Implications of MR Acoustic Noise for Patients and Workers

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Disclosures

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Objectives

- Hearing preservation is an important, but often overlooked, concern
- Basic acoustic noise concepts, theory, terminology
- How loud an MRI scanner today
- Basic introduction to human hearing characteristics
- The IEC acoustic noise limits
- How to select, use hearing protection
- How to protect hearing around an MRI (adult, pediatric, baby, fetus)

The State of Hearing Health

- We live in a noisy environment, personal ear buds (music) etc
- The only regulations relate to occupational exposures
- Only recommendations, no regulations, for personal life
- Hearing loss analysis, decades of research, all based on standard audiometric testing (controlled conditions, threshold of detectability)
  - Hearing function loss does not always result in audiometric testing loss
  - But your ability to function is NOT in a controlled condition
- A new theory emerging regarding "hidden hearing loss"
  - Two sets of hairs in ear: outer (common awareness) inner (little known)
  - Damage at the neuronal signal interface of inner hair/nerve. Likely the cause of the pain when acoustically overexposed

Additional Hearing Safety Concerns

- Loud noise of MRI is anxiety inducing. Reducing anxiety > better images
- The presentation focuses on average population protection needs
- There are a considerable number of people with:
  - Sensitive hearing. Ensuring proper protection may be sufficient
  - Those suffering ringing "Tinnitus" (or in remission) terrified of loud sounds
    - Loud sounds can restart tinnitus, or make current condition worse

Some Terminology

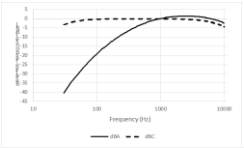
- dB = decibel
  - Deci = 1/10
  - Bel = unit of loudness (Alexander Graham Bell)

$$SPL(dB) = 20log_{10}(\frac{p}{p_o})$$

  - SPL = Sound Pressure Level
  - p_0 = the reference value (human hearing threshold: 20 µPa, @1 kHz, in air)
  - p = measured pressure
  - "2" factor converts from "field" (e.g. pressure) vs power measurements

Human Hearing Response

- Human hearing sensitivity a function of frequency and loudness
  - Used to be called "Fletcher-Munson curves" now "equal-loudness curves"
  - Idealized response curves:
    - dBA = "A" minimum loudness detection
    - dBC = "C" equal loudness perception at LOUD sound levels
  - dBA values typically used (historical reasons) but dBC is more appropriate for hearing preservation considerations
    - One generic conversion: dBC = dBA + 7
  - "dB" typically implies unweighted (or dBZ)
    - Or sloppiness…



More Terminology

- NRR = Noise Reduction Rating
  - Get a group a volunteers, measure hearing threshold at various freqs
  - Same volunteers, have experts insert ear plugs, same test
  - Compute differences, do some math >>> get an "NRR"
  - Considered a flawed method because experts insert plugs. NRR "too high"
    - But it's the de facto measure
    - Some published derate factors to compensate. Literature says flawed factors
  - NRR MUST be applied to dBC numbers NOT dBA (dBC = dBA + 7)
  - Statistically possible to have protection BETTER than label
- "double hearing protection": plugs (eg NRR 30) and muffs (eg NRR 20)
  - Approximate NRR: add 5 dB to higher rating (e.g. NRR = 30 + 5)
    - A conservative, but reliable factor

Some Hearing Benchmark Numbers

dBA average exposure	Example
0	Nominal threshold of human hearing
10	Pin drop
30	Whisper
50	Refrigerator
60	Normal conversation
70 (WHO recommended 24 hr limit)	Shower
80 (range of occupational exposure limit)	Heavy traffic
90	Shouted conversation
100 (99 dBA one hour MRI exposure limit)	Monster truck audience experience
110 (Average worst MRI output, FDA)	Chainsaw
120 (WHO peak limit for children)	Thunderclap
130 (range of loudest reported MRI peak)	Jackhammer
140 (140 dBZ peak limit for adults)	Jet engine at takeoff

Acoustic Noise Dosimetry

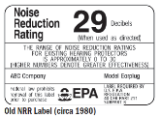
- The longer a loud noise, the higher the potentially damaging dose
- WHO recommended 24 hr dose limit: 70 dB
- The occupational exposure limit (8 hrs, 5 days/wk): 85 dB
  - WHO states occupational exposures "*… are a product of political and economic compromises and are not intended to protect all workers from any injury or illness*."
- The "Exchange factor"
  - How many dB the limit can increase for each halving of exposure duration
  - OSHA: 5 dB
  - Just about everyone else (including IEC) based on newer science: 3 dB
  - The lower exchange factor, more conservative

How loud are scanners these days?

