Chapter 10

IMAGE-GUIDED THERAPY (IGT): NEW CT AND HYBRID IMAGING TECHNOLOGIES

Devices for the Interventional Radiology (IR) Suite and the OR

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Abstract: Integrated multi-modality IGT prototypes are described for IR and OR suites of the future including procedures guided with CT and hybrid imaging devices. Radiofrequency Ablation (RFA) is an exemplary application, and the prototypes can be adapted to other procedures. To investigate pre-planning[1], a software prototype enables virtual electrode placement. Intra-procedurally, a CT-integrated robot aligns its laser to planned trajectories. Interventional tools and mini-imaging devices are registered to imagers and 3-D data sets by attaching them as robot hands, or by tracking them with electromagnetic or optical systems. Tissue response is monitored with new 3-D real-time imaging. The ultimate goal is to simplify treatment and provide benefit to the patient.

Keywords: Percutaneous ablation; image-guided therapy; interventional radiology; surgical navigation; virtual reality; medical robotics; image registration

1. INTRODUCTION

Prototype modules and devices for percutaneous, extracorporeal, and laparoscopic procedures are described in the pre-, intra-, and post procedure stages primarily for CT, X-ray C-arm based systems, and other imaging devices. These imagers allow the integration of and access to many types of equipment including navigation devices, such as robots and instrument tracking devices, and other imaging equipment such as PET, SPECT, and Ultrasound imagers.

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The leading application in the new field of 'Interventional Oncology' has been the treatment of solid tumors with percutaneous Radio-frequency Ablation (RFA). Accordingly, many of the investigative tools in this chapter are illustrated by percutaneous RFA; however, they can be adapted to other research areas such as drug delivery, gene transfection, and biological implantation, etc. Furthermore, there are many techniques used to locally and directly treat tumors such as cryogenic, brachytherapy[2], and microwave, and presently it is not known which may have clear advantages over the other.

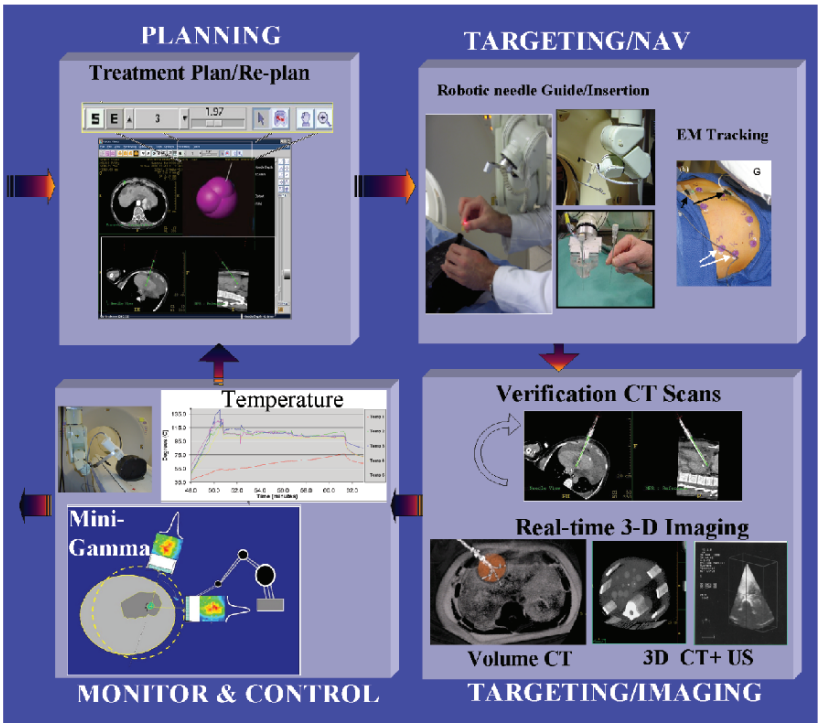

Figure 10-1. Investigative concepts and devices for RFA workflow. Upper Left: Treatment planning display to specify virtual electrodes. Upper Right: The plan is sent to a CT-integrated robot and an electromagnetic tracking system, which are used for targeting in conjunction (lower right) with real-time imaging. Lower Left: Temperature signals[3] and molecular tracers[4] can be used to monitor the target tissue location in shared 3-D coordinates.

The objectives for RFA include the general objectives for image-guided therapy (IGT) discussed in Chapter 9 and the specific objective: To accurately place single or multiple electrodes to cover the entire treatment region without heating critical structures such as the heart.

2. PRE-PROCEDURE PLANNING

For many image-guided procedures such as needle biopsies, disposable positioning grids and estimated angles may be sufficient for planning; however, there are IGT applications where computer-based treatment planning can potentially be useful. Examples include cases involving large tumors (greater than 3cm), tumors near critical structures, multiple targets, and multiple treatments.

