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Flat panel imaging of occlusion site and collateral scores for emergent large vessel occlusion

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ABSTRACT

Introduction: Flat panel imaging for emergent large vessel occlusion can be acquired prior to mechanical thrombectomy (MT). In this study, we examined patients undergoing MT with computed tomography angiography (CTA) to determine agreement on the site of occlusion and CTA collateral score (CS).
Methods: Flat Panel CTA (FP-CTA) was acquired before MT. Time between CTA and FP-CTA acquisition, site of occlusion, and CS were reported. Significant CS change was defined as > 2-point change, or any change to/from a malignant profile (CS = 0 to CS > 0, or vice versa).
Results: Eleven patients (mean age, 60.8 years; NIHSS, 17; 55.0% female) were included; IV tPA was administered to 7. Intra-reader occlusion site, dichotomous CS, and continuous CS correlation between CTA and FP-CTA were 96.6%, 90.0%, and 86.6%, respectively. Inter-reader correlation for occlusion site was 93% for CTA and 100% for FP-CTA; dichotomous CS correlation was 87% for both CTA and FP-CTA; correlation of continuous CS was 77% for CTA and 87% for FP-CTA.
Conclusion: Standard CTA and FP-CTA have high intra and inter-reader correlation determining site of occlusion and CS in ELVO setting. This angiographic tool may have potential applications for both triage and patient selection.

1. Introduction

Mechanical thrombectomy (MT) is the standard of care treatment for patients with emergent large vessel occlusion (ELVO) based on multiple randomized clinical trials [1–5]. Systems of care are now rapidly evolving to deliver these patients efficiently from the field to the angiography suite for this time-sensitive treatment [6]. A growing body of literature has demonstrated the utility of computed tomography angiograpy (CTA) collateral scores (CS) to help select patients who are most likely to benefit from intravenous (IV) thrombolysis with tissue plasminogen activator (tPA) and MT [7–9].

Modern angiographic suites with flat panel detectors (FPD) can perform multi-modal acquisitions analogous to computed tomography (CT), CTA, and computed tomography perfusion (CTP) that are routinely obtained in the emergency department for patients with acute ischemic stroke. The FPD parenchymal blood volume acquisitions appear to have good correlation with standard CTP cerebral blood volume (CBV)—the perfusion metric most closely correlated to magnetic resonance imaging (MRI) diffusion-weighted imaging (DWI) core infarct [10]. Recent meta-analysis of randomized clinical trials supports the use of advanced neuroimaging to select patients for mechanical thrombectomy [11]. However, the utility of CTP imaging has been called into question due to its inability to reliably establish core infarct volumes and challenges to standardize its application, particularly at smaller community hospitals [12].

In routine clinical practice, patients with ELVO are reliably

Abbreviations: CBV, cerebral blood volume; CS, collateral score; CT, computed tomography; CTA, computed tomography angiography; CTP, computed tomography perfusion; DWI, diffusion-weighted imaging; ELVO, emergent large vessel occlusion; FP-CTA, Flat Panel CTA; FPD, flat panel detectors; IV, Intravenous; MRI, magnetic resonance imaging; MSU, mobile stroke unit; MT, mechanical thrombectomy; tPA, tissue plasminogen activator

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identified with CT and CTA. FPD imaging in the angiographic suite may provide an alternative workflow for acute ischemic stroke patients, particularly those transferred from outside hospitals with a known diagnosis of ELVO. To further explore this concept, we performed a pilot study comparing standard CTA acquired in the emergency department to FPD-CTA obtained in the angiographic suite.

2. Methods

2.1. Patient selection

This is a prospective pilot study reviewed and approved by a medical university institutional review board, and included acute ischemic stroke patients with ELVO treated with MT at a comprehensive stroke center. All patients presenting with signs and symptoms of acute ischemic stroke received CT and CTA in the emergency department on a Lightspeed VCT Scanner (GE Medical Systems, Little Chalfont, United Kingdom) per the university stroke team acute ischemic stroke Protocol. Patients who met all inclusion and exclusion criteria for IV thrombolytic therapy were treated as per standard of care, and if diagnosed with ELVO by CTA, they were immediately transferred to the angiography suite for MT.

