Journal of Digital Imaging

Data Management Solution for Large-Volume Computed Tomography in an Existing Picture Archiving and Communication System (PACS)

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Multidetector row computed tomography (MDCT) creates massive amounts of data, which can overload a picture archiving and communication system (PACS). To solve this problem, we designed a new data storage and image interpretation system in an existing PACS. Two MDCT image datasets, a thick- and a thin-section dataset, and a single-detector CT thick-section dataset were reconstructed. The thin-section dataset was archived in existing PACS disk space reserved for temporary storage, and the system overwrote the source data to preserve available disk space. The thick-section datasets were archived permanently. Multiplanar reformation (MPR) images were reconstructed from the stored thin-section datasets on the PACS workstation. In regular interpretations by eight radiologists during the same week, the volume of images and the times taken for interpretation of thick-section images with (246 CT examinations) or without (170 CT examinations) thin-section images were recorded, and the diagnostic usefulness of the thin-section images was evaluated. Thin-section datasets and MPR images were used in 79% and 18% of cases, respectively. The radiologists' assessments of this system were useful, though the volume of images and times taken to archive, retrieve, and interpret thick-section images together with thin-section images were significantly greater than the times taken without thin-section images. The limitations were compensated for by the usefulness of thin-section images. This data storage and image interpretation system improves the storage and availability of the thin-section datasets of MDCT and can prevent overloading problems in an existing PACS for the moment.

KEY WORDS: CT, MDCT, PACS, computer applications

BACKGROUND

With the recent development and spread of multi-detector row computed tomography (MDCT), thin-section CT images have become readily available for interpretation. Many articles have stated that thin-section CT images could be useful in the detection, measurement, assessment, differentiation, preoperative evaluation, and follow-up of lesions.[1–8] However, the introduction of MDCT creates a glut of thin-section CT images[9,10] and severely overburdens the radiologists responsible for interpreting them in a picture archiving and communication system (PACS).[11] Although the selection of cases for which thin-section CT images are needed can prevent excessive increases of CT data, this selection process frequently presents difficulties before or during examinations. Furthermore, thin-section CT images are sometimes needed for interpretation after examinations. However, reconstruction of thin images is tedious to perform after examination and is impossible after the original data are erased from the CT unit. Therefore, in order

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This work has not been supported by any source of funding or financial interest.

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Online publication 12 November 2009

doi: 10.1007/s10278-009-9251-3

to facilitate the interpretation of thin-section images whenever needed, the thin-section images should be reconstructed and archived in all cases before interpretation. However, the existing PACS models are not equipped with a large amount of archiving space so that thin-section CT images cannot be obtained. Be that as it may, it is impossible to carry out unlimited expansion of a data storage system, even if the cost of storage media continues to drop. To cope with these problems, we designed an experimental CT data storage and image interpretation system for an existing PACS. This system was also evaluated for its convenience and diagnostic usefulness.

METHODS

With the renewal of our PACS (SYNAPSE 3.0 MR-001; Fujifilm, Tokyo, Japan) a year ago, we have designed and started to use an experimental data storage and image interpretation system for MDCT. With the introduction of this system, it is now possible to display the thick- and thin-section CT images side-by-side automatically and to page simultaneously showing the same slice level on the PACS workstation for all MDCT cases (Fig. 1). Furthermore, it has become possible to reconstruct multiplanar reformation (MPR) images from the stored thin-section datasets on the PACS workstation with a single click of an icon in the software (Obliquus; Fujifilm) already installed in the PACS. They were constructed on the fly during interpretation and interactive use.

