Fully automated artifact reduction method for time-resolved cone-beam CT angiography

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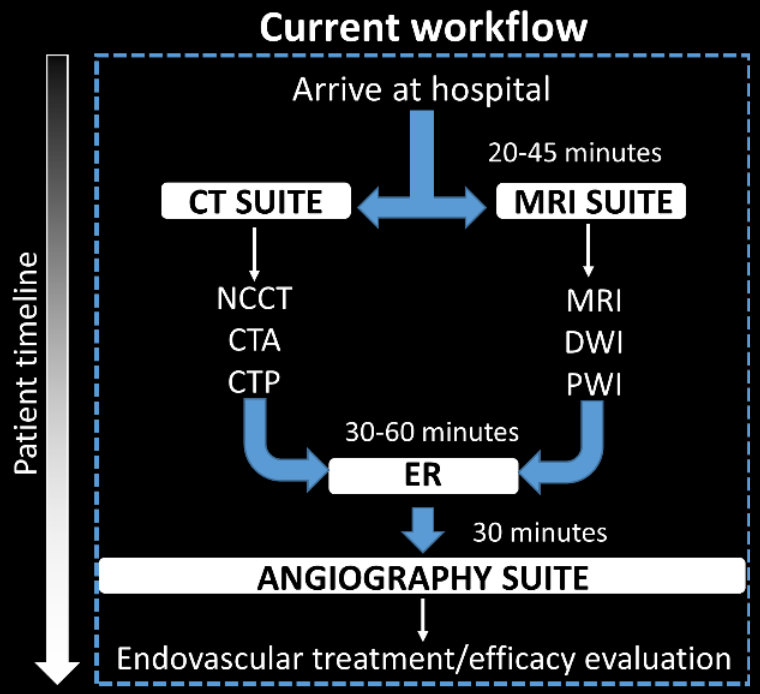
Motivation: one-stop-shop (OSS) protocol

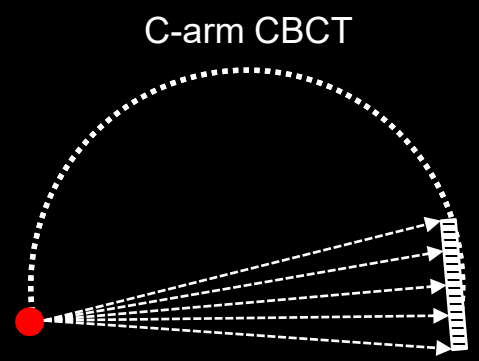
- Large Vessel Occlusion (LVO) stroke patients benefit from multi-modal imaging.
- Despite the benefits of performing this multi-modal imaging, the time needed to perform this imaging process results in significant delays to patient treatment[1].
- The desire to save time has motivated the one-stop-shop imaging paradigm for acute stroke imaging[2].



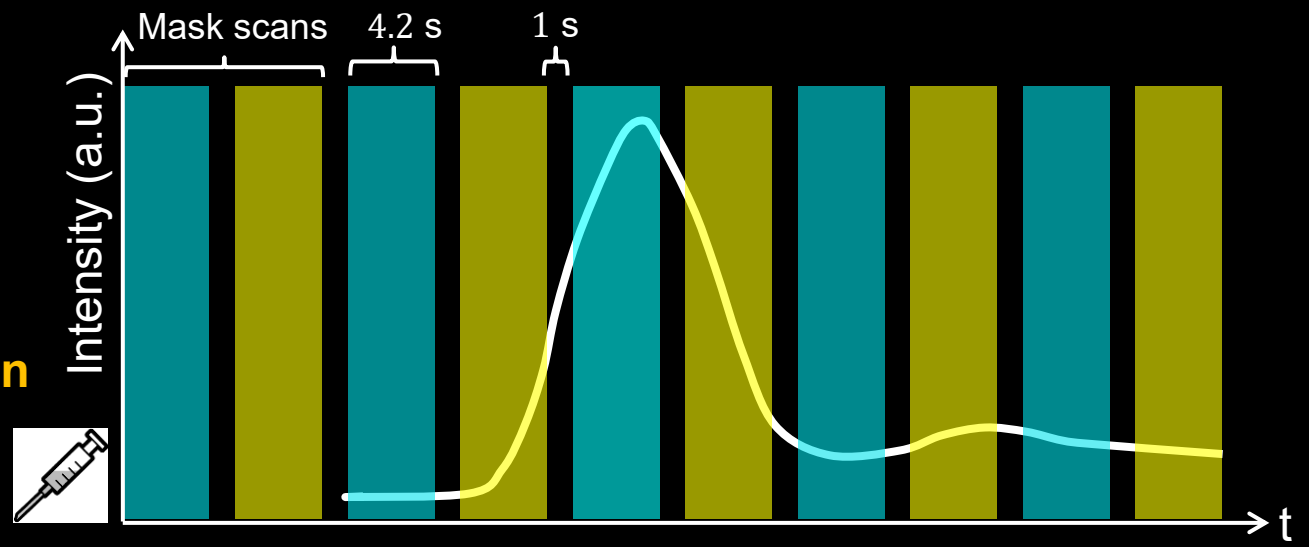
potentially save at least one hour per patient!

