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Use of a Thin-Section Archive and Enterprise 3D Software for Long-Term Storage of Thin-Slice CT Data Sets

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Rapid advances are changing the technology and applications of multidetector computed tomography (CT) scanners. The major increase in data associated with this new technology, however, breaks most commercial picture archiving and communication system (PACS) architectures by preventing them from delivering data in real time to radiologists and outside clinicians. We proposed a phased model for 3D workflow, installed a thin-slice archive and measured thin-slice data storage over a period of 5 months. A mean of 1,869 CT studies were stored per month, with an average of 643 images per study and a mean total volume of 588 GB/month. We also surveyed 48 radiologists to determine diagnostic use, impressions of thin-slice value, and requirements for retention times. The majority of radiologists thought thin slice was helpful for diagnosis and regularly used the application. Permanent storage of thin slice CT is likely to become best practice and a mission-critical pursuit for the health care enterprise.

KEY WORDS: Thin-slice CT, data storage, PACS, server-side rendering

Advances in multislice computed tomography (CT) technology have pushed the frontiers of diagnostic imaging and enabled high-resolution whole-body scanning, as well as temporal scanning at high acquisition rates to determine physiologic function.[1] The data management and network transfer requirements of this veritable deluge of diagnostic information can cripple current-generation picture archiving and communication system (PACS). This fundamental transformation in the way that diagnostic information is displayed has changed the way radiologists interpret images and is considered by many to be a "disruptive" technology.[2] Disruptive technologies are most often those quantum advances that change established practice in a specific industry or across a range of industries. Digital cameras, for example, radically altered the business model of film-based photography. Mobile phones did the same to wire-based telephone companies.

In radiology, the transformation from film to digital imaging and the accompanying increase in the numbers of images per study have posed challenges for practitioners, industry, auxiliary personnel, information technology (IT) specialists, and reimbursement models. The Society for Computer Applications in Radiology (now the Society of Imaging Informatics in Medicine) initiated the Transforming the Radiology Interpretation Process (TRIP)[3] initiative in 2003 to help educate the imaging community about this profound change.

BACKGROUND

One focus of considerable attention has been on multidetector CT imaging. As the number of images per study has drastically increased, facilities have been forced to devise strategies for handling thin-slice CT data and, in most cases, have had to work around their PACS systems.

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In many clinical settings, thin-section CT data (thickness <1 mm) is discarded after a short period of time because of storage limitations on CT scanners, stand-alone advanced visualization work stations, and PACS archives. Most commercial PACS are unable to deliver thin-slice data to the desktop in real time or provide acceptable performance to radiologists and other clinical users.[4]

Challenges Posed by Thin-Slice Data in Clinical Use

The use of thin-slice data in clinical environments today faces three major challenges. The first is the need for cost-effective storage. Although the per-megabyte cost of storing data in outside industries continues to decrease, it is still often prohibitive to store large amounts of health care data in a cost-effective manner.[5] Initially predicting a doubling of transistors per square inch of integrated circuit every 24 months, Moore's law[6] has widely been extended to include a prediction that computer and storage systems will double in performance every 2 years with a corresponding decrease in cost to the consumer. High price mark-ups, the medical device classification of PACS disk storage, and a lack of properly trained storage administrators have all prevented imaging technologies from enjoying the cost benefits of Moore's law.

The second challenge is the network requirements for facilitating real-time distribution of images and supporting data. Although networking, by its nature, should be experiencing rapid decreases in cost per Moore's law,[7] many health care facilities are not realizing these economies. This is partially the result of the high costs of continuously upgrading physical infrastructure (network cables, etc.), but is also complicated by network congestion and increased use of networking by all applications. Networking often becomes a bottleneck thwarting real-time enterprise distribution of large-volume data sets.

The third challenge involves devising adequate workflow strategies to reliably provide the right data to the specific point of care. Without a centralized architecture in place, technologists must manually route images directly to the point of care each time access to data is required. This has dramatic and deleterious effects on technologist workflow and productivity. In addition, with CT data sets now measured in gigabytes, it becomes impossible to provide these data by manual routing in real time to the radiologist waiting to interpret the study.

