CT Perfusion vs Noncontrast CT for Late Window Stroke Thrombectomy

A Systematic Review and Meta-analysis

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Abstract

Background and Objectives

Patients with acute ischemic stroke (AIS) treated with endovascular thrombectomy (EVT) in the late window (6–24 hours) can be evaluated with CT perfusion (CTP) or with noncontrast CT (NCCT) only. Whether outcomes differ depending on the type of imaging selection is unknown. We conducted a systematic review and meta-analysis comparing outcomes between CTP and NCCT for EVT selection in the late therapeutic window.

Methods

This study is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses 2020 guidelines. A systematic literature review of the English language literature was conducted using Web of Science, Embase, Scopus, and PubMed databases. Studies focusing on late-window AIS undergoing EVT imaged through CTP and NCCT were included. Data were pooled using a random-effects model. The primary outcome of interest was rate of functional independence, defined as modified Rankin scale 0–2. The secondary outcomes of interest included rates of successful reperfusion, defined as thrombolysis in cerebral infarction 2b–3, mortality, and symptomatic intracranial hemorrhage (sICH).

Results

Five studies with 3,384 patients were included in our analysis. There were comparable rates of functional independence (odds ratio [OR] 1.03, 95% CI 0.87–1.22; $p = 0.71$) and sICH (OR 1.09, 95% CI 0.58–2.04; $p = 0.80$) between the 2 groups. Patients imaged with CTP had higher rates of successful reperfusion (OR 1.31, 95% CI 1.05–1.64; $p = 0.015$) and lower rates of mortality (OR 0.79, 95% CI 0.65–0.96; $p = 0.017$).

Discussion

Although recovery of functional independence after late-window EVT was not more common in patients selected by CTP when compared with patients selected by NCCT only, patients selected by CTP had lower mortality.

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Glossary

AIS = acute ischemic stroke; **ASPECTS** = Alberta Stroke Program Early CT Scores; **CTA** = CT angiography; **CTP** = CT perfusion; **EVT** = endovascular thrombectomy; **IQR** = interquartile range; **LVO** = large vessel occlusion; **MD** = mean difference; **MeSH** = Medical Subject Headings; **mRS** = modified Rankin scale; **NCCT** = noncontrast CT; **NIHSS** = NIH Stroke Scale; **OR** = odds ratio; **sICH** = symptomatic intracranial hemorrhage; **TICI** = thrombolysis in cerebral infarction; **TLSW** = time last seen well.

Acute ischemic stroke (AIS) due to a large vessel occlusion (LVO) of the internal carotid artery or first part of the middle cerebral artery may result in significant morbidity and mortality, but treatment by endovascular thrombectomy (EVT) leads to substantially improved functional outcomes. Patients with AIS-LVO must undergo brain imaging to determine EVT eligibility. The randomized controlled trials that demonstrated the benefit of EVT in the late time window (6–24 hours from last known well) used CT perfusion (CTP) to determine EVT eligibility.[1,2] Eligible patients should have evidence of a relatively small ischemic core on CTP[1,2] and a salvageable penumbra on CTP[2] or based on the severity of clinical symptoms.[1]

Yet, it is possible that CTP may be overly restrictive for patient selection, which may potentially exclude patients who could otherwise benefit from EVT.[3] Furthermore, CTP is an advanced imaging modality that is resource intensive and not universally accessible. Due to the potential limitations of CTP in late-window AIS, the use of noncontrast CT (NCCT) ± CT angiography (CTA) has gained traction for late-window EVT patient selection. Several recent studies have attempted to compare CTP and NCCT for EVT selection in late-window AIS-LVO patients, but these studies have shown varying results.[4-8] Therefore, we conducted a systematic review and meta-analysis to compare clinical outcomes between patients with AIS-LVO treated by EVT after CTP and NCCT imaging evaluation.

Methods

Search Strategy

On October 24, 2022, a systematic literature review was conducted within the Nested Knowledge AutoLit software (version 1.46; Nested Knowledge, Saint Paul, MN) from inception, using PubMed, Embase, Web of science, and Scopus.[9] Combinations of keywords and/or Medical Subject Headings (MeSH) terms were used to conduct the search. Keywords and MeSH terms included the following: "imaging," "advanced imaging," "thrombectomy," "late window," "beyond 6 hours," "extended," "6–24 h," and others (full search strategy can be found in eAppendix 1, links.lww.com/WNL/C725). In addition to the systematic literature review, we retrieved and evaluated references from articles included in the meta-analysis and from previous meta-analyses to ensure that all relevant articles were screened. This study is reported following the Preferred Reporting Items for Systematic Reviews and Meta-analyses 2020 guidelines.

