Incorporating time to reperfusion into the FASTER model of stroke tissue-at-risk

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Introduction

Imaging-supported treatment decisions in acute stroke (in particular, whether to treat with mechanical thrombectomy) are made by estimating the amount of tissue which could be salvaged. This calculation is typically made by automated tools, using fixed thresholds on perfusion (Tmax) and Apparent Diffusion Coefficient maps. In a recent paper [1], we introduced the tool FASTER (Fully Automated Stroke Tissue Estimation using Random Forests), which gives an assessment of the tissue at risk in acute stroke beyond the usual paradigm of predefined thresholds. The FASTER system assesses the likelihood of tissue damage using decision forest classifiers, mapping local statistical features of perfusion and diffusion imaging onto maps of the tissue predicted to be lost even if reperfusion is established, and the tissue predicted to be lost only if there is no reperfusion. These models are trained only on extreme cases, in which reperfusion was total and rapid (TICI 3), or completely absent (TICI 0). The output of the model is two lesion maps, one predicting minimal tissue loss, and the other the maximum tissue loss.

In this poster we describe a method to predict intermediate tissue loss, in which a patient is totally or partially revascularized, but after a period of time (TTT) which allows further tissue loss beyond the minimum predicted by FASTER. We interpolate between the two predictions yielded by FASTER using a logistic regression model allowing the time-to-revascularization to enter the model only as an interaction term with infarction risk maps generated by FASTER.

Method

Initial FASTER Models

Two decision forest models, FASTER+ and FASTER- were trained on data from the ISLES 2016 dataset, in each case predicting voxel-wise infarction, using python and H2O. FASTER- was trained on data arising from eight patients having TICI grade 0 or 1. FASTER+ was trained on data from four patients having TICI grade 3, and recanalization within 100 minutes of imaging (TTT<100). The decision forests were trained using the segmentation forest algorithm used in the original FASTER algorithm and ISLES 2015 [2] – a variation on the usual Random Forests algorithm in which random sampling of datapoints occurs both at the patient level and at the voxel level.

The features used in the decision forest were calculated from the registered perfusion maps, and ADC maps, as follows: for each map (Tmax, TTP, MTT, rBF, rBV), the following features were calculated in n by n patches centered on the voxel, where n = 3, 5, 7,9,11 and 13: mean, and 5^{th}, 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} and 95^{th} percentile. In addition, gradient magnitude of the maps, and the mean gradient magnitude inside 3 by 3 and 5 by 5 patches were calculated. Finally, the ADC map was registered to an anatomical atlas, and atlas coordinates were calculated, together with maps generated by subtracting the values of the opposite hemisphere. Before feature calculation, the maps were first clipped as follows: all Tmax and MTT values above 20 were set to 20, all ADC values above 2600 were set to 2600, all rBF values above 100 were set to 100, and all rBV values above 10 were set to 10.

FASTER-time Model

The output of each FASTER model is a heatmap, predicting the risk that each voxel will go on to infarct. In the original FASTER model, these heatmaps are then thresholded (at values determined by the segmentation forest algorithm). In the current method, these maps are instead the input to a second machine learning algorithm: a multivariate logistic regression model. The feature vectors for the logistic model were as follows: features extracted from the FASTER- and FASTER+ maps, as above (mean, percentile, gradient magnitude, symmetry) plus :

- Interaction terms between the TICI grade and the FASTER heatmaps.
- Interaction terms between the TICI grades and the symmetry maps derived from the FASTER heatmaps
- The product of the time to revascularization and the FASTER- heatmap
- The product of the time to revascularization and the symmetry map derived from the FASTER- heatmaps

A linear model was chosen to ensure that the tissue predicted to infarct was guaranteed to increase as a function of time. Time to revascularization only enters the model as an interaction with the existing infraction risk maps, meaning that even with long time to revascularization, the predicted tissue at risk is limited to the hypoperfused tissue.

