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FELLOWSHIP FINAL REPORT

PeRfusiOn Post tHrombEcTomy (PROPHET) - A technical development and clinical validation project

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ABSTRACT

Mechanical thrombectomy (MT) is the highly effective standard of care for acute ischemic stroke with large vessel occlusion. However, up to 50% of patients experience "futile recanalization," where successful macrovascular recanalization does not translate into functional recovery. To assess the reperfusion status of treated patients the implementation of a functional FP-CTP acquisition and post-processing was established in order to evaluate patients' reperfusion status directly in the operating room. Within the scope of a multi-center project using this processing, we were able to show that perfusion imaging can distinguish different reperfusion phenotypes in treated patients, which can be used to stratify patients for further interventional or medical treatments in the acute stroke phase. We were able to show that acute acquisition is feasible, an immediately available post-processing algorithm can provide perfusion maps comparable to standard perfusion modalities and that these maps help to define the reperfusion status of patients in more detail than standard techniques.

1 - Introduction

Stroke remains a leading cause of global mortality, with mechanical thrombectomy serving as the standard of care for large-vessel occlusions. While the primary goal is achieving complete reperfusion, categorized as eTICI 3, nearly 50% of patients fail to reach this threshold, often due to distal occlusions or microcirculatory failure that are difficult to detect on standard 2D imaging.[1]

Current 2D digital subtraction angiography (DSA) frequently leads to the overestimation of perfusion, leaving salvageable brain tissue untreated. To bridge this gap, this collaborative initiative between CHRU Tours and University Hospital Bern evaluates Flat-panel detector CT perfusion (FDCTP). By providing real-time, 3D perfusion maps within the angiography suite, FDCTP aims to enhance the detection of residual deficits and guide critical intra-operative rescue maneuvers to improve patient outcomes.[2,3]

Flat-panel detector technology was designed to improve the quality of standard radiography by providing higher absorption efficiency and wider dynamic range. FDCT imaging provides high spatial resolution and can produce CT-like cross-sectional images when mounted on a rotating C-arm system in the angiosuite. In combination with contrast injection, angiograms and perfusion studies can be acquired. Until recently, FDCTP was limited to the acquisition of parenchymal cerebral blood volume (CBV) maps using a two-sweep C-arm rotation protocol that lacked the temporal resolution required for time-resolved dynamic perfusion imaging. The introduction of multi-phase FDCTP acquisition protocols overcame this limitation, allowing the acquisition of time-resolved perfusion maps such as cerebral blood flow (CBF) and time-to-maximum (Tmax) maps.[4]

2 - Experimental details

The proof-of-concept phase at CHU Tours successfully integrated flat-panel CT perfusion (FDCTP) into the acute stroke clinical pathway. This involved the installation and calibration of advanced post-processing software (including research prototypes and commercial modules) and the technical optimization of contrast delivery using a mono-injecting pump system. To ensure high-quality imaging, we refined patient selection criteria, specifically addressing the motion-artifact challenges by comparing protocols for intubated versus non-intubated patients. Through close interdisciplinary collaboration with the radiologic technician team, we streamlined the acquisition timing and data transfer, resulting in a finalized Standard Operating Procedure (SOP) that allows for rapid, reliable intra-operative perfusion assessment.

Algorithm Development

SUPER is a fully automated, deconvolution-free perfusion imaging pipeline for ischemic stroke that processes raw CTP or MRP time series in two stages: first, a lightweight signal-processing module generates surrogate perfusion parameter maps by regularizing each perfusion series with a nested peak-finding algorithm; second, a 3D nnU-Net segments infarcted or hypoperfused tissue and returns the final binary mask to assist clinical reading. The design emphasizes interpretability and robustness by combining clinically readable perfusion-map outputs with automated lesion labeling in a logically minimalist framework. We also had access to one unpublished prototype developed by Siemens Healthineers (Forchheim, Germany) and one commercially available research module from Cercare Medical (Aarhus, Denmark) which constituted comparison for the developed algorithm.

PROPHET multicenter study

The population consists of patients with symptoms of acute ischemic stroke, who underwent mechanical thrombectomy. A total of 279 patients will be enrolled. The overall objective is to investigate the potential clinical use of FDCTP acquired during or shortly after endovascular stroke treatment. For the primary objective, it will be evaluated in how many cases information from processed FDCTP maps reveals new, potentially relevant clinical information that may change treatment decisions. Secondary objectives will be evaluating diagnostic sensitivity of FPCTP maps in comparison to digital subtraction angiography for the detection of residual occlusion. This will be done with and without time restrictions for the diagnostic readers. Lastly, we will explore correlations of FPCTP findings with clinical outcomes, findings on follow-up imaging and the capacity of the technique regarding ratings of brain eloquence.

Comparison Cohort

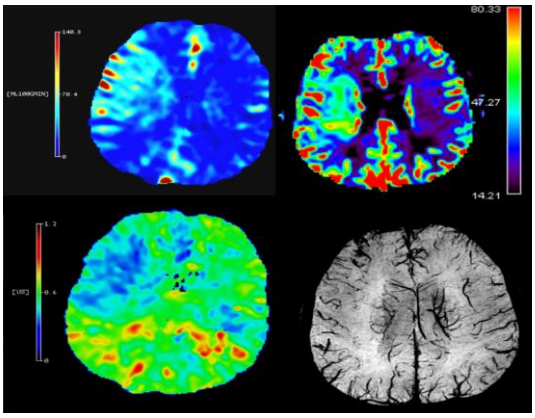
To provide a rigorous comparison, the MDCTP cohort from Vall d'Hebron University Hospital in Barcelona was propensity-score-matched 1:1 to the FPCTP cohort based on age, baseline ASPECTS, collateral status, and final eTICI score. This matched Barcelona group, treated between 2018 and 2019, served as the conventional imaging benchmark to validate the diagnostic accuracy of immediate, on-table flat-panel perfusion acquisitions.

