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Optimization of MRI Turnaround Times Through the Use of Dockable Tables and Innovative Architectural Design Strategies

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Abstract

OBJECTIVE.—The purpose of this study is to increase the value of MRI by reengineering the MRI workflow at a new imaging center to shorten the interval (i.e., turnaround time) between each patient examination by at least 5 minutes.

MATERIALS AND METHODS.—The elements of the MRI workflow that were optimized included the use of dockable tables, the location of patient preparation rooms, the number of doors per scanning room, and the storage location and duplication of coils. Turnaround times at the new center and at two existing centers were measured both for all patients and for situations when the next patient was ready to be brought into the scanner room after the previous patient's examination was completed.

RESULTS.—Workflow optimizations included the use of dockable tables, dedicated patient preparation rooms, two doors in each MRI room, positioning the scanner to provide the most direct path to the scanner, and coil storage in the preparation rooms, with duplication of the most frequently used coils. At the new imaging center, the median and mean ($\pm$ SD) turnaround times for situations in which patients were ready for scanning were 115 seconds (95% CI, 113–117 seconds) and 132 ± 72 seconds (95% CI, 129–135 seconds), respectively, and the median and mean turnaround times for all situations were 141 seconds (95% CI, 137–146 seconds) and 272 ± 270 seconds (95% CI, 263–282 seconds), respectively. For existing imaging centers, the median and mean turnaround times for situations in which patients were ready for scanning were 430 seconds (95% CI, 424–434 seconds) and 460 ± 156 seconds (95% CI, 455–465 seconds), respectively, and the median and mean turnaround times for all situations were 481 seconds (95% CI, 474–486 seconds) and 537 ± 219 seconds (95% CI, 532–543 seconds), respectively.

CONCLUSION.—The optimized MRI workflow resulted in a mean time savings of 5 minutes 28 seconds per patient.

Keywords

dockable table; MRI; turnaround time; value

Over the past several years, increased emphasis has been placed on measuring and improving the value of imaging [1–3]. Given its popularity and associated costs, MRI has

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been a frequent subject of these evaluations, with most assessments focused on improvements in hardware and software. Hardware advances have included the development of wide-bore MR scanners with a high magnetic field strength [4], novel coil designs to allow both increased resolution and an increased signal-to-noise ratio [5], and more patient-centric and comfortable equipment. Software innovations have included free-breathing techniques for acquisition of abdominal images [6], accelerated image acquisition using such novel reconstruction techniques as compressed sensing and machine learning [7, 8], MRI fingerprinting [9], and more-intuitive user interfaces.

One topic that has the potential to greatly improve the value of MRI but has not been studied as extensively as other topics is the optimization of MRI workflow [3, 10, 11]. When workflow is studied, the Lean Six Sigma approach has frequently been used to understand where process improvements can be achieved. An element of the Lean Six Sigma method involves classifying each step in the workflow as value-added, business value-added, or non-value-added activities. Value-added time is defined as an activity that benefits the patient directly, business value-added time (i.e., business VAT) encompasses activities that are required but do not directly influence patient care (such as room cleaning), and non-value-added time is time spent on activities that are not necessary and add no benefit to the patient. A recent study showed that value-added time comprised only 38% of the entire patient stay for MRI examinations, with business value-added time accounting for 32% and non-value-added time accounting for 29% [3].

One aspect of MRI workflow that has been studied very little is turnaround time, which is defined as the interval between completion of the last sequence acquisition for one patient (patient A) and initiation of the first sequence acquisition for the next patient (patient B). In the past, when data acquisition times and room times (defined as the time the patient spends in the scanning room) were relatively long, turnaround time accounted for only a small percentage of the total workflow time and was relatively unimportant. Now that hardware and software advances have significantly decreased acquisition and room times, turnaround time accounts for a larger percentage of the total workflow time and is of increasing importance. Although we have not previously formally studied turnaround time and were unable to identify published studies documenting its typical length, the estimated turnaround time at our institution is approximately 10 minutes.

