Review

Recent developments in pre-hospital and in-hospital triage for endovascular stroke treatment

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ABSTRACT

Triage describes the assignment of resources based on where they can be best used, are most needed, or are most likely to achieve success. Triage is of particular importance in time-critical conditions such as acute ischemic stroke. In this setting, one of the goals of triage is to minimize the delay to endovascular thrombectomy (EVT), without delaying intravenous thrombolysis or other time-critical treatments including patients who cannot benefit from EVT. EVT triage is highly context-specific, and depends on availability of financial resources, staff resources, local infrastructure, and geography. Furthermore, the EVT triage landscape is constantly changing, as EVT indications evolve and new neuroimaging methods, EVT technologies, and adjunctive medical treatments are developed and refined. This review provides an overview of recent developments in EVT triage at both the pre-hospital and in-hospital stages. We discuss pre-hospital large vessel occlusion detection tools, transport paradigms, in-hospital workflows, acute stroke neuroimaging protocols, and angiography suite workflows. The most important factor in EVT triage, however, is teamwork. Irrespective of any new technology, EVT triage will only reach optimal performance if all team members, including paramedics, nurses, technologists, emergency physicians, neurologists, radiologists, neurosurgeons, and anesthesiologists, are involved and engaged. Thus, building sustainable relationships through continuous efforts and hands-on training forms an integral part in ensuring rapid and efficient EVT triage.

INTRODUCTION

In medicine, the term ‘triage’ describes the assignment of resources based on where they can be best used, are most needed, or are most likely to achieve success.[1] Rapid and accurate patient triage and transport is of particular importance in time-critical conditions such as acute ischemic stroke (AIS). The average AIS patient with a large vessel occlusion (LVO) loses 1.9 million neurons per minute,[2] and every 30 min delay in recanalization decreases the chance of good functional outcome by approximately 10%.[3] Although endovascular thrombectomy (EVT) constitutes a highly effective treatment for AIS, its benefit decreases rapidly as time to treatment increases.[4] Thus, improving patient triage and transport is central to improving patient outcomes.

The goal of EVT triage is to direct AIS patients who can benefit from EVT to an EVT-capable hospital as fast as possible. While there are excellent policy statements outlining general guiding principles for the establishment of stroke systems of care,[5 6] there is likely no universal ‘right way’ of triaging patients for EVT, since EVT triage is highly context-specific, and depends on the local infrastructure and geography (eg, widespread rural geography with low hospital density vs urban area with high hospital density).[7] Furthermore, although financial and staff resources should ideally not influence EVT triage, in reality they often do. Regardless of the triage paradigm, optimization of its diagnostic accuracy and speed are central to successful performance.

In this review, we discuss key principles in evaluating and optimizing EVT triage and summarize recent promising developments and novel technologies that have the potential to improve both triage accuracy and speed. We performed a scoping review on MEDLINE/PubMed and Ovid using the search terms ‘stroke’, ‘ischemic stroke’, ‘cerebrovascular accident’, ‘mechanical thrombectomy’, ‘endovascular procedures’, ‘endovascular surgery’, ‘pre-hospital’, ‘triage’, ‘emergency medical services’, ‘emergency health service’, and ‘neuroimaging’, with a focus on randomized trials and large, prospective cohort studies. After outlining general principles on how to measure EVT triage performance and the importance thereof, we review different strategies for detecting LVO candidates in the field, measures to optimize communication between pre- and in-hospital teams such as pre-notification tools, different stroke transport paradigms and evidence behind them, and lastly strategies to optimize in-hospital workflows including stroke imaging paradigms.

PRE-HOSPITAL TRIAGE: DETECTING EVT CANDIDATES IN THE FIELD

After symptom onset, the initial call for help, and the arrival of the emergency medical services (EMS) on the scene, the EMS team assesses the patient. This assessment forms the basis for the triage decision and determines whether the patient is directed to the closest primary stroke center (PSC), capable of administering intravenous (IV) thrombolysis (figure 1). Several tools are available that can aid the EMS team in this decision, ranging from simple

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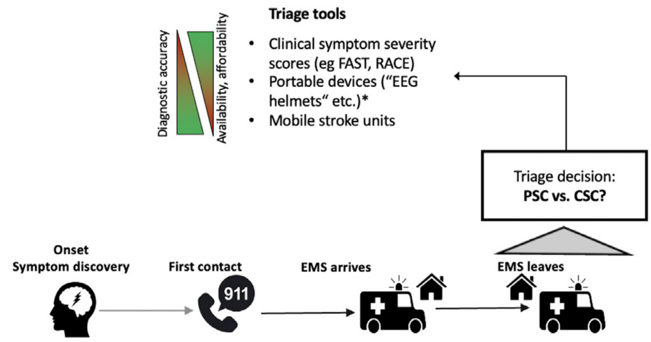

Figure 1 Pre-hospital triage from symptom onset to the initial triage decision in a ground-bound transport scenario. After symptom onset and symptom discovery, the initial call for help is initiated, either by the patient themselves or a witness. Upon ambulance arrival, the emergency medical services (EMS) team assesses the patient and, in case of suspected acute ischemic stroke, makes a triage decision—that is, the team decides whether they will target the nearest primary stroke center (PSC) or the nearest comprehensive stroke center (CSC). Numerous triage tools can aid the EMS team in making this decision, and differ in their costs, availability, ease of use and diagnostic accuracy. *See table 1 for a detailed overview. EEG, electroencephalography; FAST, Face-Arms-Speech-Time; RACE, Rapid Arterial Occlusion Evaluation.

clinical stroke severity scales to highly specialized mobile stroke units (table 1)

Clinical stroke severity scales

Clinical stroke severity scales such as Face-Arm-Speech-Time (FAST) or Rapid Arterial oCclusion Evaluation (RACE) are the simplest pre-hospital triage tools as they do not require any specialized equipment and entail no added cost to the system beyond basic training of personnel,[8] while at the same time improving pre-hospital management and shortening EVT preparation times.[9] While some pre-hospital stroke severity scales are dichotomous,[10] most provide a score in the form of points rather than a binary (LVO yes/no) output, which is more complex than a dichotomous output but allows for different cut-off choices with varying sensitivity and specificity, which can be advantageous in settings in which one has to be optimized over the other. For a detailed overview of the performance metrics of the various stroke severity scales, we refer the reader to the pre-hospital triage of patients with suspected stroke (PRESTO) study,[11] in which scales detected LVO in the anterior circulation with acceptable accuracy. RACE, G-FAST (Gaze-Face-Arm-Speech-Time) and CG-FAST (Conveniently-Grasped Field Assessment Stroke Triage) performed best, with an accuracy similar to clinician-assessed NIHSS (National Institutes of Health Stroke Scale).[11] That being said, the performance of all pre-hospital scales varies substantially across the spectrum of deficit severity. They generally perform best at both ends of the severity spectrum, which is of limited value since, in these patients, paramedics may often be able to make the diagnosis purely based on their clinical experience.[7] In patients with intermediate symptom severity, where diagnostic uncertainty is greatest, performance of clinical symptom severity scales is poorest. In some situations, certain pre-hospital triage scales may even be misguiding and, in extreme cases, may sway an EMS team from the correct diagnosis.[12] Furthermore, since they purely rely on symptom severity (having been derived from the NIHSS), clinical stroke severity scales will naturally fail to detect LVO strokes with mild symptoms, and their performance in medium vessel occlusion (MeVO) strokes is also limited. This is particularly noteworthy given that several ongoing trials aim to expand EVT indications to these two patient subgroups.[13 14] Perhaps even more important than the performance of a particular stroke scale itself is the need for the local EMS personnel to be familiar with it and comfortable using it. Several apps that have been designed to aid EMS specifically with pre-hospital stroke severity assessment and risk stratification can help to facilitate this task.[15]

