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ORIGINAL COMMUNICATION

Development and validation of the Heidelberg Neurological Triage System (HEINTS)

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Abstract

Background/objective Neurological syndromes are underrepresented in existing triage systems which are not validated for neurological patients; therefore, we developed and validated the new Heidelberg Neurological Triage System (HEINTS) in a prospective, single-center observational study.

Methods Patients were triaged according to the new triage system by nurses and physicians (stage 1) as well as trained nurses (stage 2). In stage 1, all patients presenting to the neurological emergency room (ER) were triaged by nurses and physicians. In stage 2, three specially trained nurses triaged patients according to HEINTS. The main outcomes comprised interrater agreement between nurses' and physicians' triage (stage 1), sensitivity and specificity to detect emergencies (stages 1 and 2), and improvement in triage quality as a result of training (stage 2), as well as correlation of HEINTS with hospital admissions and resource utilization.

Results In stage 1 ($n = 2423$ patients), sensitivity and specificity to detect neurological emergencies were 84.2% (SD 0.8%) and 85.4% (SD 0.8%) for nurses, as well as 92.4% (SD 0.6%) and 84.1% (SD 0.9%) for physicians, respectively. The interrater-reliability between nurses and physicians in stage 1 was moderate [Cohen's kappa 0.44, standard deviation (SD) 0.02]. In stage 2 ($n = 506$ patients), sensitivity of trained nurses increased to 94.3% (SD 1.0%), while specificity decreased to 74.8% (SD 1.9%). Correlation of HEINTS triage with hospital admission and resource utilization in both stages was highly significant.

Conclusions HEINTS predicted hospital admissions and resource utilization. Agreement between nurses and physicians was moderate. HEINTS, applied by physicians and by nurses after training, reliably detected neurological emergencies.

Keywords Triage · Neurological emergency · Emergency room

Introduction

In the past few decades, several triage systems have emerged for use in interdisciplinary emergency rooms, among which the Manchester Triage System (MTS) and the Emergency Severity Index (ESI) are employed most frequently [1–3]. All triage systems for emergency rooms (ER) in hospitals aim to identify life-threatening conditions immediately and focus on different aspects such as resource use, treatment organization and treatment order. Neurological emergencies might not be immediately fatal but nevertheless require rapid assessment and treatment [4–7]. Indeed, they are not sufficiently represented in the existing triage systems, although up to 15% of the patients presenting to an interdisciplinary ER and up to 26% of medical patients suffer from neurological diseases [8, 9]. Triage of neurological patients is

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challenging because parameters such as heart rate, blood pressure, and others in many cases do not depict the acuity of the disease. To date, there is no specific triage system for neurological emergencies and nor has a dedicated validation of the existing triage systems been conducted to assess performance in neurological patients. We aimed to create a triage algorithm specifically designed for patients presenting to a neurological ER that can be used by physicians and nurses alike. We then set out to validate this algorithm in a two staged prospective trial in which nurses, algorithm-trained nurses and physicians applied the algorithm to triage patients in a routine setting. Several studies have been published on the reliability and validity of triage systems [10–13]. The main outcome parameters of these studies include interrater-reliability and correlation of triage with mortality, resource utilization, hospital admission and admission to intensive care units (ICU) as validity criteria. Few studies compare triage of real patients to a reference standard [8, 14–17].

Methods

Algorithm development

For our newly developed Heidelberg Neurological Triage System (HEINTS), we defined four triage categories according to time periods in which the physician's assessment needed to begin (category 1: < 5 min, cat. 2: < 2 h, cat. 3: same day, cat. 4: nonurgent; Fig. 1). Five-level triage systems have been shown to be more reliable and valid than three-level systems [10, 18]. However, the most urgent category of these systems comprises patients with acute cardiorespiratory insufficiency of similar severe condition. As these patients rarely present to our neurological ER and since we felt that true neurological emergencies such as stroke and bacterial meningitis should both be treated immediately, we combined the two most urgent categories of the five-level system. Primarily, triage categories represent the order of detailed assessment by a physician. Secondarily, we chose time windows to assure patients' safety in the higher categories. In comparison to other triage systems, we chose broader time slots for the less urgent categories. This is mainly due to the fact that emergency rooms are facing increasing numbers of nonurgent patients. One author reports up to 37% (8–62%) nonurgent patients in emergency rooms in the US [19]. In Europe as well, between 11.7% and 56% of ED visits are classified as inappropriate [20]. There are many considerations how to restructure emergency care to avoid overcrowding, i.e., transferring nonurgent patients to an outpatient clinic or a physician's office. Category 3, "same day", focuses on patients who require diagnostic examinations and/or treatment that might not be provided at a standard outpatient clinic or specialist. Category 4, "nonurgent", was defined for patients who actually do not require acute assessment. However, all patients should be treated as quickly as resources allow. Accompanying this validation study, we also conducted a self-assessment of the patients evaluating the perceived urgency, the reasons for referral to the ER and other aspects [21].

