

# Strategies for Coping with Large CT Datasets: Experience at the Baltimore VA Medical Center

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## Introduction

**I**n the armamentarium of diagnostic imaging, Computed Axial Tomography (CT) has emerged as the most important tool for evaluation of suspected diseases of chest, abdomen, and pelvis.

Faster computer processing, substantial increases in storage capacity, changes in detector technology, and the introduction of multi-channel systems have resulted in dramatic reductions of scan times in recent years. The current generation of multi-channel scanners is faster than the earliest systems (which, in 1972, took 4.5 minutes of scanning and 1.5 minutes to process each “slice”) by a factor of more than five thousand. The use of multi-channel systems has resulted in a tendency to acquire images using progressively thinner collimation and to obtain additional sequences (e.g. triple phase post contrast hepatic imaging). This has resulted in an exponential increase in the volume and complexity of CT examinations. However, this extraordinary growth in image volume and complexity has not been accompanied by a concomitant increase in network bandwidth in hospital or outpatient imaging centers.

In addition to the increase in image volume, there has also been an increase in the utilization of radiolo-

gy services and cross sectional imaging in particular. Between 1993 and 1999, the use of non-invasive imaging studies in the United States increased by 3.8% while relative value units increased by a disproportionate 14.6% due to increased use of cross-sectional studies such as CT and MRI <sup>[1]</sup>.

In the opening session at the 2000 Radiological Society of North America (RSNA), society president Dr. C. Douglas Maynard warned that “radiologists will soon be overwhelmed by demand” for their services. He pointed out that relative value work units associated with medical imaging have been rising by 4% to 6% annually resulting in a doubling time in as little as 12 years. Dr. James Thrall, the chief radiologist at Massachusetts General Hospital said “the total United States imaging workload will increase by 50% between the years 2000 and 2010.” Unfortunately, the pool of diagnostic radiologists is expected to only increase approximately 20% during the same period.

Bhargavan et al <sup>[2]</sup> reported a 192% increase in the ratio of radiologist job listings to job seekers in the United States during the period of 1998-2000 and projected the radiologist shortage to increase by as much as 250% if the demand continued to increase

at its current rate. A more recently published follow-up study by the American College of Radiology <sup>[3]</sup> has reported that this radiologist staffing shortage has improved, although substantial radiologist vacancies remain within academic radiology departments. This disparity in radiologist staffing among academic and rural based practices has been previously reported <sup>[4]</sup>.

With the transition from single-detector to multi-detector CT (MDCT), CT datasets have exponentially expanded, as have the number of studies and images interpreted per radiologist. For example, in 1994, the daily number of CT images per radiologist at the Mayo Clinic in Jacksonville, Florida was approximately 1,500 <sup>[5]</sup>. For a given 10-hour workday (without breaks), this translates into an average of 24 seconds per individual CT image. Eight years later (in 2002), CT image volume increased more than ten-fold to 16,000 individual CT images per radiologist per working day. Based on current trends in CT imaging volumes, this volume at the Mayo Clinic Jacksonville is expected to increase to 80,000 CT images per day per radiologist in 2006. In a continuous 10-

hour workday, the radiologists would have to average 0.45 seconds per CT image to accommodate the change in CT workflow. Assuming that radiologists can review on average of one CT image per second, it would take more than 22 hours per radiologist per day to review all CT images. The conclusion at that facility was that in the absence of a major change in reimbursements the only viable solution is to substantially alter the radiologist workflow.

## Methods

One of the ways to cope with the increased volume and complexity of studies is to make the transition from film based to filmless operation. The Department of Veterans Affairs (VA) Medical Center in Baltimore made this transition in 1993. [Figure 1]

A number of studies <sup>[6]</sup> performed at the Baltimore VA Medical Center have documented improved productivity throughout the imaging department as well as the entire medical center by using a Picture Archiving and Communication System (PACS). The use and integration of our PACS, radiology, and hospital information systems and the use of an enter-



*Figure 1. The Baltimore VA Medical Center, which opened in January 1993, was designed for filmless and paperless operation*



*Figure 2 Cross sectional images presented in static "tile" mode rather than stack mode*

prise electronic medical record (VISTA) allowed us to re-engineer our previously inefficient workflow processes. In the CT department, the PACS has reduced the number of workflow steps from 11 to 5 resulting in a 45% decrease in CT examination times. Radiologist interpretation times dropped by 15% and there was a concomitant improvement in diagnostic accuracy associated with the use of computer workstations. Overall, our department saved approximately 25% per unit study for film-less operation in comparison with film-based operation.

