Redefining the sonography workflow through the application of a departmental computerized workflow management system

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A B S T R A C T

Purpose: The purpose of this study is to demonstrate and evaluate the effective application of a computerized workflow management system (WMS) into sonography workflow in order to reduce patient exam waiting time, number of waiting patients, sonographer stress level, and to improve patient satisfaction.

Methods: A computerized WMS was built with seamless integration of an automated patient sorting algorithm, a real-time monitoring system, exam schedules fine-tuning, a tele-imaging support system, and a digital signage broadcasting system of patient education programs. The computerized WMS was designed to facilitate problem-solving through continuous customization and flexible adjustment capability. Its effects on operations, staff stress, and patient satisfaction were studied.

Results: After implementation of the computerized WMS, there is a significant decrease in patient exam waiting time and sonographer stress level, significant increase in patient satisfaction regarding exam waiting time and the number of examined patients, and marked decrease in the number of waiting patients at different time points in a day.

Conclusion: Through multidisciplinary teamwork, the computerized WMS provides a simple and effective approach that can overcome jammed exams associated problems, increase patient satisfaction level, and decrease staff workload stress under limited resources, eventually creating a win–win situation for both the patients and radiology personnel.

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1. Introduction

1.1. Background

Radiology, which plays a more important role in today’s ever-changing medical era, has experienced the explosive growth in volume and variety of available services during the past 2 decades [1,2]. In order to solve the challenging issues of shrinking budgets, increasing cost pressure, manpower shortage, and growing demands to increase both the efficiency and quality of services under resource-limited health facilities [3–5], a simple and effective method is needed [6]. Workflow
re-engineering, that can lead to process streamlining and simplification, is inevitably a solution [7].

A radiology department is responsible for routine examinations that are frequently performed with high volume, and approximately 80% of these exams are highly structured, which are suitable targets to apply workflow management principles [8]. To keep a radiology department running smoothly and efficiently, a department must keep information flowing between working nodes and use information technology as a tool to implement checks, defaults, and automation to harvest potential benefit of simplification and standardization [6,9]. Therefore, introducing IT into the radiology departmental workflow management becomes the appropriate solution since it can target toward workflow deficiencies and enhance departmental operation in different aspects to improve quality and reduce errors [10]. IT integrated workflow management approach allows for dynamic adaptation to react quickly to the ever-changing needs in today’s radiology ecosystem. Exam process automation improves the efficiency and effectiveness of radiology services with reduced costs and faster response times from staff, especially faster report delivery to affect medical judgments in time. Such real-time radiology can benefit the patients by avoiding unnecessary waiting time from the hindrance between intramural or interdisciplinary communication. With free and accurate exchange of information available through IT means, various data and parameters can also be collected to evaluate departmental performance and identify potential defective design for further improvement [6,8,10–12].

1.2. Local problem

Our radiology department provides more than 45,000 sonography exams per year, and the sonography service volume had been increasing without the corresponding increase in the number of sonographer over the past few years (Table 1). In addition, sonography had the lowest patient satisfaction due to lengthy exam waiting time according to the annual anonymous questionnaire surveys conducted in our radiology department over the last 3 years. In order to improve the quality of service, previous workflow (Fig. 1) was scrutinized, and the following three workflow defects were identified:

1. The previous manual workflow (Fig. 1), including the sequence of initial service registration at the front desk, time scheduling, and exam room assignment, was tedious and time-consuming [13]. It was solely dependent on the experience of individual staff member, causing the process to be unreliable and prone to human errors. For instance, breast sonography may be assigned erroneously to male sonographers, or critical patients could not receive prompt exams as needed.

2. Much more patients were waiting than needed due to a crude manual exam scheduling, i.e., asking all patients to report to the front desk at two fixed time points in a day (10 am and 3 pm) and wait until the exam. The patients had to wait longer, and the sonographers were stressed out from the numerous patients waiting outside the exam rooms or interrupting the ongoing exams. Quarrels and disputes between our staff and patients often ensued.

3. There was no means to monitor the execution status of each exam room so that immediate problem detection was not possible.

