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Outcomes and potential for improvement in the prehospital treatment of penetrating chest injuries in a European metropolitan area: A retrospective analysis of 2009 – 2017

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ABSTRACT

Background: Trauma is the leading cause of death in patients <45 years living in high-resource settings. However, penetrating chest injuries are still relatively rare in Europe – with an upwards trend. These cases are of particular interest to emergency medical services (EMS) due to available invasive treatment options like chest tube placement or resuscitative thoracotomy. To date, there is no sufficient data from Austria regarding penetrating chest trauma in a metropolitan area, and no reliable source to base decisions regarding further skill proficiency training on.

Methods: For this retrospective observational study, we screened all trauma emergency responses of the Viennese EMS between 01/2009 and 12/2017 and included all those with a National Advisory Committee for Aeronautics (NACA) score ≥ IV (= potentially life-threatening). Data were derived from EMS mission documentations and hospital files, and for those cases with the injuries leading to cardiopulmonary resuscitation (CPR), we assessed the EMS cardiac arrest registry and consulted a forensic physician.

Results: We included 480 cases of penetrating chest injuries of NACA IV-VII (83% male, 64% > 30 years old, 74% stab wounds, 16% cuts, 8% gunshot wounds, 56% inflicted by another party, 26% self-inflicted, 18% unknown). In the study period, the incidence rose from 1.4/100,000 to 3.5/100,000 capita, and overall, about one case was treated per week. In the cases with especially severe injury patterns (= NACA V-VII, 43% of total), (tension-) pneumothorax was the most common injury (29%). The highest mortality was seen in injuries to pulmonary vessels (100%) or the heart (94%). Fifty-eight patients (12% of total) deceased, whereas in 15 cases, the forensic physician stated survival could theoretically have been possible. However, only five of these CPR patients received at least unilateral thoracostomy. Regarding all penetrating chest injuries, thoracostomy had only been performed in eight patients.

Conclusions: Severe cases of penetrating chest trauma are rare in Vienna and happened about once a week between 2009 and 2017. Both incidence and case load increased over the years, and potentially life-saving invasive procedures were only reluctantly applied. Therefore, a structured educational and skill retention approach aimed at both paramedics and emergency physicians should be implemented.

Trial registration: Retrospective analysis without intervention.

Abbreviations: SW, stab wound; GSW, gunshot wound; EMS, emergency medical service; ICU, intensive care unit; ALS, advanced life support; BLS, basic life support; CPR, cardiopulmonary resuscitation; NACA, National Advisory Committee for Aeronautics; SD, standard deviation; ANOVA, Analysis of Variance; ED, emergency department; REBOA, resuscitative endovascular balloon occlusion of the aorta; ISS, injury severity score.

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Introduction

In young patients under 45 years living in high-resource settings, the leading cause of death is trauma. [1] As opposed to war zones or countries like the United States or South Africa, penetrating trauma in Europe is still relatively rare, with certain regional differences. [2–11] Registry data from Germany appoint around five percent of severe trauma cases to penetrating injuries, with around half not having occurred accidentally. [3] Even though not frequent in total numbers, the relative majority of penetrating trauma to the neck, chest or abdomen accounts for stab wounds (SW) or gunshot wounds (GSW), of which almost all are the result of interpersonal violence or suicide attempts. [2,3] SW seem to be more frequent than GSW, immediate surgery is necessary in around 83%, and around half require prolonged intensive care unit (ICU) treatment. [2] Although previous data are ambiguous whether respective incidences are rising or not, an upwards trend can be noted – especially in metropolitan areas with, suspectedly, higher crime rates than in rural regions. [2,4–6,12] Penetrating trauma to the chest is of particular interest to emergency medical services (EMS) due to available advanced trauma life support treatment options in the field like chest seals, needle decompression, finger thoracostomy, chest tube placement, or resuscitative ("clamshell") thoracotomy [13–18], with the latter being increasingly recommended as a last resort in traumatic cardiac arrest [19]. As the chest is reported as the most common area of penetrating injury [5,20], it seems crucial for EMS or trauma network administrators to have an epidemiologic overview of this injury pattern in their respective regions. To date, there is no sufficient data from Austria regarding penetrating chest trauma in a metropolitan area, and no reliable source to base decisions regarding further trauma skill proficiency training on. This study therefore aimed at analyzing the respective frequencies and injury types in the city of Vienna.

