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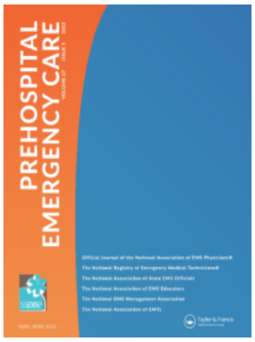

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Prehospital Stroke Triage: A Modeling Study on the Impact of Triage Tools in Different Regions

Martijne H. C. Duvekot[a,b], Bjarty L. Garcia[c], Luuk Dekker[d], Truc My Nguyen[e], Ido R. van den Wijngaard[d,f*], Karlijn F. de Laat[e], Els L. L. M. de Schryver[g], Loet M. H. Kloos[h], Leo A. M. Aerden[i], Stas A. Zylicz[j], Jan Bosch[k], Eduard van Belle[l], Erik W. van Zwet[m], Anouk D. Rozeman[a], Walid Moudrous[n], Frédérique H. Vermeij[o], Hester F. Lingsma[p], Jeannette Bakker[q], Pieter Jan van Doormaal[r], Adriaan C. G. M. van Es[s*], Aad van der Lugt[t], Marieke J. H. Wermer[d*], Diederik W. J. Dippel[b], Henk Kerkhoff[a], Bob Roozenbeek[b], Nyika D. Kruyt[d*], and Esmee Venema[p,t], on behalf of the Leiden Prehospital Stroke Study and PRESTO Investigators

[a]Department of Neurology, Albert Schweitzer Hospital, Dordrecht, The Netherlands; [b]Department of Neurology, Erasmus MC University Medical Center, Rotterdam, The Netherlands; [c]Department of Public Health and Primary care, Leiden University Medical Center, Leiden, The Netherlands; [d]Department of Neurology, Leiden University Medical Center, Leiden, The Netherlands; [e]Department of Neurology, Haga Hospital, The Hague, The Netherlands; [f]Department of Neurology, Haaglanden Medical Center, The Hague, The Netherlands; [g]Department of Neurology, Alrijne Hospital, Leiderdorp, The Netherlands; [h]Department of Neurology, Groene Hart Hospital, Gouda, The Netherlands; [i]Department of Neurology, Reinier De Graaf Gasthuis, Delft, The Netherlands; [j]Department of Neurology, LangeLand Hospital, Zoetermeer, The Netherlands; [k]Ambulance Services Holland-Midden, Leiden, The Netherlands; [l]Emergency Medical Services Haaglanden, The Hague, The Netherlands; [m]Department of Biomedical Data Sciences, Leiden University Medical Center, Leiden, The Netherlands; [n]Department of Neurology, Maasstad Hospital, Rotterdam, The Netherlands; [o]Department of Neurology, Franciscus Gasthuis & Vlietland, Rotterdam, The Netherlands; [p]Department of Public Health, Erasmus MC University Medical Center, Rotterdam, The Netherlands; [q]Department of Radiology, Albert Schweitzer Hospital, Dordrecht, The Netherlands; [r]Department of Radiology & Nuclear Medicine, Erasmus MC University Medical Center, Rotterdam, The Netherlands; [s]Department of Radiology, Leiden University Medical Center, Leiden, The Netherlands; [t]Department of Emergency Medicine, Erasmus MC University Medical Center, Rotterdam, The Netherlands

ABSTRACT

Background and purpose: Direct transportation to a thrombectomy-capable intervention center is beneficial for patients with ischemic stroke due to large vessel occlusion (LVO), but can delay intravenous thrombolytics (IVT). The aim of this modeling study was to estimate the effect of prehospital triage strategies on treatment delays and overtriage in different regions.

Methods: We used data from two prospective cohort studies in the Netherlands: the Leiden Prehospital Stroke Study and the PRESTO study. We included stroke code patients within 6 h from symptom onset. We modeled outcomes of Rapid Arterial oCclusion Evaluation (RACE) scale triage and triage with a personalized decision tool, using drip-and-ship as reference. Main outcomes were overtriage (stroke code patients incorrectly triaged to an intervention center), reduced delay to endovascular thrombectomy (EVT), and delay to IVT.

Results: We included 1798 stroke code patients from four ambulance regions. Per region, overtriage ranged from 1-13% (RACE triage) and 3-15% (personalized tool). Reduction of delay to EVT varied by region between 24 ± 5 min ($n = 6$) to 78 ± 3 ($n = 2$), while IVT delay increased with 5 ($n = 5$) to 15 min ($n = 21$) for non-LVO patients. The personalized tool reduced delay to EVT for more patients (25 ± 4 min [$n = 8$] to 49 ± 13 [$n = 5$]), while delaying IVT with 3-14 min (8-24 patients). In region C, most EVT patients were treated faster (reduction of delay to EVT 31 ± 6 min ($n = 35$), with RACE triage and the personalized tool.

Conclusions: In this modeling study, we showed that prehospital triage reduced time to EVT without disproportionate IVT delay, compared to a drip-and-ship strategy. The effect of triage strategies and the associated overtriage varied between regions. Implementation of prehospital triage should therefore be considered on a regional level.