1 Broderick *et al.*, N. Engl. J. Med. (2013)
2 Yang, et al., Stroke (2015)

Introduction: one-stop-shop (OSS) protocol

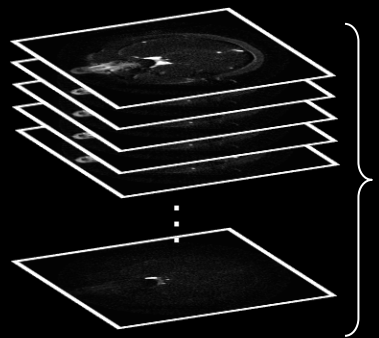


IV Injection

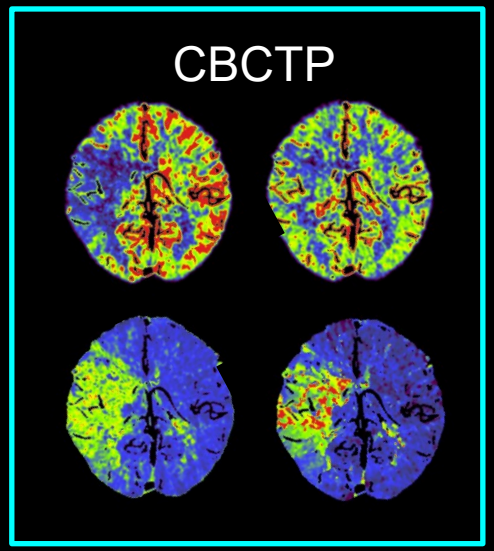


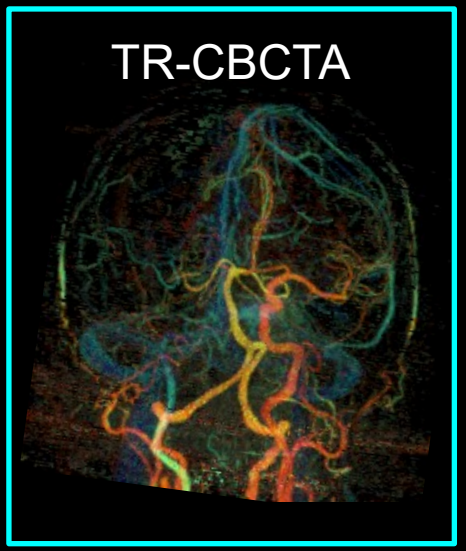
eSMART-RECON[1]

1. Li et al, IEEE TMI (2019)



256x256x200
x 40 frames

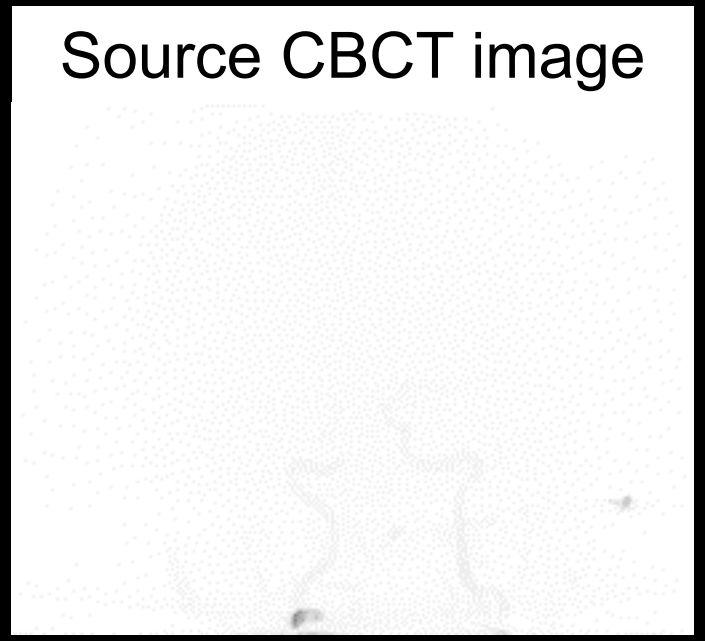




Introduction: the benefit of TR-CBCTA

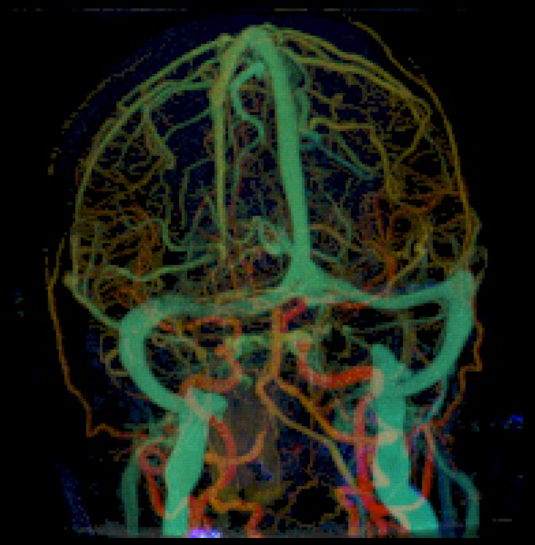
- Besides collateral analysis, color-coded time-of-arrival maps[1] can be derived from TR-CBCTA and provide complementary information of various vasculature phases.