Methods

Study population and data acquisition

The capital city of Austria, Vienna, comprises around two million inhabitants, with a steady increase in the past decades. The governmental EMS provides advanced life support (ALS) units with paramedics and emergency physician cars. This system is supported by several non-governmental organisations providing both basic life support (BLS)- and ALS units. In addition, one EMS helicopter is available (, with the possibility of others from surrounding municipalities responding to missions within the area of Vienna. Personnel-wise, the ALS paramedics have advanced training in (poly-)trauma management but can legally not perform any respective invasive interventions (e.g., thoracostomy). In Austria, there is no medical physician specialty for emergency medicine, but rather, emergency physicians are mostly anesthesiologists, internists, intensivists, trauma surgeons, or general practitioners, all board-certified for prehospital emergency medicine. Thus, their experience with trauma care varies greatly. Also, in our study period, the technique of prehospital resuscitative ("clamshell") thoracotomy was not yet taught or used in the prehospital setting in Vienna. During the study period from 2009 to 2017, applicable guidelines concerning traumatic cardiac arrest were, respectively, those by the European Resuscitation Council from 2005, 2010, and 2015. [21–23] However, these guidelines were always applied at the discretion of the emergency physician, and, as stated, according to their experience. Regarding the receiving hospitals, there are seven large trauma centers in the municipal area, with the university hospital (Vienna General Hospital) being the largest and only Level I trauma center. In addition, six other hospitals (four as Level II and two as Level III trauma centers) can be approached by the EMS. For this retrospective observational study, we screened all trauma emergency responses by the Viennese EMS between 01/2009 and 12/2017, which is the timeframe from the introduction of full digital EMS documentation in 2009 and organizational changes in 2017 (prehospital emergency physicians becoming affiliated with various hospitals and a change in the electronic patient reporting forms rendering data entry and extraction distinctively different), thus rendering conditions as homogenous as possible. Data were derived from the routine digital EMS mission documentation system for all ambulances and emergency physicians, and in case multiple files for one mission existed (e.g., one from the paramedics and one from the physician), information was merged. In addition, for those cases with the injuries leading to cardiopulmonary resuscitation (CPR), we assessed data from the EMS cardiac arrest registry. Additional data, for instance autopsy reports, came from patients' clinical hospital files and from the respective forensic physician. All data were then collectively entered in an electronic case report form. Inclusion criteria consisted of: Penetrating trauma to the chest, and a classification as National Advisory Committee for Aeronautics (NACA) score $\geq$ IV. The NACA score [24,25] – a tool for grading medical or traumatic emergencies in classes of severity from I (minor disturbance) to VII (dead) – is standardly used by the Viennese EMS and is performed as part of the mandatory electronic documentation by paramedics and emergency physicians. For this study, we chose only to include NACA $\geq$ IV, meaning *a life-threatening condition not excludable*. Study exclusion criteria comprised all other kind of trauma or penetrating trauma to areas other than the chest, and heavily incomplete data sets.

Ethical approval for this study was given by the Ethical Committee of the Medical University of Vienna, Austria (No. 2296/2017), and informed consent was waived. The study protocol complies with the Declaration of Helsinki.

Statistical analysis

We used counts, percentages, means, and standard deviations (SD) for descriptive characteristics. Associations between parameters were assessed using Analysis of Variance (ANOVA), or, if not normally distributed, Kurskal-Wallis test. A p-value of <0.05 was deemed statistically significant. Data were processed in Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA), and analyses were conducted via SPSS 22.0 (IBM, USA).

