Use of a Dedicated Server to Perform Coronal and Sagittal Reformations in Trauma Examinations

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The purpose of this study was to evaluate the impact of implementing an automated process for generating coronal and sagittal reformatted images on radiologist workflow. When performing trauma-related CT examinations of the cervical, thoracic, and lumbar spine at our institution, technologists manually generate coronal and sagittal reconstructions at the scanner console and send these images to a picture archiving and communication system (PACS) for interpretation by radiologists and clinical viewing. Although certain PACS, thin-client three-dimensional systems, and CT scanners are capable of automatically generating reconstructed or reformatted images, the systems at our institution do not support this functionality. We have recently integrated a dedicated server that is capable of automatically generating multiplanar reformatted (MPR) images from source thin-section axial images and sending these images to PACS without requiring technologist input. This dedicated server was used to generate coronal and sagittal MPRs for trauma-related spine studies in parallel with technologist-generated coronal and sagittal reconstructions. When comparing the two methods, using the dedicated server to automatically generate reformations resulted in substantial time savings for the radiologist compared to technologist-generated reconstructions. Additionally, a survey of interpreting radiologists indicated that a significant majority preferred to view the automatically generated MPRs on PACS compared to the thin-client system, considered the image quality to be good or excellent, and believed that viewing MPRs increased diagnostic accuracy and confidence. It is expected that this automated process will significantly improve radiologist workflow with respect to image interpretation time and report turnaround time.

KEY WORDS: Transforming the Radiological Interpretation Process (TRIP™), workflow, productivity, automation

INTRODUCTION

The introduction of multidetector-row computed tomography (MDCT) has had a profound impact in the clinical setting, providing

increased spatial and temporal resolution, volume coverage, and scanning speed while simultaneously improving technical efficiency.^{1,2} MDCT has become the preferred imaging modality in a variety of clinical settings because of improved accuracy, reduced imaging time, and reduced patient manipulation compared to conventional radiography and CT.^{2,3} The advantages of MDCT have not come without costs however, as these examinations result in a substantial increase in the amount of data that must be processed, interpreted, transferred, and stored.^{4,5} Thin-section source data sets from MDCT examinations range in size from 236 to 847 Mb when uncompressed and can account for 33% of the total image data in a filmless system.⁶

As a result, all institutions are acquiring MDCT images using thin collimation and reconstructing thicker section images from large volumetric data sets to reduce storage needs and network traffic.⁶ An advantage of generating multiplanar reconstructions from volumetric data sets is that viewing these images has been shown to further improve diagnostic accuracy and confidence over axial MDCT images alone in the evaluation of spinal trauma, suspected pulmonary embolism, acute appendicitis, bowel obstruction, urinary tract calculi, hepatocellular carcinoma in patients with

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cirrhosis, and pancreatic cancer.^{2,3,7-19} In addition to multiplanar reformatted (MPR) images, stacked maximum intensity projection (MIP) images have been shown to be effective in improving diagnosis of lung nodules on chest CT.²⁰⁻²² Aside from diagnostic benefits, providing multiplanar reconstructed or reformatted thick-section images on a large enterprise picture archiving and communication system (PACS) obviates the need for specialized workstations that require three-dimensional (3D) visualizing functionality to review and manipulate thin-section data sets.⁶

Although certain CT scanners, PACS, and thin-client 3D systems are capable of automatically generating multiplanar reconstructed or reformatted images from isotropic data sets, there are many enterprises where existing systems and scanners do not fully support this functionality. Technologists may need to manually reconstruct multiplanar images at the scanner, which can have a significantly negative impact on both technologist and radiologist time management and workflow. This negative impact on workflow is accentuated during periods of high volume, most notably in the setting of a busy level 1 trauma center, when manually generating coronal and sagittal reconstructions becomes a lesser priority due to increased patient throughput and injury severity. The downstream effect is that interpreting radiologists cannot review the entire imaging data set and, therefore, cannot render a diagnosis or issue a formal report until the reconstructed images are available.