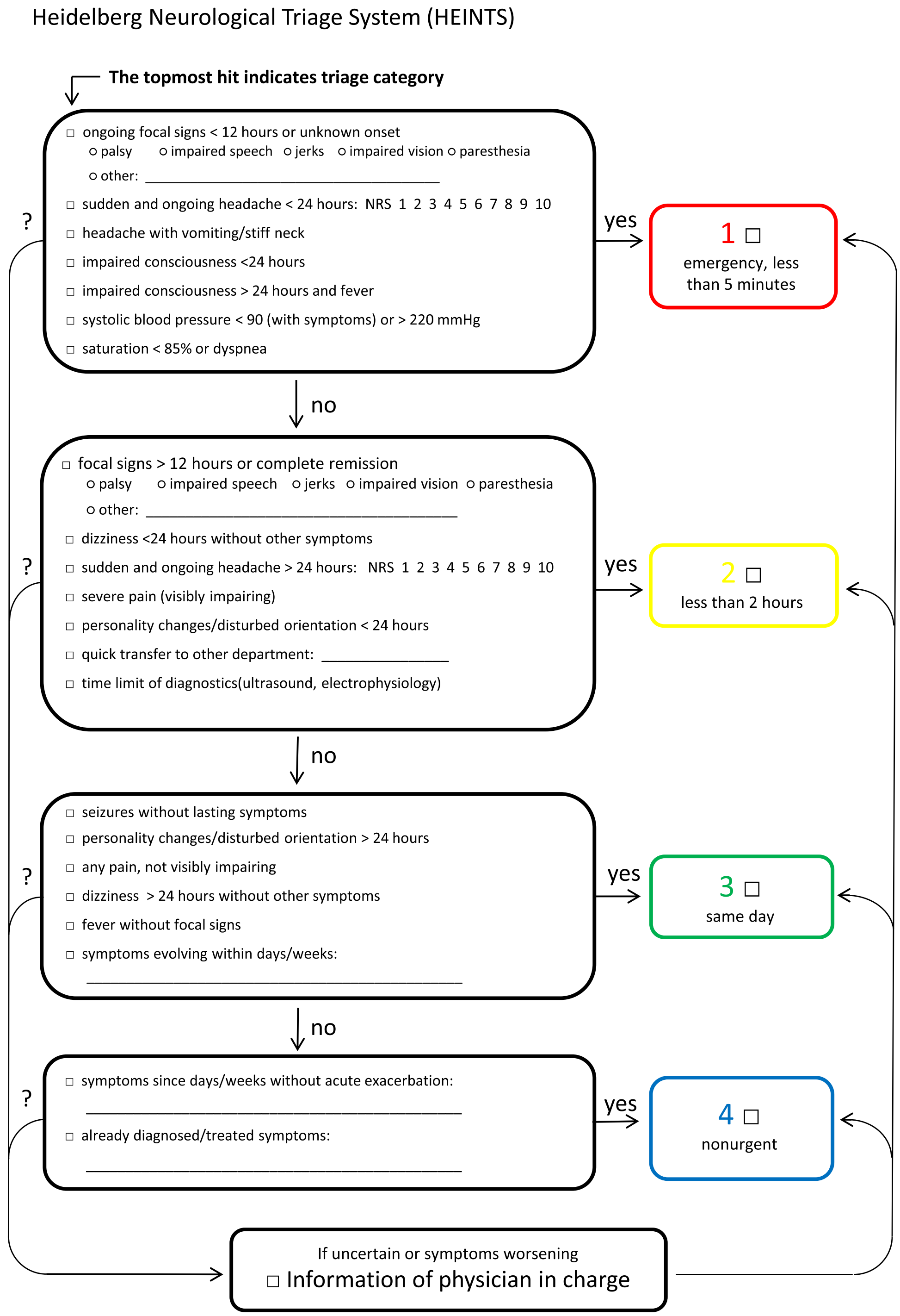
We assigned the most important neurological syndromes and conditions to the four triage categories regarding the duration of symptoms. Category 1 (immediately) comprises ischemic/hemorrhagic stroke within 12 h, bacterial meningitis, status epilepticus, seizures with lasting symptoms and coma. We assigned ischemic/hemorrhagic strokes with symptoms for longer than 12 h, transient ischemic attacks, viral meningitis, severe pain and transient global amnesia to category 2 (less than 2 h). Seizures without lasting symptoms, idiopathic headache, other moderate pain and MS relapses should be assessed by a physician the same day (category 3). Symptoms lasting for days or weeks, already diagnosed or treated disorders or asks for a second opinion were classified as nonurgent (category 4).

We chose 12 h as time window for suspected acute stroke as mechanical thrombectomy, thrombolysis studies, and treatment of basilar artery occlusion were not restricted to 4.5 h from onset in our institutional SOPs and acute stroke studies. HEINTS is based on neurological symptoms either to be identified by a structured history with the patient or through the emergency medical service (EMS) personnel report and/or a quick assessment. In HEINTS, we included vital signs (blood pressure, oxygen saturation, and temperature) and logistic aspects. Before the study, no formal triage system was in place. In a test phase of 4 weeks, nurses and physicians had the opportunity to familiarize themselves with the triage system and integrate it into their workflow. We asked them for feedback and incorporated suggestions into the algorithm (Fig. 1).

Study design

We aimed to validate our new triage system by comparing the agreement of triage between physicians in neurological training with nurses previously untrained in the use of HEINTS and second aimed to demonstrate that training of nurses in the application of HEINTS would improve their performance. The validation study was set up as a prospective, single-center, observational comparative study during routine clinical practice in two stages, combined with a retrospective chart review to validate HEINTS for neurological emergency patients. The study was conducted in the ER of the Heidelberg University Neurology Department.

Fig. 1 HEINTS triage algorithm. NRS: numeric rating scale for pain; patients were asked to indicate the intensity of pain (0 = no pain, 10 = worst possible pain). "Quick transfer to other department" refers to patients with non-neurological symptoms who should be transferred to the appropriate department as soon as possible. The four categories on the right side of the algorithm indicate the time until the assessment by a physician has to begin



Standard protocol approvals, registrations, and patient consents

According to our institutional review board, the participants (nurses, medical students working as nursing assistants, and neurologists of the ER) gave written informed consent and patients' consent was waived. The study was registered in the German Clinical Trials Register; https://www.drks.de; identifier: DRKS00013267. For the study flow diagram, see Fig. 2.

Study setting

This ER is located in a separate center ("head clinic") together with the ERs for neurosurgery, oral and maxillofacial surgery, otorhinolaryngology, and ophthalmology. There

