The TeraRecon Experience – A Neuroradiologist's Perspective

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Initial Exposure

My initial exposure to TeraRecon was at the 2001 RSNA meeting in Chicago, Illinois [1]. Just prior to this, our medical center had purchased two state-of-the-art multidetector Computed Tomography (CT) modalities for clinical applications. This CT technology was relatively new and mysterious to many of us at that time. The fact that the dataset just exploded from then current 10-20 thick cut axial images of a typical head CT study to several hundreds, just amazed many of us. We needed some method to simplify this data explosion into a workable form for our daily neuroradiology practice. My trip to RSNA was mainly focused to resolve this problem.

When I visited the TeraRecon booth at the meeting, I knew that this would turn out to be something special. The staff was very receptive to my dilemma and showed me their thick client Aquarius Workstation and the AquariusNET Server/Thin Client solutions. As soon as I sat down at the Workstation, I found their desktop interface friendly and pleasing to the eyes. The icons and buttons were very well displayed and easily read. I realized that not only did TeraRecon spend a lot of effort in software coding or "under the hood" development, but much effort went into the aesthetic appearance of the software as well. I was extremely impressed by the simple raw speed of the Workstation. In neuroimaging, and especially in cerebrovascular Computed Tomographic Angiography (CTA), visualizing the dataset in 3D format requires fast displaying and quick image refreshing with every rotation of the mouse.

Whereas competitive systems had delays displaying and refreshing images, the response of the Aquarius Workstation was astounding. I subsequently found out that the Workstation was driven by a dedicated, best-in-the-market, 3D graphic card called VolumePro [2]. On the other hand, competitive systems were limited by the use of off-the-shelf graphic cards. The use of VolumePro was unique to the Aquarius Workstation at that time and has been adapted in other competitive systems since then.

When I moved over to the AquariusNET (the Server/Thin-Client system), I became even more impressed. 3D visualization was no longer isolated to a corner of the room on a dedicated and yet powerful thick-client Workstation. This capability could now be located anywhere within our radiology departmental reading rooms. By using AquariusNET, physicians

can have similar 3D visualization capabilities in the form of Maximum Intensity Projection (MIP), Multiplanar Reformation (MPR), and Volume Rendering (VR) as on the Workstation. The difference is that these manipulations can be performed in an expedited manner and with significantly better ease-of-use for common everyday users. The brain of such computer data processing did not reside on a local radiologist's computer, but elsewhere along the network in the form of the 3D Server known as AquariusNET. The information was basically streamed back and forth between the Server and the local thin-client computer without much degradation of images. This streaming technology is what separated the TeraRecon system from other medical imaging systems at that time. To this day, no one has utilized this Server streaming technology as eloquently as TeraRecon.

Capital Investment

After learning about the system capabilities, I had to sit down and do some cost justification for the financial people at our institution. Obtaining our previous fiscal study volume was not difficult. The difficulty resided in the projected figures that I had to come up with regarding the system's ability to indirectly bring in additional revenues for the hospital. I wanted to be fair and yet conservative regarding this projection. The figures that I finally settled with were based on a consensus of rough estimates by one of our esteemed medical centers in the Washington-Baltimore Metropolitan region. [3]

After much persuasion, I finally succeeded in getting the system here to our medical center. The night prior to its arrival, I had some insomnia. I felt like a child on Christmas day, eagerly waiting to open presents under the tree. I was ecstatic about the things to come with the system on-hand in our medical center. My thoughts were everywhere from new clinical applications to research endeavors. I knew that this new capital investment in the form of Aquarius Workstation and AquariusNET would not fail. Indeed, I hoped that the system would rejuvenate our imaging department, as well as our medical center, and incorporate 3D into our daily practice. As far as our productivity was concerned, I could not have been more wrong in my initial projections - I would never have guessed how fast 3D has spread as a plague amongst our radiologists and referring physicians.