Image Reconstruction Protocol of CT

The CT scanner used in this study was a 16-detector-row CT scanner (Aquilion; Toshiba Medical Systems, Tokyo, Japan) and a single-detector spiral CT (sonic scan; Hitachi, Tokyo, Japan). Parameters for the scanning of the MDCT were: 120 kVp, automatic exposure control (Real Exposure Control, Toshiba Medical Systems), 16×0.5-mm collimation, 0.5-s rotation time, 15 helical pitch, 30–35 cm field of view, 512×512 matrix size. Two image datasets of MDCT consisting of axial thick-section datasets (thickness and intervals both of 7 mm) and thin-section datasets (thickness and intervals both of 1 mm) were reconstructed automatically from a single series of CT projection data by programmed CT scanner protocol. The thick- and thin-section axial images were used for regular interpretation, and the thin-section datasets were used for reformation of images. Parameters for the scanning of the single-detector CT were: 120 kVp, 150–250 mA, 5–10 mm collimation, 0.7-s rotation time, and 1–1.5 pitch (others, the same as for MDCT). A dataset of axial thick-section images (thickness and intervals both of 5–10 mm) was reconstructed. Thin-section images could not be reconstructed because the scanning was slow and thick images had to be selected initially when the scanning covered a wide range (such as the whole body) in clinical conditions.

Design of Data Archiving

In the redundant array of independent disks (RAID) that forms a part of the PACS, 750 GB of disk space was reserved for temporary storage of the thin-section datasets reconstructed by the MDCT. This amount of disk space was selected on the basis of our experience for the purpose of archiving for 3 months (because the average disk space which was needed for the thin-section datasets in our hospital for a day was about 11 GB). The thin-section datasets were transferred automatically to this reserved space in RAID. They were stored temporarily and were then overwritten by the system, beginning with the oldest, to keep disk space available for new thin-section datasets. The thick-section datasets were transferred automatically and stored permanently in the remaining 14 TB of disk space in RAID. This disk space was assigned to the archiving of 5 years' worth of radiographic data in our hospital on the basis of our experience (because the average disk space needed in our hospital for all of 1 day's radiographic data except for the thin-section datasets was about 10.5 GB). All image datasets (including thin-section and MPR images) were backed up on digital linear tapes (DLT). Some of the images were stored permanently as key images in the diagnostic report. A combination of gigabit and 100Base-T Ethernet networks was used for the data transfer.

Evaluations of System

The image transfer and archiving times of the thick- and thin-section datasets transferred from the CT to the PACS were measured manually for five cases selected randomly from among the cases