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CONTACT Martijne H. C. Duvekot m.duvekot@erasmusmc.nl
M.H.C. Duvekot and B.L. Garcia contributed equally to the manuscript. N.D. Kruyt and E. Venema contributed equally to the manuscript.
*Additional affiliation: University Neurovascular Medical Center Leiden-the Hague, the Netherlands.

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Introduction

Rapid reperfusion treatment is essential to optimize functional outcome of ischemic stroke patients (1,2). Treatment with intravenous thrombolytics (IVT) is available at all primary stroke centers (PSCs), while endovascular thrombectomy (EVT) is restricted to specialized intervention centers. Only patients with ischemic stroke due to large vessel occlusion (LVO), approximately 24% to 46% of all ischemic strokes, are eligible for EVT (3). Several strategies can be used to allocate patients with suspected stroke in the ambulance (stroke code patients). In the drip-and-ship strategy, all stroke code patients are allocated to the nearest stroke center to start IVT as soon as possible, followed by transfer to intervention centers in case of eligibility for EVT. However, these interhospital transfers often lead to EVT delay and are associated with worse outcome (4,5). In the mothership strategy, all stroke code patients are allocated to the nearest intervention center, consequently delaying IVT for patients who bypass closer PSCs. Furthermore, several prehospital stroke scales have been suggested to select patients with a higher likelihood of LVO stroke for direct allocation to intervention centers (6,7).

The key objective of an allocation strategy is to optimize the overall outcome of stroke patients, taking into account that improved outcomes by reduced time to EVT should outweigh the harm caused by delayed IVT for non-LVO stroke patients. Previous studies demonstrated that the effect of allocation strategies depends not only on the likelihood of LVO stroke, but also on delays related to driving times and in-hospital workflow times (8–12). Consequently, the optimal allocation strategy likely differs between regions (13).

Our aim was to estimate the effect of prehospital triage strategies for LVO on treatment delays and overtriage in different regions, using two large prehospital stroke code cohorts.

Methods

Study Design

We performed a modeling study with data from the Leiden Prehospital Stroke Study (LPSS) and the Prehospital triage of patients with suspected stroke (PRESTO) study (14,15). Both are multi-center, observational prospective cohort studies that included stroke code patients transported by ambulance between July 2018 and October 2019. The institutional review boards of the Leiden University Medical Center and Erasmus MC University Medical Center Rotterdam reviewed the study protocols and confirmed that the Dutch Medical Research Involving Human Subjects Act is not applicable. The need for informed consent was waived because the studies met the exceptions of informed consent regulations. Detailed information regarding the LPSS and the PRESTO study is described elsewhere (14–16).

Study Region and Population

Patients from four regions in the Netherlands were included by emergency medical services (EMS) paramedics (Figure 1 and Table 1). EMS in The Netherlands is organized within

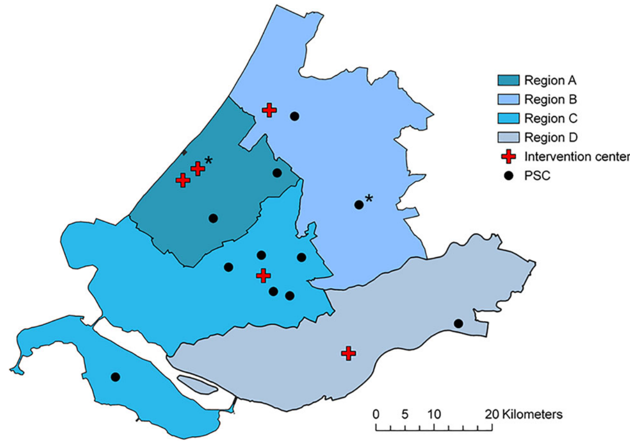

Figure 1. Geography of the study region.
PSC = primary stroke center; EVT = endovascular thrombectomy. All PSCs refer for EVT to an intervention center within their region, except for the marked PSC (*), this PSC refers to the marked intervention center (*). Ambulances were allowed to drive outside their region to adhere the allocation strategy.
Region A (Haaglanden): area of 404 km^2. Region B (Hollands-Midden): area of 831 km^2.
Region C (Rotterdam-Rijnmond): area of 863 km^2. Region D (Zuid-Holland Zuid): area of 720 km^2.

25 safety regions, of which four are included in this study. Dispatch of ambulances is coordinated from a control room. Regions A (Haaglanden) and B (Hollands-Midden) have their own control rooms. Regions C (Rotterdam-Rijnmond) and D (Zuid-Holland Zuid) have a shared control room. Dispatch and routing is not restricted to the borders of the safety regions and control rooms are in close contact with each other. The destination hospital of each patient is decided by the handling EMS paramedic based on standardized ambulance allocation protocols only requiring direct medical oversight in very specific cases. The ambulance allocation protocol always allocates a stroke code patient to the nearest hospital.

The LPSS was performed in region A with two PSCs and two intervention centers, and region B with two PSCs and one intervention center. The PRESTO study was performed in region C with six PSCs and one intervention center, and region D with one PSC and one intervention center. Inclusion criteria for the LPSS were: stroke code patient (age ≥18 years) with a positive Face-Arm-Speech-Time (FAST) test or other neurological deficits suspected of stroke as considered by EMS paramedics. Inclusion criteria for PRESTO were: stroke code patient (age ≥18 years) with a positive FAST test and blood glucose >2.5 mmol/L. During the inclusion period, all regions applied a drip-and-ship strategy that was not restricted by region borders (i.e., if the closest center was in a different region, then the patient was allocated to that center). EMS paramedics assessed items from different prehospital stroke scales before arrival at the emergency department, including the Rapid Arterial oCclusion Evaluation (RACE) scale (17). Patients who presented more than 6 h after stroke onset or the time that they were last seen well and patients without complete RACE scores were excluded from the current analysis. LVO was defined as an occlusion of the intracranial part of the internal carotid artery, M1 or M2 segment of the middle cerebral artery, or

Table 1. Regional characteristics.

