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Special Contribution

Evolving Technologies in Interventional Radiology : A Look into the Future

Krishna Kandarpa, MD, PhD
Radiologist-in-Chief, U Mass Memorial Medical Center, Professor and Chairman Department of Radiology
The University of Massachusetts Medical School

[Abstract]

In the West, chronic ailments such as cancer, and cardiovascular, neurological, and musculoskeletal diseases, will continue to drive medical developments for the foreseeable future. Our visualization of the future includes applications that palliate or preferably cure these diseases.

It is highly likely that the use and preference for imaging modalities will change with time. Imaging will evolve to provide both morphologic and functional definition of normal and diseased states so that the term 'image-guided' therapy might be soon replaced by the term "information-guided" therapy. Many exciting new devices and techniques are being developed and tested. However, one can never be certain when, and which, 'disruptive' technology will result in a fundamental paradigm shift in the practice of interventional radiology.

Key words : **Interventional Radiology, Image-guided therapy, Imaging-modalities, Functional imaging, Therapeutic devices**

Introduction

Looking into the future is a difficult ordeal ; leave alone predicting which new interventional technologies and procedures will become predominant. Wilbur Wright, who at the time was so close to inventing a technology that has influenced the course of human history, himself wrote : "I confess that in 1901, I said to my brother Orville that man would not fly for 50 years…. Ever since, I have distrusted myself and avoided all predictions." The author of this article will be no less humble about making predictions.

It was not long before the invention of flying machines, that Wilhelm C. Roentgen discovered x-rays and produced the now ubiquitous vague radiograph of the bones of his hand. In little over a hundred years, this very same technology, with the help of developments in electronic computers and mathematics, has given us multi-detector computed tomography and high-resolution 'freeze-frame' pictures of the beating human heart[1]. When a mere ten years ago, catheter-directed angiography was done routinely to study the vessels of the brain, heart, and body, today CTA (computed tomography angiography) and MRA (magnetic resonance angiography) are displacing this "invasive" modality with their improving ability to produce the exquisite three-dimensional vascular roadmaps familiar to many radiologists.

Interventional Radiology (IR), for all its rapid development and growth, is still indeed a relatively young field. And despite its youth, it has become the victim of its own success 2)-loss of turf is common and this will continue 3). Interventional radiologists often seed and grow an idea, device, or procedure? but when success arrives, the procedure is often selected away by the competition. Competition from other specialties is not necessarily bad as it can even serve as a stimulus for innovation and progress. The task ahead for IR is not to regret, but to innovate and to stay ahead of its unrelenting competitors.

Building on Success : Responding to Changing Patient Expectations with Technological Innovations

The issues concerning current limitations of IR technologies were discussed in a recent article[4]. First, most procedures are still based purely on anatomical information only. Second, guidance is primarily via two-dimensional images (projection x-ray or ultrasound), with the only robust real-time guidance being x-ray fluoroscopy. Third, devices are designed to provide "anatomic" or "morphologic" therapy (balloon angioplasty, bare stents, bland embolic agents) and do not, for the most part (an exception may be the

measurement of pressure gradients pre- and post-angioplasty) take pathophysiology into consideration. In addition, current drugs that are delivered to specific vascular beds for intended local action often results in remote complications because they are non-specific (e.g., gastrointestinal bleeding during peripheral arterial thrombolytic therapy). Finally, real-time assessment of treatment end-points is virtually non-existent and only rare, often weak, surrogates (e.g., cessation of flow following tumor embolization) serve as clues.

In the West, chronic ailments such as cancer, and cardiovascular, neurological, and musculoskeletal diseases, will continue to drive medical developments for the foreseeable future. Thus, our visualization of the future includes applications that palliate or preferably cure these diseases. It is likely that the use and preference for imaging modalities will change with time. Imaging will evolve to provide both morphologic and functional definition of normal and diseased states-such that the term 'image-guided' might be soon replaced by the term "information-guided" [4].

X-ray fluoroscopy has recently come under the scrutiny of regulatory agencies and the public. On December 17, 2002, The Daily Telegraph, a London newspaper, headlined : "Surgeons save Amy from X-ray dangers" and went on to describe how MR guidance was used in combination with minimal fluoroscopy to diagnose and treat a 'heart defect' sparing the four year old a "substantial dose of x-ray radiation." Reports such as these and informed web-savvy patients are creating a demand (dubbed as consumer 'pull') for non-ionizing imaging modalities and the equipment manufacturers are responding (providing the technological 'push'). Thus, with the coincidence of 'consumer pull' with 'technological push', one can foresee an increasing use of modalities, such as ultrasound, MR, and perhaps even optical coherence tomography, which avoid ionizing radiation all together.

Magnetic resonance and ultrasound imaging can each provide multi-planar real-time imaging and guidance. In the future, combined multi-modality imaging will provide anatomical, functional (tissue perfusion, diffusion, temperature, motion, and electrical activity), or pathophysiological (tumor viability, vulnerable plaque) information. For instance, combining CT with positron emission tomography (PET) is emerging as one means of assessing therapy with both anatomic (CT) and functional (PET) endpoints[5,6].

As new imaging modalities enter our armamentarium, new device tracking and navigation technologies will be developed and suitably optimized.

Devices themselves may evolve to become lesion-specific and customized-accommodating not only for in situ anatomy, but also to local physiology, tissue mechanical properties, and transport phenomena (e.g., heat transfer, diffusion). Clearly, drug-eluting stents are a move in this direction. Some of these therapeutic devices will be 'smart'-sensing the local environment and responding to any changes (e.g., in local compliance, or to trigger release of agents at therapeutically optimal times). Drugs and therapeutic agents that have lesion specific activity will be developed to avoid undesired remote consequences. Techniques will be developed to overcome traditional obstacles such as the blood brain barrier or to enhance entry into selected cells[7].

