Does Use of a PACS Increase the Number of Images Per Study? A Case Study in Ultrasound

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The purpose of this study was to determine if the use of a picture archiving and communications system (PACS) in ultrasonography increased the number of images acquired per examination. The hypothesis that such an increase does occur was based on anecdotal information; this study sought to test the hypothesis. A random sample of all ultrasound examination types was drawn from the period 1998 through 1999. The ultrasound PACS in use (ACCESS; Kodak Health Information Systems, Dallas, TX) records the number of grayscale and color images saved as part of each study. Each examination in the sample was checked in the ultrasound PACS database, and the number of grayscale and color images was recorded. The comparison film-based sample was drawn from the period 1994 through 1995. The number of examinations of each type selected was based on the overall statistics of the section; that is, the sample was designed to represent the approximate frequency with which the various examination types are done. For film-based image counts, the jackets were retrieved, and the number of grayscale and color images were counted. The number of images obtained per examination (for most examinations) in ultrasound increased with PACS use. This was more evident with some examination types (eg, pelvis). This result, however, has to be examined for possible systematic biases because ultrasound practice has changed over the time since the authors stopped using film routinely. The use of PACS in ultrasonography was not associated with an increase in the number of images per examination based solely on the use of PACS, with the exception of neonatal head studies. Increases in the number of images per study was otherwise associated with examinations for which changes in protocols resulted in the increased image counts.

KEY WORDS: PACS, ultrasound, workflow, archiving

THE ULTRASOUND SECTION of the Department of Radiology of University of Pennsylvania Medical Center (UPMC) provides diagnostic ultrasound examinations for inpa-

tients and outpatients. Exceptions to examination types performed are breast and carotid studies. The patient population is chiefly adult because the Children's Hospital of Philadelphia is immediately adjacent to UPMC and serves the pediatric population. UPMC does have a neonatal intensive care unit, so the Ultrasound Section performs examinations in that unit. In addition to the section in UPMC, the department also provides faculty for the Ultrasound Section at Presbyterian Hospital, a UPMC affiliate approximately 1.5 km from UPMC. The Ultrasound Section at UPMC performs approximately 17,000 examinations per year with an additional 5,000 examinations at Presbyterian. The section staff consists of 11 technologists, an aide, and 9 radiologists (some of whom cover clinical areas in addition to ultrasound). Three radiologists of the group have primary responsibility at Presbyterian Hospital, but all staff rotate through both facilities.

In the Section at UPMC, the Department has 8 ultrasound machines with a ninth machine used for portables. There are 4 Phillips/ATL Ultramark 9 HDI, 2 HDI 3000 systems, and 2 HDI 5000 machines (Phillips/ATL; Bothell, WA). Portable studies are done with one of the ATL HDI 3000 machines. The Section also has

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a General Electric Logiq 700 (General Electric Medical Systems; Milwaukee, WI) machine in the Emergency Department (ED) that is dedicated to doing ED examinations. A Medison VoluSon (Kretztechnik, Austria) machine used for three-dimensional ultrasound rounds out the department machine complement. At Presbyterian Hospital, the Section has an ATL HDI 5000 and an HDI 3000.

The core of the ultrasound PACS is a Kodak (Kodak Health Imaging Systems, Dallas, TX) ultrasound image management system. This system is no longer manufactured by Kodak; however, it is still in full operation at UPMC and Presbyterian Hospital. The system consists of a DICOM-conformant network (IEEE 802.3; 100BaseT), 6 Model 100 workstations, 9 cine loop-capable image acquisition modules (ACCESS acquisition modules; ANFS), a file server/database (ACCESS Network File Server; TANES), and a Hewlett-Packard 144-platter magneto-optical disk jukebox. Also connected to the network are a Kodak 2180 laser imager with processor and Printer Interface Unit (Kodak Health Imaging Systems, Dallas, TX), and a Codonics color paper printer (Codonics Inc, Middleburg Heights, OH). The ATL HDI 5000 machines at UPMC and the Medison VoluSon have direct connections to the PACS network via built-in DICOM interfaces. An earlier report¹ describes some of the history and development of the system and film cost savings resulting from its use.

In previous work,² the investigators described the time savings for technologists based on eliminating the handling of film. The background for the hypothesis of this study, that picture archiving communications system (PACS) use in itself might increase the number of images per examination, was based on the much-reduced labor associated with recording images. Instead of having to remove and exchange film cassettes during the examination, both the move to laser-printed film and PACS eliminated the task. However, centralized laser printing did not eliminate the task of the technologist having to go to the printer to pick up the films. Use of the PACS eliminated this additional task. In effect, acquiring images when using PACS required much less effort for the technologist. This led to the speculation that the

technologists might, therefore, take more images per case. The ready applicability of PACS to ultrasonography also has been well documented by Choplin et al,³ Wolfman et al,⁴ and Mattheus et al⁵ in the early 1990s.