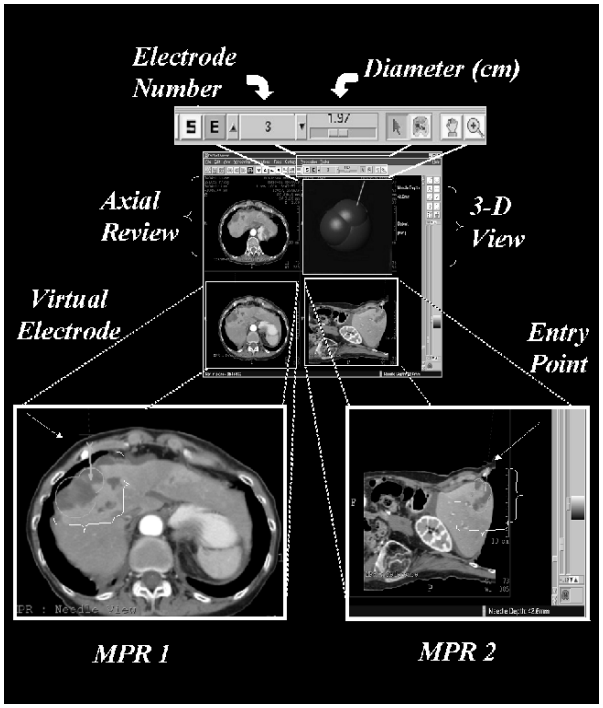

Figure 10-2. On-line RFA pre-planning screen that uses a CT data set to specify the trajectory and placement of virtual electrodes (green) with associated tumor conforming, overlapping isothermal contours (green) and skin entry point (red)[5].

On-line treatment planning is used on the scanner's host computer after the patient is scanned. Reconstructed image data sets can be automatically registered with the interventional field provided that the patient remains immobile and methods are used to manage respiratory motion[6]. If planning requires more than several minutes, however, the image data can be transferred to another computer, as is done with radiation therapy planning.

However, additional registration steps and patient positioning may be needed to implement the plan.

2.1 Treatment planning for RFA with CT data set

A prototype for on-line, point-and-click RFA planning, as shown in Figure 10-2, was developed in collaboration with Bradford Wood, M.D., NIH Clinical Center. After the patient is scanned, the 3-D CT data set is loaded and virtual electrodes are interactively placed on bi-sectional CT multi-planar reformatted (MPR) views. Each electrode contains a graphical skin entry point, a target, and a spherically-shaped ablation zone. The physician can simultaneously adjust MPR views and virtual electrode positions, and the 3-D treatment plan is updated automatically. The set of virtual electrodes form a 3-D ablation plan based on overlapping spheres. Isothermal contours are computed and displayed as overlapping circles resulting from MPR-sphere intersections (outer contours only). A shaded-surface representation of the plan is also displayed in a 3-D view port.

For review and refinement of the treatment plan, the physician can step through virtual electrodes and view the 50°C contours associated with the set. Axial images can be scrolled in a separate view port to verify that the contours cover the imaged tumor with a sufficient margin. Also, the set of virtual electrodes are stored in a patient-specific database for reference to subsequent CT scans.

The planned distance from the skin entry point to the tip of electrode is computed automatically and displayed. Also, the distance from the imaged tumor to nearby, heat sinking blood vessels can be measured.

The spherical geometry was used to model the Rita XLi electrode, but other treatment shapes could be represented in the form of ellipsoid, disc, rice kernel for High-Intensity Focused Ultrasound (HIFU, Section 4.4), and ice-ball shaped regions (cryoablation).

This prototype also provides a framework for investigation of new concepts for RFA planning such as: 1) optimization of electrode placement based on segmentation results, 2) multi-modality image-guided ablative therapies as discussed in the next section, 3) simulation and display of multiple isotherms indicating the treatment and blood flow effects, and 4) an intra-procedural means to merge treatment monitoring with the plan for re-planning.

2.2 Multi-modality planning

Inter- or intra-modality registration can provide synergistic information for both diagnosis and therapy[7] (see Chapter 9). Image-guided pre-planning

based on multi-modality data sets is being investigated for RF ablation and biopsy. The point-and-click treatment planning prototype in Figure 10-2 can be extended to use multi-modality data sets. A pre-planning screen based on pre-registered PET-CT data from the Philips Gemini scanner is shown in Figure 10-3[8]. As virtual electrodes are interactively positioned, the dual-modality data set is displayed and updated with fused axial and MPR views.

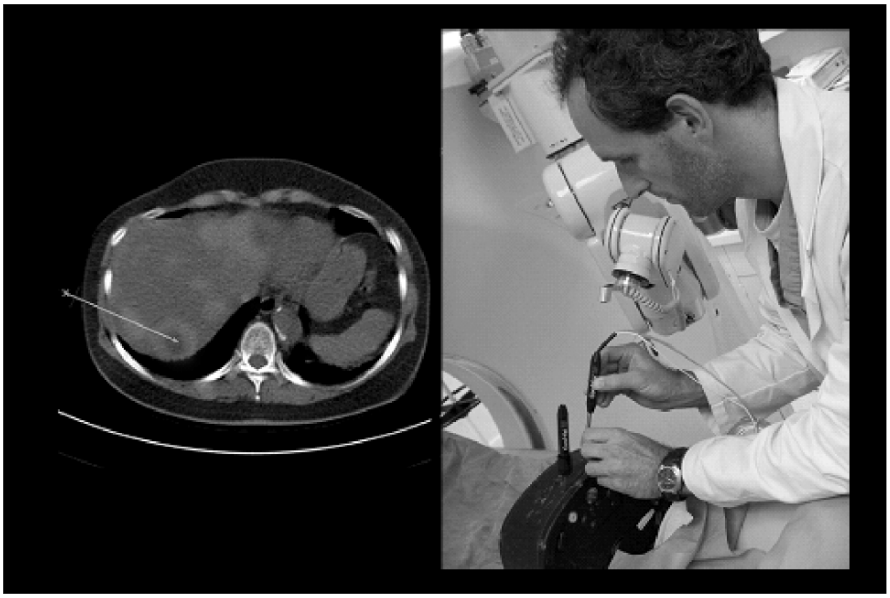

Figure 10-3. Left: F^{18}DG PET-CT data set used with point-and-click GUI to plan trajectories for CT Guided robot. Right: Dr. Wood uses laser guidance to place a Radionics triple-cluster RFA electrode in a CIRS Model 57 (CIRS Norfolk, VA) abdominal phantom.