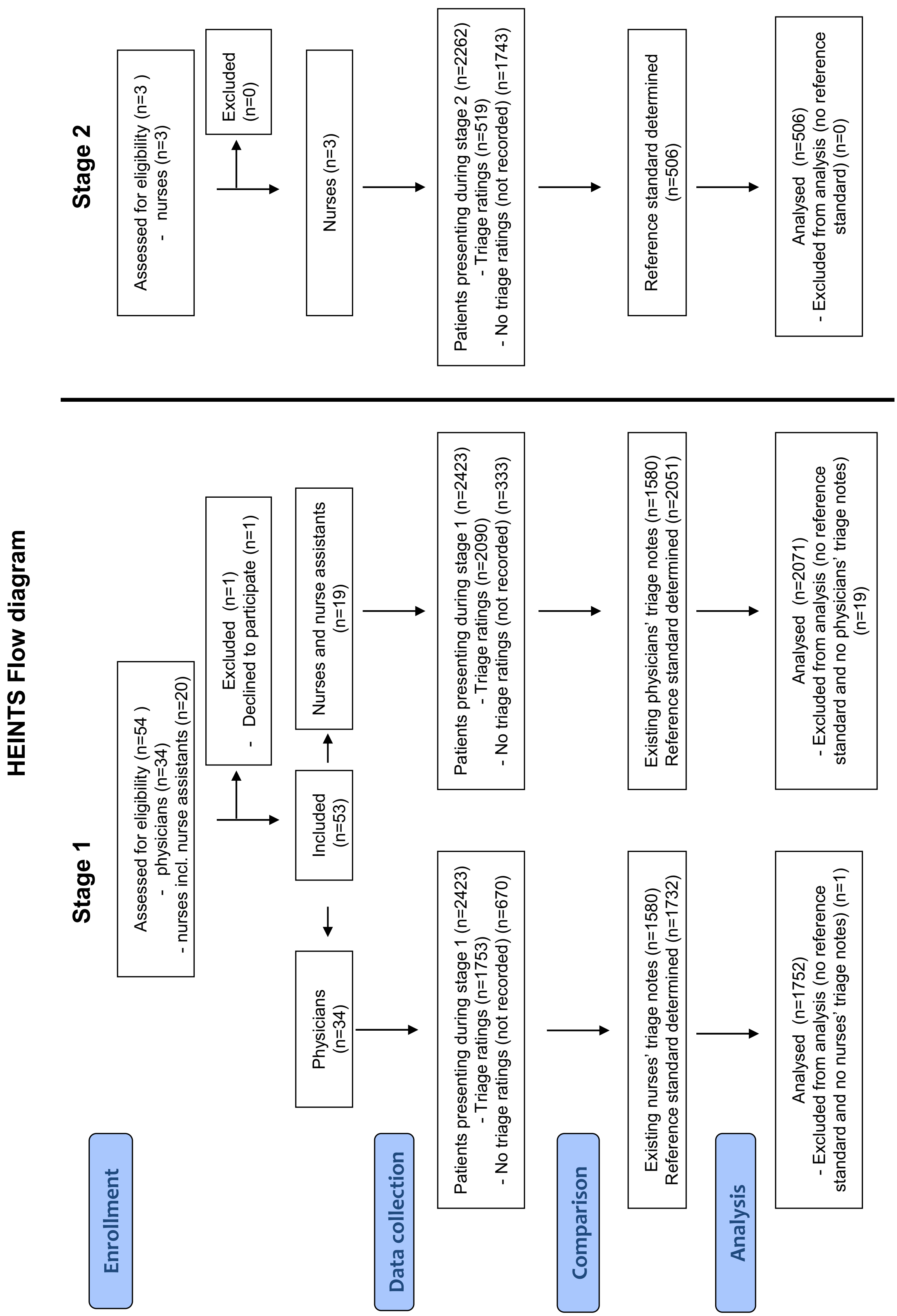


Fig. 2 HEINTS study flow diagram

Table 1 Baseline characteristics of stages 1 and 2

Parameter	Stage 1 Data ($N=2423$) (n, %)	Stage 2 Data ($N=519$) (n, %)
Sex female	1263 (52.1)	286 (55.11)
Age mean in years (SD)	56.13 (20.8)	57.63 (21.19)
< 40	629 (26.0)	125 (24.08)
40–59	647 (26.7)	122 (23.51)
50–79	794 (32.7)	182 (35.07)
≥ 80	353 (14.6)	86 (16.57)
Mode of referral (missing data)	$N=2072$ (351, 14.5)	$N=409$
Self-referral	528 (25.5)	117 (28.61)
Emergency medical service	444 (21.4)	95 (23.23)
General practitioner/specialist	308 (14.9)	42 (10.27)
Other hospital	300 (14.5)	51 (12.47)
Other department	261 (12.6)	46 (11.25)
Emergency physician	231 (11.1)	58 (14.18)
Diagnosis (missing data)	$N=2374$ (49, 2.0)	
Ischemic stroke	485 (20.4)	
Idiopathic headache	278 (11.7)	
Seizures	269 (11.3)	
Peripheral nerve palsy	136 (5.7)	
Vertigo	118 (5.0)	
Neurooncology	72 (3.0)	
Hemorrhagic stroke	71 (3.0)	
Multiple sclerosis	46 (1.9)	
Meningitis	21 (0.9)	
Other neurological disorders	504 (21.2)	
Non-neurological diagnosis	374 (15.8)	
Further treatment (missing data)	$N=2356$ (67, 2.8)	$N=506$
Discharge	1208 (51.3)	239 (47.23)
Ordinary ward	300 (12.7)	58 (11.46)
Stroke unit/intermediate care	344 (14.6)	78 (15.42)
Intensive care unit	95 (4.0)	28 (5.53)
Other department	197 (8.4)	55 (10.87)
Other hospital	212 (9.0)	48 (9.49)
Triage category (gold standard) (missing data)	$N=2356$ (67, 2.8)	$N=506$
1 (within 5 min)	399 (16.9)	107 (20.95)
2 (within 2 h)	433 (18.4)	67 (13.24)
3 (same day)	1265 (53.7)	288 (56.32)
4 (nonurgent)	259 (11.0)	50 (9.49)

Total counts vary due to missing data. For stage 2, diagnosis categories were not assessed

is one nursing team for all specialties but separate physicians for each department. Over 10,000 patients presented to the neurological ER in 2016. The neurological ER is working 24/7 and has a shift rotation. There is at least one physician in neurology training present all the times and at times with high patient turnover up to three. Between 8 am and 5 pm, there is one specialist in Neurology present as well, the rest of the time the attending is on call. Patients are either self-referring or referred by a general practitioner or a specialist, by emergency medical services (EMS), emergency physicians (EP), other departments, or other hospitals (Table 1). The study consisted of two stages. The first stage comparing physicians' with nurses' triage performance was conducted between October 2015 and January 2016. The time period of 3 months was calculated to obtain at least 1000 triage ratings for nurses and physicians. In the second stage, we evaluated triage of the trained nurses, which was conducted between October 2016 and January 2017 to obtain at least 500 triage ratings.

Procedures

Self-referring patients registered at the reception desk and were then sent to the ER where nurses received them. They were then triaged immediately or recalled for triage as soon as possible. Patients brought by EMS were immediately admitted to the ER and primarily received by nurses. Patients accompanied by EP were handed over directly to physicians and, therefore, triaged in category 1. Apart from that, nurses' triage was performed before or while vital signs were being checked, blood was taken, and possibly a venous catheter was placed. In stage 1, every nurse was equally involved in patient care; there were no special "triage nurses". Physicians triaged patients either upon arrival during presentation by EMS personnel or recalled patients for triage. Assuming that nurses' preceded physicians' triage, data for the nurses' triage were collected separately from the patients' records. Physicians' triage was noted on the medical record and patients were routinely examined and treated according to physicians' triage category in stage 1 of the study. Time of triage was documented together with triage category.

For the second stage, we further trained three nurses (ACB, LK, UW, please see "Acknowledgements") of the ER staff who had already participated in stage 1 to use HEINTS by discussing real and fictional patient cases before incorporating the triage algorithm in their routine work. They were involved in patient care like the rest of the nurses and had no "extra-time" for triage. The remaining nurses performed triage according to HEINTS algorithm within clinical routine without extra training and their triage was not assessed for the trial.