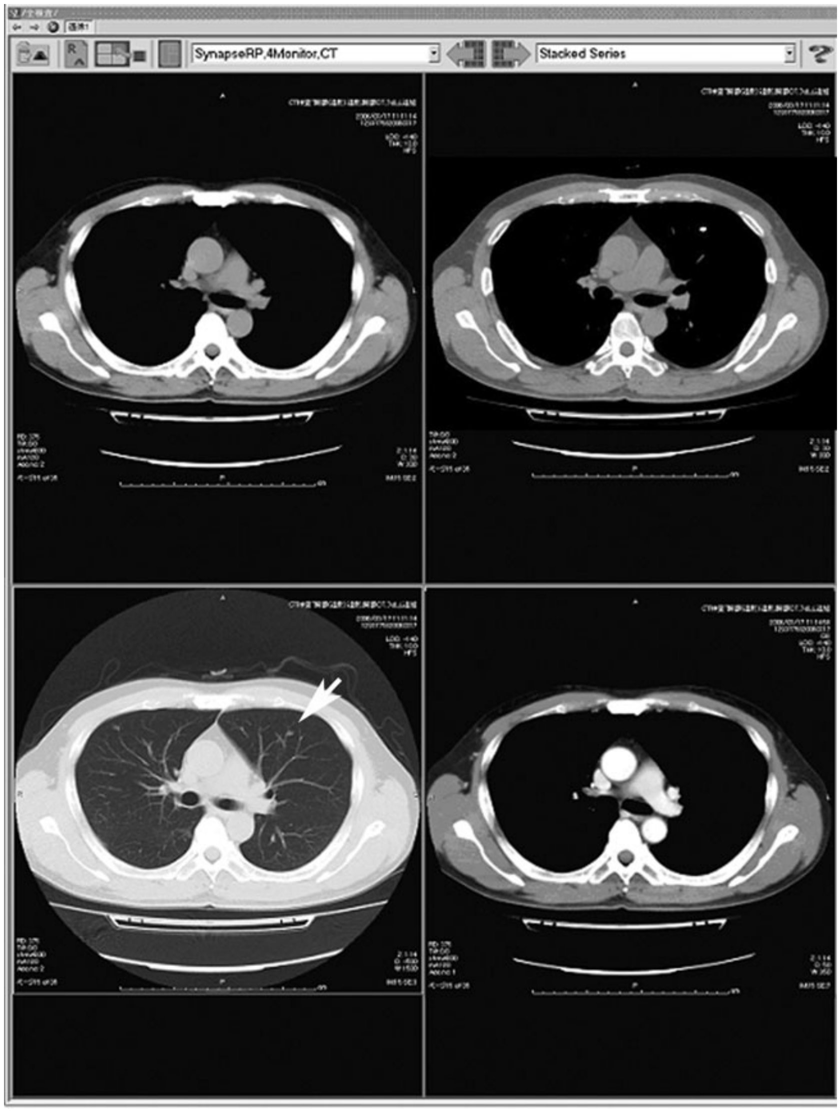

Fig 1. **An example of the PACS workstation monitor displaying thick- and thin-section CT images for detection of metastases from an ovarian tumor. The monitor is divided into four areas in each of which is located automatically and is paged simultaneously showing the same level. The chest CT with slices 7 mm thick and the lung window (*lower left of the monitor*) shows a small nodule in the left lung (*arrow*) of which diagnosis is difficult. The 1-mm-thick CT and the mediastinal window (*upper right of the monitor*) shows the marked calcification of the entire nodule, strongly suggesting the calcified granuloma but the metastatic nodule, whereas the CT with 7 mm thickness (*upper left of the monitor*) does not show calcification due to partial volume effect. The contrast-enhanced CT is shown on the lower right of the monitor. The thin-section images were definitely useful for the diagnosis of smaller lesions such as those in this case. In order to facilitate interpretation of thin-section images when the need arises, the thin-section images should be reconstructed and archived before interpretation for all cases.**

in which MDCT was performed on 1 day, because there were so many intricate and complicated log files in the communication with CT and the other systems that analyzing the image transfer and archiving times for all cases would have been very difficult. The measuring was performed after the CT examinations of the day in order to measure proper transfer times, because the transfers were interrupted during the scanning and reconstruction that have priority over transfers.

In the regular interpretations of CT by eight radiologists (five attending physicians with 12–27 years' experience and three trainees with 4–14 months' experience) during the same week, including the day on which the image transfer times were measured, the volume of images, the image retrieval times of the thick-section images with or without thin-section datasets, the question whether or not the radiologists used the thin-section images or the MPR software, the reasons why thin-section images were not used, and the image interpretation times were recorded prospectively and independently for every case. The image retrieval time was defined as the time taken to display the first image of a case. Furthermore, prospective evaluation by the radiologists for the diagnostic usefulness of the thin-section image interpretation system was performed subjectively and independently for all cases, with the use of a five-point rating scale: 5, definitely useful; 4, probably useful; 3, uncertain; 2, probably not useful; and 1, definitely not useful. "Definitely useful" was selected when the radiologists deemed that this system was clearly better for CT diagnosis than no system at all; "probably useful" was used when the system was considered good but needed some minor improvements; "uncertain" was used when it was unclear if the system was useful or not, because many minor improvements were needed; "probably not useful" was used when the system was found not to be good because many major improvements were needed; and "definitely not useful," when the system was deemed quite unfit. The training and attending radiologists made initial and second interpretations, respectively ("double readings"), and the latter radiologists alone performed the "single readings."

Statistical significance was determined by applying the chi-squared test or the unpaired Student's t test. A difference was considered significant at the level of $p<0.05$.