Robotic or passive tracking systems can be integrated with the planning display and the PET/CT imager to provide intra-operative assistance, as discussed in the next section.

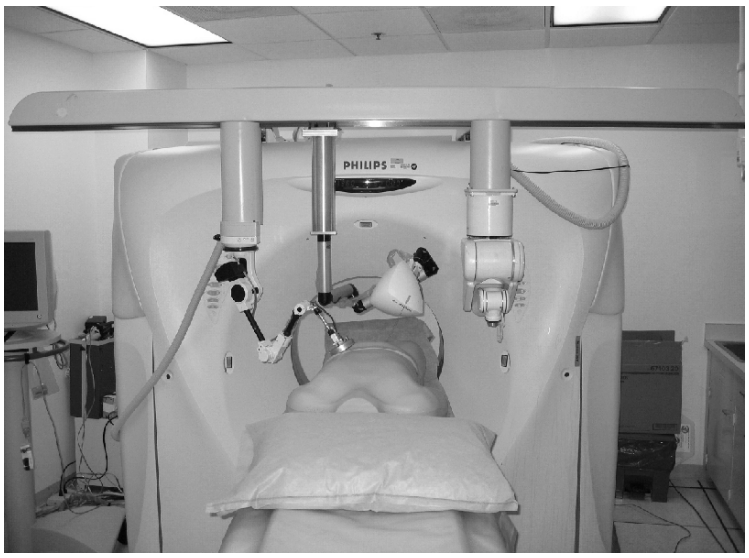

Figure 10-4. Three navigation tools integrated with the Brilliance 16 CT at the NIH Clinical Center. Left: Passive position-sensing arm tracking a US-HIFU assembly. Center): Electromagnetic generator for instrument-tip tracking. Right: Six-axis robot with laser end-effector. The retractable CT gantry frame registers diagnostic and therapeutic devices in multiple (detent) positions and in the CT's coordinate system, and facilitates their easy deployment.

3. INTRA-PROCEDURE STAGE

The treatment plan is implemented in the intra-procedure stage (Figure 10-1), with assistance from targeting (i.e., navigation) and monitoring devices. Passive navigation is an interactive 3-D search process to align a physical device (e.g., needle or electrode), in some cases to a preplanned trajectory, by tracking a corresponding virtual device within one or more static, registered tomographic data sets. Passive systems can be based on an electromagnetic sensor-generator (section 3.1.2, Figure 10-4 middle), an optical camera with LEDs (section 3.1.3), or a position-sensing articulated arm (Section 4.3, Figure 10-4 left). Each presently has advantages and trade-offs, as mentioned below. Active navigation uses a robot for automatic alignment and targeting, inside or outside the CT's aperture, based on commands received from a planning screen (shown in Figure 10-2) or a remote device (section 3.1.1).

As in the pre-planning stage, multi-modality data sets and imaging can be used in this stage. To assist with the tracking of organ and target motion, for instance, one modality can be real-time (live) and the other can be based on a

recently acquired, inter- or intra-modality (e.g., contrast enhanced) image data set. Also, to combine inter-modality information, one data set can be used to plan the acquisition of another.

During the procedure, there may be deviations from the original plan and instances where it needs to be updated. This could be due to variations in electrode placement, organ shift, or patient re-positioning. Another indication for re-planning is when the monitoring process indicates under-treated areas.

3.1.1 CT-integrated robotics

Active navigation, unlike passive navigation, does not involve a manual 3-D search process to align with a pre-planned trajectory[9,10]. Instead, a robot can automatically align its end-effector or hand, such as a guidance laser. The robot, with new end-effectors, can also assist with percutaneous needle insertion and control, inside the CT's aperture, with force feedback during fluoroscopy[11]. The PAKY (Percutaneous Kidney Access) needle driver, supported with a RCM (Rotational Center of Motion) and a manual support arm, was among the first custom prototypes for robot needle insertion to be tested clinically[12].

A CT-integrated robotic system is being investigated with Dr. Wood. A six-axis Kawasaki FS-2 robot (Figure 10-3, right, Kawasaki LTD, Wixom, MI) is rigidly attached at its base to the CT gantry (Philips Brilliance 16) and is pre-registered into the CT's 3-D coordinate system during installation. A tool coordinate is also pre-determined for the end-effectors, e.g., the laser angles. Since the patient remains on the imaging table during the procedure and since the robot software tracks table motion inside or outside the CT aperture, the robot, planning data set, and patient are mathematically co-registered at the completion of each scan without the need for intra-procedure registration steps.

After the on-line pre-planning screen in Figure 10-2 is used to place virtual electrodes, the 3-D coordinates for each electrode, specifically the target and skin entry points, are sent from the CT's host computer to the robot's C70 controller via an RS-232 serial line. The controller then semi-autonomously and automatically moves the robot to align its class II laser with the electrode's planned trajectory to assist with electrode placement. Also, the CT patient support automatically moves the interventional field into the robot's reachable workspace.

For the laser end-effector, the robot and controller are designed with redundant safety mechanisms to maintain a minimum distance of 15 cm from the patient for contact free operation. Another safety feature is that the

physician must continuously press a button to enable the robot to move between its home and target-alignment positions.

