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# Evaluating pre-hospital triage and decision-making in patients who died within 30 days post-trauma: A multi-site, multi-center, cohort study

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*Introduction:* Evaluating pre-hospital triage and decision-making in patients who died post-trauma is crucial to decrease undertriage and improve future patients' chances of survival. A study that has adequately investigated this is currently lacking. The aim of this study was therefore to evaluate pre-hospital triage and decision-making in patients who died within 30 days post-trauma.
*Materials and methods:* A multi-site, multi-center, cohort study was conducted. Trauma patients who were transported from the scene of injury to a trauma center by ambulance and died within 30 days post-trauma, were included. The main outcome was undertriage, defined as erroneously transporting a severely injured patient (Injury Severity Score $\geq$ 16) to a lower-level trauma center.
*Results:* Between January 2015 and December 2017, 2116 patients were included, of whom 765 (36.2%) were severely injured. A total of 103 of these patients (13.5%) were undertriaged. Undertriaged patients were often elderly with a severe head and/or thoracic injury as a result of a minor fall (< 2 m). A majority of the undertriaged patients were triaged without assistance of a specialized physician (100 [97.1%]), did not meet field triage criteria for level-I trauma care (81 [78.6%]), and could have been transported to the nearest level-I trauma center within 45 min (93 [90.3%]).
*Conclusion:* Approximately 14% of the severely injured patients who died within 30 days were undertriaged and could have benefited from treatment at a level-I trauma center (i.e., specialized trauma care). Improvement of pre-hospital triage is needed to potentially increase future patients' chances of survival.


## Introduction

Trauma remains a major cause of death worldwide [1–3]. Providing specialized trauma care to severely injured patients substantially improves their chances of survival [4–6]. In inclusive trauma systems, specialized care is solely provided at higher-level trauma centers. Adequate pre-hospital triage is therefore crucial and can be life-saving. Pre-hospital trauma triage is generally performed by Emergency Medical Services (EMS) professionals of the ground am-

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bulance. These professionals assess a patient's resource-need at the scene of injury and subsequently determine which level trauma center – higher or lower – is able to provide the needed resources.

Both underestimation and overestimation of a patient's resource-need result in suboptimal treatment. Undertriage – transporting a severely injured patient to a lower-level trauma center – should be prevented as it causes avertible mortality and morbidity [4–6]. Overtriage – transporting a moderately or mildly injured patient to a higher-level trauma center – should be reduced as it results in an overutilization of limited resources and extra costs [7]. As patient outcomes are directly affected by transporting severely injured patients to lower-level trauma centers, reducing undertriage generally takes precedence over reducing overtriage [8].

Data sources (e.g., trauma registries) used in previous studies that evaluated pre-hospital triage in patients who died post-trauma, miss a substantial number of deaths [9], especially in the elderly [10]. In contrast to other registries, the Dutch Trauma Registry includes all admitted trauma patients, regardless of a patient's age or injury severity, who were admitted to any trauma center (i.e., any trauma-receiving hospital) [11] and verifies mortality status after 30 days in all patients included in the registry, which offers the opportunity to adequately evaluate pre-hospital triage in these patients. Additionally, pre-hospital decision-making by EMS professionals may be influenced by multiple factors (e.g., patient acuity, a patient's pre-injury health status, on-scene assistance of a physician, field triage criteria, EMS professional judgement, trauma center proximity) [12] and was to our knowledge not previously investigated in trauma patients who did not survive the first 30 days post-trauma. A meticulous evaluation of pre-hospital decision-making is pivotal to identify possible causes of undertriage among these patients.

The aim of the present study was therefore to evaluate pre-hospital triage and decision-making in patients who died within 30 days post-trauma.

## Materials and methods

This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines [13]. The Medical Ethical Committee of the University Medical Center Utrecht judged this study as not subject to the Medical Research Involving Human Subjects Act (reference number 20/500,747).

### *Study design and setting*

This was a multi-site, multi-center, cohort study, in which eight EMSs (*Amsterdam-Amstelland, Brabant Midden-West, Brabant-Noord, Gelderland-Zuid, Rotterdam-Rijnmond, Utrecht, Zaanstreek-Waterland,* and *Zuid-Holland Zuid*) and seven corresponding inclusive trauma regions participated. The participating EMSs transport approximately 550,000 patients to a hospital annually [14] and serve a region of approximately 8000 square kilometers with a population of roughly 6.5 million people. In the Netherlands, trauma patients are generally transported by ambulance and in highly exceptional cases by helicopter from the scene of injury to an emergency department. Ambulances are staffed with an EMS professional and a dedicated driver. Dutch EMS professionals are specialized nurses licensed to deliver pre-hospital care at an advanced life support level. The dedicated drivers are licensed to deliver care at a basic life support level. In case the dispatch center expects a patient with seriously impaired vital functions, a specialized physician (e.g., a trauma surgeon) is sent to the scene of injury (often by helicopter) to assist the EMS professional. In case an EMS professional is assisted at the scene by a specialized physician, the physician is generally responsible for the pre-hospital decision-making.