Mobile stroke units

Mobile stroke units (MSUs)—that is, ambulances that are equipped with CT (and often CT angiography) capabilities—are arguably the most sophisticated and specialized pre-hospital triage tool. By ruling out intracranial hemorrhage using on-board non-contrast head CT, they allow for administration of IV thrombolysis in the field, and, if on-board, CT angiography (CTA) capabilities are available so LVOs and MeVOs can be diagnosed with high certainty, meaning EVT candidates are accurately identified and directed to the nearest EVT-capable hospital. The North American BEST-MSU and German B-PROUD trials have shown that the use of MSUs in pre-hospital stroke triage leads to improved functional outcomes.[16 17] The main disadvantage of MSUs is their high cost. For example, in the USA one MSU had annual operating costs of approximately \$1.2 million and initial set-up costs can range between \$600 000 to \$1 million.[18] However, some studies support their cost effectiveness, and these added costs may very well meet the willingness-to-pay threshold for certain healthcare systems.[19–21] The usefulness of MSUs is also highly dependent on local geography and the distance between the MSU base, the patient location, and the hospital location. In a recent modeling study, MSU utilization was most beneficial when low dispatch thresholds were used and at a travel time to the MSU between 180–200 min.[22] That being said, in the BEST-MSU trial, MSUs were shown to be beneficial when travel times were shorter as well.[17] Some regions may benefit from creative combinations of MSU and conventional ambulance resources to optimize pre-hospital triage and treatment times.[23 24]

Emerging, alternative pre-hospital triage devices

Several smaller, portable pre-hospital triage devices are currently under development, including microwave-based, ultrasound-based, and electroencephalography (EEG)-based tools (table 1). In theory, these would be more practical and affordable than MSUs, as they could be installed in regular ambulances. Needless to say, each of those tools has its own set of challenges. Performing transcranial Doppler sonography is often difficult due to an insufficient acoustic window,[25] and EEG technologies may not be able to identify EVT candidates with mild clinical deficits, since the relative preservation of brain function in these patients may not lead to signal abnormalities that are conspicuous enough to be detected. Of note, none of these portable devices is used in clinical routine, yet they still have to prove their robustness, reliability, and usefulness in the clinical setting.

PRE-NOTIFICATION: BRIDGING THE GAP BETWEEN THE PRE-HOSPITAL TEAM AND THE IN-HOSPITAL TEAM

Pre-notification of the in-hospital team, and particularly the angio team, for instance through a phone-call or an app, allows the in-hospital team to optimally prepare for patient arrival, for example, by preparing an EVT kit, clearing the angio suite, etc (figure 2). Pre-notification has been proven to reduce treatment delays, especially during off-hours, when the angio team is not

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Table 1 Tools and technologies for the pre-hospital triage of acute ischemic stroke

Pre-hospital tool	Potential indication	Examples	Advantages	Disadvantages
Clinical prediction scales	Identify patients who are likely to have large vessel occlusion based on clinical symptoms	Los Angeles Motor Scale (LAMS), Rapid Arterial oCclusion Evaluation (RACE) scale	▶ Simple, fast, easy to use with brief training ▶ Reasonably high specificity for LVO for instruments like LAMS/RACE	▶ Overall limited sensitivity for LVO, risk of missing out many patients who stand to benefit from EVT ▶ Stroke represents only a minority of EMS calls; continuous maintenance of training may be required
Mobile stroke units (MSU), on-board CT scan	Distinguish ischemic stroke from hemorrhagic stroke by ambulance-based neuroimaging	Mostly in Germany and the USA	▶ The only system that currently allows safe pre-hospital thrombolysis by definitively ruling out hemorrhage ▶ Can detect LVO with on-board angiography[90 91]	▶ Expensive investment in equipment and personnel (on-board CT tech and physician or similar provider for giving thrombolysis)
Transcranial Doppler ultrasonography (TCD)	Identifying LVO via high vessel velocities and emboli detection	Lucid Robotic System	▶ Sensitivity 91% and specificity 85% for identifying LVO per conference presentation[92]	▶ Cumbersome ▶ Operator-dependent when not robotic ▶ Some patients do not have an adequate bone window
Electroencephalography (EEG)	Identify major strokes by confirming substantial loss of neuronal activity ipsilaterally	AlphaStroke, BrainScope One	▶ Amenable to rapid quantitative interpretation at point-of-care ▶ Brainscope studied in traumatic brain injury with 92% sensitivity for abnormal CT[93]	▶ Can have high background noise especially in an ambulance ▶ Non-specific findings are common in various pathologies; Brainscope specificity 51% for abnormal CT in TBI[93]
Brain accelerometry	Identifying LVO[94]	BrainPulse	▶ Has been studied in vasospasm (81% sensitivity) and traumatic brain injury[95]	▶ High background noise may interfere with detection of LVO signal
Microwaves	Rule out hemorrhage	EMTensor, EMvision, Strokefinder	▶ Useful in ruling out large hemorrhagic strokes[96]	▶ Cannot rule out small bleeds ▶ Application limited by poor penetration of microwaves into brain
Near-infrared spectroscopy	Identifying severe stroke by visualizing brain tissue oxygenation	Infrascanner 2000	▶ Can detect large ischemia, hemorrhage ▶ Sensitivity of 88% and specificity of 91% for detecting hematomas >3.5 mL within 2.5 cm of the brain surface[97]	▶ Limited field or depth of penetration
Radiofrequency pulses	Potential to identify hemorrhage	Sense Diagnostics	▶ Can detect ICH expansion (pre-clinical studies)[98 99]	▶ Maturing technology, unclear application
Volumetric impedance phase-shift spectroscopy (VIPS)	Identify severe stroke by detecting small changes and asymmetries in electrical properties	Cerebrotech Visor	▶ Wireless visor on the head ▶ Sensitivity 93% and specificity 87% to identify severe stroke[100] (broadly defined as LVO or NIHSS >6 or ICH >60 mL or large established stroke	▶ Data have come from a derivation study to create the VIPS selection algorithm—validation is required in pre-hospital settings ▶ Technology relies on sending/receiving radio waves which can be modified by implants like plates/screws or metallic hair extensions

EMS, emergency medical services; EVT, endovascular thrombectomy; ICH, intracerebral hemorrhage; LVO, large vessel occlusion ; NIHSS, National Institutes of Health Stroke Scale; TBI, traumatic brain injury.

in-house and has to travel to the hospital.[26] This step is a critical component of integrated systems of stroke care, permitting a coordinated approach to transport and treatment of stroke patients; such integration was associated with a sustained decrease in in-hospital stroke mortality in Canada.[27] However, a large North American registry study and a recent international survey suggest that pre-notification tools are only used in 60–70% of EVT-capable hospitals, with large regional variations,[28 29] highlighting substantial potential for improvement. By using novel technologies such as natural language processing algorithms,[30] it may soon be possible to fully automate pre-notification, thereby obviating the need for manual texting/calling, which may further facilitate adoption of pre-notification in clinical practice.

