Interventional Magnetic Resonance Imaging: Basics and Applications

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CASE

Overview

- Principles
- Applications
  - Diagnostic
  - Therapeutic
    - » body, neuro intervention
- Research & future directions

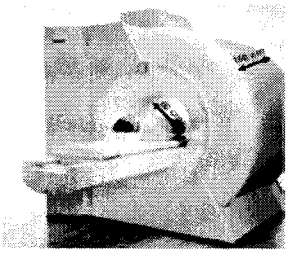
Principles - The iMRI suite

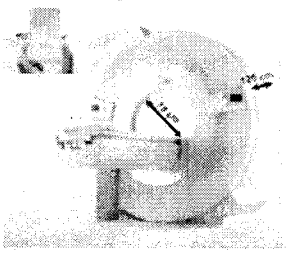
- Access to patient (initial)
  0.2 T open C-arm MF system
  (Siemens, Magnetom Open)
- In-room operation
  HR RF-shielded LCD monitor
  + MR-compatible mouse
  & foot pedal
- Rapid imaging
  Interactive guidance with MR "fluoroscopy"

Siemens 1.5T

Sonata

Espree





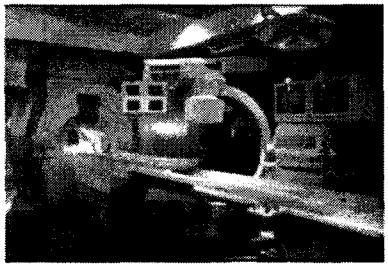
Toshiba "Grecian Temple"

General Electric SP 0.5 T
Brigham and Women's Hospital

Courtesy of Ferenc Jolesz, M.D., BWH, Boston, Massachusetts

Philips 1.5T

University of Minnesota



Courtesy of Chip Truwit, M.D., Minneapolis, Minnesota

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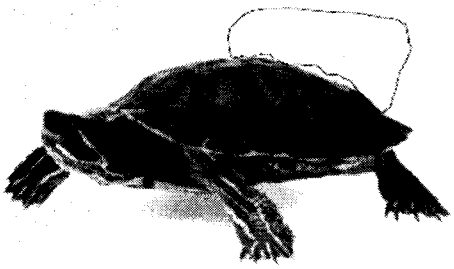
Conventional view of MR Imaging



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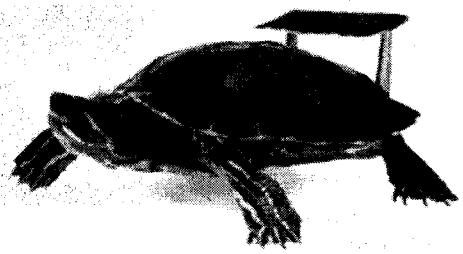
Rapid Imaging and Intervention



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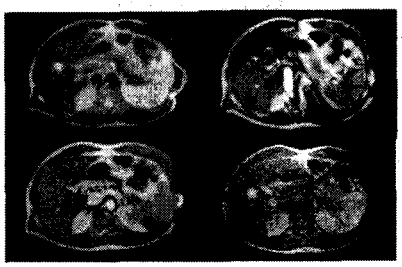
T2-Weighted Imaging

TSE7
10min



True-FISP
1.2s

FISP
3.4s

PSIF
4.7s

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Technical Considerations

- Which pulse sequence to use
- New pulse sequence to create to obtain better contrast, shorter time
- How will devices appear in the images
- What K-space coverage to use
  - Rectilinear, spiral, radial, Keyhole
  - Parallel imaging
- How will flow appear

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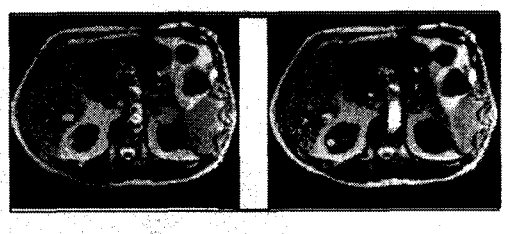
True- FISP/FIESTA



