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Correlation-based temporal similarity mapping of DSC-MRI data in patients with asymptomatic unilateral high-grade carotid stenosis

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Purpose

- high-grade internal carotid artery stenosis (ICAS) is a common cause of ischemic stroke[1]
- good results in detecting vascular disease using dynamic susceptibility contrast (DSC) MRI
- major research objective: development of quick end easy methods for the analysis of DSC-MRI data
- recent suggestion: iterative correlation-based analysis methods for MRI data of stroke patients introduced by Song et al.[2]

Patients

- 20 patients (71.2±6.4y, 15 male)
  - high-grade unilateral ICAS (>70% according to NASCET criteria)
  - or occlusion

DSC-MRI @ 3T[3]

- single-shot GE EPI,
  - TE/TR/α = 30 ms/1516 ms/60°
  - voxel size 2x2x3.5mm³
  - 26 slices
  - 80 repetitions
- bolus of 15-20ml Gd-DOTA (after a pre-bolus)

Methods: Correlation analyses

- Data analysis used SPM12[4] and custom MATLAB programs[5,6]
- After preprocessing[6], Pearson correlation was performed using
  - an iterative approach similar to Song et al[2] (method M1)
    - → initialization with mean brain time course (TC)
    - → six iterations with supra-threshold brain voxels (r > 0.6)
  - different reference TCs with short time to peak (TTP) (methods M2 – M3; see Fig. 1)
- Subtraction method (M5) calculated each voxel's TTP difference to the minimum TTP in GM (as obtained from the M2 reference TC)
- Comparison of regions with prolonged TTP to volumes with reduced CCs for methods M1-M4 and TTP subtraction maps (M5)
- Quantification of detected volumes by applying appropriate thresholds to the TTP, CC and subtraction maps (see Fig.2)

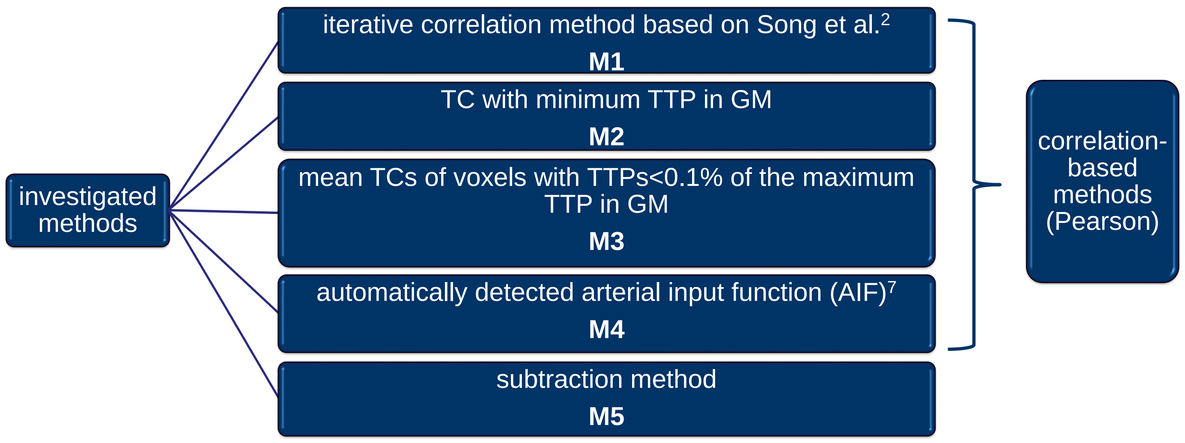

Figure 1: Overview of the five developed methods with corresponding reference time courses (TC) for correlation

