Fast and Furious: Fetal and Neonatal Imaging – Emerging Techniques

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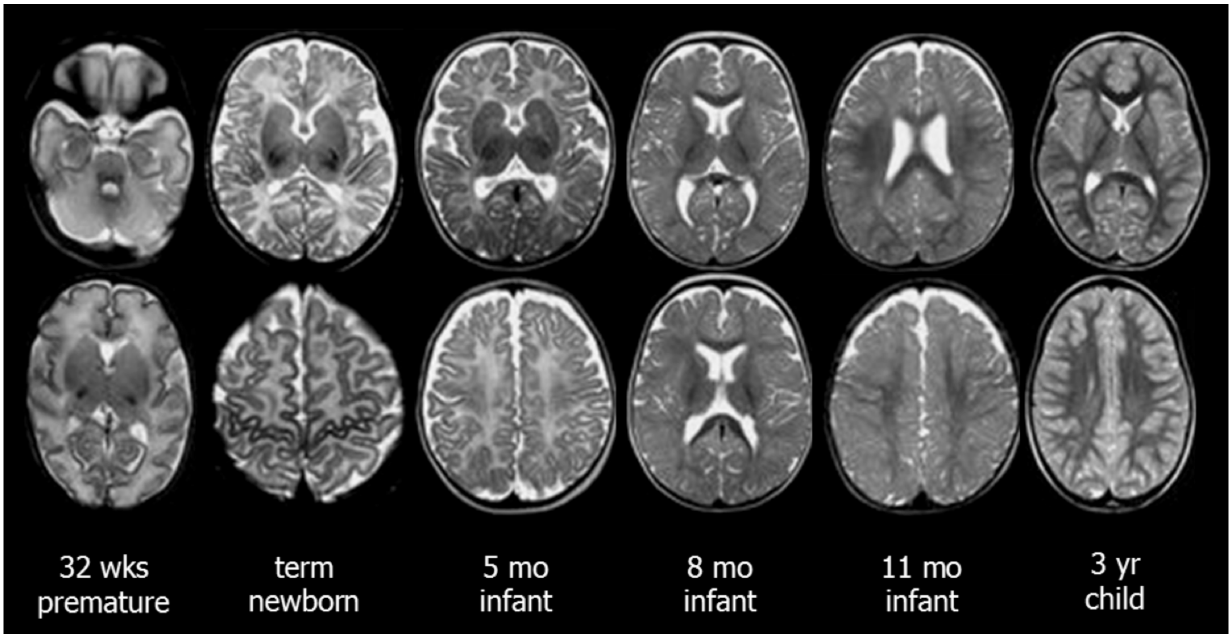
Pediatric imaging is often misunderstood as regular imaging with just a smaller field-of-view. However, this misconception becomes immediately apparent if one just looks at how much the human brain changes between the fetal and adult stage, both in terms of morphology and MR parameters.



The imaging challenges one has to face for neonatal and fetal imaging are the most extreme within the pediatric imaging space. Before one can even start imaging these patients many technical and logistical problems need to be solved. Specifically, for neonatal imaging the size of the neonate is considerably smaller than that of an adolescent or adult. While coils for almost all body parts have been optimized with regard to SNR and best parallel imaging performance, these coils are suboptimal for such small patients. Often one element of an array coil is much larger than most of the neonate. This is unfortunate because it severely impairs what can be done in terms of parallel imaging and high resolution imaging in general. Despite a few attempts to build neonatal coils, the pediatric market is often deemed not big enough for major vendors to invest in a lot of R&D or tailored coil products. Another challenge with neonates is clearly the issue with motion. The bundle & feed method is frequently used in neonates, but acoustic noise and table vibration emanating from the MR scanner often awakes the neonates. As a result, this method frequently leads to non-diagnostic imaging material, and sometimes warrants a repeat scan. Some sites have invested in MR-compatible incubators. This is a great advantage for neonatal imaging, especially in prematurely born kids, as it allows for a more controllable ambient temperature. However, costs of such incubators, their compatibility with existing RF coils, and other logistic complications often prohibit their use.