Source CBCT image



Time @ intensity reaches 30% peak

Time-of-arrival map



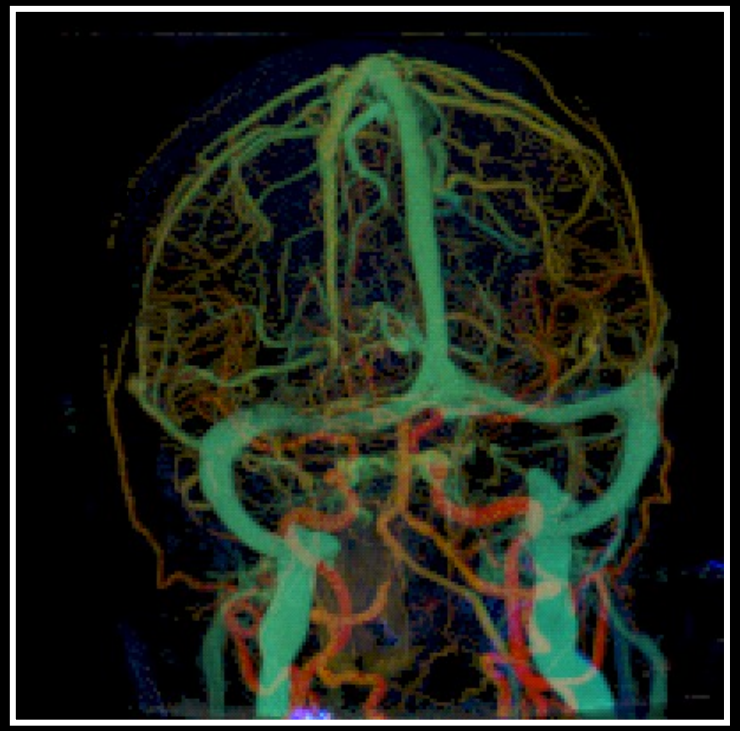
Early arrival

Late arrival

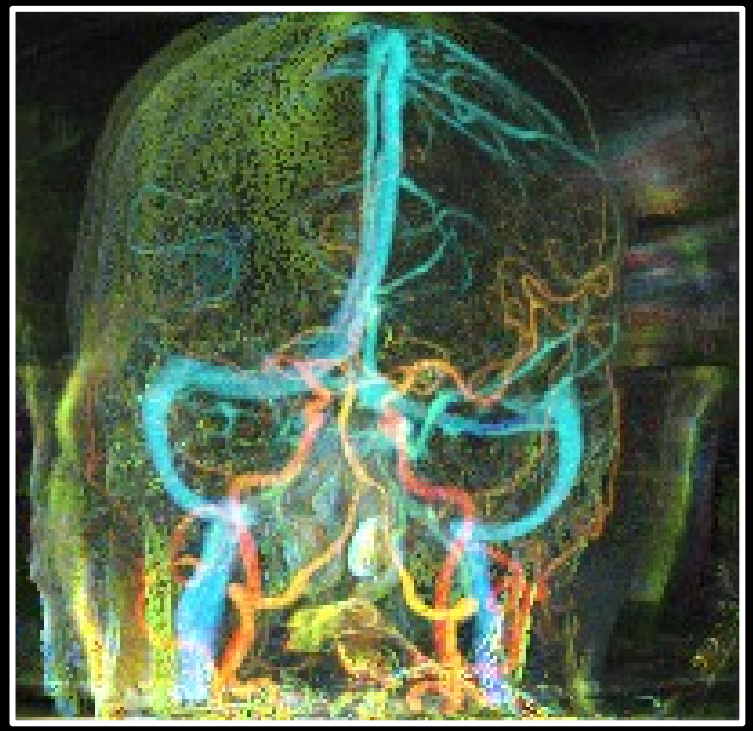
1 Cover et al; Neurosurgery (2007)

The technical limitation

- Time-resolved cone-beam CT angiography (TR-CBCTA) acquired in the angiography suite often presents mis-registration and residual bone artifacts due to patient motion and gantry instability.



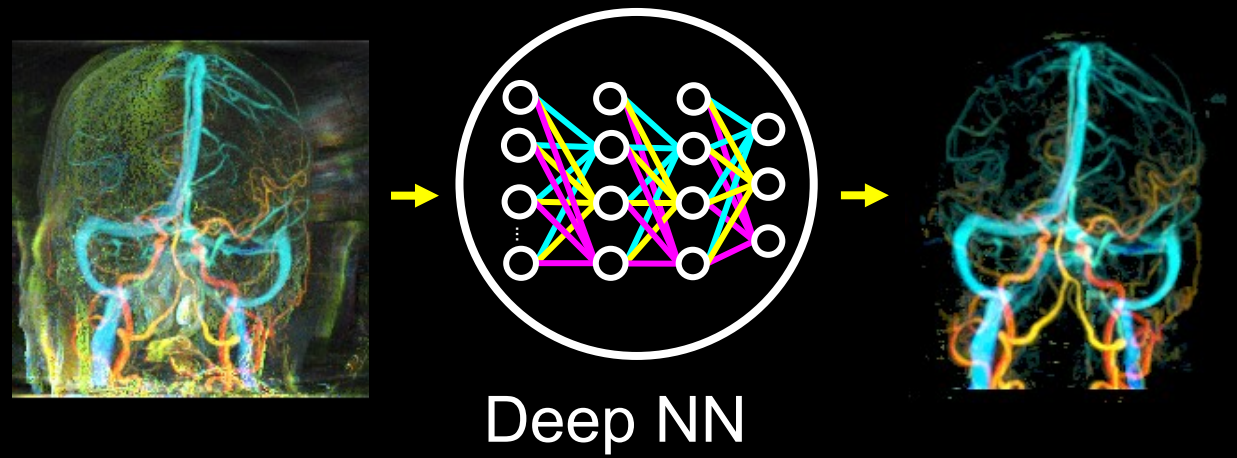
?



Ideally (very few)

In reality (majority)