Region	A ($n = 373$)	B ($n = 386$)	C ($n = 543$)	D ($n = 496$)
Name	Haaglanden	Hollands-Midden	Rotterdam-Rijnmond	Zuid-Holland Zuid
Population size	1,000,000	800,000	1,200,000	480,000
Total area (km^2)	404	831	863	720
Population density (inhabitants/km^2)	2400	950	1540	670

A1 or A2 segment of the anterior cerebral artery, as assessed on CT angiography by the local stroke team.

Allocation Strategies

We modeled the outcome of individual patients according to different allocation strategies:

- *Drip-and-ship*: each stroke code patient is transported to the nearest stroke center. EVT-eligible patients who first presented in a PSC are subsequently transferred to the nearest intervention center;
- *RACE triage* (17): each stroke code patient with a positive RACE scale (≥5 points) is transported to the nearest intervention center; others to the nearest stroke center;
- *Triage by a personalized decision tool* (8): for each stroke code patient a personalized decision tool is used to optimize allocation. We used a previously developed decision tree model that estimates and advises the destination center with the highest probability of a good outcome, defined as a modified Rankin Scale (mRS) score ≤2 at 3 months (8,18). An existing script of this model was used to estimate individual patient outcomes of this allocation strategy with R statistical software. This decision tree model used time-dependent effects of IVT and EVT extrapolated from the results of large clinical trials (1,19). Input parameters are center-specific workflow times, driving times, and the likelihood of an LVO or non-LVO stroke as estimated by the RACE scale score (Online Supplemental Table 1). For the current analysis, the probability of receiving IVT for ischemic stroke patients who presented within 4.5 hours was adjusted to 0.61 and the probability of receiving EVT for LVO stroke patients who presented within 6 hours to 0.81, calculated based on the pooled data of both studies. All other treatment assumptions and treatment effect estimates remained similar to the original model (Online Supplemental Table 1).

The drip-and-ship strategy served as a reference. We used ESRI ArcGIS Pro (version 2.0.0) to estimate driving times with geospatial analysis for the fastest possible route, without regard to time or week of day. For each allocation strategy, the expected onset-to-treatment times were calculated from the onset to departure time of the ambulance on site, with the addition of the estimated driving time and center-specific workflow times (Online Supplemental Table 1).

Outcome Measures

The main outcomes were reported separately for each region:

- Stroke code patients directly transported to intervention centers
- Patients incorrectly triaged to intervention centers (overtriage) and the number-needed-to-bypass (NNB), defined as the number of non-LVO patients (including patients with intracranial hemorrhage and non-stroke patients) who bypass PSCs for each correctly triaged LVO stroke patient. Non-LVO patients who were transported to an intervention center because it was the closest hospital, were considered correctly triaged.

For LVO patients:

- Correctly triaged patients (i.e., LVO patients directly transported to intervention centers).
- Time to EVT (minutes, mean ± SD) and treatment number.
- Reduction of delay to EVT due to correct triage.

For non-LVO ischemic stroke patients:

- Incorrectly triaged patients (i.e. non-LVO ischemic stroke patients bypassing PSCs; also, IV fibrinolytic contraindications were not assessed by the EMS paramedics and these patients were handled as non-LVO ischemic stroke patients).
- Time to IVT (minutes, mean ± SD) and treatment number
- Delay to IVT due to incorrect triage

For all ischemic stroke patients:

- Overall probability of good functional outcome (modified Rankin Scale [mRS] 0-2), calculated based on treatment eligibility and treatment times per strategy.

Secondary outcomes included the total number of patients receiving IVT and EVT and the number of interhospital transfers. Treatment eligibility was based on a time window of <4.5 h for IVT and <6 h for EVT. Each LVO patient who could be treated within 6 h was considered to be treated with EVT.

Additionally, we performed a post-hoc sensitivity analysis in which we adjusted the threshold of the personalized tool to bypass the PSC (estimated benefit of direct transportation to an intervention center >0.1% or >0.2%).

This study is reported according to the STROBE guidelines (Online Supplemental page 6).

Funding and Ethics Review

The LPSS was funded by the Dutch Brain Foundation, the Dutch Health Care Insurers Innovation Foundation, and Health Holland. The PRESTO study was funded by the BeterKeten collaboration and Theia Foundation (Zilveren Kruis). The institutional review board of the Erasmus MC University Medical Center Rotterdam has reviewed the study protocol and confirmed that the Dutch Medical Research Involving Human Subjects Act was not applicable. Therefore, ethical approval was not required. Because this study met the exceptions of informed consent regulations, the need for informed consent was waived.

