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Should Post-Processing Be Performed by the Radiologist?

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Abstract Post-processing of volumetric data sets lands in a fuzzy boundary between the technologist and the radiologist. Is this the role of the technologist as part of image preparation? Or is it the beginning of the diagnostic process by the radiologist? Technology advances in real-time server side rendering platforms is challenging the traditional role of expensive dedicated advanced visualizations workstations with dedicated personnel. Will this also challenge the role of a dedicated 3D post-processing technologist?

Keywords 3D reconstruction · Web technology · Volume rendering · Image visualization

Radiologists should be performing post-processing: Reuben Mezrich, MD, PhD

Opening Statement

There is a small museum in Florence, Italy about a block from the Uffizi that has a marvelous collection of statues by Michelangelo, featuring the original David and a copy of the Pieta. But to me the most amazing works that line the hallways leading to and from the heroic David. These are some of his unfinished works, with parts of people arising from blocks of marble and granite. These clearly illustrate Michelangelo's answer to how he came to create his pieces of art: "I simply uncover the figures I see trapped inside the stone—chipping away till they are released"

To a large extent, this is what Radiologists do—we uncover the anatomy hidden inside the images. In the "olden" days, before cross-sectional imaging was possible, Radiologists could look at one or two views and read the subtle changes in lines and margins to "see" the disease that distorted the 3D anatomy. As cross-sectional imaging (CT, MRI, Ultrasound) became available, radiologists would skim through hundreds of images that comprised the stack and create a 3D view in their head. The more experienced among them could twist and turn the imagined "virtual" image to understand the anatomy better and then describe, as best they could, what they saw in their mind's eye.

With the advent of 3D workstations, the task of describing to others what Radiologist's "saw" became easier. The speed and availability of software helped the radiologist visualize complicated anatomy. A severe limitation on the general utility of the software has been the marginal ability to segment anatomy, except in special cases (bones, vasculature after contrast injection). In these special cases, segmentation is basically done by setting a threshold, and it has become relatively easy to create stunning anatomical images of the axial and appendicular skeleton and of the entire vascular tree, especially including the coronary and carotid arteries. In these special cases, 3D visualization can be essentially automated and there is little the radiologist must add, except in cases of poor signal-to-noise (perhaps due to suboptimal contrast injection or large body habitus). Technologists are helpful in obtaining these views—especially with older, slower, software, but with modern software, these views can be automatically created—even before the radiologists calls up the study at his PACS workstation—for review.

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But in most applications—examining soft tissue tumors (whether brain or body or bone) or complicated fistulas or diffuse or complex infections—segmentation is complicated and generally not possible. 3D imagery of the type possible with bone or blood vessels is not possible and multi-planar views—whether linear or curved—are better suited for illustrating complex anatomy. Except in rare cases, the cardinal planes (x or y or z axes) are not helpful requiring arbitrary oblique or multi-oblique views. But what oblique plane, and at what point of origin? This cannot be known a priori for if we knew that much about the anatomy, there probably would not be much need for any imaging.

And so the radiologist must choose the plane and isolate the anatomy, he wants to explore and demonstrate—much like Michelangelo chipped away till he uncovered what he saw. Now that hardware and software have improved to the point that his every gesture reveals what he wants, the radiologist can twist and turn the image till it gives up its secret, revealing to him and to his colleagues the true nature and extent of disease.

This can only be done interactively and cannot—at this time—be relegated to a technologist. This may all change when soft tissue segmentation becomes robust, but given the complexity of that problem, it may be some time till that is feasible.

So for now, it seems that there are two opportunities.

In the case of osseous or vascular structure, software and hardware have advanced to the point where little human interaction is needed and 3D structures can be automatically generated that illustrate the nature and extent of disease with great accuracy. In most other cases, 3D volumetric imagery is rarely helpful or even possible and interactive, iterative techniques—usually with oblique or multiblique linear or curved views—are necessary to illustrate complicated disease. But this can only be done by the radiologist who understands how anatomy is distorted and invaded and otherwise changed by disease—not by a technologist or even software following a protocol.

Radiologists should not be performing post processing: Krishna Juluru, MD

Opening Statement

Advanced post-processing describes the manipulation of radiographic images to derive additional qualitative or quantitative data. Modern imaging devices and protocols, whether in CT, MRI, or ultrasound, generate large volumes of information that enhance not only our diagnostic roles, but treatment planning as well. There are multiple technologies available to manage this post-processing, and a lab dedicated to mastery of these technologies ensures that the tools are used properly and thoroughly. The goals of such a lab are to meet clinical needs, maximize quality, minimize costs, and provide scalability for future growth [1].