Conventional supervised deep learning method

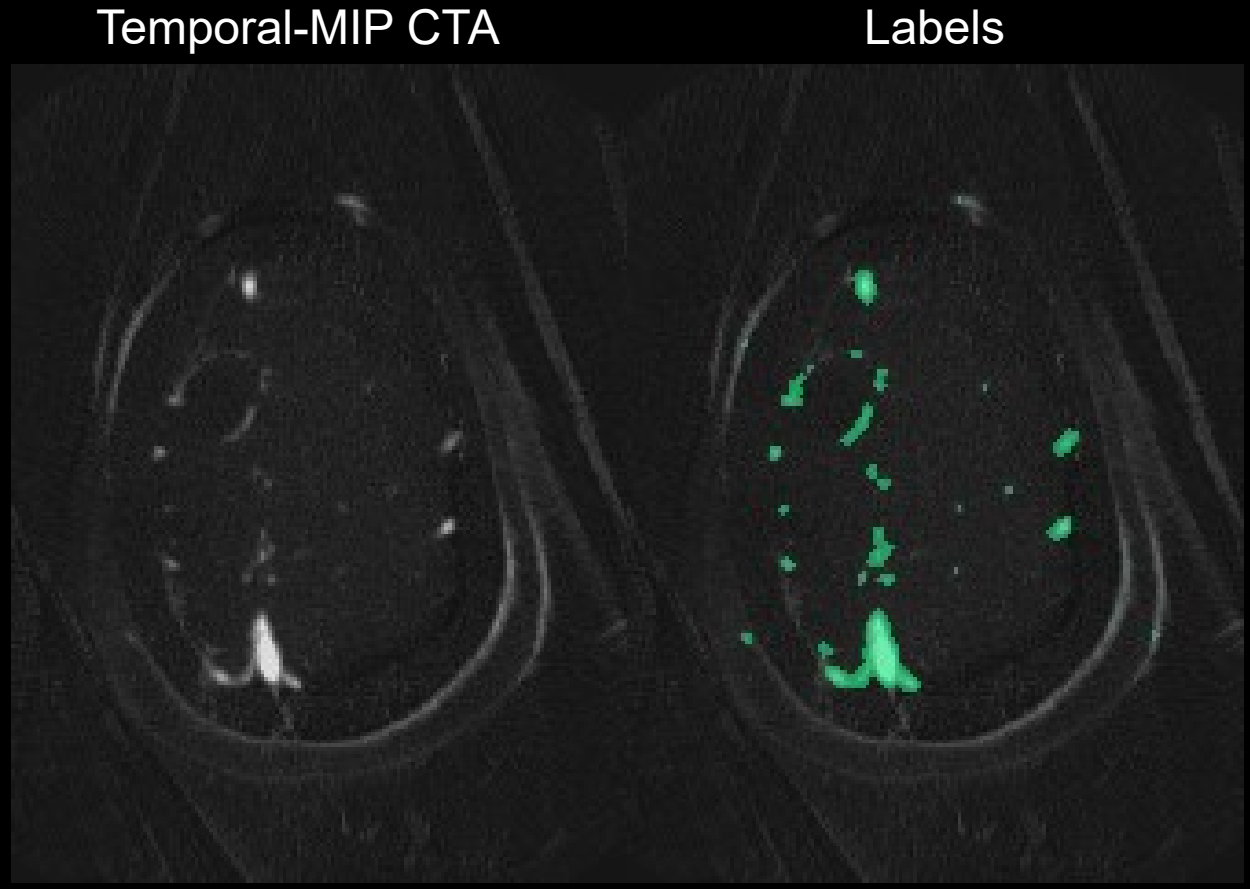


- Implementation details[1]
  - Network architecture: U-Net
  - Input: 256 x 256 (axial image) x 40 frames, TR-CBCTA via eSMART-RECON[2]
  - Training target: 256x256 hand-labeled vasculature map
  - Output: 256x256 Probability map
  - Training data: 50 patient cases, 5-fold cross-validation

1. Juan et al; RSNA. (2019)
2. Li et al, IEEE TMI (2019)

Laborious hand annotation process

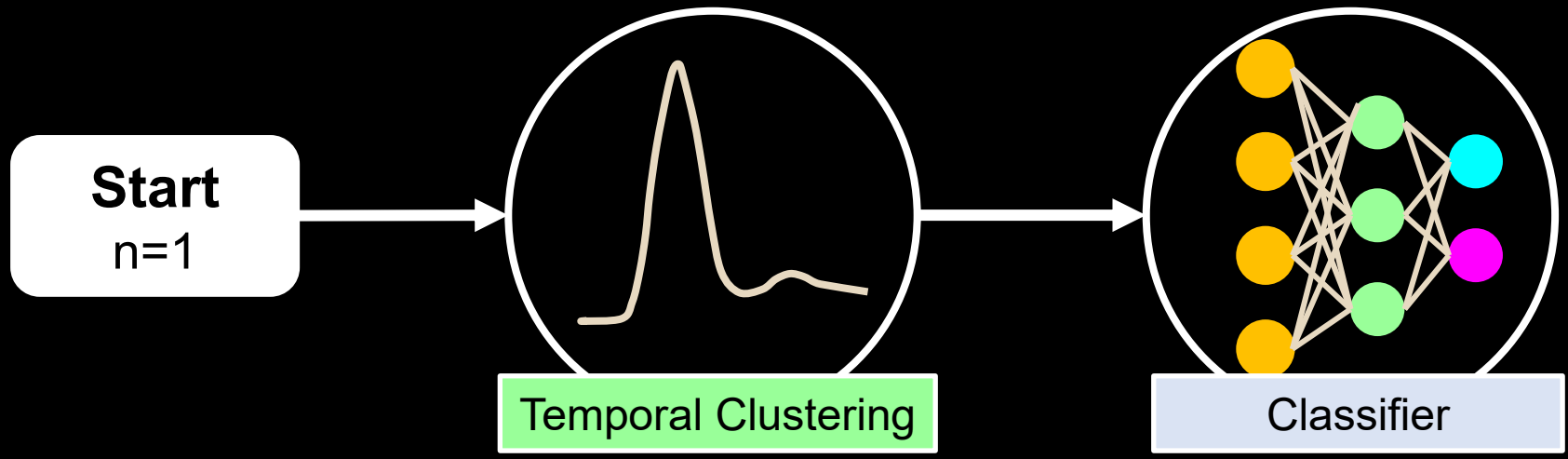
- Vasculature is hand-labeled in Temporal-MIP images for each patient.
  - >200k labeled voxels/patient
- Need special medical domain knowledge.



Objective

- To develop a fully-automated machine learning method to effectively reduce artifacts in TR-CBCTA in angiography suites.