2.2. Angiographic imaging

Standard transfemoral arterial vascular access was obtained and subsequent FPD-CTA was acquired before MT via a pigtail aortic arch injection. Data were acquired on 1 of 3 interventional C-Arm cone beam CT systems: either an Artis Q/Artis Zee Biplane or an Artis Zeego (Siemens Healthcare AG, Forchheim, Germany) running software versionVC21. A 6-second neuro parenchymal blood volume protocol (commercially available product) was selected for each patient prior to thrombectomy (12 s acquisition time; 496 frames; 70 kVp; 1.2 μGy/frame) and 2 projection image runs were acquired: (1) the native mask (tissue imaging), and (2) the native fill (injection of contrast). During the second rotation, the patient was injected with 122 ml of 25% contrast dye at 4 ml/s, 500 psi and imaging acquisition was initiated by the operator once filling of the superior sagittal sinus was observed, indicating adequate cerebral contrast perfusion. (Fig. 1).

The native fill (Dyna CTA) acquired data were reconstructed on a workstation (X-Workplace, Siemens Healthcare AG, Forchheim, Germany) using software version VB21C to produce the FP-CTA. Each FP-CTA reconstructed dataset was the equivalent of the standard brain Hounsfield unit windowing with a matching slice thickness to the similar CTA acquired in the emergency room. Pre-angio suite CTA windowing was set to 90/30 window level (90 width, 30 level). The setup, rotational acquisition, and post processing time is a total of 2 min.

2.3. Collateral score analysis

Patient baseline characteristics and details of treatment and outcome were retrospectively collected. Three blinded board certified neuroradiologists read CTA and FPD-CTA datasets and determined the site of occlusion and the CSs using an OsiriX platform (v 5.8.5 32 Bit) dicom reader that allowed windowing and 3-dimensional MIP and orthogonal reconstructions similar to standard PACS workstations. CSs were reported using the Malignant Collateral Score profile in continuous (0–4) and dichotomous (0 vs. 1–4) fashion (Figs. 2 and 3) [9]. This scale has been previously validated in both IV tPA and MT-treated patients to predict both infarct core by DWI at presentation and functional outcome independent of recanalization status [7,9]. A significant change in CS was defined as a > 2-point change in CS between 2 reader's interpretations or any change to malignant profile (CS = 0 from CS > 0) or vice versa. Time between CTA and FPD-CTA acquisition was also recorded. Intra-reader correlation of occlusion site between CTA and FPD-CTA and CS change (dichotomous and continuous) between the CTA and FPD-CTA acquisitions for each patient were recorded. Additionally, inter-reader agreement of occlusion site and CS (dichotomous and continuous) were reported between paired readers for both CTA and FPD-CTA. Comparison of means was performed for continuous variables with Medcalc statistical calculator (MedCalc Software, Ostend, Belgium).

Fig. 1. Bolus Tracking Acquisition for FP-CTA. Dilute contrast fills the major dural sinuses (arrowhead = sagital sinus; arrow = transverse-sigmoid junction), indicating brain parenchymal contrast saturation adequate for rotational acquisition of the FP-CTA.

3. Results

A total of 11 patients were enrolled in the study. The mean age was 60.8 years, 55.0% Female with an average NIHSS of 17 at presentation. Seven of the 11 patients were treated with IV tPA. Ten of 11 patients had anterior circulation occlusion of the M1 or ICA terminus with a single basilar occlusion. Average time between CTA and FPD-CTA was 98.4 min (range, 66–121; standard deviation, ± 17.3). A total of 5 patients (50.0%) had both CTA and FPD-CTA at the hub, while the remaining patients were transferred from spoke hospitals where CTA was performed with subsequent FPD-CTA at the hub. One patient did not have CTA prior to treatment, so pre and post comparisons were limited to 10 patients. However, inter-reader comparisons for occlusion site and collaterals were reported. There was no significant difference in time from CTA to FPD-CTA in hub versus transfer patients (92.4 ± 15.7 vs. 104.4 ± 18.3; 95% confidence interval, −12.9–36.9; $p = .30$).