MATERIALS AND METHODS

As part of a study of activity-based costing done in the ultrasound section, detailed information about the cost of all aspects of performing an examination were accumulated. Among these were a set of data about the number of sheets of film (multiformat camera and laser printed) and number of color prints made per examination. The section had standardized on the number of images per sheet of film and paper (6 on 1 for multiformat films, 15 on 1 for laser-printed film, and 6 on 1 for paper color prints). These data were stratified by the type of examination performed and were accumulated prospectively during the 1994 through 1995 period. The ultrasound PACS was installed in late 1995, but was only interfaced to 3 machines at the time. By November 1996, the system was connected to all but one machine, and the section decided to reduce film usage. At first, a single sheet of film was printed per case, but the studies were read from the workstations. Shortly thereafter (December 1996), the system had proven reliable enough to discontinue printing film. On moving from a temporary location (necessitated by Departmental construction) to a new area in the department, the laser printer that had been dedicated to ultrasonography was dropped from the installation plan. Since December 1996, the ultrasound section has been "filmless" for diagnosis. Films still are printed for patients referred to outside institutions, for medicolegal reasons, and for some teaching conferences.

The data on the number of films per examination from the cost study were used as the film "baseline." For the PACS images, the system database keeps a count of the number of black and white and color images in each examination. To obtain a sample of examinations for the PACS part of the study, examinations were selected at random from section log books. To obtain a sample that reflected the practice of the section, however, there were approximate target numbers for each of 12 examination types that corresponded to those of the film baseline. PACS data were accumulated retrospectively for the 1998 through 1999 period. This period was chosen because it was after the system had been in full use for a year, reducing the "learning curve" bias. Also, the system had been very stable and reliable over this period, so the technologists and radiologists had few concerns about images being "lost."

The film data consisted of lists of the number of sheets of film (8- × 10-inch multiformat and 14- × 17-inch laser print) and color paper used per examination. To translate these into numbers of images, the number of sheets of each type of medium was multiplied by the number of images usually recorded per sheet. By the time the data were accumulated, the printing formats were standardized within the section. The potential error introduced by this method (from partially exposed sheets of film or paper) is discussed subsequently.

Table 1. Number of Images Per Examination Type for Film and PACS Periods

Examination	Nfilm	NPACS	Total images		B&W images		Color images	
			Film	PACS	Film	PACS	Film	PACS
Abdomen, complete	43	21	40.3 (11.3)	41.0 (10.5)	39.6 (11.1)	37.0 (9.2)	0.7* (2.3)	4.0* (3.8)
Pelvis, transabdominal	46	20	24.0* (11.1)	36.4* (16.2)	24.0* (11.1)	33.1* (16.4)		3.3* (2.5)
Scrotal/testicular	42	13	51.9 (18.1)	47.2 (12.1)	41.1 (13.9)	37.1 (8.5)	10.9 (11.7)	10.1 (5.7)
Retroperitoneal, complete	48	22	39.0 (10.9)	39.0 (10.8)	39.0 (10.9)	37.2 (10.5)		1.8* (2.2)
Ultrasound-guided needle biopsy	21	3	13.6 (4.4)	12.3 (13.9)	13.6 (4.4)	10.7 (11.6)		1.7 (2.4)
Neonatal head	36	6	32.5* (6.6)	49.0* (8.3)	32.5* (6.6)	48.8* (8.4)		0.2* (0.4)
Pelvis, transvaginal	40	25	24.9* (9.1)	35.2* (11.6)	23.1* (8.2)	31.4* (11.1)	1.9* (3.9)	3.7* (2.4)
Thyroid	41	11	36.4 (11.6)	36.5 (11.8)	33.0 (10.6)	32.4 (10.3)	3.4 (4.8)	4.1 (2.9)
Obstetric, complete	134	32	42.9 (16.4)	46.5 (19.8)	39.6 (16.1)	45.8 (19.1)	3.2* (3.5)	0.7* (1.8)
Abdomen, limited	20	9	27.0 (7.6)	26.3 (14.8)	27.0 (7.7)	23.1 (13.7)		3.2* (3.9)
Extremity veins	19	11	44.9 (18.0)	34.2 (15.3)	23.7 (12.2)	17.3 (12.8)	21.2 (13.3)	16.9 (12.8)
Abdominal vessels	33	2	40.1 (15.5)	40.5 (8.5)	26.4 (10.3)	29.5 (5.5)	13.7 (11.5)	11.0 (3.0)
Totals	523	175	38.9 (16.9)	39.2 (15.7)	33.1 (14.2)	35.0 (15.7)	5.8* (9.1)	4.1* (5.5)

Note values are shown as mean $\pm$ (SD).

