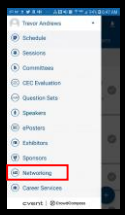
We Need to Talk!

- This is intended to be the start of a community discussion.
- A panel Q&A at the end of this session
- To encourage more time for discussion, my talk will be shorter than posted in the schedule

Send Me Your Questions!



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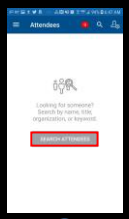

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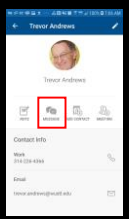

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RF Coil Testing: Hardware, Reconstruction, and Standard Methods

Trevor Andrews, PhD, DABMP (MRI), MRSE (MRSC™)
Assistant Professor, Mallinckrodt Institute of Radiology
Washington University in St Louis School of Medicine

Washington University in St. Louis School of Medicine

Hmmm…OK, that would take a solid hour, if not more

MIR Mallinckrodt Institute of Radiology

RF Coil Testing: Getting Started

Trevor Andrews, PhD, DABMP (MRI), MRSE (MRSC™)
Assistant Professor, Mallinckrodt Institute of Radiology
Washington University in St Louis School of Medicine

Washington University in St. Louis School of Medicine

More believable!

MIR Mallinckrodt Institute of Radiology

Relevant Current Financial Disclosures

- None

Relevant Affiliations/Biases

- Current Chair or the Working Group for Magnetic Resonance Testing and Quality Assurance (WGMRQA)
- Member: International Electrotechnical Commission (IEC), SC 62B, MT 52 (Maintenance of the IEC 62464 series, Magnetic resonance equipment for medical imaging)
- Former Philips clinical scientist/developer
- Former Philips and GE user
- New Siemens user (2.5 months)
- I am an MR Physicist
- I love MRI!

WGMRQA Sponsored Session

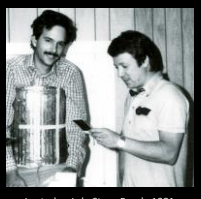
- Our goal: provide value to AAPM member (who are generally not MRI physicists)
- RF Coil Evaluation is most of the ACR annual MRI system assessment
- There are many poorly documented snags
- A definitive AAPM document could be years(!) away, if ever
- This session will hopefully start a fruitful discussion to help bridge the gap

Coil Testing Life Hack (from Joe Och)

- For In-house physicists:
  - Try spreading out annual coil tests to 4 quarterly (or 12 monthly) test sessions
  - This makes it easier to slip required testing onto a busy scanner schedule

Hardware

- Details about RF coils is often:
  - Out-of-date
  - Not clinically relevant
  - Proprietary



Lauterbur Lab, Stony Brook, 1981
Lung Coil

Typical Coil Info

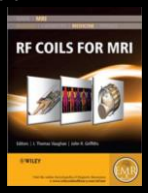
- Marketing brochures

Biased?

Incomplete?

Suggested Reading

- Rare textbooks

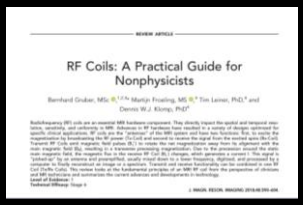


Pub 2012

- Pretty technical
- Not very clinical
- Already seems slightly old
- But at least newer than Hoult textbook!

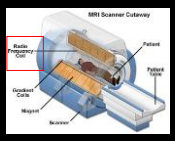
Suggested Reading

- Perhaps an easier starting point



Receive Coil Basics

- Circularly Polarized (CP) or Quadrature Coils
  - 1 receive channel
  - Several older T/R coils (e.g. Quad Body Coil)



Receive Coil Basics

- Phased Array Coils
  - Multiple channels
  - Can be "surface coils" (e.g. spine arrays) or "volume coils" (e.g. 8ch Knee coil)
  - Useful for parallel imaging
  - Channels may be combined under some conditions

Reconstruction

- Later speakers will present more details
- Remember:
  - Noise estimation is key to coil assessment
  - Under the best of conditions it is subject to many potential confusing effects
  - Noise is often manipulated during vendor reconstruction
  - Rarely are details made available to clinical physicists by vendor

Reciever Coil Testing: Common Metrics

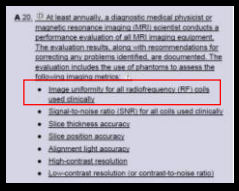
Some great "classic" metrics for describing image quality

- SNR
- Uniformity

I'll talk a bit more about uniformity. (The other speakers will dig more into SNR.)