![Table 1 – Service volume and number of sonographers from 2007 to 2009.](image)

<table>
<thead>
<tr>
<th>Year</th>
<th>Sonography service volume (exams performed)</th>
<th>Number of sonographers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>45,732</td>
<td>5</td>
</tr>
<tr>
<td>2008</td>
<td>49,100</td>
<td>5</td>
</tr>
<tr>
<td>2009</td>
<td>50,133</td>
<td>5</td>
</tr>
</tbody>
</table>

![Fig. 1 – Manual workflow before the computerized workflow management system.](image)
Thus, in order to solve all these problems as a whole with improved efficiency and equal quality of sonography services, applying IT solutions into workflow management system (WMS) became the mandate and logical strategy for this difficult situation.

The purpose of this study is to demonstrate and evaluate the effective application of a computerized WMS into sonography workflow in order to reduce patient exam waiting time, number of waiting patients, sonographer stress level, and to improve patient satisfaction.

2. Materials and methods

2.1. Development environment

The development environment is a radiology department with 29 full-time-equivalent radiologists and 5 sonographers performing more than 45,000 sonography exams annually in a tertiary care public hospital with 1413 beds.
2.2. **Infrastructure of the computerized WMS**

We built a computerized WMS (Fig. 2) to transform the manual workflow since October 2009 with a collaborative team composed of radiologists, IT specialists, and radiographers. The rationale to redesign our workflow management system was to target and overcome the three deficiencies from our previous manual workflow with IT integration. The new WMS consisted of an automated patient sorting algorithm, a digital signage broadcasting system of patient education programs, a real-time monitoring system, exam schedules fine-tuning, and a tele-imaging support system.

The automated patient sorting algorithm, the digital signage broadcasting system, and the real-time monitoring system were developed in Microsoft.net 3.5 framework using Visual studio 2008 as integrated desktop environment to yield all necessary ASP code-based webpages. To avoid further workload on the database farm of our existing radiology information system (RIS)–PACS web-based platform, Microsoft SQL 2008 was chosen for a repository of the new WMS to operate as a parallelizing yet stand-alone system. The exam schedule fine-tuning was designed under our hospital’s mainframe-based hospital information system, which was an interactive computer system from IBM's Patient Care System. The tele-imaging support system used commercialized broadcasting and recording devices from DistanceDoc (Mediphan, Canada) with webpage access capability. For users, except for the exam schedule fine-tuning, the computerized WMS ran within the window frame of the web browser and on the same webpage that displayed RIS information.

2.2.1 **Automated patient sorting algorithm**

An automated patient sorting algorithm (Fig. 3) was devised to assign waiting patients to the proper sonography exam room based on the exam priority, exam type, and gender. Under this algorithm, critical patients were automatically identified and ranked highest in priority, who would then receive the examination as soon as possible, while other waiting patients of that exam room would be notified of this emergent exam from the digital signage system. Then, patients scheduled for a gender-specific exam would be assigned to the appropriate exam room. Finally, the remaining patients were evenly distributed among the available sonographers.

2.2.2 **Digital signage broadcasting system of patient education programs**

Digital signage broadcasting system enhanced patient education through video programs played via electronic displays. The video programs were customized individually among the different exam rooms according to the ongoing exam types and provided all the need-to-knows to the viewers, especially safety-related. The patients could enjoy the education programs tailored for each specific exam while waiting. If there was a critical patient requiring immediate examination, news flash messages would be displayed, acting as an adjunctive role of the automated patient sorting algorithm.

2.2.3 **Real-time monitoring system**

This monitoring system (Fig. 4) provided the real-time status of each exam room via a floor plan demonstration, including the who (number of waiting patients and current patient number), when (exam waiting time represented by three different colors: green indicating a waiting time of less than 20 min, yellow indicating a waiting time of 20–30 min, and red indicating a waiting time of more than 30 min), where (exam room number), and what (type of exam). This information was available to everyone. Our staff could access detailed exam patients information instantly from a webpage through hyperlinks (Fig. 4) while the patients could see basic exam room status via the digital signage system. Such system enabled our staff to be able to detect and hence solve any problem instantly.

2.2.4 **Exam schedule fine-tuning**

The sonography exam scheduling of our department prior to October 2009 was done manually with patients being scheduled in a crude fashion, i.e., asking all patients to report to the front desk at two fixed time points in a day (10 am and 3 pm), which resulted in a longer exam waiting time. To resolve this issue, monthly intramural meetings were held to discuss over fine-tuning sonography exam schedules by analyzing the data from the month before. After several months of discussion and analysis, a 15-min interval time slot per exam turned out to be the reasonable length of time to allocate each exam appointment, thereby spreading out the exams evenly throughout the working hours and preventing potential jamming situations. Furthermore, the fine-tuned scheduling system was integrated into the hospital information system, so that the clinical doctors could make exam appointments more patient-friendly.