Finally, much has been written about the interventional room of the future. Such innovative thinking will result in a radical ergonomic re-design of most procedure suites. These suites will certainly include medical robots and advanced information systems[8]. A "smart-PACS"-might be envisioned that will provide the desired information to the interventionalist simply by monitoring the movements of the physician's eyes — the eyes may replace the mouse-click!

The Evolution of the Interventional Procedure

In considering developments that will affect the way we perform interventions, it is perhaps useful to organize them in terms of the tasks one goes through to provide minimally invasive diagnosis and therapy : 1) access and introduction of devices, 2) device visualization and navigation to the target, 3) lesion visualization, 4) delivery of therapy, and 5) monitoring of the adequacy of the treatment (endpoints). In adopting this approach for the discussion, it is difficult to separate the concomitant evolution of therapeutic devices and imaging modalities (especially MR) since both are constantly modified to optimize the performance of the therapeutic procedure.

Access, Device Introduction & Visualization, and Navigation

Although there are many more imaging modalities today than during the nascence of interventional radiology (when only x-ray fluoroscopy was available), none of these new modalities can presently replace x-ray fluoroscopy. None of them can provide a "one-stop" means for adequately visualizing devices both during access & introduction and during navigation to the target; fluoroscopy often remains the modality of choice for these multiple tasks.

Ultrasonography is often used for directly accessing vessels and lesions in solid organs, but generally

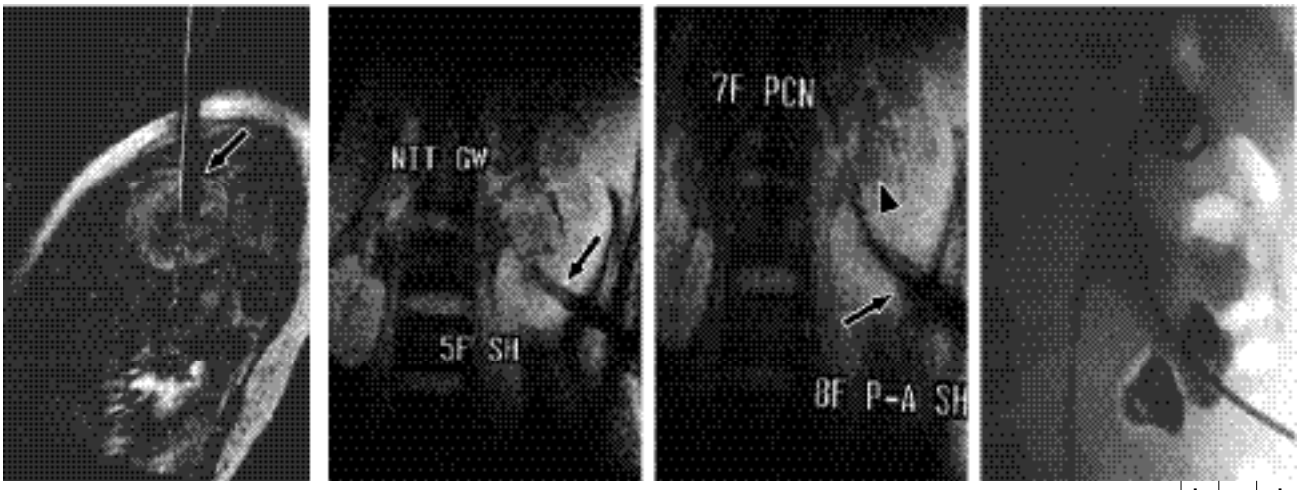


Fig.1 Passive needle artifact (arrows) shows needle tip in lower-pole renal calyx and interactive planning tract (delete) a | b | c | d

a : Placement of percutaneous nephrostomy tube with interactive MR-guidance : The artifact is created by the susceptibility of the 22 g MR-compatible needle and displacement of adjacent tissues.

b : Following access to the lower-pole calyx, a 5-French coaxial micro-puncture sheath (5 FSH) and Nitinol guidewire (NIT GW) are curled in the renal pelvis. The micro-catheter and indwelling dilator are well visualized (arrow), whereas the Nitinol wire is not visible.

c : 8.5-French peel-away sheath, sheath dilator (arrow), and hydrophilic guidewire (arrowhead) in place. The components are well visualized but not easy to differentiate.

d : 8-F Nephrostomy tube are placed and locked, but the tip position is difficult to determine except by x-ray contrast study. (Reprinted with permission from Reference 10 ; Courtesy : K. Kandarpa, MD, PhD.)

speaking once the needle is introduced, the visualization of guide-wires and catheters becomes difficult since they weave in and out of the imaged volume. Even so, devices themselves are not imaged with the same resolution inherent to x-ray fluoroscopy. Ultrasound has been touted as a modality for performing office-based angioplasty procedures, but this is not common practice. Nevertheless, it is used for guiding simpler intravascular procedures such as leg varicose vein ablations.

Visualization of needles with MRI may be passive or active. Passive visualization relies on the MR susceptibility artifact created by the needle material and by the displacement of adjacent tissues[9]. The 'visualized' needle is often several times the diameter of the actual needle **(Fig.1)**. In addition to this, a tip artifact (that can be subtracted with soft-ware manipulation) is created depending upon the orientation of the needle relative to the B0 magnetic field[9]. Today, with rare clinical exceptions, although one is able to quite successfully perform biopsy and drainage procedures modeled after computed tomography techniques, the latter modality is by far more efficient and cheaper.

Handheld optical navigation/guidance devices have long been available for mounting 'rigid' MR-compatible needles that are visualized coursing through MR image volumes (by cross-registering the device frame-of-reference with that of the scanner)[10]. Unfortunately, in reality needles often bend as they course through tissue planes, so such devices are not useful for navigating flexible guide-wires and catheters. Although, the passive visualization of needles with MRI may be sub-optimal, there are niche uses for such devices for accessing lesions in the head and abdomen (e.g., lesions high in the liver dome). Visualization of passive-artifact devices may be further enhanced by the use of near real-time of fast MR imaging. Wacker et al.[11] has developed a MR-tracking method using a true FISP (fast imaging steady state precession) sequence on a 0.2T scanner (Siemens Open Magnetom) and obtained near real-time images at 1frame every 1.3 seconds to guide a needle (susceptibility-based artifact without a tag) into a liver dome lesion (delineated well only by MRI). This group has used passive device tracking with near real-time imaging for placing biliary drainage catheters in humans[12].