In the Netherlands, pre-hospital patient allocation is guided by the field triage criteria of the Dutch National Protocol of Ambulance Services (NPAS) [15], which are depicted in Fig. 1. The protocol was derived from the American Field Triage Decision Scheme (FTDS) [8] and contains comparable criteria for highest level of care (i.e., Dutch level-I trauma care). In the Netherlands, every inclusive trauma region comprises at least one level-I trauma center, which is equipped to treat severely injured patients. These centers meet the criteria for providing highest level of trauma care, as defined by the American College of Surgeons Committee on Trauma (ACSCOT) [8,16]. Dutch level-II and level-III trauma centers are considered lower-level trauma centers, designated to treat mildly and moderately injured patients [16]. In the Netherlands, no trauma patients are transported by ambulance to non-trauma centers. Seven of the 11 Dutch inclusive trauma regions participated in this study, which comprise 67 trauma centers: seven level-I trauma centers and 60 lower-level trauma centers.

### *Patients*

All trauma patients, transported from the scene of injury by a ground ambulance of the participating EMSs, to any emergency department in the participating trauma regions, between January 1, 2015 and December 31, 2017, who died within 30 days post-trauma, were included. Patients were excluded if they were not transported to a trauma center (e.g., died at the scene of injury), were transported to a non-participating trauma region or survived the first 30 days post-trauma. Trauma patients were identified in unfiltered EMS records with an a previously validated selection tool, which was able to select trauma patients with an accuracy of 98.9% (95%-CI, 98.3–99.2) [17].

### *Data collection*

Data were collected by the members of the Pre-hospital Trauma Triage Research Collaborative (PTTRC) to construct a prospective cohort to evaluate pre-hospital triage, of which the patients who died within 30 days post-trauma were evaluated in the present study. Additional information on the collection of EMS records can be found in a prior study performed by the PTTRC [17]. Ambulance records were prospectively collected and consisted of patient demographics, pre-hospital vital signs, and free text fields filled out by EMS professionals. The free text fields contained, among others, a description of the trauma mechanism, diagnostic findings, and considerations regarding the provided pre-hospital treatment(s). Ambulance records were linked to data from the seven inclusive trauma regions collected for the Dutch Trauma Registry. All admitted Dutch trauma patients are prospectively included in this registry [11] and Dutch patients who are discharged from the emergency department are generally not severely injured [17,18]. The registry gathers, among others, all injuries diagnosed within 30 days post-trauma and certain clinical outcomes (e.g., 30-day mortality). The Abbreviated Injury Scale (AIS) 2005, update 2008 was used by trained data registrars to classify injuries and compute Injury Severity Scores (ISS) [19]. Mortality status was verified after 30 days by using the electronic patient documentation system and/or the Personal Records Database (in Dutch, *Basisregistratie Personen*). A combination of deterministic and probabilistic linkage was used to merge the ambulance records with the data from the registry. The patient-record-identifier was used to perform deterministic linkage. For patients with a missing identifier (e.g., patients transported by an EMS to a non-corresponding trauma region), a previously validated prediction model, that comprises several characteristics of the patient/accident (e.g., date of injury, gender, date of birth) was used to perform the probabilistic