Screening Process

Studies satisfying our predetermined PECO were included. The population was patients with late-window AIS undergoing EVT, the Exposure was CTP, the Control group was NCCT ± CTA, and the Outcomes of interest were as follows:

1. Primary outcome: functional independence defined as modified Rankin scale (mRS) 0–2
2. Secondary outcomes: successful reperfusion defined as thrombolysis in cerebral infarction (TICI) score 2b–3, symptomatic intracranial hemorrhage (sICH), and mortality

We excluded studies that did not compare patient outcomes based on imaging modality, studies that did not report late-window AIS, abstracts, case reports, or case series with less than 5 patients, studies that did not use EVT, letters to the editor and technical notes, duplicate records, and secondary analyses. Only studies that reported both CTP and NCCT ± CTA were included, and single-arm studies were excluded. "Late-window" AIS was defined as AIS presenting 6–24 hours from stroke onset or after last known well. Wake-up strokes were not included.

The initial title and abstract screening was followed by a full-text screening, both of which were performed by 2 authors. In both the initial and full-text screening stages, a third senior author was consulted to adjudicate any discrepancies.

Data Extraction

Data extraction was conducted within the Nested Knowledge AutoLit software by 2 authors to ensure accuracy. The extracted data included study characteristics, baseline characteristics of included patients, and outcomes of interest. After the initial extraction, an additional author assessed data for any inconsistencies or discrepancies.

Risk of Bias

The Newcastle Ottawa Scale was used to assess the risk of bias.[10] Risk of bias assessment was conducted by 2 authors independently, and a third senior author adjudicated any conflicting assessment when necessary. The following rating system was used: "good" quality: 3 or 4 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain; "fair" quality: 2 stars in selection domain AND 1 or 2 stars in comparability domain AND 2 or 3 stars in outcome/exposure domain; "poor" quality: 0 or 1 star in selection domain OR 0 stars in comparability domain OR 0 or 1 stars in outcome/exposure domain.[11]

Standard Protocol Approvals, Registrations, and Patient Consents

Ethics approval was not required for this study. This systematic review and meta-analysis is registered in PROSPERO (registration number: CRD42022377408).

Statistical Analysis

All data were analyzed using R software version 4.2.1. Using the "meta" package, we computed odds ratios (ORs), mean differences (MDs) and their corresponding 95% CIs using a random-effects model. To calculate the CI of the random-effects estimate, we used a restricted maximum likelihood estimator with Jackson modification of the Hartung-Knapp/Sidik-Jonkman variance correction.[12-15] In case of significant effect sizes ($p < 0.05$), we conducted leave-one-out analyses as sensitivity analyses to explore the influence of individual studies on the main results.

Heterogeneity was assessed with Q statistic and I^2 test. Heterogeneity was considered significant when I^2 value >50% or $p < 0.05$.[16,17] In case of significant heterogeneity, a sensitivity analysis was performed with removal of outlier studies to bring the heterogeneity to an insignificant level. Outlier studies were identified using the method previously described in the literature.[18] Because less than 10 studies were included in the analysis, neither Egger test for assessing publication bias nor meta-regression was possible.[19]

Data Availability

Data that support this study are available from the corresponding author on reasonable request.

Results

Search and Screening Results

After the removal of 138 duplicate records, we retrieved 128 records for further screening. An additional 60 records were sought for retrieval through bibliomining, and 2 records were identified through expert recommendation. Ultimately, 5 studies were determined to satisfy our PECO and inclusion and exclusion criteria (Figure 1).