3.1. Intra-reader occlusion site and CS comparisons between CTA and FPD-CTA

The correlation of the site of occlusion on CTA and subsequent FPD-CTA averaged 96.6% with 100% concordance for 2 readers and 90% for the third reader who classified the CTA as an ICA occlusion and the FPD-CTA as a proximal M1 occlusion in 1 patient. There was an average 90.0% concordance for the dichotomous CSs with 2 readers having 100% concordance and 1 reader reporting 2 decrements in collaterals—from a good to malignant CS profile, and 1 increment from malignant to good CS profile—for an agreement of 70%. The continuous CTA CS and FPD-CTA CS had an average agreement of 86.6% with 2 readers at 100% concordance, and the third reporting 60% concordance

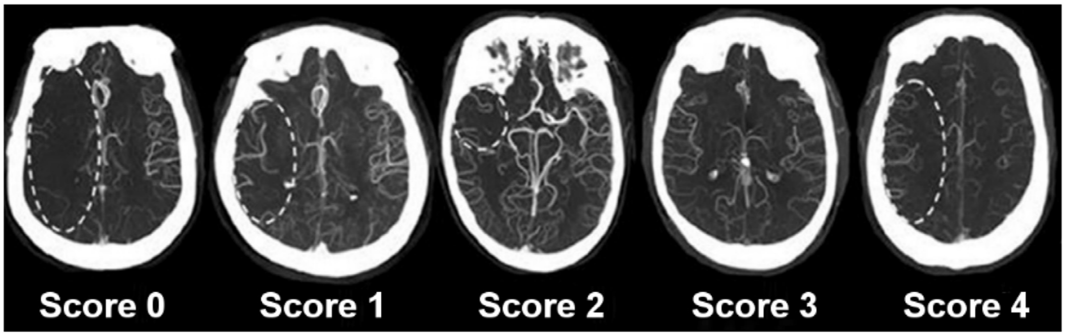

Fig. 2. Collateral Score System: 0 = absent collaterals > 50% of an M2 territory; 1 = diminished collaterals > 50% M2 territory; 2 = diminished collaterals < 50% M2 territory; 3 = Collaterals equal to contralateral side; and 4 = increased collaterals. CS of 0 has been validated as a predictor of large infarct core with DWI MRI at presentation and poor outcome independent of successful recanalization. (Image reproduced with permission from Souza et al. [9].)

with 3 decrements (2 to malignant CS = 0 and a third reduced by 3 points from 4 to 1) and 1 increase of > 2 points from 0 to 3 (Fig. 4).

3.2. Inter-reader comparisons of CTA and FPD-CTA occlusion site and CSs

The average agreement on the CTA occlusion site was 93% with 2 paired comparisons agreeing 90% of the time, and the third paired comparison at 100%. There was 100% agreement with all 3 readers on the FPD-CTA site of occlusion with no discrepant readings. The average agreement on the dichotomous CTA CS was 87% with 2 paired comparisons of 90%, and a third with 80% agreement between the 2 readers. The average agreement on the dichotomous FPD-CTA CS was 87% with 2 paired comparisons of 90% concordance, and a third with 80% agreement between the readers. The average agreement on the continuous CTA CS was 77% for all 3 paired comparisons with 70% agreement on 2 paired comparisons, and 90% on the third. The average agreement on the continuous FPD-CTA was 87% for the 3 paired comparisons with 90% agreement on 2 paired comparisons and 80% on the third.

4. Discussion

In this pilot study, we were able to demonstrate the feasibility of performing FPD-CTA acquisition in order to evaluate both the site of intracranial occlusion and the collateral status of patients with ELVO. We found strong concordance between FPD-CTA and standard CTA on both occlusion site and collateral status.