Initial System Setup

At our institution, we are in the midst of transitioning into Enterprise PACS. Currently, we are still in the film business, which causes much inefficiency within our workflow. However, since the installation of Aquarius Workstation and AquariusNET at the institution, several of these workflow inefficiencies have been eliminated. Presently, we have the thick-client Workstation positioned where the most high-powered users are physically located during the day. This is where most vascular imaging studies are read and where complicated post-processing is needed. In addition, each reading room is equipped with thin-client software on desktop computers that can independently access the image dataset residing on the Server. It is this thin-client / server connectivity that has made the lives of my fellow radiologists and residents much easier. Not only are the powerful basic 3D tools available to everyone within the Radiology department, but also the server acts temporarily as an image archiving site for old comparisons for the missing films not found in our film library.

Our department also has a homegrown Teleradiology system that has served as a bridge between our film-based Radiology department and a near future fully Enterprise PACS [4]. Not only has this Teleradiology system served our on-call teams at night, but also during the day it has served as an image-viewing station of old comparison archive. This system has a 2 Terabyte server, which has equated to almost 1.5 years of imaging archive currently in our department.

AquariusNET has the capability to DICOM Query this Teleradiology Server, adding an image viewing capability in addition to 3D processing capability. In fact, some people find the TeraRecon AquariusNET system easier to use than our homegrown Image Viewer System. My Neuroradiology fellow uses only the AquariusNET to view images from home and on-site in order to interact more efficiently.

Start-up Learning Curve

As I unveiled the system to my colleagues, one of my concerns was the learning curve of the AquariusNET. Most of my colleagues would have to use it on a daily basis. My concern was alleviated as soon as the application specialist sat down with me. In less than an hour, I was up and running a 3D dataset on the computer. The intent of the AquariusNET is to simplify the process of 3D image processing and viewing. I believe that the TeraRecon developers succeeded quite well. I was able to segment a carotid artery and toggle it from VR, MIP, and MPR in several clicks, and finally demonstrated in the form of rotation views in both orthogonal planes. The ease of use assured me that I would not have any problems in introducing this 3D portal to the rest of my colleagues. In fact, some of the end-users have become so proficient in it that they have yet to seek my staffs' assistance. AquariusNET from TeraRecon is a winner in my book.

The Workstation was expectably a bit more challenging. Designed with a power user in mind, it has infinitely more tools and processes built into the application. I initially felt quite overwhelmed during the application teaching. However, like my first car, it needed to be taken several times around the block until I could get comfortable. My only word of advice on the Workstation is not to let it overwhelm you. Absorb what you need in the first round of application teaching. Later, spend some time with it and you will not only become a better user, but you will also be able to generate some important questions and issues on the return trip of the application specialist a short period down the road. Then, the resolved questions will reinforce the learning process for you.

PACS Integration

For those not so lucky to have PACS at their institution, the TeraRecon system (both the Workstation and the AquariusNET) can be a freestanding system. However, if you have PACS, the system can integrate with most PACS solutions in today's market. Additionally, the TeraRecon system can serve as another layer of image archive mechanism for the short-term at no additional cost. At our institution, we have started integrating the AquariusNET in our PACS workflow for our Radiologists and residents. Our staff continues to view cross-sectional studies as they always have on PACS, but if they want to view the dataset in 3D, then the AquariusNET is launched within the PACS. In a matter of seconds, a 3D image is displayed from the dataset ready for continuing interpretation. This integration of the Thin-Client was so seamless in PACS that the Thin-Client was up within seconds upon launching without much downtime. This solution works best for us without further expenditure on an expensive but less advanced 3D package from the PACS vendor. The flexibility of the TeraRecon system, both as a free-standing and as PACS-integrated system, is the strong point for those institutions who may not be ready for a totally digital imaging department at first, but know that the system is not a throw-away if you want to move toward total digitalization down the road.

