Application of a "Shutter–Speed" Model to Analysis of Dynamic Contrast Enhancement in Prostate Tumours

M. Lowry[1], B. Zelhof[1], M. D. Pickles[1], P. Gibbs[1], and L. W. Turnbull[1]
[1]Centre for MR Investigations, University of Hull, Hull, United Kingdom

Introduction Conventional T_2-weighted imaging is now generally supplemented with DCE-MRI in order to improve the specificity of detection of malignant lesions within the prostate. However, there still remains some ambiguity since all tissues within the prostate may enhance and the currently favoured 2-compartment enhancement model (1) shows considerable overlap in mean K^{trans} values. The aim of the current study was to assess the ability of the "shutter-speed" enhancement model (2) to differentiate benign from malignant disease within the peripheral zone.

Methods Sixteen consecutive patients with elevated PSA and biopsy confirmed prostate malignancy were referred for staging of their tumours prior to radical prostatectomy. All were scanned, at least 6 weeks after biopsy, with a 3T GE Signa Infinity using an 8-element torso phased-array receiver coil. As part of a standard clinical imaging study the following series were acquired: high resolution axial T_2W FSE to assess the gland and surrounding structures, three axial 3D FSPGR series at 3°, 6° & 18° flip angle and a dynamically-acquired, multi-phase axial 3D FSPGR with 18° flip angle. Contrast, 0.1 mMol·kg^{-1} of Gd-DTPA, was pump-injected at 3 ml·s^{-1} after 17s of scanning. All FSPGR series were acquired over a 300mm x 300mm x 100mm FOV with a 256 x 128 matrix and 20 locations per slab. With TR = 5.1ms, TE = 2.1ms and an ASSET factor of 2 we were able to achieve a temporal resolution of 6.68s per volume thus providing 50 samples in 5'34".

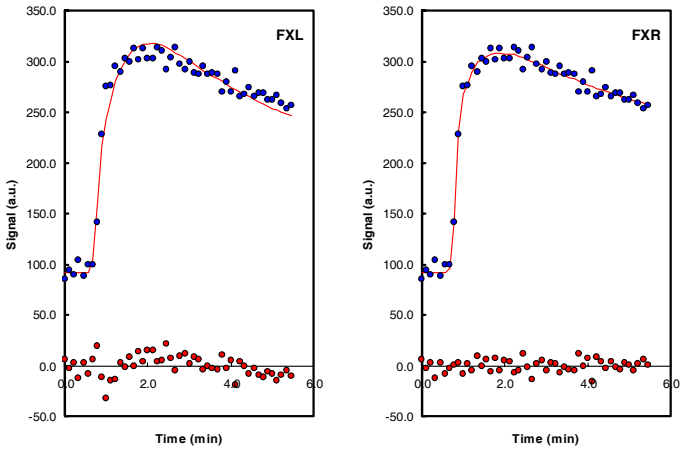
Pharmacokinetic parameters were obtained for hand-drawn ROIs in tumour, BPH and apparently normal peripheral zones (PZ) using the following scheme. First a blood signal time course was obtained from an ROI placed centrally within the left femoral artery on an image slice sufficiently distal so as to reduce in-flow effects. This time course was converted to [Gd] with the relationship $[Gd] = (1/T_{1,t} - 1/T_{1,0})\cdot\Re^{-1}$ using T_1 values obtained from the multiple flip angle FSPGR images and a Gadolinium relaxivity ($\Re$) of 4.01s^{-1}·mM^{-1}. Tissue ROI signal intensity time courses (S_t) were then fitted to expressions describing the relationship between thermodynamic [Gd] and S_t for fast-exchange limit (FXL) and fast-exchange regime (FXR) kinetic models (2) using the blood [Gd] time course as an AIF. All processing was performed interactively on a SunBlade 2000 workstation using software developed in IDL.

Param	PZ (16)		BPH (16)		Tumour (15)	
Model	FXL	FXR†	FXL	FXR†	FXL	FXR†
T_1 (s)	1.52 ± 0.44		1.58 ± 0.24		1.31 ± 0.34*	
K^{trans} (min^{-1})	0.12 ± 0.06	0.18 ± 0.11	0.34 ± 0.16*	0.59 ± 0.35*	0.31 ± 0.12*	0.51 ± 0.19*
V_e	0.25 ± 0.08	0.45 ± 0.17	0.35 ± 0.10*	0.53 ± 0.14	0.33 ± 0.10*	0.52 ± 0.15
tau (s)		0.53 ± 0.17		0.36 ± 0.14*		0.39 ± 0.11*

†,all parameters P ≤0.05 cf FXL; * P ≤0.05 cf PZ

Results The mean arterial blood T_1 of 1.54 ± 0.58s obtained in these studies is consistent with independent rigorous measurements (3,4) thus providing confidence for its use in obtaining our arterial input function. We also confirmed the lower T_1 of tumour tissue observed previously (5).

In all 16 cases the FXL fitting demonstrated evidence of model inadequacy as described by Yankeelov et al (2) by showing a temporal mismatch between the fitted curves and data. Fitting with the FXR model removed this mismatch and increased the value of all pharmacokinetic parameters significantly as shown in the table. The significantly higher K^{trans} of tumours was 3.7±2.6 fold greater than PZ for FXR as opposed to only 2.9±1.4 for FXL. Although showing considerably variability between subjects K^{trans} was always greater in tumour than in apparently normal PZ within subjects. The difference in V_e between tumour and PZ was no longer significant with the FXR model, however, the new parameter, *tau*, representing intracellular water lifetime, was significantly lower in both BPH and tumour compared to PZ.



Systematic temporal mismatch of fitted FXL model (left, -) to experimental data (•) from ROI within prostate carcinoma with residuals (•). FXR model (right, -) exhibits improved fitting.

Discussion The FXR model shows promise in improving the discrimination of tumour from normal tissue. The variability of tumour K^{trans} values precludes its use in differentiating BPH from tumour and emphasizes the need to identify normal areas for comparison within each patient. The combination of decreased tissue T_1 together with elevated K^{trans} may however, allow tumour to be distinguished from BPH. In addition to characterising tumour vessels through K^{trans} the FXR model also provides information relating to tumour cell characteristics since the value of *tau* relates both to cell wall permeability and to cell volume (6). Ultimately both parameters may prove useful in treatment monitoring.

References **1.** Tofts et al, JMRI 10:223-232 (1999). **2.** Yankeelov et al, MRM 50:1151-1169 (2003). **3.** Lu et al, MRM 52:679-682 (2004). **4.** Dobre et al, MRI 25:733-735 (2007). **5.** Lowry et al, Proc ISMRM 14:110 (2006). **6.** Landis et al, MRM 42:467-478 (1999).