Motion correction consensus Q & A

Q1: Did the authors consider suggesting criteria for how to reject motion-corrupted transients?
A1: Our consensus paper recommends prospective real-time motion correction. Rejecting motion-corrupted transients is done retrospectively, post-acquisition in post-processing and it was discussed in the quantification consensus paper published in the same special issue NMR Biomed. 2020 Feb 21:e4257. doi: 10.1002/nbm.4257
A2: We note that there are several limitations with rejecting motion-corrupted transients: 1) it does not correct for the change in position of the voxel relative to the head which lead to quantification errors; 2) it can be done only for SVS and not for MRSI where discarding transients means discarding k-space points resulting in aliasing image artifacts; 3) discarding transients lowers the SNR; 4) it is mainly used as a method to improve spectral quality to correct frequency change and linewidth due to motion, or to remove transients affected by large artifacts such as lipids.
A3: For real-time correction we describe a strategy that discards transients on the fly when motion detected by the navigator is larger than a set threshold, however those transients are reacquired at the end to recover SNR for SVS, or in the context of MRSI to recover k-space points and SNR. Hence, we recommend a strategy that combines real-time rejection of motion-corrupted transients followed by the reacquisition of those transients in the same scan. The robustness of such a combined approach is visible especially for J-difference spectral-editing.

Q2: What type of prospective motion correction would you recommend to all VENDORS to implement for SVS MRS? What is needed to get to convince VENDORS to implement prospective MOCO for MRS?
A: We recommend vendors to implement MoCo methods that update both position and B0 field. For position update both external (optical camera) and internal tracking (navigator) methods work very well. However, for field update a field navigator is needed to measure the field every TR and make the updates of the shim currents. Hence, there are two possibilities at the moment: 1) using and internal tracking navigator that measures both position and B0 field every TR; 2) a hybrid approach where position is tracked by optical camera and the B0 is measured by an internal field navigator (in the case of SVS could be a simple navigator that measures only projections while for MRSI an fieldmap imaging sequence is needed). A third approach might be possible in future using only an optical camera and an anatomical scan of the head with EM computational modelling which could predict the B0 field based on the head position, however this is not available at the moment and will require considerable effort and computational power to implement and run in real-time.

Q3: What do you recommend for MRSI and for better H2O suppression and less lipid contamination?
A: We recommend prospective real-time motion correction with shim update and reacquisition of the corrupted transients which will help with better water suppression and less lipid contamination in MRSI acquisition in the presence of motion. Especially frequency selective water suppression is dependent on a narrow pass band or narrow transition band, either in CHESS-like (WET, VAPOR) or metabolite cycling methods, so any change in frequency and shimming will degrade the suppression efficiency, and conversely MoCo will preserve water suppression during motion. Broad band inversion recovery water suppression may be less dependent on the shim quality but metabolite have significantly lower SNR compared to other methods. However, the techniques themselves regarding MRSI acquisition and water/lipid suppression were discussed in detail in the other papers focused particularly on these topics in the same special issue.

Q4: Why would 1 degree rotation cause a 20% change in concentration, the dice coefficient of the voxel is still close to 1…

A: We have described in the paper how we derived these numbers. This question would be correct if the rotation axis would be in the center of the voxel. However, the rotation axis of any voxel in the brain is not through the center of the voxel, but through the atlanto-axial joint, which is approx in the center of the brain. So the farther away the voxels from the rotation axis the larger their displacement will be for the same rotation angle: displacement = 2*distance*sin(angle/2) ~= distance*angle for small angles. For example for a head of AP diameter of 220 mm a voxel in the frontal pole can be 11 cm away from the center of rotation and the displacement for 1 deg rotation is (3.14/180)*110 =1.92 mm, which would give approx. 20% change in volume overlap (2mm/10mm = 20%) for a voxel of 10 mm. We note that all advanced tracking methods, including optical camera and image based (volumetric) navigators, have precision better than 0.1 mm and 0.1 deg. The numbers in the Table 2 are intended to make readers aware how large the quantification error can be in the worst-case scenario motion. In addition to the voxel overlap, if the voxel moves through a sharp field gradient (possible outside the voxel especially in SVS either because of the shim or susceptibility changes close to the VOI), this could add substantially to the error.

Q5: In preclinical settings – what to use especially if we want to look at the cerebellum where we have more movement (animal is fixed)

A: It depends on the animal size, mice or a large mammal such as a monkey. We assume the question is probably related to mice imaging. We are not aware of tracking devices for mice, external devices would probably have difficulty with mobile hair and skin of the mouse, internal navigators would need really high resolution. In the case of mouse, small brain pulsation due to blood flow and respiration can cause frequency shifts especially at large fields >= 4.7T. Often the head is fixed in a stereotactic system and the body moves, changing the field, and corrupting the measurement in the head. In this case dynamic field measurement and correction might also be useful. A frequency navigator that tracks the frequency due to respiration or scanner drift might be enough to correct the effects, or post-processing methods that do frequency alignment or spectral corregistration. Probably voxel displacement is small for well-fixed head and position update might not be needed in most cases. For a large animal such as monkeys, tracking devices and navigators used for MoCo in humans might work well, but this should be investigated, we did not review relevant literature.

Q6: If using NMR field probes for B0 correction, what spatial order of B0 estimation would be needed?

A: NMR probes are great for rapid field changes like those associated with respiration. However, the probes don't measure the field inside the head. This can be inferred/modelled from measurements outside the head but there are sources inside the volume and therefore this estimate will not necessarily be accurate. If only linear terms or only low spatial order field components can be corrected anyway, these measurements may be sufficient (but it still also depends on the extent of the VOI for the spectroscopy measurement). Using few field probes can be useful to correct a global shift of the main frequency (zero order) due to respiration for example at the high field. If a larger array of field probes is used together with computational modelling it could be used to estimate and predict the field pattern inside the head (based on head anatomy and EM modelling) and calculate the shim currents necessary to correct the field pattern. However, the computational needs might be too large at the moment for real-time use.