Enterprise 3D

Today's high tech world is not just about mechanics and circuitry in the modalities. I often remind myself that technology exists in everyone of us. We Radiologists naturally evolve into this "high-tech" role by the virtue of our trade. Interestingly, our referring physicians also are starting to turn hi-tech. An example of such a case is the 3D visualization of a dataset generated from a multidetector CT or thin-cut sequence from an MRI. There was a belief that 3D visualization could assist Radiologists to make better diagnosis. Well, I think that this capability can equally assist our referring physicians in making better decisions in their patient care. Thus, the dilemma exists on whether we should isolate this 3D visualization capability solely in the Radiology Department, or should we allow it beyond the departmental walls into the clinical wards, outpatient areas, ER, institutional office practices, etc. The latter notion was not feasible until the TeraRecon Thin-Client/Server system (AquariusNET) came into play.

Earlier, the 3D ability was in the form of a snapshot 3D picture sent on film or over the PACS server. If you wanted to interact with 3D images dynamically, the common answer would be to invest in expensive hardware and software at individual viewing stations around the enterprise. This solution was too expensive for any financial officer to consider as a plausible purchase for any fiscal year. The TeraR-

econ Thin Client / Server model can make all this possible within the enterprise without "breaking the bank" financially. The technology is based on the central server doing all the math and reconstruction of a dataset and then streaming the images over the network to the computer where the free Thin-Client software resides. Thus, these satellite computers with the Thin-Clients don't have to be "top-gun" stations; they can be your average Joe computers with basic hardware.

What may undermine this physical setup is not the computers and the server, but the backbone network infrastructure. As long as you have a good networking map in your enterprise, image streaming can be very fluid with every mouse movement of the 3D image on your computer display. At our institution, we currently run a mixture of 10Mbit and 100Mbit networking across the enterprise, which I think is the standard at many institutions. So far, I have not seen much problem with this setup. We are about to upgrade our network to Gigabyte for better streaming of images, but all institutions may not need this setup.

My plan is to provide this portal of 3D visualization to all corners of our institution because I think it adds another layer of armamentarium of diagnostic tools to our referring physicians. All the areas within the enterprise I allude to are important, but it should not be restricted just there. Of particular importance is the operating room where split-second decisions are sometimes made based on ever changing patient status during the procedure. I think that pre-surgical planning can be done based on the 3D dataset of whatever organs of interest are specific for the particular patient. This information can now be translated to intraoperative viewing, assisting the surgeon to complete his/her task much more easily and more accurately. I believe that the TeraRecon system can provide this portal for our colleagues to achieve their goals much more effectively.

System Application

I am always thinking of new applications for the system on-hand at our institution. Until I can achieve my goals of bringing 3D to the mass audience within our enterprise, I utilize what I have to bring medical care into the forefront. I would like to share with you several experiences in which I applied the system to my advantage.

Our institution is one of the major neurovascular medical centers in the area. It is very common for patients to get referred here for advanced medical care. One night, when I was on-call with my fellow physician, a patient with subarachnoid bleed was transferred to our medical center overnight. Our neurosurgical house officer ordered a Computed Tomographic Angiogram (CTA) of the head for initial examination. It was initially interpreted by our in-house radiology resident as a right middle cerebral aneurysm. Until CTA is proven in literature to be a trusted substitute for Digital Subtraction Angiogram (DSA), our neurosurgical colleagues will order DSA in conjunction to CTA for absolute diagnosis as is common in most institutions [5].

Upon arriving early the next morning, I went over the CTA study. The patient indeed had an aneurysm where it was initially interpreted by the house staff. Interestingly however, this aneurysm location did not fit with the pattern of subarachnoid hemorrhage on-hand. Upon further review on the Aquarius Workstation using several powerful visualizing tools, I was able to find a much smaller Anterior Communicating Artery (ACom) aneurysm that was indeed barely perceptible in the source images or MPR images. It was only in VR 3D format that I was able to see it clearly and distinctively. I communicated this new finding to the neurosurgical house staff and attending surgeons, as I believe this was the "presenting aneurysm" instead. An hour later, I started performing the DSA of this patient. I was able to obtain multiple views as best as I could, given that the patient was not very cooperative during the exam. I also performed 3D rotational DSA, but that did not turn out diagnostic. Thus, the best demonstration of this aneurysm resided in 3D CTA dataset best demonstrated on the Aquarius Workstation. This really intrigued the neurosurgeon because he (and many others)

had always heralded DSA as the "gold standard" in neurovascular work.