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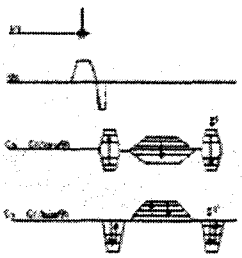
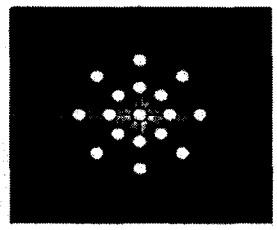
Other Trajectories-Radial





Ideal Case:

All projections centered

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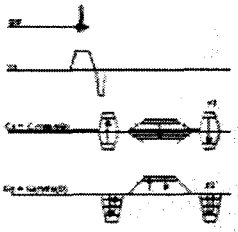
Real Time Imaging



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Spiral Imaging

Sequence diagram

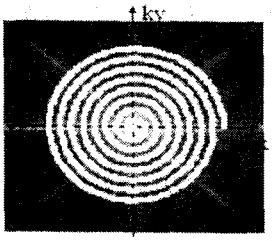
RF

Gz

Gx

Gy

K-space trajectory

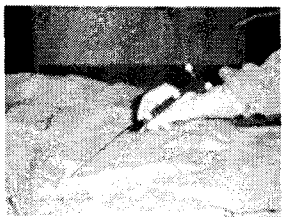


Principles - Instrument Tracking

Free-Hand Technique

Principles - Instrument Tracking

Optically-Linked System



Applications

MR-Guided Procedures
Historical Perspective

1986	Mueller et. al.	Radiology	Liver
1987	Lufkin et. al.	AJR	H&N
1988	Lufkin et. al.	AJR	Body
1989	Duckwiler et. al.	Radiology	H&N

Applications

Interventional MRI Today
4 distinct areas

- Minimally-Invasive Diagnostic Procedures
- Minimally-Invasive Therapeutic Procedures
- Catheter-based procedures
- Intra-operative MR guidance

Minimally-Invasive Diagnostic Procedures

Biopsy & Aspiration

Applications - Biopsy & Aspiration

Role of MR Guidance

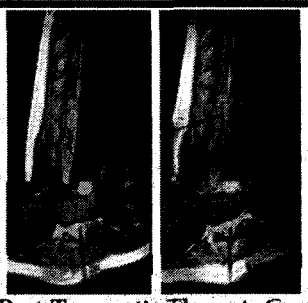
- To avoid surgical exploration and open biopsy performed solely for the purpose of tissue diagnosis
- *Not* to replace other modes of non-invasive diagnosis or other methods of minimally-invasive tissue sampling

Applications - Biopsy & Aspiration

What is particular about

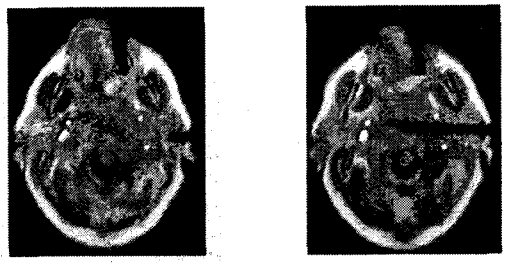
MR Guidance ?

High soft-tissue contrast



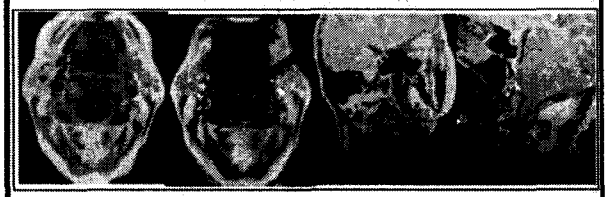
Post-Traumatic Thoracic Cyst
Aspiration as Diagnostic Challenge