RESULTS

Table 1 shows a comparison of the CT examination data of 246 CT examinations that had thin-section datasets with those of the 170 CT examinations that did not have thin-section datasets in this study, and Table 2, a comparison of the volume of images and the image retrieval times between the two groups. Table 3 and Figure 2 show the evaluation of the thin-section datasets by the radiologists. The mean age of the subjects with thin-section datasets was significantly higher than that of the subjects without thin-section datasets. Among those who underwent only abdominal examinations, the number of subjects with thin-section datasets was significantly greater than that of those without, and among those undergoing both abdominal and pelvic examinations, the number with thin-section datasets was significantly less than the number without. The subjects whose CTs were judged normal and those in whom abdominal lesions were diagnosed by CT were significantly more numerous in the group with thin-section datasets than in that without; as was the number who underwent contrast-enhanced CT in the thin-section dataset group compared with that in the other group.

The total number of images and the total image transfer and archiving time of the five randomly selected cases were, respectively, 3,574 and 40 min, 50 s (average 0.69 s/image). The image transfer and archiving times per image are the

Table 1. CT Examination Data

	Thin slice		
Factors	+ ($n = 246$)	− ($n = 170$)	p Value
Sex (M/F)	141/105	89/81	0.32[a]
Age (years)	64.9 ± 14.5	61.4 ± 16.2	0.02[b,c]
Scan area			
Brain, head, and neck	9	6	0.94[a]
Chest	39	35	0.21[a]
Chest and abdomen	16	11	0.99[a]
Chest, abdomen, and pelvis	36	32	0.26[a]
Abdomen	111	36	5.1×10^{-7}[a,b]
Abdomen and pelvis	33	46	4.9×10^{-4}[a,b]
Pelvis	2	4	0.20[a]
CT diagnosis			
Normal	114	104	2.3×10^{-3}[a,b]
Brain, head, and neck lesions	2	0	0.24[a]
Chest lesions	28	24	0.41[a]
Abdominal lesions	84	29	1.2×10^{-4}[a,b]
Pelvic lesions	6	8	0.21[a]
Musculoskeletal lesions	4	1	0.34[a]
Vascular lesions	8	4	0.59[a]
Contrast enhancement			
Enhanced	176	92	5.9×10^{-10}[a,b]
Not enhanced	70	78	2.6×10^{-4}[a,b]

Data are presented as means ± SD
[a]Statistically significant difference
[b]Calculated by the chi-squared test
[c]Calculated by unpaired Student's t test

Table 2. Image Volume and Retrieval Time

Factors	Thin slice + ($n = 246$)	Thin slice − ($n = 170$)	p Value
Volume of image/case			
Number of images			
Total	751.8 ± 243.2	83.5 ± 2.8	1.6×10^{-44}[a,b]
Thin slice	647.5 ± 210.0	0	1.6×10^{-47}[a,b]
Data volume (megabytes)			
Total	395.0 ± 127.8	43.9 ± 1.5	2.4×10^{-43}[a,b]
Thin slice	340.2 ± 110.3	0	1.6×10^{-47}[a,b]
Image retrieval time/case (seconds)	6.07 ± 1.30	4.71 ± 0.46	3.6×10^{-4}[a,b]

Data are presented as means ± SD
[a]Statistically significant difference
[b]Calculated by unpaired Student's t test

same for thick- and thin-section images because they depend only on data volumes. Therefore, the average image transfer and archiving times of the group which had the thick-section images together with thin-section datasets and of that without thin-section datasets were calculated as 8 min and 43.5 s/case and 57.3 s/case, respectively.

The average percentages of use of thin-section images and MPR software by the radiologists were 79% and 18%. The reasons why thin-section images were not used were that no lesions, including indistinct lesions, were found on the thick-section images, and so these thick-section images alone were used and were judged to be normal (86%), and the lesions were so obvious that they judged that thin-section images were not needed for evaluation (14%). The average volume of images, the times taken to retrieve the images, and the image interpretation times of the thick-section data of subjects with thin-section datasets were significantly larger and longer than that of the data of subjects without thin-section datasets. The average assessment of this system by the radiologists using the five-point rating scale was 4.4 (out of a possible 5.0).

