Disclosures

• Research grant support
  – Elbit Medical imaging Ltd (InSightec-Image guided treatment)
  – NIH
    • National Center for Image guided therapy
  – GEHC

• Consultant
  – Elbit Medical imaging Ltd (InSightec-Image guided treatment)
Learning Objectives

• Understand Interventional MR
  – Devices, Equipment, Safety & Infrastructure

• Applications
  – MR Thermometry

• Current/Future imaging and therapeutic techniques

• MR guided prostate Bx

• MRgFUS-uterine fibroids

• URL:
Acknowledgments


- Special Thanks to Angela Roddy-Kanan RN, and Janice Farihurst RT for help and slides
Current trends in healthcare

• “Aging boomers” More elderly patients
  – 17%- 25% > 65 yrs by 2030

• Reduced hospitalization time
  • Personalized medicine
  • Surgery changing: From invasive to minimally invasive to noninvasive
    – Out patient facilities smaller sites/ less overhead

• Decrease length of stay (LOS)

• Increased off site care: Telemedicine/telemonitoring

• Increasing role of imaging
  – Biomarker/surrogate markers
  – Personalized medicine
  – More image-guided interventions

• US increase in self pay/self coverage
  • Est to increase to 50%
  • Increase patient choice and control in caregivers

OLDER ,
LESS TIME,
MORE IMAGES
MORE PERSONALIZED
The Vision

MR intervention

Recycle your e-waste today with this new program!

http://www.dummies.com/WileyCDA/
The IGT Vision

- Replace the eye with multimodality imaging
- Replace the hand with image controlled devices
- Integrate therapy with intraoperative imaging
- Develop image-guided therapy delivery systems for multiple clinical applications
- Change invasive procedures to minimally invasive or non-invasive ones
The Challenge

“Imaging has become essential not only for the detection and monitoring of disease but also for intervention. Methods of acquiring, analyzing, and displaying this information in real time during the intervention must be improved.”

Richard L. Ehman, MD, William R. Hendee, PhD, Michael J. Welch, MD, N. Reed Dunnick, MD, Linda B. Bresolin, PhD, Ronald L. Arenson, MD, Stanley Baum, MD, Hedvig Hricak, MD, PhD, and James H. Thrall, MD

(Radiology 2007, 10.1148/radiol.2441070058)
What is surgery?

Hand – eye coordination
Key Enablers

IMAGING TECHNOLOGY

EYE

HAND

No, Doctor. I don’t know where’s today’s patient.
IGT-Changing the face of Surgery

Integration of advanced imaging technology into the Operating Room

**THERAPY DELIVERY SYSTEMS**

- **GEHC**
- **Phillips**
- **Siemens**

0.5T MRI

1.5T MRI

GEHC/Insightec
Types of Procedures May Dictate Magnet Type
MR Surgical Suite

MRI and X-ray Compatibility

Provided by Jolesz et al.
The Goal of Image-guidance

To maximize therapy to target with no loco-regional effects

Allows physician to see beyond the Surface

Define Targets/ Control Interventions
- Define Target-Imaging
- Direct therapy-Imaging
- Deliver & Control therapy
- Disease-eradicated, controlled, relieved, palliated
Role of imaging

- Localization
- Targeting
- Navigation
- Monitoring
- Control

Diagnostic Imaging
Surgical Planning
Interactive Imaging
Dynamic Imaging
Quantitative Imaging
• Milestones
• Multidisciplinary approach
  – Computer science, Image processing, Bioengineering, Robotics
  – Radiology, Surgery, Rad Onc, Ob/Gyn, Anesthesia
• Multimodality approach
  – MRI, PET, CT, US
• Multiple vendors and industries
  – Equipment
    • Anesthesia devices
    • Visualization, tools, IT
• Multiple funding sources
  – NIH, Industry
• Training tracks
  – NIH grant-R25 fellows in IGT

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MRT: The first decade 1996-2006
Nursing, Safety & Equipment Challenges

• MR safety
• Location of IMRI
• Equipment and Imaging
• Codes
• Draping patient/magnet
• Positioning patients
MR Safety

• Develop P & P & Assign “safety officer
  – has the responsibility of making sure that the MR safety policies are updated and adhered to and that staff working in the MR area have received safety training.