During the past ten years, we (and other early adopters of film-less operation) have observed and documented the transformation of the radiologist's interpretation process. Our experience suggests that this tends to occur in the following progressive phases:

1. Film-based interpretation using alternators and multiple view boxes.
2. Static soft-copy interpretation using workstations rather than films. In this phase, cross sectional images are still presented in the static "tile" mode similar to film. Radiologists typically request four or more monitors to simulate film alternators and view boxes. Radiologists judge the image quality of con-

ventional radiographs and cross sectional images based on how closely they simulate the "look" of film. [figure 2]

3. Dynamic interpretation of images characterizes the next phase. Radiologists learn to rapidly and intuitively adjust the window and level (with and without presets) of the images and to use other workstation tools such as zoom, pan, and measurement functions. Pomerantz et al <sup>[7]</sup> at the University of Maryland provided evidence of the importance of dynamic image interpretation by stating that the application of additional window/level settings resulted in improved conspicuity and characterization in 67% of CT examinations that were abnormal, and that their use substantially affected the final diagnosis in 18% of these cases without a significant increase in interpretation time.
4. Stack mode characterizes the next phase in image interpretation for CT and other cross sectional studies and takes advantage of the human eye's innate ability to detect motion or other changes in a visual field. With stack mode, sequential images within a study or sequence are "stacked" on top of each other and reviewed in a cine or movie fashion, re-

quiring less monitor “real estate”, permitting review of multiple sequences, and facilitating comparison of a current and prior studies.

The use of stack mode has increased interpretation efficiency as well as accuracy. Beard et al from the University of North Carolina School of Medicine documented that images displayed in stack mode were interpreted significantly faster<sup>[8]</sup> and Drs. Mathie and Strickland at the Hammersmith Hospital in London<sup>[9]</sup> documented improved speed (by a factor of 3.2 to 5.7) and performance in stack mode in comparison with tile mode.

Linked stack mode is available on most sophisticated PACS workstations. This feature synchronizes multiple stacked images (e.g. MRI sequences) within a single examination or across a current and one or more prior examinations. This feature does not seem to be optimally implemented on many PACS workstations and is not used as often as it should be by radiologists.

Today’s radiology residents and their counterparts in medical and surgical subspecialties learn to interpret radiographs using stack mode without having to unlearn the film based paradigm; a nice advantage over those of us that have had to unlearn the interpretation process using film including such antiquated skills as the use of a hot light, holding the film at an oblique angle to see life support lines, and the use of a minifying lens to better detect lung nodules.

5. Volumetric navigation is the fifth phase in the transformation of the radiology interpretation process. This phase represents a major paradigm shift in which the process of review of images (multi-planar, variable “slice” thickness, 3-D) is separated from the manner (i.e. axial) in which they were acquired and reconstructed. This phase has been accelerated by the crisis precipitated by the rapid transition to the use of multi-detector CT scanners, which have now become the de facto standard in the marketplace.

As more facilities gain experience with soft-copy interpretation, radiologists are discovering that the first four phases of interpretation (especially film) are inadequate for the large numbers of images generated from these multi-detector systems. A routine CT of the thorax using an 8 or 16 detector scanner can generate 30 sheets of films each for lung, mediastinum, and liver settings. Our experience has been that even the use of stack mode is not sufficient for review of all of the images associated with studies that may average 360 to 720 images for a routine CT of the thorax, or abdomen and pelvis and 1,500 to 3,000 images for a CT angiography “runoff” study.