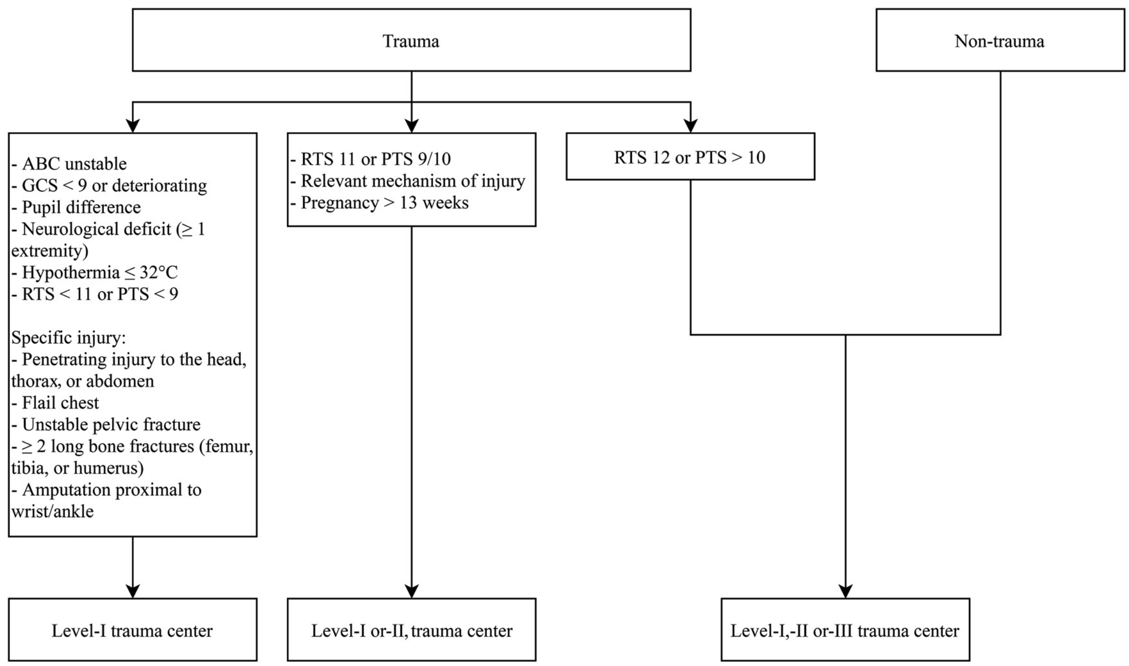


**Fig. 1.** Field triage criteria of the Dutch National Protocol of Ambulance Services (NPAS).
In some areas with long expected transport times, it may be preferred to initially stabilize a severely hemodynamically unstable patient at the nearest hospital that is able to provide an adequate trauma response, if meeting an specialized physician during transport (in Dutch, rendez-vous) is not possible.
GCS: Glasgow Coma Scale; RTS: Revised Trauma Score; PTS: Pediatric Trauma Score.

linkage. This model merges pre-hospital with hospital data with an accuracy of 100.0% (95%-CI, 100.0–100.0) [17].

Postal codes were used to estimate scene of injury locations and exact addresses were used for hospital locations. Both were converted into latitude and longitude coordinates with Open Street Map (OpenStreetMap, Cambridge, UK) [20]. The haversine method was used to select the two nearest level-I trauma centers. Transport times to these centers were estimated using Bing Maps (Microsoft$^{TM}$, Redmond, US) [21], while taking day of the week and hour of the day into account. The shortest estimated transport time to a trauma center was selected as estimated transport time.

*Outcomes and definitions*

The main outcome was undertriage, defined, in accordance with the current guidelines of the Dutch Health Care Institute and the ACSCOT [8], as erroneously transporting a severely injured patient (i.e., a patient with an ISS of 16 or greater) to a lower-level trauma center. Severely injured patients who were transported to a lower-level trauma center as they were hemodynamically unstable or wished/requested not to receive specialized trauma care as a result of their poor pre-injury health status (e.g., patients with a do-not-resuscitate order) according to the records filled out by the EMS professionals, were not considered undertriaged. The following factors were investigated to evaluate EMS professionals' pre-hospital decision-making: patient acuity (i.e., hemodynamic stability), a patient's wish/request not to receive specialized trauma care as a result of their poor pre-injury health status, assistance of a specialized physician, field triage criteria, EMS professional judgement, and trauma center proximity.

*Statistical analysis*

Median values with interquartile ranges (IQRs) were used to describe continuous variables. Frequencies with percentages were used to describe nominal and ordinal variables. Pre-hospital variables with missing values were Glasgow Coma Scale, systolic blood pressure, and respiratory rate. Missing data were analyzed and appeared to be missing at random. A predictor matrix was created to perform multi-level multiple imputation that accounted for cluster differences [22] and generated 48 imputed datasets based on 20 iterations per set. All datasets were used to perform the analyses of variables with missing data. All statistical analyses were performed using R (version 4.0.3) [23].

## Results

From January 2015 to December 2017, 165,404 trauma patients were transported from the scene of injury by an ambulance of the participating EMSs to a trauma center. After excluding 295 patients (0.2%) who were transported to a trauma center in a non-participating trauma region and 162 993 (98.5%) as they survived the first 30 days, 2116 patients (1.3%) were included. An overview of the patient flow is provided in Fig. 2.