Results

Epidemiology of penetrating chest trauma in Vienna

Fig. 1 gives an overview of the study population. During our study period between 2009 and 2017, the Viennese EMS responded to 480 cases of penetrating chest injuries in the NACA categories IV-VII (NACA IV: $n = 274$ or 57%; NACA V: $n = 153$ or 32%; NACA VI: $n = 11$ or 2%; NACA VII: $n = 42$ or 9%). These cases are 0.02% of the roughly 2.420.000 total EMS missions in the observational period. Most patients (83%) were male, 64% were >30 years old, while 32% were between 18 and 30 years old, leaving 4% of pediatric and adolescent patients >18 years of age. 355 SW (74%), 77 cuts (16%) and 40 GSW (8%) were reported. About 56% of patients were injured by another party, 26% of injuries were self-inflicted, and 18% were of undetermined cause.

The total case numbers rose from $n = 23$ in 2009 to $n = 66$ in 2017 ($p<0.001$), and while the population in the city increased as well by around 200.000 people, the incidence per capita rose from 1.4 per 100,000 to 3.5 per 100,000 inhabitants of Vienna. On average, 53.3 cases (= 3.0 per 100,000) of penetrating chest injuries in a severe condition of NACA IV or higher were treated per year, amounting to around one case per week. Most penetrating injuries occurred during nighttime from 10:00 p.m. and 06:00 a.m. (39%), closely followed by the period between 02:00 p.m. and 10:00 p.m. (37%) in the afternoon and evening. Cases were relatively evenly distributed regarding the days of the week, with only slightly higher numbers on weekends ($p = 0.075$). In 82% of cases, an emergency physician was present in addition to the

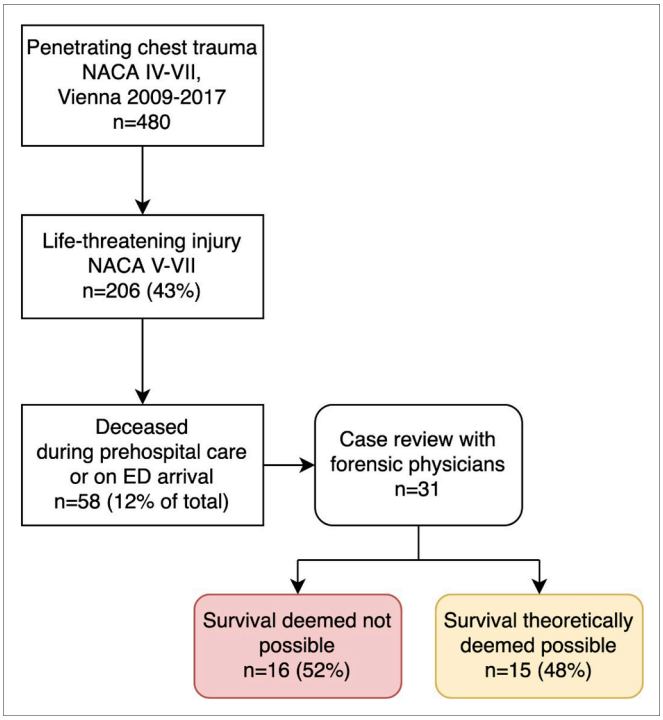

Fig. 1. Overview of the study population and the epidemiology of penetrating chest trauma in the National Advisory Committee for Aeronautics (NACA) score categories IV-VII. ED = emergency department.

paramedics. On average, the emergency physician response cars attended to less than one case per month, naturally meaning a lot fewer per individual physician in the duty roasters. The mean time spent by the EMS on scene was 26 (SD: 16) minutes, with significantly differing periods regarding NACA subclassifications (*Fig. 2*).

Regarding the 23 different political districts of Vienna, the respective case incidences were distributed significantly inhomogenously, ranging from the fourth district only showing one case during the study period and the tenth district having 71 cases. Incidences per 100.000 capita in the districts were also varying significantly, with the first district (the historic city center and tourist magnet) demonstrating the highest with 91 per 100.000 inhabitants. Incidence data of the Viennese districts can be found in *Supplemental Figure 1*, and Viennese population demographics and case details along with timing details are depicted in *Fig. 3*.

Injury details and mortality rates

Of all 480 cases, 75% had a Glasgow Coma Scale (GCS) of 14 or 15 on EMS arrival, meaning patients being awake, and 13% were deeply unconscious with a GCS of 3. Only 9% of cases received advanced airway interventions including supraglottic devices, endotracheal intubation or coniotomy.