The physician then aligns the physical RFA electrode with the laser beam and advances the electrode, with verification CT scans, to the pre-measured depth. To compare planned and actual electrode positions, the verification image data set is loaded into the pre-planning software. Each pre-stored virtual electrode can be selected and its position can be compared and aligned with the corresponding imaged electrode, which then updates the ablation plan. The physical electrode or the remaining virtual electrodes in the plan can then be repositioned to decrease the likelihood of under treated tissue.

Miniature (e.g., hand-held) imaging and extracorporeal therapeutic devices can also be attached to the hand of the robot, which automatically registers them into the CT's 3-D coordinate system (see Figure 10-4, left and Figure 10-11 left and right), either inside or outside the CT's aperture.

3.1.2 Electromagnetic tracking

Tracking sensors can be attached to interventional, surgical, or imaging devices to provide real-time 3-D positional information of the device. The position information can be used to display the actual position of the device relative to real-time or pre-acquired images once the transformation between tracking space coordinates and image coordinates has been established. This registration transformation can be determined manually, semi-automatically, or automatically.

Non-line-of-sight systems[13] such as EM tracking only require the tracked device to be anywhere in the operating range of the system, with no requirements for visibility, which opens up the possibility of tracking devices inside the patient during interventional and minimally-invasive procedures.

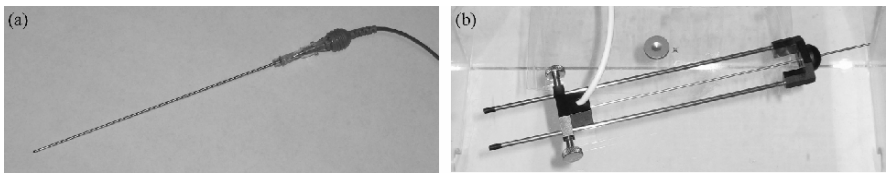

Figure 10-5. (a) Tracked stylet/sheath combination for biopsies, and (b) tracked needle guidance device for radiofrequency ablations (Traxtal Inc.). For biopsies, the tracked stylet is removed from the sheath and replaced by the actual biopsy needle once the device is in place. For radiofrequency ablations, the RFA needle with up to 3 prongs can be inserted through coaxial holes in the guidance device.

The accuracy of EM tracking systems can be compromised by secondary electromagnetic fields, such as those generated by eddy currents in conductive metal plates. The smaller sensor size, however, in combination with the ability to track non-line-of-sight, can outweigh some of the limitations.

For example, when tracking a laparoscope[14], an optical tracking sensor has to be attached near the handle. Any small error in the tracked orientation of the device is amplified to a larger positional error at the tip. With EM tracking, the sensor can be attached very close to the tip, thus providing accurate positional information of the relevant part of the instrument without the need for position extrapolation.

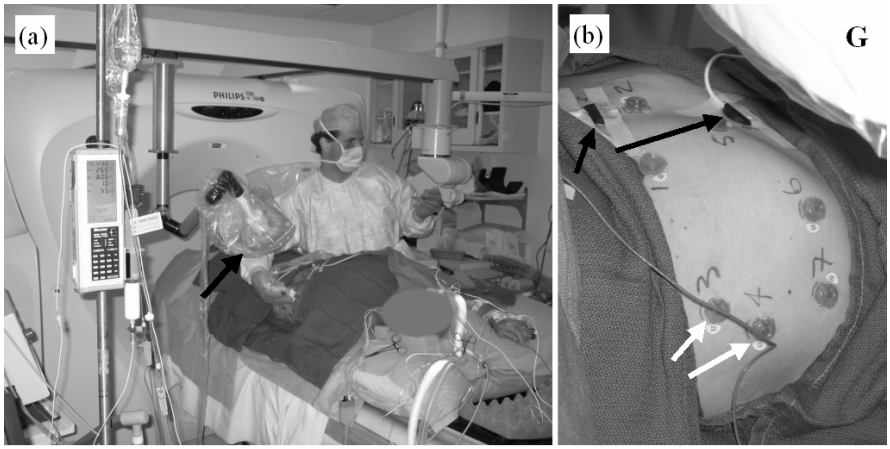

Figure 10-6. (a) The EM field generator (black arrow) is attached to the CT scanner using an articulated arm, and is positioned close to the needle insertion point during the intervention. (b) Close-up of the sterilized area shows the EM generator (G), the fiducial skin markers used for registration (white arrow), and 6 DOF reference trackers used for motion compensation studies (black arrows).

The feasibility of using EM tracking to guide biopsies and RFA procedures in conjunction with pre-operative CT scans is being investigated in collaboration with Dr. Wood. In this study, needles with integrated miniaturized EM sensor coils are used (Figure 10-5). The EM field generator (Northern Digital Imaging, Waterloo, CA) is attached to the CT scanner (Philips Brilliance 16) using an articulated arm, and is manually positioned and locked above the patient near the skin entry point (Figure 10-6). The pre-operative CT scan is obtained after placing six fiducial skin markers in the workspace of the tracking system. The image data is automatically transferred to a workstation, which runs the custom tracking software. To

register EM tracking coordinates with image coordinates, the fiducial markers are manually identified in the pre-operative image, and the markers are momentarily contacted with a tracked needle. Once registration is established, a virtual image of the tracked needle is shown relative to MPRs of the CT volume at the needle location. After identification of the target location using a single mouse click in the pre-procedure image, an additional target display shows the location of the target relative to the needle tip. It provides visual feedback about the distance between needle tip and target, and about the angular deviation between the current and targeted needle direction (Figure 10-7). Additional skin trackers are used to monitor respiratory and patient motion.