TRANSPORT PARADIGMS: BALANCING THE TIME TO IV THROMBOLYSIS VERSUS TIME TO EVT

One of the main goals of pre-hospital EVT triage, besides recognizing AIS, is to direct patients who are likely to be EVT candidates to an EVT and IV thrombolysis-capable hospital (comprehensive stroke center, CSC) to minimize time to EVT and prevent further infarct progression.[31] At the same time, patients who are unlikely to be EVT candidates should be directed to the closest PSC, to minimize time to IV thrombolysis (ie, onset to needle time). With regard to IV thrombolysis at the CSC in EVT candidates, several recently published randomized controlled trials[32–36] have investigated the question whether IV thrombolysis could be forgone in EVT candidates presenting directly to the CSC; overall, the current evidence from these trials does not support withholding IV thrombolysis in these patients, although there are some subgroups in which the added benefit of IV thrombolysis should be further investigated. The only randomized controlled trial on the drip-and-ship versus mothership transport question (Direct Transfer to an Endovascular Center Compared with Transfer to the Closest Stroke Center in Acute Stroke Patients With Suspected LVO—RACECAT) found no difference in outcomes between the two transport paradigms, although the very well-organized stroke transfer system in which the trial was conducted (with its short door-in-door-out times in the participating PSCs) may not be representative for PSCs in other jurisdictions.[37] Besides these two traditional transport

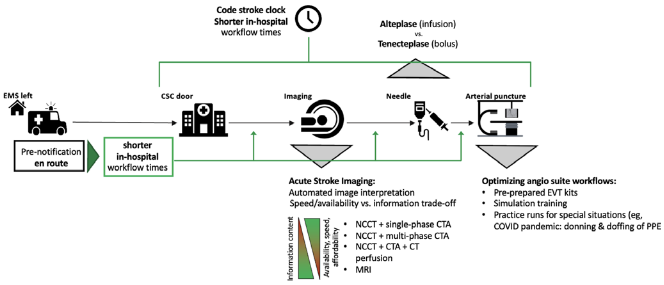

Figure 2 Pre- and in-hospital triage from the time of emergency medical services (EMS) leaving the scene to arterial puncture in a direct-to-mothership scenario. Once EMS leaves the scene, a pre-notification is sent to the comprehensive stroke center, so that the in-hospital team can get prepared before patient arrival (eg, during the night the angio team may have to travel to the hospital, the angio suite can be cleared in advance, etc). This helps to shorten in-hospital workflows. A code stroke clock keeps track of the overall in-hospital workflow time, serves as an internal quality control tool, and identifies potential time delays that can be avoided. Various imaging protocols can be used for treatment decision-making, ranging from simple protocols that include only non-contrast CT (NCCT) of the head and CT angiography (CTA) to more complex protocols that include CT perfusion imaging or MR imaging (MRI). While information content is greater in the latter, availability and speed are generally better in the former. In case of intravenous thrombolysis, either alteplase, which is administered as an infusion over 1 hour, or tenecteplase, which can be administered as a bolus, is given. In the angio suite, workflows can be streamlined by using pre-prepared endovascular thrombectomy (EVT) kits that shorten preparation time by avoiding assembling the required EVT materials. Simulation training and practice runs can improve workflows as well, especially in exceptional circumstances such as the COVID-19 pandemic, in which donning and doffing of personal protection equipment (PPE) and airway management add an additional layer of complexity to patient management in the angio suite.

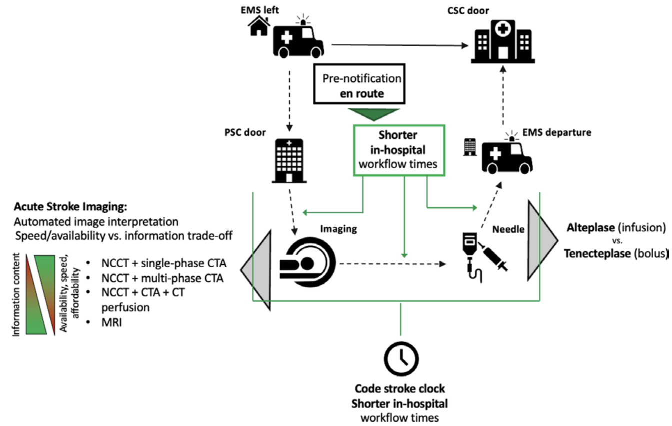

Figure 3 Pre- and in-hospital triage from the time of emergency medical services (EMS) leaving the scene to arterial puncture in a drip-and-ship scenario. Once EMS leaves the scene, a pre-notification is sent to the primary stroke center (PSC), so that the in-hospital team can get prepared before patient arrival (eg, during the night, the stroke neurology attending on call may have to travel to the hospital). This helps to shorten in-hospital workflows. A code stroke clock keeps track of the overall in-hospital workflow time, serves as an internal quality control tool, and identifies potential time delays that can be avoided. Various imaging protocols can be used for treatment decision-making, ranging from simple protocols that include only non-contrast CT (NCCT) of the head and CT angiography (CTA) to more complex protocols that include CT perfusion imaging or MR imaging (MRI). While information content is greater in the latter, availability and speed are generally better in the former. Especially in smaller PSCs with low case volumes, automated image interpretation could be of great help to guide less experienced readers through the imaging findings. In case of intravenous (IV) thrombolysis, either alteplase, which is administered as an infusion over 1 hour, or tenecteplase, which can be administered as a bolus, is given. The latter is more practical to handle and could substantially shorten door-in-door-out times in cases in which one wants to avoid transporting the patient in the ambulance with a running IV thrombolysis infusion. CSC, comprehensive stroke center.

paradigms, several additional innovative transport paradigms have emerged over the last years.