Baseline characteristics of the included patients are displayed in Table 1. The included patients had median age of 83.8 years (IQR, 72.5–89.7), 1062 (50.2%) were male, and their injuries resulted in a median ISS of 9 (9–25). More than half of the patients (1351 [63.8%]) were mildly or moderately injured (ISS < 16), of whom many (797 [59.0%]) suffered from a severe injury (AIS ≥ 3) of the lower extremities. The severely injured (ISS ≥ 16) patients more often were men (498 [65.1%] vs. 564 [41.7%]), more frequently showed deviating vital signs (541 [70.7%] vs. 132 [9.8%]), and more often had severe injuries to the head and thorax (532 [69.5%] and 254 [33.2%] vs. 57 [4.2%] and 62 [4.6%], respectively) than the mildly or moderately injured patients.

*Pre-hospital triage*

A total of 128 severely injured patients (16.7%) were transported to a lower-level trauma center (Table 2). Twenty-five of these patients (19.5%) were consciously transported to a lower-level trauma center: 16 (12.5%) as they were considered hemodynamically un-

**Table 1**
Baseline characteristics of patients who died within 30 days post-trauma.

| | All $n$ = 2116 | Mildly or moderately injured (ISS < 16) $n$ = 1351 | Severely injured(ISS ≥ 16) $n$ = 765 |
|---|---|---|---|
| **Patient characteristics** | | | |
| Age (years)* | 83.8 (72.5–89.7) | 86.9 (81.2–91.5) | 71.3 (50.8–82.9) |
| Age < 16 (years) | 17 (0.8) | 0 (0) | 17 (2.2) |
| Age ≥ 65 (years) | 1756 (83.0) | 1303 (96.4) | 453 (59.2) |
| Male sex | 1062 (50.2) | 564 (41.7) | 498 (65.1) |
| ASA classification ≥ 3 | 1013 (47.9) | 788 (58.3) | 225 (29.4) |
| **Trauma mechanism** | | | |
| Fall < 2 m | 1501 (70.9) | 1225 (90.7) | 276 (36.1) |
| Traffic injury | 296 (14.0) | 71 (5.3) | 225 (29.4) |
| Fall ≥ 2 m | 145 (6.9) | 29 (2.1) | 116 (15.2) |
| Penetrating injury | 40 (1.8) | 2 (0.1) | 38 (5.0) |
| Submersion | 34 (1.7) | 0 (0) | 34 (4.4) |
| Asphyxia | 34 (1.6) | 1 (0.1) | 33 (4.3) |
| Burns/explosion | 16 (0.8) | 4 (0.3) | 12 (1.6) |
| Other | 43 (2.0) | 16 (1.2) | 27 (3.5) |
| **Pre-hospital vital signs** | | | |
| Systolic blood pressure < 90 mmHg | 83 (3.9) | 19 (1.4) | 64 (8.4) |
| Respiratory rate > 29/min or < 10/min | 166 (7.7) | 48 (3.6) | 118 (15.4) |
| Glasgow Coma Scale < 13 | 605 (28.6) | 84 (6.2) | 521 (68.1) |
| Revised Trauma Score < 12 | 682 (32.2) | 132 (9.8) | 550 (71.9) |
| **Severe injury (AIS ≥ 3)** | | | |
| Head | 589 (27.8) | 57 (4.2) | 532 (69.5) |
| Face | 22 (1.0) | 1 (0.1) | 21 (2.7) |
| Neck | 18 (0.9) | 1 (0.1) | 17 (2.2) |
| Thorax | 316 (14.9) | 62 (4.6) | 254 (33.2) |
| Abdomen | 47 (2.2) | 3 (0.2) | 44 (5.8) |
| Spine | 96 (4.5) | 15 (1.1) | 81 (10.6) |
| Upper extremity | 9 (0.4) | 3 (0.2) | 6 (0.8) |
| Lower extremity | 890 (42.1) | 797 (59.0) | 93 (12.2) |
| **ISS*** | 9 (9–25) | 9 (5–9) | 26 (24–34) |

Values in parentheses are percentages unless indicated otherwise.
* Values are median (interquartile range). AIS, Abbreviated Injury Scale; ASA, American Society of Anesthesiologists; ISS, Injury Severity Score. Systolic blood pressure missed in 28.0%, respiratory rate in 35.5%, and Glasgow Coma Scale in 18.6% of the patients, all were multiply imputed. Values derived from multiply imputed variables were rounded to zero decimals.