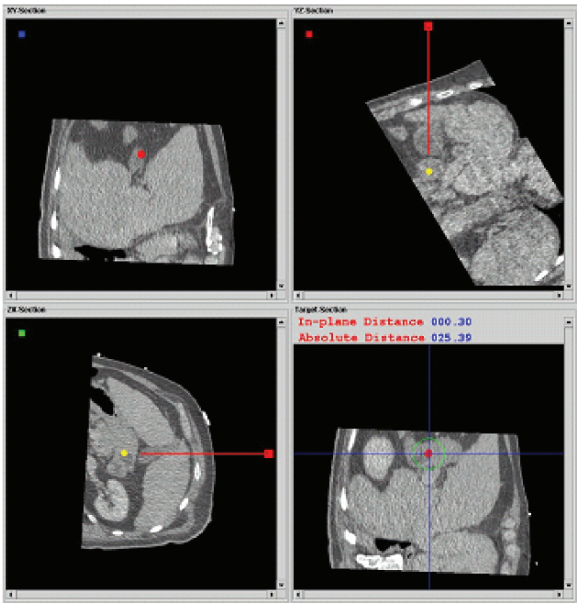

Figure 10-7. The tracked needle is visualized relative to the pre-op CT scan using three orthogonal MPRs at the tip of the needle. The yellow spot indicates the manually selected target position. The target display in the lower right provides visual and numeric information about the current distance from the target and about the alignment of the needle with the target.

3.1.3 Optical tracking in the operating room

Although EM navigation systems can track devices within the body, optical tracking may have advantages over EM tracking (EMT) in the fully equipped OR. The accuracy of EMT in the OR could be susceptible to interference of metal devices such as surgical instrument trays, anesthesia

carts, etc. Also, the larger working range of optical systems may be advantageous in the OR.

The Optical Position Measurement System (OPMS), introduced in the early 1990's by several manufacturers and referred to as 'frameless stereotaxy', enables special surgical instruments to be tracked in real-time and displayed in registration with a pre-operative CT or MR data set. These instruments are equipped with infrared emitting diodes (IRED), which can be seen by OPMS cameras to triangulate their position in 3-D space. Registration, as with other tracking devices, is the calculation of the coordinate transformation from the coordinate system of the pre-operative images to the coordinate system of the intra-operative position measurement system. During surgery, the position measurement system continuously measures the position and orientation of surgical instruments (*tracking*) and the position of the instruments is visualized in the pre-operative image, i.e., 'virtual reality'. This allows the surgeon to accurately navigate in the pre-operative images without having direct visual contact to the structures of interest and helps him or her to perform complex manual tasks.

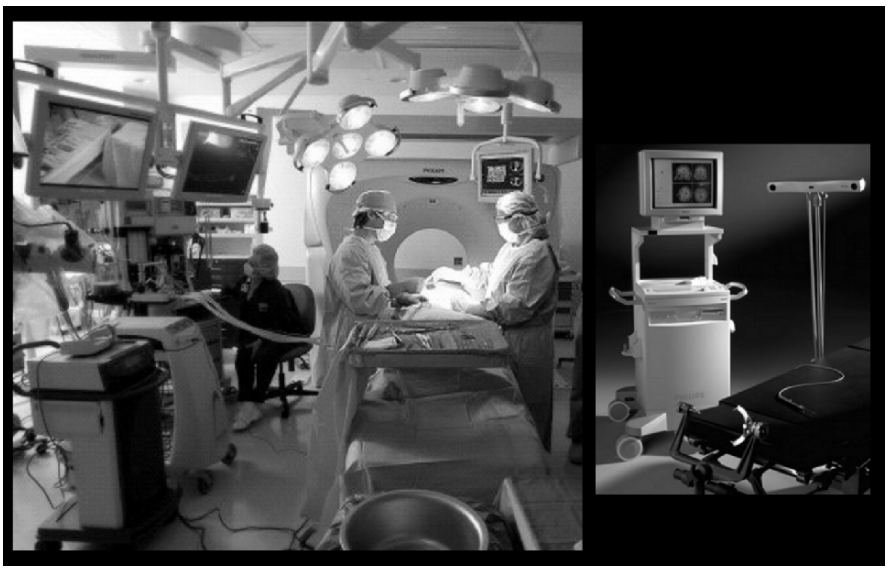

Figure 10-8. Left: Intra-operative CT (Philips Brilliance 16) at Celebration Health Florida Hospital in collaboration with Drs. Gary Onik and Joseph Redan. Right: The Philips EasyGuide, an early surgical navigation system consisting of a computer, a monitor, an optical position measurement device, and special surgical instruments.

Soon after the first optical navigation systems were used clinically, questions arose regarding how accurate these systems were in comparison to

free-hand surgery and well-established tools like stereotactic frames. A crucial issue for the clinical acceptance of surgical navigation systems is the overall application error. Application error is the positioning error occurring between target locations in pre-operative images versus the position in intra-operative patient space. Simulations[15] showed that application error strongly depends on the clinical protocol used (especially on the registration method), the position and orientation of the surgical instrument, and the resolution of the images used. However, in a typical clinical setup the accuracy of navigation systems is comparable to the accuracy of stereotactic frame systems[16].

