Advances in T1-based fluid oxymetry

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We recently described a method to measure oxygen partial pressure (pO_2) in low-protein body fluids, such as urine, vitreous, and cerebrospinal fluid (CSF), by measuring R1 (=1/T1) quantitatively.[1-3] Since these reports, several advances have been made. Enough measurements in normal young adults have been made to estimate the mean and standard deviation. Also, we have evaluated other fluid collections, including fetal CSF and vitreous *in utero*. Measurements and simulations to understand potential errors from protein content and partial volume artifact are presented.

Methods and Results

A dualshot (T_{SR1} = 3 s, T_{SR2} = 10 s) nonequilibrium saturation recovery single-shot fast spin echo sequence[2,3] with non-selective T2 preparation (700ms) followed by short TE (60 ms) readout and non-selective refocusing pulses was used to measure quantitative fluid R1. The equation pO2 (mmHg) = (R1 – 0.2127)/2.49e-4 was used to convert to pO2.[2] First, a phantom study was performed to determine the effect of protein. Between 0 and 5 g/L of bovine serum albumin was added to distilled water at exposed to room air. R1 and R2 measurements were performed at 1.5 T at 37C (Fig 1). These show that R2 is about 8 times more sensitive to protein levels than is R1; expected pO2 errors are approximately 11 mmHg/(g/L protein). Partial volume errors were examined by two-compartment modeling (Fig 2), demonstrating that extreme T2-weighting effectively minimizes such errors. Results of pO2 measurements in bladder urine, vitreous, and lumbar and cerebral CSF pO2 in young adults are shown (Table 1), and, with the exception of vitreous, are roughly concordant with limited prior literature values. Fig 3 is a pO2 map of the pelvis of a pregnant 25 yo woman, showing differences in oxygenation between maternal bladder urine (62±18 mmHg) and the CSF of her 30 wk fetus (124±90 mmHg).

Discussion

As expected, R1 is much less sensitive to protein content than R2; pO2 errors are estimated at about 11 mmHg/(g/L protein); different sized and charged proteins may have different behavior. Use of ultralong effective TE minimizes pO2 errors from partial volume of surrounding tissues. For effective TE of 750 ms, models suggest that 50% partial volume is tolerated with only 5 mmHg pO2 error. pO2 values in normal adults are roughly concordant with those measured invasively. The only exception is the vitreous, where pO2 appears to be overestimated and has high variability; this may reflect differences in the populations studied, be related to eye motions or blinking,[4] or due to unanticipated R1 effects of the collagen gel of the vitreous. Initial images of fetal fluid emphasize the value of a non-invasive measurement; pO2 values appear roughly concordant with adult values in CSF and vitreous. This method may be valuable for evaluating fetal well-being *in utero*.

Table 1: Comparison of MR and invasive

Region (n)	MRI	Literature	Refs
Lat vent CSF (11)	52±14	44-74	5,6
Cisternal CSF (11)	62±29	31-74	7,8
Cortical CSF (11)	138±46	---	---
Lumbar CSF (7)	69±22	40-57	8-10
Vitreous (11)	63±34	9-20	11,12
Bladder urine (12)	63±16	25-80	13-15

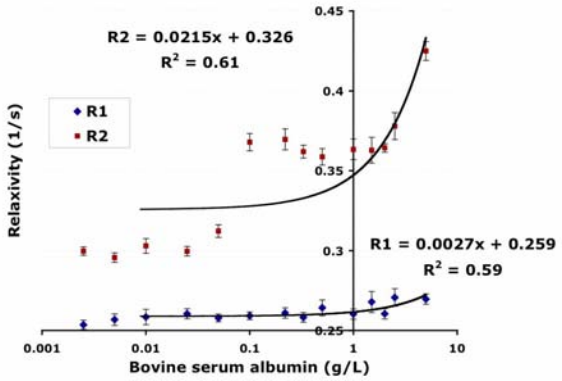

Fig 1: Effects of protein level on water R1 and R2, 37 C

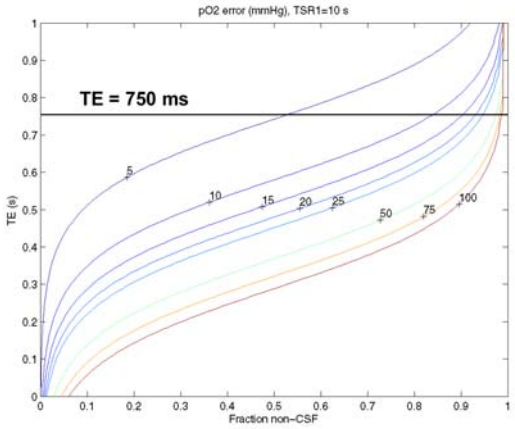

Fig 2: 2-compartment model of partial volume pO2 error, as a function of effective TE and fraction of non-fluid in the voxel.

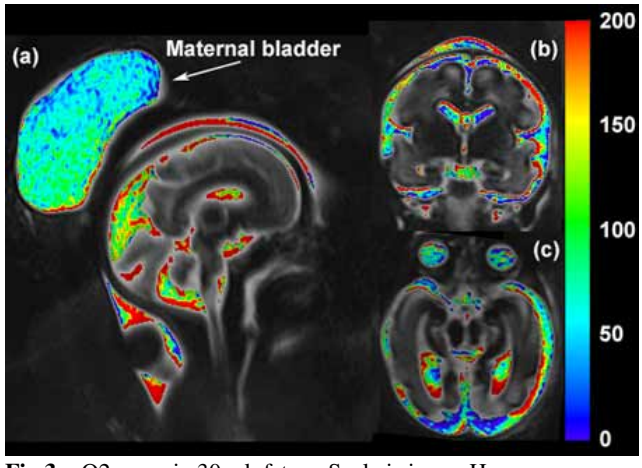

Fig 3: pO2 maps in 30 wk fetus. Scale is in mmHg.

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