• Magnetic field is always present

• Design your suite to allow careful planning of “Zones”
  – Zone 1 - hallway outside suite
  – Key card access ONLY
    • Zone 2 - waiting room within suite
    • Zone 3 - areas adjacent to magnet room
    • Zone 4 - room that houses magnet

• Screening /training of staff & Screening of patients

• Hazards
  – Projectiles of ferrous objects
  – Heating of ferrous implants
MR Safety Signage
Staff Training/Screening & Patient Screening

Non Patient Screening

On Line Training

2004 Edition

© NIH National Center for Image-Guided Therapy, 2007
Instrument Challenges

- MR Instrument language
  - MR safe
  - MR compatible
  - MR conditional
- Availability of MR safe instruments
- Controlling ferrous instruments
- Color coding
Instrument/Equipment Testing

Test with hand held magnet
Color code appropriately: Green – GO-Safe
Image if necessary
Skull pins, biopsy needles, retractors, head clamp

• Red is not safe (stop)
• Green is safe (go)
Anesthesia

- Anesthesia machine
- Patient monitor
- IV poles
- Different equipment
  - Extra time for preparation
- Safety issues
  - Can’t monitor ischemia
  - No mesh ET tubes
  - No crossing of EKG wires
  - No internal temp measurement
MR Technologist is the Watch Dog
Coils, Draping and Imaging

• RF coil placed around area of interest
• Can be placed before (unsterile) or after (sterile) draping
• Coil gets plugged into side of magnet
Medical Emergencies

- Bring pt out of room
- Have designated code area
- Push button to release locked doors
- Quench magnet only if needed

Anesthesia Emergency Button
Located in magnet room
Alarms in main recovery room
Releases locked doors to suite for 1 hour

Area with code cart, defibrillator oxygen, pt monitor etc
3D Slicer Surgical simulation software

Provided by Pieper et al.
Neurosurgery Milestone

BWH completes 1,000th Intraoperative MR-guided Craniotomy

In August 1996, neurosurgeons at Brigham and Women’s Hospital (BWH) performed the world’s first intraoperative MR-guided brain tumor craniotomy, successfully removing a tumor using the most advanced imaging techniques available.

As BWH marks the 10th anniversary of this landmark procedure, Neurosurgery, Neuroradiology and Magnetic Resonance Therapy (MRT) teams last month combined to perform the hospital’s 1,000th intraoperative MR-guided craniotomy.

"This milestone is testament to how effective this
MR guided Cryotherapy

MRI of iceball compared with 24 h contrast enhanced MRI

Estimate of cryonecrosis:

Volume and location of signal void iceballs

Volume and location of decreased enhancement cryoablative area
3D Slicer

• Image Processing
  – Segmentation
  – Registration
• Model Building
• Scene Graphs
• Also Supported by NAC P41, NAMIC U54
• Open Source

image provided by Dr. Silverman
Overview of BWH Prostate IGT program

- 1997-Est D’Amico & Tempany
  - MRg Brachytherapy (1-2/wk):
    - 472 men treated (9/29/06)
  - MRg Biopsy (1-2/month): 68 men

- Use MR images to plan, guide and monitor intervention
  - Pre-procedure 1.5T/3T multi-parametric data
  - Procedure 0.5T Non-rigid registration

- Open interventional magnet
  - GE Signa SP 0.5T system
  - Allows transperineal access
Prostate Cancer: Some facts

- 1.5 million biopsies/year
- 25 million men have at least one negative biopsy
- 230,000 new cases diagnosed in 2005
- Est. 450,000 new cases in 2015
- Approx 4-8% disease specific mortality rate
Focal right sided tumor with ECP

Axial T2W

Sag T2W

PZ

CG
Prostate imaging

Detection
Staging
Prostate biopsy
Brachytherapy
SPL
High Performance Computing
Gigabit network
Terabyte storage