Advanced imaging has evolved greatly in the past decade alone. Tools considered state-of-the-art in the past included multiplanar reconstruction, maximum/minimum intensity projection, shaded surface displays, and volume rendering. These tools have largely become routine on current applications. Modern tools include vessel centerline extraction with analysis of vessel diameter, area of lesions, and degree of stenosis; perfusion analysis in patients with stroke; automated lesion analysis (tumor size, dynamic enhancement characteristics) and generation of parametric maps; virtual colonoscopy; and organ segmentation. These tools may need to be purchased individually, or they can be provided as a package in some advanced visualization solutions.

The clinical demand to perform post processing is high, and there are several successful dedicated labs throughout the country. The lab at Massachusetts General, for example, processes over 91 examinations per day. Five to ten percent of CTs, 20% of MRIs, and 20% of ultrasounds performed at that institution are processed as volumetric data [2]. A lab operated by Spectrum Health in Grand Rapids, MI, was processing about 30 cases per month when it opened in 1997, growing to over 600 cases per month by March, 2008. Lab services include processing of trauma injuries to pre- and postsurgical planning. The lab, according to its director, "is propelling us to the front of the pack when it comes to advanced visualization [3]."

With this demand, quality control is crucial. When used properly, the advanced visualization tools provide valuable clinical information. However, when used improperly, information obtained from the tools can be meaningless at best and dangerous at worst. It can take up to 6 months of training before technologists are comfortable with the technologies [2]. Notes Gordon Harris, PhD, director of the Massachusetts General lab, "You really need to have dedicated staff and equipment to adequately provide this type of service [2]."

In a highly specialized practice, it may be possible for a single radiologist or small group to attain mastery in a subset of post-processing tools. However, the greater the volume and breath of cases a radiologist is expected to interpret, the harder it is to maintain mastery in any one skill, including post-processing. Furthermore, the greater the number of radiologists there are for interpreting a particular variety of study, the greater the potential for variability in post-processing outcomes if individual radiologists are expected to perform this task. Trust and confidence with referring physicians is built not only with delivery of a quality product, but with a consistent presentation of that product. This is much easier to control with a dedicated post-processing lab than with individual radiologists.

Quality can also be measured by responsiveness to customer needs, whether that customer is the referring physician or even the radiologists. In a busy imaging practice, radiologists are presented with an examination, provide an interpretation, and then proceed to the next case. Outside of specialty conferences, time for discussion is limited. Creation of specialized views, whether for surgical planning or simply for presentation in a conference, is often left to the few good-willed radiologists who are knowledgeable in post-processing, operating systems, file formats, and data export. Technologists in a post-processing lab can perform this role, thereby becoming another customer service node in the department of radiology. They can also work with technologists at the modality to ensure that acquisition technique is compliant with post-processing demands. The 3D Lab at the University of Michigan consults with nursing staff for pre-procedural preparation of cardiac and CTA patients. It also ensures residents and fellows prescribe proper protocols for studies requiring post-processing, and assists faculty in preparing presentation materials for academic work [4].

Costs and return on investment from running a dedicated post-processing lab can be difficult to determine. Advanced post-processing, however, does have immediate payoff to patient care and satisfaction of the referring physician. Notes one author, “Marketing clout and patient satisfaction can override direct ROI considerations” [3]. Delegating components of the imaging workflow to technologists is not new to radiology. There exist dedicated CT, MRI, and ultrasound technologists who are experts in the use of their equipment. On the image acquisition side, studies have shown that the ability to scan one additional outpatient per day adds over $100,000 per year to the bottom line [1]. It makes economical sense to hire staff to keep the entire workflow moving smoothly. This is applicable not only to image acquisition, but also to post-processing. The creation of all vascular views for a CTA can take 45–60 min in untrained hands [2]. Such views are not optional, but must be created for certain cases to be billed correctly (CTA/MRA). A dedicated lab can deliver this product with a high degree of quality, reliability, and efficiency, freeing the radiologist to perform the interpretive task that he/she is trained to do. Just as ultrasound technologists are trained to obtain high-quality images for presentation to and interpretation by a radiologist, so too can post-processing technologists be trained, with benefits not only in quality, but also in throughput.

A successful post-processing service must also be scalable. Spectrum Health's lab has seen a steady trend upward in volume. Of equal importance is that the lab is pulling in business with urology, cardiology, and pediatric studies, keeping patients from going to other facilities [3]. A dedicated lab will be more capable of keeping pace with increasing volumes and changes in technology than individual radiologists. In a high-volume environment, a high demand for post-processing, quality assurance, cost-effectiveness, and scalability are all important reasons to maintain a dedicated post-processing laboratory.

Radiologists should be performing post-processing: Reuben Mezrich, MD, PhD.