Based on the Workstation findings, the neurosurgeon went ahead and scheduled the surgery for the anticipated clipping of the ACom aneurysm. After performing a craniotomy, he and his chief resident assistant explored the region where they thought the aneurysm would be located using standard neurosurgical landmarks. After trying for almost 2 hours, they were not able to find this evasive aneurysm on the standard view. He then paged me to the OR to discuss my certainty of this aneurysm that was only best demonstrated on CTA. I told him that I was very certain of my initial finding and that he should not abandon his search.

At that moment, I thought of utilizing the AquariusNET in the OR. I brought my laptop computer to the OR and hooked in the hospital network jack. I was connected to the TeraRecon 3D Server in no time. I quickly generated and displayed a volume rendered 3D image using the captured scene I previously saved on the workstation and sent over to the server (this is indeed a great time-saving tool). Next, I displayed the 3D VR image in an angle similar to the neurosurgeon's perspective at that moment in the patient. Using the tools on the AquariusNET, I was able to measure distances from certain vascular landmarks that the neurosurgeon can correlate with clinically. After much effort from his part and my on-site visualization guidance on my laptop, he was able to find this small aneurysm. Indeed, the aneurysm was hidden behind a major artery, which was also demonstrated on CTA. This small aneurysm was subsequently clipped, and soon after, the patient was back to the Neurosurgical Intensive Care Unit. The neurosurgeon was really impressed with the technology and was very glad of my assistance. He was hopeful that we would work together on such cases in the future utilizing this technological advancement in mobile medical imaging.

A second situation pertains to the power of the system applying Remote Access technology through the use of High Speed Internet (Cable Internet, Digital Subscriber Line (DSL), Satellite DSL, T1, T3, etc.). This allows an individual to apply the Thin Client / Server system from outside the institution through a secured Virtual Private Network (VPN) connection. I had a chance to utilize this capability one night.

It was a recent Thanksgiving Holiday and I was with my family at a dinner event away from my home. Late in the evening, a stable patient was admitted into the hospital with unilateral 3rd Cranial Nerve ophthalmologic symptom suggestive of an underlying unruptured aneurysm. The neurosurgical house staff called me to discuss the situation and I suggested a CTA that night to learn about the patient's clinical stability. At this point, I was driving home with my family in typical holiday traffic. When I got home, I immediately logged onto the hospital network using our VPN connection. Since I have DSL at my residence, I made some alteration in data streaming compression to take into account the bandwidth of the high speed Internet. By using AquariusNET, I was able to review the CTA in 3D formats and detected a suspected aneurysm. The tools at hand allowed to me to accurately measure the size of the aneurysm proper and neck, which are important for decision-making. I reported back to the house staff and that immediately set into motion the surgical care plan for the following morning.

Next morning, I processed the CTA officially on the Aquarius Workstation in-house. The images were astounding. I showed both the attending Neurosurgeon and his Chief Resident the images both on the Workstation high-resolution display and color printouts. They were indeed impressed! I went ahead and tried to do the DSA for CTA correlation as our Neurosurgeons are still skeptical about this new technology (this may change however soon enough after this incident). However, that morning, the patient was very combative, and as a result, we were unable to get a very good DSA study. As a matter of fact, CTA images produced on the Workstation gave them all the information they needed to schedule surgery that morning. Postoperatively, the neurosurgeon told me that the aneurysm's morphology and location were exactly where I showed them on the CTA on the Aquarius Workstation. I am glad I was able to provide good service professionally without much sacrifice of family life in this particular setting.

Conclusion

In conclusion, I want to stress that good patient care can be achieved by utilizing modern technology, as exemplified by the use of Aquarius Workstation and AquariusNET by TeraRecon Inc.

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