Method: hybrid artifact reduction framework



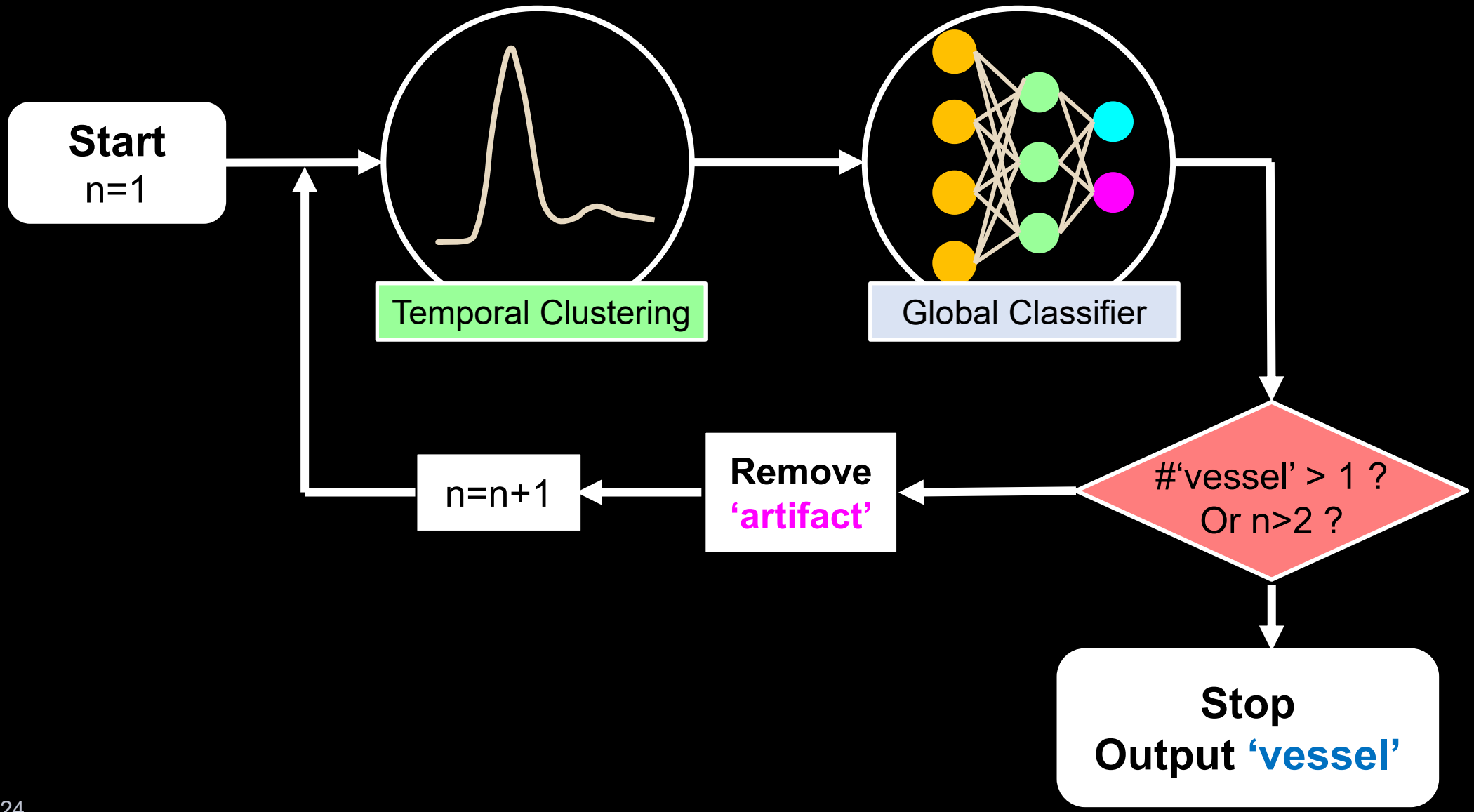
Input: SMART-RECON Denoised CTA [1,2]
Volume dim: 256x256x200
Time points: 40

Method: K-Means clustering
Input: 40-D temporal curves
Output: 4 clusters
Format: volumetric mask

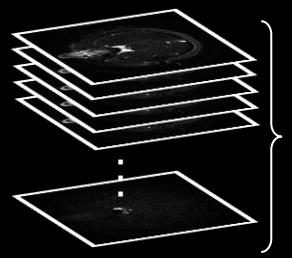
Method: Supervised Learning
Input: 256x256x200 clustering masks
Target: manual labeling, 'vessel', 'artifact'
Output: prediction score (threshold=0.5)

1. Chen et al; MedPhys. (2015) 2. Li et al, IEEE TMI (2019)

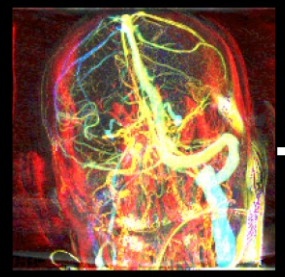
Method: artifact reduction framework



An example of working pipeline



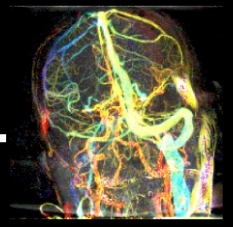
4D data



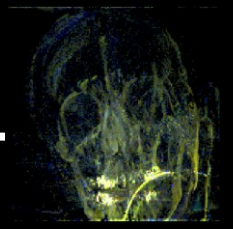
Input map

N=1

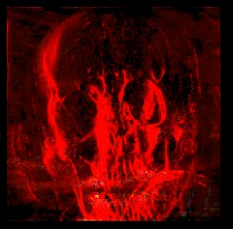
Cluster → Classifier → SC ✖



Cluster 1 → ‘vessel’