FEM Based Deformation
Mutual Information
MR Robotics

Prostate cancer
Image guided therapy

CALGB/Novartis-STI571
Prostate cancer imaging and Brachytherapy program-Today

MR IMAGE

TREATMENT PLANNING

NEEDLE PLACEMENT

PZ

Urethra

Ant Rect

0% 50% 100%
MR-guided prostate biopsy clinical research program

- Clinical need
  - TRUS high false negative
  - MR Bx Target + Sextant/octant

- Need target validation method
- Need ‘free-hand’ or Robot assisted approach

3D-Slicer* adapted for prostate procedures and target definition, trajectory planning and guidance

* http://www.slicer.org/
Slicer prostate biopsy module
Real time intra-operative images and registered pre-operative image can be fused to aid in needle guidance. Images not otherwise available in the operating room can be utilized.
Case history

- 61yo Male Chemical plant manager
  - PSA history (4 prior biopsies)
    - Feb 2000 12.5 Biopsy negative
    - Dec 2000 14.7 Biopsy Negative
    - Feb 2001 13.9
    - April 2001 15 Biopsy negative
    - Sept 2001 14.7
    - Sept 2002 21.7 Biopsy(15 cores); Negative

- MR exam
  - Feb 2003- 2cm lesion left side

- MR guided targeted prostate biopsy
  - 8/13/03 (PSA 18.8)
    - Prostate Adenocarcinoma: GG 4+7 in 4/7 (2 target cores)

- 11/03 radical prostatectomy
  - 3.5 cm bilateral tumor confined to prostate
Current challenges

• Prostate diagnosis and therapy in high-field, closed-bore scanner (3T)
  – High-quality imaging,
  – More prevalent in clinics and hospitals.

Mechanical guide to accurately reach lesion under image guidance is necessary.
Challenge: Workspace

458mm

83.0mm

perineum

550mm
Robot-assisted In-bore Needle Placement

Vertical Motion Mechanisms

Optical Encoder

Pneumatic Cylinder

GE 3T Excite bore

robotic needle

patient
Magnetic Resonance guided Focused Ultrasound surgery

MR thermometry
Real-time feedback
focal heating
History of FUS

- 1926 Wood & Loomis
  - High Intensity US biological effects on unicellular organism
- 1942 Lynn et al
  - First therapeutic use of FUS-Liver
- 1942 Fry et al-Animal brain
- 1950 Fry Brothers
  - Open craniotomy, intraoperative sonications Parkinson’s Disease
- 1975 Lele-”Ideal surgical tool”

- 1993 Hynenen, Cline & Jolesz et al
  - MRg FUS & First MRg FUS using single element transducer in tumor of rabbit muscle
MRgFUS: critical features

- **MR imaging**
  - Anatomic resolution
  - Superior soft tissue differentiation
- **Real time MR thermometry**
  - Proton resonance frequency shifts, with temp changes
- **Immediate MR treatment outcome**
  - Post treatment MR with IV Gadolinium
Focused Ultrasound Surgery of Rabbit Tumor

Provided by Hynynen et al.
Thermal Development of a 10 Second Sonication

- 1.1 seconds
- 4.5 seconds
- 7.9 seconds
- 11.3 seconds
MRgFUS clinical applications

- Breast
  - Fibroadenoma
  - Breast cancer
- Uterine fibroids
- Brain
- Liver
- Prostate
MRgFUS system Components

1.5T magnet  
General Electric  
Pre-procedural-post  
imaging  
Patient Table  
ExAblate 2000 *  
• Docks to MR scanner  
• Consists of electronics  
and transducer in  
water bath  

ExAblate 2000 *  
Insightec Inc  
Phased Array Transducer  
• In sealed water bath on  
patient table  
• Connects to positioning  
system  
• Moves in X-Y, tilt and roll  
directions  

ExAblate 2000*  
Operator Console  
• Controls all treatment  
planning and operation  
• Thermal imaging  
analysis/display  
• Sits next to SIGNA MR  

* Insightec Inc, Haifa, Israel
Clinical trial Protocol

- Planning beam path
  - Avoid bowel
  - Scar
  - 4cm from sacrum
- 100 cc’s tissue
- 15mm from outer surface
- 3hrs sonnications
- IVCS
- Start Rx
- Low power build up
- To therapeutic power
Uterine fibroid thermal ablation with MRI-guided focused ultrasound