We examined those cases with especially severe injury patterns (=NACA V-VII, n = 206, 43% of total included patients) more closely and assessed patients' final diagnoses and/or autopsy results: Pneumothorax was the most common injury (n = 59 or 29%), including 3 tension pneumothoraces. We would like to note that diagnosing a tension pneumothorax is hard once it has been treated, so the regarding numbers may not be highly reliable. Other traumata of the chest cavity included hemothorax (n = 28 or 14%), an injured lung (n = 18 or 9%), or an injured heart (n = 18 or 9%). There were 15 (7%) pericardial effusions and 3 (2%) pericardial tamponades. Pulmonary vessels were affected in four cases (2%), and reported massive blood loss was found in 36 cases (18%).

Highest mortality (either pre-hospital scene or ED) was seen in injuries to the pulmonary vessels (mortality: 100%) or the heart (mortality: 94%), in tension pneumothorax (mortality: 80%) or the lung (mortality: 72%), and with massive blood loss (mortality: 72%). Pericardial effusion, cardiac tamponade, and hemothorax (on either side) each showed a mortality of 60–65%.

In 52 cases (25%), the so-called "cardiac box" (= the area demarcated by the clavicles, the xiphoid process, and both mammillae) was injured. Note that a patient could have had multiple injuries and thus appear more than once in the given numbers.

Traumatic cardiac arrest and autopsies

Since we were mainly interested in patients that could, potentially, have been treated more effectively by the EMS, we tried to learn as much as possible about the 58 individuals (12% of total included or 28% of the

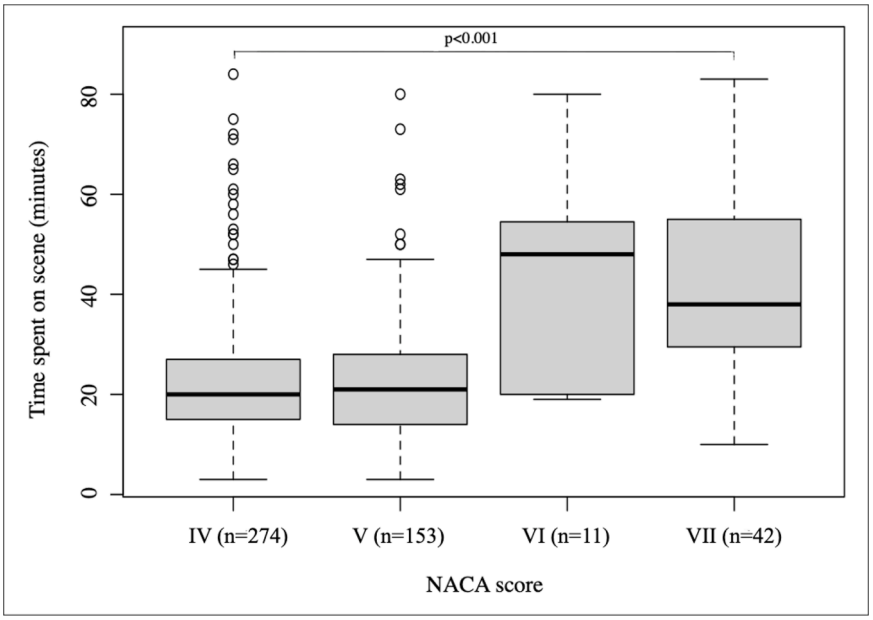

Fig. 2. Time spent by the EMS on scene, classified into National Advisory Committee for Aeronautics (NACA) score categories IV-VII.