According to a recent study by Roos et al., patient management and data reconstruction were the most time-intensive steps in modern CT workflow.²³ One potential solution to this problem was developed by Jeong et al. who described using an MPR Gateway server to automatically generate on-the-fly MPRs from thin-section image data sets according to predefined rules.¹ They did not, however, directly compare the technologist-dependent method of manually reconstructing multiplanar images with the MPR Gateway method of automatically generating MPRs. Furthermore, the system did not provide the ability to automatically generate stacked MIP images.

In this study, we evaluate the average time required for technologists to manually generate coronal and sagittal reconstructed images and

compare it to the time required for a dedicated server to automatically generate coronal and sagittal reformatted images from source thin-section images for trauma-related spine studies. Additionally, we surveyed interpreting radiologists to assess how often coronal and sagittal reformations were reviewed during routine workflow, viewing preferences, general quality of reformatted images, and perceived effect on confidence and diagnostic accuracy.

MATERIALS AND METHODS

This study was exempt from institutional review board approval. The dedicated server used in this study is a commercially available product (AquariusAPS, TeraRecon Inc., San Mateo, CA) that can be programmed to generate MPR and/or MIP images based on user-defined filters and rules. In our current workflow, all of the CT scanners send reconstructed axial images to a Digital Imaging and Communications in Medicine (DICOM) router. The router sends thick-slice reconstructions (3–5 mm) to the PACS and thin-slice reconstructions (0.6–2 mm) to our enterprise thin-client 3D server. When we implemented the dedicated server for MPR/MIP, we programmed the DICOM router to send an additional copy of all thin-slice data to the dedicated MPR/MIP server.

The server workflow was based on filters and clinical protocols. The filters defined which studies would be selected for processing based on DICOM header information, primarily study description (0008, 1030), series description (0008, 103E), and modality (0008, 0060). The clinical protocol defines what type of post-processing images would be generated (MIP versus MPR), the orientation of the images (coronal versus sagittal), and image parameters (slice thickness and overlap). Additional options were also available including the order of the images (L→R versus R→L for sagittal images and A→P versus P→A for coronal images), as well as the ability to “trim” empty slices from the beginning and end of the image stack.

After implementation of the dedicated server, the PACS database was queried over a 1-month period using the exam codes for cervical, thoracic, and lumbar spine CT examinations performed in the emergency department to generate a list of appropriate studies. The “acquisition time” associated with

each study represented the time at which the axial acquisition was completed. The “study time” for a specific series (coronal or sagittal) represented the time at which the reformation was completed. These times were confirmed by observing the technologists and comparing times recorded from the scanner to the times provided in the DICOM headers ($n=8$). To evaluate the time delay for technologists to generate reformations for cervical, thoracic, and lumbar CT spine studies, the “acquisition time” for the axial images was compared to the “study time” for the coronal and sagittal reformations. To evaluate the time required for the dedicated server to automatically generate reformations for the same CT studies, we reviewed the server log to determine when source images arrived at the dedicated server as well as when reformations were completed and sent to the PACS server. Times to generate coronal and sagittal reformations were compared using an unpaired t test to determine statistical significance.

After the initial assessment period using trauma-related CT studies of the spine, the dedicated server was configured to also generate coronal and sagittal reformations for all CT examinations of the abdomen and pelvis and coronal and sagittal MIP images for CT examinations of the chest to evaluate for pulmonary nodules. The time required for the dedicated server to automatically generate reformations and send them to PACS was determined from the server log in the same manner as previously described. Evaluation of the time delay for technologists to generate these reformations was not assessed because these image sets were not part of the routine imaging protocols.

When the process of automatically generating coronal and sagittal MPRs and MIPs had been in effect for >3 months, a nine-question survey was sent to 30 radiologists to assess how often coronal and sagittal reformations were reviewed, viewing preferences (PACS or thin-client software), general quality of reformatted images on the PACS and thin-client software, effect of viewing coronal and sagittal reformations on confidence level, and how often viewing coronal and sagittal reformations altered the initial diagnosis based solely on axial images (Fig. 1).