Rebuttal

When 3D post-processing was first introduced in the early 1980s, it ran on special purpose processers (e.g., those made by Silicon Graphics) that were separate from the PACS workstations. The user interface was at best unfriendly, the process was time-intensive and unforgiving (mistakes required starting over), and the CT scanners had limited resolution being a far cry from the isotropic quality needed for good 3D. There was, not surprisingly, pushback by the radiologists at the time who raised all the arguments given by Dr. Juluru, including that it took time away from the important interpretive effort, and it was just “eye candy” that did not add value—partly because the resolution was limited and partly because any good radiologist could “see” the 3D picture in his head, or so they said. But it was sometimes helpful to the surgeon, and besides, there was money to be made by providing the 3D images, and so 3D labs were created that mostly focused on osseous structures (spine, complex fractures) or vascular structures (aorta, renal arteries). No radiologist input was needed in creating or interpreting these images and they were relatively easy to do since they were usually of much higher contrast than the surrounding tissue.

But technology has marched on. Modern CT scanners create submillimeter voxels by default. 3D engines live “in the cloud” and are available at any PACS workstation. The user interfaces are now intuitive and fast enough so that shapes are manipulated as if by thought. There is also much automation so that complex osseous structures and vascular systems, even coronary artery distributions can become simple presets. 3D can, and should be, at least as much of an aid to interpretation as zooming an image or changing level and window or measuring the size of a lesion (which by the way, can now be easily measured in 3D). Complex anatomy, not just bones and arteries, are better understood as volumetric structures and interpretation of disease is enhanced and often arrived at quicker when using 3D tools. 3D is no longer just “eye candy” but rather a valuable tool for the physician who needs to interpret disease and act on that interpretation. If it will be a technologist, or perhaps even the clinician who creates the 3D image, one might ask what the added value of the radiologist is in the interpretation. The clinician might correctly wonder if he can do without the radiologist's help, Dr. Juluru uses ultrasound as an example of a technology where technologists do much of the work. That is true, and that is largely what has enabled obstetricians, urologists, and cardiologists to now claim ultrasound as their own. This will happen in much of CT if radiologists do not take responsibility for creating and interpreting all of the data—even that data that is best appreciated with 3D software.

Radiologists should not be performing post-processing: Krishna Juluru, MD

Rebuttal

If only we could all be like Michelangelo—a Renaissance painter, sculptor, engineer, architect, and poet. With stone, hammer, and chisel, he was able to uncover the perfect human form. I wonder, however, how he might have done had he been asked to use an advanced visualization tool to determine the myocardial ejection fraction from a cardiac MRI or create a curved-planar reformatted image through the internal carotid artery in order to determine the degree of stenosis.

The modern 3D workstation provides more than artistic images alone. It provides data that affects patient management. Furthermore, multiple different workstations exist, and the tools are rapidly changing in functionality and usability. There is no question that these tools should be incorporated into a modern radiology practice. The question is, on whom do we place the responsibility of mastering these tools? Do we expect the radiologist to be the 'Renaissance Man' (or Woman), such that he/she is facile not only with the interpretation of imaging data, but also with the acquisition of that data, or do we entrust a group of other professionals to help in this process? Valid arguments can be made on both sides, and the specifics of the radiology practice are important. The end result, however, must be a high-quality, reproducible product that is generated efficiently.

In a small-group, low-volume setting, it may be best to operate on the renaissance-radiologist model. In a large-group, large-volume setting, however, this model will suffer from deterioration in quality and loss of operational-efficiency. As the size of a group grows, it becomes increasingly difficult to keep each member up-to-date on technological advances. It becomes progressively more difficult to update the advanced visualization tools because it requires the consensus of all the users and additional training. As the volume of the practice increases, the renaissance-radiologist model also fails in efficiency. Time spent in generating advanced visualization output is time lost in reading an additional scan. The majority of this output does not require the radiologist's personal attention to generate. Rather, it needs her input to ensure accuracy. The radiologist may not be trained in how to generate the curved planar reformatted image of the carotid artery, but once generated, he can verify that it was performed correctly and that the stenosis measurements are accurate. The same concept holds true for measurements of cardiac function, volumetric measurements of liver segments for surgical planning, calculation of brain perfusion, and many, many other image-processing tasks.

Modern image processing has gone well beyond artistic representations of human anatomy. I would suspect that even Michelangelo would have been impressed. Many gains can be realized by utilizing trained technologists for dedicated tasks, such as operating CT, MRI, or ultrasound equipment. In large-group, large-volume settings, a dedicated image post-processing laboratory ensures high-quality, reproducibility, and efficiency, and can be a profitable business model.

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