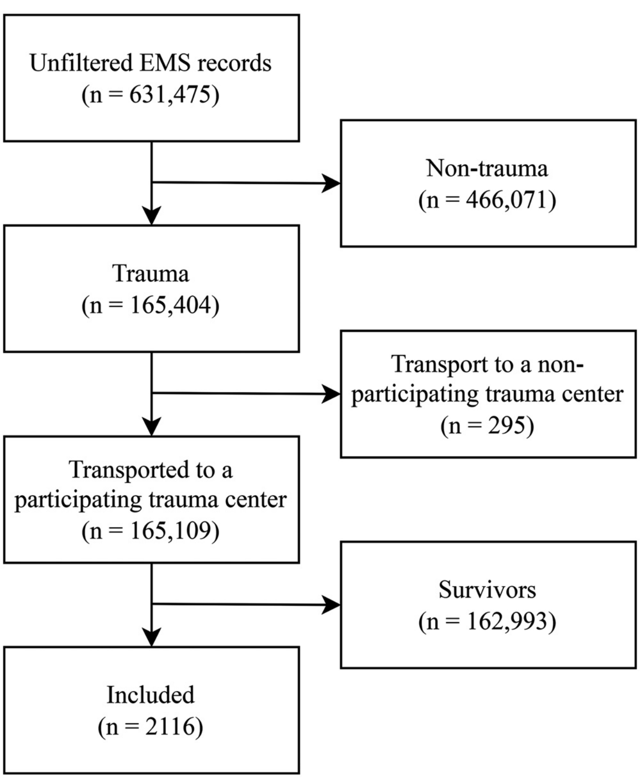


**Fig. 2.** Study flowchart.
EMS: Emergency Medical Services.

stable and 9 (7.0%) as they wished/requested not to receive specialized trauma care as a result of their poor pre-injury health status. The other 103 patients (80.5%) were not identified as severely injured patients at the scene of injury and were considered undertriaged. More than half of the undertriaged patients (54 [52.4%]) died within the first week post-trauma (Fig. 3). Twelve undertriaged patients (11.6%) were transferred from the primary hospital to a different trauma center and another 12 patients (11.7%) died after discharge from the primary hospital.

*Pre-hospital decision-making*

The characteristics of triaged severely injured patients are displayed in Table 2. Severely injured patients who were correctly transported to a level-I trauma center were more severely injured than undertriaged patients (median ISS of 26 [IQR, 25–35] vs. 22[17-26]), had less often severe comorbidities 147 [23.1%] vs. 67 [65.0%], and more often had deviating vital signs (502 [78.8%] vs. 28 [27.2%]). Undertriaged patients often were elderly (98 [95.1%]) with a severe head or thoracic injury (74 [71.2%] and 29 [27.9%], respectively) as result of a minor (< 2 meter) fall (82 [79.6%]).

Factors that may have influenced the pre-hospital decision-making in severely injured patients are displayed in Table 3. In three undertriaged patients (2.9%) the EMS professional was assisted by a specialized physician. A minority of the undertriaged patients met the field triage criteria for level-I trauma care of the Dutch NPAS and the American FTDS (22 [21.4%] and 34 [33.0%], respectively). Table S1 (supplementary information) provides an overview of the criteria of the Dutch NPAS and the American FTDS that were met by severely injured patients. Adding systolic blood pressure < 110 mmHg in elderly patients as a criterion to the

**Table 2**
Pre-hospital triage and characteristics of triaged severely injured patients who died within 30 days post-trauma.