Passive visualization can be enhanced through the incorporation of paramagnetic markers, such as dysprosium oxide, that produce a localized susceptibility artifact on devices such as guide-wires and catheters. Bartels and colleagues[13] have used such 'tagged' devices to demonstrate balloon angioplasty of swine aortas under MRI guidance using contrast-enhanced (Gadomer-17, a blood pool agent) MR fluoroscopy (Philips 1.5T) at one frame per second **(Fig. 2)**.

Active coils are technically more sophisticated and

function as local antennae and have been placed on catheters for tracking them under MR-guidance[14, 15]. They may also be useful for producing local images as described further below. Some of these MR active catheters have evolved to provide continuous intravascular guidance for carotid stent placement in swine[16, 17].

Although high-speed MR (fluoroscopic) imaging is being developed in the lab to help with "near real-time" visualization and navigation of devices, conventional MR images (and images from other modalities) are also being incorporated with x-ray fluoroscopy to provide multi-modality guidance roadmaps for interventions **(Fig.3)**. At Guy's hospital in London, for example, segmented 'translucent' 3-D MR images of the heart are superimposed on the x-ray fluoroscopic image by automated registration utilizing optical tracking of the patient and imaging systems.

The use of complimentary multi-modality image roadmaps is not confined to x-ray-guided navigation alone. Electromagnetic field (EMF) tracking is being investigated at the NIH as a potential tool for navigating devices utilizing previously acquired images that are cross-registered to the EMF using external fiduciaries on the subject. The EMF may be also used for steering and deflecting appropriately designed devices (for example RF probes to ablate lesions or endovascular guidewires).

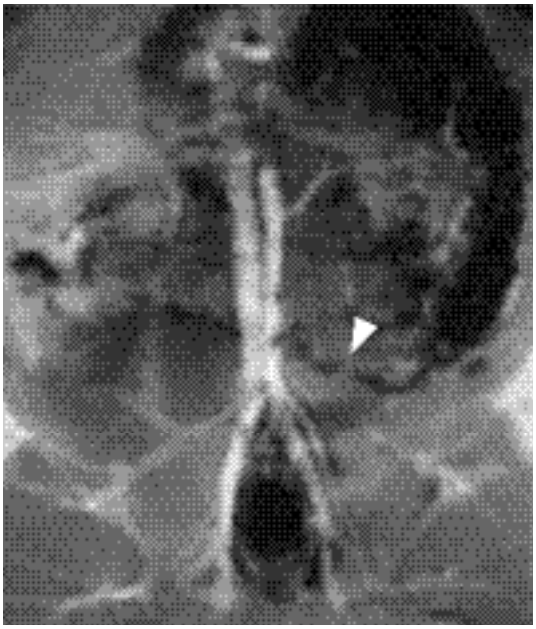


Fig.2 One frame from a series of dynamic passive tracking images, acquired in a pig after administration of an intra-vascular contrast agent. The paramagnetic ring markers on the fiberglass guide wire as well as the vasculature (aorta and IVC) are clearly visualized. (Reprinted with permission from Reference 13 ; Courtesy : Drs. LW Bartels and CJG Bakker)

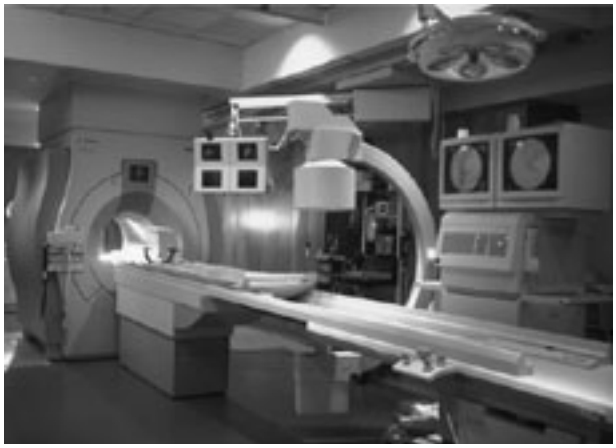


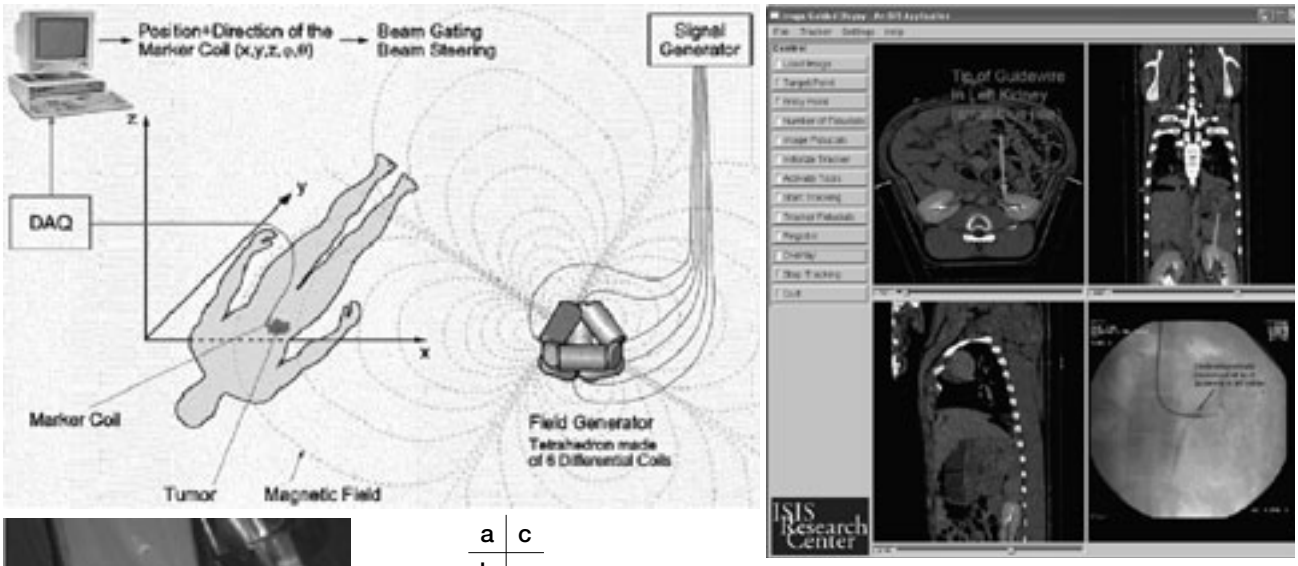
Fig.3 Philips XMR : A 1.5T MRI Scanner is installed co-axially with a digital subtraction angiography unit. The combination is beneficial for introducing and navigating catheters and guidewires under fluoroscopy while monitoring therapy with MRI. (Courtesy : Philips Medical Systems)