Figure 1 PRISMA Flowchart Detailing the Literature Review Process
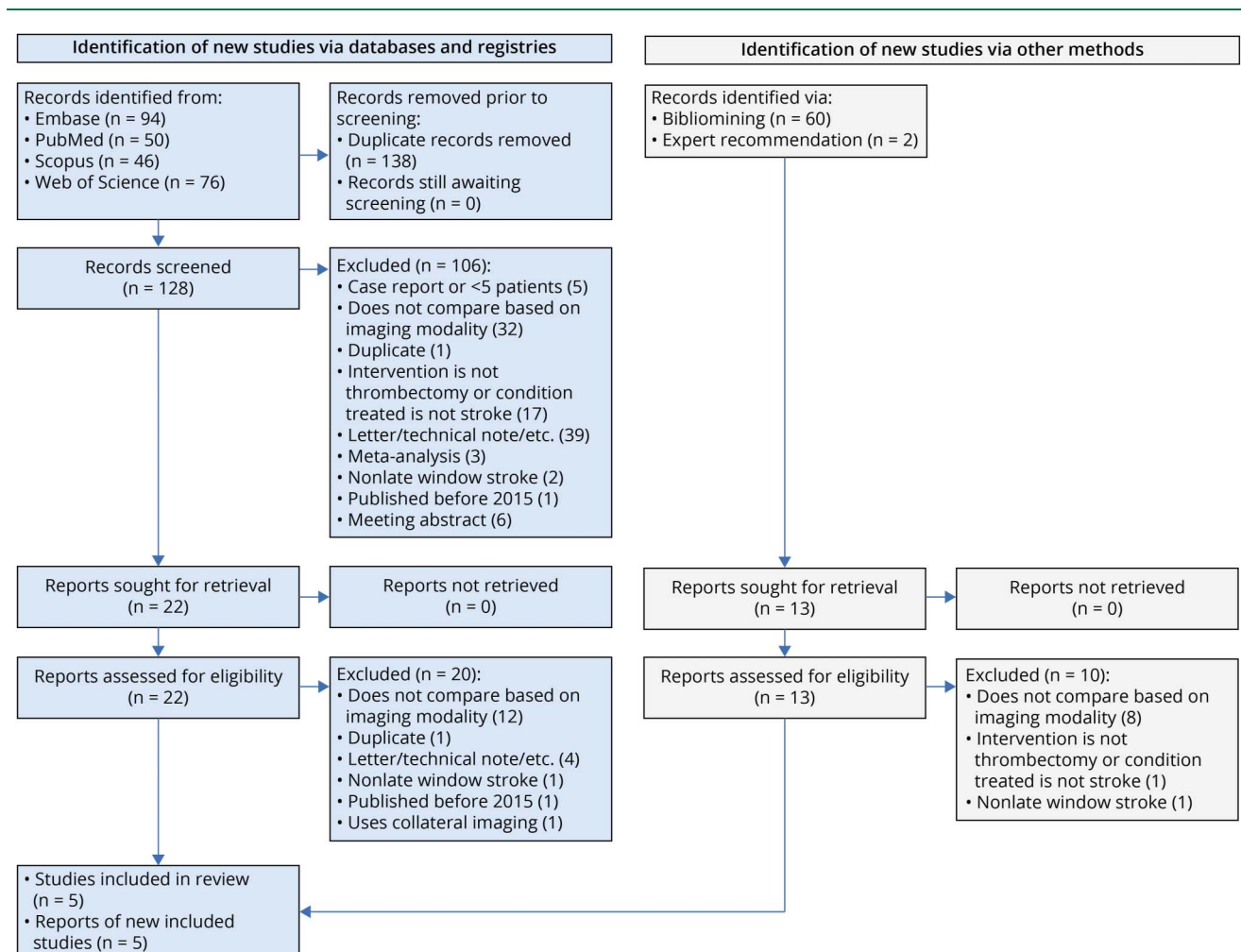
PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-analyses.

Study Characteristics and Risk of Bias

Of the 5 included studies, 3 used a retrospective design and all 5 were multicenter studies, with a total sample size of 3,384 patients. The size of the included studies ranged from 106 patients to 1,286 patients. All 5 of the studies included in our analysis were determined to have "good" quality (eTable 1, links.lww.com/WNL/C725). Patient characteristics are reported in Table 1. There were no significant differences between CTP-selected and NCCT-selected patients in the frequency of male sex (OR 0.88, 95% CI 0.76–1.01; $p = 0.07$), IV thrombolysis (OR 0.75, 95% CI 0.51–1.10; $p = 0.14$), and baseline NIHSS score (MD −0.86, 95% CI −1.97 to 0.25; $p = 0.13$). Compared with NCCT-selected patients, CTP-selected patients had a 45.6-minute greater onset to puncture time (MD 0.76 hours, 95% CI 0.43–1.09; $p < 0.001$) (eFigures 1 and 2).