- Relative to older published literature acoustic noise output has held *approximately constant*
  - A remarkable achievement, considering gradient perf. improvements
  - Average: ~115 (max ~127), Peak (average) ~123 (max ~135) (all dBA)
    - Data from FDA during MT40 mtg (Aug 2016 – Aug 2018 510k submissions)
    - Nearly independent of 1.5T, 3T (but acoustic noise expected to scale with B0)
    - A mix of MGAN (some), MCAN (most) (MS-4 test methods)
      - MGAN = max gradient, MCAN = max clinical
  - But who runs a scanner at max, constantly, for entire scan protocol?
  - Good quality ear plugs, used correctly provide lots of safety margin

Selecting Hearing Protection

- Use only hearing protection with proper label and/or information insert
  - There are some weird products out there and not properly labeled
- MR vendors have done calculations and specify minimum Noise Reduction Rating (NRR) suitable for patient protection
  - Please find and use recommendation
- There are many excellent ear plugs out there with high NRR (e.g. 33)
  - I personally prefer the softer plugs, easier to insert
  - Please consider getting small plugs for those with small ear canals
- Make sure the ear muffs have no metal in them!
- But good protection = hard to hear instructions!
  - Technically an entertainment system solves that, but…



Old NRR Label (circa 1980)

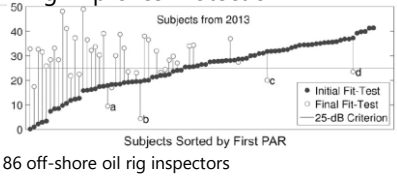
Protecting Adult Hearing

- Ear plugs are an inexpensive and effective solution
  - But must be inserted correctly!
- "Double Hearing Protection" (addition of ear muffs) when possible
- Compress ear plug into a tight cylinder for DEEP insertion
  - Compression ridges compromise performance
  - You can't insert an earplug deep enough to damage ear, but the "hurt" reaction is normal
- A wide range of ear canal sizes (women smaller)
  - There are small sizes available, but you have to look for them

Protecting Children, Infants, Fetus

- Good luck, its more difficult…
- Get smaller earplugs
- Ear muffs do exist for children
- "stick on" (over ear) ear pads for babies "neonatal noise guards"
- "shaved down" adult ear plugs believed not good because "air ridge" may form and effectively no protection
- Incubators do provide some additional protection
- One MR vendor has a foam insert (positioned against bore liner)
- Concern about kids swallowing/choking ear plugs
- Fetus well protected. Make sure mother on pad (stop vibrations)
  - No deleterious MRI effects have been found
  - Loud, lengthy occupational exposure DO impact fetus

Training Improves Protection



From Murphy *Int J Audiol.* 2016 Nov 2016; 55(11):688-698.

- 86 off-shore oil rig inspectors
  - presumably would know how to use hearing protection, use all the time
  - Protections of ZERO – 40+ dB
  - Training pulled many of them over the 25 dB target protection
- Think about patients who probably just given ear plugs, no training
- This graph also shows why 50% derate factors likely excessive

Inserting, Testing Hearing Protection

- Foam plugs require rolling plug into tight cylinder
- Pulling ear back helps align for insertion (see package insert instructions)
- Consider using "Oto-ease" to lubricate earplug
  - Approximately 5 dB gain in realized hearing protection
- I am aware of one highly respected institution where techs insert plugs
- Please teach patients how to insert ear plugs, then inspect + test
- Three testing suggestions:
  - Visually obvious if earplug barely in ear canal. Also easy to pull out
  - Can the person hear you whisper to them?
  - Say "Testing 123", then cup hands over ears, repeat "Testing 123".
    - Proper earplug insertion should not cause large change in volume

Regulations and Recommendations

- Somewhere in system documentation is a statement of NRR recommended to protect patient for one hour. Please comply
- MR limit (99 dB) a derivation of the best occupational limits:
  - Time scaling of 8 hr to 1 hr exposure (+9 dB)
  - 5 dB forgiveness for short (1 hr) exposure (single exposure in week)
  - 85 dB occupational limit + 9 dB + 5 dB = 99 dB
- Occupational exposure limits are guidelines to long term exposures. Is extrapolation to short exposures realistic? Doubtful.
  - The WHO also suggests "*…that patrons of entertainment venues should not be exposed to sounds levels greater than 100 dBA during a four-hour period … no more than four times a year.*"
    - Note this a recommendation without hearing protection
    - By dosimetry scaling factors, implies 106 dBA for one hour, 4x year is OK

One trivia fact for Physicists

- Did you know you can hear RF pulses?
- "Microwave hearing"
- The RF heating causes a tiny thermo-elastic tissue expansion
- You can hear it IF there are no gradients
  - A very quiet "click click" sound

Summary

- For patient comfort, well-being USE HEARING PROTECTION!
- When possible, use double hearing protection
- Really important to instruct, inspect ear plug insertions and test
- Get the appropriate hearing protection tools
- Determine the minimum NRR recommended for your scanner
- Extra care for our smaller patients!

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