4. MONITORING AND CONTROLLING

During image-guided procedures in the interventional radiology suite or the operating room, the physician monitors, measures, or visualizes the effect of the treatment. This important feedback is used to make adjustments in treatment delivery to decrease the risk for under-treated tissue. Techniques for image-guided monitoring are expected to grow rapidly as active areas of research. Future intra-procedural monitoring will include targeted contrast agents and many other types of real-time molecular imaging such as tracer-labelled monoclonal antibodies or liposomes with therapeutic payloads.

For the example application of RFA, some early measurements and devices for monitoring include: temperature or current impedance feedback, dynamic visualization of CT contrast enhancement, and live 3-D ultrasound registered with CT.

4.1 Temperature monitoring

In vivo temperature measurement is obviously an important measurement during thermal ablation. The measurement can be derived from the thermocouples embedded in the electrode tine tips (XLi, Rita Medical, Fremont, CA) and is used by RFA generators (Rita Medical) to adjust the power delivered to the electrode.

Temperature measurements can also be superimposed on the original planning images and compared with simulations and resulting isotherms. Image-based temperature monitoring with MR is established and is under feasibility investigation with CT. The image-based feedback can be used by the physician to re-position electrodes, e.g., more heat may be required to heat a tumor near a large blood vessel. Since this electrode re-positioning is a form of targeting and targeting requires some form of planning, it can be seen that the stages of image-guided therapy can overlap.

4.2 Volume CT fluoroscopy

Volume (3-D) CT fluoroscopy could improve feedback during image-guided procedures. Increasing rows of detectors in CT enables CT Fluoroscopy (CTF) to be extended from 2-D to 3-D visualization modes at increasing frame rates. The simulation of 3-D visualization methods, previously restricted to retrospective review on a workstation, are under investigation for 3-D CTF[17]. Volume CTF for the 3-D deployment of RFA tines is shown in Figure 10-9. A sequence of images is presented from axial, coronal, and sagittal viewpoints using an abdominal phantom with simulated respiratory motion. A blood orange was embedded in the phantom to simulate a 5 cm diameter tumor.

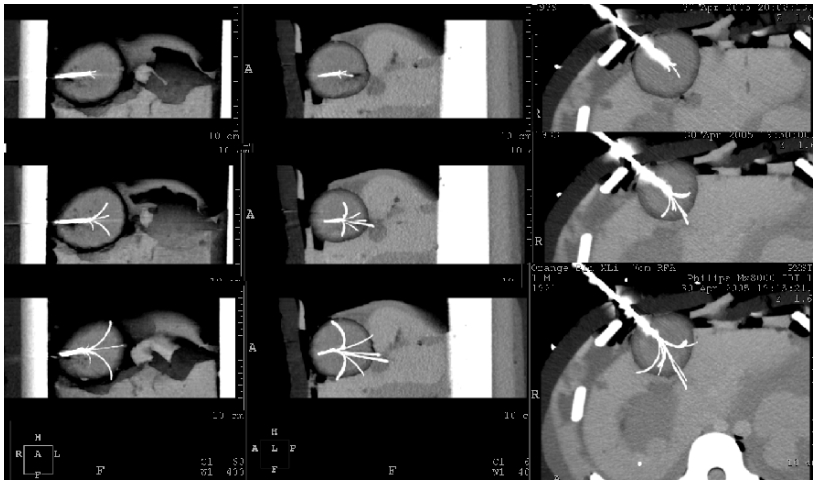

Figure 10-9. Simulated volume CT fluoroscopy (three selected frames) with left (coronal view), middle (sagittal view), and right columns (Axial view). Volume Maximum Intensity Projection is used to visualize the deployment of electrode tines in an abdominal phantom with blood orange representing a tumor.

Volume CTF could also be used for dynamic perfusion imaging[16] of the tumor to monitor the treatment effects like coagulation necrosis. Other applications for 3-D CTF include the insertion of a skinny, bending needle with a double angle trajectory toward a 5 mm target and advancing a catheter in a vascular tree.

Dose mitigation strategies, such as intermittent volume CTF, low tube current, anti-scatter grids, and needle holders, can be deployed.

4.3 Live ultrasound combined with CT data set

An emerging multi-modality technique is to register real-time imaging (projection, tomographic, or sector) with a 3-D retrospective image data set. This can be accomplished with a 3-D tracking system (electromagnetic, optical, or position sensing arm).

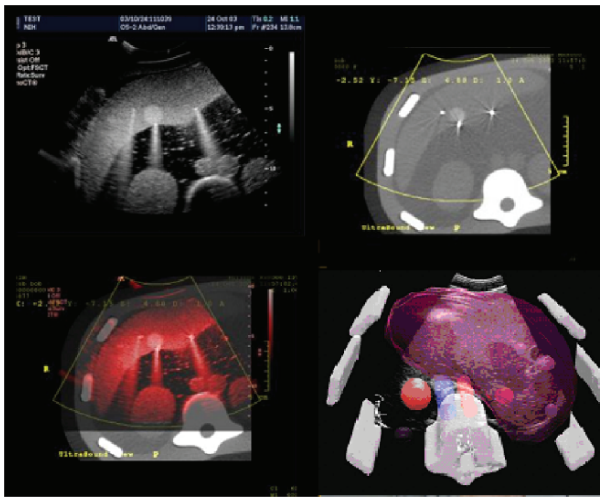

Figure 10-10. An ultrasound transducer is tracked in 3-D CT data. This co-display shows the registration on three markers[18]. (Supported by a Grant from the SIR Foundation-formerly CIRREF-Pilot Research Grant Program). The lower right shows a real-time US image registered with segmented CT[19].