Unparalleled vascular conspicuity



Previous Surgical Trans-Oral Biopsy
Infection with Spinal Cord
Compression

Double oblique capabilities



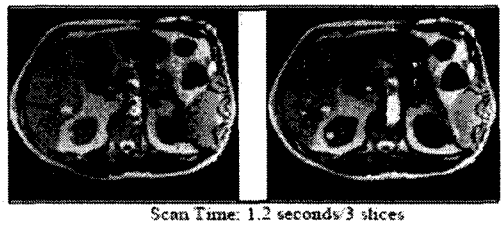
C-2 Vertebral Biopsy
Multiple Myeloma

Applications – Biopsy & Aspiration

Primary indications

Applications – Biopsy & Aspiration

Primary Indications
CT and US Occult Lesions



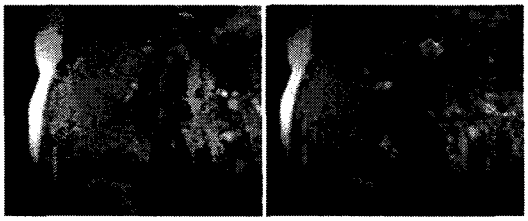
Scan Time: 1.2 seconds/3 slices

Applications – Biopsy & Aspiration

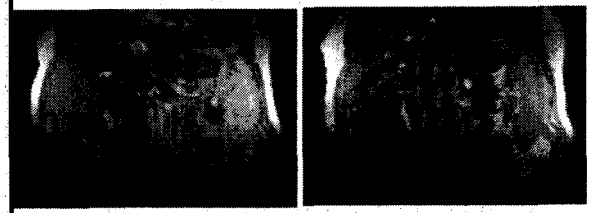
Primary Indications
Complex anatomy e.g. liver dome

Applications – Biopsy & Aspiration

Primary Indications
Transiently Enhancing Lesions



Transiently Enhancing Lesions



Minimally-Invasive Therapeutic Procedures

Tissue Ablation:
- Thermal
- Chemical

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Applications – Thermal Ablation

Sources of Thermal Energy

- Radiofrequency
- Microwave
- Nd-YAG or Diode Laser
- Focused Ultrasound
- Cryotherapy (liquid Nitrogen)

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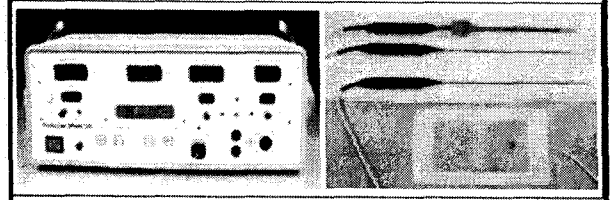
Sources of Thermal Energy - RF

RF Generator | RF Electrodes



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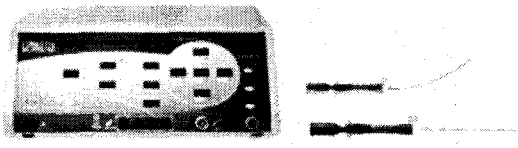
Sources of Thermal Energy - RF

RF Generator | RF Electrodes



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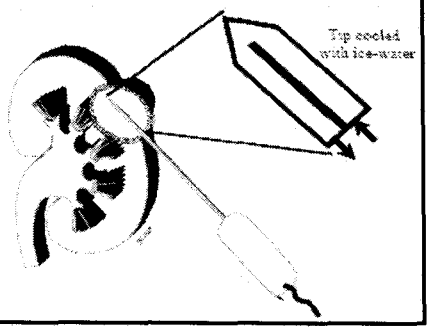
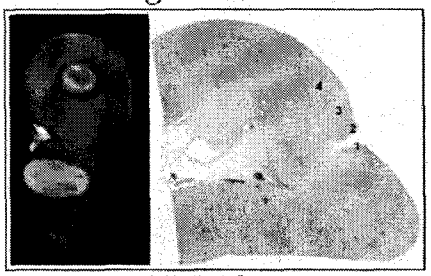
Sources of Thermal Energy - RF



