both under and outside the staff’s locus of control may be inaccurate [7]. Consequently, process improvement targets must be identified in an objective manner.

In our project, we used process analysis to objectively identify opportunities to reduce average MRI access time. Despite the role of imaging access time on the quality of care for a diverse range of patients, little has been previously published [8]. The few radiology process analysis and redesign projects reported have either overlooked or viewed improvements in access time as a secondary outcome [5, 9–13].
Methods
Overview
The project was the initiative of the Institute for Clinical Radiology and Nuclear Medicine (ICRNM) of Universitätsmedizin Mannheim (UMM), a tertiary care hospital in Germany affiliated with Heidelberg University. ICRNM provides 8600 MRI scans annually with all scans scheduled for 60 min of total MRI-processing time. (Total MRI processing time is defined as the time between when a patient is called for preparation until the scanner room is ready for the next patient.) Emergency patients were scheduled ad hoc. Outpatients were asked to arrive 30 min before their appointment. Clinical study team members (K.L., S.B., S.O.S. and G.W.) initially attributed inefficiencies in MRI processing and access delays to a high incidence of emergency cases and patients’ late arrival. The study team also included a health services researcher (D.T.), a data manager (M.J.) and a medical student (S.T.) from outside ICRNM.

Data collection
Data were collected over 3 weeks (14 April–2 May 2008) for scans scheduled on one of the four MRIs (Vision 1.5 T, Harmony 1 T, Sonata 1.5 T and Avanto 1.5 T, from Siemens, Inc., Munich, Germany). ICRNM shares the MRIs with other clinical departments (e.g. Neuroradiology). As a result, the time available for ICRNM scheduling varied across the MRIs. Restrictions in MRI scheduling also existed due to technical reasons (see Fig. 1). For example, the Sonata (1.5 T) had a shorter magnet, restricting some abdominal studies (e.g. combined abdominal and pelvic scans). The Avanto (1.5 T) was the only MRI used for whole-body scans. The Sonata and Avanto were the only two MRIs used for cardiac scans. All scanners from Siemens, Inc., Munich, Germany.
performed 6 months following request) were excluded. A label attached to the MRI request form was used for data collection. All staff members involved in routine MRI service delivery (receptionists, technicians and physicians) were trained to use the label and to refer to radio-controlled clocks placed within the department.

Factors with potential influence on MRI workflow were also collected: oral contrast media (OCM) used, patient confined to bed, medication required before scan, emergency case (based on retrospective review) and intravenous (IV) catheter placed. When needed, IVs were placed with the patient lying on the scanner table. Although ICRNM’s policy stated inpatients should be transported with a usable IV in place, this was perceived to be often not the case. Additional data were abstracted from ICRNM’s information system [inpatient/outpatient, scan type (i.e. region scanned), multiple scans performed in a single appointment, scanner used, patients’ age [categorized as ≤8 years, 9–59 years and ≥60 years]]. All data were anonymized with respect to patient, referrer and staff identities.

### Analysis

Access time, preparation time, scan time, post-processing time and total MRI processing time were calculated based on the data collected. The utilization rate for each scanner was assessed by taking the sum of recorded scan times for a scanner for a given day and dividing by ICRNM’s available hours for the scanner. We also reviewed the number of emergency cases and late arrivals, with late arrival defined as >5 min past the appointment time.

Multivariate linear regression modelling was used to investigate the factors influencing total MRI processing time using SPSS software (SPSS, Inc., Chicago IL, USA). Segments of total MRI processing time were also examined. No missing data were imputed. Significance was assessed at \( P < 0.05 \) and \( P < 0.0125 \), after simple Bonferroni correction for multiple testing [14].

### Results

#### MRI access times

A total of 447 MRI scans were initially scheduled for the data collection period, with 360 scans performed after cancellations by either the patient or ICRNM staff (Table 1). Average MRI access time, excluding emergency cases, was 44 (± 45) days (interquartile range (IQR) = 47 days) for outpatients and 3 (± 5 days) (IQR = 5 days) for inpatients.

#### Emergency cases and late arrivals

Twenty scans (5.6%) were retrospectively assessed as emergency cases. Excluding emergencies, cases with OCM use, and records with missing time points (\( n = 59 \)), 46 patients (12.8%) arrived late, arriving on average 21 (± 14 min) after their scheduled appointment (IQR = 20 min). Over 60% of outpatients did not arrive at the requested 30 min time prior to their appointment, but on average arrived before their scheduled appointment time. The number of emergency cases and late arrivals were both lower than the clinical study team members had \textit{a priori} expected.