Dhillon et al. reported data from a national stroke registry. Alberta Stroke Program Early CT Scores (ASPECTS), clot location, and parenchymal imaging findings were not reported.[7]

Nguyen et al. reported data from a multinational cohort. ASPECTS were comparable between CTP-selected patients (median 8, interquartile range [IQR] 7–9) and NCCT-selected patients (median 8, IQR 7–9). Patients with NIH Stroke Scale (NIHSS) scores of 6 or more, occlusion of the internal carotid artery or proximal middle cerebral artery (M1/M2 segments), prestroke mRS scores of 0–2, and time last seen well (TLSW) to treatment of 6–24 hours were included.[6]

Nogueira et al. reported data from the Trevo Retriever Registry, a prospective multicenter registry. ASPECTS were comparable between CTP-selected patients (median 8, IQR 7–9) and NCCT-selected patients (median 8, IQR 7–9). Patients with occlusions involving the intracranial internal carotid artery or the M1/M2-segments of the middle cerebral artery, premorbid mRS score of 0–2, and TLSW to arterial puncture 6–24 hours were included.[4]

Porto et al. reported data from the Stroke Thrombectomy and Aneurysm registry. ASPECTS were comparable between CTP-selected patients (median 8, IQR 7–9) and NCCT-selected patients (median 8, IQR 7–9). Patients with NIHSS score of 6 or higher, pre-stroke mRS of 0–2, anterior circulation large vessel (internal carotid artery, middle cerebral artery M1/M2 segment) occlusion, and TLSW to arterial puncture of 6–24 hours were included.[5]
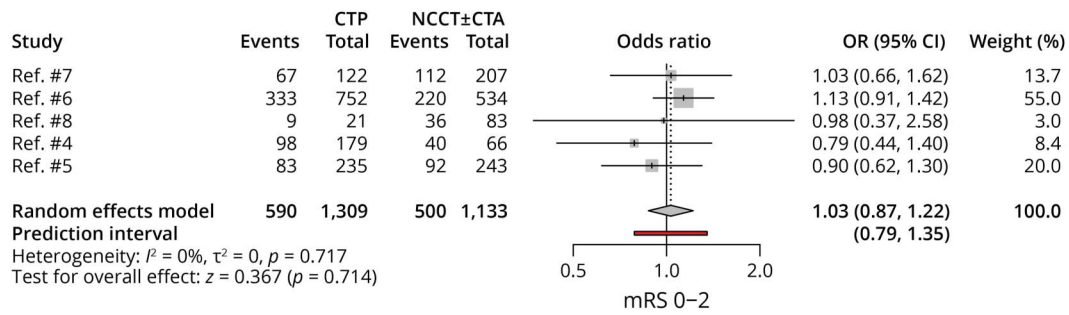
Dekker et al. reported data from the Multicenter Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands (MR CLEAN) database, a multicenter, prospectively maintained registry. ASPECTS were comparable between CTP-selected patients (median 7, IQR

Table 1 Demographic Profile of Patients in the 5 Studies Included in the Meta-analysis

	Studies									
	Dhillon et al.[7]		Nguyen et al.[6]		Nogueira et al.[4]		Porto et al.[5]		Dekker et al.[8]	
Comparison arm	CTP	NCCT ± CTA	CTP	NCCT ± CTA	CTP	NCCT ± CTA	CTP	NCCT ± CTA	CTP	NCCT ± CTA
No. of patients, n	378	668	752	534	180	67	280	419	21	85
Age, median (IQR)	NA	NA	69 (58–80)	71 (58–81)	NA	NA	70 (60–81)	68 (57–78)	NA	NA
Age, mean (SD)	NA	NA	NA	NA	66.7 (14.5)	65.8 (15.1)	NA	NA	65.8 (14.4)	67.4 (14.7)
Male sex, n (%)	188 (50)	366 (55)	346 (46)	261 (49)	74 (41)	39 (58)	134 (48)	193 (46)	10 (48)	37 (44)
Baseline NIHSS, median (IQR)	16 (10–21)	16 (9–20)	16 (11–19)	17 (13–21)	15 (10–19)	16 (9–20)	14 (8–19)	15 (10–19)	13 (8–17)	16 (12–20)
IV tPA use, n (%)	104 (28)	226 (34)	91 (12)	126 (24)	48 (27)	16 (24)	40 (14)	59 (14)	4 (19)	20 (24)
Medical history, n (%)										
Hypertension	185 (49)	304 (46)	544 (72)	385 (72)	NA	NA	212 (76)	280 (67)	NA	NA
Diabetes	55 (15)	85 (13)	189 (25)	129 (24)	NA	NA	80 (29)	114 (27)	NA	NA
Atrial fibrillation	71 (19)	137 (21)	219 (29)	191 (36)	NA	NA	102 (36)	141 (34)	NA	NA
Prior CVA	50 (13)	96 (14)	NA	NA	NA	NA	49 (18)	66 (16)	NA	NA
Timing										
Onset to puncture, h	11.2 (4.2)	10.3 (4.1)	11.3 (8.4–15.2)	10.4 (7.8–14.4)	10.2 (7.5–14)	9.3 (6.8–14.5)	12.4 (8.2–17)	11 (7.8–15.5)	8.6 (7–10.2)	8.4 (6.9–11.1)