In this system, the subject (with external fiduciary markers) is placed within the EMF **(Fig.4)**. The external markers are used to cross-register previously acquired images from any modality (CT, MR, PET). A marker-coil is placed on the device to be navigated through the body, it is detected in the EMF field and a representative icon is superimposed (+/-5㎜ of actual position) onto the images that are presented on the monitor. The operator is able to see the superimposed device marker travel through the images as if this was occurring in real-time[18]. The EMF tracking system serves as a mini-GPS for navigating through images, yet it does not require simultaneous intra-procedural use of expensive imaging modalities (such as CT and MR) that can be more cost-effectively used for routine diagnostic imaging. This technology has been used successfully for the experimental placement of IVC filters[19] and TIPS[20], and carotid stents (personal communication : B. Wood) in swine.

Lesion Visualization and Definition

Multi-modality Fusion Imaging

Many new modalities and combinations of modalities (e.g., XMR, PET-CT, SPECT-CT) are being investigated in order to improve lesion visualization and to guide minimally invasive procedures. In addition to multi-modality imaging methods discussed elsewhere in this paper, Philips Medical Systems (Andover, MA) and the National Institutes of Health (Bethesda, MD) are developing a combined CT + US dual modality (image fusion) technology that provides better visualization of structures that, for instance, may be obscured by gas or bone if US alone is used **(Fig.5)**. Once CT better defines



a c
b

Fig.4
a : Electromagnetic Tracking System components and set up (Northern Digital, Inc. Reproduced with permission from Seiler PG, et al. Phys Med Biol 2000 ; 45 : N103-N110)
b : External fiducial markers.
c : Position of guide wire in pig renal artery superimposed in real-time on previously acquired CT images (three planes) and corresponding actual position on fluoroscopy (Courtesy : Brad Wood, MD (NIH)).

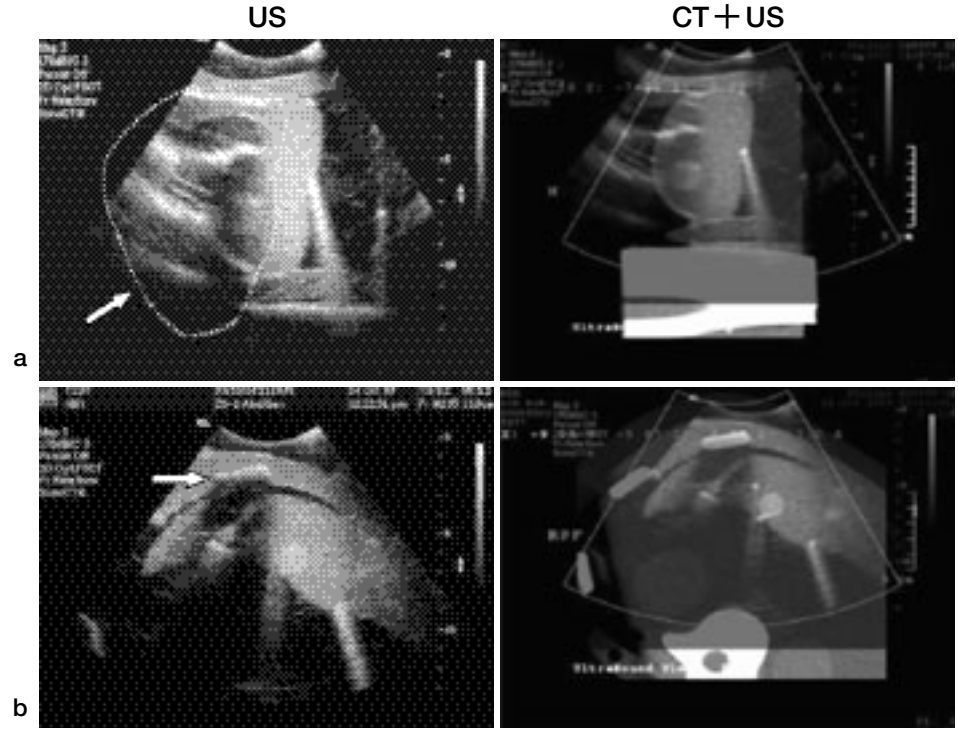


Fig.5 Ultrasound images of abdominal phantom on left demonstrate overlying gas (a) and rib (b) obscuring the lesions below. Fused cross-registered CT scans on right clarify the information and improve visibility of the lesion (Courtesy : Brad Wood, MD (NIH)).

the target and obscuring structures, it can be blended back and forth with the US image for the intervention. Additionally, once a three-dimensional data set of fused images of the target is available, a precision robotic arm directly integrated to the CT gantry can be programmed to perform the procedure or implement a treatment plan with remote human input.