As noted previously, MSUs allow for IV thrombolysis in the field, and, if equipped with CTA capabilities, for accurate identification of LVO stroke, which has been shown to improve functional outcomes.[16 17] Use of mobile interventional stroke teams, in which the angio team travels from the mothership to a smaller thrombectomy-capable hospital closer to the patient, are another promising alternative that has been shown to reduce workflow times and improve short-term neurological outcomes, with a trend towards better long-term functional outcomes.[38]

Since the local hospital landscape and transport resources as well as the efficacy of in-hospital teams are highly variable, the results of the aforementioned studies are unique to the environment in which they were conducted and cannot necessarily be generalized to other jurisdictions. Each local environment must find their own optimal transport paradigm based on local workflow times and available resources. Conditional probability modeling allows systems to take local geography and workflow efficacy into account while simulating different transport paradigms, and can aid in determining the best transport paradigm for a given environment or scenario.[22 39]

IN-HOSPITAL PHASE: STREAMLINING WORKFLOWS AND REDUCING THE COGNITIVE LOAD OF THE TEAM

The potential for time-savings in the in-hospital phase is substantial.[29] As such, several concepts have been developed to streamline in-hospital workflows, to shorten the time from patient arrival to reperfusion as much as possible.

Rapid patient assessment and use of a ‘code stroke clock’

On patient arrival, only absolutely necessary procedures should be performed before EVT. In many hospitals, EVT candidates still undergo chest x-rays or Foley catheter insertion before EVT, which is largely unnecessary and time-consuming.[29] The use of a ‘code stroke clock’—a clock that measures workflow times—is a simple and easy-to-implement measure that increases the time awareness of the in-hospital team, and thereby shortens workflow times[40 41] (figures 2 and 3).

Eliminating unnecessary workflow steps in the in-hospital pre-EVT phase

Saving time in the in-hospital phase can often be achieved by simple measures, such as eliminating unnecessary workflow steps. In a survey study among 248 stroke physicians and neurointerventionalists, electrocardiograms were performed in 26% and even chest x rays were taken in 4% before EVT.[29] By simply foregoing or postponing those procedures to the post-EVT time period, time could be saved. Taking the patient to the CT scanner on the EMS stretcher or administering IV thrombolysis

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in the CT scanner suite after the non-contrast head CT are other simple but effective measures to improve workflow times.[42]

Direct-to-angio paradigms

In direct-to-angio workflows, the patient is transported directly to the angio suite for on-table imaging, rather than stopping by the CT/MR scanner for conventional cross-sectional imaging. A recent randomized controlled trial (Direct to Angiography Suite Without Stopping for CT Imaging for Patients With Acute Stroke—ANGIOCAT)[43] suggested that direct-to-angio workflows may decrease in-hospital workflow times and improve clinical outcomes when using a direct-to-angio paradigm.[43] However, another randomized trial was stopped early because of substantial delays in time to imaging and subsequently time to IV thrombolysis, in the direct-to-angio arm.[44] The benefit of direct-to-angio paradigms therefore still must be proven; they could constitute a promising alternative mainly for large centers with sufficient staff resources, an all-time available angio suite, and 24/7 in-house tech coverage.

Translational simulation training

Simulation team training is another simple but highly effective tool to improve the speed of patient assessment and concerted team-work.[45] It has been widely adopted for health professional education and traditionally for procedural task training, communication and teamwork. Recently, in situ simulation has put the simulation into the clinical environment, facilitating transfer of knowledge and skills into real-world practice. As a relatively new concept, translational simulation allows for quality improvement by linking simulation training to identify latent quality threats with health service priorities and patient outcomes.[46] This is particularly helpful when the team has to adapt to new situations and practice new workflow steps, such as donning and doffing personal protection equipment and disposal of contaminated material during 'protected code stroke' protocols during the COVID-19 pandemic.[47 48]

Acute stroke imaging protocols

The overarching goal in acute ischemic stroke imaging is to obtain the information that is needed for EVT decision-making as fast as possible, with minimal delays between image acquisition and interventional team notification and treatment planning.[49] No time should be lost by obtaining additional imaging that is not necessary to answer these questions. Most centers use CT-based imaging protocols due to the greater availability and affordability of CT compared with MRI, the relative absence of contraindications to CT in the acute stroke setting, and the faster image acquisition time with less sensitivity to motion.

At a bare minimum, non-contrast head CT is needed to rule out intracranial hemorrhage and roughly assess the extent of ischemic damage. CTA allows for visualization of an EVT target occlusion (LVO or MeVO) and visualizes the cervical vasculature and aortic arch, which allows for appropriate choice of EVT devices. Multi-phase CTA has some benefits over conventional single-phase CTA, as it improves occlusion detection, particularly for MeVOs, which are increasingly treated with EVT, and allows for a more accurate evaluation of collateral blood supply in the ischemic territory.[50–52]

Although for late time window patients (6–24 hours from last known well), current guidelines recommend using perfusion imaging for EVT patient selection; the increased accuracy of penumbra and core estimation with advanced imaging should be balanced against the additional time lost and the risk of 'decision paralysis' due to unnecessary and potentially confusing or even misleading information. More recent data from a British national registry study[53] and the CLEAR study suggest that simpler imaging paradigms using non-contrast CT (NCCT) and single- or multiphase CTA may be equally capable of selecting patients for late time window EVT[54–57] compared with CT perfusion.[58]

In transfer patients, the additional question arises whether imaging should be repeated at the CSC before EVT. In a recent single center study, repeat imaging was associated with a median time delay of 20 min and rarely changed the treatment decision, suggesting that repeat imaging should not be routinely performed.[59]

Automated image processing and analysis

Advanced visualization technologies and automation of image processing and analysis could be of particular value for stroke triage in smaller hospitals (eg, PSCs with limited neuroimaging experience), or hospitals in which trainees are the primary image readers off-hours. Examples for such (semi-)automated image analysis modules include automated hemorrhage detection,[60 61] ASPECTS (Alberta Stroke Program Early CT Score) scoring,[62–65] LVO detection,[66 67] and generation of perfusion maps from multiphase CTA.[68–70] These technologies could transform the acute stroke imaging workflow by (1) improving diagnostic accuracy (reduced risk of misdiagnosis), (2) timely 'rescue' of patients who have been missed in the earlier parts of the prehospital workflow (eg, patients with atypical or mild symptoms for whom no code stroke was initiated), and (3) linking automated detection of stroke imaging findings with instant notification of physicians and stroke teams, which could enable rapid concerted responses.

IV thrombolysis

So far, combined IV thrombolysis and EVT is the standard of care for AIS with EVT target occlusion. As mentioned before, the role of IV thrombolysis in EVT candidates in the direct-to-mothership scenario has recently been questioned by several randomized controlled trials,[32–36] and in summary they could not show benefit of a 'dry' direct-to-EVT paradigm. The use of IV tenecteplase, which can be administered as a bolus, instead of a continuous infusion required in alteplase, could potentially decrease in-hospital workflow times, particularly in drip-and-ship settings, since the patient could be transported to the EVT-capable hospital immediately after the tenecteplase bolus has been administered without a running infusion.