2.2.5 **Tele-imaging support system**

A broadcasting and recording device was installed onto each sonography machine, which broadcasted the real-time console images simultaneously onto any computer and be accessed via a webpage. The radiologists could check on the ongoing sonography exams without the need to walk into each exam room [14]. Solving problems encountered by the sonographers were achieved via mouse clicking and consultation phone calls. Through the use of mobile devices with internet access, such as smartphones or tablets, the radiologists were able to perform the same tasks anywhere outside the hospital. This system allows sonographers to quickly confirm on the exam images taken with the radiologists, especially when the radiologists were not readily available.

2.3. **Measurement of improvement**

Most of the complaints, dissatisfaction, and quarrels between the patients and staff originated from lengthy exams waiting. Therefore, exam waiting time, sonographer stress level, and patient satisfaction regarding exam waiting were measured.

*Exam waiting time*, defined as the difference in time between initial front desk registration and the moment a patient is called for examination, before and after implementing the computerized WMS was calculated from these two timestamps of each exam in the database [15].

Sonographer stress level was assessed through a visual analogue scale (VAS) before and after deploying the computerized WMS. This scale consisted of a 10 cm line drawn on a paper
Sonography exam orders

Critical patients

Scheduled patients

Male

Female

Male specific exam (TRUS†, testicular, penile sonography)

Gender-neutral exams

Female specific exam (breast sonography, age < 60‡)

The next sonographer available

Male sonographer

Evenly distributed among sonographers

Female sonographers

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†TRUS: transrectal ultrasound
‡Females under 60 years old are assigned to female sonographers to maintain a sexual harassment free workplace environment

Fig. 3 – Automated patient sorting algorithm.

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Mouse click

1. Green indicates a waiting time of less than 20 minutes
2. Yellow indicates a waiting time of 20 to 30 minutes
3. Red indicates a waiting time of more than 30 minutes

Fig. 4 – Miniature illustration of the real-time monitoring system interface. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)
that represented the stress levels to measure. The sonographer was informed that one end of the line represented the absence of the stress and the other symbolized the most intense stress the sonographer could imagine. The sonographer scored the intensity of stress level marking the point between both ends that more accurately represented the strength of the stress experienced. The result was quantified measuring the distance from zero to the point marked by the sonographer [16].


We were also interested if the computerized WMS would affect the total amount of examined patients before and after the intervention, so the number of examined patients per month was recorded from the database.

2.4 Data collection

From March 2009 to September 2009, the exam waiting time and the number of examined patients receiving sonography exams in the radiology department were recorded (n = 18,939). Stress levels (VAS) of all sonographers (n = 5) were also assessed every two months. Patient satisfaction regarding exam waiting was collected by distributing anonymous questionnaires (n = 120) over one month (April 2009).

After the computerized WMS was implemented since March 2010, the exam waiting time and the number of examined patients receiving sonography exams were recorded (n = 19,656) until September 2010. Stress levels (VAS) of all sonographers (n = 5) were assessed every two months. Patient satisfaction regarding exam waiting was collected by distributing anonymous questionnaires (n = 120) randomly over one month (April 2010).

From October 2009 to February 2010, the computerized WMS was still under construction and field testing, so the data during this period of time was excluded. No personal identifying information was collected (such as name or address) throughout the study.

2.5 Statistical analysis

Independent samples t-test was used to analyze the difference of exam waiting time; Paired samples t-test was used to analyze the difference of sonographer stress level and the number of examined patients; χ² test was used to analyze the difference of patient satisfaction regarding exam waiting before and after computerized WMS implementation. Interval variables were presented as mean ± standard deviation (or 5 and 95 percentile if data were skewed), while categorical variables were summarized as frequencies and percentages. A p value less than 0.05 was considered to indicate significant differences. The data were analyzed with SPSS software (v:19.0).