Cluster 2 → ‘artifact’



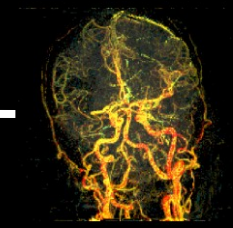
Cluster 3 → ‘artifact’

Cluster 4 → ‘artifact’

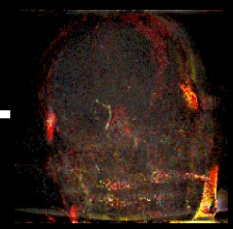
N=2

Cluster → Classifier → SC ✔

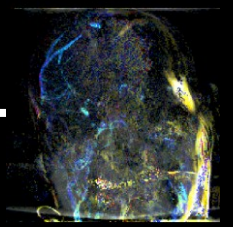
Cluster 1 → ‘vessel’



Cluster 2 → ‘vessel’



Cluster 3 → ‘artifact’



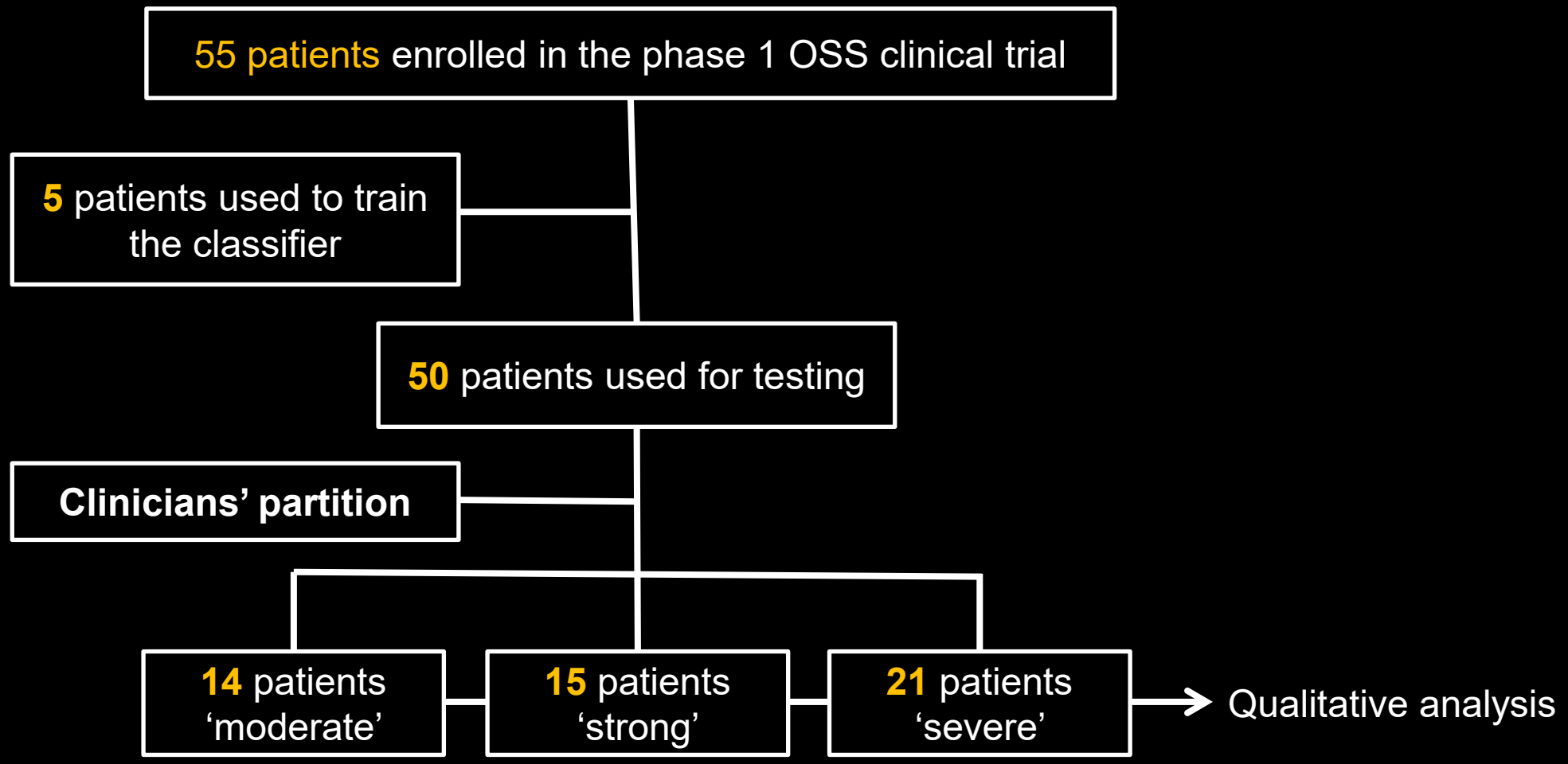
Cluster 4 → ‘artifact’