| | Level-I trauma center $n$ = 637 | Lower-level trauma center $n$ = 128 | | |
|---|---|---|---|---|
| | | Undertriaged $n$ = 103 | Hemodynamically unstable $n$ = 16 | At a patient's wish/request $n$ = 9 |
| **Patient characteristics** | | | | |
| Age (years)* | 67.5 (45.4–80.2) | 85.5 (80.1–88.9) | 58 (30–70) | 82 (71–90) |
| Age < 16 (years) | 16 (2.5) | 0 (0) | 1 (6) | 0 (0) |
| Age ≥ 65 (years) | 341 (53.5) | 98 (95.1) | 6 (38) | 8 (89) |
| Male gender | 434 (68.1) | 45 (43.7) | 13 (81) | 6 (67) |
| ASA classification ≥ 3 | 147 (23.1) | 67 (65.0) | 4 (25) | 7 (78) |
| **Trauma mechanism** | | | | |
| Fall < 2 m | 186 (29.2) | 82 (79.6) | 2 (13) | 6 (67) |
| Traffic injury | 212 (33.3) | 10 (9.7) | 3 (19) | 0 (0) |
| Fall ≥ 2 m | 107 (16.8) | 5 (4.9) | 2 (13) | 2 (22) |
| Penetrating injury | 37 (5.8) | 0 (0) | 1 (6) | 0 (0) |
| Submersion | 30 (4.7) | 1 (1.0) | 3 (19) | 0 (0) |
| Asphyxia | 28 (4.4) | 0 (0) | 4 (3) | 1 (11) |
| Burns/explosion | 10 (1.6) | 2 (1.9) | 0 (0) | 0 (0) |
| Other | 25 (3.9) | 2 (1.9) | 0 (0) | 0 (0) |
| Unknown | 2 (0.3) | 1 (1.0) | 1 (6) | 0 (0) |
| **Pre-hospital vital signs** | | | | |
| Systolic blood pressure < 90 mmHg | 56 (8.8) | 3 (2.9) | 4 (25) | 1 (11) |
| Respiratory rate > 29/min or < 10/min | 107 (16.8) | 5 (4.9) | 4 (25) | 2 (22) |
| Glasgow Coma Scale < 13 | 482 (75.7) | 21 (20.4) | 11 (69) | 7 (78) |
| vRevised Trauma Score < 12 | 502 (78.8) | 28 (27.2) | 13 (81) | 7 (78) |
| **Severe injury (AIS ≥ 3)** | | | | |
| Head | 446 (70.0) | 74 (71.2) | 6 (38) | 7 (78) |
| Face | 21 (3.3) | 0 (0) | 0 (0) | 0 (0) |
| Neck | 17 (2.7) | 0 (0) | 0 (0) | 0 (0) |
| Thorax | 219 (34.4) | 29 (27.9) | 5 (31) | 1 (11) |
| Abdomen | 41 (6.4) | 2 (1.9) | 1 (6) | 0 (0) |
| Spine | 72 (11.3) | 8 (7.7) | 1 (6) | 0 (0) |
| Upper extremity | 5 (0.8) | 1 (1.0) | 0 (0) | 0 (0) |
| Lower extremity | 73 (11.5) | 17 (16.3) | 2 (13) | 1 (11) |
| **ISS*** | 26 (25–35) | 22 (17–26) | 25 (22–35) | 25 (19–26) |
| **ISS ≥ 24** | 516 (81.0) | 48 (46.2) | 11 (69) | 6 (67) |

Values in parentheses are percentages unless indicated otherwise.
* Values are median (interquartile range).AIS, Abbreviated Injury Scale; ASA, American Society of Anesthesiologists; ISS, Injury Severity Score. Systolic blood pressure missed in 24.1%, respiratory rate in 29.9%, and Glasgow Coma Scale in 18.2% of the severely injured patients, all were multiply imputed. Values derived from multiply imputed variables were rounded to zero decimals.

**Table 3**
Pre-hospital decision-making in severely injured patients who died within 30 days post-trauma.

| | Level-I trauma center $n$ = 637 | Lower-level trauma center $n$ = 128 | | |
|---|---|---|---|---|
| | | Undertriaged $n$ = 103 | Hemodynamically unstable $n$ = 16 | At a patient's wish/request $n$ = 9 |
| **External involvement in decision-making** | | | | |
| Assistance of a specialized physician | 315 (49.5) | 3 (2.9) | 1 (6) | 1 (11) |
| **Field triage criteria for level-I TC** | | | | |
| Dutch NPAS | 498 (78.2) | 22 (21.4) | 16 (100) | 6 (67) |
| American FTDS | 561 (88.1) | 34 (33.0) | 14 (88) | 7 (78) |
| **Estimated transport time** | | | | |
| To original destination* | 21.2 (13.4–31.2) | 12.3 (7.6–17.6) | 18 (11–21) | 14 (11–21) |
| To nearest level-I TC* | 21.0 (12.9–30.7) | 31.6 (20.6–38.7) | 38 (29–46) | 28 (17–29) |
| To original destination < to nearest level-I TC | 2 (0.3) | 96 (93.2) | 15 (94) | 8 (89) |
| ≤ 30 min to nearest level-I TC | 466 (73.2) | 45 (43.7) | 5 (31) | 7 (78) |
| ≤ 45 min to nearest level-I TC | 596 (93.6) | 93 (90.3) | 11 (69) | 8 (89) |

Values in parentheses are percentages unless indicated otherwise.
* Values are median (interquartile range).EMS, Emergency Medical Services; FTDS, Field Triage Decision Scheme; NPAS, National Protocol of Ambulance Services; TC, trauma center.Systolic blood pressure missed in 24.1%, respiratory rate in 29.9%, and Glasgow Coma Scale in 18.2% of the severely injured patients, all were multiply imputed. Values derived from multiply imputed variables were rounded to zero decimals.