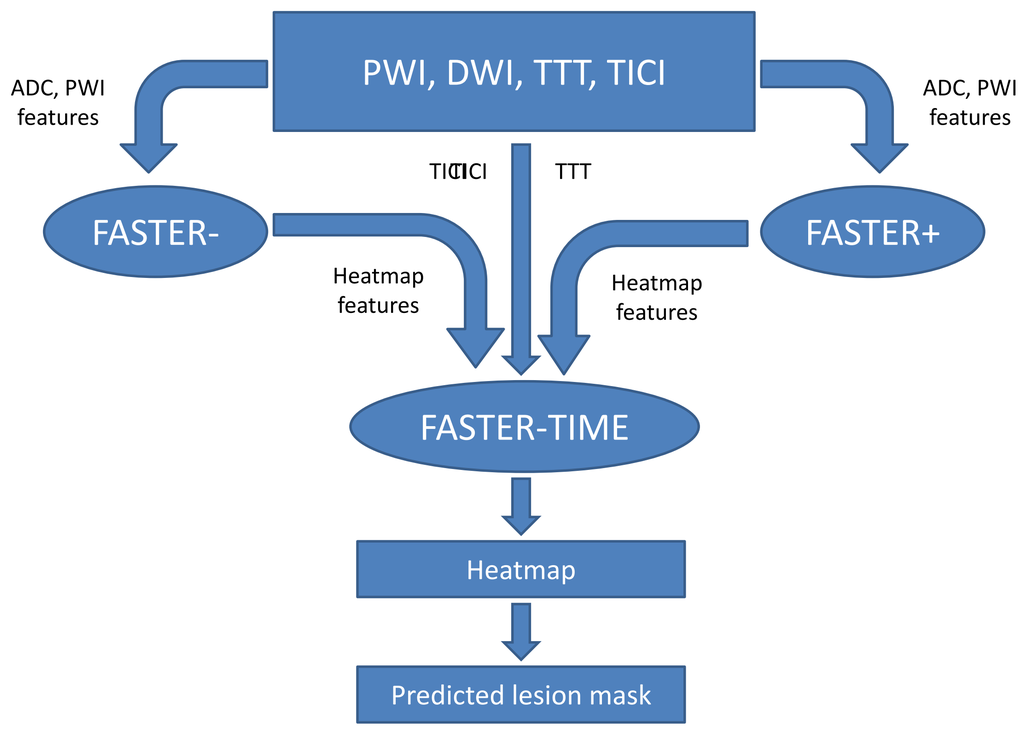

Figure 1 – Workflow of the FASTER-TIME model: best-case and worst-case lesion heatmaps are calculated using FASTER- and FASTER+, then synthesised with the TICI and TTT data to produce a final heatmap, which is then thresholded to yield the final lesion mask

Results

We evaluated the method on the ISLES training data, using leave-one-out cross-validation, to estimate the efficacy of the model. We assessed the performance of the model using the platform and metrics provided by the ISLES challenge, namely: Dice coefficient, Hausdorff distance, average symmetric surface distance, precision and recall. Results are shown in the table below (as of Oct 11^{th} 2016) with the method highlighted in blue.

		ASSD		Dice		Hausdorff Distance		Precision		Recall	
User	Covered Cases	average	std	average	std	average	std	average	std	average ▲	std
mckir1	29 / 30	5.68	4.49	0.33	0.28	31.42	16.66	0.71	0.30	0.27	0.25
kwony1	29 / 30	5.29	4.40	0.42	0.22	39.93	21.29	0.54	0.28	0.47	0.26
maieo1	26 / 30	6.30	4.89	0.40	0.26	33.88	19.79	0.49	0.27	0.50	0.33
shenh1	29 / 30	6.26	5.86	0.44	0.24	34.13	23.16	0.45	0.29	0.58	0.22
leelh1	29 / 30	5.92	4.80	0.41	0.22	49.89	24.77	0.39	0.21	0.60	0.28
choiy1	29 / 30	6.30	4.75	0.41	0.21	63.68	22.18	0.36	0.21	0.68	0.28
mahmq3	5 / 30	0.73	0.49	0.94	0.05	89.27	6.35	0.97	0.02	0.92	0.08