*Values are significantly different (2-tailed *t* test, unequal variances and sample sizes).

The film baseline data consisted of 523 examinations distributed over 12 examination types. PACS data incorporated 175 examinations in the same type categories. Although the distribution of examinations selected per examination type approximately represented the examination frequency done in the section, this was not exact, particularly for the film data (the purpose of those data was originally cost identification, so the goal was to have as many examinations in each type as possible).

RESULTS

The data are summarized in Table 1. A simpler representation is shown in the following figures. Figure 1 shows the mean number of images per examination, total (black and white plus color) for all examination types and all examinations overall (last column). Figure 2 shows the mean number of black and white images per examination and Fig 3 plots the same for the mean number of color images per examination.

Note that, averaged over all examination types, the mean number of images per examination is per not significantly different between the film period (38.9 images per exam) and the PACS period (39.2 images per exam). Some

examination types, however, did show significantly different numbers of images between film use and PACS operation. Testing of differences between means was done using the 2-tailed *t* test for unequal sample sizes and assuming unequal variances. A probability of $\leq .05$ for chance differences accounting for the results was used as the limit for rejecting the null hypothesis.

For the complete abdominal examination, the number of color images was significantly higher for PACS ($P < .01$). For transabdominal pelvic studies, all numbers of images were significantly different with the larger number from the PACS examinations (total images, $P < .001$ black and white images, $P < .001$ color images, $P < .001$). The complete retroperitoneal examination had a significantly ($P < .001$) higher number of color images during the PACS period. Neonatal head ultrasound scan was another examination type for which the PACS period showed a significantly larger number of total, black and white, and color images ($P < .001$, $P < .005$, $P < .001$, respectively). The same is true of the transvaginal

Fig 1. A plot of the total number of images per examination type for film (gray bars) and PACS (black bars).

pelvic study ($P < .001$, $P < .001$, $P < .05$ for total, black and white, and color images, respectively). Color images had a significant difference between the film and PACS periods for obstetric and limited abdominal images, although in the case of the obstetric studies, the number of color images was significantly less ($P < .001$) during the PACS period. The limited abdominal study showed the reverse; more color images during the PACS period ($P < .001$).

Over all examinations, although the total number of images and the number of black and white images were not significantly different between the 2 study periods, the number of color images was significantly larger for the film-based period ($P < .025$).

For all examination types that had significant differences in numbers of images between the 2 periods, the authors reviewed the protocols for updates and changes.

DISCUSSION

The lack of an overall difference in the number of images per examination between the

film and PACS periods argues against the hypothesis that more images are acquired in an ultrasound PACS environment. However, as noted in the Results section, some examination types did have significantly different numbers of images between the 2 periods. Further examination of changes in protocol (and in some cases, hardware) may account for these differences.

The increased number of color images (from a mean of 0.7 for film to 4 for PACS) included in the abdominal examination is explained readily by the increased use of color flow Doppler in abdominal imaging studies. This is true for both the complete and limited abdominal examination types. The ready availability of color flow Doppler makes it simple for the technologists to survey the liver vasculature as part of the examination. In fact, the mean number of color images for PACS could be accounted for by the 4 color images more frequently obtained (the 3 hepatic veins plus the main portal vein) since the section made the transition away from film. The same argument can be used to explain the increased number of color images in the retroperitoneal examination. A single color flow Doppler im-

Fig 2. A plot of the number of black and white images per examination type for film (gray bars) and PACS (black bars).

age of each kidney can provide a qualitative assessment of the presence of arterial and venous blood flow.

Between the 2 study periods, the pelvic examination types (both transabdominal and transvaginal) had changes in protocol. A more detailed examination of the endometrium of the uterus (with measurements and a color flow Doppler study) and routine color flow Doppler assessment of ovarian blood flow were added to these examination types. Together, these protocol changes add 3 to 5 color images and 2 to 4 black and white images per examination. If the maximum of both color and black and white images are added, that nearly accounts for the difference in the total number of images per examination (24 and 24.9 images for the 2 film-based and 36.4 and 35.2 images for the PACS-based pelvic examination types). A review of a few PACS-based pelvic examinations selected at random showed that the trend was to include at least the maximum number of the images the examination protocols dictate.