The Promise of Thin-Slice Data

The potential benefits of thin-slice CT data clearly outweigh the challenges posed in efficient management, routing, and storage. Three-dimensional (3D) imaging and volumetric reconstruction provide a viable strategy for viewing the deluge of information contained in a multithousand image CT study.[8] Clinicians are no longer restricted to two dimensions when measuring tumors and anatomic features and can make more accurate volumetric measurements.[9] Thin-slice imaging provides much better resolution than thicker-slice data sets and facilitates enhanced temporal reconstruction of data with volumetric registration and subtraction of prior studies.[10]

A Phased Model of Thin-Slice Workflow

As health care enterprise users inside and outside of radiology escalate demands for real-time access to imaging data, the IT infrastructure is increasingly challenged to deliver high levels of performance in a cost-effective manner. Many 3D systems are initially presented as a value-added feature for PACS systems already in production. Once released to the enterprise, however, access to thin-section data sets for 3D and multiplanar reconstruction (MPR) quickly becomes mission critical for hospital IT staff. Although addressing these changes is ideally proactive, in most settings the phases from initial challenges to maturity follow an incremental development process that carries with it both advantages and drawbacks. We propose a three-phase process maturity model to describe current workflow associated with implementation and effective management of thin-slice CT data sets.

Phase 1: Initial Discovery

In this phase, thin-slice CT is captured at the modality and manually routed to a thick-client work station. Models are built, and screen captures are sent back to a separate PACS for archiving and distribution. Thin-slice data are discarded after space runs out on the local work station. The advantage in this phase is ease of deployment, whereas the significant disadvantage is the limited window of access to imaging data. Thin-slice data are lost after a fixed period of time. Moreover, the necessary workflow for routing is technologist-heavy, images are not delivered in anything approaching real time to radiologists, and the number of users is limited.

Phase 2: Centralization with Server-Side Rendering

With IT improvements and upgrades, thin-slice CT data are captured at the modality and manually routed to a central 3D archive. 3D and MPR models can be created on the fly with server-side rendering for real-time delivery to the radiologist. Multiple thick-client work stations can query and retrieve on demand. Models are built, and screen captures are sent back to a separate PACS for archiving and distribution. Thin-slice data are discarded after space runs out on the 3D archive. The advantages in this approach include a single destination for routing, with fewer demands on technologists; real-time access to the 3D data across the enterprise; on-demand query-and-retrieve access for thick-client specialty work stations, and longer term access to thin-slice data. The disadvantage is the demand from users for longer term storage of data. Even when these demands are satisfied, in this phase the thin-slice data are lost after a fixed period of time.

Phase 3: Thin-Slice Archive as Part of the Medical Record

In this phase, thin-slice CT data are captured at the modality and automatically routed to the central PACS archive. All thick-client specialty