Angio suite preparation

Immediately after the in-hospital team has been informed about the arrival of a potential EVT candidate, the angio suite should be cleared and prepared for EVT. Although only used by approximately one out of two stroke teams, pre-prepared stroke kits that contain the basic equipment needed for EVT can reduce preparation time in the angio suite and thereby decrease time to arterial puncture.[29 71–73] The EVT procedure itself, including the equipment used, should be standardized as much as possible to reduce the cognitive load of the angio team, as this has been repeatedly shown to decrease time to reperfusion.[72 73]

Regarding the role of anesthesia, previous studies have shown conflicting results. While cohort studies suggest worse clinical outcomes when general anesthesia is used,[74 75] single-center randomized trials suggest similar outcomes.[76 77] In any case, suboptimal anesthesia workflow results in time delays.[74] Thus, the anesthesia team should be included in the pre-notification

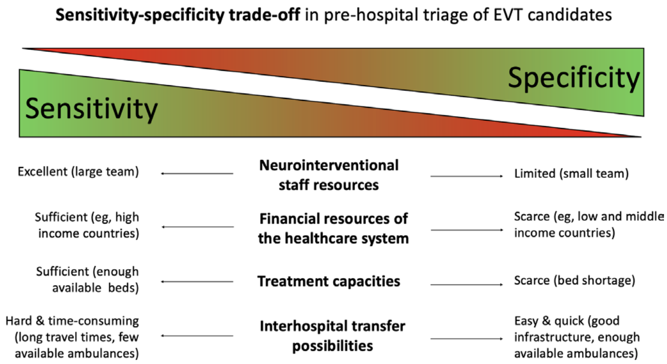

Figure 4 Sensitivity-specificity trade-off in pre-hospital triage of endovascular thrombectomy (EVT) candidates. Factors favoring high sensitivity at the cost of lower specificity are shown on the left. Factors favoring high specificity at the cost of lower sensitivity are shown on the right.

messages and, ideally, an anesthesiologist is available by default in the angio suite, particularly during the COVID-19 pandemic, in which intubation before EVT is often indicated in airway/breathing-compromised COVID-19 patients.[47]

Besides the aforementioned factors, the choice of EVT access route, devices, and techniques also influences the time from arterial puncture to reperfusion. As this article is focused on getting the right patient to the angio suite, a detailed review of EVT techniques is beyond its scope. However, irrespective of the particular technique used, simulation task training can improve operator skills and safety and thereby help to shorten the time from arterial puncture to reperfusion.[45]

MEASURING EVT TRIAGE PERFORMANCE

Commonly accepted triage accuracy measures include sensitivity (the probability of transporting a patient who can benefit from EVT directly to an EVT-capable center), specificity (the probability of not transporting a patient who cannot benefit from EVT to an EVT-capable center), and the positive and negative predictive value (the proportion of true positives and true negatives among all positive and negative cases). Importantly, when considering sensitivity and specificity, one cannot be maximized without compromising on the other. In other words, increased sensitivity comes at the cost of decreased specificity and vice versa. As the goals of EVT triage are highly specific to the individual situation, the decision regarding which metrics to prioritize will also depend on specific circumstances (figure 4). In some scenarios, the priority will be to maximize specificity—that is, only treating those patients who are most likely to benefit from EVT, even at the cost of potentially withholding treatment from some patients who may be eligible. This might be the preferred strategy to gain traction for EVT adoption in a lower-resource environment such as a low- or middle-income country—the goal being to achieve success in a more highly-selected population with the highest chances of treatment effect, before support is gained to allocate resources to broader populations. In other situations, for example, in high-income countries with sufficient available resources, one may choose to maximize sensitivity— ensuring all possible EVT-eligible patients are evaluated at EVT-capable hospitals/CSCs—at the cost of potentially evaluating some patients who are ultimately deemed ineligible for EVT. Irrespective of the circumstances, EVT triage accuracy is important, and effective triage should keep time delays to EVT as short as possible in any given scenario. The speed component of EVT triage performance can in theory easily be captured by measuring workflow times, with suggested benchmark times that have been published by the Society of Neurointerventional Surgery's standards and guidelines committee[78] (see online supplemental table 1) and the American Heart Association/American Stroke Association brain attack coalition.[79] To reliably measure workflow performance, consistent and accurate definitions of EVT triage, transport time intervals, and workflow time intervals are however needed. Although several consensus and statement papers have been published on the topic and may provide guidance,[80–85] no single universally accepted 'minimum reporting standard' for EVT workflows has yet emerged.

As a general principle, there is agreement that systems should aim to report broader, all-encompassing workflow times rather than fractionated time intervals to provide a more complete picture and avoid the potential for bias. Furthermore, time intervals should use automatically captured time-points (eg, DICOM (digital imaging and communications in medicine) time stamps) rather than manual data entry to avoid additional work and human errors, and describe the distribution of workflow metrics in a comprehensive way, for example, by providing the mean and standard deviation.[85 86] Of note, workflow performances are ideally assessed in large, multicenter registries such as the American Heart Association's 'Get with the Guidelines' registry tool,[87] with mechanisms that ensure all patients are included in the database, in order to avoid 'cherry-picking' and provide a realistic image of workflow performance over time.

CONCLUSION

The landscape of EVT triage is constantly changing, and several trials are ongoing that may soon broaden EVT indications. Furthermore, new neuroimaging methods, EVT technologies, and adjunctive medical treatments are undergoing continuous development and refinement. These changes will influence EVT triage. For example, IV tenecteplase may soon replace IV alteplase as the default thrombolytic agent, making PSC-CSC interhospital transfer easier. In case neuroprotectants such as nerinetide become standard of care,[88] in-hospital workflows and organization will need to change to allow for timely administration of these additional adjunctive treatments. Stroke legislation, either at a regional or national level, can catalyze and guide these efforts and improve overall accessibility to stroke care at the population level.[89] Irrespective of these moving parts, teamwork is key to efficient EVT triage; thus, engaging paramedics and primary stroke centers is just as important as adoption of new triage technologies. Without their support, EVT triage paradigms will always lag behind the evidence and never achieve their maximum performance. Building sustainable relationships between the involved parties, and motivating and engaging all players, both at the pre- and in-hospital stage, will require continuous efforts and ongoing education and training, which should ideally include regular hands-on simulation training workshops and in-person site visits at PSCs and EMS hubs. The optimization of EVT triage is an active process requiring concerted efforts that cannot simply rely on passive flow of knowledge.