Results

Patient and Regional Characteristics

Of 3321 recruited stroke code patients, 1798 were included in the current analysis (Figure 2). We excluded 1523 patients because of presentation more than 6 h after last seen well ($n = 995$), age less than 18 years ($n = 1$), or incomplete RACE scores ($n = 527$). Regions A and B had higher percentages of patients with stroke mimics and (consequently) lower percentages of stroke code patients treated with IVT compared with regions C and D (Table 2). The percentages of patients with LVO stroke from the total number of stroke codes ranged from 7% to 11% between the regions.

Outcomes

As can be seen in Table 3, with the triage strategies, the number of strokes code patients primarily allocated to an

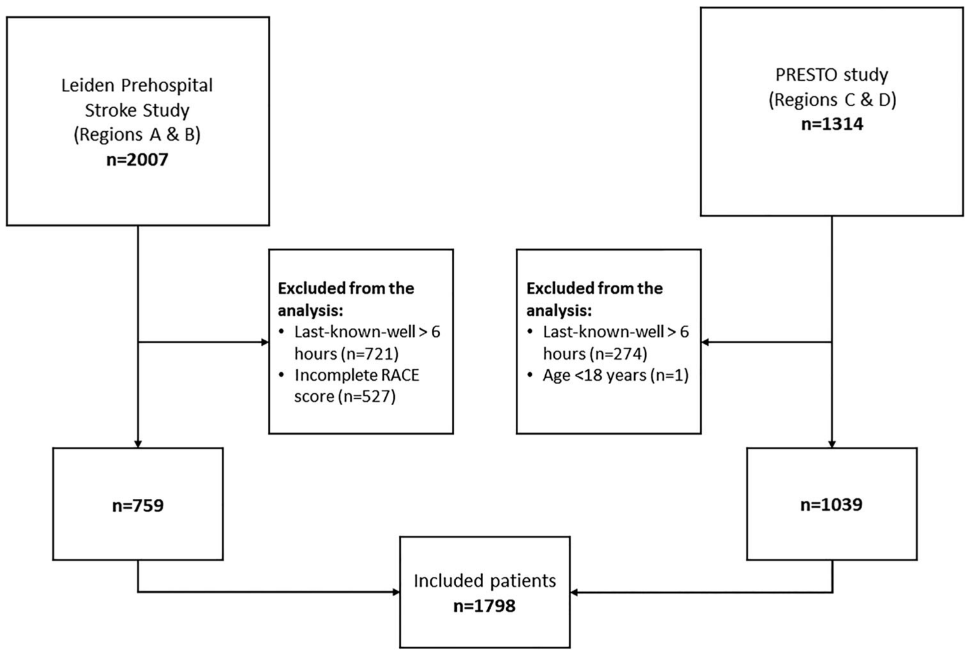

Figure 2. Inclusion flowchart.

Table 2. Patient characteristics stratified by region.†

Region	A ($n = 373$)	B ($n = 386$)	C ($n = 543$)	D ($n = 496$)	Total cohort ($n = 1798$)
Age, years	70 (58-79)	72 (59-80)	71 (60-80)	73 (63-82)	72 (60-80)
Sex, (women)	180 (48%)	175 (45%)	256 (47%)	223 (45%)	834 (46%)
Clinical assessment					
Prehospital RACE score	1 (0-2)	1 (0-2)	2 (0-4)	1 (0-3)	1 (0-3)
Prehospital RACE $\geq$ 5	33 (9%)	42 (11%)	120 (22%)	81 (16%)	276 (15%)
Admission NIHSS score	2 (1-4)	1 (0-4)	2 (1-7)	2 (0-6)	2 (0-5)
Workflow times (minutes)					
Onset-to-alarm	51 (17-137)	53 (21-132)	49 (15-121)	55 (19-146)	52 (18-134)
Onset-to-door	82 (57-138)	86 (50-153)	80 (52-151)	90 (55-176)	85 (54-155)
Final diagnosis					
Ischemic stroke	144 (39%)	167 (43%)	267 (49%)	255 (51%)	833 (46%)
LVO* stroke	29 (8%)	27 (7%)	62 (11%)	39 (8%)	157 (9%)
Non-LVO stroke	115 (31%)	140 (36%)	205 (38%)	216 (44%)	676 (38%)
Intracranial hemorrhage	21 (6%)	25 (7%)	37 (7%)	35 (7%)	118 (7%)
TIA	70 (19%)	76 (20%)	95 (18%)	96 (19%)	337 (19%)
Stroke mimic	138 (37%)	118 (31%)	144 (27%)	110 (22%)	510 (28%)
Treatment received					
Intravenous thrombolytics	66 (18%)	102 (26%)	165 (30%)	160 (32%)	493 (27%)
Endovascular thrombectomy	13 (3%)	18 (5%)	54 (10%)	37 (8%)	122 (7%)

Data are median (IQR) or n (%), unless otherwise indicated.
RACE = Rapid Arterial oCclusion Evaluation; NIHSS = National Institutes of Health Stroke Scale; LVO = large vessel occlusion; TIA = Transient Ischemic Attack; CTA = CT angiography.
*LVO was defined as an occlusion of the intracranial part of the internal carotid artery (ICA), the middle cerebral artery segment M1 or M2 or the anterior cerebral artery segment A1 or A2, assessed on CTA.
†Number of missings: Leiden Prehospital Stroke Study data: NIHSS $n = 182$, onset-to-door and onset-to-alert $n = 12$, PRESTO data: NIHSS $n = 6$, onset-to-alert $n = 112$, onset-to-door $n = 32$.

