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# A five-colour colour-coded mapping method for DCE-MRI analysis of head and neck tumours

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AIM: To devise a method to convert the time–intensity curves (TICs) of head and neck dynamic contrast-enhanced (DCE) magnetic resonance imaging (MRI) data into a pixel-by-pixel colour-coded map for identifying normal tissues and tumours.

MATERIALS AND METHODS: Twenty-three patients with head and neck squamous cell carcinoma (HNSCC) underwent DCE-MRI. TIC patterns of primary tumours, metastatic nodes, and normal tissues were assessed and a program was devised to convert the patterns into a classified colour-coded map. The enhancement patterns of tumours and normal tissue structures were evaluated and categorized into nine grades (0–8) based on the predominance of coloured pixels on maps.

RESULTS: Five identified TIC patterns were converted into a colour-coded map consisting of red (maximum enhancement), brown (continuous slow rise-up), yellow (rapid wash-in and wash-out), green (rapid wash-in and plateau), and blue (rapid wash-in and rise-up). The colour-coded map distinguished all 21 primary tumours and 15 metastatic nodes from normal structures. Primary tumours and metastatic nodes were colour coded as predominantly yellow (grades 1–2) in 17/21 and 6/15, green (grades 3–5) in 3/21 and 5/15, and blue (grades 6–7) in 1/21 and 4/15, respectively. Vessels were coded red in 46/46 (grade 0) and muscles were coded brown in 23/23 (grade 8). Salivary glands, thyroid glands, and palatine tonsils were coded into predominantly yellow (grade 1) in 46/46 and 10/10 and 18/22, respectively.

CONCLUSION: DCE-MRI derived five-colour-coded mapping provides an objective easy-to-interpret method to assess the dynamic enhancement pattern of head and neck cancers.



## Introduction

Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) produces information about the vascularity of cancers and has the potential to be used to detect and characterize tumours, and evaluate treatment response. In head and neck cancers DCE-MRI has been reported as a potential tool for identifying primary tumours and metastatic nodes,[1–4] differentiating benign from malignant tumours,[5–8] and monitoring the treatment response.[9,10]

The most common methods to process the DCE-MRI data involve parametric contrast-enhancement analysis based on the DCE time–intensity curves (TICs) to produce parameters such as bolus arrival time, mean signal intensity, and maximum contrast enhancement,[8,11] or quantitative analysis using pharmacokinetic models[9,12] to produce physiological parameters such as endothelial permeability coefficient ($K^{trans}$).[13] Parametric analysis requires the accurate placement of specific regions of interest (ROIs) in the most appropriate area of the tumour, so this approach is considered as subjective and time-consuming, particularly in cases of multiple small lesions. Manual ROI analysis

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displays an average DCE parameter over the selected area, potentially cancelling out the heterogeneous characteristics in the ROI. On the other hand, the greatest advantage of pharmacokinetic models is that directly physiology-related parameters can be estimated instead of the heuristic parameters. However, estimations of physiological parameters are subject to various sources of bias and variance from patient-related factors, acquisition-dependent factors and image analysis factors.[14] Moreover, physiological parameters extracted from pharmacokinetic models are also difficult to correlate with histopathological findings for verification.[15]

It has been acknowledged that TIC shapes are closely associated with physiological parameters that can be extracted by means of the pharmacokinetic model analysis.[16] In fact, increased tumour angiogenesis has often been represented by a typical TIC pattern with rapid wash-in and wash-out.[17,18] This characteristic TIC pattern is less sensitive to variations in the MRI protocol. As such, condensation and visualization of DCE-MRI TIC patterns into pixel-by-pixel colour maps provides an alternative solution for subjective DCE-MRI data analysis that helps shorten the process of reading a study and assist in tumour diagnosis. Colour-coded maps potentially may also provide additional tumour heterogeneity information on a pixel-by-pixel basis to eliminate the averaging cancellation in an ROI. For example, a three time-point (3TP) method produces a three-colour (red, green, blue) colour-coded map based on the TIC patterns determined by three judiciously selected specific time points.[19,20] The 3TP method has been reported for the detection and characterization of breast lesions in DCE magnetic resonance mammography.[21–23] Comparable sensitivity, specificity, and accuracy have been achieved compared with the traditional visual rating and the ROI contrast-enhancement analysis.[23]

TICs have been reported for a range of tumours in the head and neck.[8,11,24] The aim of the present study was to devise and evaluate a novel pixel-by-pixel five-colour colour-coded mapping method for highlighting tumours and differentiating tissues in the head and neck.