Some standards may not make sense!

- The Joint Commission, 2015, Standard EC.02.04.03



A 20. At least annually, a diagnostic medical physicist or magnetic resonance imaging (MRI) scientist conducts a performance evaluation of all MRI imaging equipment. The evaluation results, along with recommendations for correcting any problems identified, are documented. The evaluation includes the use of phantoms to assess the following imaging metrics:

- Image uniformity for all radiofrequency (RF) coils used clinically
- Signal-to-noise ratio (SNR) for all coils used clinically
- Slice thickness accuracy
- Slice position accuracy
- Alignment light accuracy
- High-contrast resolution
- Low-contrast resolution (or contrast-to-noise ratio)

Uniformity?
Even for surface coils?!?

Relevant IEC Tests

IEC 62464-1 (Determination of essential image quality parameters)

Sorry, but this may not help with RF coil testing in the hospitals.

- Single slice testing method
- No mention of coil element testing (but Field Service treats this like a "Gold Standard")

IEC 62464-1

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Relevant NEMA Tests

- MS 1-2008 (R2014) – Determination of Signal-to-Noise Ratio (SNR) in Diagnostic Magnetic Resonance Imaging
- MS 3-2008 (R2014) – Determination of Image Uniformity in Diagnostic Magnetic Resonance Images
- MS 6-2008 (R2014) – Determination of Signal-to-Noise Ratio and Image Uniformity for Single-Channel Non-Volume Coils in Diagnostic MR Imaging
- MS 9-2008 (R2014) – Characterization of Phased Array Coils for Diagnostic Magnetic Resonance Images

?

MS 3-2008

- **GRAY-SCALE UNIFORMITY MAP**
  - The percentage deviation from a midrange pixel value expressed in a gray-scale histogram map (5 gray levels). Philips may be the only one that uses this in their field service coil testing tool.
- **PEAK DEVIATION NON-UNIFORMITY**

$$N = 100 * \frac{S_{max} - S_{min}}{S_{max} + S_{min}}$$

- **ACR-MRAP (Percent Image Uniformity)**

$$N = 100 * \left(1 - \frac{S_{max} - S_{min}}{S_{max} + S_{min}}\right)$$

MS 3-2008

- **NORMALIZED ABSOLUTE AVERAGE DEVIATION (NAAD)**
  - A measure of uniformity defined by the average absolute deviation from the mean within the MROI, normalized with respect to the mean within the MROI.

$$NAAD_s = 100\left(1 - \frac{1}{\bar{Y}N}\sum_{i=1}^{N}(|Y_i - \bar{Y}|) + \frac{1}{\bar{Y}n}\sum_{j=1}^{n}(|Y_{ij} - \bar{Y}_i|)\right)$$

NAAD reduces the noise sensitivity of the Peak Deviation non-uniformity measure by using all pixel values within the MROI and computing the average absolute deviation from the average value within the MROI.

Relevant ACR Tests

Volume Coil
- SNR (SNR_{ACR} or SNR_{NEMA})
- Percent Image Uniformity (PIU)
- Percent Signal Ghosting (PSG)

Surface Coils
- SNR is at "hotspot"
- Uniformity?

Phased Array
- SNR is by coil element
  - Alternatively: Single image SNR

Relevant ACR Tests

Things you might have missed:

- In the section on Phased Arrays:

"It is recommended that the qualified medical physicist/MRI scientist perform a more detailed assessment of coil performance by measuring SNR for each element of an RF array coil in a manner similar to the surface coil SNR assessment. This test may require special settings prior to image acquisition or access to the service functions of the system so that separate images of each independent RF channel can be acquired and displayed."

