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)

\[ SPL(dB) = 20 \log_{10} \left( \frac{p}{p_0} \right) \]

➢ SPL = Sound Pressure Level
➢ \( p_0 \) = the reference value (human hearing threshold: 20 \( \mu \)Pa, @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 freq
  ➢ 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
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...
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

➢ 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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