## Materials and methods

### *Patients*

MRI was performed in patients with untreated head and neck squamous cell carcinoma (HNSCC) who had no previous history of a head and neck cancer. The primary tumours were confirmed by biopsy, while lymph node metastases were diagnosed on imaging criteria. All patients gave their informed consent for DCE-MRI examination. Ethical review board approval was obtained for this prospective analysis of the acquired DCE-MRI data.

### *MRI*

DCE-MRI examinations were performed on a 3 T MRI machine (Philips Medical Systems, Best, The Netherlands) using a 16-channel head and neck array coil. A T1-weighted three-dimensional (3D) gradient echo sequence was used with repetition time (TR) of 3.9 ms, echo time (TE) of 0.9 ms, flip angle of 15°, field of view (FOV) of 230 mm × 230 mm × 100 mm and matrix size of 128 × 128 × 25. A sensitivity encoding (SENSE) factor of 4 was used. Twenty-five 4 mm thick axial sections were reconstructed to cover the entire tumour area. One hundred and eighty-five dynamic images were acquired for each section with a temporal resolution of 2.59 s/frame within the total scan time of 480 s. The contrast medium injection was given in the from a bolus injection of Gd-DOTA (Dotarem, Guerbet, France), with a concentration of 0.1 mmol/kg of body weight, using a power injector pump (Medrad, Pittsburgh, PA, USA) set at an injection rate of 2.5 ml/s through a 21 G intravenous catheter in the right antecubital vein. This injection was followed by a 20 ml saline flush at the same injection rate. The injection of the contrast medium was commenced 6 s after the baseline MRI acquisitions. Immediately after the DCE-MRI examination, contrast-enhanced anatomical images were acquired using a fat-saturated 3D turbo spin-echo (TSE) sequence with the imaging parameters: 10 ms TE, 620 ms TR, turbo factor = 4, 230 mm × 180 mm × 200 mm FOV, 0.55 mm × 0.79 mm × 4 mm voxel size, number of average = 2.

### *TIC classification and colour coding*

Five major TIC patterns were identified in the tumours and normal structures. Type I consisted of a rapid rise to the highest signal enhancement among the five TIC types and then a rapid decrease in intensity. Type II featured fast signal enhancement (wash-in) and then a relatively rapid wash-out phase. Types III and IV had a similar wash-in phase to type II, with the major difference that type III had an intensity plateau and type IV had an increase in intensity after the wash-in phase. Type V featured a continuous slow increase in the signal intensity along the entire time course. Types I–V were proposed to be colour coded with red (I), brown (II), yellow (III) green (IV), and blue (V).

Motion correction and image registration were performed automatically on the MRI console prior to data export. A bespoke Matlab2009b (The MathWorks, Natick, MA, USA) program was developed to classify the DCE-MRI TIC patterns and generate the colour-coded map images offline on a workstation equipped with a 3 GHz processor and 3.5 Gb memory.

Prior to classifying the curve patterns, TICs were smoothed by a Lowess (locally-weighted least squares) regression filter with a span of 10% to alleviate the dynamic signal fluctuation. The TIC classification was performed using the algorithm described as follows. First, the pixels with an average signal intensity lower than a cut-off value of 40 (approximately 10% of the average signal intensity for all pixels, in arbitrary unit) along all time points were considered as background or noise, and excluded from colour coding. The maximum enhancement (the highest image intensity) in the TIC and the corresponding time point for each pixel were recorded. If the maximum enhancement of one pixel is greater than the average plus two times the