RESULTS

The average time delay attributable to the technologist for generating coronal and sagittal

reformations of the cervical spine was 15 min and ranged from 3 to 57 min ($n=48$; Table 1). The average time required for the dedicated server to automatically generate coronal and sagittal reformations for the same studies was 1 min with a range of 1 to 2 min ($n=33$). The difference was statistically significant ($p<0.0001$). The average time delay attributable to the technologist for generating coronal and sagittal reformations of the thoracic and lumbar spine was 33 min and ranged from 8 to 127 min ($n=26$ for each type of study). The average time required for the dedicated server to automatically generate coronal and sagittal reformations for the same studies was again 1 min with a range of 1 to 2 min ($n=26$). The difference was also statistically significant ($p<0.0001$). The average time delay for sending the axial images to the dedicated server was 3 min with a range of 1 to 10 min ($n=15$).

On average, it took technologists <1 min to set the reconstruction parameters, correct the axes for patient positioning, and initiate the reconstruction protocol ($n=8$; maximum, 2 min). There was no measurable effect on patient turnaround time at the scanner.

The average time required for the dedicated server to automatically generate coronal and sagittal reformations for routine CT examinations of the abdomen and pelvis was 2 min with a range of 1 to 4 min ($n=18$). The average time required for the dedicated server to automatically generate coronal and sagittal MIP images for CT examinations of the chest for suspected pulmonary embolism was 2.5 min with a range of 2 to 4 min ($n=21$).

Eighteen radiologists responded to the web-based survey regarding automatically generated coronal and sagittal MPRs and MIPs, including both fellows and faculty members. Of the respondents, 86% indicated that they routinely reviewed coronal and sagittal reformations. Seventy-six percent preferred to review the reformatted images on the PACS rather than the thin-client program due to familiarity with the existing PACS program, ease of use, speed, and because it was not necessary to log into another software program on a separate computer. The quality of reformatted images was considered equal between the PACS and thin-client software with 94% indicating that images on PACS were good or excellent compared to 88% using the thin-client program. Seventy-six percent noted that viewing coronal and sagittal

Evaluation form: Coronal and sagittal MPR images for CT abdomen/pelvis studies

1. How often do you review coronal and sagittal MPR images in your evaluation of CT abdomen and pelvis examinations?

Percentage of cases

- ☐ 0-20%
☐ 21-40%
☐ 41-60%
☐ 61-80%
☐ 81-100%

2. How do you review coronal and sagittal MPRs?

- ☐ Centricity PACS ☐ TeraRecon ☐ Both

3. Which viewing software do you prefer to use and what is the most important reason why?

- ☐ Centricity PACS ☐ TeraRecon

- ☐ Familiarity with system
☐ Ease of use
☐ Faster
☐ Studies available sooner
☐ Ability to manipulate images

☐ Other _____

4. Are there any additional reasons why you prefer one system over another (select all that apply).

- ☐ Centricity PACS ☐ TeraRecon

- ☐ Familiarity with system
☐ Ease of use
☐ Faster
☐ Studies available sooner
☐ Ability to manipulate images

☐ Other _____

5. What is the general quality of coronal and sagittal MPRs viewed with Centricity PACS?

- ☐ Poor ☐ Fair ☐ Average ☐ Good ☐ Excellent ☐ N/A

6. What is the general quality of coronal and sagittal MPRs viewed with TeraRecon?

- ☐ Poor ☐ Fair ☐ Average ☐ Good ☐ Excellent ☐ N/A

7. Does viewing coronal and sagittal MPRs provide more confidence in making a finding/diagnosis?

- ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time

8. Does viewing coronal and sagittal MPRs alter your initial finding/diagnosis based on axial images?

- ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ All the time

9. What is your level of training?

- ☐ First year resident
☐ Second year resident
☐ Third year resident
☐ Fourth year resident
☐ Fellow
☐ Attending

Fig 1. Evaluation form for coronal and sagittal MPR images for abdominopelvic CT studies. An identical form was used to evaluate coronal and sagittal MIP images for chest CT studies.

Table 1. Comparison of Average Time for Manual Reconstruction Compared to Automatic 3D Server Reformation

Study	Average manual reconstruction time (min)	Number of studies	Average 3D Server reformation time (min)	Number of studies
Trauma CT cervical spine	15 (3–57)	48	1 (1–2)*	33
Trauma CT thoracic spine	33 (8–127)	26	1 (1–2)*	26
Trauma CT lumbar spine	33 (8–127)	26	1 (1–2)*	26
CT abdomen and pelvis	n/a	n/a	2 (1–4)	18
CT chest	n/a	n/a	2.5 (2–4)	21

* $p < 0.0001$

MPRs and MIPs increased confidence often or all the time, and 69% indicated that viewing MPRs and MIPs sometimes or often altered the initial interpretation based solely on axial images.