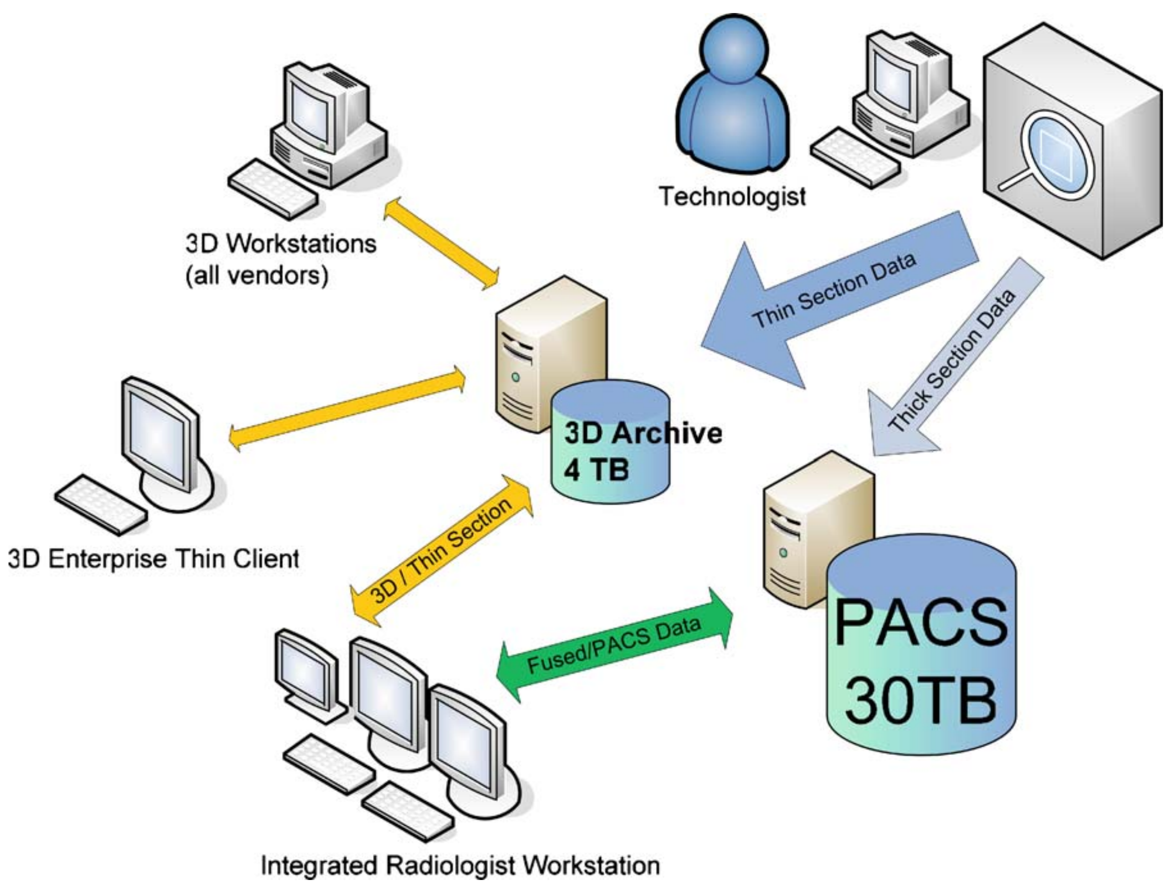

Fig 1. Configuration of thin-section archive and PACS.

work stations and 3D specialty systems can query and retrieve or cache to provide real-time 3D/MPR to the enterprise. The clear advantages is in long-term access to thin-slice data sets, with accompanying benefits to PACS, including more integrated imaging workflow (Integrating the Healthcare Enterprise standards can be implemented, for example). One disadvantage to this approach is the danger that the volume of thin-slice data may break the PACS system. Unless server-side rendering is used, the effects on the network can be severe. Storage and network architectures should be planned to accommodate increased volumes.

MATERIALS AND METHODS

We built a long-term, thin-slice archive and measured data storage over a period of 5 months. We then surveyed 48 radiologists to determine diagnostic use, impressions of thin-slice value, and requirements for retention times. Our goal was to determine not only the current value of thin-slice data, but also to identify the perceived value to the diagnostic process if cost and availability were not issues.

We installed an enterprise-capable, server-side 3D application with a two-way server and 4-TB thin-slice archive (AquariusNet, TeraRecon, San Mateo, CA, USA). In this architecture, technologists at the modality manually send thick-section (3–5 mm) data sets to PACS and then manually send thin-slice (<1 mm) data sets to the new archive (Fig. 1). Radiologists would create models with the 3D application and export key images back to PACS for permanent storage. Additionally, clinical users outside of Radiology could directly access the 3D application and create their own models. For the initial 5 months of use, we measured the number of CT studies, mean slice volume per study, and total CT data volume stored. CT data were generated by one 4-slice and three 16-slice scanners. The 3D software program was available in all radiology department reading rooms and radiologist office work stations.

A web-based customer survey was created by using freely available, open-source tools (phpESP v1.7.5, MySQL, Apache, SUSE Linux). We queried 48 radiologists on patterns of use, diagnostic value, and retention requirements for these slice data.

RESULTS

A mean of 1,869 CT studies were stored per month, with an average of 643 images per study and a mean total volume of 588 GB/month. The total storage volume reached 3 TB within 5 months.

Forty-three of 49 (87.8%) radiologists found the 3D imaging application helpful for diagnosis.

