

Multimodality Imaging and Image-Guided Surgery

Advances in imaging provide physicians with the confidence to confront procedures previously thought impossible.

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Imaging plays a critical role in the medical management of nearly every type of pathology. Clearly, the decision to perform an intervention or surgery is heavily based on the interpretation of the relevant anatomy as determined by a variety of imaging technologies. Advances in the field of imaging frequently outpace clinical applications. Today, it is possible to discern detailed anatomic features to the submillimeter level and to assess physiologic conditions, relative amounts of blood flow, and the potential for malignancy using sophisticated techniques. Yet, many of these studies require multiple modalities, or alternatively, require the clinician to interpret the results of several types of assessments before embarking on a given form of therapy.

MULTIMODALITY IMAGING

Multimodality imaging refers to the synthesis of data acquired from multiple imaging modalities. Most commonly, the term refers to exploiting synergies between anatomic modalities such as CT, and functional modalities such as positron emission tomography (PET). Fusion images allow clinicians to differentiate tissue types using functional data within the context of excellent spatial resolution.

PET accomplishes its functional assessment by using a radiotracer, in which a positron-emitting moiety is paired with a biologically active molecule. With the use of fluorodeoxyglucose, for example, areas with high glucose metabolism, such as tumors, concentrate the radioisotope and show up as “hot spots.” PET scans are commonly used to assess for malignant disease, yet recent research continues to identify different biological targets, and we review advances in the field of vascular disease. PET has made a dramatic impact on our ability to assess coronary artery

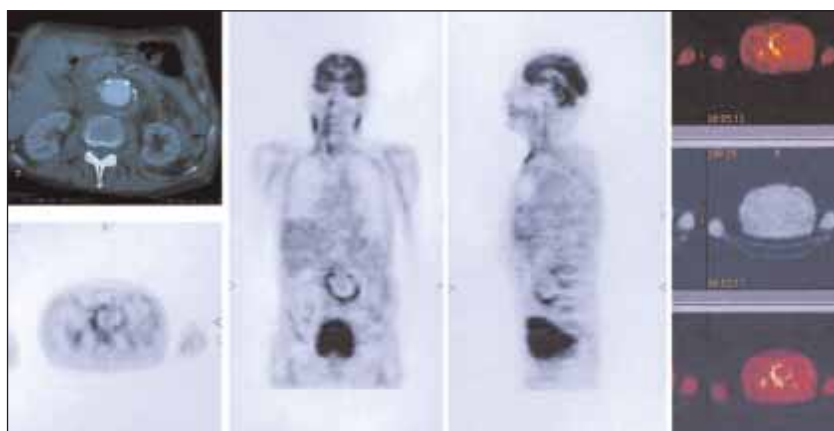


Figure 1. This partially ruptured abdominal aortic aneurysm is characterized by increased metabolic activity of the aneurysmal wall as evidenced by positive PET imaging. On the right side, the upper image corresponds to the emission image, the second image is a transmission image area, and the third image is a fusion of the two previous images. (Reprinted with permission from Sakalihasan N, et al. *Eur J Vasc Endovasc Surg*. 2002;23:431-436.¹)

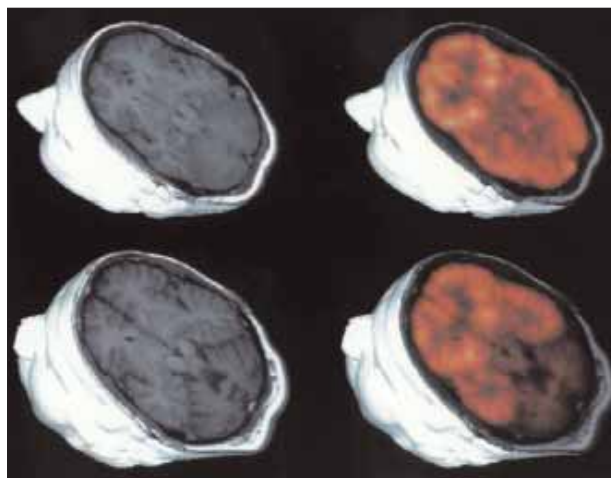


Figure 2. Normal and cerebellar ataxia subject, merged MRI/PET scan. (Reprinted with permission from Rehm K. Visualization in medical imaging. Course notes. Spring, 2002.²⁾