DISCUSSION

When comparing the two methods for generating reformations in trauma-related CT examinations of the cervical, thoracic, and lumbar spine, using the dedicated server to automatically generate reformations resulted in substantial time savings for the interpreting radiologist compared to technologist-generated reconstructions. Even when considering the additional time required for sending axial images from PACS to the dedicated server, the overall time savings was 11 min per cervical spine study and 32 min per thoracic and lumbar spine study. This is expected to reduce the average image interpretation time (time from study completion to study interpretation) and report turnaround time (time from study completion to report completion) for cervical spine CT studies by 11 min and thoracic and lumbar spine CT studies by 32 min. Approximately 200 trauma-related CT spine studies are performed in the emergency department at our institution each month, highlighting the overall time savings for interpreting radiologists who no longer have to wait for the reconstructed images to arrive in the PACS prior to interpretation.

When evaluating technologist workflow, it was surprising to find that the average time for technologists to manually set the reconstruction parameters, adjust axes for patient positioning, and initiate the reconstruction process at the scanner was <1 min and never more than 2 min. The most plausible explanation for the considerable overall delay in generating reconstructions is that patient throughput is prioritized, as these studies are performed in the emergency department with relatively high volume. This was confirmed in

discussing the findings with the technologist supervisor. On numerous occasions, scanning of a second patient took place before the reconstruction process was initiated for the initial patient.

The time required for the dedicated server to automatically generate coronal and sagittal MPRs for CT studies of the abdomen and pelvis and MIPs for CT studies of the chest for pulmonary nodules was not significantly different from the previously described trauma-related CT studies. With implementation of the dedicated server, interpreting radiologists can benefit from the improved diagnostic accuracy and confidence afforded by coronal and sagittal reformations without any impact on technologist time management or workflow. Additional storage requirements for thick-section coronal and sagittal reformatted images on the PACS ranged from 130 MB for cervical spine studies to 200 MB for lumbar spine studies and CT chest studies (MIP images). The additional time required to interpret MPR and MIP image sets was not evaluated in this study. Jaffe et al. previously determined that the mean time to interpret coronal reformations (5.1 min) was not significantly different from the mean time to interpret transverse images (4.9 min) for abdominal CT examinations when reviewing the study in only one plane.²⁴ A study evaluating the benefits of the routine use of coronal and sagittal reformations concluded that radiologists should consider the routine use of at least one additional plane to the axial series in analyzing abdominopelvic CT studies.²⁵ It would be reasonable to assume that the additional time required for interpreting either additional coronal or sagittal images ranges from 1 to 5 min for each CT examination.

One important difference between the two methods for generating coronal and sagittal reformations is that the technologist adjusts the plane of reformation to correct for patient obliquity on the axial images, whereas the dedicated server reformats source axial images without correction.

However, the results of the web-based survey indicate that interpreting radiologists prefer viewing MPRs and MIPs on the PACS and consider image quality to be equivalent when using the PACS compared to the thin-client program. Only one respondent indicated that they preferred to review images on the thin-client 3D software because of the ability to actively manipulate the plane of viewing. Regardless, using the dedicated server does not interfere with the ability of the technologist to generate additional reconstructions from the volumetric source data, as it is kept in storage for approximately 12 h.

CONCLUSIONS

Using a dedicated server to automatically generate coronal and sagittal reformats in trauma-related CT examinations of the cervical, thoracic, and lumbar spine significantly reduces the time between when the study is performed and when the reformats are available on PACS to be interpreted by a radiologist and for distribution to clinical staff. The substantial time savings is expected to improve radiologist workflow and productivity, particularly at institutions where on-the-fly reformatting is not available on the enterprise PACS or cannot be automatically generated on the CT scanner. A majority of interpreting radiologists preferred to view the reformats on PACS, considered the image quality to be good or excellent when viewed on PACS, and believed that viewing reformats increased diagnostic accuracy and confidence.

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