+

Output map

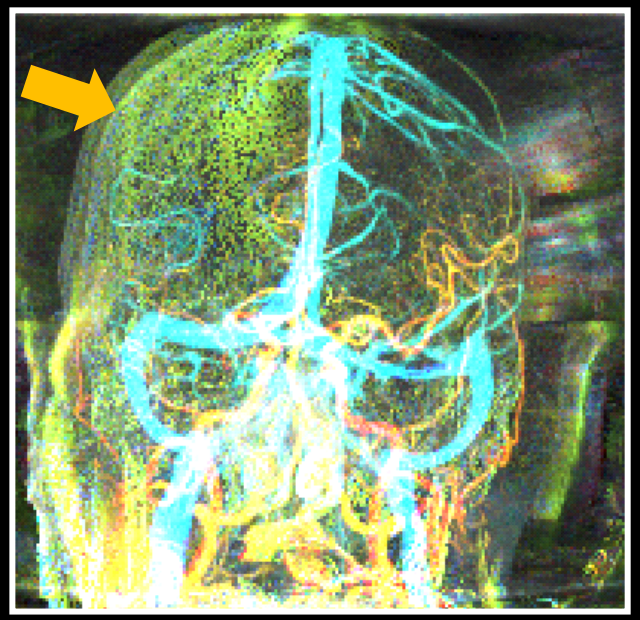
Methods: study schema

- IRB approved and HIPAA compliant study

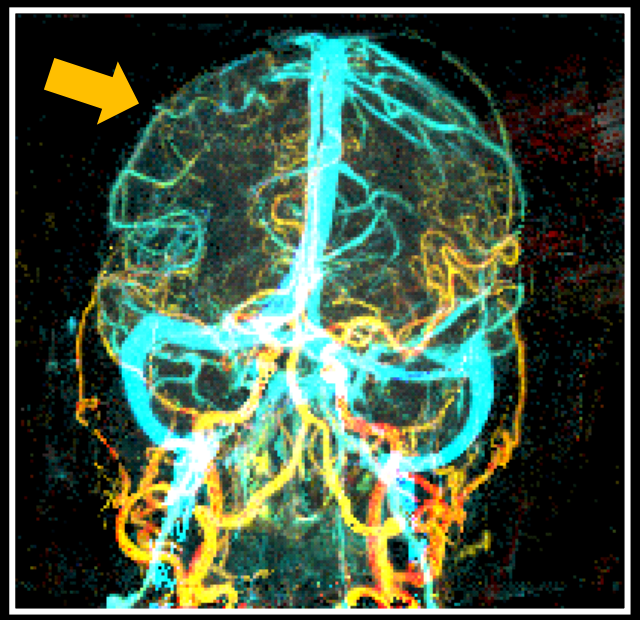


Results I: a case with strong artifacts

Original

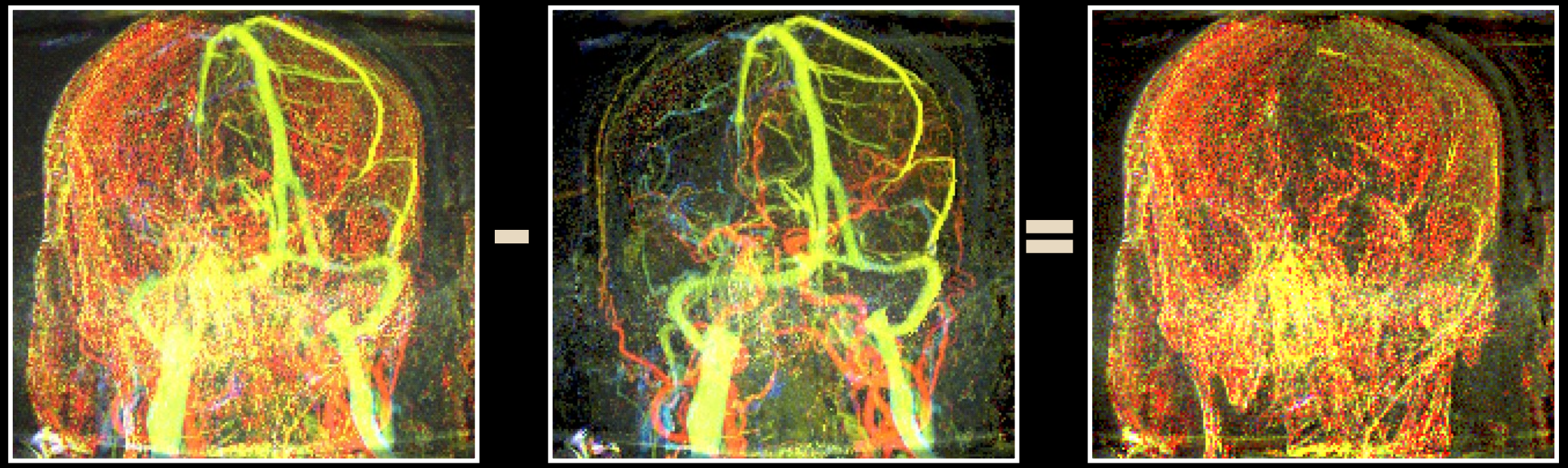


Proposed



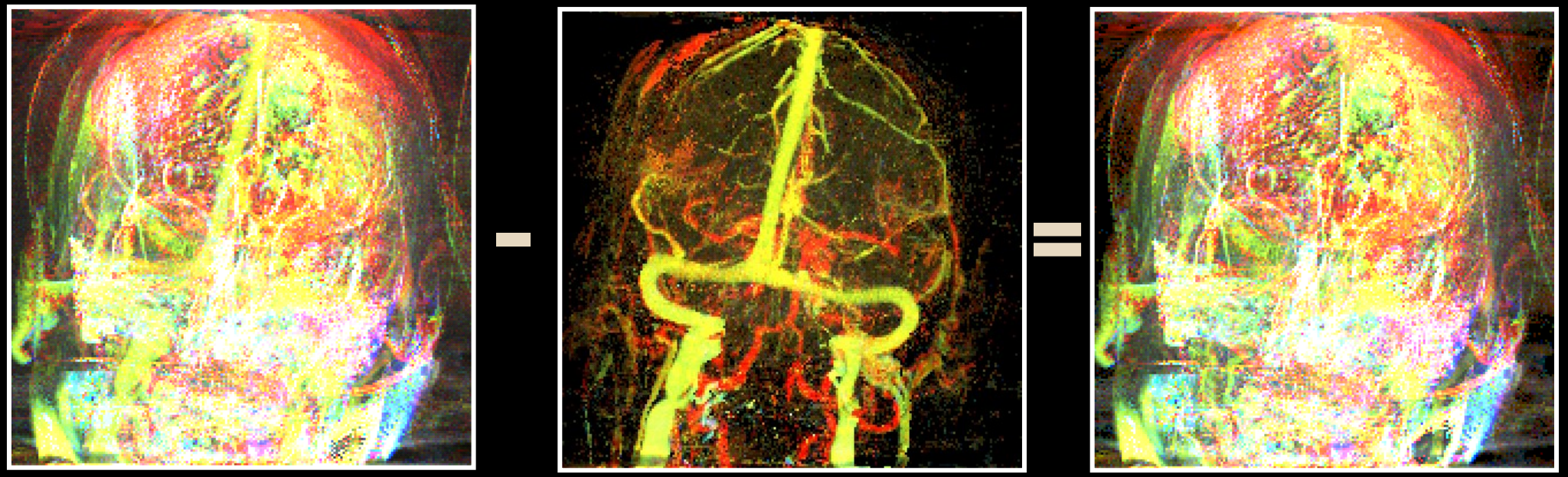
Results II: a case with strong artifacts