Reference standard

To compare triage ratings with the "true" urgency level, we determined a reference standard. The reference standard is composed of the same four time categories for physicians' treatment (less than 5 min, less than 2 h, same day, and nonurgent) as triage categories. Two experienced neurologists (HMO and HJ, one involved in the development of the algorithm, one independent) rated the category based on the information of the physicians' ER reports. The medical reports were written at the end of ER treatment, irrespective of hospital admission or discharge and contained history, clinical examination, vital signs, laboratory results, imaging, other diagnostics, and an epicrisis including the (assumed) diagnosis. Classification into the time categories was based on the initial assignment of diagnoses to time categories. When in doubt, categories were assigned according to the maximum time the patient could have waited without risking deterioration. Patients with diseases that may have received a time-critical treatment, irrespective of the final treatment (e.g., stroke with possible thrombolysis), were categorized as 1, whereas patients who retrospectively did not require urgent treatment (e.g., Todd's paralysis, peripheral nerve palsy) were classified in less urgent categories. Rating was performed independently and blinded for triage. If ratings differed (27% in stage 1, 29% in stage 2), cases were reviewed until consensus was reached.

Additionally, we wanted to understand the reasons for incorrect triage of true emergencies (reference standard category 1). We, therefore, analyzed the documented patient's history and retrospectively applied the HEINTS algorithm to it.

Triage according to Emergency Severity Index

We aimed to compare HEINTS to a widely used triage system, the Emergency Severity Index (ESI). As no triage system was in place when we introduced HEINTS, it was not feasible to train all nurses to triage patients prospectively according to two systems. We, therefore, retrospectively assessed ESI levels for all high-urgency patients (standard reference category 1) following the guidelines from the ESI implementation handbook, version 4 [22]. Whereas level 1 is unambiguously defined as "immediately requiring life saving interventions", level 2 is more imprecisely defined as "high risk situation". Neurological patients in level 2 are specified as "severe headache associated with mental status changes, high blood pressure, lethargy, fevers, or a rash; sudden onset of speech deficits or motor weakness; sudden onset of "worst headache of my life"; all patients with a reported seizure". There is no indication regarding the duration of symptoms or possible remission. Hence, we dichotomized triage according to ESI to detect neurological emergencies in levels 1–2 vs. 3–5.

Data collection

We collected the following data from patients' records, study documentation, and electronic hospital documents: demographics, mode of referral, and further treatment; hospital admission/transfer/discharge, diagnosis, triage ratings by nurses and physicians, time of admission, time of triage, and resources used in the ER. We reported the mode of referral to our ER, for example, patients brought by EMS from another hospital were recorded as "other hospital" and not as "EMS". Resources included radiological imaging, lumbar puncture, ultrasound, electrophysiological examinations, consultation of other departments, and parenteral drug or fluid administration. We excluded laboratory blood tests as they were routinely taken from almost every patient admitted to the neurological ER.

Outcomes

Primary outcome in stage 1 was to determine whether triage based on HEINTS algorithm is equivalent when performed by nurses or physicians. Secondary outcome parameters included the agreement of triage ratings to the standard reference, the comparison of time to triage by nurses and physicians, the correlation of triage with resource utilization in the Emergency Room, and further treatment. For assessment of safety, we analyzed emergency patients (according to reference standard) missed by triage. In stage 2, we wanted to determine whether training of nurses to apply the HEINTS algorithm improves quality of triage.

Time to triage (Ttriage) was measured from time of ER admission, i.e., the electronically registered time of patient registration to the documented time of triage and was recorded in both stages. Minimal time was defined as 1 min if triage was performed before or during registration (especially for patients brought by EMS). The triaging process itself was not measured. Extracted from our patient information system (SAP ECC 6.0 EhP8 IS-H/i.s.hmed, SAP, Walldorf, Germany) during stage 1, we recorded time from registration to first contact with the physician (Treg-phys), time from first contact with the physician to discharge of the ER (Tphys-end), and total waiting time (Twait), i.e., Treg-phys plus any waiting time between first contact with the physician until discharge (i.e., waiting for ultrasound, radiology, etc.). For comparison of Treg-phys, Tphys-end, and Twait, we used the same time period from the previous year, prior to the introduction of HEINTS.

Statistical analysis

All statistical analyses were performed with SPSS version 20 (SPSS Inc. Chicago, IL). Cohen's kappa coefficient was used to assess the interrater-reliability. As diagnostic performance criteria, sensitivity and specificity for identification of category 1 by triage (compared with the reference standard) were determined. Furthermore, we calculated overtriage (more urgent triage category) and undertriage (less urgent triage category) rates compared to the reference standard. For the analysis of the missed emergencies, we used χ^2 test to compare stages 1 and 2.

The association of the four triage categories and four possible levels of care [discharged, admitted to normal ward, admitted to (hyperacute) stroke unit (SU)/intermediate care unit (IMC) and admitted to intensive care unit (ICU)] was evaluated using Spearman's rank correlation coefficient. Level of care was considered an ordinal variable. Admission levels (discharged vs. hospitalized and admitted to SU/IMC/ICU vs. other treatment) were compared to triage with χ^2 test and contingency coefficient. The association between triage category and resource utilization was analyzed using Spearman's rank correlation. For processing times, data were expressed as hours and minutes with median and interquartile range and the Mann–Whitney test was used to compare group differences. This is an explorative trial. Resulting *p* values are not adjusted for multiplicity and must be interpreted descriptively.

Data policy

Anonymized data can be shared by request from any qualified investigator for purposes of replication procedures and results.

Results

In stage 1, all 34 physicians and 19 of 20 nurses including 5 nurse assistants working in the ER participated in the study. One nurse was excluded due to missing informed consent. During this stage from October 21, 2015, to January 22, 2016, a total of 2423 patients presented to the ER. We obtained 2090 nurses' (86%) and 1753 physicians' (72%) triage documents, and ER reports were available for 2356 patients. In stage 2 from October 21, 2016, to January 16, 2017, 3 nurses participated in the study. Five hundred and fifteen triage ratings were included in stage 2, for which we had 506 correlating ER reports.

Patient characteristics

The baseline characteristics of the patients of both stages are presented in Table 1. About half of the patients presented to our ER without prior physician's assessment (self-referring or brought by EMS). 10.8% of the patients (261 of 2423) were transferred from other departments; few of them were classified as urgent (18 in category 1, 35 in category 2). The most frequent diagnoses were ischemic stroke, headache, and seizures. Three hundred and seventy-four of 2423 patients (15.4%) had non-neurological diseases. About one-third (832 of 2356, 35.3%) of the patients were classified as urgent (category 1 and 2). More than half of the patients (1208 of 2356, 51.3%) were discharged after treatment in the ER (Table 1).