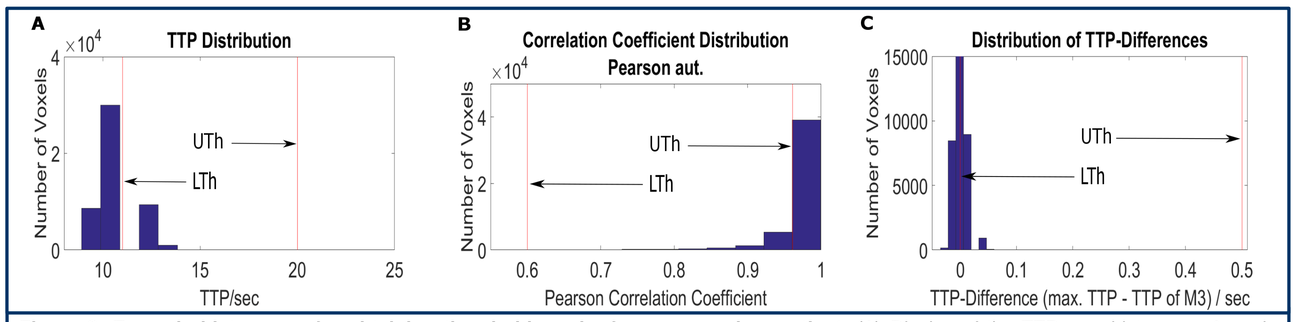

Figure 2: Example histograms for obtaining threshold masks for an exemplary patient. (A) Display of the TTP-map histogram. As only prolonged TTPs are of interest, a lower threshold (LTh) is set after the bin containing the majority of voxels. An upper threshold (UTh) is set to exclude late TTPs due to noise. (B) Illustration of the analogous procedure for CC-maps, where voxels with CCs lower than the majority of CCs are identified. In indistinct cases, thresholds were adjusted according to visual assessment of CC-maps in Vinci8. (C) TTP distribution of M5 with fixed thresholds at 0 and 0.5sec.

Table 1: Patient averages (mean ± standard deviation (SD)) of region volumes with prolonged TTP and reduced correlation coefficients (CCs) as identified by methods M1 – M5

	brain volume / voxel (GM + WM mask on DSC data)	TTP-map (region with prolonged TTP)	**M1** (Pearson auto.)	**M2** (min. TTP GM)	**M3** (< 0.1% of max. TTP in GM)	**M4** (AIF)	**M5** (subtraction method)
mean ± SD over all patients (n = 20)	46789 ± 5479	31,6 ± 13,8 %	36,8 ± 11,0 %	34,3 ± 7,7 %	34,9 ± 11,4 %	39,1 ± 11,9 %	26,5 ± 12,1 %
deviation from TTP-map region with prolonged TTP		± 0 % reference region	+ 5,2 %	+ 2,7 %	+ 3,3 %	+ 7,5 %	-5,1%