DISCUSSION

There are many papers stating that the thin-section images of MDCT are regularly used and helpful for diagnosis[1–8]. Our radiologists used 79% of thin-section images and 18% of the MPR software, and their evaluations led to the same results (Table 3). They did not interpret all the thin-section images but depended on the findings in thick-section images or on the type of disease. For example, when the radiologists judged that the CT images of a case were definitely normal or that the lesions were obvious on thick-section images, they did not in many cases use thin-section images. Furthermore, only when they needed additional findings such as craniocaudal and anteroposterior information did they use MPR software. As a result, this software was not used very frequently.

The calculated image transfer and archiving times of the thick sections with thin-section datasets were longer than that without thin-section datasets, the mean difference being 7 min and 46.2 s. Also, the times taken to retrieve the images and for image interpretation of the thick sections with thin-section datasets by the radiologists were significantly longer than those without thin-section datasets because of the significantly greater volume of images. However, the differences of the average image retrieval and interpretation times were 1.3 s and 3 min and 45 s, respectively. We defined the image retrieval time as the time taken to display the first image of a case. The retrieval time of the second and subsequent images depends on the performance of the PACS; in the case of our PACS, it is an instantaneous process. Therefore, the differences between average image retrieval times were small. Our results and a year's experience of using the system suggest that these delays are compensated by the usefulness of thin-section images and to raise no problems in the daily routine. In fact, our methods were approved by the radiologist in this study.

Table 3. Evaluation of the System by Radiologists

Factors	Radiologist 1	2	3	4	5	6	7	8	Average
Use of thin-section images (%)	79	75	67	78	80	96	36	94	79
Use of multiplanar reformation software (%)	0	0	24	31	10	4	12	25	18
Usefulness (average rating scale)	4.8	4.7	4.6	4.5	3.9	4.2	4.0	4.3	4.4

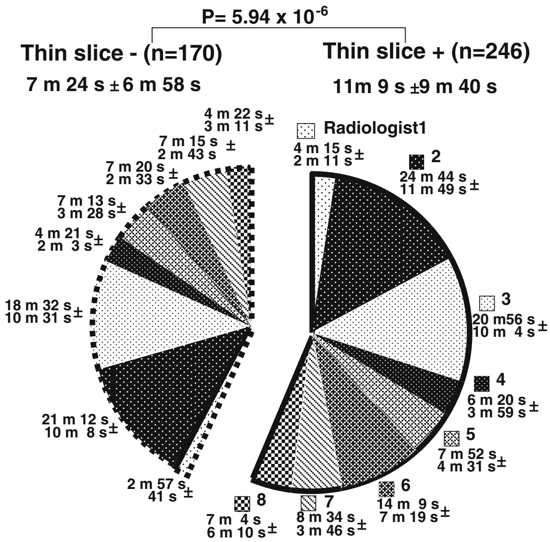

Fig 2. Time (average minutes and seconds ± SD) taken for interpretation of images by eight radiologists. The time taken to interpret thick-section images together with thin-section images (*Thin slice +*) was significantly greater than the times taken without thin-section images (*Thin slice −*). Statistical significance was calculated by the unpaired Student's *t* test.

When the thin-section MDCT data are used for interpretation, a very large amount of disk space becomes essential for archiving the massive volume of thin-section CT images created. Permanent archiving of all images in the PACS is best. However, expansion of archiving space is often technically difficult and costly, and unlimited expansion is impossible. Our literature search brought to light only two reports offering solutions to this problem.[12,13] Lee KH et al.[13] described a method of using a mini-PACS for storing thin-section datasets, while thick-section datasets were stored in the main PACS, which contains the mini-PACS. Meenan et al.[12] proposed a similar thin-slice CT archiving model. These methods are effective for archiving the thin-section datasets produced by MDCT using the limited disk space of data storage devices in the main PACS. However, when multiple data storage systems such as theirs are employed, users are forced to operate PACS workstations wastefully for interpreting CT using both thick- and thin-section images because they are not qualified to organize the integration of these different systems. If the multiple storage systems are not integrated, users must spend valuable time searching through many lists and comparing the thick- and thin-section images. Furthermore, when the thick- and thin-section images are displayed on different monitors or windows, and when there is some distance between these, the user constantly look from one to the other—a tiring process. No proposals for solving these problems have been made. In contrast, we have created a single data storage system in which overwritable disk spaces are set aside for thin-section datasets in the main RAID of PACS. This system allows the thick- and thin-section images to be displayed side-by-side automatically, with coordinated, simultaneous page-turning showing the same slice level on the PACS workstations. Furthermore, MPR images were reconstructed using thin-section datasets on the PACS workstations using the MPR software by merely a single click of the icon. These two procedures were evaluated as very efficient for interpretation by the radiologists.