Accordingly, the position and orientation of the US transducer is tracked in the CT's 3-D coordinates and used to automatically select CT MPR planes, which are co-planar and registered with the US images. Ultrasound-CT registration and fusion take advantage of the temporal resolution of US (30 frames per second) and the spatial resolution of CT (21 line-pairs per cm). This technique, which has been extended to 3-D US, may be extremely useful during the targeting process, when shadowing from bone or gas resulting from the burn can obscure visualization of the interventional field. Also, US contrast agents, co-located with CT, could have an important role in the future.

4.4 HIFU guided with CT and diagnostic US

Intra-procedure IGT can be extended to three imaging modalities (e.g., CT, US, NM) and these, along with therapeutic devices, can each be co-

registered into a common coordinate system. A tri-axial probe for image-guided High Intensity Focused Ultrasound (HIFU) was fabricated[20] (Focus Surgery, Indianapolis, IN): A diagnostic US transducer was co-axially embedded in a 1 MHz therapeutic US transducer. The dual-US assembly is attached as end-effectors on a position sensing and lockable articulated arm. The arm registers the diagnostic US probe into 3-D CT coordinates to reformat CT images that are co-planar with the live US images.

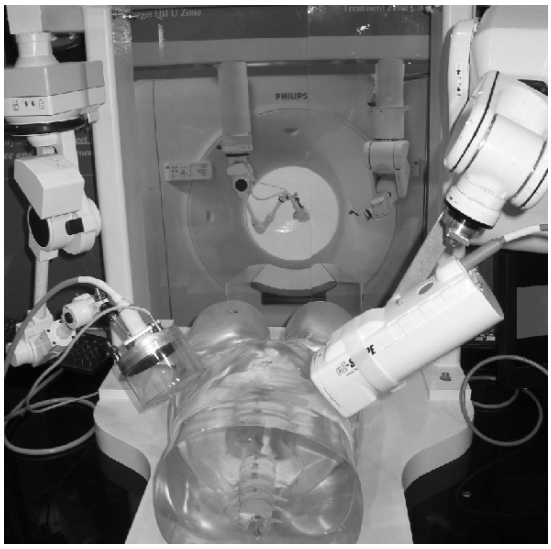

Figure 10-11. Three-modality image-guided therapy: Imaging and therapeutic devices for targeting and monitoring can be attached as hands of navigation devices, thereby registering them into the CT's 3-D coordinate system. A mini-gamma camera is attached to the robotic arm (right) and a dual modality (therapeutic and diagnostic) ultrasound transducer is attached to the position-sensing arm (left). Both can be navigated, aligned, and locked onto the target tissue location (RSNA'04 infoRad Exhibit, Photo by A. Viswanathan, NIH Research Fellow).

4.5 X-ray imaging in the operating room

Using static pre-operative image data can have limitations. In neurosurgery the phenomenon of brain shift was discovered, i.e. after opening the dura for brain tumour resection, the brain deforms and the pre-operative images no longer reflect the intra-operative morphology. This is more significant after the tumour has been resected. A strategy to circumvent these problems of tissue deformation and patient movement is intra-operative imaging. Almost all imaging modalities, which are used for diagnostic purposes, can also be used in the OR. Intra-operative X-ray and

ultrasound have been in use for some time, and intra-operative CT (Figure 10-8) and MRI are either in use or are being investigated.

Intra-operative imaging also allows for further automation of the procedure. While non-integrated navigation devices require a manual registration procedure, intra-operative imaging with an integrated navigation device can bypass the registration step. If during imaging, the geometrical imaging properties of the imaging system are known and its position relative to the patient is determined, e.g. with the help of a position measurement system, the registration transformation can be calculated automatically. In order to determine the imaging properties of the imaging system, a *calibration* procedure must be done, either at the installation of the imaging system or pre-operatively. For this purpose, a calibration phantom with known geometry or markers is imaged. The calibration phantom must also be visible to the position measurement system in order to allow registration of the calibration image with the external coordinate system.

C-arm x-ray is used intra-operatively on a routine basis in many surgical disciplines and in Interventional Radiology (IR). Applications range from orthopedics and traumatology to cardiology. Navigation systems using intra-operative X-ray images offer several advantages over conventional methods. Since navigation uses position measurements to generate an overlay of the instrument on the image, radiation dose for both staff and patient can be significantly reduced in comparison to real-time imaging.

4.5.1 Instrument tracking with C-arm fluoroscopy

For navigation using intra-operative X-ray images, a surgical C-arm can be used. As when tracking a US probe or mini-gamma camera in the CT's coordinates, the C-arm can be equipped with a tracker of the position measurement system in order to measure its position and orientation[21,22]. In order to overlay instrument positions onto X-ray images, the imaging properties of the X-ray system must be known. The imaging properties of a surgical C-arm consist of the X-ray generation and detection part, which can be modelled by a simple pinhole camera model, and the image intensifier. Image distortions due to the image intensifier can be described as a pin-cushion distortion due to the curved form of the X-ray entry window, an image shift, an image distortion, and an 'S'-shaped distortion due to an external magnetic field[23,24]. These distortions can be corrected for by a third order polynomial approach with sufficient accuracy[21].