American FTDS would have increased the number of undertriaged patients who met its criteria for level-I trauma care to 39 (37.9%). The estimated transport time to the nearest level-I trauma center was longer for undertriaged patients than for the severely injured patients transported to a level-I trauma center (median: 31.6 min [IQR, 20.6–38.7] vs. 21.0 min [12.9–30.7]; > 30 min: 58 [56.3%] vs. 171 [26.8%]). In 96 undertriaged patients (93.2%) the estimated transport time to their original destination was shorter than to the nearest level-I trauma center and in 93 undertriaged patients (90.3%) the estimated transport time to the nearest level-I trauma center was 45 min or less.

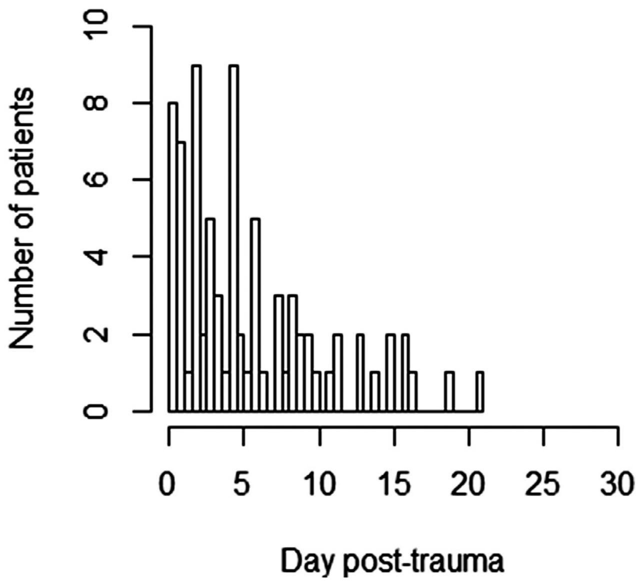


**Fig. 3.** Day of death of the undertriaged patients.
Day of death missed in the 12 patients (11.6%) who were transferred and in the 12 patients (11.7%) who were discharged from the primary hospital.

## Discussion

This multi-site, multi-center, cohort study evaluated pre-hospital triage and decision-making in trauma patients who died within 30 days post-trauma. We found that 14% of the severely injured (ISS $\geq$ 16) patients who did not survive the first 30 days were undertriaged (i.e., erroneously transported to a lower-level trauma center). Undertriaged patients were often elderly with a severe head and/or thoracic injury as a result of a minor (< 2 m) fall. A majority of these patients were triaged without assistance of a specialized physician (97%), did not meet field triage criteria for level-I trauma care (79%), and could have been transported to the nearest level-I trauma center within 45 min (90%). This study illustrates that improving pre-hospital triage could potentially increase future trauma patients' chances of survival.

The strengths of this study were its generalizability, interregional linkage of patient records, and standardized methods used to collect data. First, eight different EMSs covering different types of regions (urban, suburban, and rural) participated in this study, which increases the generalizability of our results to a general pre-hospital trauma population [24]. Second, records from eight different EMSs were linked to records from seven different inclusive trauma regions, minimizing the chance of selection bias (i.e., missed patients who died post-trauma). Third, the data were prospectively and systematically gathered in a standardized manner by the EMSs and the Dutch Trauma Registry. Moreover, the Dutch Trauma Registry includes all trauma patients,regardless of their age or injury severity, who are admitted to any trauma center (i.e., any trauma-receiving hospital) [11]. Furthermore, an extensive evaluation of pre-hospital triage and decision-making was possible as result of the adequate linkage of the pre-hospital and hospital data. Linkage of both data sources is essential, as self-transported (i.e., non-referred) patients should be excluded to determine undertriage rates of EMSs. Only these rates can directly be improved by EMSs, in contrast to undertriage rates provided by trauma regions.

A limitation of the current study is that patients transported to a trauma center in a non-participating trauma region were excluded. However, the chance of selection bias was minimized by the interregional linkage of pre-hospital and hospital data (295 of the 165,404 records [0.2%] could not be linked). Moreover, a substantial number of patients die after the 30th day post-trauma [25] and were therefore not included in this study. As mortality status is currently only verified after 30 days by the registry this was the best available offset to maximize the follow-up period and minimize missing patients. More automated techniques based on electronic health record data are needed to extend the follow-up period of trauma patients included in registries to further improve trauma research on mortality [10,26]. Furthermore, due to the anonymization needed to link the pre-hospital and hospital data we were not able to retrieve causes of death. Finally, patients who died at the scene of injury or during transport were not included in this study. However, as these were patients in whom resuscitation was terminated at the scene of injury or during transport, as patients who died at the emergency department are included in the registry, treatment at a level-I or a lower-level trauma center will probably not have influenced most of these patients' chances of survival.