Table 3. Effect of allocation strategies per region.

Region A ($n = 373$)	Drip-and-ship	RACE triage	Personalized tool
Directly transported to intervention center, % (n)	61 (226)	63 (235)	72 (267)
Overtriage to intervention center, % (n)	–	1 (4)	3 (11)
Number-needed-to-bypass (NNB)	–	2.0	7.4
LVO ischemic stroke patients ($n = 29$)			
Correctly transported to intervention center, % (n)	69 (20)	79 (23)	86 (25)
Time to EVT, mean ± SD	167 ± 67 ($n = 25$)	166 ± 72 ($n = 26$)	170 ± 76 ($n = 26$)
Reduction of delay to EVT due to correct triage, mean ± SD	–	78 ± 3 ($n = 2$)	41 ± 12 ($n = 4$)
Non-LVO ischemic stroke patients ($n = 115$)			
Overtriage to intervention center, % (n)	0 (0)	3 (4)	23 (27)
Time to IVT, mean ± SD	114 ± 62 ($n = 50$)	114 ± 62 ($n = 50$)	114 ± 62 ($n = 50$)
Delay to IVT due to incorrect triage, mean ± SD*	–	5 ± 4 ($n = 5$)	3 ± 3 ($n = 8$)
All ischemic stroke patients ($n = 144$)			
Overall probability of good outcome (mRS 0-2)	48.7	48.8	48.8
Region B ($n = 386$)	**Drip-and-ship**	**RACE triage**	**Personalized tool**
Directly transported to intervention center, % (n)	41 (158)	47 (181)	53 (205)
Overtriage to intervention center, % (n)	–	3% (10)	5% (18)
Number-needed-to-bypass (NNB)	–	10.5	53.0
LVO ischemic stroke patients ($n = 27$)			
Correctly transported to intervention center, % (n)	74 (20)	81 (22)	78 (21)
Time to EVT, mean ± SD	169 ± 64 ($n = 27$)	163 ± 68 ($n = 27$)	163 ± 66 ($n = 27$)
Reduction of delay to EVT due to correct triage, mean ± SD	–	39 ± 36 ($n = 4$)	49 ± 13 ($n = 5$)
Non-LVO ischemic stroke patients ($n = 140$)			
Overtriage to intervention center, % (n)	0 (0)	6 (16)	11 (29)
Time to IVT, mean ± SD	101 ± 46 ($n = 81$)	103 ± 46 ($n = 81$)	103 ± 46 ($n = 81$)
Delay to IVT due to incorrect triage, mean ± SD*	–	10 ± 4 ($n = 9$)	8 ± 3 ($n = 16$)
All ischemic strokes ($n = 167$)			
Overall probability of good outcome (mRS 0-2)	48.7	48.8	48.8
Region C ($n = 543$)	**Drip-and-ship**	**RACE triage**	**Personalized tool**
Directly transported to intervention center, % (n)	8 (46)	29 (157)	30 (164)
Overtriage to intervention center, % (n)	–	13% (71)	15% (82)
Number-needed-to-bypass (NNB)	–	1.8	2.3
LVO ischemic stroke patients ($n = 62$)			
Correctly transported to intervention center, % (n)	15 (9)	79 (49)	73 (45)
Time to EVT, mean ± SD	179 ± 61 ($n = 57$)	163 ± 66 ($n = 58$)	163 ± 66 ($n = 58$)
Reduction of delay to EVT due to correct triage, mean ± SD	–	31 ± 6 ($n = 35$)	31 ± 6 ($n = 35$)
Non-LVO ischemic stroke patients ($n = 205$)			
Overtriage to intervention center, % (n)	0 (0)	17 (34)	20 (40)
Time to IVT, mean ± SD	114 ± 60 ($n = 125$)	116 ± 59 ($n = 125$)	116 ± 59 ($n = 125$)
Delay to IVT due to incorrect triage, mean ± SD*	–	15 ± 3 ($n = 21$)	14 ± 3 ($n = 24$)
All ischemic strokes ($n = 267$)			
Overall probability of good outcome (mRS 0-2)	48.4	48.6	48.6
Region D ($n = 496$)	**Drip-and-ship**	**RACE triage**	**Personalized tool**
Directly transported to intervention center, % (n)	68 (338)	74 (367)	85 (422)
Overtriage to intervention center, % (n)	–	5% (23)	15% (76)
Number-needed-to-bypass (NNB)	–	3.8	9.5
LVO ischemic stroke patients ($n = 39$)			
Correctly transported to intervention center, % (n)	77 (30)	92 (36)	97 (38)
Time to EVT, mean ± SD	191 ± 76 ($n = 39$)	188 ± 76 ($n = 39$)	187 ± 77 ($n = 39$)
Reduction of delay to EVT due to correct triage, mean ± SD	–	24 ± 5 ($n = 6$)	25 ± 4 ($n = 8$)
Non-LVO ischemic stroke patients ($n = 216$)			
Overtriage to intervention center, % (n)	0 (0)	6 (12)	18 (38)
Time to IVT, mean ± SD	120 ± 61 ($n = 130$)	120 ± 61 ($n = 129$)†	120 ± 61 ($n = 130$)
Delay to IVT due to incorrect triage, mean ± SD*	–	7 ± 7 ($n = 6$)	4 ± 5 ($n = 17$)
All ischemic stroke patients ($n = 255$)			
Overall probability of good outcome (mRS 0-2)	48.6	48.6	48.6
Total cohort ($n = 1798$)	**Drip-and-ship**	**RACE triage**	**Personalized tool**
Directly transported to intervention center, % (n)	43 (768)	52 (940)	59 (1058)
Overtriage to intervention center, % (n)	–	6 (108)	10 (187)
Number-needed-to-bypass (NNB)	–	2.4	4.8
LVO ischemic stroke patients ($n = 157$)			
Correctly transported to intervention center, % (n)	50 (79)	83 (130)	82 (129)
Time to EVT, mean ± SD	178 ± 66 ($n = 148$)	170 ± 70 ($n = 150$)	170 ± 71 ($n = 150$)
Reduction of delay to EVT due to correct triage, mean ± SD	–	33 ± 8 ($n = 47$)	33 ± 7 ($n = 52$)
Non-LVO ischemic stroke patients ($n = 676$)			
Overtriage to intervention center, % (n)	0 (0)	10 (66)	20 (134)
Time to IVT, mean ± SD	113 ± 58 ($n = 386$)	114 ± 57 ($n = 385$)†	114 ± 57 ($n = 386$)
Delay to IVT due to incorrect triage, mean ± SD*	–	12 ± 4 ($n = 41$)	9 ± 3 ($n = 65$)
All ischemic stroke patients ($n = 833$)			
Overall probability of good outcome (mRS 0-2)	48.4	48.7	48.7