3. Results

3.1. Decrease in exam waiting time

The sonography exam waiting time of 18,939 patients during March 2009 to September 2009 (30.50 ± 20.40 min, 5th percentile = 7.17 min, 95th percentile = 65.22 min) had decreased significantly (t = 54.25; 95% confidence intervals of difference = 9.82–10.55 min; p < 0.001) compared to the waiting time of 19,656 patients during March 2010 to September 2010 (20.30 ± 16.17 min, 5th percentile = 0.88 min, 95th percentile = 47.90 min).

3.2. Decrease in sonographer stress level

The sonographer stress levels were assessed three times before and after the implementation of the computerized WMS. However, VAS from one sonographer was not included into our statistical analysis due to the retirement of one sonographer and the recruitment of another new staff. The sonographer stress level evaluated by VAS had decreased significantly from 7.46 ± 1.00 cm to 2.33 ± 0.68 cm (t = 7.44; 95% confidence intervals of difference = 2.94–7.34; p = 0.005; n = 4) after introducing the computerized WMS.

3.3. Increase in patient satisfaction regarding exam waiting time (Table 2)

Patient satisfaction regarding exam waiting time was significantly different (Pearson’s χ² = 47.73; p < 0.001) before and after the use of computerized WMS. The percentage of “satisfied” and “very satisfied” patients after the intervention has increased from 51.6% to 85.8%, indicating an increase in patient satisfaction.

3.4. Increase in the number of examined patients

The number of examined patients increased significantly from 2705.57 ± 211.03 persons to 2808.00 ± 227.12 persons per month (t = –6.64; 95% confidence intervals of difference = –140.19 to –64.67; p = 0.001) after introducing the computerized WMS.
3.5. **Decrease in the number of waiting patients at different time points in a day**

Fig. 5 illustrates the distribution change of sonography exam waiting patients over time from two same weekdays of different weeks chosen randomly before and after the application of computerized WMS. The number of waiting patients at the different time points in a day has markedly decreased.

4. **Discussion**

Our experience suggests that WMS modification with systems-level intervention through IT means, such as the one described, is a simple but feasible strategy for quality improvement in resource-limited settings. Our computerized WMS is proven to be beneficial from the hospital, medical personnel, and patient points of view. The total number of examined patients has increased significantly after the implementation of the computerized WMS. Furthermore, given the challenging logistics of applying a new WMS onto a pre-existing manual workflow, the total cost of our new WMS was approximately $80,000 US dollars, including every piece of hardware and software newly installed. In addition, it took only 5 months of preparation, installation, field testing, and staff training for our new WMS to be fully operational. From the hospital’s point of view, the overall cost (in time and money) was rather inexpensive while capable of increasing the total number of examined patients under limited budget and human resources.

Our computerized WMS not only decreases the exam waiting time, but also the number of waiting patients in a day is also decreased. From the patients’ points of view, the patient satisfaction regarding exam waiting has increased significantly because the patients do not need to wait as long and are able to anticipate when the exams will take place from the real-time monitoring system [20]. While the patients are waiting outside the exam room, they will be preoccupied and can learn from the digital signage education programs, which may help to ease the anxiety from the lack of understanding of the medical exam [21].

From the sonographers’ points of view, our computerized WMS offers several benefits. The interactive interface of our WMS uses the same web page that displays RIS information, which was easy to adapt to with relative ease in transition over a short period of time. The automated patient sorting algorithm saves the time of manually sorting patients into the suitable exam rooms. The real-time monitoring system allows the sonographers to understand the waiting status of the exam room compared to absolutely ignorant of the condition outside the exam room prior to the computerized WMS. Whenever there is an emergent examination, patient jam, or the need for second opinion from the radiologists, real-time monitoring system, and tele-imaging support system prompt problem detection and solving to take place. Fine-tuning exam schedule can prevent patient jam situation by evenly distributing patients across the day rather than gathering all the patients to wait at a certain time. All the aforementioned strategies contribute to relieve the sonographers stress level and subsequently maintain the quality of examination [22]. The streamlining of workflow through the application of the computerized WMS allows the sonographers and patients to be able to see the bigger picture and be in a better position in the working dynamics.