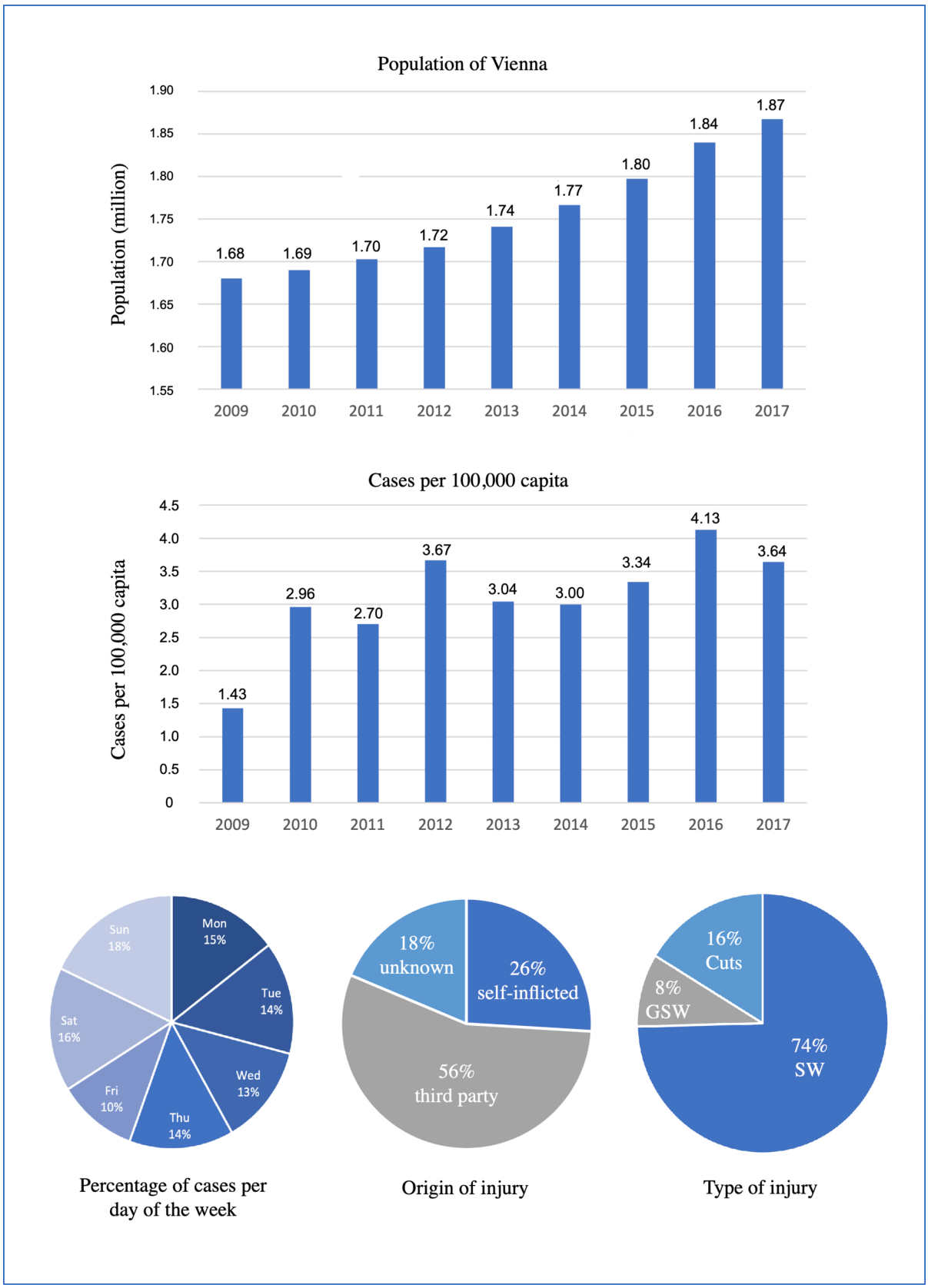

Fig. 3. Viennese population demographics and respective cases of severe chest trauma per 100,000 capita, as well as details on the timing, the origin, and the type of injuries.

NACA V-VII patients) who died during the prehospital treatment phase or at the emergency department (ED) at hospital arrival. We were given the chance to receive information from the respective forensic physician in 31 cases, which stated exsanguination ($n = 26$ or 45% of NACA VII patients) as one of the main causes of death. Cardiac tamponade, hypoxia, and air embolism were each listed once (each 2%), and five patients (9%) yielded an "other" cause of death (e.g., "destroyed" heart, subarachnoid hemorrhage, multiorgan failure, brainstem injury).