RACE = Rapid Arterial oCclusion Evaluation; LVO = large vessel occlusion; IVT = intravenous thrombolytics; mRS = modified Rankin Scale.

*Not all non-LVO ischemic stroke patients were treated with IVT due to contraindications, which explains the difference between the number of delayed IVT patients with the number of overtriaged patients.

†In this scenario, one patient arrived outside the treatment window for IVT due to incorrect triage.

Because results regarding treatment and treatment times in Table 3 were modeled based on predefined assumptions, results might show differences between the results from Table 2.

intervention center increased, most with the personalized tool (18% in region A to 257% increase in region C). With RACE triage this was somewhat smaller in all regions (4% in region A to 241% in region C). The NNB was highest with the personalized tool (2.3 in region C to 53.0 in region B), and more modest with RACE triage (1.8 in region C to 10.5 in region B).

The number of correctly transported LVO patients increased with prehospital triage strategies. This was most pronounced in region C (15% to 79% with RACE triage and 73% with the personalized tool). Mean time to EVT decreased in all regions, except for region A. This was caused by one additional patient who did not fall out of the 6 h time window due to correct triage and could therefore be treated with EVT. RACE triage reduced delay to EVT of correctly triaged patients between 24 ± 5 min for six patients (15%) in region D (mean time to EVT 188 ± 76 min) and 78 ± 3 min for two patients (7%) in region A (mean time to EVT 166 ± 72 min). Delay to EVT was reduced for more patients when using the personalized tool: 25 ± 4 for eight patients (21%) in region D (mean time 187 ± 77 min) and 41 ± 12 for four patients (14%) in region A (mean time 170 ± 76 min).

With RACE triage, incorrectly transported non-LVO ischemic stroke ranged from 3% (region A) to 17% (region C). This was somewhat higher across the regions with the personalized tool, from 11% (region B) to 23% (region A). The mean IVT delay due to incorrect triage was smallest with the personalized tool: from 3 ± 3 min (for eight patients) in region A to 14 ± 3 (for 24 patients) in region C. With RACE triage this was somewhat higher: 5 ± 4 min (for five patients) in region A, to 15 ± 3 min (for 21 patients) in region C. Overall, the probability of a good outcome for ischemic stroke patients improved minimally with prehospital triage in all regions compared to the drip-and-ship strategy ($p < 0.001$).

Treatment percentages of IVT (for all ischemic strokes) ranged from 46 to 62% (Online Supplemental Table 2). The number of interhospital transfers decreased most in region C, from 48 in the drip-and-ship scenario to 13 with both prehospital triage strategies.

The sensitivity analysis showed that overtriage with the personalized decision tool can be reduced when the threshold to bypass a PSC is increased (Online Supplemental Table 3).

Discussion

In this modeling study, we used individual patient data to estimate the effect of allocation strategies in four different regions. We found that prehospital triage with the RACE scale or a personalized tool expedites EVT without a disproportionate delay to IVT, though this differed between regions. Importantly, RACE triage resulted in relatively modest overtriage rates and thereby limited effect on patient flows. The estimated differences in patient outcome between the allocation strategies were small, though we expect that these differences could become clinically relevant on a population level. Prehospital triage will always be a tradeoff between expediting EVT and delaying IVT for those patients bypassing closer PSCs. In this respect, it is important to realize that large meta-analyses demonstrated that every 10 min of decrease in time to EVT results in an increase of 1% on the probability of good functional outcome, while 10 min of delay in IVT results in a decrease of 0.33% on the probability of good functional outcome (1,20). Furthermore, it is important that the effect of prehospital triage strategies differs per region.