Abbreviations: CTA = CT angiography; CTP = CT perfusion; IQR = interquartile range; IV tPA = IV tissue plasminogen activator; NA = no data available; NCCT = noncontrast CT; NIHSS = NIH Stroke Scale.

Figure 2 Forest Plot of Rates of mRS 0–2

Study	CTP Events	CTP Total	NCCT±CTA Events	NCCT±CTA Total	Odds ratio	OR (95% CI)	Weight (%)
Ref. #7	67	122	112	207		1.03 (0.66, 1.62)	13.7
Ref. #6	333	752	220	534		1.13 (0.91, 1.42)	55.0
Ref. #8	9	21	36	83		0.98 (0.37, 2.58)	3.0
Ref. #4	98	179	40	66		0.79 (0.44, 1.40)	8.4
Ref. #5	83	235	92	243		0.90 (0.62, 1.30)	20.0
Random effects model	590	1,309	500	1,133		1.03 (0.87, 1.22)	100.0
Prediction interval						(0.79, 1.35)	

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.717$
Test for overall effect: $z = 0.367$ ($p = 0.714$)

CTA = CT angiography; CTP = CT perfusion; mRS = modified Rankin scale; NCCT = noncontrast CT; OR = odds ratio.

5–9) and NCCT-selected patients (median 9, IQR 7–10). Patients with anterior circulation large vessel (intracranial carotid artery, middle cerebral artery M1/M2 segment, or anterior cerebral artery A1/A2 segment) occlusion and TLSW or symptom onset to arterial puncture of beyond 6.5 hours were included.[8]

Functional Independence (mRS 0–2)

Five studies, with 2,442 patients, compared functional independence rates between CTP-selected and NCCT-selected patients. There were comparable rates of mRS 0–2 between the 2 groups (OR 1.03, 95% CI 0.87–1.22; $p = 0.71$), and no heterogeneity was noted among these studies (Figure 2).

Successful Reperfusion (TICI 2b–3)

Five studies, with 3,370 patients, compared successful reperfusion rates between CTP-selected and NCCT-selected patients. Patients with CTP selection achieved higher rates of successful reperfusion (OR 1.31, 95% CI 1.05–1.64; $p = 0.015$), with no heterogeneity noted among studies (Figure 3).

sICH

Five studies, with 3,012 patients, compared sICH rates between CTP-selected and NCCT-selected patients. There were comparable rates of sICH between the 2 groups (OR 1.09, 95% CI 0.58–2.04; $p = 0.80$); however, there was significant heterogeneity noted among studies ($I^2 = 67\%$, $p = 0.017$) (Figure 4). On removal of the outlier study,[5] the results still yielded comparable rates of sICH between the 2 groups (OR 0.76, 95% CI 0.52–1.10; $p = 0.15$) (eFigures 3 and 4, links.lww.com/WNL/C725).
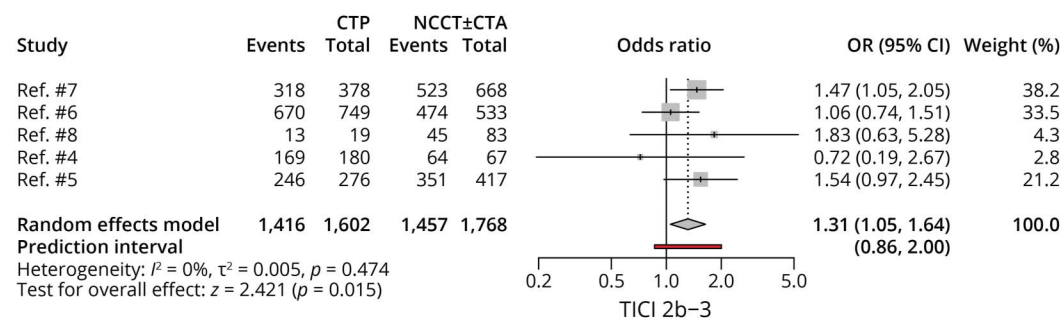
Mortality