disease and the need for revascularization.³ It has been shown that PET can be used to assess the tendency of abdominal aortic aneurysms to expand and/or rupture (Figure 1).⁴ Inflammation within carotid plaques can be targeted, and this principle has been applied toward the assessment of carotid disease and risk for stroke.⁵ Similarly, this concept has been applied to the use of PET in diagnosing vasculitis.⁶ By targeting the components of a clot, it is speculated that PET could be applied to the diagnosis of deep venous thrombosis.⁷ The role of PET in plaque detection will be expanded as methods are developed that target specific plaque components.⁸⁻¹⁰

The power of multimodality imaging is realized fully only after the fusion of images from different modalities. This allows anatomic features to be correlated, which is an essential part of interpreting one image in the context of another. Registration is a necessary step in effectively interpreting multimodality images. Hardware fusion, in which images of different modalities are acquired in a single session and in a common reference frame, requires specialized equipment. PET/CT fusion scanners provide an excellent example. But, what about PET/MRI, which is currently infeasible for technical reasons related to the magnet? The two images will be misaligned because they were acquired in different sessions.

CURRENT CHALLENGES

Software fusion refers to the registration of images in which visual structures (objects and edges) in one image are aligned with structures in the corresponding images. Registration is the only solution to fusing modalities such as PET/MRI. Image registration remains an active area of research, in part due to the inefficiency of current imple-

mentations (approximately 30 minutes for 3D to 3D registration) but also to extend the concept of registration to correlating radically different images: high- and low-resolution images, images with different dimensions, and real and virtual images.

An essential aspect of image acquisition is the contrast protocol. With the advent of multimodal technologies, the benefit of a single agent that produces contrast in more than one imaging modality has been recognized. Researchers have designed dual optical/MRI contrast agents using visible wavelength fluorophores and gadolinium chelators conjugated with dextran.¹¹ Also, investigations into nanoparticles promise to deliver simultaneous MRI, ultrasound, and fluorescence contrast.¹² The potential to link renal dysfunction with renovascular issues, further delineate causes of hepatic failure, and detail the neural pathways in several psychological disorders depends on the development of these technologies.

Visualization of the data acquired during image acquisition is often overlooked. Workstations with improved three-dimensional rendering views have already made a considerable impact; however, the interpretation of large amounts of volume data challenges radiologists and clinicians alike. Current strategies for displaying more than one modality at a time in a clinically useful manner include color-map overlay (Figure 2), volume-on-slice overlay (Figure 3), and side-by-side display. As sophisticated as these imaging studies may appear, the results are typically displayed in a rather primitive manner, largely because clini-

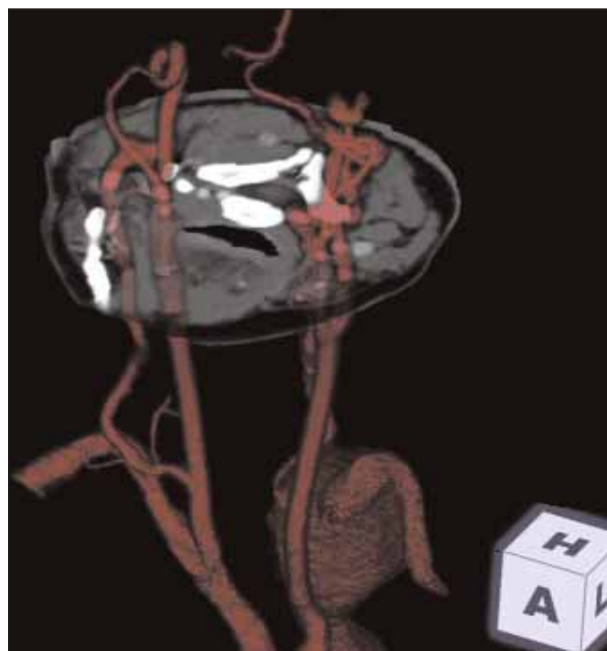


Figure 3. Fluoroscopy image with volume-rendered CT data overlaid.



