Journal of Digital Imaging

Radiology Workstation Design for the Medical Intensive Care Unit

Adrian Moise and M. Stella Atkins

The "one-size-fits-all" approach for radiology workstation design is not good enough anymore. While most of the picture archiving and communication system (PACS) vendors are racing to add more features to the radiology workstation, there is little interest in addressing the specific needs of other hospital departments. Significant delays in the availability of radiology reports are often caused by the fact there is not enough Intensive Care Unit (ICU) volume to justify a full time radiologist. Consequently, the radiologist assigned to cover the ICU exams, most likely working from a different building, will read the ICU exams only at certain times, depending on the limitations for remote image availability. This paper addresses the main objectives in designing a digital radiology workstation for use in the medical ICU (MICU), requiring enhancements to current PACS systems. Our suggestions for PACS improvement follow the ICU digital workflow starting with the transfer of the images from the modality, continuing with the presentation of the radiology examination to different types of users (radiologists or ICU staff), up to the creation and distribution of the reports.

KEY WORDS: radiology workstation, PACS, ICU, image display

MEDICAL ICU DEPARTMENTS have a grouping of beds for patients requiring critical care that require intensive monitoring. Often patients only stay for a short time. Nonroutine (problem-specific) chest radiographs comprise 25% to 40%[1] of all ICU examinations. These radiographs require an extreme range of intensities to provide diagnostic information on all parts of the chest, the endovascular lines and drains. Magnetic resonance, computed tomography, or ultrasound is sometimes used to provide additional information on the status of a patient.

Intensive care unit physicians require more rapid access to images and radiology interpretations than physicians in most hospital settings. The ICU physicians are asked to make rapid decisions based on limited and usually incomplete information on patients who are strangers and for whom prior medical information is not available. This situation creates high risks for malpractice (third after obstetrics and operating room).[2] For acutely ill patients, the delay before the formal report becomes available is sometimes too long and may affect patient care. Therefore, in a traditional film environment, ICU staff must run to the Radiology Department to obtain a report indication, as it is rare for a radiologist to be present in the ICU. While this solution can be fast and complete, it offers little opportunity for improvement [1]. Leaving the ICU is inconvenient for the ICU members, who are generally busy with patient case.[3]

The introduction of Picture archiving and communication system (PACS) and the availability of a reading station in the ICU can reduce the delay in communication between the ICU physician and the radiologist. However, in the early stages of PACS implementation, film digitization was a major bottleneck in the prompt flow of radiological information to the ICU. Film digitization was both unreliable (19% of exams never digitized) and slow (62 minutes median time between exam acquisition and film digitization), contributing to a median time elapsed from exam completion until the

From the Medical Imaging Laboratory, School of Computing Science, Simon Fraser University; Society for Computer Applications in Radiology, Burnaby, British Columbia, Canada.

Correspondence to: Adrian Moise, Medical Imaging Laboratory, Simon Fraser University, 8888 University Drive, Burnaby, BC, Canada V5A 1S6; e-mail: {amoise}@cs.sfu.ca

Online publication 19 March 2002
doi:10.1007/s10278-002-5025-x

report dictation of 5 hours.[4] More recently, in environments where film digitization has been replaced by computed radiography (CR), significant improvement in the availability of images and reports has been achieved.

During the first phase of a PACS implementation[5] the median elapsed time from exam completion until interpretation by radiologist was 1.86 hours, while the median elapsed time from exam completion until report transcription was 3.43 hours Horii et al. reported that PACS shortened the time from request to image review by the ICU physician, from 1.35 hours to 0.93 hours.[6] Other reported benefits of the introduction of PACS include a reduced number of examinations per patient day (from 1.3 $\pm$ 0.60 to 1.09 $\pm$ 0.69), a reduced median elapsed time from exam completion until image review by ICU staff (from 2 hours 32 min to 1 hour 35 minutes), and a decreased time to clinical action (from 3 hours 21 minutes to 2 hours 6 minutes).[7]

Despite all these reported improvements in the report turnaround time, the delay from image acquisition until report transcription is still too long for the ICUs requirements. Consequently, running to the Radiology Department to get the interpretation on a critical examination is still the primary means by which ICU staff can get fast exam interpretation. We propose extensions to the PACS design that will lead to improved patient care. Our goal is to allow the ICU staff to remain within view of their patients, by providing direct and convenient access to radiology images and reports on a digital workstation within the ICU. This will require enhancements to the PACS workflow in both the radiology and the ICU departments.