3 - Results and discussion

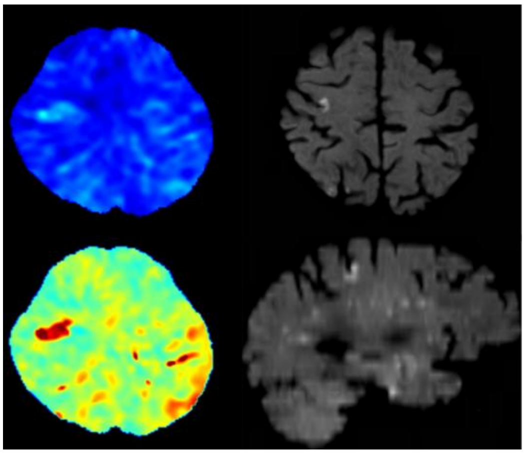
Proof of Concept and detection of perfusion states

In the participating centers a proof-of-concept phase was established, and at CHU Tours the acquisition protocols and algorithm for post-processing were implemented. This allowed for the detection of different disease states in an initial pilot phase. The different states of perfusion abnormalities detected on FPCTP were: Macrovascular hypoperfusion due to residual occlusions, immediate post-interventional hyperperfusion, microvascular hypoperfusion and perfusion delays related to competing collaterals. Some examples of different perfusion states in successfully reperfused patients included in the PROPHET study successfully recanalized can be found below.

(1) Patient with immediate post-interventional hyperperfusion in the recanalized territory (left side, upper row: CBF Map, left side lower row OEF map; right side, upper row CBF Map of MRP on 24h follow-up; right side lower row, SWI showing less vein susceptibility artifacts related to higher oxygenation):



(2) Patient with a persisting macrovascular distal occlusion after successful reperfusion: (left side, perfusion imaging immediately after MT; right side, DWI 24h follow-up on MRI).



While perfusion abnormalities after thrombectomy have been described and are well characterized,[5] their detection immediately after thrombectomy using novel imaging techniques immediately in the operating room is new. Defining perfusion states for patients immediately in the acute phase can lead to new therapeutic options and may guide additional medical management, i.e., the application of intra-arterial thrombolysis.[6]

Comparison study

At the time of this report the PROPHET study is ongoing. An interim analysis in comparison with standard multidetector CT after thrombectomy yielded the following results. In a propensity-score-matched analysis of 98 patients (49 per group), immediate intra-operative FPCTP demonstrated comparable diagnostic utility to shortly delayed multidetector CT perfusion (MDCTP). Technical feasibility was high, with 96% of FPCTP maps being assessable versus 100% of MDCTP. Both modalities showed a high correlation with residual occlusion status: delayed perfusion was present in 92% of FPCTP and 85% of MDCTP cases with DSA-confirmed residual occlusions. Notably, in cases rated as successful macrovascular reperfusion (eTICI 2c-3), perfusion-angiography discordance was observed in 36% (FPCTP) and 27% (MDCTP) of patients, frequently revealing missed distal branch occlusions or competitive collateral flow. In the FPCTP cohort, perfusion maps identified true vessel occlusions in 24% (6/25) of cases originally classified as eTICI 3 by the operator, highlighting significant operator overestimation of reperfusion success. Furthermore, FPCTP successfully detected acute proximal reocclusions (3%) occurring immediately after the final DSA run while the patient was still on the table. In cases with residual occlusion (eTICI 0-2c), MDCTP showed a non-significant trend toward higher rates of restored perfusion (11% vs. 4%), likely reflecting the longer time interval from the procedure (median 24 min for MDCTP vs. 9 min for FPCTP). These data suggest that FPCTP provides robust, real-time hemodynamic data equivalent to conventional MDCTP, enabling immediate identification of salvageable tissue and facilitating intra-operative rescue therapies without the delay of patient transfer. The paper associated with this research is currently under review.

The final results of the ongoing PROPHET study will be published once available.

4 - Conclusion

The implementation of an intra-operative flat-panel perfusion acquisition in acute stroke patients is feasible and harbors the potential to acquire perfusion maps classifying perfusion states of patients after interventional stroke treatment. This includes the detection of missed vessel occlusion on 2D DSA, highlighting that the technique may be used to mitigate operator overestimation of reperfusion success. Further research is needed to define the role of flat-panel perfusion within the framework of rescue therapies in acute stroke workflows.

5 - Perspectives of future collaborations with the host laboratory

While perfusion imaging is particularly helpful in acute ischemic stroke patients, intra-operative perfusion imaging may also be helpful in other diseases. Its potential value extends to intra-arterial medical or mechanical spasmolysis in patients suffering from vasoaspasms after a subarachnoid hemorrhage to evaluation of hemodynamics in parent artery occlusions or other forms of vessel sacrifice needed for patient treatment. Within the established collaborative network including CHU Tours, we will further evaluate the value of intra-operative perfusion imaging in stroke and other diseases within the framework of the prospective follow-up PROPHET – Global project. Further it is envisaged to continue the teaching course regarding intra-operative flat-panel imaging in a yearly fashion with alternating locations in Bern and Tours, the next congress is planned in Bern on November 06/07 2026: Advanced peri-operative Imaging in the angio suite: "We can only treat what we see". We look forward to contributing to this emerging technique in a continued international and collaborative endeavor.

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