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REFERENCES

1 Iserson KV, Moskop JC. Triage in medicine, part I: concept, history, and types. *Ann Emerg Med* 2007;49:275–81.
2 Saver JL. Time is brain--quantified. *Stroke* 2006;37:263–6.
3 Menon BK, Almekhlafi MA, Pereira VM, *et al*. Optimal workflow and process-based performance measures for endovascular therapy in acute ischemic stroke: analysis of the Solitaire FR thrombectomy for acute revascularization study. *Stroke* 2014;45:2024–9.
4 Saver JL, Goyal M, van der Lugt A, *et al*. Time to treatment with endovascular thrombectomy and outcomes from ischemic stroke: a meta-analysis. *JAMA* 2016;316:1279–88.
5 Adeoye O, Nyström KV, Yavagal DR, *et al*. Recommendations for the establishment of stroke systems of care: a 2019 update. *Stroke* 2019;50:e187–210.
6 Jauch EC, Schwamm LH, Panagos PD, *et al*. Recommendations for regional stroke destination plans in rural, suburban, and urban communities from the prehospital stroke system of care consensus conference: a consensus statement from the American Academy of Neurology, American Heart Association/American Stroke Association, American Society of Neuroradiology, National Association of EMS Physicians, National Association of State EMS Officials, Society of NeuroInterventional Surgery, and Society of Vascular and Interventional Neurology: endorsed by the Neurocritical Care Society. *Stroke* 2021;52:e133–52.
7 Goyal M, Ospel JM, Kim BJ, *et al*. A Bayesian framework to optimize performance of pre-hospital stroke triage scales. *J Stroke* 2021;23:443–8.
8 Zhao H, Coote S, Pesavento L, *et al*. Large vessel occlusion scales increase delivery to endovascular centers without excessive harm from misclassifications. *Stroke* 2017;48:568–73.
9 Araki H, Uchida K, Yoshimura S, *et al*. Effect of region-wide use of prehospital stroke triage scale on management of patients with acute stroke. *J Neurointerv Surg* 2022;14:677–82.
10 Patel MD, Thompson J, Cabañas JG, *et al*. Performance of the vision, aphasia, neglect (VAN) assessment within a single large EMS system. *J Neurointerv Surg* 2022;14:341–5.
11 Duvekot MHC, Venema E, Rozeman AD, *et al*. Comparison of eight prehospital stroke scales to detect intracranial large-vessel occlusion in suspected stroke (PRESTO): a prospective observational study. *Lancet Neurol* 2021;20:213-221.
12 Ganesh A, van de Wijdeven R, Ospel J, *et al*. Evaluating the diagnostic performance of prehospital stroke scales across the range of deficit severity: analysis of the PRESTO study. *Stroke* 2022.
13 Goyal M, Ospel JM. Adapting pre-hospital stroke triage systems to expanding thrombectomy indications. *Neuroradiology* 2021;63:161–6.
14 Goyal M, Ospel JM, Menon BK, *et al*. MeVO: the next frontier? *J Neurointerv Surg* 2020;12:545–7.
15 Martinez-Gutierrez JC, Chandra RV, Hirsch JA, *et al*. Technological innovation for prehospital stroke triage: ripe for disruption. *J Neurointerv Surg* 2019;11:1085–90.
16 Ebinger M, Siegerink B, Kunz A, *et al*. Association between dispatch of mobile stroke units and functional outcomes among patients with acute ischemic stroke in Berlin. *JAMA* 2021;325:454–66.
17 Grotta JC, Yamal J-M, Parker SA, *et al*. Prospective, multicenter, controlled trial of mobile stroke units. *N Engl J Med* 2021;385:971–81.
18 Harris J. A review of mobile stroke units. *J Neurol* 2021;268:3180–4.
19 Kim J, Easton D, Zhao H, *et al*. Economic evaluation of the Melbourne mobile stroke unit. *Int J Stroke* 2021;16:466–75.
20 Reimer AP, Zafar A, Hustey FM, *et al*. Cost-consequence analysis of mobile stroke units vs. standard prehospital care and transport. *Front Neurol* 2019;10:1422.
21 Sriudomporn S, Rachmad Nugraha R, Ahuja N, *et al*. The cost effectiveness of mobile stroke unit in the United States. *Health Serv Res* 2020;55:47.
22 Holodinsky JK, Kamal N, Zerna C, *et al*. In what scenarios does a mobile stroke unit predict better patient outcomes?: a modeling study. *Stroke* 2020;51:1805–12.
23 Kate MP, Jeerakathil T, Buck BH, *et al*. Pre-hospital triage of suspected acute stroke patients in a mobile stroke unit in the rural Alberta. *Sci Rep* 2021;11:4988.
24 Shuaib A, Jeerakathil T, Alberta Mobile Stroke Unit Investigators. The mobile stroke unit and management of acute stroke in rural settings. *CMAJ* 2018;190:E855.
25 Antipova D, Eadie L, Makin S, *et al*. The use of transcranial ultrasound and clinical assessment to diagnose ischaemic stroke due to large vessel occlusion in remote and rural areas. *PLoS One* 2020;15:e0239653.
26 Lin CB, Peterson ED, Smith EE, *et al*. Emergency medical service hospital prenotification is associated with improved evaluation and treatment of acute ischemic stroke. *Circ Cardiovasc Qual Outcomes* 2012;5:514–22.
27 Ganesh A, Lindsay P, Fang J, *et al*. Integrated systems of stroke care and reduction in 30-day mortality: a retrospective analysis. *Neurology* 2016;86:898–904.
28 Lin CB, Peterson ED, Smith EE, *et al*. Patterns, predictors, variations, and temporal trends in emergency medical service hospital prenotification for acute ischemic stroke. *J Am Heart Assoc* 2012;1:e002345.
29 Ospel JM, Almekhlafi MA, Menon BK, *et al*. Workflow patterns and potential for optimization in endovascular stroke treatment across the world: results from a multinational survey. *J Neurointerv Surg* 2020;12:1194–8.
30 Mayampurath A, Parnianpour Z, Richards CT, *et al*. Improving prehospital stroke diagnosis using natural language processing of paramedic reports. *Stroke* 2021;52:2676–9.
31 Kollikowski AM, Cattus F, Haag J, *et al*. Progression of cerebral infarction before and after thrombectomy is modified by prehospital pathways. *J Neurointerv Surg* 2022;14:485–9.
32 Suzuki K, Matsumaru Y, Takeuchi M, *et al*. Effect of mechanical thrombectomy without vs with intravenous thrombolysis on functional outcome among patients with acute ischemic stroke: the SKIP randomized clinical trial. *JAMA* 2021;325:244–53.
33 Zi W, Qiu Z, Li F, *et al*. Effect of endovascular treatment alone vs intravenous alteplase plus endovascular treatment on functional independence in patients with acute ischemic stroke: the DEVT randomized clinical trial. *JAMA* 2021;325:234–43.
34 Yang P, Zhang Y, Zhang L, *et al*. Endovascular thrombectomy with or without intravenous alteplase in acute stroke. *N Engl J Med* 2020;382:1981–93.
35 Fischer U, Kaesmacher J, Strbian D, *et al*. Thrombectomy alone versus intravenous alteplase plus thrombectomy in patients with stroke: an open-label, blinded-outcome, randomised non-inferiority trial. *Lancet* 2022;400:104–15.
36 LeCouffe NE, Kappelhof M, Treurniet KM, *et al*. A randomized trial of intravenous alteplase before endovascular treatment for stroke. *N Engl J Med* 2021;385:1833–44.
37 Ribo M. *RACECAT results presented at ESO-WSO 2020*, 2020.
38 Morey JR, Oxley TJ, Wei D, *et al*. Mobile interventional stroke team model improves early outcomes in large vessel occlusion stroke: the NYC MIST trial. *Stroke* 2020;51:3495–503.
39 Holodinsky JK, Williamson TS, Demchuk AM, *et al*. Modeling stroke patient transport for all patients with suspected large-vessel occlusion. *JAMA Neurol* 2018;75:1477–86.