The construction of a new outpatient MRI center provided us with the opportunity to reengineer our MRI workflow. During this reengineering process, we concentrated on assessing steps that affected the turnaround time. Our hypothesis was that by redesigning all the steps in the process, including the architectural design of the center, we would be able to decrease the turnaround time by at least 5 minutes for patients undergoing MRI.

Materials and Methods

The present study was exempt from institutional review board approval because it was performed for the purposes of quality improvement.

In preparation for the construction of a new outpatient imaging center that would contain two MRI scanners (one 3-T scanner [Magnetom Vida, Siemens Healthcare] and one 1.5-T scanner [Magnetom Aera, Siemens Healthcare]), a process improvement team was assembled by the chair of the department of radiology at our institution. The committee consisted of all the different stakeholders involved in outpatient MRI workflow, including radiologists, MRI technologists, schedulers, front desk personnel, departmental administrators, members of the radiology and medical center information technology departments, and members of the medical center's real estate and development staff. This team met biweekly for several months to define the current outpatient MRI workflow and its limitations as well as to determine potential optimizations that could be implemented at the new outpatient center.

Elements that were discussed included the pros and cons of the use of dockable tables, whether or not to include dedicated MRI preparation rooms and what their optimal location would be, the number of doors needed for each MRI scanning room, the route and number of turns required to travel from the preparation rooms to the scanning rooms, the angle of placement of the MRI scanners in the scanning room, the storage location of coils, the need for duplicate coils for each machine, and the optimal number of technologists per machine. The changes that were chosen were then tested and optimized during several trial runs in the new imaging center, with rooms and tables blocked out until the team agreed on a final workflow.

After the center was constructed and a 2-month training period was completed, the median and mean turnaround times were measured for each scanner at the new center as well as for six scanners with differing magnets at two existing outpatient centers (two Magnetom Skyra 3-T scanners, one Magnetom Prisma 3-T scanner, one Magnetom Aera 1.5-T scanner, and two Magnetom Avanto 1.5-T scanners [all from Siemens Healthcare]), for the 4 months from March 1, 2018, to June 30, 2018. The imaging case mix at the new center was 56% body imaging, 31% neuroimaging, and 13% musculoskeletal imaging. For the six magnets at the existing centers, the case mix was 14% body imaging, 35% neuroimaging, and 51% musculoskeletal imaging. Turnaround time was defined as the interval between completion of the last sequence acquisition for one patient (patient A) and initiation of the first sequence acquisition for the next patient (patient B). Turnaround times were measured both for situations in which patient B was prepared and ready for scanning at the time that the last scan was finished for patient A (hereafter referred to as situations in which patients were ready for scanning) and for all situations, including those in which patient B was not ready when the last scan acquisition for patient A was finished. A patient was considered ready if the following factors were in place: coils were placed on the patient; the IV needle was inserted (if necessary); all examination instructions for the patient (breathing instructions, information on the importance of holding still, use of an emergency squeeze ball, and warning the patient about the loud noise of the machine) were relayed; and earplugs were inserted. The percentage of time that patient B was ready for scanning was calculated for each scanner used. The median and mean ($\pm$ SD) turnaround times and the 95% CIs were calculated. The *p* values were calculated using the Mann-Whitney test.

All time points were obtained directly from the scanner log files. To this end, a software tool has been developed that runs as background task on each MRI scanner and that automatically transmits the information about all executed sequences, including adjustment procedures, to a central server where the sequence timings are then aggregated into examinations and stored in a database for later analysis. Furthermore, the server application was connected to the department's scheduling system so that the time point captured when a patient in the preparation room was ready for scanning could be associated with time of entry of the examination in the database. The developed software tools are part of the open-source Yarra framework (Yarra Client version 0.52 / Yarra LogServer version 0.8, Center for Advanced Imaging Innovations and Research) for MRI systems.