Original **Proposed** **‘Artifact’**



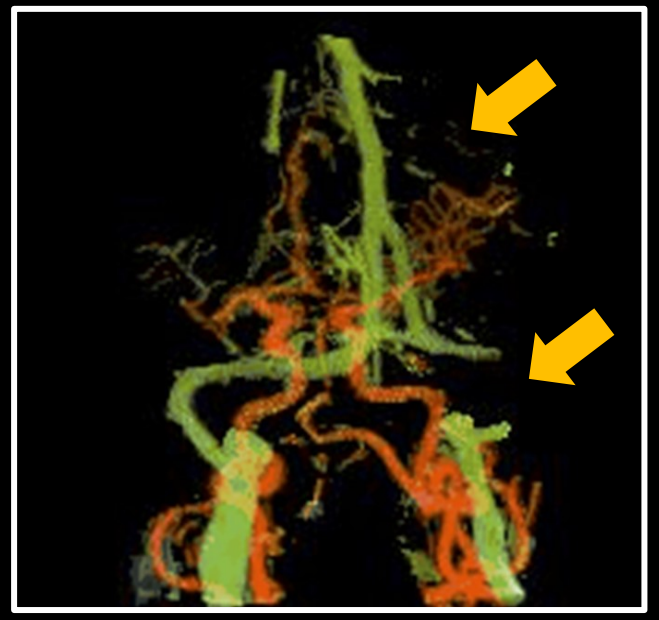
Results III: a case with severe artifacts

Original **Proposed** **‘Artifact’**

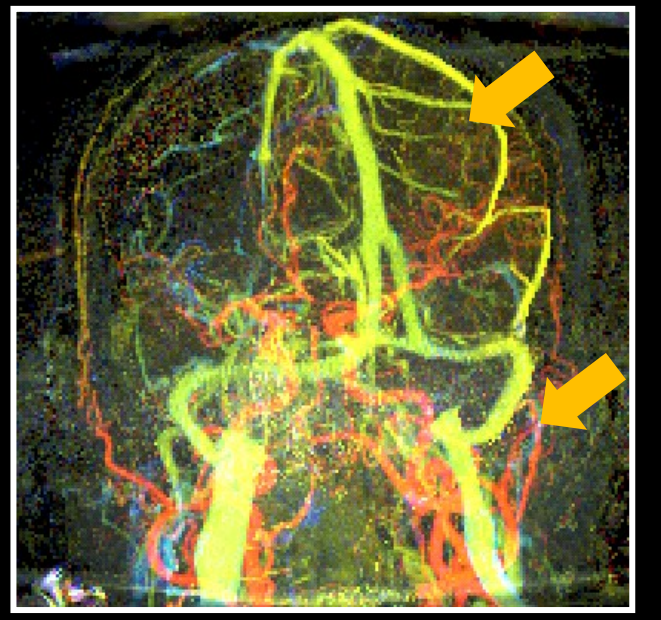


Robustness analysis: moderate artifacts

DeepNN [1]



Proposed

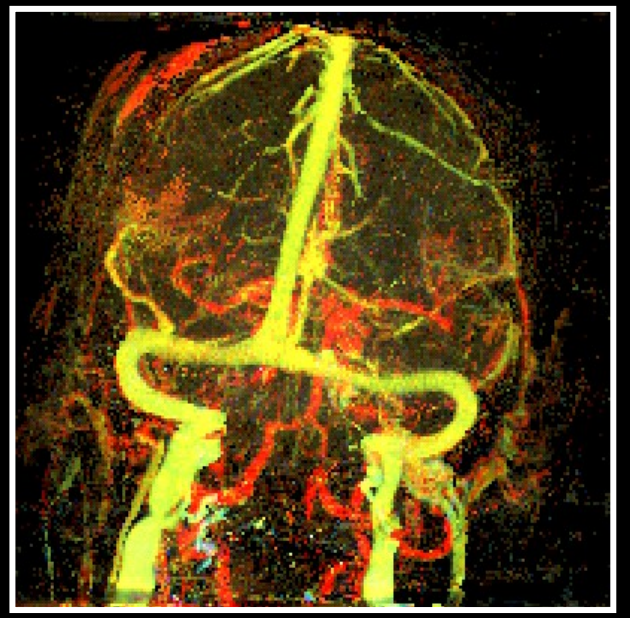


1. Juan et al; RSNA. (2019)

Robustness analysis: severe artifacts

DeepNN [1]

Proposed



1. Juan et al; RSNA. (2019)

Conclusion

- Robust artifact reduction has been achieved for clinical cases in the test cohort regardless of their initial artifact levels.
- After artifact reduction, the visualization of TOA maps clearly shows different contrast enhanced phases of vessels.