### **Coping with Information Overload**

Radiologists are currently using several strategies to cope with this information overload. The most common of these is to acquire images using a multi-detector scanner using thin collimation such as 0.75, 1.0, or 1.5 mm and then reconstruct the images that are sent to PACS using much thicker (e.g. 5 mm. or 8 mm.) sections. This can result in a three to ten fold reduction in the number of images sent to PACS for review by the radiologists. Technologists can then perform additional reconstructions or rendering on the original dataset, using a dedicated CT workstation for additional perspectives. These can include sagittal and coronal reconstructions of the spine, CT angiography of the vasculature, coronal images of the bowel for CT colonography, “fly through” images of the colon for colonoscopy, 3D rendering, and others.

Unfortunately, this approach is unsatisfactory for several reasons. It requires additional time, especially for angiographic rendering. Due to the complexity and time required, technologists only perform multi-planar, 3D, and other rendering in only a subset of cases. Additionally, the reconstructed images unnecessarily take up a good deal of archival, network, and workstation memory space. From the radiologist’s perspective, this approach does not allow flexibility from case to case to determine whether the images should be reviewed in the sagittal or coronal or oblique planes in addition to the axial images, nor does it facilitate flexibility in review of 3D images by the radiologists. When the technologists do not perform these additional reconstructions, radiologists are typ-

ically constrained to review images in the axial plane at a pre-determined, relatively thick plane of section. This negates the advantages of the multi-detector scanners for routine studies and minimizes their added value over conventional helical scanners.

A major advantage of the current generation of multi-detector CT scanners is that they provide an entrée into the tremendous potential of volumetric acquisition and display. This is made possible by the combination of thin collimation that allows the scanner to acquire isotropic voxels and the larger area of the body that can be scanned in a given period of time using this thin collimation. A 40 cm. field of view, for example, would require an approximately 0.78 mm reconstructed “slice” (400 mm/512 pixels) to achieve an isotropic voxel. CT studies that approach this level of collimation and image reconstruction can be rapidly and smoothly rendered in any plane or viewed as a “3D” image.

Volumetric navigation using an advanced workstation frees the radiologist (and clinician) from the previously imposed shackles of conventional CT. An image of the spine, for example, can be instantaneously and interactively rendered at such a workstation and reviewed as a sagittal or coronal dataset at any slice thickness. This can be augmented with 3D and maximum intensity projection (MIP) rendering as well. The pulmonary arteries can be reviewed using relatively thick slice coronal or oblique perspectives with or without the use of MIP rendering. The colon, in our experience, is best depicted in the coronal plane while the liver and spleen may be examples of organs best reviewed in the axial plane but perhaps using a MIP rendering algorithm. The vasculature of the thorax, abdomen, pelvis and other areas may be optimally reviewed in various planes according to their orientation within the body and are also probably best rendered as a MIP image.

There is a paucity of scientific data in the medical imaging literature on the clinical added value of advanced workstation tools such as multi-planar and 3D processing tools, with the exception of the use of MIP processing for lung nodule detection. Gruden et al <sup>[10]</sup> found that the use of a MIP (maximum intensity projection) algorithm resulted in increased ability to

detect central pulmonary nodules for both “senior” and “junior” readers as well as an improved ability to detect peripheral nodules for their “junior” readers. Other investigators have found similar advantages of this use of MIP projections. Similar advantages will undoubtedly be found for other advanced workstation algorithms such as ray sum, minimum intensity projection, as well as routine application of multi-planar imaging. 3-D imaging, once considered to be “eye-candy” for referring clinicians and patients, can be very useful, in our experience, in providing a general survey of an area and for portraying anatomic structures such as the ribs that course in an oblique plane.

Although volumetric navigation, the fifth phase of our TRIP, has tremendous potential to address the image overload problem and to improve diagnostic accuracy, it poses some unique and perhaps, daunting challenges as well. Perhaps the biggest of these is the concern that we might be trading image volume overload for clinical image information overload. The near instantaneous, interactive 3D and multi-planar reconstructions used routinely for studies such as a CT of the thorax, abdomen, or pelvis now render images of the spine and other bones, pulmonary and abdominal and pelvis vasculature, and other structures that are comparable to those that previously required special acquisition and reconstruction protocols.