We went through the reports together with the forensic physician and tried to identify patients that had died from treatable causes, especially those where more- or more intense EMS treatment could potentially have changed the clinical course. Out of the available 31 reports, we identified 16 cases (52%) where survival would definitely not have been possible as deemed by the forensic expert – of those, six patients had been found dead on EMS arrival. This leaves 15 patients who might have been salvageable: Of those, eight patients had a pneumothorax or hemothorax, one had suffered from pericardial effusion, and one exsanguinated from several superficial incisions.

Cardiopulmonary resuscitation (CPR) was initiated by the EMS in 24 patients (41% of NACA VII cases), eight of which were transported to the hospital with ongoing CPR. The first documented heart rhythm was asystole in 13 (54%)-, pulseless electrical activity in 10 (42%)-, and ventricular fibrillation or pulseless ventricular tachycardia in 1 (4%) case. None of the 24 patients survived. Only in five CPR situations (9% of NACA VII patients and 21% of CPRs), the patients had received specific treatment (by at least unilateral thoracotomy) from the EMS. It is also worth mentioning that the time spent on scene increased significantly when CPR was performed (from 20.6 [9.6] to 36.1 [16.6] minutes, $p<0.001$; data only available in patients that were transported). Overall, regarding all penetrating chest injuries, the EMS had only performed thoracostomy in eight patients although 59 pneumothoraxes and/or hematothoraces had been found later on. On ED arrival, 34 patients had a thoracostomy or chest tube done immediately by the hospital physicians.

Discussion

Key findings of this study were the epidemiologic description of penetrating chest trauma in Vienna, and the, so far, reluctant application of invasive – potentially life-saving – procedures.

A wind of change

Incidences and causes of penetrating chest injuries in Vienna are fairly consistent with European literature: most of the patients were stabbed rather then shot and penetrating injuries are, overall, rare, with a caseload of around one per week in our study period. Also the fact that most of our study population is male and was injured by another party is consistent with existing studies. [2–9] The even higher percentage of male victims in international data when compared to Vienna [2] cannot be fully explained. Although Vienna is regarded as a relatively safe city by its inhabitants and Austria has a strict civilian weapon ownership legislation, we could show an upwards trend of penetrating chest trauma in incidences – a tendency also reported from other metropolitan areas worldwide [2,4–6,12] and frequently leading to public outcries after tragic cases [26,27].

Reluctant invasive interventions

Environmental-wise, the metropolitan area of Vienna would theoretically provide excellent conditions for caring for severely injured patients and features all links in a chain of (potential) survival [28] for traumatic cardiac arrest: The EMS can be on scene in around 8–12 min, there is one Level I-, four Level II, and two Level III trauma centers, and a helicopter service is on duty when possible, depending on weather conditions. Naturally, these response times, should always be as short as possible and thus pose a potential future goal for improvement.

Although immediate and invasive treatment may increase survival in penetrating trauma [29,30], relatively few invasive procedures were performed on our study population: During the 9-year study period, only 8 out of 480 patients received a chest tube in the field, but 34 had a thoracostomy or chest tube done immediately after arriving at the ED, suggesting that the need and indication for the procedure might have been there already during the prehospital phase. This is also supported by recent data from the USA suggesting at least high-quality ALS measures and important invasive procedures must be started / conducted before rapid transport. [30] Our on-scene times of roughly between 20 and 35 min would probably allow this.

This paradox combination of rising incidences, a high morbidity and mortality burden of affected patients, and clear rules of conduct [19,31,32] on the one hand, and the reluctancy of the EMS towards invasive measures on the other hand was somewhat surprising for the authors. Especially regarding traumatic cardiac arrest patients, being those with the most severe injuries and with the most favourable risk/benefit ratio for invasive procedures, the low number of performed interventions, the potentially salvageable individuals as suggested by the forensic physician, and a 100% mortality should now spark the desire to improve our system. However, one must bear in mind that in the study period, no obligatory education or training on, for instance, resuscitative thoracotomy was conducted, and that problem awareness of emergency physicians towards their own skills in this regard surely was suboptimal. Moreover, proficiency in bespoke interventions can hardly be achieved or maintained with attending the calculated less than one case per month per emergency physician response car. [33–35] We acknowledge that most physicians not only work EMS shifts but also in hospitals, and that there are also other pathologies than penetrating trauma necessitating, for example, the placement of a chest tube; however, in total, the overall proficiency remains questionable. In addition, the non-technical skills required for successful task execution must be acquired and trained. [36]