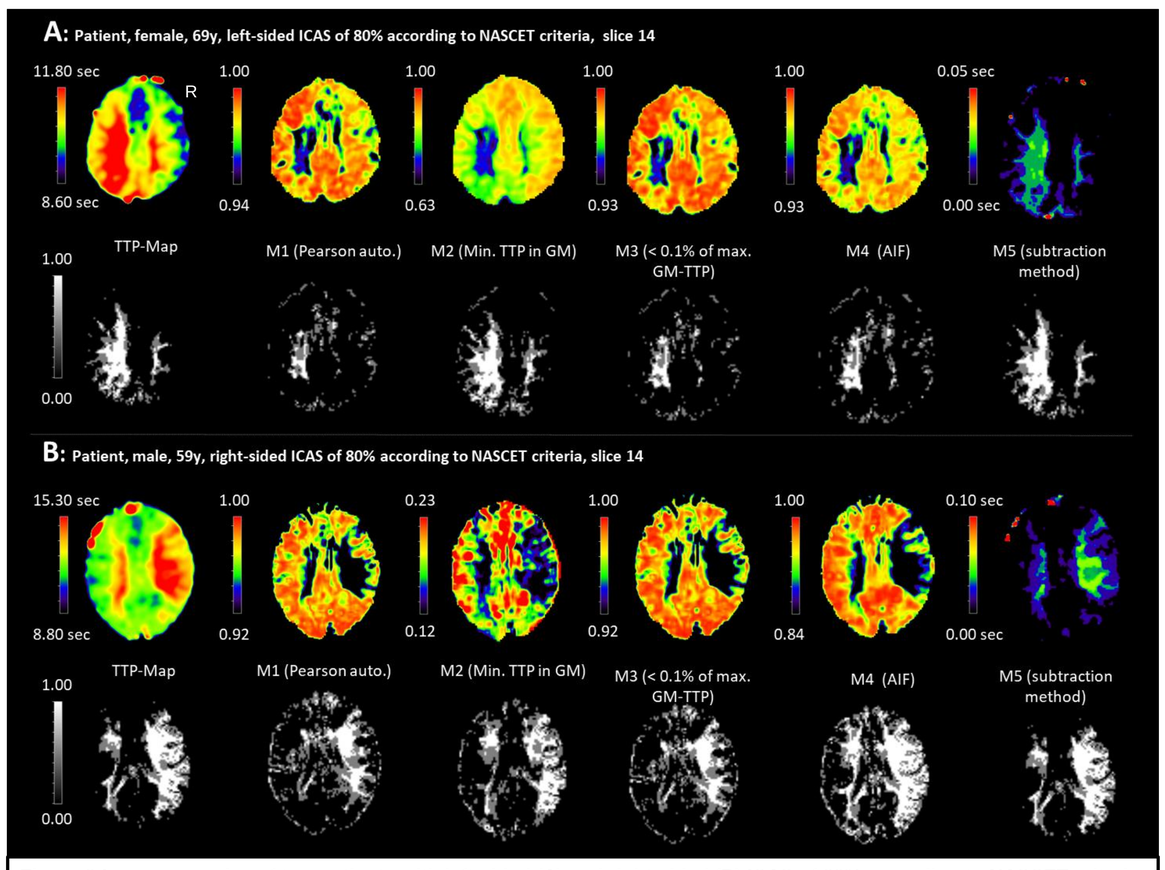

Figure 3:Image examples of two patients with left-sided (A) and right-sided (B) ICAS of 80% according to NASCET criteria.
Maps displayed in the first row for (A) and (B), respectively, from left to right: reference TTP-map, CC-maps for methods M1-M4 and the TTP subtraction map. The second row depicts corresponding maps (greyscale 0 to 1), resulting from thresholding (Fig. 2), for generating masks for the determination of the affected volumes. Red areas in the TTP-maps correspond to areas with prolonged TTP, which appear dark (=poor correlation) in the correlation maps having employed reference TCs with short TTP.

Results

- Figure 3 shows examples of two patients (A, B) where correlation and subtraction analysis revealed areas with low CCs corresponding reasonably well to areas with prolonged TTP.
- M1 and M3 showed good or acceptable results in all patients, M2 in 75%, M4 in 95%, and M5 in 90% of all patients (visual rating with regard to spatial congruency; rater MW).
- M4 identified the largest lesion regions (+7.5%), M5 the smallest (-5.1%) (Table 1).
- Challenges:
  - low CC values of M1 also detected regions with short TTPs in addition to prolonged TTPs.
  - M2 completely failed or yielded poor CC-maps in one or four patients, respectively.
  - AIF-detection employed for M4 reliably found good quality TCs with shortest TTP in all patients, low-CC volumes tended to be larger than the reference region (Table 1).
  - thresholding CC-maps for performance analyses was difficult in some patients due to poor image quality or nearly uniform CC-values (≈1.0, i.e. homogenous TTP)

Discussion & Conclusion

- All methods (except M2) successfully identified ≥ 90% of regions with prolonged TTP
- Overall, the results were promising but several issues remain:
  - the iterative method (M1) shows precision deficits since low CCs could also mean short TTPs
  - M2 is highly sensitivity to noise, producing poor results in 25% of all patients and thus, appears not suitable for broader use
  - correlation with the AIF (M4) tended to identify larger regions than the TTP-based reference
  - the subtraction method (M5) failed in two patients with only slightly prolonged TTPs, but revealed excellent congruence with the visually identified TTP regions in 18 patients.
  - M5 it is by far the fastest method with a processing time of 18±5 sec compared to 686±12sec (M1), 235±13sec (M2), 130±11sec (M3), 119±4sec (M4) [Lenovo ThinkPad X201 with Intel® Core™ i5 CPU, 8GB RAM, 64 bit Windows 10].

→ with further methodological improvements, these techniques may provide a quick clinical assessment of perfusion status in the future.

References: **1.** Petty GW et al. Stroke 1999;30:2513–6. **2.** Song S. et al. PLoS ONE 2017;12:e0185552. **3.** Philips: Philips Healthcare, Hamburg, Germany. **4.** SPM12: Statistical Parametric Mapping software (SPM12) Version 6225. **5.** Matlab: MATLAB and Statistics Toolbox Release 2016a, The MathWorks, Inc., Natick, Massachusetts, United States. **6.** Kluge A. et al. MRI 34(4) (2016): 410-421. **7.** Hedderich D. et al. Proc. Intl. Soc. Mag. Reson. Med. 25. (2017). **8.** Vinci software, Max-Planck-Institut für neurologische Forschung, Cologne, Germany.