Our abdominal and thoracic sub-specialists have asked whether this paradigm shift makes them more “responsible” for review and dictation of more detailed reports of the musculoskeletal system and spine and of the individual vessels now visualized on a routine CT study. Should radiologists specifically and routinely comment, for example, on the renal arteries, aortic and iliac arteries, superior and inferior mesenteric arteries, and so on with every routine CT of the abdomen and pelvis? What are the implications of this detailed review on the time required to dictate a study? How should these cases be billed given that a single acquisition can generate many types of studies that would have otherwise generated multiple billing codes? Should, sub-specialists such as angiographers or neuro-radiologists read or review each routine CT of the thorax or abdomen in an academic practice?

Another major challenge is access to 3D and multi-planar workstations and their integration into the workflow of a PACS. In most departments, these high-end workstations are much more expensive than typical PACS workstations and are commonly purchased with a new CT or MR scanner. These workstations are often not networked to each other and consequently images must be pushed or routed to a hard drive on an individual workstation from the modality, which can require a good deal of time for large and complex CT studies. Comparison studies are rarely available on standalone workstations due to the limited archival space associated with these individual workstations. Additionally, non-radiology healthcare providers do not have access to the workstations but rather to rendered images that are pushed from the workstation to the PACS. On the whole, this typical set-up is inefficient, cost-ineffective, and provides inconvenient and limited accessibility to images.

At the Baltimore VA Medical Center and the University of Maryland Medical System, we use the AquariusNET from TeraRecon, Inc. for advanced visualization. It runs on a Microsoft Windows™ based personal computer client. The central server provides the “horsepower” for advanced processing in a client server model. In our current configuration, approximately one dozen PC clients can share the server simultaneously. Thus each generic “vanilla” PC connected on the network functions as though it had the power and speed of a dedicated high-end 3D/multiplanar advanced workstation. All of the images that have been acquired on the multi-channel CT scanner are pushed to the central AquariusNET server and are then made available to the thin-client personal computers located throughout the department and the hospital.

The radiologists at the two medical centers use the AquariusNET software as an adjunct to image interpretation using a commercial PACS. CT studies are reconstructed using 5 mm or comparable slice thickness in the axial plane, and in some cases sagittal and coronal planes, and are sent to and archived using the commercial PACS. The CT studies are also sent to the AquariusNET server using thin (e.g. 0.75 mm) axial sections and are also archived on the server and

an additional separate CT archive. The workflow is relatively inefficient due to limited integration of the two systems. New and prior studies are retrieved using commercial PACS. The radiologists then utilize the AquariusNET software to review the images in the sagittal, coronal, and oblique planes in addition to review of maximum intensity projection and “3D” images.

In order to determine how these advanced workstation functions were being used as an adjunct to axial image interpretation using the commercial workstation, we have developed software to provide an automatic audit of the AquariusNET workstations. When the study was performed soon after the workstation became available, the AquariusNET workstation was used as an adjunct to the conventional PACS workstation in 39% of body imaging CT studies. This number has increased since the study was performed and we currently use it in more than 90% of cases. We found that users spent an average of 42% of the time reviewing images in the coronal plane and 38% reviewing images using the maximum intensity projection technique or as “3D” images. Approximately 16% of the time was used for review of sagittal images and only 4% for the axial plane (which was already available in 5mm sections on the conventional PACS). The average speed of review in the axial plane was 14 images per second, which is faster than the coronal and sagittal review speed, which were 10 and 9 images per second respectively.

As the number of images associated with CT increases in the future, the arguments for the use of a thin client server model become increasingly persuasive. There are several advantages of the client/server model based on our experience.

1. The thin client/server model has obviated the need for us to replace the existing PC's throughout the department and hospital with high performance workstations with large amounts of memory. Multi-planar, MIP, and 3D speed are maintained even over a wireless network or our VPN (virtual private network).
2. The use of the client/server model for large datasets such as our 2,000 image CT angiography studies eliminates the unacceptably

long delays associated with the transfer of images from a PACS to a thick client workstation.

3. The relatively high performance combined with the ability to immediately review images in multiple planes without waiting for image transfer to a remote workstation is advantageous for at-home teleradiology applications.