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40 Fousse M, Grün D, Helwig SA, *et al*. Effects of a feedback-demanding stroke clock on acute stroke management: a randomized study. *Stroke* 2020;51:2895–900.
41 Marto JP, Borbinha C, Calado S, *et al*. The stroke chronometer - a new strategy to reduce door-to-needle time. *J Stroke Cerebrovasc Dis* 2016;25:2305–7.
42 Kamal N, Shand E, Swanson R, *et al*. Reducing door-to-needle times for ischaemic stroke to a median of 30 minutes at a community hospital. *Can J Neurol Sci* 2019;46:51–6.
43 Requena M, Olivé-Gadea M, Muchada M, *et al*. Direct to angiography suite without stopping for computed tomography imaging for patients with acute stroke: a randomized clinical trial. *JAMA Neurol* 2021;78:1099–107.
44 Pfaff JAR, Schönenberger S, Herweh C, *et al*. Direct transfer to angio-suite versus computed tomography-transit in patients receiving mechanical thrombectomy: a randomized trial. *Stroke* 2020;51:2630–8.
45 Kurz MW, Ospel JM, Advani R, *et al*. Simulation methods in acute stroke treatment: current state of affairs and implications. *Stroke* 2020;51:1978–82.
46 Nickson CP, Petrosoniak A, Barwick S, *et al*. Translational simulation: from description to action. *Adv Simul* 2021;6:6.
47 Khosravani H, Rajendram P, Notario L, *et al*. Protected code stroke: hyperacute stroke management during the coronavirus disease 2019 (COVID-19) pandemic. *Stroke* 2020;51:1891–5.
48 Kurz MW, Ospel JM, Daehli Kurz K, *et al*. Improving stroke care in times of the COVID-19 pandemic through simulation: practice your protocols! *Stroke* 2020;51:2273–5.
49 Yaeger KA, Rossitto CP, Marayati NF, *et al*. Time from image acquisition to endovascular team notification: a new target for enhancing acute stroke workflow. *J Neurointerv Surg* 2022;14:237–41.
50 Menon BK, d'Esterre CD, Qazi EM, *et al*. Multiphase CT angiography: a new tool for the imaging triage of patients with acute ischemic stroke. *Radiology* 2015;275:510–20.
51 Ospel JM, Volny O, Qiu W, *et al*. Impact of multiphase computed tomography angiography for endovascular treatment decision-making on outcomes in patients with acute ischemic stroke. *J Stroke* 2021;23:377–87.
52 Ospel JM, Bala F, McDonough RV, *et al*. Interrater agreement and detection accuracy for medium-vessel occlusions using single-phase and multiphase CT angiography. *AJNR Am J Neuroradiol* 2022;43:93–7.
53 Dhillon PS, Butt W, Podlasek A, *et al*. Association between time to treatment and clinical outcomes in endovascular thrombectomy beyond 6 hours without advanced imaging selection. *J Neurointerv Surg* 2023;15:336–42.
54 Albers GW, Marks MP, Kemp S, *et al*. Thrombectomy for stroke at 6 to 16 hours with selection by perfusion imaging. *N Engl J Med* 2018;378:708–18.
55 Nguyen TN, Abdalkader M, Nagel S, *et al*. Noncontrast computed tomography vs computed tomography perfusion or magnetic resonance imaging selection in late presentation of stroke with large-vessel occlusion. *JAMA Neurol* 2022;79:22–31.
56 Nogueira RG, Jadhav AP, Haussen DC, *et al*. Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. *N Engl J Med* 2018;378:11–21.
57 Menon BK, Ospel JM, McTaggart RA, *et al*. Imaging criteria across pivotal randomized controlled trials for late window thrombectomy patient selection. *J Neurointerv Surg* 2021;13:985–9.
58 Mocco J, Siddiqui AH, Fiorella D, *et al*. Positive: perfusion imaging selection of ischemic stroke patients for endovascular therapy. *J Neurointerv Surg* 2022;14:126–32.
59 van Meenen LCC, Arrarte Terreros N, Groot AE, *et al*. Value of repeated imaging in patients with a stroke who are transferred for endovascular treatment. *J Neurointerv Surg* 2022;14:84. 88
60 Kuang H, Najm M, Menon BK. Joint segmentation of intracerebral hemorrhage and infarct from non-contrast CT images of post-treatment acute ischemic stroke patients. In: Frangi A, Schnabel J, Davatzikos C, eds. *Medical image computing and computer assisted intervention – MICCAI 2018*. Cham: Springer, 2018.
61 Chung KJ, Kuang H, Federico A, *et al*. Semi-automatic measurement of intracranial hemorrhage growth on non-contrast CT. *Int J Stroke* 2021;16:192–9.
62 Kuang H, Najm M, Chakraborty D, *et al*. Automated aspects on noncontrast CT scans in patients with acute ischemic stroke using machine learning. *AJNR Am J Neuroradiol* 2019;40:33–8.
63 Kuang H, Qiu W, Najm M, *et al*. Validation of an automated aspects method on non-contrast computed tomography scans of acute ischemic stroke patients. *Int J Stroke* 2020;15:528–34.
64 Kuang H, Menon BK, Sohn SI, *et al*. EIS-Net: segmenting early infarct and scoring ASPECTS simultaneously on non-contrast CT of patients with acute ischemic stroke. *Med Image Anal* 2021;70:101984.
65 Qiu W, Kuang H, Teleg E, *et al*. Machine learning for detecting early infarction in acute stroke with non-contrast-enhanced CT. *Radiology* 2020;294:638–44.
66 Qiu W, Kuang H, Nair J, *et al*. Radiomics-based intracranial thrombus features on CT and CTA predict recanalization with intravenous alteplase in patients with acute ischemic stroke. *AJNR Am J Neuroradiol* 2019;40:39–44.
67 Matsoukas S, Morey J, Lock G, *et al*. AI software detection of large vessel occlusion stroke on CT angiography: a real-world prospective diagnostic test accuracy study. *J Neurointerv Surg* 2022. [Epub ahead of print: 27 Jan 2022].
68 Kuang H, Qiu W, Boers AM, *et al*. Computed tomography perfusion-based machine learning model better predicts follow-up infarction in patients with acute ischemic stroke. *Stroke* 2021;52:223–31.
69 Qiu W, Kuang H, Ospel JM, *et al*. Automated prediction of ischemic brain tissue fate from multiphase computed tomographic angiography in patients with acute ischemic stroke using machine learning. *J Stroke* 2021;23:234–43.
70 d'Esterre CD, Trivedi A, Pordeli P, *et al*. Regional comparison of multiphase computed tomographic angiography and computed tomographic perfusion for prediction of tissue fate in ischemic stroke. *Stroke* 2017;48:939–45.