Neonatal head studies showed a significant increase in the number of black and white images (and color, although a smaller overall

contribution to the difference) with 32.5 images during the film period and 49 for PACS. The authors believe that this may be one examination type for which the use of PACS has contributed directly to the increase in the number of images per examination. First, a study of the posterior fossa of the head was added to the protocol, but this typically adds 3 or 4 images per examination. The authors believe the larger difference has to do with the use of PACS making the technologist's work simpler. Almost all neonatal head studies are done on the patient floor ("portably") rather than in the section. During the film-based period, the technologist assigned to do portable studies had to take along a sufficient number of film cassettes to perform the examinations. Because performing portable studies means traveling to a number of different locations in the hospital, the technologists found it easier to take a stack of cassettes rather than returning to the Section after each examination. Because of this, they tended to restrict the number of images they took per examination to the minimum to avoid "running out" of cassettes. When this did happen, they either had to bring the stack back

Fig 3. A plot of the number of color images per examination type for film (gray bars) and PACS (black bars).

to the section or have the aide carry an unexposed set to them. Carrying a stack of up to 10 film cassettes on the ultrasound machine also was unwieldy, and the high turnover rate for cassettes was, in part, the result of having them fall off the machine during the transport process. With PACS implementation, both the frame grabbers and the machines with DICOM interfaces built in have a large capacity for storing images as a result of included hard disk drives. The current method for performing portables is to store the images on the frame grabber acquisition unit hard disk, and when the technologist returns to the section, the unit is connected to the PACS network, and the stored studies are transferred. With no cassettes to handle, the advantage of acquiring only the minimum number of images per study is obviated.

A decrease in the number of color images per examination for the obstetric examinations (from 3.2 to 0.7) from the film to PACS periods was at first puzzling. However, the authors believe that this difference is the result of hardware changes in the section. A common practice

for obstetric ultrasonography is to provide the patient with a picture of the fetus. During the film-based period most of the machines had dedicated color paper printers attached to them. Although they could be used for printing any images from the machine, the most common use was to print out the picture of the fetus and give it to the patient before she left. Typically, this involved printing a black and white image (or 4 to 6 images on one sheet) on one of these printers. The cost for this printing was the same whether black and white or color images were printed, so during the cost identification study, any print made on the color printers was counted as a color image. As these printers started to wear out, rather than continue repair and replace to them, the section believed it to be less expensive to add a high-quality paper printer to the printing network. This network had been installed before full PACS implementation.² With centralized printing, the Codonics printer on the network took over for the individual color printers. Prints from this printer also were considered color prints for purposes of cost identification during the film-

based period. However, with PACS implementation, a color image is not any image printed to the printer, but a color image stored in the system. Although the section still prints fetal pictures for the obstetric patients, they are almost always black and white, and for this study were counted as such despite being printed on a color printer. Note that for cost accounting purposes, this assumption would not be made; rather, because (as for our older color printers) the cost per print is the same whether black and white or color, any print made on the Codonics printer is charged as color print.

As mentioned in the Materials and Methods section, the method of determining the number of images per examination for the film-based period was to use the count of sheets of film and color paper and multiply by the number of images per sheet. Although there is some potential for overestimating the number of images in this way (for example, if a sheet of film is not fully exposed, it still would be counted as a sheet, and multiplying that by the typical number of images per sheet would give a falsely high value, the authors believe that this sort of error is minimal. The main reasons for this are that both the multifformat cameras, and later the centralized printing control panels, provided visual feedback to the technologist about the number of images recorded. The multifformat cameras were set to record 6 images per "sheet" of film; inserting an unexposed cassette into the camera resulted in the display on the camera being reset to 6 and would count down as images were taken. The centralized printing network had a control box on each machine that had a graphic display; it would show a schematic sheet of film and would change the state of the represented images as they were recorded. For the centralized printing system, it also was possible to erase an undesired frame. If a technologist was concentrating on the examination, she or he might take one "last" image and realize that it was a single frame on a whole sheet of film. Rather than either "waste" the rest of the sheet or add images to fill it, if the image was not critical, it could be deleted. As a result, very few sheets of film had fewer than the full number of images recorded on them.

CONCLUSION

With the addition of new ultrasound imaging techniques, including 3-dimensional, extended field of view, and the ability to capture full-motion sequences, ultrasonography is among the imaging subspecialties that is showing a trend toward an increased number of images per study [6]. Both multidetector computed tomography and magnetic resonance imaging now are producing examinations with several hundred to over a thousand images. However, the trend is not simply the result of it being simpler or more convenient to create these large image sets, but tends to be driven by clinical applications.

Although PACS may enable, or be necessary for, examinations with large numbers of images, the use of the PACS itself does not increase the number of images acquired per examination. This question is particularly relevant for ultrasonography (as it would be for digital fluoroscopy), because the technologist or radiologist has a choice over the number of images acquired during an examination. With the exception of neonatal head ultrasound scan the reduced workload that using the PACS provides did not result in technologists taking a significantly larger number of images. When numbers of images per examination increased, changes in protocol are believed to account for that increase.

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