Comparison of nurses' and physicians' triage

For 1580 patients, both nurses' and physicians' triage were recorded. Interrater-reliability measured by Cohen's kappa was moderate (κ 0.44, SD 0.02, $p < 0.001$). Compared to the reference standard, nurses had a higher undertriage rate (16.4%, SD 0.8%, Table 2) than physicians (8.7%, SD 0.7%). Overtriage was equal among the two triaging groups (32.8% and 35.4%, SD 1.0%, and 1.1%). The sensitivity of identifying emergencies (reference standard category 1) was 84.2% (SD 0.8%) for nurses and 92.4% (SD 0.6%) for physicians; specificity was 85.4% (SD 0.8%) and 84.1% (SD 0.9%), respectively. In stage 2, sensitivity for category 1 was higher (94.3%, SD 1.0%; specificity 74.8%, SD 1.9%) and undertriage markedly decreased (4.9%, SD 1.0%) at the expense of overtriage (46.8%, SD 2.2%). The negative predictive value of patients triaged as nonurgent (category 3 and 4) was 87.4% (SD 0.7%) for nurses and 89.2% (SD 0.7%) for physicians and also increased after nurses were trained (stage 2): 94.7% (SD 1.0%).

Missed emergencies

In the first study stage, a total of 61 emergencies (retrospectively categorized as category 1 according to reference standard) were mistriaged by nurses and/or physicians (2.6%). We analyzed main reasons for the incorrect triage in Table 3. Insofar as it is possible to discern retrospectively, 17 of 2356 patients (0.7%) were mistriaged due to failure of the algorithm as their patient history key features were not sufficiently represented in the algorithm, and 35 of 2356 patients (1.5%) were mistriaged due to incorrect application of HEINTS. In the second stage, only six patients were not correctly identified as category 1 (1.2%).

Table 2 Detection of emergencies, over- and undertriage

	Nurses	Trained nurses	Physicians
Sensitivity of cat. 1 (SD)	84.2% (0.8%)	94.3% (1.0%)	92.4% (0.6%)
Specificity of cat. 1 (SD)	85.4% (0.8%)	74.8% (1.9%)	84.1% (0.9%)
Undertriage (SD)	16.4% (0.8%)	4.9% (1.0%)	8.7% (0.7%)
Overtriage (SD)	32.8% (1.0%)	46.8% (2.2%)	35.4% (1.1%)
Negative predictive value of categories 3 and 4 (SD)	87.4% (0.7%)	94.7% (1.0%)	89.2% (0.7%)

We analyzed the detection of the most urgent cases (category 1) according to nurses' and physicians' triage (stage 1) and triage of specially trained nurses (stage 2). Triage was compared to the reference standard. Sensitivity and specificity of detection of category 1 were calculated. Furthermore, under- and overtriage (all categories) were calculated. Additionally, negative predictive value of the nonurgent patients (categories 3 and 4 combined) was calculated. Standard deviation (SD) is indicated for all results

Hospital admission

Triage categories correlated with the level of further care (i.e., discharge, admission to normal ward, admission to SU/IMC, or admission to ICU). Spearman's rho was − 0.488 ($p<0.001$) for nurses' and − 0.533 ($p<0.001$) for physicians' triage in stage 1 and − 0.527 ($p<0.001$) in stage 2. Triage was associated with discharge from the emergency room (nurses χ^2 329.689, $p<0.001$, physicians χ^2 346.388, $p<0.001$; contingency coefficient 0.369 and 0.401, respectively) and admission to IMC/SU including ICU (nurses χ^2 442.720, $p<0.001$, physicians χ^2 398.821, $p<0.001$; contingency coefficient 0.418 and 0.431, respectively). Percentages of patients discharged or admitted in each triage category are presented in Fig. 3a, b. Regarding patients further admitted to ICU, 93.5% were triaged in category 1 by nurses, 97.7% by physicians and 100% by trained nurses in stage 2.

Resource utilization

The amount of resources used in the ER correlated significantly with the triage category for nurses and physicians (Spearman's rho nurses 0.461, physicians 0.531, $p<0.001$). Figure 3c, d shows the means of resources with SD.

Triage performance according to clinical syndromes

In Table 4, we analyzed the sensitivity and specificity to detect emergencies in different diagnosis groups within stage 1. Sensitivity was lowest for patients with neurooncological disorders and patients with meningitis/meningoencephalitis (nurses 66.7% and 60.0%, resp.; physicians 66.7% and 75%, resp.). For some categories (idiopathic headache, vertigo, inflammatory CNS disease), sensitivity could not be calculated due to no urgent cases in these groups.

Processing times

In stage 1, nurses performed triage significantly faster than physicians for all patients [Ttriage median 8 min (IQR 3–14 min) vs. 11 min (IQR 3–33 min), $p<0.001$] and especially for the subgroups of less urgent [category 2–4;

Table 3 Missed emergencies

	Stage 1 (total number of patients 2356), *n* (%)	Stage 2 (total number of patients 506), *n* (%)	*p* value
Total	61 (2.6%)	6 (1.2%)	0.058
Failure of the algorithm			
Vague history	6 (0.3%)	1 (0.2%)	
Vertebrobasilar stroke	10 (0.4%)	1 (0.2%)	
Secondary deterioration	1 (0.04%)		
Sum	17 (0.7%)	2 (0.4%)	0.412
Application error of the algorithm			
Systolic blood pressure > 220 mmHg	12 (0.5%)	1 (0.2%)	
Transfer with known diagnosis	5 (0.2%)	1 (0.2%)	
Onset > 4.5 h	8 (0.3%)	1 (0.2%)	
Minor symptoms	10 (0.4%)	1 (0.2%)	
Sum	35 (1.5%)	4 (0.8%)	0.221
Other (individual mistakes, unclear reasons)	9 (0.4%)		0.164

Missed urgent patients (reference standard category 1) by nurses or physicians were analyzed for the reason of mistriage. In nine cases of stage 1, reasons for mistriage remained incomprehensible. Total numbers and percentages regarding all patients with a reference standard are indicated. Missed emergencies are compared between stages 1 and 2 using χ^2 test; *p* values are indicated median 8 min [IQR 3–14 min) vs. 15 min (IQR 5–37 min), $p < 0.001$] and self-referring patients [median 9 min (IQR 4–14 min) vs. 21 min (IQR 9–48 min), $p < 0.001$]. In the second stage of the study, nurses performed triage even faster for all patients and all subgroups [overall median 4 min (IQR 2–7 min), category 2–4: median 2 min (IQR 1–4 min), self-referral: median 5 min (IQR 3–9 min)].