Endovascular Plaque Imaging

Although superficial vessels have long been imaged with external US transducers and MR coils, endovascular plaque imaging is becoming increasingly more pertinent not only for purposes of atherosclerosis research, but also clinically to identify plaques that are unstable and vulnerable to rupture. Intravascular ultrasound is the most developed of the technologies that enable arterial wall imaging. IVUS is also the most widely used method in clinical practice[21]. Technical improvements in ultrasound tissue characterization will likely further improve plaque visualization and assessment of wall mechanical properties[22].

There has long been an interest in endoluminal MR imaging with small caliber catheters, but economical rather than technical limitations appear to have kept these devices from becoming commercially viable. It is quite likely, however, that in the future, mural imaging with endovascular MR catheters may be clinical employed **(Fig.6)**[23, 24]. As with other metallic devices such as guide wires, imaging coils pose a risk of internal heating[25]-these limitations must be overcome prior to routine clinical use.

As previously stated, detailed MR imaging of the wall of superficial arteries, such as the carotids, is possible with dedicated external coils. Such visualization may be further enhanced by special labeling techniques. Scientists at Washington University in St. Louis have developed molecular imaging techniques using gadolinium-loaded nano-particles to visualize atherosclerotic plaques (PMS communication). The nano-particles (e.g., perfluorocarbon emulsions) carry a surface 'payload' (Gd-DTPA) and the 'targeting system'-in this case monoclonal antibodies to specific

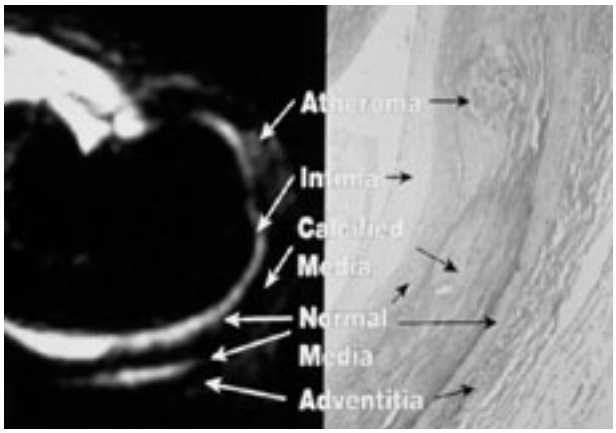


Fig.6 Endoluminal spin-echo MR images of freshly excised human popliteal artery (left). Slightly brighter lesion at 2 O'clock represents a fatty atheromatous deposit. Intimal hyperplasia, calcified segment of media, and adventitia are clearly visualized. Photomicrograph (H-E stain) shows corresponding histology (right). (Reproduced with permission from Reference 23. Courtesy : K. Kandarpa, MD, PhD)

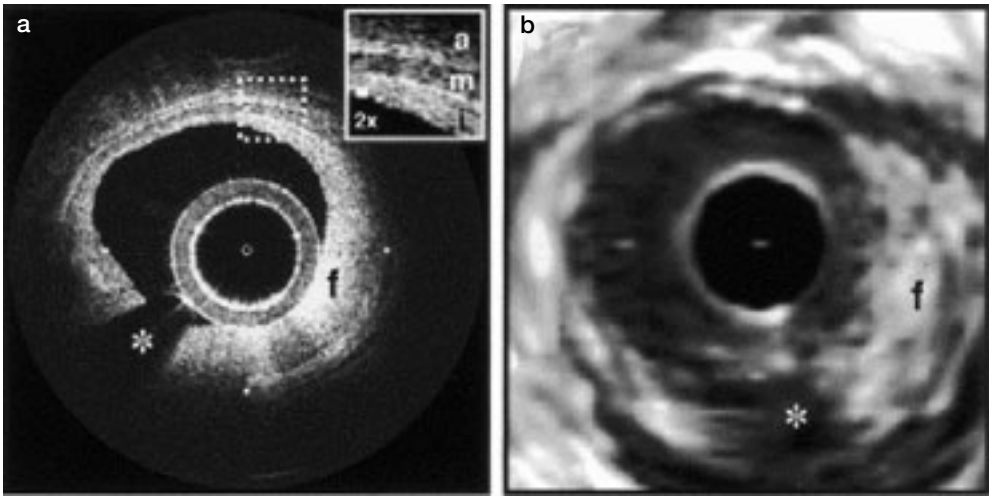


Fig.7 Fibrous coronary plaque imaged in vivo by optical coherence tomography (OCT) (a) and intravascular ultrasound (IVUS) (b). (a) From 9 o'clock to 2 o'clock, this OCT image demonstrates visualization of the intima (with intimal hyperplasia [i]), media (m) and adventitia (a). The internal and external elastic laminae are visible as signal-rich lines bordering the media (inset). A plaque extending from 2 o'clock to 9 o'clock contains a homogeneous, signal-rich region consistent with fibrous plaque (f) that is partially obscured by a guidewire shadow artifact (*). (b) In the corresponding IVUS image, the fibrous plaque (f) is also visualized. Tick marks, 1 mm. (From Reference 27, reprinted with permission ; Courtesy : Stuart L. Houser, MD)

receptors (alpha five-beta three) associated with angiogenesis within the early atherosclerotic plaque. Imaging of an experimentally created rabbit carotid artery plaque clearly shows evidence of biological activity related to angiogenesis in the vasa vasorum (because of a 100,000-fold increase in relaxivity with Gd-labeling). Such methods are extremely useful for research with potential for future clinical applications.

Intravascular Optical Coherence Tomography (OCT) uses back-reflected low coherence infrared light, much as acoustic waves are used for ultrasound imaging, to produce high-resolution (under 50 microns) images of atherosclerotic plaques **(Fig.7)**. This technology has the promise of providing structural detail that can help identify 'vulnerable' plaques[26, 27]. The information obtained has been used for the mechanical analysis of plaque vulnerability[28]. OCT-based needles have been designed that can perform in vivo biopsy and assess nuclear morphology like chromatin density without removing tissue (B. Wood: verbal communication). Catheter-based OCT devices are ideal for providing a "local look" or "optical biopsy" deep within the body since the infrared light does not penetrate deeply. In addition, it may be possible to administer light-sensitive agents that accumulate within vulnerable plaques (or other lesions) and to locally photo-activate therapy at an appropriate time.

