Toward Optimal Pediatric Nuclear Medicine Imaging
A discussion for imaging professionals and medical physicists

It is inherently challenging to optimize protocols for pediatric nuclear medicine. In general, optimal protocols provide the maximum image quality (benefit) at a minimum of risk. In nuclear medicine, images are required to perform a range of clinical tasks from detection of disease to monitoring a therapeutic response. It is difficult to quantify, and therefore maximize, image quality for this range of tasks.

On the risk side of the equation, in pediatric imaging, there are risks associated with the scan duration and injected activity. Specifically, longer scan durations are associated with increased risk of motion artifacts, patient discomfort, and complications from potential sedation. Likewise, increased injected radioisotope activity is linked with an uncertain but possible increased risk of radiation-induced cancer. While quantifying image quality is challenging, quantifying risk from radioisotope activity is even more untenable. First, it is difficult to accurately estimate patient-specific radiation dosimetry in pediatric NM procedures because of the diverse pediatric population with varying morphology, organ sizes, and tissue kinetics. Moreover, we have extremely limited knowledge of the long-term risk from these low levels of radiation. In brief, it is not possible to find the "optimal" protocol that perfectly balances the benefit versus risk performance. In the absence of truly “optimal” protocols, we generally try to develop protocols that seek to provide sufficient image quality with the lowest risk to the patient. In any discussion of risk from medical imaging, it should be stressed that the benefits of appropriate imaging studies generally far outweigh any patient risk.

Below is a brief review of some of the protocol design considerations in pediatric nuclear medicine. In short, there are numerous options to adjust image quality and to reduce risk to the patient. The expert consensus guidelines from North America 1 and EANM 2 provide recommendations on injected activity for various studies. The outline below lists other parameters for adjusting image quality.

1. **Patient Preparation**
   Appropriate patient preparation is essential for image quality. Different imaging studies warrant certain protocols; please see references below for more details. Furthermore, any preparation that can calm the child prior to imaging will help keep the child quiet and still during the imaging study.

   - **PET:**


   - **NM:**


2. **Injected Activity**
   Expert panels have provided recommendations for injected activity in pediatric nuclear medicine. In nuclear medicine, the square root of image noise (standard deviation of
pixel values) will decrease linearly with injected activity. Observer studies have proven that detection performance is directly related to the inverse of image noise; therefore, if you double the injected activity the detection performance will increase by a factor of the square root of two. This assumes that the imaging system is not experiencing substantial deadtime, which is a valid assumption considering in most imaging studies we could increase the injected dose by > 5x before reaching a system’s maximum count rate.


3. **Acquisition Options**
   a. **Patient Positioning**
   b. **Collimator selection/PET imaging mode (2D vs 3D)**
   For gamma imaging, the collimator selection trades off sensitivity for resolution. In general, if the study is primarily for detection of large features, a low resolution/high sensitivity collimator should be used. Refer to the following article or NM reference books for appropriate collimator selection. For PET imaging, fully 3D PET is the only available option for newer systems, while older systems support 2D and 3D PET. Evidence has shown that the benefit of increased sensitivity of fully 3D PET generally outweighs the challenges of increased scatter and computation particularly in the smaller pediatric population.


c. **Acquisition Duration**
   Along with injected activity, acquisition duration has a direct relationship with total detected counts, image noise, and detection performance. If acquisition duration is doubled the detection performance will increase by a factor of the square root of two. In general, it is best to perform scans for as long as can be tolerated by the patient and by the resources of the imaging clinic. Longer scan durations are associated with increased risk of motion artifacts, patient discomfort, and complications from potential sedation.


d. **Miscellaneous Settings (zoom, pixel size, etc)**
   There are numerous other acquisition settings on gamma and PET cameras. These generally trade sensitivity for resolution. Also, systems offer a range of data corrections to remove erroneous components, such as scatter, from the detected signal. The appropriate use of corrections depends on the imaging study.

4. **Image Reconstruction Options**
   After tomographic data collection (SPECT and PET), images need to be reconstructed into transaxial slices.

   a. **Analytic vs. Iterative Algorithms**
   Analytic methods (such as filtered back projection) offer a fast, linear method to estimate the radiotracer distribution. Iterative methods (such as ordered subset expectation maximization) are more computationally intensive and generally (although not always) provide better noise performance than analytic methods.

   b. **Bias versus Variance**
All reconstruction methods offer parameters to adjust the bias versus variance performance of the algorithm. In other words, it is possible to tradeoff resolution performance for reduced noise or improve resolution at the expense of increased noise. In FBP, the type and size of the pre-backprojection filter can be selected. In OSEM, the number of iterations/subsets and the post-reconstruction smoothing can be selected. These settings are often the fastest/easiest way to improve the image quality of an already acquired patient study. Special care should be exercised in these settings to insure that all previously discussed parameters are appropriate. For example, if an image study appears too noisy, the solution may be to increase the reconstruction filtering rather than increase injected dose or acquisition duration for the next study.

5. Post-processing considerations (review workstations with filtering, hybrid-image fusion)

Review workstations offer a range of tools to help interpret images. Most nuclear medicine packages offer additional post-processing filtering tools to reduce image noise on-the-fly during review. This can also be performed with slice averaging and with MIP-style rotating views. Furthermore, hybrid-imaging systems, such as PET/CT and SPECT/CT, offer linked views of functional and anatomic images. This linked view has been shown to increase confidence and evaluation performance compared to individual functional review. This may impact protocol selection; for example, a low-dose SPECT performed on a SPECT/CT, with the added value of a localization CT, may provide equivalent diagnostic utility as a regular dose standalone SPECT image.

Additional resources for radiation dosimetry in Nuclear Medicine:


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