Treg-phys was similar in stage 1 to the previous year [median 33 min (IQR 23–59 min) vs. 32 min (IQR 18–53 min), $p = 0.25$]. Tphys-end, however, was significantly shorter in stage 1 than in the previous year and reduced by 14 min [median 1 h 37 min (IQR 1 h 14 min–1 h 52 min) vs. 1 h 51 min (IQR 1 h 24 min–2 h 10 min), $p = 0.011$] and Twait was also significantly reduced by 17 min [median 1 h 21 min (IQR 48 min–1 h 38 min) vs. 1 h 38 min (IQR 1 h 10 min–2 h 4 min), $p < 0.001$].

Comparison with the Emergency Severity Index

Retrospective triage into ESI levels 1–2 versus 3–5 showed a comparable sensitivity for high-urgent patients as triage according to HEINTS: stage 1 87.5% (SD 1.6%), stage 2 85.0% (SD 3.4%). Specificity could not be calculated as we triaged only high-urgent patients (reference standard category 1) according to ESI.

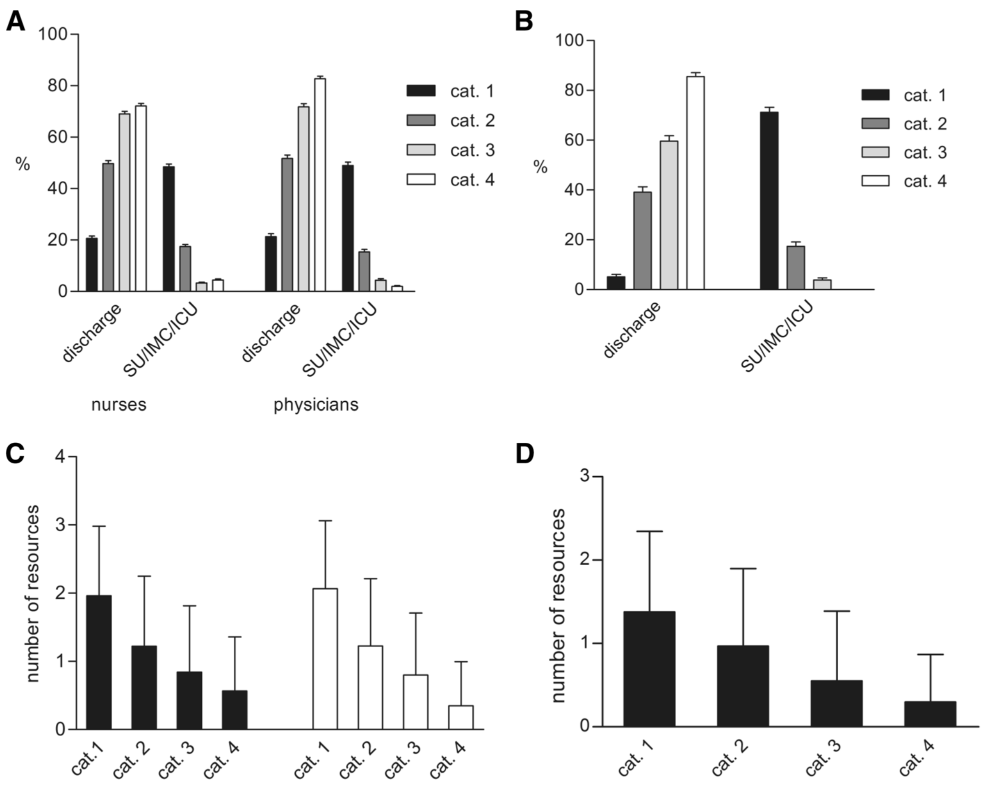


Fig. 3 Correlation of further treatment and resource utilization with triage. **a**, **b** Triage categories correspond to discharge after treatment in the ER as well as to admission to stroke unit (SU)/intermediate care (IMC) or intensive care unit (ICU). Columns show percentage of patients of each triage category with standard deviation (**a** of stage 1 and **b** of stage 2). Total counts of patients triaged by nurses and physicians of stage 1: nurses cat. 1: 555, cat. 2: 571, cat. 3: 638, cat. 4: 326; physicians cat. 1: 534, cat. 2: 473, cat. 3: 588, cat. 4: 158. Total counts of stage 2: cat. 1: 203, cat. 2: 158, cat. 3: 121, cat. 4: 37. **a** Triage by nurses is depicted on the left, triage by physicians on the right side. Discharge: nurses χ^2 329.689, $p < 0.001$, physicians χ^2 346.388, $p < 0.001$; contingency coefficient 0.369 and .401, $p < 0.001$. Admission to stroke unit/IMC/ICU: nurses χ^2 442.720, $p < 0.001$, physicians χ^2 398.821, $p < 0.001$; contingency coefficient 0.418 and 0.431, $p < 0.001$. **b** Discharge: χ^2 77.945, $p < 0.001$; contingency coefficient 0.363, $p < 0.001$. Admission to stroke unit/IMC/ICU: χ^2 109.792, $p < 0.001$; contingency coefficient 0.419, $p < 0.001$. **c**, **d** Increased resource utilization correlates with a more urgent triage category. Resources included imaging, ultrasound, electrophysiology, lumbar puncture, parenteral fluid or drug administration or consultation of other departments. Columns represent the mean of used resources with SD (**c** of stage 1 and **d** of stage 2). **c** Nurses' triage is depicted in black, physicians' in white. Spearman's rho for nurses − 0.461 and physicians − 0.531, $p < 0.001$). **d** Spearman's rho was − 0.409, $p < 0.001$

Table 4 Triage of diagnosis groups

	Nurses			Physicians		
	Sensitivity % (SD)	Specificity % (SD)	*n* total (*n* category 1)	Sensitivity % (SD)	Specificity % (SD)	*n* total (*n* category 1)
Stroke	85.8 (1.6)	83.4 (1.7)	494 (289)	93.3 (1.2)	79.0 (1.9)	451 (270)
Idiopathic headache	0	87.7 (2.0)	261 (1)	100 (0)	85.8 (2.4)	213 (1)
Vertigo	0	98.0 (1.4)	102 (2)	0	92.7 (2.8)	84 (2)
Seizures	82.6 (2.6)	71.6 (3.1)	213 (23)	100 (0)	75.7 (3.2)	176 (21)
Meningitis/meningoencephalitis	60.0 (12.2)	63.6 (12.0)	16 (5)	75.0 (12.0)	66.7 (13.1)	13 (4)
Neurooncology	66.7 (6.2)	88.9 (4.2)	57 (3)	66.7 (7.5)	91.9 (4.3)	40 (3)
Inflammatory CNS	n/a	n/a	42 (0)	n/a	n/a	33 (0)
Peripheral nerve palsy	100 (0)	93.8 (2.2)	115 (2)	100 (0)	93.8 (2.5)	97 (1)
Other neurological disorders	80.0 (1.9)	87.3 (1.6)	423 (15)	85.7 (1.8)	86.3 (1.8)	358 (14)
Non-neurological diseases	85.7 (1.9)	82.2 (2.1)	325 (21)	94.1 (1.4)	79.4 (2.5)	265 (17)