Five studies, with 3,148 patients, compared mortality rates between CTP-selected and NCCT-selected patients. Patients with CTP selection had lower rates of mortality (OR 0.79, 95% CI 0.65–0.96; $p = 0.017$), with no heterogeneity noted among studies (Figure 5).
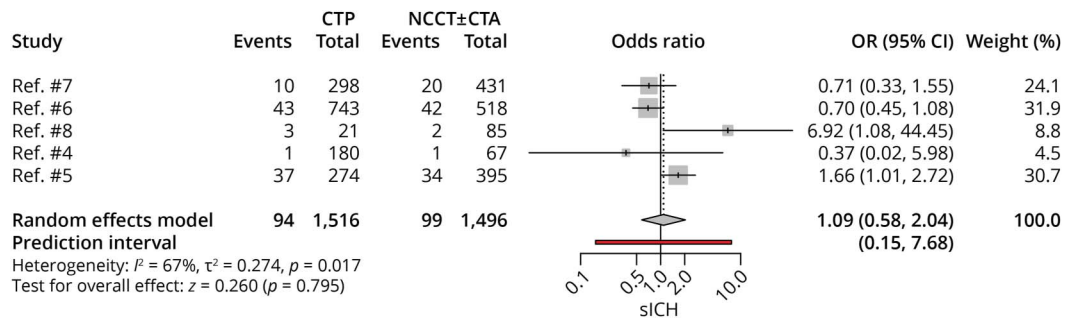
Discussion

In this systematic review and meta-analysis, we found that patients with AIS-LVO selected for EVT in the late therapeutic window by CTP achieved similar rates of functional independence and had similar rates of sICH when compared with patients selected by NCCT only, despite having higher rates of successful reperfusion. Our results are important because they suggest that NCCT might be sufficient to select patients with AIS for EVT during the late therapeutic window.

Figure 3 Forest Plot of Rates of TICI 2b–3

Study	CTP Events	CTP Total	NCCT±CTA Events	NCCT±CTA Total	Odds ratio	OR (95% CI)	Weight (%)
Ref. #7	318	378	523	668		1.47 (1.05, 2.05)	38.2
Ref. #6	670	749	474	533		1.06 (0.74, 1.51)	33.5
Ref. #8	13	19	45	83		1.83 (0.63, 5.28)	4.3
Ref. #4	169	180	64	67		0.72 (0.19, 2.67)	2.8
Ref. #5	246	276	351	417		1.54 (0.97, 2.45)	21.2
Random effects model	1,416	1,602	1,457	1,768		1.31 (1.05, 1.64)	100.0
Prediction interval						(0.86, 2.00)	

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0.005$, $p = 0.474$
Test for overall effect: $z = 2.421$ ($p = 0.015$)

CTA = CT angiography; CTP = CT perfusion; NCCT = noncontrast CT; OR = odds ratio; TICI = thrombolysis in cerebral infarction.

Figure 4 Forest Plot of Rates of sICH

Study	Events	CTP Total	Events	NCCT±CTA Total	Odds ratio	OR (95% CI)	Weight (%)
Ref. #7	10	298	20	431		0.71 (0.33, 1.55)	24.1
Ref. #6	43	743	42	518		0.70 (0.45, 1.08)	31.9
Ref. #8	3	21	2	85		6.92 (1.08, 44.45)	8.8
Ref. #4	1	180	1	67		0.37 (0.02, 5.98)	4.5
Ref. #5	37	274	34	395		1.66 (1.01, 2.72)	30.7
Random effects model	94	1,516	99	1,496		1.09 (0.58, 2.04)	100.0
Prediction interval						(0.15, 7.68)	

Heterogeneity: $I^2 = 67\%$, $\tau^2 = 0.274$, $p = 0.017$
Test for overall effect: $z = 0.260$ ($p = 0.795$)

CTA = CT angiography; CTP = CT perfusion; NCCT = noncontrast CT; OR = odds ratio; sICH = symptomatic intracranial hemorrhage.