MRI-based temperature mapping

Brigham & Women’s Hospital, Boston, MA
Thermal dosimetry-based control and post-treatment imaging
MR imaging-Guided Focused ultrasound surgery for uterine leiomyomas: A feasibility study

MRgFUS
prostate cancer treatment
Specific Challenges in Prostate Cancer

- In vivo marker of biological behavior
- In vivo definition of index disease
- Focal therapy/monitoring
  - Image guided/controlled and delivered
Prostate MRgFUS-Animal

A

Prostate

Transducer

B

Courtesy Insightec Inc
Animal MRgFUS/Insightec

Figure 3: Prostate lesion: A Coronal planning image with accumulated dose; B Post treatment Coronal T1w contrast enhanced subtraction image; C Pathology image (post treatment dissection)
Bone MRgFUS

Pain palliation of bone metastases
Reduce pain meds

- Wide Beam Approach
- Low energy usage
- Short Treatment Time

MR-guided focused ultrasound surgery (MRgFUS) for the palliation of pain in patients with bone metastases—preliminary clinical experience
R. Catane et al. Annals of Oncology 2006
MRgFUS of focal liver disease

Wadyslaw Gedroyc MD St Mary’s Hospital London, England  Doron Kopelman MD HaEmek Medical Center, Afula, Haifa Israel, Yael Inbar MD Sheba Medical Center, Tel-Hashomer Israel

Planning spot overlay on T2w MR coronal image

Treated dose following FUS treatment shown on T2w MR coronal image

Contrast enhanced T1w subtraction image showing the lesion.

Macro pathology image one month following the procedure showing the central hepatic vein and the adjacent lesion

T1w coronal MR image showing the lesion that was created

Micro pathology image

Results – Experiment II
MRgFUS of focal liver disease
Wadyslaw Gedroyc MD St Mary’s Hospital London, England  Doron Kopelman MD HaEmek Medical Center, Afula, Haifa Israel, Yael Inbar MD Sheba Medical Center, Tel-Hashomer Israel
Brain tumor thermal ablation with MRI-guided focused ultrasound

Noninvasive brain tumor ablation using transcranial focused ultrasound

ExAblate 3000, 4000 (InSightec, Haifa, Israel)
BWH IGT Vision for the future

- Widespread/multidisciplinary IGT
- Multi-modal imaging and multi faceted therapies
- BBB disruption
  - Targeted drug delivery
- Ablations
  - Thermal (FUS), cryo, laser
- Image guided thoracotomy, mastectomy
- Robotic or enabling technologies
AMIGO
Advanced Multimodality Image-Guided Operating Suite

PET/CT
OR
3T MRI
Amigo Components

- Modular multi-room facility
  - Surgical/interventional suite Table System
  - MRI (Magnetic Resonance Imaging)
  - Focused Ultrasound Surgery (FUS)
  - Other Imaging: US, X-RAY, Pet-CT
- Navigation software and 3D SLICER
- Interactive and Adaptive imaging Platforms
- Live image display systems-data wall
- Full IT integration
PET/CT-guided Biopsy

Viable tumor

No viable tumor

Silverman, Morrison et al BWH

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MIPAV – Medical Image Processing and Visualization (MIPAV) software – NIH
McAuliffe et al IEEE Proceedings 2001
For More Information

- National Center for Image Guided Therapy
  - http://www.ncigt.org
- Surgical Planning Laboratory
  - http://www.spl.harvard.edu
- National Alliance for Medical Image Computing
  - http://www.na-mic.org
Conclusions

Revolutionary “game-changing” technologies

• Multiple clinical applications

• Clinical integration into practice has many challenges:
  – Health care inertia/System constraints
  – Technical Resources
  – Growth/Investment issues

• Significant demands at early stage of penetration
  – Be cost effective
  – Be efficient
  – Enormous challenges--Not for the faint of heart

• All are disruptive technologies

Bottom line motivator:
Extra-ordinary rewards and benefits for our patients
Bottom Line: Improved Patient Care

- Provide new capabilities that transcend human limitations in intervention
- Increase consistency and quality of interventional treatments