Sources of Thermal Energy - RF

Pathologic Confirmation



Merkle, Shonk, Ducrot, et al. AJR 173:1) 543-

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Image Guidance

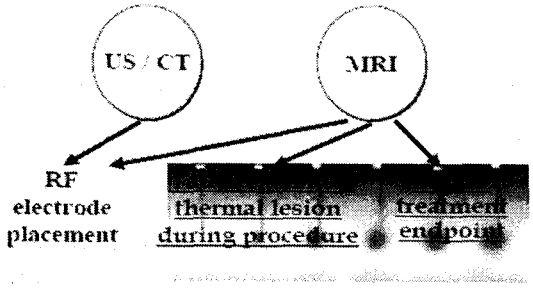

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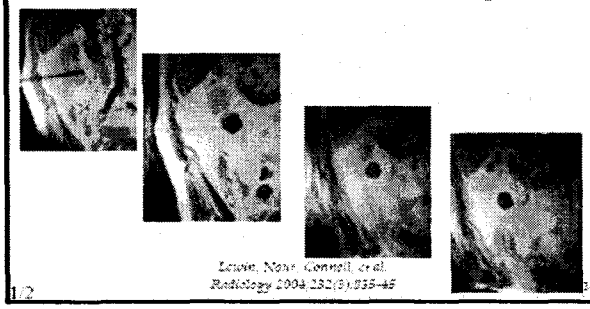
Image Guidance - MRI

Residual Tumor & Treatment Endpoint



Louie, Nour, Connell, et al. Radiology 2004;232(3):935-45

1/2

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Image Guidance - MRI

PSIF

Echo Shifted Imaging with Spin Echo

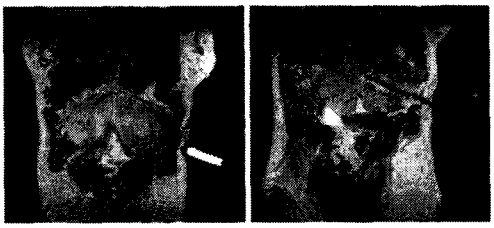


Image Guidance - MRI

Image Guidance - MRI

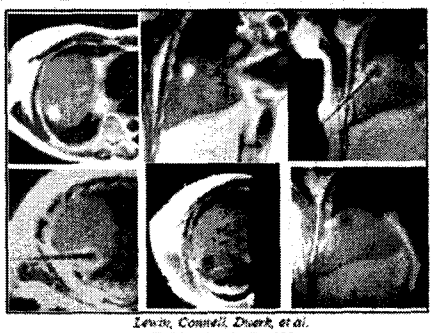
Tissue Necrosis Imaging

Merkle, Shonk, Duerk, et al. [illegible]

UHC / CWRU Experience

- Determine technical feasibility and efficacy of interactively controlled interstitial thermal ablation performed completely within MR system
- Phase I trial to assess morbidity, mortality, toxicity published 1998
- Phase II trial for determination of efficacy ongoing – Initial results published 2004

Phase I Clinical Trial



Lewin, Connell, Duerk, et al. JMRI, 8(1): 40-47, 1998

Our Group's Experience

- Determine technical feasibility and efficacy of interactively controlled interstitial thermal ablation performed completely within MR system
- Phase I trial to assess morbidity, mortality, toxicity published 1998
- Phase II trial for determination of efficacy ongoing – Initial results published 2004

Phase II Clinical Trial

- **Kidney malignancies**
- **Liver metastases**
- **Other sites of solid tumor**

Phase II Trial - Kidney Patients

- 18 patients with renal tumors (age = 25-83/mean = 71.2 y)
- 16 eligible for phase II trial with tumor ≤ 4 cm
- 2 treated under compassionate use with tumors > 4cm
- 2 →MR-guided aspiration
- All had contraindications to or refused surgery
- Written informed consent and IRB approval

Phase II Trial - Morbidity

- Minimal intraprocedural discomfort totally controlled by intravenous sedation & local anesthesia.
- Few patients required oral acetaminophen for analgesia on evening of treatment.
- No patient required pain medication on discharge next morning.
- 4/18 small perirenal hematomas, no treatment necessary.