The main finding of our meta-analysis is the comparable rates of functional independence among patients selected for EVT in the late window using CTP or NCCT. This finding was consistent across all 5 studies included. Our meta-analysis showed higher rates of successful reperfusion and lower rates of mortality among patients selected by CTP. The higher rate of reperfusion seen in the CTP group is noteworthy because successful reperfusion is strongly associated with better functional outcomes in patients undergoing EVT.[20,21] Thus, better functional outcomes would have been expected in the CTP group based on the greater rate of successful reperfusion in this group; yet, such difference was not seen. The difference in mortality in favor of the CTP group remains unexplained, though one could speculate that centers with access to CTP may also have greater intensive care resources. Without individual patient data, it is difficult to ascertain why lower rates of mortality were observed in CTP-imaged patients while functional independence was comparable between NCCT-imaged and CTP-imaged patients. It is possible that the analysis for mortality was underpowered, given that deaths are less frequent than functional independence.

Of note, a recent meta-analysis found that there was no difference between CTP and NCCT not only for functional independence and sICH but also for successful reperfusion and mortality.[22] However, this previous meta-analysis experienced a high degree of potential bias because single-arm studies were included. A meta-analysis from 2018 analyzing randomized trials found that patients undergoing EVT within 8 hours of symptom onset with advanced imaging achieved higher rates of successful reperfusion, which is consistent with our present findings.[23]

Utilization of NCCT would provide multiple clinical and logistic benefits. NCCT is more cost-effective and readily available compared with more advanced imaging, such as CTP.[24,25] In addition, CTP is associated with potential treatment delays, complications due to contrast administration, and increased radiation exposure.[26-28] Noninferiority of NCCT for late-window AIS would therefore increase access to EVT for patients who are at facilities where CTP is not available. However, it remains to be determined whether a substantial number of patients selected for late-window EVT based on NCCT are undergoing futile treatment. In early time windows (0–6 hours), the FRAME study found that approximately 20% of patients who underwent EVT lacked evidence of a salvageable penumbra, and the frequency of favorable outcomes in these patients was no better than that in patients historically treated with medical therapy alone.[29] Further study is needed to determine whether a similar issue

Figure 5 Forest Plot of Rates of Mortality

Study	Events	CTP Total	Events	NCCT±CTA Total	Odds ratio	OR (95% CI)	Weight (%)
Ref. #7	39	378	98	668		0.67 (0.45, 0.99)	23.5
Ref. #6	159	752	125	534		0.88 (0.67, 1.14)	51.7
Ref. #8	3	21	22	83		0.46 (0.12, 1.72)	2.1
Ref. #4	20	180	6	67		1.27 (0.49, 3.32)	4.0
Ref. #5	38	180	78	285		0.71 (0.46, 1.11)	18.7
Random effects model	259	1,511	329	1,637		0.79 (0.65, 0.96)	100.0
Prediction interval						(0.58, 1.08)	

Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.544$
Test for overall effect: $z = -2.385$ ($p = 0.017$)
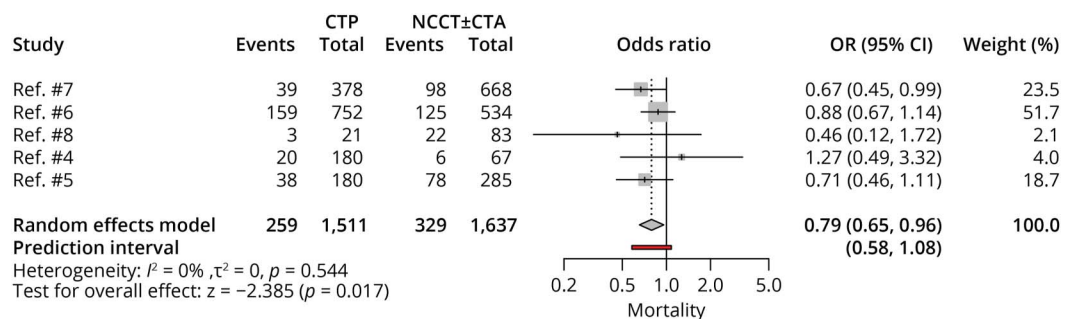
CTA = CT angiography; CTP = CT perfusion; NCCT = noncontrast CT; OR = odds ratio.

may occur in the late window. In addition, evaluating AS-PECTS using NCCT requires expertise, and centers contemplating the use of NCCT may consider the need for adequate training to ensure that scoring is accurate.

