From Bench to Brain: Recent Advances in Devices Used in Neuro-Interventions

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Disclosures

- Research Grants (last 12 months):
  - NINDS, NIBIB, NCI
  - Philips Healthcare
  - Fraunhofer Institute
  - Stryker Neurovascular
  - Codman Neurovascular
  - Medtronic Neurovascular
  - InNeuroCo Inc
  - Blockade Medical
  - CereVasc LLC
  - Cook Medical
  - Medtronic
  - Microvention
  - Neuravi
  - Spineology Inc
  - Silk Road
  - Wyss Institute

- Consulting (fee-per-hour, last 12 months):
  - Stryker Neurovascular
  - Harris Beach, Expert Witness
  - Codman Neurovascular

- Investment (Stocks):
  - Boston Scientific Inc
  - InNeuroCo Inc

Challenges in Neuro IR

- 3 mm
Two Approved Treatments: Both Target Vessel Revascularization

• Pre-Clinical Modeling has had an Impact:

With and without treatment with IV tPA


With and without treatment with IV tPA

Stent-Retriever Thrombectomy

MR CLEAN, NEJM Jan 2015
SWIFT PRIME, NEJM June 2015
EXTEND IA, NEJM March 2015
SWIFT PRIME, NEJM March 2015
ESCAPE, NEJM March 2015
EXTEND IA, NEJM Mar 2014

Devices for Recanalization

US FDA Cleared
Penumbra
Merci
Trevo

Solitaire
pReSet
Penumbra Separator 3D
Phenox (AJNR 2011)

Penumbra
Penumbra
Penumbra
Penumbra
New Generation of Cerebrovascular Devices

- Challenge in device development for cerebrovascular applications has historically been MINIATURIZATION

- New generation of manufacturing technology has enabled braiding wires as small as 25μm or laser cutting features as small as 5μm.

- Materials science developments are enabling a host of potential polymers and metals for endovascular implants

- Challenge – HOW CAN WE SEE THEM!

Stents and Stent-retrievers

Laser Cut Hypotubes
Example: SAC

58 y-o F, incidental L supraclinoid aneurysm, failed surgery

New generation stents

Barrel® VRD – Marker Bands
Barrel Marker 6X (Around Barrel)
Proximal Barrel Marker 1X (End of Barrel)
Distal Barrel Marker 1X (Start of Barrel)
Proximal Tip Marker 1X
Distal Tip Marker 3X (Stem of Barrel)

New generation stents

Barrel VRD Marker Bands
The FD Generation

Pre-Procedure

6 month follow-up

"Flow Disrupters"

Application-Specific Requirements

- FAST reconstruction – minutes
  - Typically ~2 min
  - Information is acted on (peri-procedural)
- Full-brain coverage preferred
- ~50 µm spatial resolution
- Contrast resolution: device, vessel (iodine) and brain

XperCT (DynaCT): CT-like Soft Tissue Contrast due to Pixel Binning

2×2 pixel binning:
- Reduce noise by averaging signals
- Soft tissue contrast
- Reduce data to be transferred through imaging pipeline
- Reduce reconstruction time
- Reduce spatial resolution

VasoCT: Non-Binned Reconstruction for High Spatial Resolution

Non-binning performed to:
- Enhance spatial resolution
- Fine detail
- Reduced detector format to control data and reconstruction time
- Lower signal-to-noise
  Patel et al, AJNR 32, 2011
**Bench/Animal - VasoCT**

**Contrast Injection Optimization**

**Phase II: Clinical Evaluation**

- IRB Approved
- 57 CBCT examinations (55 patients)
- 52 Included, 5 Excluded
- 54% GA, 46% CS
- 44 post coil
- Blinded Review (3 experienced interventional neuroradiologists from various institutions)
**Summary of Clinical Results**

- **Strengths**
  - Reliably adequate visualization (> 95%)
  - In most cases, excellent visualization (> 60%)
  - 29% with notable findings

- **Limitations**
  - Stent-coil relationship in 25%
  - Low ICC for vessel quality

- **Work in Progress**
  - Intravenous contrast administration
  - Photon starvation

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- 60 y-o f, R ICA aneurysm
- post-SAC embolization
- A1 Protected?

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**Patel et al. AJNR, 2011**
**Preliminary Data**

- 45 y/o M previous SAH from PICA aneurysm.
- 6-mo FU of stent-coiled of unruptured rt superior hypophyseal artery aneurysm.
- CE-CBCT shows thin line of neointimal hyperplasia.

Patel et al. AJNR, 2011

**In Vivo Validation: Methods**

- **Baseline**
- **Post Cutting Balloon**
- **Post Stent Placement**

**In Vivo Validation: Analysis**

- CE-CBCT
- Histology

3 ml/s for 57.5ml (5.8% OmniPaque 350), 3 s delay
**Calculation of In-Stent Hyperplasia**

\[
\text{Stent Area} - \text{Lumen Area} = \text{in-stent hyperplasia}
\]

**VasoCT and Histomorphometry:**

Excellent Agreement with Stent Area

\[
R^2 = 0.97 \\
slope = 1.14 \pm 0.04 \\
Y \text{ int.} = -0.78 \pm 0.28 \\
p < 0.0001
\]

VasoCT and Histology Lumen Area Correlate Well, but VasoCT Overestimates

\[
R^2 = 0.93 \\
slope = 1.07 \pm 0.06 \\
Y \text{ int.} = 0.87 \pm 0.32 \\
p < 0.0001
\]

Vessel pulsation results in CE-CBCT overestimation
77 y-o F presented with left sided numbness. MRI showed right temporal-parietal infarct and MRA suggestive of right M1 stenosis confirmed with DSA, >70%. Treated with PTA and 3x15mm stent.
VasoCT-DSA Clinical Comparison

![Graphs showing stenosis comparison with VasoCT and DSA](image)

$r^2 = 0.84$

$slope = 0.76 \pm 0.07$

$p < 0.0001$

Bias = 3.29%

SD Bias = 9.20%

Summary

- IA-VasoCT validated against gold-standard histomorphometry in an animal model
  - In Vivo imaging modality with nearly histological precision
  - Lower limit of neointimal hyperplasia is 0.79 mm²

- Clinical evaluation demonstrates practical workflow, and agreement with gold-standard DSA
  - IV VasoCT requires further evaluation
  - DSA must be in proper projection

Other Applications: Micro-bAVMs

- 42 y-o M, ruptured bAVM Lt Superior Colliculus, 3mm.
  - Post-embolization (nBCA) control angiogram shows complete obliteration
  - 6, 12 and 36 mo FU show continuous re-growth (~2mm)
Other Applications:
Micro-bAVMs

- 10-mo post-treatment DSA and MRI
- Complete cure of AVM with stereotactic radiosurgery
- No off-target side-effects

Van der Bom et al. JNIS 2013
Other Applications: Image Guided CED

- Multi-modal image fusion
- XperGuide to target
- VasoCT confirms cannula location

Results: Probability Map of Acute Spread
Intravascular Imaging

K van der Marel, et al., JNIS; 2016

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DSA-Based Intra-Aneurysmal Flow

Baseline After FD implantation

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Contrast wave map

Optical Flow Tracker

3D reconstruction

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O Bonnetous et al., Med Phys, 2012
V. Mendes Pereira et al., AJNR 35 (2014): 156-163
Dose Reduction

7/17/2014; 43 y/o M; diffusive SAH (supratentorial, R paramesial); diagnostic angiogram to assess source of bleeding

Clarity – 53% Dose Reduction

- Image Processing Chain
  - Real-time motion correction
  - Image contrast-dependent temporal averaging
  - Image noise reduction
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