Results

The elements affecting turnaround time that were optimized included the use of dockable tables, with two tables used for each scanner; the construction of one dedicated preparation room adjacent to each MRI scanner; the presence of two doors in each MRI scanning room, with one door directly connected to the preparation room (Fig. 1); the angle of placement of the MRI scanner in the scanning room that allowed the most direct path from the preparation room to the scanner and the least amount of acute angulation; and coils availability in the preparation rooms, with duplication of the two most frequently used coils (head and neck coils and body coils). The presence of two doors in each scanning room allowed one door to be used for taking a patient out of the scanning room and the other door to be used for bringing a patient into the scanning room. This allowed separate pathways for each patient, ensuring patient privacy. No difference was noted regarding the number of technologists, because both the new and the old centers had teams of two technologists per scanner, with an additional technologist serving as an expeditor to bring patients to the preparation rooms before scanning and to escort the patients back to the dressing room after scanning. The additional costs for the two dockable tables and duplicated coils were \$330,000 for the 1.5-T scanner and \$410,000 for the 3-T scanner, according to the manufacturer's list prices.

For patients assessed with the two scanners at the new center, the median and mean turnaround times in situations in which patients were ready to undergo scanning ($n = 1800$) were 115 seconds (95% CI, 113–117 seconds) and 132 ± 72 seconds (95% CI, 129–135 seconds), respectively. For patients who were evaluated using the six existing scanners at our center ($n = 3665$), the median and mean turnaround times for situations in which patients were ready to undergo scanning were 430 seconds (95% CI, 424–434 seconds) and 460 ± 156 seconds (95% CI, 455–465 seconds), respectively ($p < 0.0001$). The median and mean turnaround time for situations including all patients assessed at the new center ($n = 2890$) were 141 seconds (95% CI, 137–146 seconds) and 272 ± 270 seconds (95% CI, 263–282 seconds), respectively. For patients evaluated using the existing scanners at our institution ($n = 6331$ patients), the median and mean turnaround times for situations including all patients assessed were 481 seconds (95% CI, 474–486 seconds) and 537 ± 219 seconds (95% CI, 532–543 seconds), respectively ($p < 0.0001$). A total of 62% of patients at the new center and 58% of patients at the existing centers were ready to undergo scanning when the prior patient's examination was finished.

Discussion

Studies have shown that there is significant room for removal of inefficiencies in time and processes in MRI workflow because the value-added time comprised only 38% of the total patient experience for MRI examinations [3]. The mean turnaround time when patients are ready to undergo scanning at our institution, excluding our new imaging center, is 7 minutes 40 seconds. For room times with a duration of 25 minutes, this accounts for approximately one-third of the entire time the patient spends in the scanning room, and if room times are decreased to 15 minutes, it would account for approximately 50% of the time the patient spends in the scanning room. Decreasing turnaround times would allow an increased number of available examination time slots per day per machine. This would increase the value of MRI by increasing the availability of MRI for patients, increasing the productivity of each MRI scanner and the MRI technical teams, decreasing the time patients need to be in the MRI department, and providing increased revenue for the MRI department. For example, if a center schedules each examination to last for 45 minutes and is open 15 hours per day, a mean of 20 examinations can be performed each day. If 5 minutes could be saved per examination, an additional two examinations could be performed per scanner per day. At our center, which has two scanners, if the mean MRI reimbursement is \$500 per examination, the additional revenue would equal \$2000 per day. Under the assumption that the center is open 250 days per year (weekdays only and not on holidays), this revenue translates into \$500,000 per year. If the center is open 355 days per year (all days except holidays), the increased revenue would equal \$710,000 per year.