Phase II Trial – Preliminary Results

- 10 patients with primary kidney malignancy
- No tumor recurrence.
- Average follow-up: 25 ± 9.4 months
  Longest follow-up: 41.7 months

Lewin, Nour, Connell, et al.
Radiology 2004;232(3):835-845

Phase II Trial – Preliminary Results

Male patient
D.O.B. 12/11/1925

Left upper pole RCC
3 cm

Phase II Trial – Preliminary Results

on time = 22 min

Phase II Trial – Preliminary Results

Intra-Operative MR Imaging

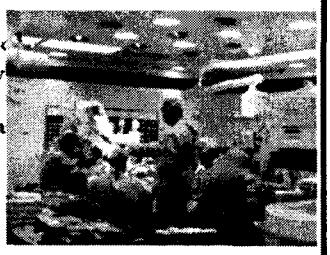
Historical Perspective

- Brigham & Women's Hospital - Boston - June 1995
- University of Heidelberg, Germany - Dec. 1995
- University of Erlangen, Germany - 1996
- University Hospitals of Cleveland / CWRU March 1997
- Long Beach Memorial
- U. Minnesota
- U. Cincinnati
- UCLA
- ....
- St. Joes/Barrow July 2006

Intra-operative MR Imaging

Surgical Suite

- Operating suite standard
  - HEPA filtered positive pressure ventilation
  - Anesthesia gas column
  - Viewboxes, electrical outlets, telephones, network connections



Intra-operative MR Imaging

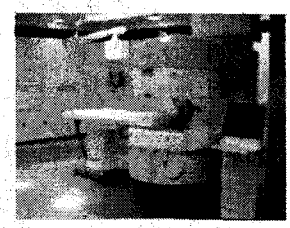
Surgical Suite

- Standard surgical instruments
- Titanium versions of retractors, specula, brain biopsy needles, and curettes
- Standard operating microscopes, electrocautery, cortical stimulator, and fiberoptic headlamps

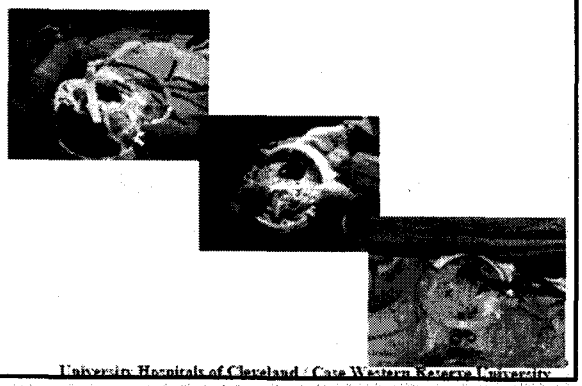
Intra-operative MR Imaging

Surgical Suite

- 0.2 T imager (Siemens Open Viva)
- Prototype surgical table
- Color-coded flooring (20 mT, 0.5 mT, and 0.15 mT field)

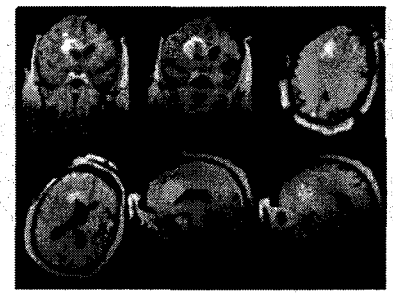


University Hospitals of Cleveland / Case Western Reserve University



University Hospitals of Cleveland / Case Western Reserve University

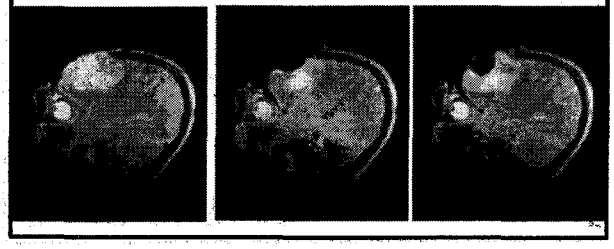
High-Grade Astrocytoma



High-Grade Astrocytoma

Intra-Operative Tumor Localization

32-year-old woman with frontal lobe glioma



Intra-Operative Tumor Localization

40-year-old woman with sphenoid wing meningioma

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Chemical Ablation

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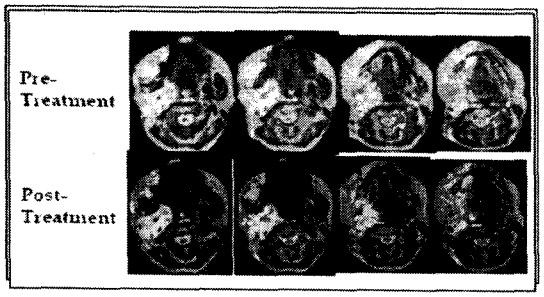
MR Image-guided Sclerotherapy

Low-Flow Vascular malformations



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Catheter-Based Procedures

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Applications – Intravascular MRI

Why on earth would anyone want to use MRI to guide angiography?