This technique has important implications for the triage of patients being evaluated for MT. Acute ischemic stroke with ELVO is an acute time-sensitive emergency; therefore, any potential pathway to reduce the time to recanalization is essential with direct impact on outcome. The inherent delay in transferring patients has been demonstrated to disqualify up to 30% of patients due to infarct progression upon arrival to a MT-ready hospital [13]. These data are based on progression of ASPECTS scores. In contrast, 10–25% of IV tPA treated patients will experience reperfusion following IV tPA and would also not require MT [14,15]. There has been discussion with the advent of FPD angiographic imaging to bypass the emergency department and go directly to the angiography suite for definitive diagnosis and treatment of ELVO. This "one-stop shop" approach has been described in a recent case report, but to date there have not been any larger scale studies that systematically examine the accuracy of using FP-CTA to find occlusion site and collaterals compared with standard CTA [16]. This approach is also resource heavy as stroke mimics and non-ELVO acute ischemic stroke triage in an angio suite is likely not feasible in most centers. In contrast, the emergency-department–bypass paradigm fits well with the workflow of mobile stroke units (MSUs) that can perform standard CT/CTA in the field and diagnose ELVO and administer tPA prior to hospital admission [17]. The other group of patients who may be well-suited to skip emergency department triage are transfer patients who have been diagnosed with ELVO at an outside hospital.

The validation of FPD imaging to determine occlusion site and collaterals with similar accuracy to standard CT is necessary to advocate an expanded role in stroke triage for this technology. To that

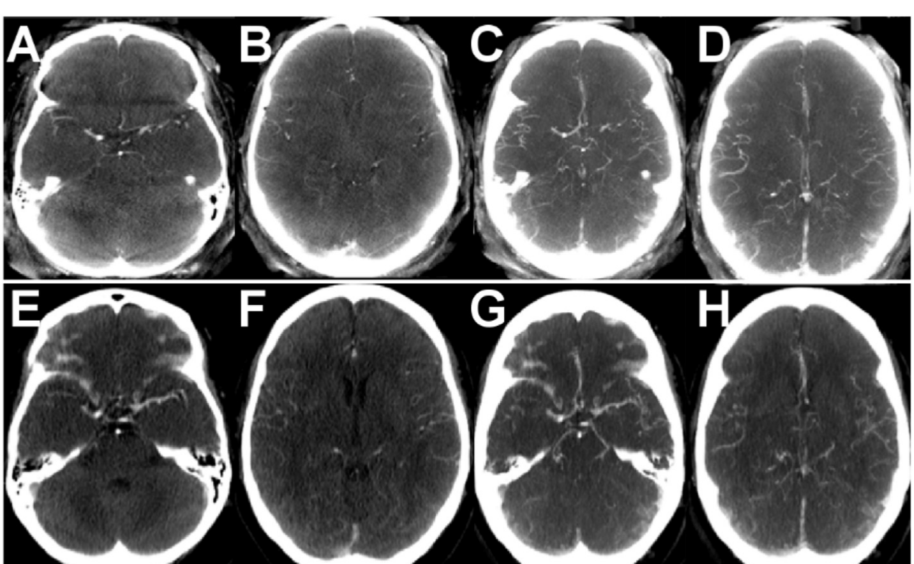

Fig. 3. Representative Case Using Collateral Scores. (A–D) FP-CTA of patient with right MCA M1 occlusion and CS of 3 or 4 per all 3 readers. (A, B) Source images. (C, D) MIP reconstruction. (E–H) CTA of same patient demonstrating right MCA M1 occlusion with CS of 2 or 3 per all 3 readers. (E, F) Source images. (G, H) MIP reconstruction.