Relevant ACR Tests

Things you might have missed:

"To minimize potential problems with ghosting wrapping around into the phantom, it is preferable, where possible, to choose a FOV that is at least twice the size of the phantom in the phase-encoding direction."

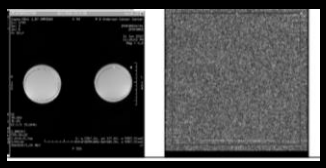
Relevant ACR Tests

Things you might have missed:

- "For single slice measurements, the slice thickness should be chosen to optimize the noise measurement while still providing adequate signal in the phantom. This is typically between 1 mm and 5 mm depending on the field strength."

Other Methods Possible

- For example, on Philips you can do a repeated scan where the 2nd scan has the RF and Gradients turned OFF!



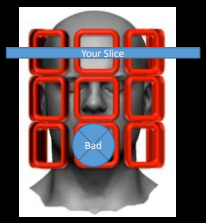
DM Reeve, AAPM 2010

A Few Suggestions

- Test the whole coil
- Uniformity tests may not be useful for some coils
- Consider coil element tests
- T/R coils are extra concerning
- Healthy flex coil images can look weird

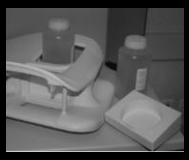
Coil Positioning is Critical

- A far away slice (or far away phantom) may not detect a bad element



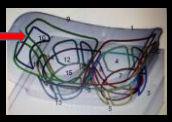
Example: Axilla Element of Breast Coil

- Coil element locations can effect reasonable choices for testing



DM Reeve, AAPM 2010

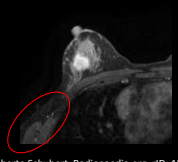
But if this coil element (covering the axilla) is failing, the signal in the bottle might not be non-uniform.



Unfortunately, coil element location information seems to be only available from the vendor (not from IEC, ACR, etc.). Philips provides this directly in the coil selection sections of the UI for some newer software version.

Some Coil Elements Are More Important Radiologically

- Axilla is an especially critical portion of the breast for the radiologist to see clearly.
- So, if anything this is a particularly important element to test.



Case courtesy of Dr Roberto Schubert, Radiopaedia.org, rID: 15118

Be Aware of the Design "Defects"

During the annual RF coil testing, we are NOT trying to pass judgment on coil design.

We are trying to determine whether this coil is in need of repair (and should be replaced).

Unfortunately we are stuck with the design which might have poor uniformity

Designed to Be Non-Uniform

- Uniformity is a critically important image quality clinically.
- BUT many coils have poor uniformity even when working their best.
- (Coil engineers sometimes prioritize SNR over signal uniformity.)
- Coil designs with poor uniformity limit the utility of uniformity as a coil testing metric

Designed to Be Non-Uniform

Example: Philips Invivo Foot Ankle Coil

A "perfectly" functioning foot ankle coil has by design an element at the toes that will produce "hotspot".

So, if the SNR from that element drops, it could actually IMPROVE the uniformity of the sagittal image!!!

Vendor Coil Element Tests

- Advantages
  - Very sensitive compared to composite image testing
  - Generally well-vetted
  - Convenient automated analysis
  - The fastest path to Field Service solution
- Disadvantages
  - Require special vendor passwords or even physical "dongles"(e.g. Philips)
  - Analysis details not clearly explained

T/R Coils: Extra Concerns

BTW, if your transmit/receive coil fails the annual (receive) coil tests, it might also have transmit problems.

(So, this might also be a direct MR safety concern)

Coil Oddity

- Even "simple" coils can be complex
  - Coil loop in axial plane will have very low signal
  - Foot and head end of coil loops will have drop off (This coil is not broken!)

Use axial slices to avoid confounding signal dropoff

Summary

- General educational sources regarding RF coils are available, albeit limited in direct utility and time-consuming to absorb
- Many testing procedures documents can be found, but they have their limitations
- Suggestion beyond the "standard advice"
  - Test the whole coil
  - Uniformity tests may not be useful for some coils
  - Consider coil element tests
  - T/R coils are extra concerning
  - Healthy flex coil images can look weird

Thank You!