Sensitivity and specificity to detect real emergencies (category 1 according to gold standard) was analyzed within diagnosis groups in stage 1. Percentages are indicated with standard deviation (SD). Total counts and counts of real emergencies (category 1 according to gold standard) are indicated

Discussion

HEINTS represents the first published triage system developed specially for neurological emergency patients in the literature. In this prospective validation study, it showed an acceptable sensitivity to detect the most urgent patients—category 1—of 84.2% (specificity 85.4%) for untrained nurses and 92.4% (spec. 84.1%) for physicians. After training, nurses' sensitivity increased to 94.3%, while specificity decreased. Undertriage was 16.4% (untrained nurses) and 8.7% (physicians), decreasing to 4.9% after training of the nurses. Overtriage ranged between 32.8% and 46.8%. The negative predictive value of triaging less urgent categories was high (nurses 87.4%, trained nurses 94.7%, physicians 89.2%). Construct validation criteria, such as resource utilization, hospital admission and recognition of patients as urgent (category 1) who were subsequently admitted to the ICU showed highly significant correlation to triage categories.

Appropriate validation of triage systems is subject of a controversial debate in the literature. Like the other authors [11, 13], we believe that comparing triage categories to the "true" urgency level, i.e., a gold standard constitutes the best criterion for assessing validity. However, rating "true" urgency is challenging [23] and there is no agreement about criteria for the reference standard. For this reason, the other authors prefer construct validity criteria (i.e., mortality, hospital admission, ED length of stay, etc.) to assess the performance of triage systems [24, 25]. Here, we present both validation methods.

Sensitivity to detect high-urgency patients as well as over- and undertriage also appear to be a useful and simple way to compare triage systems. The largest validation study of the MTS with 288,000 patients compared the five-level MTS triage system to a three-level reference standard [12]. In this study, the sensitivity to detect high-urgency patients was between 48 and 87% (specificity 84–94%) [12]. Undertriage ranged from 6.2 to 14.1%, overtriage from 26.9 to 44.0%. Another study applied a reference standard to the MTS that included 2400 patients, which is the most similar to ours [8]. They found that 19% of the highest emergency category "red" and 59% of category "orange" were not correctly identified by MTS (not specifying about over- and undertriage). Another study compared the validity of MTS, ESI, and an informally structured triage system to a reference standard, including 900 patients [16]. It showed a very low sensitivity to detect the most urgent patients for MTS: sensitivity for recognition of category 1 was 17% and category 2 34%. Triage using the ESI showed a low sensitivity as well: recognition of patients of urgency level 2 was 36%, while level 1 was not assessed. Specificity was high (> 95%) in both MTS and ESI. Undertriage using ESI was 20%, using MTS 11%. Comparing these findings with our results (sensitivity 94.3% in stage 2), HEINTS seems to show a very acceptable performance for both nurses and physicians, being higher than in most comparable studies. We provide an analysis of the reasons leading to mistriage of the most urgent patients showing that the majority (35 out of 61 in stage 1, 4 out of 6 in stage 2) were due to errors in the application of the algorithm. Although undertriage of a highly urgent patient could be potentially devastating, triage with HEINTS shows a good sensitivity for the high-urgent patients and a low rate of undertriage in comparison with the triage studies mentioned above [8, 12, 16].

Correlating triage with hospital admission and resource utilization showed significant, though only moderate results (ranging from 0.363 to 0.461 for hospital admission and from − 0.409 to − 0.531 for resource utilization). In the literature, comparable results are reported for ESI for both validation criteria (hospital admission 0.398–0.486, resource utilization 0.379–0.683) [16, 24, 26–31].

We assessed triage performance of formally untrained and trained nurses. There are only few publications about explicit training effects on performance in triage. One study reported a considerable decrease in undertriage after training in ESI (26.3–9.3%) [32]. Similar effects are reported from the other authors as triage accuracy rises from 42.3 to 92.3% after training [33]. For a broader implementation of HEINTS in other hospitals, a structured training is being developed. This should be used to systematically train nurses before implementing HEINTS and to continuously improve their skills.

In addition to validation, several studies assessed interrater-reliability of triage scales using Cohen's kappa. In one study, the authors compared ratings of a triage nurse to the rating of an MTS expert of 167 patients and had an almost perfect agreement with triage categories (weighted κ 0.954) [24]. In other studies analyzing interrater-reliability of MTS with patient scenarios, unweighted Cohen's kappa ranges between 0.31 and 0.76 [11]. Similar results are reported for interrater-reliability of ESI: κ 0.40–0.91 [10]. Comparing our result of a moderate agreement [34] (κ 0.44 between nurses and physicians) to other studies is difficult as results were obtained in different settings (patient scenarios vs. real patients, retrospective assessment of triage level based on records of triage nurses vs. separate history, ratings of triage nurses vs. triage "experts" vs. physicians, etc.). Therefore, further assessment of interrater-reliability is desirable.

We assessed the performance of the algorithm in different diagnosis groups in stage 1 (Table 4). Most categories showed similar results as the overall performance. The lowest values for sensitivity to detect real urgencies were found for patients with neurooncological disorders or meningoencephalitis. This may be a result of (1) the small numbers of real urgencies in these categories which impairs the statistical validity and (2) the wide range of symptoms that are sometimes very unspecific. However, this is an interesting finding that should be addressed in further research.

Analyzing the time to triage showed that nurses performed triage significantly earlier than physicians (after 8 vs. 11 min, and 4 min in stage 2). Time to triage ranges between 0.95 min and 10 min in the literature [35–38]. As a prompt triage is indispensable for a rapidly initiating treatment in highly acute medical conditions, time to triage is an important safety aspect especially in settings without a designated "triage nurse". Nonetheless, our results support the notion that triaging should be performed by nurses, who usually do have the most immediate contact with the patient. Importantly, by retrieving processing times from our patient information system, we found that the average time from admission of a patient to the first contact with a physician was not reduced by introducing HEINTS, but rather that processing times, including the total patients' waiting time, were subsequently better, indicating an overall improvement in patient flow within the ER.