Incorporation of Non-morphologic Information to Improve Lesion Definition

As alluded to earlier, morphological or anatomical information alone is often insufficient and the addition of functional information significantly improves the ability to diagnose and adequately treat lesions. The combination of cardiac motion maps with electrical activity maps, for instance, may better guide tailored therapy than a mere anatomic view of an aneurysmal anterior left ventricular wall. Similarly, damage to critical motor strips located close to a cerebral lesion can be avoided by using intra-operative MRI functional maps produced during activation of the strip through voluntary motion of a finger or toe[29]. Non-visual MR spectroscopic tracings have been used along MRI of the brain for guiding biopsies. Such techniques are applicable elsewhere in the body[30].

Therapy and Monitoring

Many new forms of therapy are in the horizon. Radiofrequency, cryotherapy, and microwave ablation are in vogue and lasers are re-entering the IR armamentarium with new or refined applications (e.g. varicose vein ablation with lasers and RF). One advantage of using MR for monitoring therapy is the ability to map tissue temperature. Percutaneous radiofrequency ablation of selected tumors is increasingly common in most major medical centers worldwide. The group at the University of Technology in Aachen, Germany, has used MRI monitoring for RFA, as well as cryo-ablation with MR temperature monitoring (single-shot ZOOM imaging with FFE sequence), for treating liver lesions (PMS communication). Temperature monitoring is especially useful to treat sub-capsular lesions adjacent to critical sites such as the dome of the liver or the gall bladder. High-intensity focused US (HIFU), although as yet not widely used, is showing some promise for non-invasive ablation of uterine fibroids combined with treatment planning and monitoring with MR imaging[31].

The demand for high-resolution imaging and a wish to minimize the use of x-ray fluoroscopy provide the impetus to explore alternative vascular guidance modalities. MRI is one such modality that shows promise. Unfortunately, MRI, as noted above, has not been able to act a one-stop modality for all stages of an intervention. Thus, some manufacturers have combined x-ray fluoroscopy for introducing devices and navigational guidance with MRI for better defining lesions and monitoring therapy. Beucker et al[32], have elegantly demonstrated the use of this combined strategy to successfully place iliac artery stents in swine with correct positioning and deployment within six minutes **(Fig.8)**. They did this using a Philips XMR unit that has a 1.5T MR scanner positioned along a linear track in the same head-to-toe axis as the angiography unit. Only the puncture was performed under fluoroscopic guidance. Subsequently a fiberglass wire with dysprosium markers is introduced into the aorta and a self-expanding Nitinol stent is deployed using real-time MR-fluoroscopy at 20 image frames per second accomplished with a radial scanning and sliding window reconstruction technique. The high-speed images that are generated provide sufficient resolution to complete procedures much faster than had previously been reported in humans[33].

The group at UCSF has used XMR-guidance to deliver trans-catheter iron-labeled chemotherapeutic agents into a liver tumor in a human (PMS communication). Angiographic monitoring of the embolization procedure is corroborated with MR images that concomitantly show a corresponding loss of signal on the MR images as the iron particles enter the tumor vasculature. In addition, similar methods have been used to close atrial septal defects (ASD)[34] and demonstrate the feasibility of MR-guided monitoring of intra-myocardial injections using needle-tipped catheters that are guided into the ventricle with x-ray fluoroscopy[35]. The latter technique holds promise for monitoring the delivery of drugs,

genetic materials, stem cells, or other agents directly into the myocardium.

Recently the use of multi-modality image-fusion for delivering and monitoring therapy has been demonstrated. Wood and co-workers at the NIH have precisely placed RFA probes into tumors using fused CT + PET images to locate the active portion of the tumor within liver lesions **(Fig.9)**. Post-treatment segmented images help isolate active tumor from dead or necrotic tumor-acting to provide 'near real-time' endpoints-and suggesting further treatment when necessary. Obviously, such techniques are also useful for guiding a biopsy needle to the active portion of the tumor — thereby increasing the diagnostic yield and obviating the need for multiple samples.