In our system, the thin-section datasets have become available temporarily in existing PACS disk space for interpretation and for reconstruction of images (e.g., three-dimensional CT images, MPR images, and virtual CT endoscopic images) before the dataset is deleted by the system. The thick-section datasets of MDCT have thus, by the introduction of our system, become retrievable by the PACS workstations without becoming overwhelmed by the massive amounts of thin-section datasets. When the temporary storage system of datasets is designed to be compatible with our system, the images do not become accessible easily after a defined period of time. We have reserved the disk space for archiving a 3-month accumulation of thin-section datasets, and there have been no problems, partly because interpretation and image reconstruction were not carried out after more than 3 months had passed since the examinations and thick-section images were available for comparison with previous images for interpretation. Furthermore, for legal issues concerning subsequent deletion of the thin-section images that were used in the primary interpretation by radiologists, the images stored permanently as key images (including thin-section images) in the diagnostic report could be seen easily and quickly, and all (including thin-section) image datasets could be made available by retrieving backups in DLT, though this is a somewhat formidable task.

We should point out the following limitation to this study: There may have been some bias in the selection of one of the two CT machines because this study was performed under daily clinical conditions. The selection of MDCT or the single-detector CT was made carefully by the physicians who ordered examinations, with consideration for the needs of the subjects, the demands of their diseases, and the urgency of the examinations. There were statistically significant differences between the group that had thin-section datasets and that which did not, in the subjects' ages, the scan area, the CT diagnosis, and the contrast enhancement. There were significantly more examinations with thin-section datasets in subjects who underwent abdominal examinations and contrast-enhanced studies than in those without thin-section datasets, and fewer in those who had examinations of both abdomen and pelvis, because MDCT with advanced time resolution was selected to perform dynamic contrast-enhanced studies for the evaluation of complicated abdominal neoplasms, whereas a single-detector spiral CT was selected for simple examination of the abdomen and pelvis. The images were produced more by dynamic studies than by regular studies. Consequently, the former examinations involve a greater volume of images and, therefore, require a larger number of image transfers, and more archiving and retrieval than the latter. These biases in selection, when present, may have been one reason for the prolongation of the interpretation times with thin-section images, but the true difference may have been shorter. On the other hand, the subjects with thin-section datasets were significantly older, and the results of their CT examinations were normal, but the difference, although significant, was small. However, without these limitations, the results of the radiologists' evaluation of this system would probably have been even better.

The presumed benefit of not archiving the entire volumetric dataset is cost-saving, resulting from decreased storage requirements. Indeed, introduction of this system led to $240,000 savings in the cost of expanding the data storage system in our institute compared with that for 5 years' archiving of thin-section CT images. We do not believe that our system is the best of all. However, when the PACS has been installed and expansion of the archiving spaces is difficult for either cost or technical reasons, we believe our system is good for the effective utilization of thin-section CT datasets for the time being.

CONCLUSION

Our new data storage and image interpretation system improves the storage system and availability of thin-section datasets of MDCT in existing PACS and can prevent the accumulation of an overwhelming glut of data for the moment.

ACKNOWLEDGMENTS

The authors thank Mr. C. W. P. Reynolds for his careful correction of this manuscript.

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