From several vantage points fetal imaging is often preferred over neonatal imaging. The womb resembles a perfect neonatal intensive care unit (NICU) and many features we need to generate artificially (e.g. MR-compatible incubator) are provided by nature with fetal MRI. Over the last few years, fetal MRI exams have not only focused on imaging anatomy but also on functional and neurological exams. A couple of years ago, one may not have thought fetal MR exams were possible with adequate image quality, but recent results are simply astonishing. Similar to neonatal imaging, fetal as well as mom's motion (e.g. respiration and peristalsis) are challenges. Thus, the standard practice of imaging is currently to scan as fast as possible to freeze-out any motion. However, fetal imaging is further challenged by the distance and size of the RF coils relative to the fetus. Also mom's girth and her finding a comfortable (and not dangerous decubitus) position within the magnet are further logistical challenges.

A major technological advantage for fetal MRI has been the introduction of wide-bore systems that makes it easier for moms to be positioned comfortably in the magnet. A key emerging technology for fetal imaging is the use of fast imaging sequences. Here, the most important ones are balanced steady state free precession imaging and single-shot fast spin echo. These techniques provide excellent contrast between fetal tissue and fluids (e.g. CSF, blood, amniotic fluid), which helps to delineate abnormal anatomy. When played in cine-mode, these sequences also provide an exquisite means to perform neurological exams *in utero*. To freeze out motion, acquisition speed is the key for these methods. Typical methods for scan time reduction, such as partial Fourier imaging and parallel imaging, are often used (if coil geometry permits it). More recent methods, such as compressed sensing (CS), will be of benefit, too. Here, one can anticipate that CS will not only provide an important role in speeding up acquisitions, but also to improve image quality in an otherwise notoriously SNR-starved fetal exam. As one migrates to higher magnetic field strengths there are increasing concerns with higher RF energy deposition. Cleverly designed FSE-readout trains that maintain contrast at greatly reduced SAR values, such as hyperechoes and variants, are very appealing to fetal MRI.

Other emerging techniques for fetal imaging are diffusion-weighted imaging to assess lung maturation (e.g. surfactant estimation) and, of course, diffusion-tensor imaging (DTI). Due to the location of the head in the womb and absence of the classical air pockets seen on regular MR scans (e.g. sinuses and auditory canals), susceptibility artifacts in fetal DTI are less of a problem. If at all, mom's bowel gas can generate distortions. Fetal motion is much more of a problem despite the relatively fast acquisition. Here, smart 3D slice-to-volume registration methods have been developed for different MR sequences, including DTI. For DTI, however, one needs to be aware of that -- in addition to spatial alignment -- the altered diffusion-encoding needs to be considered if one wants to compute the full tensor information. Despite large motion, several attempts have also been made to perform *in utero* functional MRI (fMRI) in animals and humans. One approach was to use restricted field-of-view pulses to avoid exciting tissue outside the fetus' head and to reduce geometric distortions/increase spatial resolution. For stimulation either light or vibro-acoustic stimuli or an oxygen-breathing paradigm was used.

The use of parallel imaging as well as compressed sensing is also a major emerging technology for neonatal imaging. Again, CS can help to push the scan acceleration beyond what is currently feasible with regular parallel imaging, and can also improve SNR. These accelerated methods have altered the way that cardiovascular and body imaging can be performed these days. Faster imaging exams will help to reduce the number of general anesthesia (GA) cases. This is important because many of these patients are very sick and GA poses an additional risk to them. DTI and other advanced neuroimaging methods (such as quantitative MT or CSI) are also becoming used more often for neonatal imaging. Together with 3D slice-to-volume registration, these advanced scanning techniques have delivered some very impressive results. Another emerging technique in this arena is prospective motion correction. Here, pose changes of the neonates head are recorded either with the MR navigators (that is, recording these changes using the imaging sequence) itself or via some external devices, such as pickup coils or optical tracking devices. For either method, the MR scanner automatically adjusts slice plane orientation and location to adapt to these pose changes.

In summary, major strides have been made in advancing MR technology. Some of these methodological advances are making it now into the field of fetal and neonatal MRI. That said, because of huge logistic and equipment challenges as well as due to the lack of patient cooperation, fetal and neonatal MRI is probably one of the most challenging disciplines for MR imaging. This is further exacerbated by a ‘too-small-of-a-market’ assumption that is common to all vendors. This, in turn, leads to too few dedicated coils and sequences that are available for fetal and neonatal imaging.