Conclusion

Healthcare priorities, expectations of the public, and

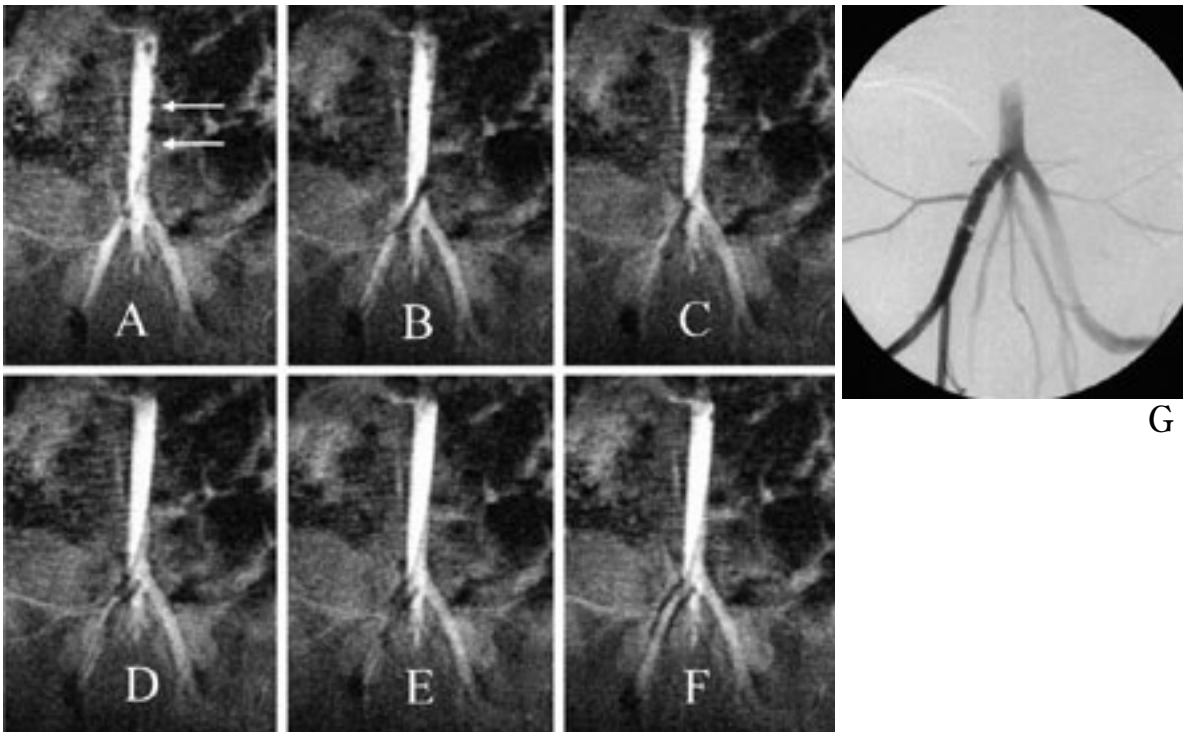


Fig.8 Real-time images acquired with a radial scanning technique during stent placement in the right iliac artery.
A : Dysprosium markers on a guidewire allow visualization of the non-metallic wire (arrows),
B : The catheter-mounted non-ferromagnetic stent is well depicted after positioning in the aorta,
C : The stent is withdrawn to the position of deployment, and
D-F : the stent deployment is controlled under real-time conditions,
G : fluoroscopic check image. (Reproduced with permission from Reference 32. Courtesy : A. Beucker, MD)

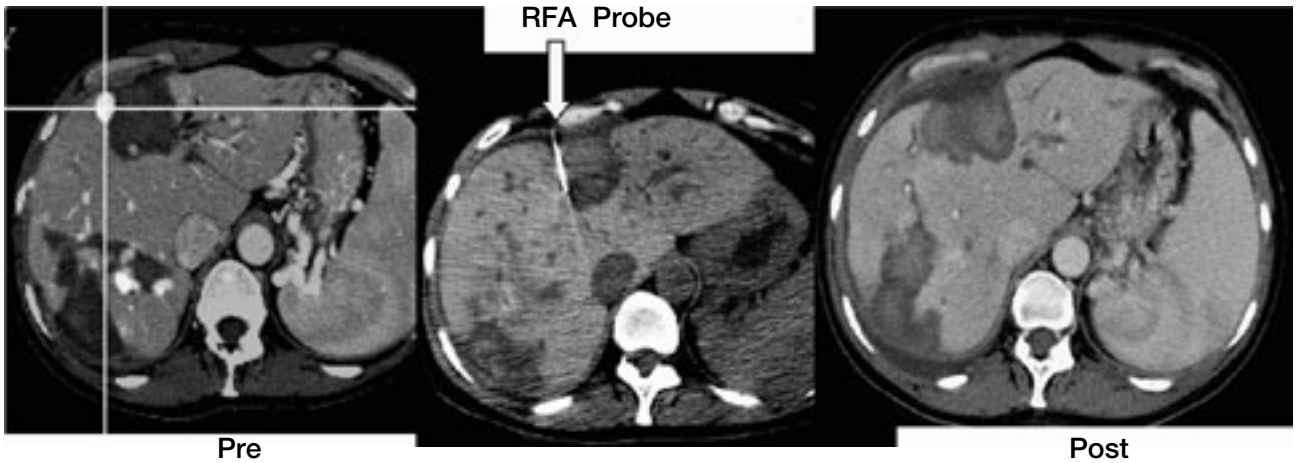


Fig.9 Fused CT and PET images guide precise radiofrequency probe placement for ablation. Similar methods may be used for biopsy needles to improve diagnostic yield. (Courtesy : Brad Wood, MD (NIH))

technological advances are motivating the development of imaging modalities that avoid prolonged exposure to ionizing radiation during therapeutic interventions. Interdisciplinary collaboration between physicians, life-scientists, physicists and engineers is paramount for such advances to become reality. Multi-modality imaging, especially when combined with functional imaging or information, will take us closer to the much-needed 'real-time endpoints' for assessing adequacy of therapy. Techniques that provide virtual guidance through 3-D(and 4-D) datasets, such as with EMF guidance, will allow more efficient use of diagnostic equipment and free up these expensive resources from prolonged sequestration for interventions.

Computer-aided navigation and robotic guidance of devices will bring further precision to procedures. Advanced methods for motion stabilization, for instance, present the physician with a 'virtually' still representation of the beating heart. Robots will enhance 'manual' dexterity by filtering out tremor and scaling hand-motion to prevent inadvertent movement of instruments. Robots will also enable remote('tele-presence') mentoring of physicians, if not actual remote interventions.

Tissue engineering techniques will be widely applied for creating biocompatible artificial replacements for vascular and non-vascular structures. Computer modeling of tissue mechanical properties(combined with techniques such as ultrasound tissue characterization-[22] and transport phenomena can assist in improving and tailoring the design of endovascular devices[36]. Smart devices with micro-sensors can provide feedback on local physiological conditions(tissue-level feedback) and allow timely-locally or remotely activated-therapeutic interventions. Resorbable implants can be used for providing temporary treatment and may even serve as drug-delivery platforms. The principle of the drug-eluting stent will be applied to micro-beads that would serve both as embolic materials as well as drug-carriers. However, prior to the routine availability of such devices, much work needs to be completed on the fate of the breakdown products of resorbable materials and the release profiles of agents eluted from devices.

Imaging and therapy will get to smaller scales. Emerging new 'destructive energies' to treat large gross lesions have already been discussed. Advances in the design of MR micro-coils are already providing exquisite high-resolution images of small parts such as the orbit, nipple, and skin **(Fig.10)** and opening fertile ground for innovative minimally invasive therapies.