FEATURES OF THE PACS WORKSTATION IN THE RADIOLOGY DEPARTMENT

The image review workstation should be tailored to the user's profile. For the radiologist, a special filtering mechanism of current unreported studies must be available to list the patients currently in the ICU. A priority mechanism in the PACS is required to allow "STAT" (urgent) examinations coming from the ICU to move ahead of routine examinations. If automatic loading of the next examination is implemented in PACS, the next study to be displayed will be selected in priority sequence. This feature requires tight integration with RIS/HIS and all imaging modalities.

A notification mechanism must inform the radiologist when a STAT exam is sent from the imaging modality into the PACS system. When such a notification arrives, the radiologist may choose to "park" (put on hold) the current examination and to load the ICU exam for reporting, or finish the current exam and read the newly arrived STAT exam next.

FEATURES OF THE PACS WORKSTATION IN THE ICU

The digital workflow should be improved with the use of contextual information specific to the ICU. The patients currently in the ICU ward should be listed by name or bed number. If tracking the patient's position in the ICU is not done automatically, bed initialization functions such as *Move*, *Clear*, and *Init* should be implemented.[8] When idle, the radiology workstation should display a *gestalt* of the current patient situation, such as a thumbnail image of the last examination for every patient. From this "emergency review" or "View all beds" mode[9] (a 4×5 layout of 256×256 pixel thumbnails), any patient can be selected by name or by the thumbnail for the corresponding bed number. For a "historical review" of the selected patient, ICU specific hanging protocols[10] should be used to minimize the time wasted in rearrangement of the images on the monitors and in unnecessary soft-copy manipulation of the images.[11] For example, the most recent examination should be displayed in real-size on the left monitor, and the last four priors should be displayed four up on the right screen in reverse chronological order (other authors suggest 6,[12] 8[6] and 16[8] "iconified" priors). A double-click with the mouse could be used on any of the prior images to switch its display back and forth between real size and the four-up layout. A "daily overview" mode, listing for comparison the two most recent exams for every patient, will be particularly useful at the beginning/end of shift rounds. The tools available for diagnosis will adapt to the utilization pattern[7] corresponding to the user's role (radiologist or ICU physician) and to the type of disease investigated[16] (information supplied by RIS/HIS).

The digital workstation should be flexible enough to deal with incorrect or incomplete patient demographic information. Image comparison should be possible under common situations such as misspelled names or multiple identification numbers for the same patient. A "smart live updates" notification mechanism should check for close matches of patient information of every new study against the list of patients currently in the ICU ward. This mechanism must inform the ICU staff when a new image or radiology report (either formal or "wet") is available. After the new information is examined, the notification may be turned off, depending on the user's role (nurse, resident, or faculty).

In some clinical environments, a money-saving strategy could allow the ICU physicians to perform the first interpretation of radiology examinations.[13] This is not a new trend, because ICU physicians often act as substitutes for other specialists (cardiologists, gastroenterologists, orthopedists, general surgeons). For better patient care, the radiologist should still be consulted on high-risk patients or on exams difficult to interpret. The workstation must detect the availability of reports for the current examination, either from the user's selection (the study was opened for review or for reporting) or by querying the RIS/HIS. The PACS should support *preliminary interpretation* from ICU physicians, which will be available when the radiologist dictates the final report.[14] A notification mechanism should be implemented to inform the ICU staff of the various discrepancy types (serious, moderate, or low risk).

Reliable and Fast—New Toolkit and User Interface

Reliability (up-time 99.999%) and speed—these are the most important objectives for the radiology workstation in the ICU. The use of two or four monitors is recommended to reduce the time for image review and interpretation as compared with single-monitor workstation.[15] The user interface presented should be tailored to the task facing the ICU staff, corresponding to the *image review mode* (radiology interpretation available) or *interpretation mode* (requires extra attention and possibly more advanced image manipulation tools). Whenever the study displayed has an associated radiology report (the image was already interpreted), a reduced, disease oriented[16] set of features for "*streamlined*"[17] "*heads-up*" reading should be presented to the user. Some tools, such as Window/Level (W/L) zoom and pan, should be "always on" through a dedicated mouse button or by using custom input hardware. Because of the wide variation in radiographic exposure, an automatic adjustment of brightness and contrast can significantly reduce the W/L manipulation required for study comparison.[18] CR display presets based on image processing optimized for specific findings and pathologies[19] could facilitate image comparison and standardize display across examination type. Other tools (grayscale invert, edge enhancement, magnifier glass) should be available on a toolbar and on a context-sensitive right-click context menu. Infrequently used tools should be "hidden," but available on user request or whenever the radiologist's interpretation is not available. The user interface should be adaptive, corresponding to such factors as the user's role: attending physician, fellow, resident, intern. Another criterion relevant for the user interface customization is the manipulation pattern associated with the type of study: for example, for Pediatric ICU, W/L and invert will be often used to detect the tips of the catheters or edges on pulmonary opacities, while for Neonatal ICU, zoom is used for detection of subtle tubes and automatic shuttering (removal of unexposed background[20]).