This difference can partly be explained by differences in case mix of the stroke code populations. Regions A and B (LPSS) used broader inclusion criteria than regions C and D (PRESTO study), which probably resulted in fewer RACE-positive patients and consequently in a lower percentage of LVO strokes. Differences in geographical characteristics also play a role and can explain differences in outcome, for example the NNB. In region C, centers are located closely together in a densely populated area with six PSCs and only one intervention center. Therefore, prehospital triage strategies led to an increase in direct transportation of LVO patients to intervention centers while delay to IVT remained relatively small. However, this also resulted in a substantial increase of incorrectly triaged stroke code patients presented primarily in the intervention center. In regions A, B, and D, given the geographic positions of the centers, triage with the personalized tool led to considerably more overtriage and a higher NNB compared to RACE triage because all patients with (small) potential benefits of faster EVT were allocated to intervention centers. Direct allocation to an intervention center will be favored in these regions even when the likelihood of LVO is low, because the potential effect of EVT delay is large when the PSCs are relatively distant from the intervention center.

The RACECAT trial, situated in a nonurban region with much larger travel times between PSC and intervention center (average transfer time 45 min), randomized 1401 patients between mothership and drip-and-ship in patients with positive RACE scales (21). Their results indicate that RACE triage did not improve nor worsen clinical outcomes (22,23). However, these findings are not generalizable to other regions with different geographical characteristics and workflow times. Previous modeling studies demonstrated differences in optimal allocation strategies based on geographic characteristics, workflow times, and LVO likelihood. However, these studies were mostly conducted in simulated cohorts or geographies and often excluded non-LVO patients, thus lacking the important data to estimate overtriage (9,11,24–27). In contrast, we used data from a prehospital stroke code cohort (also including non-stroke patients) with patient-specific and center-specific time metrics.

Limitations of our study include the use of some assumptions for model-based approaches. Travel times were modeled with a geographic system, but could have differed in real life due to traffic congestion or speeding by the ambulance. Furthermore, different inclusion criteria of stroke code patients and EMS paramedic expertise with the use of RACE scale between the regions probably explain some differences that cannot merely be attributed to the allocation strategies or geographies. However, these differences also reflect clinical practice. Next, we could only include patients with complete RACE scales, which could have introduced some selection bias. However, in the LPSS population we found no differences in baseline characteristics, LVO status, final diagnosis, or clinical outcome in patients with or without complete RACE (data not shown). Furthermore, because stroke code patients with symptom onset exceeding 6 h were excluded, extrapolating our results to this subgroup has to be done with caution. Lastly, our study was not powered to demonstrate differences in clinical outcome. However, based on our modeling it seems likely that the implementation of prehospital triage strategies on a larger scale can improve clinical outcomes of ischemic stroke patients (13).

Implementation of RACE triage is straightforward, but it does not take into account other variable factors such as local driving times or workflow times. The personalized tool takes these factors into account and is adaptive to a specific region. For example, real-time driving times can be used and workflow times can be adjusted if in-hospital workflows are improved. Currently, this decision tool has been processed into the Stroke Triage app, which is planned to be implemented in region C and D soon. This application uses a route planner to estimate real-time driving times. Of note, the negative effects of overtriage are not necessarily limited to non-LVO ischemic stroke patients, as crowding in intervention centers might affect local health care. On the other hand, we regarded patients with (severe) intracranial hemorrhage who bypassed a PSC as overtriage, where it could be argued that these patients might benefit from direct transport to centers with neurosurgical facilities. Potential capacity issues might also differ between regions or hospitals, so this is important to consider before implementing prehospital triage strategies. To minimize overtriage, the sensitivity of this personalized tool to bypass PSCs can be adjusted, as shown in our sensitivity analysis. We want to emphasize that prehospital triage strategies have different effects between regions, and decisions on prehospital triage should ultimately be taken on a regional level. This study is a demonstration on how to estimate the effect of prehospital triage strategies, which can aid local health policy makers in making better-informed decisions.

Conclusion

In a modeling study of two large cohorts of stroke code patients, prehospital triage with the RACE scale or the personalized decision tool reduced the time to EVT in all regions without disproportionate delay of IVT compared to the drip-and-ship model. The effect of triage strategies and the associated overtriage varied between regions. Implementation of prehospital triage should therefore be considered on a regional level.

Acknowledgments

Leiden Prehospital Stroke Study Investigators:

Local Principal Investigators:

Karlijn F. de Laat[a], Els L.L.M. de Schryver[b], Loet M.H. Kloos[c], Leo am Aerden[d], Stas A. Zylicz[e], Jan Bosch[f], Eduard van Belle[g], and Ido R. van den Wijngaard[h]

Study Coordinators:

Truc My Nguyen[a] and Nyika D. Kruyt[i]

[a]Department of Neurology, Haga Hospital, The Hague, The Netherlands; [b]Department of Neurology, Alrijne hospital, Leiderdorp, The Netherlands; [c]Department of Neurology, Groene Hart Hospital, Gouda, The Netherlands; [d]Department of Neurology, Reinier De Graaf Gasthuis, Delft, The Netherlands; [e]Department of Neurology, Lange Land Hospital, Zoetermeer, The Netherlands; [f]Ambulance services Holland-Midden, Leiden, The Netherlands; [g]Emergency Medical Services Haaglanden, The Hague, The Netherlands; [h]Department of Neurology, Haaglanden Medical Center, The Hague, The Netherlands; [i]Department of Neurology, Leiden University Medical Center, Leiden, The Netherlands

