# FLORET sodium MRI of articular cartilage in the knee joint at 7T

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**Purpose.** To implement the FLORET sequence [1] for sodium MRI of articular cartilage and compare signal-to-noise ratio (SNR) and sodium concentration with 3D radial acquisition. Quantitative sodium MRI in the knee joint is of great interest as it can provide direct biochemical information on the proteoglycan content in cartilage, the loss of which can be associated with early degeneration of cartilage due to osteoarthritis (OA) [2]. However, sodium NMR signal is very weak compared to proton signal (~3500 lower in cartilage) and decays very fast (T2short~1ms, T2long~15ms, T1~25ms), therefore non-Cartesian ultrashort TE (UTE) sequences must be used to acquire the data with many projections or averages and low resolution (4-5 mm isotropic in general). In order to be more sensitive to sodium content within cartilage only, it is preferable to perform fluid suppression for removing partial volume effect from surrounding synovial fluid, but at the cost of a lower SNR [3]. In this work, we consider the FLORET sequence for $^{23}$Na imaging which features high k-space filling efficiency and oversampled trajectory. This latter feature may allow for undersampled data acquisition and reconstruction with compressed sensing (CS) [4] leading to faster scans.

**Methods.** 5 healthy subjects (4 males, mean age 35.8±6.4 years) were scanned on a 7T Siemens scanner with an in-house built double-tuned coil (8ch-$^{23}$Na/4ch-$^{1}$H). Data acquisition: Four data acquisitions were performed: 3D radial and FLORET, with and without fluid suppression by adiabatic inversion recovery [3] (Fig 1.) with the common parameters (distance unit in mm, time unit in ms): FOV 220 isotropic, TE 0.2, TR 70, FA 80°/0.6, Nyquist resolution 3.4, ADC duration 6.4, TA 15:00; for FLORET: 3 hubs/45°, 332 interleaves/hub, 13 averages; for 3D radial: 12,800 projections. Fluid suppression was performed using adiabatic inversion recovery with a WURST20 pulse [5] of amplitude 240 Hz, duration 10 and TI 24; for FLORET IR: 188 interleaves/hub, 13 averages; for 3D radial IR: 7,250 projections; for both IR sequences: ADC duration 4.8, Nyquist resolution 4.6, TR 140, TA 17:00. All images were reconstructed using standard 3D regridding with a nominal resolution of 2 mm (110 voxels isotropic). SNR measurement: SNR was calculated as mean signal divided by the standard deviation (std) of noise. Noise std was measured over 4 slices with only background noise. Mean signal was measured in regions-of-interest (ROI) of 25 voxels over 4 consecutives slices. ROIs were selected in patellar (PAT), femoro-tibial lateral (LAT) and medial (MED), and femoral condyle (CON) cartilage. Tissue sodium concentration (TSC) quantification: TSC maps were calculated using linear regression from phantoms' signal with known sodium concentrations (agar 4% + 100, 150, 200, 250, 300 mM of NaCl). Prior to image reconstruction and sodium quantification, the raw data was filtered using a Gaussian function in order to increase the SNR. TSC was measured on the same ROIs as for SNR measurements.

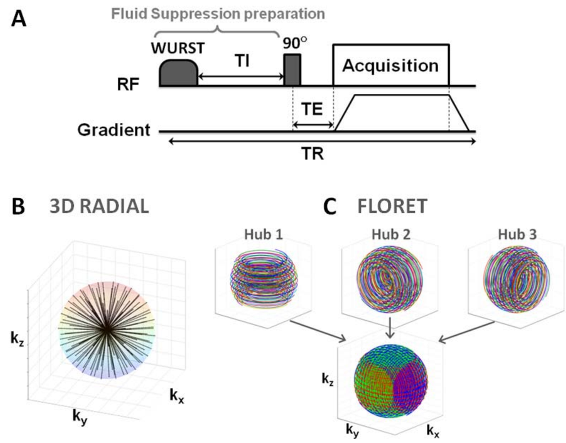


**Fig 1. (A)** UTE sequence chronogram with fluid suppression by adiabatic IR. (**B**) 3D radial k-space trajectory. (**C**) Floret k-space trajectory for 3 hubs.