Automation of Most Routine Tasks

Productivity will be high when the interpretation time, user fatigue, and tool usage are reduced without a negative impact on the patient care. An ICU oriented hanging protocol should deal with the automatic loading of relevant priors, automatic image orientation,[21] and automatic shutter (especially for pediatric images). To encourage the use of image-processing tools by ICU personnel, a "return to original" and one level "undo" should be implemented and easily accessible.

Improve Availability and Use of Radiographic Reports

Interpretation of radiography by the nonradiologist physician has an impact on the accuracy of radiographic interpretation, so the PACS/workstation design should focus on the availability and use of radiographic reports. In a film-based environment, a *conversation* (in person or by phone) is the quickest and most common way of getting a radiographic report. The use of a digital dictation system is not as efficient because of delays before the formal reports become available. Sometimes the radiologists will provide "we read," either by faxing preliminary reports to the ICU or by attaching a note to the radiological examination.

In a digital environment, the availability of reports can be improved by providing PACS and workstation support for soft-copy preliminary reports in the form of audio voice clips attached to every reported examination. Whenever report dictation is done through voice recognition, automatic text string searches should be used for the detection of high-risk clinical problems[2] and also for the detection of "synopsis" for the radiographic findings. When ad hoc diagnosis entry or "canned reports" can be used, the transcription phase can be skipped entirely, thus greatly improving report turnaround times.

THIS IS THE QUESTION

Is it better to build one radiology workstation that works "OK" for many modalities (CT/MR, CR, Ultrasound, and Nuclear Medicine) and many classes of users (radiologists, ICU physicians, referring physicians, surgeons, and residents) or to build several digital viewers, each of which excels in only a specific environment?

An all-inclusive solution ("workhorse"[22] workstation) provides flexibility, power, and cost-saving benefits. Still, we think we must be able to peel away the unnecessary functionality from a multipurpose workstation, tailoring it to individual departments and user types. We propose a software metaphor inspired from operating systems design: Various "flavors" of workstation will share a common *kernel*; the extra functionality layers will be wrapped around the kernel to ensure custom-built specificity. Such bundled packages may include video teleradiology, DICOM viewing station, and full teleradiology;[23] among other features. This way several specialized devices can be efficiently built on the same skeleton, and each will evolve to its own best design.[24] The perfect solution will be a symbiosis of hardware and software that will do nothing that couldn't have been done before, except that is does it right.

FUTURE DIRECTIONS

Image distribution and simultaneous access to images represent major advantages of PACS, and they lay off the foundation for teleradiology and cooperative interpretation. Such features allow the ICU physician to remain within the ICU and still benefit from real-time consultation with a radiologist. The OSIRIS project used the HERMES protocol for master/slave synchronization of remote workstation.[25] Bellon et al. described a system based on Java's "Web PC" paradigm, which used applets for synchronization.[26] The importance of remote consultation with a specialist is acknowledged by the ongoing effort of the Digital Imaging and Communication in Medicine Workgroup 11 to standardize the *collaboration mode*.

Advances in teleradiology, coupled with technological advances for hardware portability and faster wireless transmission, will allow excellent report turnaround times. Desktop-replacement high-performance notebooks, with 1600×1200 pixel LCD screens, are now available and affordable. Mobile computing devices such as the IBM ThinkPad TransNote or the Tablet PC could help the radiologist to handwrite a wet report, and then send the digital notes to the ICU staff through a fast wireless connection.

ACKNOWLEDGMENTS

The authors are grateful to the Canada Natural and Engineering Research Council for funding this research.