### Factors influencing total MRI processing time

Excluding emergency cases, 22.6% of inpatients arrived without a usable IV in place. An IV had to be placed in 46.7% of all cases (inpatients and outpatients) before proceeding (see Table 1). In addition to scan type, performing multiple scans \((\beta = 33.57, P < 0.01)\), using OCM \((\beta = 13.58, P < 0.01)\), placing IVs \((\beta = 5.00, P = 0.04)\), and scanning patients \(\leq 8\) years of age \((\beta = 0.41, P = 0.03)\) were found to significantly influence total MRI processing time (Table 2). Of these, only performing multiple scans significantly influenced all segments of total MRI processing time.
Table 2 Multivariate linear regression models investigating process-related factors and their influence on total MRI processing time and segments of total MRI process time (preparation time, scan time and post-processing time)

<table>
<thead>
<tr>
<th>Factors</th>
<th>Preparation time model&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Scan time model&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Post-processing time model&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Total MRI processing time model&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>17.38 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>33.40 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>14.03 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>61.14 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI abdomen</td>
<td>-7.52 0.07</td>
<td>-18.78 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-5.45 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-26.84 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI brain</td>
<td>-12.93 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-19.43 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-5.22 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-31.77 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI breast</td>
<td>-11.26 0.13</td>
<td>-24.34 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-6.23 0.06</td>
<td>-34.99 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI full body</td>
<td>-4.24 0.43</td>
<td>1.88 0.66</td>
<td>-5.46 0.02</td>
<td>-3.31 0.66</td>
</tr>
<tr>
<td>MRI Extremity/joint</td>
<td>-11.89 0.01**</td>
<td>-8.30 0.02*</td>
<td>-5.02 0.01*</td>
<td>-20.81 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI heart</td>
<td>-13.99 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-5.10 0.19</td>
<td>-7.34 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-21.31 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI neck</td>
<td>-13.61 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-15.48 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-4.53 0.06</td>
<td>-28.43 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI pelvis</td>
<td>-10.22 0.01**</td>
<td>-12.31 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-4.84 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-21.51 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI retroperitoneum</td>
<td>-9.00 0.07</td>
<td>-11.54 0.01**</td>
<td>-3.49 0.12</td>
<td>-18.89 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI partial spine</td>
<td>-15.13 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-16.49 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-2.67 0.21</td>
<td>-31.83 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>MRI total spine</td>
<td>4.26 0.44</td>
<td>0.67 0.88</td>
<td>-5.19 0.04*</td>
<td>6.18 0.43</td>
</tr>
<tr>
<td>MRI thorax</td>
<td>-12.89 0.12</td>
<td>-28.33 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>10.71 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-21.18 0.10</td>
</tr>
<tr>
<td>Emergency case</td>
<td>10.32 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-1.82 0.53</td>
<td>-1.36 0.38</td>
<td>8.29 0.09</td>
</tr>
<tr>
<td>Use of oral contrast media</td>
<td>1.58 0.48</td>
<td>13.58 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-1.32 0.18</td>
<td>13.36 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>Multiple scans performed</td>
<td>9.59 0.04*</td>
<td>22.17 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>4.93 0.02*</td>
<td>33.57 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
</tr>
<tr>
<td>Placement of IV catheter</td>
<td>4.44 0.01**</td>
<td>3.16 0.02*</td>
<td>-0.45 0.55</td>
<td>5.00 0.04*</td>
</tr>
<tr>
<td>Age ≤8 years&lt;sup&gt;e&lt;/sup&gt;</td>
<td>3.23 0.43</td>
<td>9.10 0.01**</td>
<td>0.68 0.70</td>
<td>0.41 0.03*</td>
</tr>
<tr>
<td>Age ≥60 years&lt;sup&gt;e&lt;/sup&gt;</td>
<td>-0.09 0.96</td>
<td>-0.76 0.57</td>
<td>0.57 0.43</td>
<td>12.98 0.86</td>
</tr>
<tr>
<td>Avanto 1.5 T MRI&lt;sup&gt;f&lt;/sup&gt;</td>
<td>2.10 0.42</td>
<td>7.31 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-1.67 0.14</td>
<td>6.92 0.06</td>
</tr>
<tr>
<td>Harmony 1 T MRI&lt;sup&gt;f&lt;/sup&gt;</td>
<td>2.28 0.46</td>
<td>7.95 &lt;sup&gt;0.01**&lt;/sup&gt;</td>
<td>-2.62 0.05</td>
<td>5.73 0.19</td>
</tr>
<tr>
<td>Sonata 1.5 T MRI&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1.77 0.53</td>
<td>0.80 0.72</td>
<td>-0.80 0.52</td>
<td>0.91 0.82</td>
</tr>
<tr>
<td>&lt;sup&gt;r&lt;/sup&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.15</td>
<td>0.38</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>&lt;sup&gt;u&lt;/sup&gt;</td>
<td>335</td>
<td>348</td>
<td>330</td>
<td>316</td>
</tr>
</tbody>
</table>

Significant factors are shown in bold: *significant at $P < 0.05$, **significant at $P < 0.0125$, after simple Bonferroni correction for multiple testing [15].