The use of NCCT may be a reasonable choice for late-window AIS, but there are yet no randomized data to support this imaging triage pathway. The TWIST trial recently reported that in patients with wake-up stroke (including AIS due to LVO) triaged with NCCT, there was no benefit from IV tenecteplase over no thrombolysis.[30] It is possible that patients selected with CTP have more favorable collateral blood flow, which may account for the higher rates of successful reperfusion after EVT in these patients. However, results for the DEFUSE-3 trial showed that good collaterals were associated with a reduced growth of the ischemic core but not with better functional outcome.[31] Of note, most patients selected for EVT in the late window would be expected to have a CTA along with an NCCT. Yet, the value of collateral rating or core assessment on CTA was not evaluated in the studies included in our meta-analysis.

Our meta-analysis has limitations. Because comparing imaging modalities for late-window EVT is a topic that has gained interest recently, we were able to include only 5 studies in our analysis, most of which were retrospective analyses. Therefore, the impact of any individual study may have disproportionally influenced the results of our analyses. The low number of studies also meant we were unable to perform meta-regression to test for the effect of different individual confounders. We did not have access to patient-level data, further compromising our ability to test for confounders. Similar and relatively high ASPECTS in patients selected with both imaging modalities (median ASPECTS of 8) implies that patients in the included studies had small cores, which may have limited the difference in treatment effect.[32] There was heterogeneity in the time frame in which outcomes were reported, with Dhillon et al. reporting functional independence at 6 months post-EVT and mortality in the hospital. Finally, we were unable to account for single-phase and multi-phase CTA due to inconsistent reporting among included studies.

In this meta-analysis, we found that patients with AIS treated with EVT in the late window (6–24 hours) had similar rates of functional independence and sICH but a lower rate of successful reperfusion and higher rate of mortality, when selected by NCCT when compared with CTP. While these findings suggest that that NCCT may be a valid alternative to CTP when evaluating EVT candidacy during the late therapeutic window, prospective and randomized studies comparing CTP and NCCT are needed to confirm this possibility.

Acknowledgment

Disclosure

Publication History

Appendix Authors

Name	Location	Contribution
Hassan Kobeissi, BS	Department of Radiology, Mayo Clinic, Rochester, MN; College of Medicine, Central Michigan University, Mount Pleasant	Drafting/revision of the article for content, including medical writing for content; major role in the acquisition of data; study concept or design; and analysis or interpretation of data
Sherief Ghozy, MD	Department of Radiology, Mayo Clinic, Rochester, MN	Drafting/revision of the article for content, including medical writing for content; major role in the acquisition of data; study concept or design; and analysis or interpretation of data
Gautam Adusumilli, MD	Department of Radiology, Massachusetts General Hospital, Boston	Drafting/revision of the article for content, including medical writing for content; and major role in the acquisition of data
Cem Bilgin, MD	Department of Radiology, Mayo Clinic, Rochester, MN	Drafting/revision of the article for content, including medical writing for content; major role in the acquisition of data; and study concept or design

Appendix *(continued)*

Name	Location	Contribution
Hatem Tolba, MD	Department of Neurology, Medical College of Wisconsin, Milwaukee	Drafting/revision of the article for content, including medical writing for content
Melika Amoukhteh, MD	Department of Radiology, Mayo Clinic, Rochester, MN	Major role in the acquisition of data
Ramanathan Kadirvel, PhD	Department of Radiology, and Department of Neurologic Surgery, Mayo Clinic, Rochester, MN	Study concept or design
Waleed Brinjikji, MD	Department of Radiology, Mayo Clinic, Rochester, MN	Drafting/revision of the article for content, including medical writing for content; study concept or design
Jeremy J. Heit, MD, PhD	Department of Radiology and Neurosurgery, Stanford University, CA	Drafting/revision of the article for content, including medical writing for content; study concept or design; and analysis or interpretation of data
Alejandro A. Rabinstein, MD	Department of Neurology, Mayo Clinic, Rochester, MN	Drafting/revision of the article for content, including medical writing for content; study concept or design; and analysis or interpretation of data
David F. Kallmes, MD	Department of Radiology, Mayo Clinic, Rochester, MN	Drafting/revision of the article for content, including medical writing for content; study concept or design; and analysis or interpretation of data

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