Our own PACS team, endeavoring to establish and maintain the RIS and PACS of our hospital over the last decade [23], is familiar with a radiology departmental workflow, from order placing, order filling, imaging acquisition, structured reporting, to all the intricate logistics behind an enterprise-wide imaging and reports distribution. Therefore, when we saw the need to fundamentally change the workflow of our department, we decided to create an original WMS with our...
The computerized WMS was made possible from the collaboration between radiologists, radiographers, and IT specialists that had worked closely along every step of infrastructure development. The WMS was tailored to our needs and was capable of continuous customization and flexible adjustment as we wish whenever a problem was encountered. The web-based design interface was most convenient and readily available to each member of the team, allowing timeless and boundless access to everyone. Numerous online meetings were held to exchange expertise and to communicate ideas, to ensure the smooth interaction between members of the entire team, to review and identify problems, to expand the scope of our service, and to maintain the proper functioning of the entire system. The computerized WMS ultimately enables a way to multidisciplinary teamwork and cooperation between staff of different fields and backgrounds to reach a common goal – to improve patient satisfaction and the quality of our service in the current environment of the healthcare complexity [6].

We believe technologies should empower the medical staff to benefit more patients, not to introduce more complexity resulting in further cost in time and money [24]. Our computerized WMS, although linear and not most innovative, provides a simple and effective approach toward a realistic problem encountered in everyday radiology departmental operation. The results from our study have proved the clinical significance of our method in quality improvement. It can be easily reproduced with relatively low IT and hardware requirement especially in relatively resource-poor environments. Moreover, this study used a thorough approach to evaluate the degree of quality improvement and effectiveness of the computerized WMS from the hospital, medical personnel, and patient points of view.

However, our study has a few limitations. First, the implementation of our computerized WMS was carried out at a single organization only and requires further studies to ensure successful reproducibility and smooth workflow streamlining in other healthcare institutes. Secondly, more frequent assessments of sonographer stress level assessment through VAS is needed to eliminate potential influences from particular patient behavior towards the sonographers because the sonographer stress levels were assessed only three times before and after the intervention. Thirdly, because there was no control group, we could not specifically eliminate the effects of unmeasured external environmental factors operating regionally and nationally that might have served as confounders. Lastly, analysis on the impacts of other outcome could also be considered in future researches, including cost-effectiveness analysis on revenue and expenditure, medical error reduction analysis, patient relationship improvement analysis, etc.

5. Conclusion

We report a computerized WMS with systems-level intervention via IT means, which is a simple but feasible strategy for quality improvement in resource-limited settings through continuous multidisciplinary teamwork and cooperation. The computerized WMS can overcome jammed exams associated problems, increase patient satisfaction level, and decrease staff workload stress under limited resources, eventually creating a win–win situation for both the patients and radiology personnel.

Summary points
What was already known on the topic?

- Radiology department is responsible for routine examinations that are frequently performed with high volume production, and approximately 80% of these examinations are highly structured, which is a suitable target to apply workflow management principles.
- Introducing information technology solutions into radiology workflow management are powerful strategies to enhance departmental operation through exam process automation to improve the efficiency and effectiveness of radiology services.

What this study added to our knowledge?

- Multidisciplinary teams and strategies are essential due to the complexity of healthcare system.
- Patient exam waiting time and sonographer stress level can be reduced with computerized workflow management approach.
- The number of examined patients increased after the transformation from manual workflow to computerized WMS.
- Patient satisfaction increase when the patients’ waiting time shortens and when they are able to anticipate when the exams will take place.
- Understanding the number of waiting patients and the current waiting status of all the patients outside the exam room help to decrease sonographers’ stress level.

Authors’ contributions

Study concepts was given by Tsung-Lung Yang, Wei-JuHn Chen, Ming-Feng Li. Study design was given by Tsung-Lung Yang, Ming-Feng Li. Data acquisition was done by Wei-JuHn Chen. Quality control of data and algorithms was given by Wei-JuHn Chen. Data analysis and interpretation was done by Ming-Feng Li, Jerry Tsai, Huey-Shyan Lin, Huay-Ben Pan. Statistical analysis was done by Ming-Feng Li, Huey-Shyan Lin. Manuscript was prepared by Ming-Feng Li, Jerry Tsai. Manuscript was edited by Ming-Feng Li, Jerry Tsai. Manuscript was reviewed by Tsung-Lung Yang, Huay-Ben Pan.

Conflict of interest

There are not any potential conflicts of interest including employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications and registrations by Ming-Feng Li et al.
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