To adapt and overcome

This study clearly indicates the need to adapt the prehospital system to provide the invasive trauma management procedures that patients need. Also, novel in-hospital techniques such as extracorporeal CPR or resuscitative endovascular balloon occlusion of the aorta (REBOA; especially for infradiaphragmatic injuries) could potentially increase the number of cardiac (peri-)arrest patients that can appropriately and sensibly be brought to a trauma center by the EMS in the future. [37–41] Current recommendations state expertise, equipment, environment, and elapsed time as cornerstones for complex interventions such as resuscitative thoracotomy [19,42,43]; First stage-wins have already been achieved: Austria has reformed its emergency physician training and -examination program, for instance now requiring a certain number of clinically performed chest tubes [44], portable ultrasound machines have been introduced to all emergency physician cars in Vienna – a diagnostic tool that is internationally used for the evaluation of penetrating chest trauma [45–48] –, and resuscitative thoracotomy is now started to be structurally taught due to promising international data [19,49]. Specific trauma team-training, a parallel focus on non-technical skills and decision making, and a program for skill retention pose an additional challenge and are yet to be developed; medical simulation – also on animal models – could play an important part. [50–53] Most importantly, all personnel involved must support a no-blame policy and see the current non-proficiency in mentioned procedures as a challenge rather than failure. [54,55]

Outlook and future research

Following this study period ranging until 2017, future endeavours should focus on the subsequent years. Comparisons with this study,

more detailed insight into patients' actual pathologies or causes of death, other outcomes, follow-ups, and the integration of more organizational and clinical variables into analyses could be considered. We encourage the involvement of forensic physicians, as they can provide invaluable insights into what transpired during and after the EMS mission. [56]

Limitations

This study contains several limitations: Data were partly incomplete due to the retrospective nature of their assessment. For instance, it was not possible due compare patient outcomes with the respective trauma centers and their levels in Vienna. Also, certain information that would have been interesting to include was not available because the standard EMS reporting forms just did not have those data points (e.g., injury severity scores (ISS) or details on blood loss). Another issue was the reliability of reporting of injured structures as we did not have access to radiologic images but had to use the information provided in the written reports. Further, our sample of just 31 forensic reports is relatively small, and judging whether a patient could have survived or not was mostly an expert opinion and not based on other influencing factors which we did not have information on (e.g., elapsed timeframes, speed of blood loss, etc.). The present study can only report associations rather than causality as the data usually did not allow a direct link between the injured structure and the cause of death. Lastly, our work comprised patients from a single, high-resource metropolitan region and thus, generalization of the findings to other settings and systems, even in Austria, may be limited. However, our findings are likely to be applicable to various cities around the world, and a mentioned intervention / education program may be widely appropriate. The noted inhomogeneity of case numbers in the various Viennese districts can on the one hand be seen as a potential selection bias, but on the other hand this depicts, for instance, the tenth district being a social and crime hotspot. A future focus on preventive work by law enforcement could be discussed. Also, the used methodology could be used in other metropolitan EMS to assess the adequacy of prehospital penetrating trauma management.

Conclusion

Severe cases of penetrating chest trauma are rare in Vienna and happened about once a week during the study period from 2009–2017. Both incidence and case load increased over the years, and potentially life-saving invasive procedures have only been applied reluctantly in the prehospital setting. Therefore, a structured educational and skill retention approach aimed at both paramedics and emergency physicians should be implemented.

Data availability

Data can be inquired from the corresponding author upon reasonable request. This is in accordance with national law.

Funding

None

Declaration of Competing Interest

We declare: Mario Krammel is medical director of the Viennese EMS. Sebastian Schnaubelt is Vice-Chair of the Austrian Resuscitation Council. Both do not see these affiliations as conflicting with the content of the manuscript at hand. The other authors declare no COI relevant to this study.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2023.110971.

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