

# 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. Thus, my trip to RSNA was mainly focused to resolve this problem.

When I visited the TeraRecon booth at the meeting, I knew this would turn out to be something special. The staff were very receptive to my dilemma and showed me their thick client Workstation and the Server / Thin Client solutions. As soon as I sat down at the Workstation, I found their desktop interface relatively friendly and pleasant to the eyes. The icons and buttons were very well displayed and easily read. I saw much effort went into the esthetic appearance of the software just as much as the application’s coding “under the hood” developments. But, what really impressed me was 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.

The response of the Workstation was astounding as compared to other competitive systems where there were delays in image display refreshing rate. All these findings became obvious to me when I subsequently found out that Workstation was driven by a dedicated best in the market 3D graphic card called *VolumePro* [2], unlike other systems where 3D visualization were software driven and were limited by the off-the-shelf graphic card. This was indeed unique to the TeraRecon Workstation at that time and has been adapted in other competitive systems since then.

When I moved over to the Server / Thin Client system, I became even more impressed. Suddenly, 3D visualization no longer was isolated to a corner of the room on a dedicated and yet powerful thick-client Workstation. This capability can now be anywhere within our radiology departmental reading rooms where Dr. X and Dr. Y can have these same 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 local computer thin-client 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**

Knowing of the system capabilities, I now had to sit down and do some math for cost justification for my financial people at our institution. Obtaining our previous fiscal study volume that required 3D capabilities were not that 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, as this wasn't done in a very widespread manner up to that time. I wanted to be fair and yet conservative regarding this projection because realistically, I didn't want to fail with this capital investment by excessive final projections. 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 several tries, I finally succeeded in getting the system here to our medical center. The night prior to its arrival here, I actually had some insomnia. The cause of this was not over anything complicated that one would face in the business world of healthcare. Instead, the feeling was one metaphorically described as a child on Christmas Day prior of opening all the toys under the tree. I basically was ecstatic about the things to come with the system on-hand in our medical center. My thoughts were basically everywhere from new clinical applications to research endeavors. I knew this new capital investment in the form of the TeraRecon Workstation and Thin-Client / Server system would not fail here. As a matter of fact, I hoped the system would rejuvenate our imaging department, let alone our medical center, to incorporate 3D into our daily practice. So far as I looked at our productivity, I could not have been more wrong in my initial projections as 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 currently in the midst of transitioning into Enterprise PACS. Currently, we are still in the film business, which in itself provides much inefficiency within our workflow. However, since the installation of the TeraRecon Workstation and Server 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. Currently, that location is near where I reside and where the staff attends to consultations with the referring clinicians. In addition, each reading room is equipped with thin-client software on desktop computers,

which independently can access the image dataset residing on the Server. It's this thin client / server connectivity that has made the lives of my radiology attendings / fellows / 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 those missing films not found in our film library for various reasons commonly seen in a non-digital imaging department.

We also have within our department a homegrown teleradiology system that has been a bridge for us from a film department to a near future fully Enterprise PACS [4]. Not only has this system served as a teleradiology system for our on-call teams by night, but also during the day it has served as imaging viewing stations of old comparison archive. In essence, this system has a 2 Terabyte server, which has equated to almost 1.5 years of imaging archive currently in our department. With TeraRecon's AquariusNET server in place, the thin client system has the capability to DICOM Query this Teleradiology Server, adding an image viewing capability in addition to 3D processing capability. As a matter of fact, some people find the TeraRecon thin-client system easier to use than our homegrown Image Viewer System. My Neuroradiology Fellow actually only uses the thin client to view images from home and on-site as he found he can interact more efficiently.

### **Start-up Learning Curve**

One of my concerns was how am I going to unveil this system to my colleagues, especially the Thin-Client as this is the interface they will interact with most in their workflow. Well, my concern went by the wayside as soon as the application specialist sat down with me. Literally, within less than an hour of my time, I was up and running a 3D dataset on the computer. The intent of the Thin-Client was to simplify the process of 3D image processing and viewing in which I believe 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, with final demonstration in the form of rotation views in both orthogonal planes. The ease of use was my key in knowing that I will not have any problem in introducing this 3D portal to the rest of my colleagues for their usage. As a matter of fact, some of the end-users have become so proficient in it that to this day they have yet to seek my staff's assistance. This Thin-client product is a winner in my book.

The Workstation of course was expectably a bit more challenging. Since this thick-client was designed with a power user in mind, it has infinitely more tools and processes built into the application. I initially felt very overwhelmed during the application teaching. However, like your first car, it needed to be taken several times around the block until you can get comfortable in the long haul. Such feeling I felt with the Workstation initially, but the more I interacted with it, the more it became clearer to me. My only word of advice on the Workstation is not to let it overwhelm you. Instead, absorb what you need in the first round of application teaching. Afterward, spend some time with it and you will not only become a better user, but you will 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 act as better reinforcement to the learning process for you.

