# Importance of Biexponential T2* and Partial Volume Effect Corrections on Quantification of Sodium Concentrations and Fixed Charge Density of Articular Cartilage with $^{23}$Na-MRI at 7T

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**Target Audience:** Researchers aiming to apply sodium MRI in articular cartilage research

**Purpose:** Quantification of sodium ($^{23}$Na) concentration and fixed charge density (FCD) with $^{23}$Na-MRI are dependent on the postprocessing steps and corrections applied to measured $^{23}$Na signal intensity (SI). Here we demonstrate how the correction for relaxation times and the correction of signal attenuation due to partial volume effect (PVE) affect the calculated $^{23}$Na-concentrations and thus FCD of articular cartilage of a knee joint.

**Methods:** The $^{23}$Na imaging of the knee joint was performed in an asymptomatic volunteer with an optimized 3D-vTE- spoiled GRE (SPGR) -sequence[1] at 7T (<u>$^{23}$Na-MRI</u>: TR = 11 ms, $TE_1$ = 1.42 ms, flip angle (θ) = 33°, resolution of 1.5 x 1.5 x 2.8 mm$^3$). All $^{23}$Na-images were corrected for $B_1$ inhomogeneity by calculating the correction maps using a cylindrical phantom filled with $^{23}$Na solution. The SI of manually segmented tibial and femoral tissue ($S_{xy}$) were corrected with factors obtained from SPGR signal equations using a) T1 and monoexponential T2*[2] (T1 = 20 ms, T2* = 9.1 ms)[3] or b) T1 and biexponentially analyzed T2* (T1 = 20 ms, T2*short = 0.9 ms, $A_{short}$ = 0.34, T2*long = 13.3 ms, $A_{long}$ = 0.66)[3,4]. The biexponentially corrected signal ($S_0$) was further divided with PVE-correction factors ($PVE_{cf}$, Eq. 1) obtained by determining the mean tibial and femoral cartilage thickness ($x_{tibia}$ = 2.8 ± 0.9 mm, $x_{femur}$ = 2.5 ± 0.8 mm) from 3D-DESS images (TR/TE = 7.81/2.62 ms, isotropic resolution of 0.34 x 0.34 x 0.34mm$^3$) and fitting them to a function describing the attenuation of signal (Fig. 1a).[5] Average water fraction (*f* = 0.75) of the cartilage tissue was also taken into account in all methods.[4] The corrected SIs of cartilage tissue were fitted to a $^{23}$Na calibration curve (linear fit to mean SI of four calibration phantoms corrected for T1 and monoexponential T2* ($^{23}$Na = 100-250 mM) and mean background noise ($^{23}$Na = 0 mM)) to obtain the corresponding $^{23}$Na concentrations (Fig. 1b).[6] FCD was calculated with respect to $^{23}$Na – concentration of synovial fluid ([$^{23}Na_{sf}$] = 150mM): FCD = [$^{23}Na_{sf}$]$^2$ / [$^{23}$Na (x,y)] - [$^{23}$Na (x,y)].[6]

$$S_0(x,y) = S_{xy}(x,y) * \frac{1 - \cos\theta * \left(e^{-TR/T1}\right)}{\left(1 - e^{-TR/T1}\right) * \sin\theta\left(A_{short} * e^{-TE_1/T2^*short} + A_{long} * e^{-TE_1/T2^*long}\right)} * \frac{B_1(x,y)}{f * PVE_{cf}} \quad (Eq.1)$$

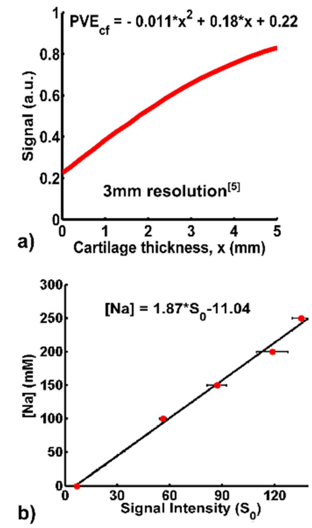


**Fig 1:** (a) Signal attenuation with respect to tissue thickness (adopted from Moon et.al 2013)[5]. (b) Sodium calibration curve (phantom and noise values presented with red).

**Results:** The $^{23}$Na concentrations of tibial and femoral cartilages using monoexponential T2* correction were (mean ± SD, all slices) 107 ± 31 and 98 ± 34 mM (Fig. 2a). The biexponential T2* correction of signal increased $^{23}$Na to 141 ± 40 and 129 ± 43 mM (up to +33%, Fig. 2b), respectively. Biexponential T2* correction combined with PVE correction resulted in 251 ± 68 and 236 ± 78 mM (up to +179%, Fig. 2c) $^{23}$Na concentrations and FCDs of -168 ± 83 mM and -157 ± 92 mM (Fig. 2d), respectively. The low $^{23}$Na concentrations of monoexponentially and biexponentially T2* corrected data resulted mainly in positive FCD values.

**Discussion and Conclusion:** Importance of taking into account the biexponential T2* values and the signal attenuation due to PVE of $^{23}$Na MRI were investigated in determining the $^{23}$Na-concentration and FCD of tibial and femoral cartilage. The $^{23}$Na concentrations calculated in this study were in agreement with previously reported $^{23}$Na concentrations (240mM – 270mM)[2,6] only after applying both the biexponential T2* and PVE corrections to $^{23}$Na SI. Also in order to determine the fixed charge density (FCD)[6] of articular cartilage, both biexponential T2* and PVE corrections were needed to reach adequate $^{23}$Na concentrations. These results suggest that the biexponential decay of T2* and especially the signal attenuation due to PVE are important for correct evaluation of $^{23}$Na concentration in knee cartilage even at high field strength (7T) and with images of fair resolution (in-plane 1.5 x 1.5mm, slice thickness 2.8mm).

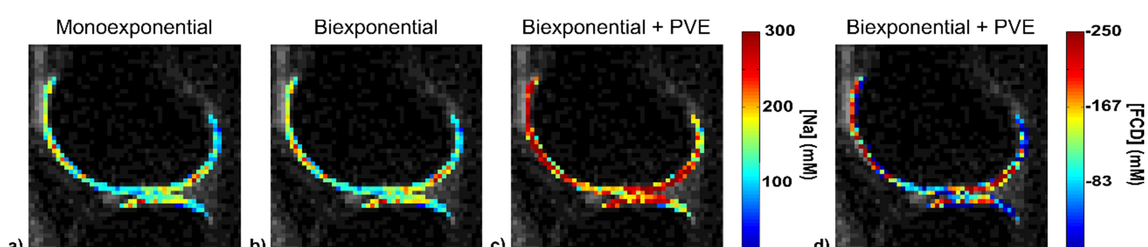


**Fig 2:** Sodium maps of tibiofemoral cartilages from a mid-sagittal slice of the knee calculated using (a) monoexponential T2* SI correction and (b) biexponential T2* SI correction. (c) Sodium and (d) FCD –maps with biexponential T2* and PVE corrections.

**References:**[1] Deligianni, X. *et al. Magn Reson Med* 70 (5), 1434-39. 2013. [2] Wheaton, A.J. *et al. Radiology* 231**,** 900–5. 2004. [3] Madelin, G. *et al. NMR Biomed.* 530–537. 2012. [4] Madelin, G. *et al. Radiology* 268**,** 481–91. 2013. [5] Moon, C.H. *et al. J. Magn. Reson. Imaging* 38**,** 1063–1072. 2013. [6] Shapiro, E.M. *et al. Magn. Reson. Med.* 47**,** 284–291. 2002.