Comparing the retrospectively calculated sensitivity of ESI-based triage of emergencies, we found similar values for HEINTS in stage 1 for nurses, but higher sensitivity for physicians and trained nurses in stage 2. Owing to methodological aspects, however, this comparison is hampered. Moreover, ESI level 2 in particular is only vaguely defined and ESI only assesses motor and speech deficits, whereas impaired vision, gait disturbances, or paresthesia, etc. are not specified.

The assessment of validity in our study is limited, as it was a single-centre study in a specialized ER at a University Hospital. Due to the special setting, the choice of the emergency room by self-referring patients or EMS preceded triage might have influenced the outcome. Furthermore, as mentioned above, there is no definite agreement on criteria for the gold standard of a true urgency level. To show superiority of HEINTS as triage tool for neurological patients, a direct, similar comparison with existing triage systems would be desirable. Additionally, the integration, applicability and use of HEINTS in an interdisciplinary ER needs to be prospectively evaluated and is currently on its way. We do believe that HEINTS could be easily incorporated into an interdisciplinary triage system, e.g., by switching to HEINTS in an early stage of another triage system. Therefore, we provide a suggested algorithm how HEINTS could be integrated into ESI in Fig. 4. Of note, a triage system should always be adapted to current research. Therefore, we suggest to modify the time window for suspected stroke in Fig. 4 to 24 h due to new clinical practice as a result of new data [39, 40].

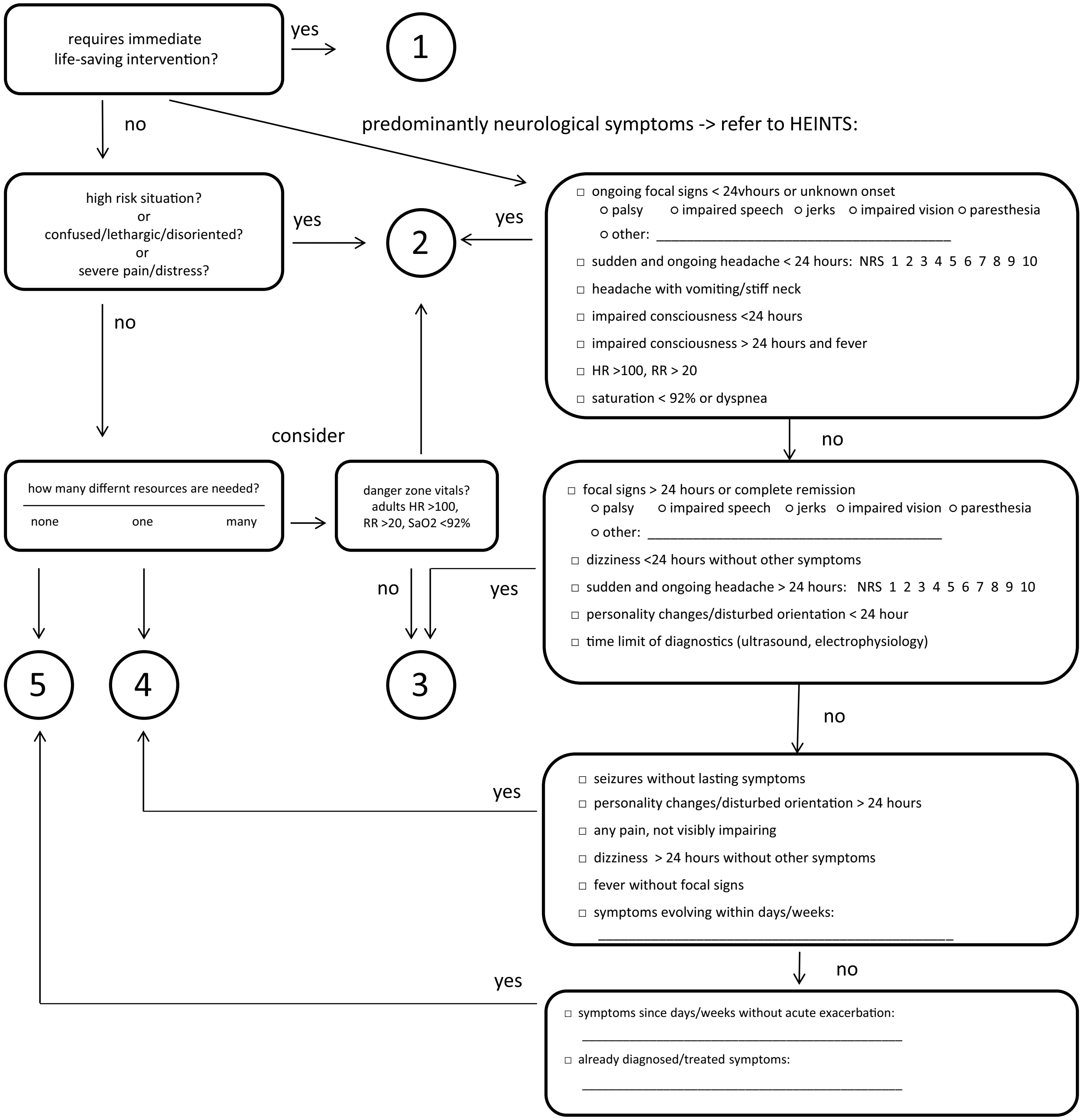


Fig. 4 Integration of HEINTS into ESI. Example of how HEINTS could be integrated into ESI for interdisciplinary emergency rooms. We made slight changes to HEINTS to avoid discrepancies between the two algorithms

Conclusion

HEINTS reliably detected neurological emergencies in patients presenting to a dedicated neurological ER and triage categories were highly significantly correlated with construct validity criteria. Triaging of neurological patients by nurses was preferable, particularly regarding time management, to physicians' triaging. Specialized training of nurses in the use of HEINTS increased sensitivity in identifying neurological emergencies.

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Compliance with ethical standards

Conflicts of interest Dr. Oßwald, Mrs. Harenberg, Dr. Jaschonek, Dr. Mundiyanapurath, and Prof. Rauch have nothing to disclose. Dr. Purrucker reports personal fees from BMS Pfizer, Boehringer Ingelheim and Akcea, outside the submitted work. Dr. Ringleb reports personal fees from Bayer, BMS Pfizer, Boehringer Ingelheim, Grants from Deutsche Forschungsgemeinschaft, outside the submitted work. Dr. Nagel reports personal fees from Brainomix, BMS Pfizer, Boehringer Ingelheim and Medtronic, outside the submitted work.

Ethical standards The study was approved by the institutional review board.

Informed consent Written informed consent was obtained from the participants (nurses, nurse assistants and physicians working in the emergency room). Patients' consent was waived.

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