Early Changes in the Apparent Diffusion Coefficient following Ischemic Stroke in Canines

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Introduction

Diffusion imaging is often used to detect and assess acute ischemic stroke. Infarcted tissue can be acutely predicted by regions with decreased diffusion, quantified by reductions in the apparent diffusion coefficient (ADC).[1] Defining the stroke infarct and the penumbra are important, particularly when considering thrombolysis with tPA. Human stroke is highly heterogeneous, both in terms progression and severity, as well as radiographic findings. For example, in two patients with the same occluded vessel, the size of the infarcted core and the penumbra, the rate and the amount of growth of the core into the penumbra are often different. By understanding the differences in stroke progression and how these differences are seen with imaging, therapeutic decisions may be further improved. Here we examine the initial decrease in the ADC using an embolic stroke model in canines.

Methods

Ischemic stroke was induced in 10 dogs using a previously described embolic model.[2] Pre- and post- stroke diffusion imaging was performed (TE/TR = 93 ms/5000 ms, b = 1000 s mm^{-2}, FOV = 24 cm × 14.4 cm, matrix = 144 × 144) and ADC maps constructed. On the final post-stroke ADC map, a region-of-interest (ROI) was drawn in the infarct core (central 25%) and in the contralateral normal tissue. These ROIs were projected to all ADC maps. Using the average pre-stroke ADC, the normalized ADC change at each time point were calculated. ADC time changes were fit to a 2-parameter exponentional curve, $\Delta ADC(t) = \Delta ADC_{max}(e^{-kt} - 1)$ where ΔADC_{max} was the final ADC change (plateau), k was the exponential rate constant and t was time. Kolmogorov-Smirnov tests were used to test if ΔADC_{max} and k could be characterized by normal distributions and regression analysis performed, as appropriate. Stroke severity was characterized as mild, moderate or severe by tricotimizing the ADC_{max} values obtained from curve-fitting.

Results

The average ΔADC_{max} and k values were -41.2% ± 8.8% and 0.0422 min^{-1}± 0.0182 min^{-1}, respectively. These two parameters were normally distributed (Kolmogorov-Smirnov tests). Linear regression analyses showed a significant relationship between ΔADC_{max} and k (R^2 = 0.61, p = 0.0080). We trichotomized ΔADC_{max} values for mild, moderate and sever strokes, using cut-off points at $\mu_{\Delta ADC} \pm 0.67\sigma_{\Delta ADC}$ ($\mu_{\Delta ADC}$ = -41.2% and $\sigma_{\Delta ADC}$ = 8.8%) so half of the strokes were defined as moderate. From this, two strokes were mild (average ΔADC_{max} = -30.9% ± 4.7%), six were moderate (average ΔADC_{max} = -40.1% ± 3.0%), and two were severe (average ΔADC_{max} = -54.5% ± 7.2%). The average k values in the mild, moderate and severe stroke groups were 0.062 min^{-1} ± 0.007 min^{-1}, 0.043 min^{-1} ± 0.015 min^{-1}, and 0.021 min^{-1} ± 0.013 min^{-1}, respectively. Examples of representative fitted curves of mild, moderate and severe strokes are shown in the Figure.

Discussion

The regression analysis indicated that ΔADC_{max} and k were significantly related; therefore only one parameter was used to group the stroke severity. ΔADC_{max} is more intuitive as it represents the plateau of the ADC drop, so it was used to classify the stroke groups. Common clinical descriptors of stroke are mild, moderate and severe;[1] as such we defined three groups by ΔADC_{max}. Time of stroke onset cannot be determined using ADC from one time point. Two time points are required if we assume that k and ΔADC_{max} are inversely correlated. Three time points are required if k and ΔADC_{max} are not treated as correlated. The relationship of ΔADC_{max} and k, indicates that stroke severity is related to the time-course of stroke evolution – more severe strokes paradoxically taking longer to evolve.

References

1. Gonzalez RG *AJNR* 2006; **27**: 728-735
2. Ryder RC *et al. Proc ISMRM* 2003; 1193.

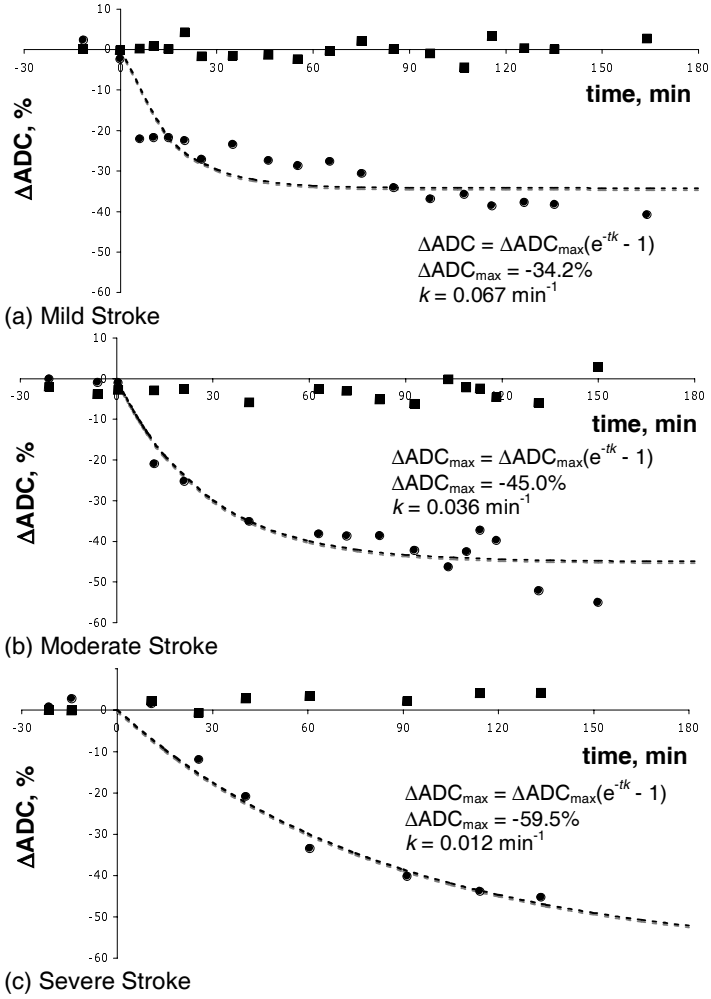

Figure. Sample curves from each of the defined stroke groups. Circles are from the stroke ROI and squares are from the contra-lateral normal