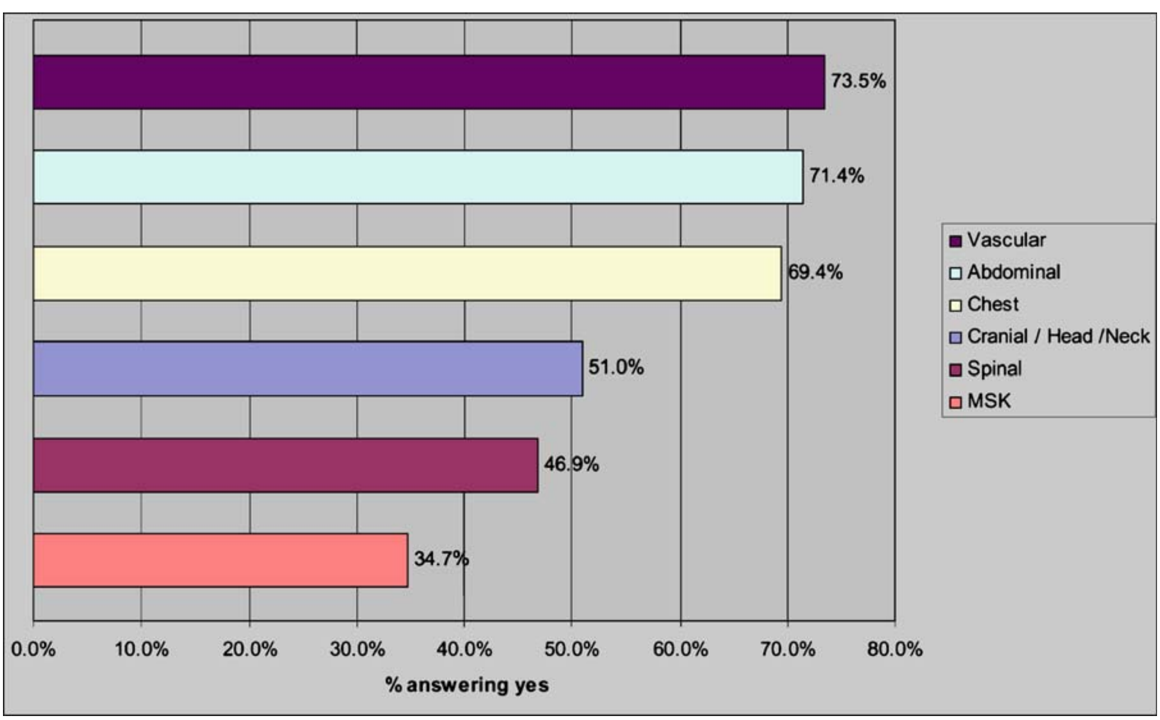

Fig 2. Percentages of radiologists answering “yes” for active use in various anatomic sections.

Although 83.7% regularly used the application in reading rooms, 40% also used the application in their offices or other areas. When asked about focused areas of use, radiologists indicated the data were useful for a variety of anatomic regions and structures (Fig. 2), including some areas of radiologic specialization that have not traditionally relied on 3D CT data.

When asked about retention requirements, 51% wanted thin-section CT data to be available for at least 6 months, 18.4% wanted these data to be available for at least 1 year, and 6.1% wanted retention for 5 years or more. Among the illuminating responses received in the free text portion of the survey were the following:

- "Six months of storage is a minimum. Forever would be better."
- "[The system] is now a vital piece of how I practice."
- "I don't feel comfortable reading without thin section any longer."

DISCUSSION

Our 3D imaging system was met with early approval from and was actively utilized by the majority of users. It proved to be a valuable accessory tool to our main PACS system. The system facilitated enterprisewide distribution and availability of thin-section CT data for 3D image generation for up to 5 months, extending the window of time that these data were available for clinical use. Radiologists reported that this was helpful for diagnosis and used it for a variety of anatomical sections, even in those areas not traditionally reliant on 3D imaging (e.g., musculoskeletal radiology).

Our storage requirements remained steady until the upgrade of our CT scanners in early 2006. At that time, we upgraded our CT scanners from three 16-slice and one 4-slice to one 16-slice, two 40-slice, and two 64-slice scanners. Before this upgrade, the 3D archive could hold 6 months of storage with 4 TB direct attached storage. At present, our archive holds slightly less than 90 days of storage, even after doubling storage capacity to 8 TB. Even with innovative solutions, the challenges to cost-effective and efficient long-term storage are a constant in imaging IT.

CONCLUSION

Thin-slice CT has both long-term diagnostic and research value. Storage of thin-slice CT data sets as part of the permanent medical record is likely to become a recognized best practice and a mission critical pursuit for the health care enterprise. However, retaining these data and delivering them to the enterprise with real-time performance will require a fundamental shift in PACS architecture and data storage models. We see server-side rendering as a real solution to the problem of delivering large-volume CT data sets to the enterprise in real time.

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