71 Zerna C, Assis Z, d'Esterre CD, *et al*. Imaging, intervention, and workflow in acute ischemic stroke: the Calgary approach. *AJNR Am J Neuroradiol* 2016;37:978–84.
72 Frei D, McGraw C, McCarthy K, *et al*. A standardized neurointerventional thrombectomy protocol leads to faster recanalization times. *J Neurointerv Surg* 2017;9:1035–40.
73 McTaggart RA, Yaghi S, Baird G, *et al*. Decreasing procedure times with a standardized approach to ELVO cases. *J Neurointerv Surg* 2017;9:2–5.
74 Menon BK, Sajobi TT, Zhang Y, *et al*. Analysis of workflow and time to treatment on thrombectomy outcome in the endovascular treatment for small core and proximal occlusion ischemic stroke (ESCAPE) randomized, controlled trial. *Circulation* 2016;133:2279–86.
75 Powers CJ, Dornbos D, Mlynash M, *et al*. Thrombectomy with conscious sedation compared with general anesthesia: a DEFUSE 3 analysis. *AJNR Am J Neuroradiol* 2019;40:1001–5.
76 Simonsen CZ, Yoo AJ, Sørensen LH, *et al*. Effect of general anesthesia and conscious sedation during endovascular therapy on infarct growth and clinical outcomes in acute ischemic stroke: a randomized clinical trial. *JAMA Neurol* 2018;75:470–7.
77 Zhang Y, Jia L, Fang F, *et al*. General anesthesia versus conscious sedation for intracranial mechanical thrombectomy: a systematic review and meta-analysis of randomized clinical trials. *J Am Heart Assoc* 2019;8:e011754.
78 McTaggart RA, Ansari SA, Goyal M, *et al*. Initial hospital management of patients with emergent large vessel occlusion (ELVO): report of the standards and guidelines Committee of the Society of NeuroInterventional Surgery. *J Neurointerv Surg* 2017;9:316–23.
79 Leifer D, Bravata DM, Connors J.J. (Buddy), *et al*. Metrics for measuring quality of care in comprehensive stroke centers: detailed follow-up to brain attack coalition comprehensive stroke center recommendations. *Stroke* 2011;42:849–77.
80 Wahlgren N, Ahmed N, Dávalos A, *et al*. Thrombolysis with alteplase for acute ischaemic stroke in the safe implementation of thrombolysis in Stroke-Monitoring study (SITS-MOST): an observational study. *Lancet* 2007;369:275–82.
81 Saver JL, Warach S, Janis S, *et al*. Standardizing the structure of stroke clinical and epidemiologic research data: the National Institute of Neurological Disorders and Stroke (NINDS) Stroke Common Data Element (CDE) project. *Stroke* 2012;43:967–73.
82 Ormseth CH, Sheth KN, Saver JL, *et al*. The American Heart Association's Get With the Guidelines (GWTG) - Stroke development and impact on stroke care. *Stroke Vasc Neurol* 2017;2:94–105.
83 Acker JE, Pancioli AM, Crocco TJ, *et al*. Implementation strategies for emergency medical services within stroke systems of care: a policy statement from the American Heart Association/American Stroke Association expert panel on emergency medical services systems and the Stroke Council. *Stroke* 2007;38:3097–115.
84 NHTSA. Nemesis: national EMS information system, 2021. Available: https://nemsis.org [Accessed August 11 2021].
85 Goyal M, Saver JL, Ganesh A, *et al*. Standardized reporting of workflow metrics in acute ischemic stroke treatment: why and how? *Stroke: Vascular and Interventional Neurology* 2021;1:e000177.
86 Holodinsky JK, Kamal N, Wilson AT, *et al*. Workflow in acute stroke: what is the 90th percentile? *Stroke* 2017;48:808–12.
87 Smaha LA, American Heart Association. The American Heart Association Get With The Guidelines program. *Am Heart J* 2004;148:S46–8.
88 Hill MD, Goyal M, Menon BK, *et al*. Efficacy and safety of nerinetide for the treatment of acute ischaemic stroke (ESCAPE-NA1): a multicentre, double-blind, randomised controlled trial. *Lancet* 2020;395:878–87.
89 Uchino K, Man S, Schold JD, *et al*. Stroke legislation impacts distribution of certified stroke centers in the United States. *Stroke* 2015;46:1903–8.
90 John S, Stock S, Masaryk T, *et al*. Performance of CT angiography on a mobile stroke treatment unit: implications for triage. *J Neuroimaging* 2016;26:391–4.
91 Cerejo R, John S, Buletko AB, *et al*. A mobile stroke treatment unit for field triage of patients for intraarterial revascularization therapy. *J Neuroimaging* 2015;25:940–5.
92 Endovascular Today. Expedite study evaluates neural analytics' portable transcranial Droppler technology to measure early strokes, 2017. Available: https://evtoday.com/news/expedite-study-evaluates-neural-analytics-portable-transcranial-doppler-technology-to-measure-early-strokes [Accessed 6 December 2020].
93 Hanley D, Prichep LS, Bazarian J, *et al*. Emergency department triage of traumatic head injury using a brain electrical activity biomarker: a multisite prospective observational validation trial. *Acad Emerg Med* 2017;24:617–27.
94 Auerbach PS, Baine JG, Schott ML, *et al*. Detection of concussion using cranial accelerometry. *Clin J Sport Med* 2015;25:126–32.

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95 Smith WS, Browne JL, Ko NU. Cranial accelerometry can detect cerebral vasospasm caused by subarachnoid hemorrhage. *Neurocrit Care* 2015;23:364–9.
96 Persson M, Fhager A, Trefná HD, *et al*. Microwave-based stroke diagnosis making global prehospital thrombolytic treatment possible. *IEEE Trans Biomed Eng* 2014;61:2806–17.
97 Robertson CS, Zager EL, Narayan RK, *et al*. Clinical evaluation of a portable near-infrared device for detection of traumatic intracranial hematomas. *J Neurotrauma* 2010;27:1597–604.
98 Kandadai MA, Korfhagen JJ, Beiler S, *et al*. In vivo testing of a non-invasive prototype device for the continuous monitoring of intracerebral hemorrhage. *J Neurosci Methods* 2014;235:117–22.
99 Korfhagen JJ, Kandadai MA, Clark JF, *et al*. A prototype device for non-invasive continuous monitoring of intracerebral hemorrhage. *J Neurosci Methods* 2013;213:132–7.
100 Kellner CP, Sauvageau E, Snyder KV, *et al*. The vital study and overall pooled analysis with the VIPS non-invasive stroke detection device. *J Neurointerv Surg* 2018;10:1079–84.

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