Figure 4. A CT-like image acquired with the Siemens DynaCT (Siemens Medical Solutions USA, Inc., Malvern, PA). (Reprinted with permission from Smyth JM, et al. *Biomed Imag Intervent J.* 2006;2:e48.¹³)

cians remain most comfortable with two-dimensional data presentation. Advances in image postprocessing promise to aid in converting bulky volumetric datasets into streamlined analytical models that are more easily processed and visualized.¹⁴ As new methods are developed to convey the extremely large amounts of anatomic and physiologic data that can be acquired, perception by physicians will have to evolve.

FLUOROSCOPY AND CT

Traditional fluoroscopy provides real-time, high-resolution, low-contrast images in two dimensions through the use of an image intensifier. The development of a flat-panel detector to replace the image intensifier has enabled fluoroscopy to transition into three dimensions, producing a CT-like image (Figure 4). The contrast resolution of CT is approximately 1 Hounsfield unit (HU), whereas the contrast resolution of a CT-like image is around 10 HU.¹³ Note that CT fluoroscopy is not meant to replace diagnostic CT but to be used as a tool that will supplement interventional procedures.

The ability to acquire data in three dimensions during an intervention has led to the fusion of three-

dimensional datasets with the two-dimensional images displayed on typical monitors. The C-arm is used to rapidly rotate, obtaining serial images of the area in question in a radial fashion. The three-dimensional reconstruction can be registered with subsequent real-time fluoroscopic images and projected to offer the clinician the ability to work in three dimensions. The process by which the image is registered and displayed is the subject of considerable research efforts on the part of many imaging equipment manufacturers. Data can be rendered volumetrically and overlaid on the fluoroscopic image, making the anatomy much more identifiable, a fused two-dimensional/three-dimensional dataset can be created, or the information can be placed side by side.

IMAGE-GUIDED LAPAROSCOPY

Laparoscopic surgery is the display of the operative field using real-time video.¹⁵ The laparoscopic surgeon frequently "memorizes" a preoperative image to navigate toward a tissue of interest. A recent advancement is the availability of intraoperative imaging, such as ultrasound, that the surgeon correlates with what is appearing on the laparoscopic display screen. As an example, Ukimura et al¹⁶ have demonstrated the feasibility of using transrectal ultrasound to guide laparoscopic navigation in radical prostatectomy.

Another example relates to the interpretation of normal tissue versus that of tumor. This is traditionally accomplished with the use of preoperative imaging modalities such as CT, coupled with pathologic examination of specimens during a procedure (frozen sections). During a laparoscopic procedure, the surgeon must recall the details of the image in order to navigate. One improvement is the real-time registration of the two-dimensional image from the laparoscopic camera with the preoperative three-dimensional modality. This simple approach restores the connection between what is imaged before surgery and the actual anatomy that confronts the surgeon.¹⁷

CT-guided laparoscopic surgery is the real-time registration of laparoscopic instrumentation with intraoperative CT. By correlating the tracking of the instrument to the location of a lesion on a dynamically acquired CT image, the surgeon can benefit from an awareness of where the instrument should be directed. We now have three views: the preoperative CT in three dimensions, the laparoscopic camera view in two dimensions, and the intraoperative CT-like image in three dimensions. Progress must still be made in the real-time registration of incoming three-dimensional data with two-dimensional video images from the laparoscope.¹⁸

CONCLUSION

Advances in imaging will provide surgeons and interventionists with greater confidence to achieve successful outcomes as well as confront additional types of procedures previously thought impossible. We discussed specifically the role of multimodality evaluation in preoperative planning and patient selection as well as the currently unknown potential of C-arm CT fluoroscopy to improve navigation. The everyday utility of these dramatic developments, however, remains to be seen. ■

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