### **PACS Integration**

For those not so lucky to have PACS at their institution like us initially, the TeraRecon system, both Workstation and Thin client / Server, 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 redundancy for the short-term at no additional cost or resource to your hospital budget or networking highway, respectively. At our institution, we have started integrating the thin-client in our PACS workflow for our Radiologists and Residents. Our staff would continue to view cross-sectional studies as they always have on PACS, but if they wanted to view the dataset in 3D, then the TeraRecon Thin-Client would be launched within 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 from the hospital for a 3D package from the PACS vendor that is much more expensive and less advanced. The flexibility of the TeraRecon system, both as a free-standing and as PACS-integrated system, is the strength point for those institutions who may not be ready for a totally digital imaging department at first, but knowing that the system is not a throw-away if you want to move toward such status down the road.

### **Enterprise 3D (Figure 1)**

In today's high tech world, we must not forget it doesn't stop at just the mechanics and circuitry in the modalities. I often must remind myself that it exists in everyone of us. Radiologists naturally evolve into this "high-tech" role just by the fact of our trade. But, our referring physicians also are starting to earn this similar label. Such a case can be said to 3D visualization of a dataset generated from a multidetector CT or thin-cut sequence from an MRI. It used to be said that 3D visualization can assist Radiologists to make better diagnosis. Well, I think this capability can equally assist our referring physicians do make 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. This latter notion was not possible until the TeraRecon Thin-Client/Server system came into play.

The 3D ability beforehand was in the form of snapshot 3D picture sent on film or over the PACS server. If you want to interact with 3D images dynamically, the common answer used to be to invest in expensive hardware and software at individual viewing stations around the enterprise. This solution was simply too expensive for any financial officer to consider as a plausible purchase for any fiscal year. The TeraRecon 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, but can be your average Joe computers with basic hardware that most enterprises configure these days.

What may undermine this physical setup is not in the computers and 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 10Mbps and 100 Mbps networking across the enterprise, which I think is the standard at many institutions. So far, I haven't seen much problem with this setup. We are about to upgrade our network to Gigabyte which will only make things better for streaming images, but may not be necessary for all institutions out there who are considering such similar 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 being made based on ever changing patient status during the procedure. I think 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 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 achieve my goals of bringing 3D to the mass audience within our enterprise as that takes much commitment from the institution as a whole, I utilize what I have to bring medical care into the forefront. Thus, I would like to share with you several situations in which I applied the system to my advantage.

At our institution, we are one of the major neurovascular medical centers in the area. Thus, it is very common that patients get referred here for further higher care. Such a case was one night when I was on-call with my fellow when 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 similar in most institutions [5]. Upon arriving in-house 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 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 very uncooperative during the exam. I also performed 3D rotational DSA, but that also didn’t turn out diagnostic. Thus, the best demonstration of this aneurysm resided in 3D CTA dataset best demonstrated on the TeraRecon workstation. This really intrigued the neurosurgeon as to him and many others, DSA has always been heralded as the “gold standard” in neurovascular work.

So, basically, 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 going at it for almost 2 hours, they weren’t able to find this evasive aneurysm on standard view. He then paged me to the OR to discuss my certainty of this aneurysm that was only best demonstrated on CTA. I basically told him that I was very certain of my initial finding and that he shouldn’t abandon his search. At that moment, an idea came to me in the form of utilizing the Thin Client in the OR. I went and got my laptop computer, which has this software installed in it. I brought my laptop computer to the OR and hooked in the hospital network jack and boom! 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). I then 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 thin-client, 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 very hopeful that we maybe involved in future cases together utilizing this technological advancement in mobile medical imaging.

A second situation really 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 apply such capability one night. Such night was on a recent Thanksgiving Holiday where I was with my family at a dinner event removed from my home. Late in the evening, a stable patient was admitted into the hospital with unilateral 3<sup>rd</sup> Cranial Nerve ophthalmologic symptom suggestive of an underlying unruptured aneurysm. The neurosurgical house staff called me to discuss of the situation and I suggested a CTA tonight so we would know what we were sitting on

with the patient completely stable clinically. At this point, I was with my family driving home in somewhat typical holiday traffic for this metropolitan area. 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 this type of high speed internet. I was then able to review the CTA in 3D formats and detected a suspected aneurysm through the use of the TeraRecon thin-client. 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 that night for the following morning.

Next morning, I processed the CTA officially on the TeraRecon Workstation in-house. The images were astounding as I showed the Neurosurgeon attending and his Chief Resident the images both on the Workstation high-resolution display and Color printouts. They were very impressed indeed! 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). However, this patient that morning was very combative, and as the 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 gave me feedback that the aneurysm's morphology and location were exactly where I showed them on the CTA on the TeraRecon system. The moral of this story is that good patient care can still be achieved by utilizing modern technology that the TeraRecon Workstation + Thin-Client / Server model provide for the modern day radiologists. I am glad I was able to provide good service professionally without much sacrifice of family life in this particular setting.

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