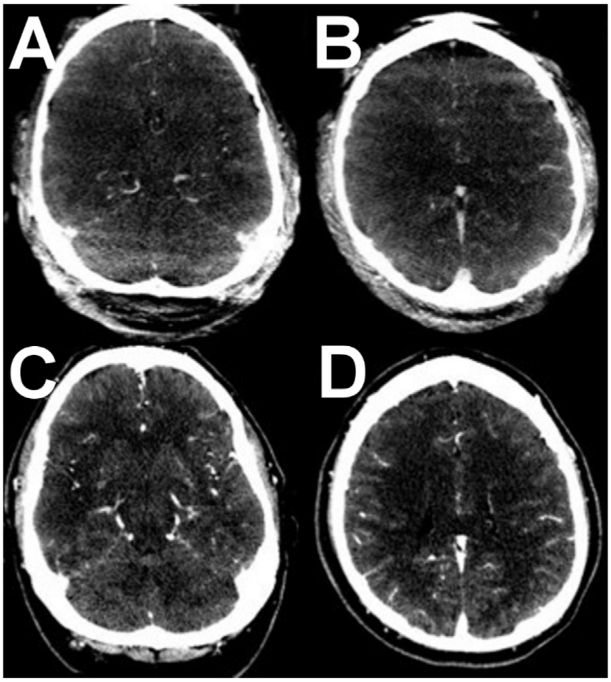

Fig. 4. Discrepancy in Collateral Scores Between Dyna CTA and CTA. (A, B) Dyna CTA of patient with a right MCA M1 occlusion read as collateral score of 0, 1, and 1. (C, D) Corresponding matched CTA slices read as collateral scores of 4, 2, and 3.

end, we performed this pilot study in patients who have undergone both standard CT/CTA and FP-CT/CTA and demonstrated excellent correlation in terms of identifying both the site of occlusion and collateral status. In our study this was done with intra-arterial injection requiring transfemoral access, but this could also be accomplished via a peripheral IV route similar to a CT/CTA in the emergency department [10].

Despite some patients transferring from outside hospitals and the inherent time delays we did not identify a single patient who was rated with a significant decrement in collaterals by all or even a majority of readers. Our transfer times and distances were relatively short compared with other studies, and our sample size of patients was also smaller [13]. Due to the small number of patients in our study, we were therefore not able to comment on the frequency and potential clinical impact of decrement in collaterals. However, the re-evaluation of occlusion and collateral status can provide important information on spontaneous or thromboytic premoted recanalization and core infarct prior to MT that may impact the need for treatment after a long transfer interval and may also have prognostic value [7–9]. This direct to angio approach for confirmed ELVO transfers from MSUs or outside hospitals has the time-saving advantage of obviating the additional delay of imaging in the emergency department, and subsequent transport to the angiography suite.

4.1. Strengths and limitations

The current limitations of the FPD imaging include the lower resolution of the FPD-CT—compared with standard CT—to identify signs of early infarction. ASPECT scores and signs of early infarct have a high inter-rater variability with standard CT; therefore, we did not feel this is as important as improving resolution of FPD-CT for detecting acute intracranial hemorrhage [18]. Recent pilot data are encouraging—they have demonstrated high sensitivity and specificity for intracranial and subarachnoid hemorrhage of FPD-CT compared with standard CT [19]. Currently, we feel the FPD technique is best suited to patients from outside hospitals or MSUs who have already had a CT/CTA, excluding hemorrhage and confirming large vessel occlusions, but require rapid vascular imaging to reassess occlusion status and collaterals. Another approach is to have a hybrid angiography suite with either standard CT or MRI capabilities. The advantages of the FPD approach over the hybrid suite is the reduced cost of the FPD system and lower radiation exposure. In comparison with MRI, the FPD-CTA approach is faster with less patient transport and is not limited in its application by implanted devices, such as permanent pacemakers.

This study has several limitations, including the small number of patients, precluding correlation with clinical outcomes, and a heavy predominance of anterior circulation stroke. In addition, only one of many validated collateral scores was evaluated and the FPD-CTA was performed via a more invasive intra-arterial injection with only a single phase of collateral imaging acquisition.

5. Conclusions

The strong correlation of CTA and FPD-CTA demonstrated in this study concerning occlusion site and CS is an important addition to the growing literature on the validity and utility of FPD acquisitions for the diagnosis and treatment of ELVO. As these techniques are improved, we feel that more diagnostic and treatment decisions can be made in the angiographic suite, which is the treatment environment, and will lead to reductions in time to reperfusion and improve outcomes. Further studies will be needed to refine these techniques and validate the clinical benefits of this approach over the current standard of care.

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