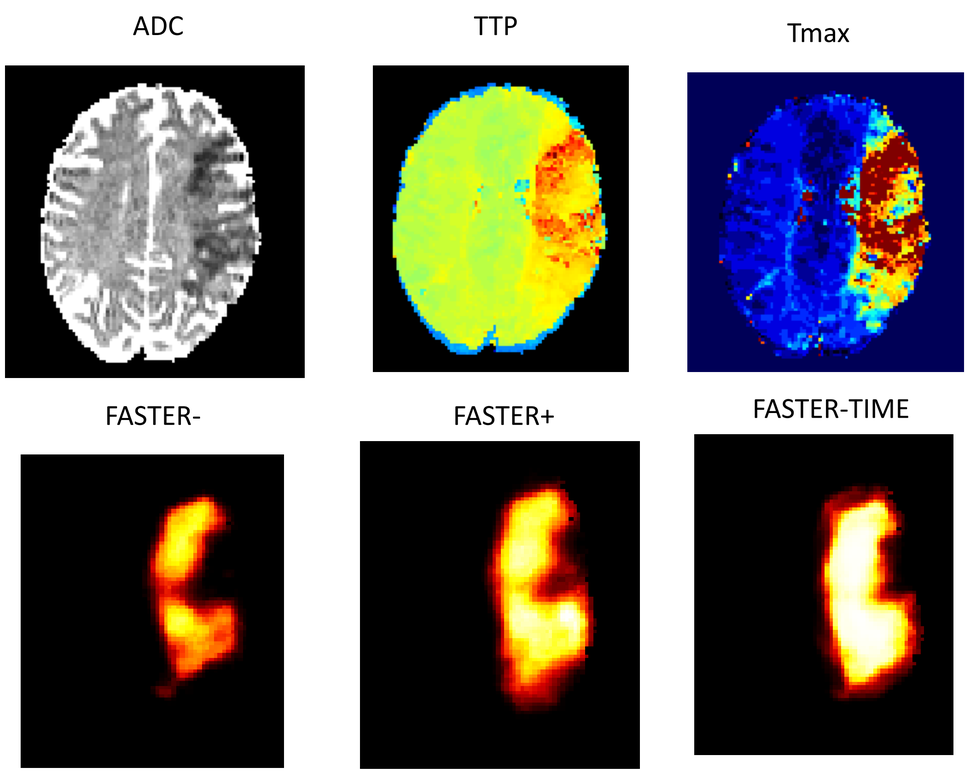

Figure 2 – Results of FASTER+, FASTER- and FASTER-TIME applied to an ISLES Test case (3), TICI = 2b, TTT = 220

Conclusions

We provide a method for extending the existing FASTER model of stroke tissue at risk with temporal evolution of the infarction. The method is based only on easily interpreted features extracted from well-known perfusion and diffusion maps: features derived from Tmax, TTP and ADC were the most predictive of tissue outcome. Application of the method to a new case takes less than two minutes in the python/h2o implementation, making it usable in the acute setting where “time equals brain”.

The method performs in much more cautiously than other lesion prediction methods, having a substantially higher precision, and a lower recall, than other competing methods. The method underperforms in terms of Dice coefficient, but is competitive in terms of ASSD and Hausdorff distance. Since FASTER is eventually intended as a tool to assess the applicability of mechanical thrombectomy, further study is necessary to discover which measures are most clinically meaningful.

Acknowledgements

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References

[1] McKinley, Haeni et al., Fully Automated Stroke Tissue Estimation using Random Forests, in press, Journal of Cerebral Blood Flow and Metabolism
[2] [McKinley, Haeni et al., Segmenting the Ischemic Penumbra: a decision forest approach with automatic threshold finding. In **Brainlesion: Glioma, Multiple Sclerosis, Stroke and Traumatic Brain Injuries, LNCS 9556, 2015**