REFERENCES

1. Shile PE, Kundel HL, Seshadri SB, et al: Factors affecting the electronic communication of radiological information to an intensive-care unit. Telemed Telecare 2:199-204,1996

2. Rucker DW, Johannes RS, Finley SW, et al: Designing an emergency medicine physician workstation to support risk management in decision making. Proc AMIA Annual Fall Symposium, 1996

3. Redfern R, Kundel H, Polansky M, et al: A picture archiving and communication system shortens delays in obtaining radiographic information in a medical intensive care unit. Crit Care Med 28:1006-1013, 2000

4. Shile E, Kundel L, Seshadri B, et al: Clinical demand for and access to images and interpretations of chest radiographs in a medical intensive care unit serviced by an integrated PACS-radiology information system. Proc SPIE 2165:467-471, 1994

5. Redfern R, Kundel H, Seshadri SB, et al: PACS workstation usage and patient outcome surrogate. Proc SPIE 3035:424-430,1997

6. Horii S, Kundel H, Redfern R, et al: PACS workstations in the emergency department: impact on workflow in radiology and emergency medicine. Proc SPIE 3980:196-203, 2000

7. Andriole PK, Storto ML, Gamsu G, et al: Impact and utilization studies of a PACS display in ICU setting. Proc SPIE 2711:286-289, 1996

8. Nahmias C, Kenyon DB, Tan L, et al: Design and implementation of an integrated PACS workstation in the ICU. Proc SPIE 3035:268-275, 1997

9. Bellon E, Feron M, Van den Bosch B, et al: PACS/HIS integration in handling and viewing ICU images generated by a phosphorplate scanner. Proc SPIE 2711:126-136, 1996

10. Strickland NH, Allison DJ: Default display arrangements of images on PACS monitors. Radiol 68:252-260, 1995

11. Moise A, Atkins MS: Workflow Oriented Hanging Protocols for Radiology Workstation. J Digit Imaging 15(Suppl 1), 2002

12. Strickland NH: PACS: filmless radiology, Arch Dis Child 83:82-86, 2000

13. Simon HK, Khan NS, Nordenberg DF, et al: Pediatric emergency physician interpretation of plain radiographs: is routine review by a radiologist necessary and cost effective? Ann Emerg Med 27:295-298, 1996

14. Siegel E, Groleau G, Reiner B, et al: Computerized follow-up of discrepancies in image interpretation between emergency and radiology departments. J Digit Imaging 3(suppl 1):l8-20, 1998

15. Reiner B, Siegel E, Hooper F, et al: Effect of screen monitor number on radiologist productivity in the interpretation of portable chest radiographs using a picture archiving and communication system., J Digit Imaging l0(suppl 1):175, 1997

16. Horii SC, Kundel HL, Shile P, et al: Intensive care unit referring physician usage of PACS workstation based on disease categories. Proc SPIE 2165:456-466, 1994

17. Horii S, Feingold E, Kundel H, et al: PACS workstation functions: usage differences between radiologists and MICU physicians. Proc SPIE 2711:266-271, 1996

18. Rottenberg GT, Chin RJS, Alien CM, et al: Portable chest radiology in intensive care: comparison of a new dual characteristic film-screen system (insight) incorporating a flexible grid with a standard film-screen system, Clin Radiol 51:494-498, 1996

19. Andriole KP, Gould RG, Webb R: Finding-specific display presets for computed radiography soft-copy reading. J. of Digit. Imaging 12 (suppl 1):3-5, 1999

20. Brill PW, Winchester P, Cahill P, et al: Computed radiography in neonatal and pediatric intensive care units: a comparison of 2.5 K $\times$ 2 K soft-copy images vs digital hard-copy film. Pediatr Radiol 26:333-336, 1996

21. Evanoff MG, McNeill KM: Automatically determining the orientation of chest images Proc SPIE 3035:299-307, 1997

22. Foord KD: PACS workstation respecification: display, dataflow, system integration, and environmental issues, derived from analysis of the Conquest Hospital pre-DICOM PACS experience. Eur Radiol 9:1161-1169, 1996

23. Engelmann U, Schroter A, Baur U, et al.: Design of the next generation teleradiology. Proc Euro PACS 97:121-124, 1997

24. Moise A, Atkins MS: New trends in radiology workstation design. J Digit Imaging 15(suppl 1), 2002

25. Welz R, Ligier Y, Ratib O: Design of a cooperative teleradiology system. Telemed J 1:195-201, 1995

26. Bellon E, Wauters J, et al: Using WWW and Java for image access and interactive viewing in an integrated PACS. Med Inform 22:291-300, 1997