Within each model, the constant represents a base time. The coefficient ($\beta$) given for each factor can be interpreted as the average additional (or reduction in) time required when the factor is present.

<sup>a</sup>Preparation time model = model of factors influencing time between when a patient is called in for their appointment and when their MRI scan begins.

<sup>b</sup>Scan time model = model of factors influencing time between when a patient’s MRI scan begins and when their scan ends.

<sup>c</sup>Post-processing time model = model of factors influencing time between when a patient’s MRI scan ends and when the scanner room is prepared for the next patient. Image reconstruction (i.e. additional processing of an MRI scan before the scan is read) was not explicitly included in the measurement of post-processing time as these steps were not uniformly taken immediately after an MRI scan was performed.

<sup>d</sup>Total MRI processing time model = model of factors influencing time between when a patient is called in for their appointment and when the scanner room is prepared for the next patient.

<sup>e</sup>MRIIs performed on patients 9–59 years of age serve as the reference group.

<sup>f</sup>MRIIs performed on the Vision 1.5 T scanner serve as the reference group. All scanners were products of Siemens, Inc. (Munich, Germany).

MRI scanner utilization rates

The average scanner utilization rate ranged from 43.7% (Vision) to 59.8% (Avanto; Fig. 1). The maximum utilization rate on any given day was 78.6% (Sonata). The minimum was 26.7% (Sonata).

Discussion

Significant delays and variation in MRI access times were observed, especially among outpatients, providing support for ICRNM’s improvement initiative. The measured rate of emergency cases and late arrivals were less than the clinical study team members initially perceived. Several factors were found to significantly influence total MRI processing time beyond scan type: performing multiple scans, using OCM, placing IVs and scanning younger patients. Available capacity was found for all scanners.

Performing multiple scans and using OCM are both intrinsic parts of the MRI process for many patients. Similarly, ICRNM cannot limit the age of patients scanned. These factors cannot be avoided, but can be accounted for
in the scheduling process. ICRNM’s prior reliance on a standard 60-min appointment did not accommodate non-modifiable total MRI processing time variation. Further, placing IVs with the patient lying on the MRI table needlessly tied up the MRI room when the scanner was not active.

**MRI process improvements**

As a result of our process analysis, the following recommendations were made.

**Preparation:** placement of IVs should be performed outside the scanner room, as suggested in prior studies [5, 13]. The policy of inpatients being transferred with usable IVs in place should be reinforced.

**Scheduling:** scans should be scheduled more flexibly using one of the three expected total MRI processing times. A policy of rescheduling outpatients who arrive later than a given cut-off time should also be considered.

**Future process improvement teams**

The divergence between clinical study team members’ initial perceptions of process obstacles and the objectively identified workflow inefficiencies is not surprising and can be explained by attribution bias (i.e. an individual is more likely to emphasize external causes, outside their control, when examining reasons behind events) [7]. The use of mixed quality improvement teams, including both insiders and outsiders to the process being addressed, may limit the risk of attribution bias. Reducing bias and increasing accuracy in process analysis may then lead to improved effectiveness in process redesign efforts [7].

**Strengths and limitations**

The reliability and accuracy of data collected depended upon cooperation and coordination among all ICRNM staff. Initially, study goals and methods were not sufficiently communicated. As a result, additional training and communication was required. Further, although we aimed to collect data during representative operations, the study period included a holiday (1 May) during which only emergency cases were scheduled/data were not collected. This break-in scheduling may have affected volume and workflows on days prior and following the holiday.

Further, almost 20% of scans originally scheduled for the data collection period were cancelled. This cancelation rate may be an artefact of the study period chosen, however, the rate was not perceived as unusual. In future studies, the reasons for and timing of cancelations should be collected to investigate possible influences on scanner utilization rates.

Finally, our report only describes the first phase of a Plan-Do-Check-Act cycle [15]. In the end, planned upgrades to the MRI scanners and software were completed concurrent to implementation of our recommendations. As a result, it is not possible to accurately measure the effect of our recommendations, apart from the software and hardware upgrades, on scanner utilization rates and MRI access times.

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**References**