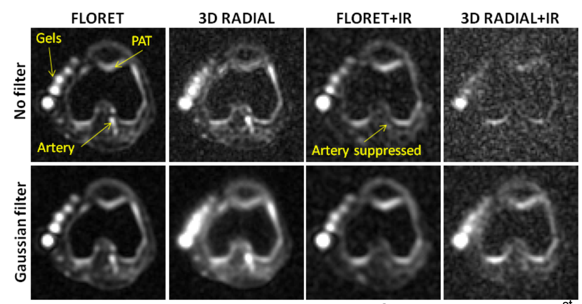


**Fig 2. Transverse sodium images from 1 subject.** 1st row: no filter. 2nd row: Gaussian filter applied on data prior to reconstruction: filter is $f(k) = \exp(-2k^2/k_{max}^2)$. All images are shown with the same range of pixel values.

**Table 1. SNR comparison (non-filtered data)**

| SNR | FLORET | | 3D RADIAL | | FLORET + IR | | 3D RADIAL + IR | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Std | Mean | Std | Mean | Std | Mean | Std |
| PAT | **23.4** | 4.5 | **14.8** | 2.2 | **19.8** | 2.7 | **9.6** | 1.1 |
| MED | **23.6** | 4.4 | **19.9** | 2.8 | **18.8** | 2.8 | **11.5** | 1.4 |
| LAT | **23.4** | 4.5 | **21.3** | 2.6 | **17.5** | 1.9 | **11.0** | 1.4 |
| CON | **28.8** | 4.1 | **22.5** | 1.8 | **23.2** | 1.3 | **13.0** | 0.5 |
| Mean ± Std | **24.8** ± 2.7 | | **19.6** ± 3.4 | | **19.8** ± 2.4 | | **11.3** ± 1.4 | |

**Table 2. TSC comparison (from filtered data)**

| TSC [mM] | FLORET | | | 3D RADIAL | | | FLORET + IR | | | 3D RADIAL + IR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Std | CV (%) | Mean | Std | CV (%) | Mean | Std | CV (%) | Mean | Std | CV (%) |
| PAT | **167.7** | 44.8 | 26.7 | **162.3** | 33.3 | 20.5 | **265.0** | 79.0 | 29.8 | **269.4** | 74.5 | 27.7 |
| MED | **167.8** | 26.0 | 15.5 | **215.1** | 38.9 | 18.1 | **246.6** | 43.7 | 17.7 | **339.3** | 90.7 | 26.7 |
| LAT | **157.6** | 25.7 | 16.3 | **215.2** | 35.6 | 16.6 | **210.6** | 46.7 | 22.2 | **307.4** | 98.2 | 31.9 |
| CON | **174.2** | 19.4 | 11.1 | **217.4** | 45.0 | 20.7 | **266.3** | 39.4 | 14.8 | **342.0** | 112.6 | 32.9 |
| Mean | **166.8** | **29.0** | **17.4** | **202.5** | **38.2** | **19.0** | **247.1** | **52.2** | **21.1** | **314.5** | **94.0** | **29.8** |

**Results and Discussion.** Sodium images (Fig. 2) show clear improvement in visualization of cartilage with FLORET and good fluid suppression with IR. Gaussian filtering improves cartilage visualization (which is necessary for 3D radial IR), but induces blurring, mainly on 3D radial images. On average over all subjects, SNR is improved by ~30% when using FLORET without IR and ~77% with IR (Table 1), compared to 3D radial for the same acquisition time. TSC without IR show lower values than IR-TSC (Table 2) as TSC from cartilage is overshadowed by the presence of synovial fluid (140 mM) within the voxels (and blurring). TSC from IR data is therefore the only quantity of clinical interest for assessing OA (characterized by decrease of TSC). IR-TSC measurements show less variability with FLORET IR (CV~20%) compared to 3D radial IR (CV~30%). IR-TSC from FLORET is in closer agreement to values found in the literature in healthy human cartilage (around 250 mM) [6] than from 3D radial which over-evaluates IR-TSC, probably due to low SNR and therefore is less accurate in sodium quantification.

**Conclusion.** FLORET can be applied to articular sodium imaging and improves data acquisition efficiency [1] compared to 3D radial. It can be used to increase SNR due to a more homogeneous k-space filling, and therefore to reduce acquisition time or to increase resolution. Future work will include CS reconstruction on undersampled FLORET data for decreasing even more the sodium scan time at both 7T and 3T. FLORET-IR sodium MRI will then be applied to patients for detecting early signs of OA.

**References.** [**1**] Pipe J. MRM 66, 2011. [**2**] Reddy R, MRM 53, 1998. [**3**] Madelin G, JMR 207, 2010. [**4**] Lustig M, MRM 58, 2007. [**5**] Kupce E, JMR A115, 1995. [**6**] Borthakur A, NMR Biomed 19, 2006.