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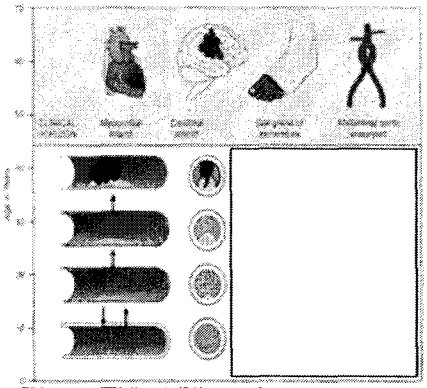

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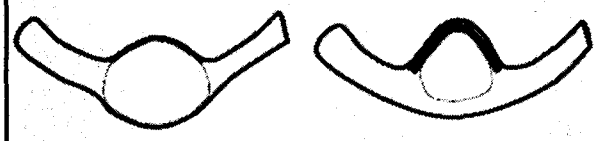
The issue is " Plaque vulnerability"



More vulnerable
Less bulge

Less vulnerable
More bulge

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Applications – Intravascular MRI

X-ray angiography is limited to "lumenology"

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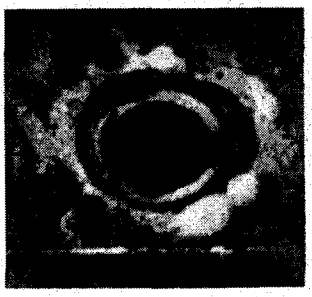
Applications – Intravascular MRI

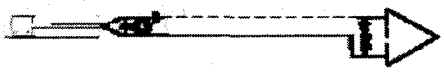
Intravascular MR imaging provides lumen morphology...

...*plus* vessel wall information

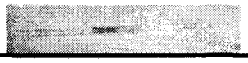


Enabling Technologies

- Real-time active catheter tracking
- Automatic scan plane positioning
- Adaptive image parameter system