Prior to the first operation a calibration phantom (see Figure 10-11) is attached to the image intensifier, which allows collecting data for image intensifier distortion correction and determination of the position of the focal point of the X-ray tube. The phantom is removed before the operation.

The image intensifier distortion is influenced by external magnetic fields such as the earth's magnetic field. Therefore the model parameters to describe the imaging geometry of the C-arm depend on its position and orientation. The calibration step thus needs to be repeated for typical positions of the C-arm.

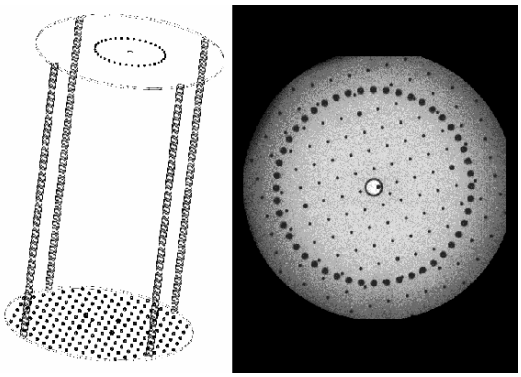

Figure 10-12. Calibration phantom (left) to correct for image intensifier distortion and position of focal spot of the X-ray tube. X-ray image (right) of the calibration phantom. (From[22], Copyright: Robotic Publications Ltd., 2004).

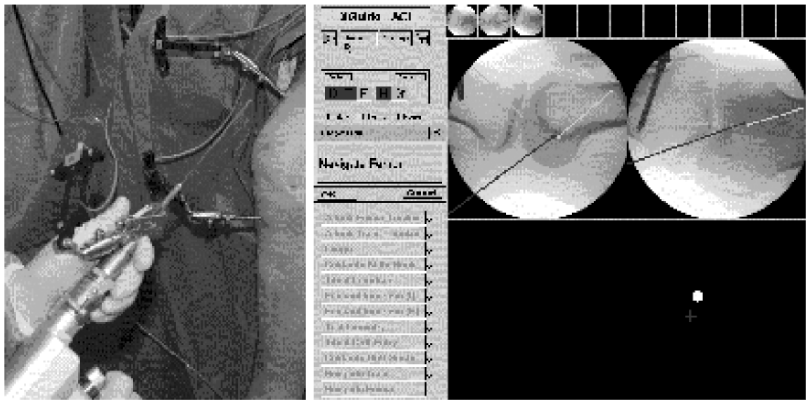

Figure 10-13. Left: Intra-operative situation during drilling of the femoral canal. Note that femur, tibia, and drill guide are equipped with trackers for the position measurement system. Right: Screen shot during drilling of the femoral hole. The red line shows the drill guide in both a-p and lateral C-arm images. The green and blue lines are the planned tibial and femoral canals. In the lower right a targeting tool provides additional geometrical feedback. (From[22], Copyright: Robotic Publications Ltd., 2004).

The surgical navigation system described above has been used in orthopedics for computer-assisted replacement of the Anterior Cruciate Ligament (ACL)[21]. Rupture of the ACL is a common trauma in sports. The common reconstruction is by an autologous tendon, usually the medial third of the patellar tendon or semitendinosus tendon. This procedure is a biomechanically difficult task. The correct placement of the graft, especially the isometry of the tibial and femoral insertion points, is critical to the success of the procedure and the stability of the knee. During conventional arthroscopy the planning of the insertion points and accurate execution of the plan is difficult due to limited overview in the knee.

5. POST-PROCEDURE TREATMENT RESPONSE

Whether performed in the OR or IR suite, many procedures require imaging as treatment follow-up. Ideally, in some interventional oncology cases, post-procedure imaging would not be needed if sufficient and conclusive intra-procedure feedback was provided as to whether or not the local treatment was complete. This ideal has not yet been realized, but could be with advances in molecular imaging.

After an episode of RFA treatment, imaging is used to determine if a portion of the tumor is untreated; thereby, necessitating re-treatment. For RFA, this is typically a contrast enhanced CT scan between 1-7 days after the procedure.

To check for marginal recurrence, tumor size can be tracked over longer periods with sequential CT scans using established criteria for measuring tumor size, e.g., RESIST or WHO, or a 3-D criteria. More recently, on some protocols, PET-CT, SPECT-CT, or dynamic MR are being used to track the response of the tumor with a potentially higher accuracy than CT. This can help further differentiate a heterogeneous tumor and indicate the need for re-treatment based on functional or molecular information.

6. SUMMARY

New technologies for IGT were reviewed for the interventional radiology suite and the operating room of the future. This included new methods for multi-modality, point-and-click treatment planning, multi-modality image targeting with active and passive navigation devices, monitoring with real-time 3-D imaging, and post treatment follow-up.

Some of the devices, such as optical, electromagnetic, and articulated arm navigation systems, have advantages and trade-offs. In some cases,

more investigation is needed for further automation, verification and validation, and to determine which methods or devices are best for a given application and venue. Some prototypes and projects are in the early exploratory phase, and others are being used in clinical protocols.

Multi-modality treatment planning and real-time targeting and monitoring will eventually become seamlessly integrated, more fully automated, and easier to access and use during the procedure. Many devices and imagers can be integrated, used in combination, and can share common coordinate systems and image data.

Further merging of molecular imaging and image-guided therapy will significantly increase the amount of pre- and intra-procedure visualization. Integrating image-guidance devices with this additional visualization will lead to significant benefits for the patient and will ultimately, at least in some cases, facilitate the need for only one episode of image-guided care.

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