In the present study, 16 patients (13%) were consciously transported to lower-level trauma centers as they were considered hemodynamically unstable by EMS professionals. Even though the Dutch NPAS allows EMS professionals to transport hemodynamically unstable patients in exceptional cases to the nearest hospital, is considering these patients as correctly triaged debatable. Since the concept of the golden hour was introduced [27], there is an ongoing debate on the impact of transport times on mortality in hemodynamically unstable patients. A recent study found that an increase in total pre-hospital time was associated with increased mortality in a general trauma population [28]. Other previous studies did not find an association between pre-hospital time and mortality in physiologically abnormal trauma patients [29] or only in certain patients [30] after the first pre-hospital hour [31]. In our study, the estimated transport time to a level-I trauma center of most hemodynamically unstable patients (69%) and the lion's share of the undertriaged patients (90%) was 45 min or less. This implies that, in most cases, transport time to a level-I trauma center itself should not have been a reason for transport to a lower-level trauma center. Moreover, the estimated transport time to the nearest level-I trauma center was substantially longer for undertriaged patients (> 30 min in 55%) than for severely injured patients transported to a level-I trauma center (> 30 min in 27%), which suggests that transport time to a level-I trauma center might influences a patient's chance of being undertriaged. Future research could focus on the causal relationship between transport time and mortality/undertriage.

Pre-hospital triage of severely injured patients is difficult and needs improvement. Evaluating field triage through well-designed research is the first step in improving pre-hospital trauma care [32]. We found that a majority of the patients who died post-trauma and were transported to a lower-level trauma center (81%), were not identified as severely injured at the scene of injury. Most of these patients (95%) were elderly, which is in accordance with previous studies that investigated undertriaged patients [6,18,33-35]. A possible cause for underestimating injury severity in elderly is that low-energy accidents may result in serious injuries in this population [36]. EMS professionals should therefore be cautious to exclude possible fatal injuries in elderly that suffered from a low-energy trauma. Moreover, we found that in a majority of the undertriaged patients the decision-making was performed without assistance of a specialized physician (97%). Previous research found that the decision-making of EMS professionals is an important source of variation in pre-hospital triage [37]. Additional training of EMS professionals may therefore reduce undertriage and could possibly decrease preventable deaths [37].

A majority of the undertriaged patients (79%) did not meet the Dutch field triage criteria for level-I trauma care. The present study adds knowledge on characteristics of undertriaged patients who died within 30 days post-trauma, which could be used to improve the currently used field triage criteria. Possible improvements could for example be: replacing the criterion 'Glasgow Coma Scale score < 9 or deteriorating' of the Dutch NPAS by 'Glasgow Coma Scale score < 14′ or adding the criterion systolic blood pressure < 110 mmHg in elderly patients to the American FTDS. Such modifications should however be investigated in studies including all pre-hospital trauma patients to assess the potential effect on overall triage rates. Moreover, the currently used protocol is a static decision scheme and previous research has shown that it is limited in identifying severely injured patients [17,18], as were the other previously developed triage tools [38]. Another solution, in this era of digitalization and emerging technology, would be to integrate a pre-hospital prediction model in a mobile application to enable EMS professionals to calculate a patient's probability to be severely injured at the scene of injury [39]. Such prediction model could complement EMS professionals in their intuition as it is able detect more subtle patterns of signs and symptoms, whereas it is almost impossible to disentangle and weigh all contributing factors by heart. Further research is needed to determine whether undertriage rates will decrease by putting such pre-hospital prediction model into practice.

## Conclusion

Approximately 14% of the severely injured deceased trauma patients were erroneously transported to a lower-level trauma center. These undertriaged patients could have benefited from treatment at a level-I trauma center (i.e., specialized trauma care). Improvement of pre-hospital triage is needed to potentially increase future patients' chances of survival. Additional training of EMS professionals, modifying the currently used pre-hospital field triage criteria and/or implementing a pre-hospital prediction model into practice are possible strategies to achieve this.

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Availability of data and material: available upon a reasonable request that needs to be approved of the participating Emergency Medical Services and trauma regions, provided that appropriate ethical approval is sought.

Code availability: available upon request

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2022.02.047.

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