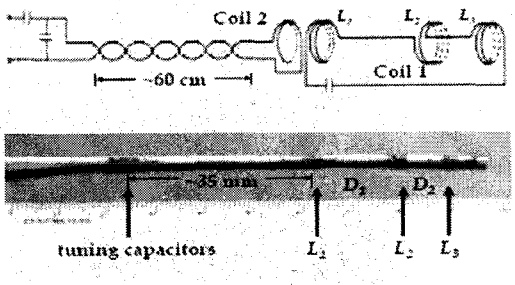


Tracking Catheter used to catheterize Renal Artery

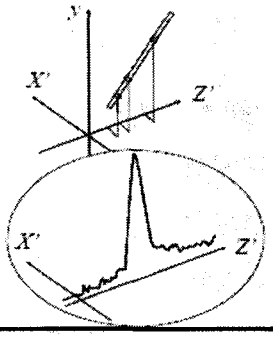


Tracking Balloon Catheter used to deploy stent

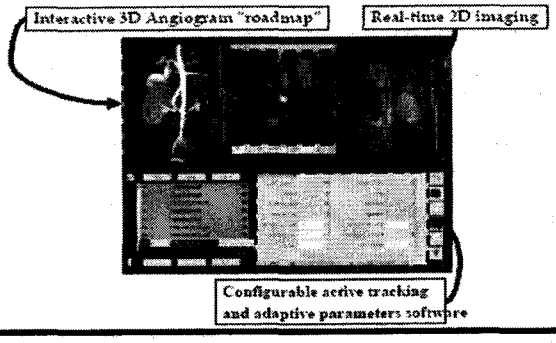
Micro RF Receive Coil



Active Catheter Tracking

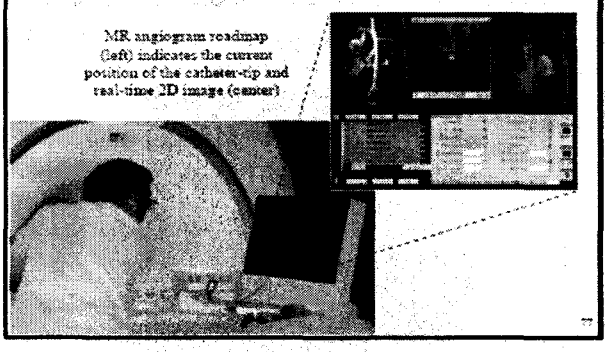


Physician Interface

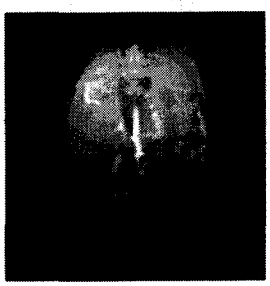


Interventional Set-up

MR angiogram roadmap (left) indicates the current position of the catheter-tip and real-time 2D image (center)



Active Tracking & Adaptive Imaging



Experimental Protocol

- Induce renal stenosis in six healthy farm pigs
- Document renal stenosis using X-ray angiogram
- Perform pre-procedural MR angiogram for evaluation of disease and planning
- Catheterize renal artery under MR guidance
- Perform stent-supported angioplasty using MR to monitor the delivery of therapy
- Evaluate treatment efficacy using MR
- Document residual stenosis using X-ray angiogram

Results: Pre-procedural Phase

X-Ray Angiogram and MRA estimates of stenosis are highly correlated

In this study, stenosis estimates differed by approximately 1.3%

Results: Intra-procedural Phase

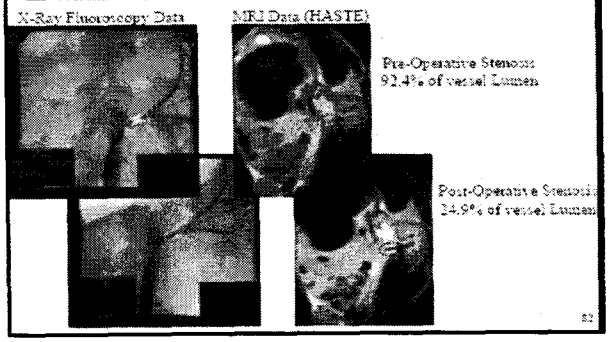
While catheterizing renal artery, adaptive tracking software adjusts the number of radial Interleaves per image.

~5 min

While advancing balloon catheter to renal artery and deploying stent, adaptive tracking software adjusts image FOV.

~5 min

Results: Post-procedural Evaluation



Results

- **Average pre-operative stenosis: 53.6%**
- **Average post-operative residual stenosis: 14.9%**
- **All procedures were a technical success and performed without complications**
- **Difference between MR and X-ray: 1.3%**
- **Predicted stent placement accuracy:**
  0 +/- .78mm (pixel size in real-time images)
- **Observed stent placement accuracy:**
  .98 +/- .69 mm (Center of Stent to Center of Stenosis)
- **Time required for intervention:**
  25 min (15 planning, 5 catheterization, 5 stenting)

Conclusions

MR image-guided minimally-invasive chemical and thermal therapy has great potential for treatment of benign and malignant diseases

High lesion and vascular conspicuity and multiplanar capabilities make MR-guided biopsy and aspiration useful in a wide range of clinical settings

Intra-operative MRI has positive impact in the majority of cases, and adds an acceptably small amount of time to neurosurgical procedures

Intravascular MR imaging and MR-guided vascular intervention hold great promise for the diagnosis and treatment of vascular disorders

Conclusions

- **Safe Interventional and intraoperative MRI is possible but requires careful attention to a number of operator-dependent factors**
- **Education and experience are essential to maximize benefits and minimize risk**