The ability to review images in multiple planes and in 3D has been enthusiastically received by our medical and surgical colleagues at the VA who have learned to use the workstation effectively in their own subspecialty areas for clinical and educational purposes. The non-radiologists, in particular, seem to appreciate the “more anatomic” perspective provided by 3D, MIP, and multi-planar rendered images.

A number of our radiology colleagues have expressed their discomfort with the practice of giving non-radiologists access to these volumetric navigation capabilities. Their concern is that the added value and control of the radiologist might be significantly diminished when clinicians have full access to an interactive volumetric dataset. Interestingly, part of their stated apprehension is founded on the belief that the cross sectional images are relatively obscure and thus need to be interpreted by a radiologist unlike the more intuitive 3D and multi-planar images that can be rendered by giving the clinicians access to the entire dataset. Unlike radiologists, clinicians may be less wedded to axial sections and may not have to unlearn a dependence on axial imaging in a manner similar to the way that residents do not have to unlearn film based interpretation.

A similar concern was also expressed in the radiology community twelve years ago when PACS was first introduced. A number of early PACS adopters in academic radiology departments decided that images should not be made available outside the radiology department to clinicians at all or that they should only be made available after a report was generated and signed. Just as the vast majority of departments have decided to grant non-radiology healthcare providers access to images prior to a report being generated, it seems inevitable that non-radiologists will eventually be given access to the full volumetric da-

taset, whether for primary or secondary diagnosis or for teaching purposes.

Perhaps the biggest barrier to the transition to volumetric navigation has been the lack of integration and availability of this capability in the current generation of PACS workstations. It is not practical for a radiologist interpreting a study using a PACS workstation to walk (or even slide) over to a dedicated 3D/multiplanar workstation and then back to the PACS workstation. Similarly, we have found that despite access to volumetric navigation tools at the PC in the reading room, radiologists find it inconvenient to switch between the PACS workstation and an adjacent multi-purpose PC and consequently do not use it in every study. Another challenge is that image navigation may not be a linear, sequential process as is review of a set of axial images but may be performed in a less organized fashion with a radiologist reviewing a portion of a dataset in one plane and other portions using other views. A fascinating exhibit at the RSNA's InfoRad 2002 anticipated and addressed this problem by using a “completion cube” which was progressively colored in as different regions of the image volume were reviewed to keep track of which anatomic areas had been (and had not been) seen during the course of the interpretation of a study.

Therefore, in order for the majority of users to attain the fifth stage in the radiology interpretation process, there must be much better integration of these functions into the PACS workstation and into the radiologist's routine workflow. A number of PACS vendors are currently working on an integrated solution in which volumetric navigation becomes a routine part of the radiologist display or hanging protocols. In order for this to occur, volumetric navigation must be not only affordable but it must also be very fast. Any solution that substantially increases the amount of time required for interpreting a CT or any other type of radiology study is unlikely to be practical or successful. The extraordinary challenge to the vendors and to the radiology community in general will be to determine a way to make these powerful tools available in the routine reading process but to not add significantly to the time required to interpret the study.

What might a phase 5 radiology interpretation process consist of when integrated into the routine “hanging protocol” for a CT study of the chest, for example? The following is one of an almost infinite number of ways that a vendor might implement volumetric navigation at a PACS workstation.

*A slowly rotating, “3-D” rendered color image of the chest and upper abdomen appears automatically on the right upper third of the large LCD monitor. For the first few seconds it appears as a surface reconstruction and then it changes to a “3-D” rendering that depicts the bones, heart, and other vasculature of the chest and upper abdomen*

*Additional views representing coronal, sagittal, and axial planes appear in three other windows. These begin to slowly display sequential images in a cine fashion until the radiologist moves a cursor over one of these windows (e.g. the coronal view). This window then replaces the larger 3D rotating image and as the radiologist quickly moves through the stack of coronal images (which are reconstructed “on the fly” as 3 mm thick sections according to the radiologist’s preference), the localizer in the sagittal image window is automatically updated.*