The opening of a new MRI center provided our department with the opportunity to optimize our MRI turnaround workflow to achieve 5 minutes of time savings. The primary change in our workflow involved the decision to use two dockable tables for each scanner, have dedicated preparation rooms, and ensure that coils, some of which were duplicated, are available in the preparation room. Collectively, these changes allowed the following steps in the turnaround time workflow to take place without affecting or increasing turnaround time: positioning patients and making them comfortable on the table, applying and positioning coils, and having patients insert earplugs. They also eliminated the time required to walk a patient into the room, which can be time consuming for ill or elderly patients, and the time spent having a patient sit up after the scan and then walk out of the room. In addition, no time was required to clean the table between patients. With use of the new optimized workflow, the only time required between patients was the time needed to undock the table, wheel the patient out of the room through one door, and wheel the next patient into the room through the second door and then dock the table. Although no patient surveys were used as part of this study, these optimization steps have the potential to improve patient satisfaction. The presence of a dedicated preparation room allows the patient to be prepared for scanning without being rushed and also provides a private setting in which the technologist may explain the examination to the patient. In addition, it allows the patient to dismount the table after the examination without any need to rush so that the next patient can mount the table.

When the new and existing centers were compared, the difference in the mean turnaround time for patients who were ready was 328 seconds, which is greater than the goal of 5 minutes of time saved. For all patients, including those who were not ready when the prior

patient's examination was finished, the improvement in the mean turnaround time was slightly less (265 seconds). Of interest, the difference in median turnaround times for all patients was 340 seconds, indicating that when patients were not ready, several long delays occurred that led to a significant difference between the mean and median turnaround time.

An increased cost was associated with our new workflow. The manufacturer's list price for the two dockable tables and coils that needed to be duplicated was \$330,000 for the 1.5-T scanner and \$410,000 for the 3-T scanner. It is important to note, however, that the actual cost was less than list price, because it is standard to receive substantial discounts with the purchase of MRI hardware. An increased cost was also associated with the construction of the MRI preparation rooms. It was impossible to calculate this increased cost during our construction because we did not accept bids for construction of the center without the preparation rooms. However, with a projected increase in revenue of at least \$500,000 for the center per year, we believe that a return on investment would occur within 1–2 years.

Simply decreasing turnaround time does not ensure realizing the projected increase in revenue. It requires revision of the MRI schedule to decrease the time scheduled for each examination, thus allowing an increase in the total number of examination slots. At our oldest centers, examination times are 30, 45, or 60 minutes, depending on the type of examination performed. At our new center, we have 30-minute examination times only, although we do use two time slots for certain examinations, such as MR enterography and MRI of the prostate. These double examinations currently comprise approximately 10% of our examination time slots, slightly decreasing the potential increased revenue.

A more difficult issue that can limit the advantage of the new MRI workflow is ensuring that a patient is ready when the prior patient's examination is finished. A total of 38% of patients at our new imaging center were not ready on time, which was not significantly different from the finding at our existing centers that 42% of patients were not ready. The major causes of patients not being ready included patients arriving late or not showing up for their examination. Although this does not limit the potential for increased revenue, it can affect patient satisfaction by decreasing on-time performance and extending the patient's stay at the imaging center. We are currently studying methods to improve the readiness of patients, including asking patients to arrive earlier than their scheduled examination time, deploying patient aides to help patients through their registration process, and having patients complete safety questionnaires electronically before arriving for their examination.

In summary, we have developed a new MRI turnaround workflow to eliminate non–value-added time. Our new workflow includes the use of dockable tables, dedicated MRI preparation rooms, and duplication of commonly used coils. The new workflow allows a mean time savings of 5 minutes 28 seconds per patient. This time savings improves the value of MRI by increasing the availability of MRI for patients, decreasing the time that patients spend in the MRI department and increasing potential revenue for the MRI department.

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Fig. 1—.
Architectural drawing of relationship of preparation room to MRI scanning room and angulation of scanner within scanning room. EQUIP = equipment, RM = room, PREP = preparation. (Used with permission from NYU School of Medicine)