New forms of therapy that may be introduced with trans-catheter techniques will include stem cells, cell constituents(e.g., mitochondria), liposomes, genetic material, and combinations thereof.

Novel therapeutics agents will be developed along with advances in molecular diagnostics that will reveal the functions not only of organs, but of their component cells and in vivo molecular processes. This form of functional imaging will allow the rapid assessment of the efficacy of therapy.

In the future, rapid and precise tissue characterization will become far more important for the oncologist, and it will be the interventional radiologist who will obtain targeted biopsies using multi-parametric, multimodality guidance. Sequential biopsies will be needed to determine target expression, drug susceptibility, drug efficacy and prognosis. Such information will guide decisions regarding patient-specific drug cocktails and treatment timing, since these decisions will be based upon genomics and proteomics of biopsies rather than upon simple tissue histology.

Optical imaging using fluorescently labeled agents will reveal lesions that can be biopsied with pinpoint accuracy. Other new forms of imaging(e.g., terahertz imaging) may yet become clinically relevant.

Interventionalists at the NIH are already designing the operating rooms of the not so distant future-devices such

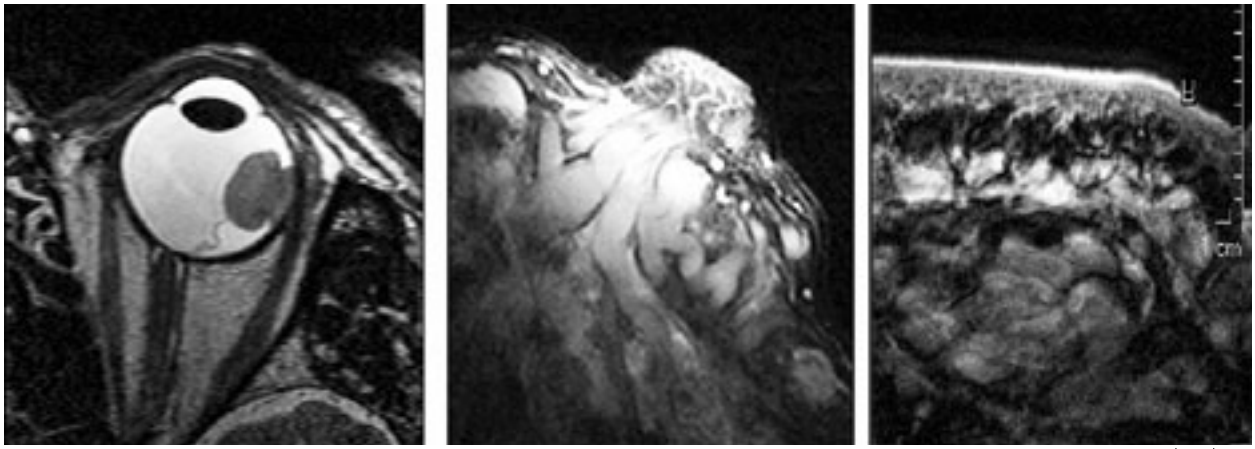


Fig.10 MR micro-coil images of the orbit(a), nipple(b) and skin(c) (Courtesy : Philips Medical Systems) **a | b | c**

as ultrasound probes, HIFU transducers, and robotic arms are already being mounted mechanically on frames of high-speed multi-detector CT scanners **(Fig.11)**. Such single frame units provide 'mechanical registration' and obviate a need for soft-ware-based correction of the spatial coordinate frames of the component devices. The actual intervention may become as easy as a 'point and click' function.

Such simplification of procedures will raise questions about the role of the interventional radiologist. How will these advances affect the interventional radiologist? Is this really interventional radiology any longer? How must the interventional radiologist evolve to survive and be active in these exciting developments? The answer partly is that interventional radiologists themselves must continue to play an active role in bringing this vision to reality or risk losing the exciting opportunities to other disciplines. We must discard the pure 'procedural identity' that originally defined our specialty. It is increasingly important to adopt a clinical presence (don't own the procedure, own the patient) and move on to new arenas (oncology, gynecology, neurology, etc.) that do not at present have the attention of our competitors. Creativity and inventiveness brought IR here, but it is equally important to adopt the clinical skills of our competition. We must therefore judiciously combine our traditional technical skills with new clinical skills and place ourselves squarely in front of the patient everyday. Interventional radiologists must adapt to the new competitive realities or we must accept the unhappy consequences.

For all sad words of tongue or pen,
The saddest are these : "It might have been!"
John Greenleaf Whittier

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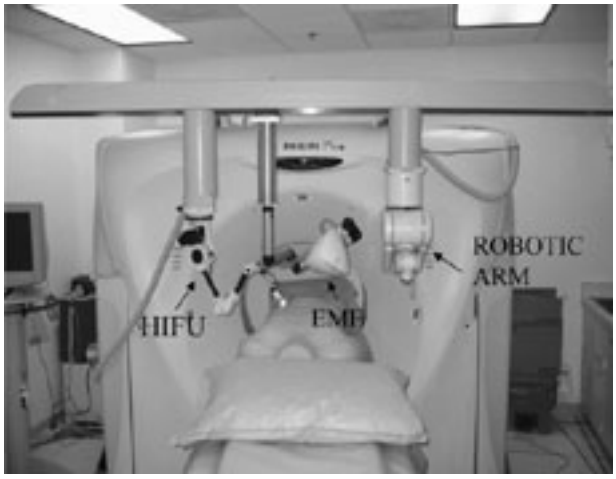

Fig.11 Prototype CT Scanner developed by the NIH and Philips Medical Systems incorporates tools that are mounted on a stereotactic frame : diagnostic US, high-frequency focused-ultrasound (left), EMF tracking (middle), robotic arm for precise "point-and-click" needle placement. This system allows for precise cross-registration of the spatial frame-of-reference of the patient (scanner) with that of the tool (Reprinted with permission from : Touring the Radiology Department of the Future. Health Imaging and IT 2005 ; August : 16-22 ; Courtesy : Brad Wood, MD (NIH) and Philips Medical Systems)

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