PRESTO investigators:

Executive Committee:

Diederik W.J. Dippel[a], Bob Roozenbeek[a,b], Henk Kerkhoff[c], Hester F. Lingsma[d], Aad van der Lugt[b], Adriaan C.G.M van Es[e], Anouk D. Rozeman[c], Walid Moudrous[f], and Frédérique H. Vermeij[g]

Study coordinators:

Esmee Venema[a,d]; Martijne H.C. Duvekot[a,c]; and Ruben M. van de Wijdeven[a]

Steering Committee:

Diederik W.J. Dippel[a], Bob Roozenbeek[a,b], Hester F. Lingsma[d], Aad van der Lugt[b], Adriaan C.G.M. van Es[e], Henk Kerkhoff[c], Anouk D. Rozeman[c], Walid Moudrous[f], Frédérique H. Vermeij[g], Kees C.L. Alblas[g], Laus J.M.M. Mulder[h], Annemarie D. Wijnhoud[i], Lisette Maasland[j], Roeland P.J. van Eijkelenburg[k], Marileen Biekart[l], M.L. Willeboer[m], and Bianca Buijck[a,n]

Imaging Committee:

Bob Roozenbeek[a,b], Henk Kerkhoff[c], Aad van der Lugt[b], and Adriaan C.G.M. van Es[e]

Imaging Core Laboratory

Aad van der Lugt[b], Adriaan C.G.M. van Es[e], Pieter Jan van Doormaal[b], Jeannette Bakker[o], Jan-Hein Hensen[p], Aarnout Plaisier[q], and Geert Lycklama à Nijeholt[r]

Local principal investigators:

Diederik W.J. Dippel[a], Bob Roozenbeek[a,b], Aad van der Lugt[b], Amber Hoek[s], Henk Kerkhoff[c], Anouk D. Rozeman[c], Jeannette Bakker[o], Erick Oskam[t], Walid Moudrous[f], Jan-Hein J. Hensen[p], Frédérique H. Vermeij[g], Mandy M.A. van der Zon[u], Egon D. Zwets[v], Kees C.L. Alblas[g], Laus J.M.M. Mulder[h], Jan Willem Kuiper[w], Annemarie D. Wijnhoud[i], Bruno J.M. van Moll[i], Aarnout Plaisier[q], Lisette Maasland[j], Mirjam Woudenberg[x], Roeland P.J. van Eijkelenburg[k], and Arnoud M. de Leeuw[y]

Local trial coordinators:

Anja Noordam-Reijm[l] and Timo Bevelander[m]

PhD/Medical students:

Vicky Chalos[a,b,c], Eveline J.A. Wiegers[d], Lennard Wolff[b], Dennis C. van Kalkeren[a], Jochem van den Biggelaar[a], and Jasper D. Daems[a]

[a]Department of Neurology, Erasmus MC University Medical Center, Rotterdam, The Netherlands; [b]Radiology & Nuclear Medicine, Erasmus MC University Medical Center, Rotterdam, The Netherlands; [c]Department of Neurology, Albert Schweitzer Hospital, Dordrecht, The Netherlands; [d]Public Health, Erasmus MC University Medical Center, Rotterdam, The Netherlands; [e]Department of Radiology, Leiden University Medical Center, Leiden, The Netherlands; [f]Department of Neurology, Maasstad Hospital, Rotterdam, The Netherlands; [g]Department of Neurology, Franciscus Gasthuis & Vlietland, Rotterdam, The Netherlands; [h]Department of Neurology, Ikazia Hospital, Rotterdam, The Netherlands; [i]Department of Neurology, IJsselland Hospital, Rotterdam, The Netherlands; [j]Department of Neurology, van Weel Bethesda Hospital, Dirksland, The Netherlands;

[k]Department of Neurology, Rivas Zorggroep Beatrix Hospital, Gorinchem, The Netherlands; [l]Ambulance Service Rotterdam-Rijnmond, Barendrecht, The Netherlands; [m]Ambulance Service Zuid-Holland Zuid, Papendrecht, The Netherlands; [n]Rotterdam Stroke Service, Rotterdam, The Netherlands; [o]Radiology, Albert Schweitzer Hospital, Dordrecht, The Netherlands; [p]Radiology, Maasstad Hospital, Rotterdam, The Netherlands; [q]Radiology, IJsselland Hospital, Rotterdam, The Netherlands; [r]Department of Radiology, Haaglanden Medical Center, The Hague, The Netherlands; [s]Emergency Medicine, Erasmus MC University Medical Center, Rotterdam, The Netherlands; [t]Emergency Medicine, Albert Schweitzer Hospital, Dordrecht, The Netherlands; [u]Radiology, Franciscus Gasthuis & Vlietland, Rotterdam, The Netherlands; [v]Emergency Medicine, Franciscus Gasthuis & Vlietland, Rotterdam, The Netherlands; [w]Radiology, Ikazia Hospital, Rotterdam, The Netherlands; [x]Radiology, van Weel Bethesda hospital, Dirksland, The Netherlands; [y]Radiology, Rivas Zorggroep Beatrix hospital, Gorinchem

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