*The radiologist then reviews the axial images using a thick slab MIP algorithm in order to discern small lung nodules. Images from a previous CT of the thorax are similarly displayed in parallel on a second monitor in such a manner that the comparable images from the previous examination are displayed in identical windows that move in concert with the navigation performed on the current exam.*

## Conclusion

What will be the future of diagnostic imaging in the context of our TRIP? The transformation of the radiology interpretation process will continue to evolve at a rapid pace. The next phases will be heavily influenced by future research in the area of imaging informatics and will probably involve the use of decision support systems. Image review by the radiologist will be augmented substantially by computer based cuing or CAD (computer assisted diagnosis) that will be able to circle a cluster of microcalcifications on a mammogram or create a color overlay to highlight a suspected lung nodule on a conventional radiograph or CT, or a suspicious hepatic lesion on a set of MRI sequences. Clinical information from the electronic medical record, results of previous examinations, and clinical and imaging expert systems and the indication for the current study will be utilized to optimize image navigation and computer cuing and CAD programs and to suggest diagnostic possibilities. Comparison with large computerized reference image datasets may also be used routinely by radiologists to facilitate more rapid and accurate diagnosis. These future additions to the armamentarium of the radiologist will also create additional challenges and concerns that will undoubtedly require the creativity and expertise of many members of the medical imaging community.

Although the transformation of the radiology interpretation process will take us into new territory along a yet to be determined route, I believe that the radiology community will be able to stay in the driver’s seat as long as we keep our eyes and our minds open to change and as long as we continue to allocate time and energy and resources to investigate the roads that lie just around the bend.

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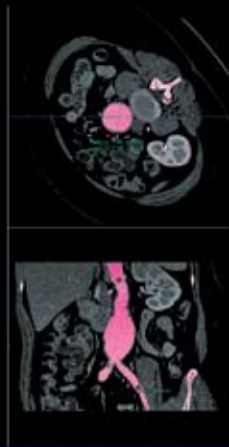
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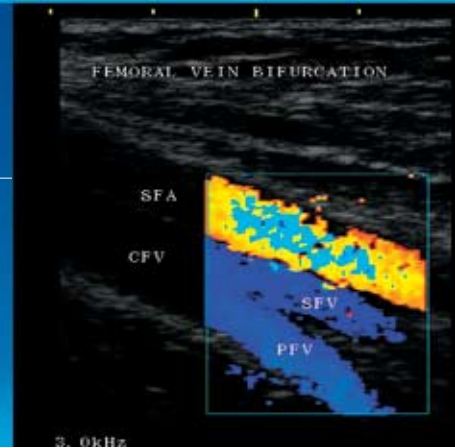
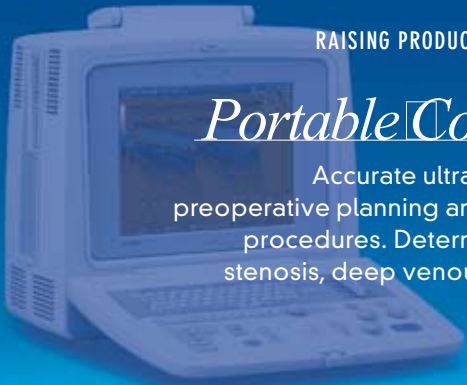
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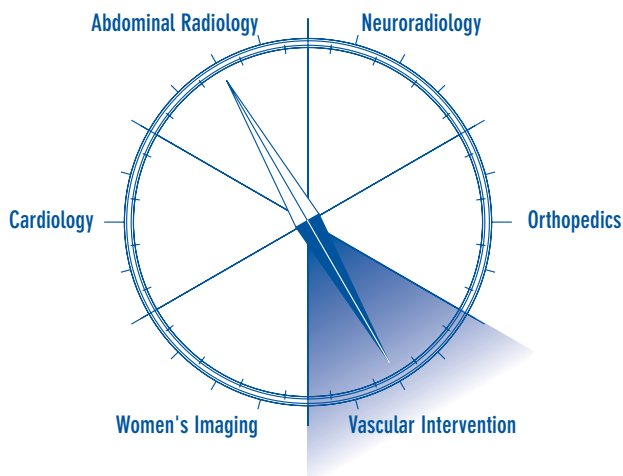
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