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Trauma referral audit impact assessment on the outcomes of injured patients via an interrupted time-series analysis: an 11-year before-and-after study of trauma cases at the Maharaj Nakorn Chiang Mai hospital, Thailand

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Abstract

Background Overcrowding in emergency departments (EDs) due to injured patients who do not need urgent treatment can lead to less efficacious healthcare outcomes for those that do. The trauma referral audit (TRA) was developed to support medical staff and ensure that the injured receive treatment timely and efficiently.

Methods Data on 14,399 injured patients referred to Maharaj Nakorn Chiang Mai Hospital between 2007 and 2017 were analyzed to examine the impact of the full TRA program implemented at the end of 2010. Injury severity was measured by using the injury severity score (ISS) whereby a score > 9 points infers severe injury. The impact of the establishment of TRA was examined using the trend of referrals and an interrupted time-series analysis of monthly mortality among patients with severe injury.

Results The median ISS of the patients in 2010 was 9 [4–18] and slightly increased to the highest score of 16 [8–25] in 2017. The proportion of patients with less severe injuries (ISS ≤ 9) decreased after the full implementation of TRA (55.4% in 2010 compared to 42.3% in 2017). Overall mortality was 6% (5.5% vs. 6.2% for the pre- and post-full TRA periods, respectively), and the mortality rate tended to increase from 4.77% in 2011 to 7.59 in 2017. The monthly mortality rate was estimated at 7.22% [95% confidence interval (CI) = 5.89–8.56%] with a significant increase of mortality in the post-full TRA period by 1.57% [0.16-2.98%] and in the annual trend of 0.11% [0.05-0.16%]. However, when considering severely injured patients only, the level and trend of the mortality rate were no different.

Conclusions Although the TRA program could help reduce patient overcrowding in EDs, it does not reduce the risk of mortality. Revision of the referral and in-hospital care guidelines accounting for these relevant factors might lead to a decrease in mortality.

Trial registration Clinical trial number: Not applicable.

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Keywords Trauma referral audit, Interrupted time series

Background

Injuries and deaths due to road traffic crashes are major public health problems in developing countries [1, 2], accounting for more than 85% of all deaths and causing more than 90% of the disability-adjusted life years lost worldwide [1]. In 2018, the World Health Organization (WHO) reported that road traffic injuries are the leading cause of death for children and young adults under 30 years old, and 1.35 million people are killed in road traffic crashes each year [3]. Thailand has the highest rate of road fatalities in the world (32.7/100,000 people) [3, 4], with them being the leading cause of disability and death [3]. In a previous study in Saraphi Hospital, Chiang Mai, the authors reported that 38.5% of the total traffic crash cases were due to brain trauma [5]. Injuries from road traffic crashes are a major cause of referrals to emergency departments (EDs) and often need emergency surgery that requires significant amounts of resources and time, both of which can be reduced by improving trauma care [6].

After road traffic crashes, falls are the second leading cause of unintentional injury deaths worldwide. They are usually experienced by elderly people with impaired balance and vision, weak muscles, lack of exercise, having an outdoor lavatory, and/or higher body mass index and are more prevalent in females [7–9]. Falls are a growing and under-recognized public health issue from which an estimated 684,000 individuals die globally and over 80% are in low- and middle-income countries (60% in the Western Pacific and South East Asia regions). The results from a previous study in southern Iran indicate that the most common injury source for males is car and motorcycle crashes whereas females were mostly victims of falls and pedestrian crashes. The authors also suggested that unintentionally caused injuries were more prevalent than transportation-related injuries among the elderly [3]. Especially, the mortality of adults over the age of 60 years old related to falls is the highest cause worldwide [10].

A shortage of healthcare workers is a major issue affecting healthcare service application efficiency, and in Thailand, the number of physicians and nurses is insufficient for the number of patients. A previous study conducted in Thailand uncovered that there are average shortages of 31% and 26% of nurses and physicians, respectively [11]. The number of physicians per 1,000 people in Thailand is lower than the average estimated number reported in upper- and middle-income countries (0.8 vs. 1.2 per 1,000 people) [12]. A shortage of healthcare workers can lead to issues related to time management and overcrowding in EDs. Primary care physicians play an important role in assessing patients to provide them with appropriate and timely medical services, both for common illnesses and emergencies [13, 14]. Although the resuscitation process has been standardized, there might be problems due to a lack of systematic management in practical situations [6, 15]. The National Institute of Emergency Medicine in Thailand reported that 60% of patients who visited the ED did not need urgent treatment. Moreover, too many patients unnecessarily admitted to the ED might lead to less efficacy of service. Therefore, effective patient assessment during the pre-hospital process could reduce overcrowding in hospitals [13]. However, delays in referrals contribute to substantial disability and death [16].

Chiang Mai, the largest city in the north of Thailand, has the highest number of road traffic crashes in the northern region (35,760 injuries in 2022) and ranks in the top five areas in Thailand [17]. The average number of injuries treated in EDs between 2014 and 2019 was approximately 14,000 per year. If there are many injured patients in inadequate facilities, then efficiently transferring severe patients to trauma centers is critical. In these situations, it is important to rapidly assess and isolate multiple trauma patients [18]. Due to Maharaj Nakorn Chiang Mai Hospital being a regional hospital in northern Thailand that provides both ED and in-patient services, the total number of injury cases treated per year is 200,000 [19]. At this rate, issues related to overcrowding and a healthcare worker shortage will play an important role in administering services in Maharaj Nakorn Chiang Mai Hospital.

To deal with these issues, a referral audit procedure following the National Institute of Emergency Medicine guidelines has been developed to support ED patients to receive treatment promptly and efficiently [20]. Moreover, this complies with the National Highway Traffic Safety Administration guidelines for interfacility patient transfer [4, 21]. The results of a Trauma Team Activation case study on the treatment of critically injured patients conducted in the ED of Songkhla Nakarin Hospital in 2009 indicate that the waiting time for treatment at the ED decreased from 184 to 85 min and the mortality rate at 28 days decreased from 66.7 to 46.3% [22]. Maharaj Nakorn Chiang Mai Hospital performed quality assurance of the referral audit process in 2007 with the goal that the critically injured must be treated by personnel with specialized expertise in caring for the injured quickly, safely, and appropriately without causing death to injured people due to errors in the treatment process. Subsequently, the trauma referral audit (TRA) program was developed and established at the end of 2010.

The primary objective of the present study is to evaluate the results of the full implementation of the TRA program by comparing the health outcomes before and after its full implementation. The results of this study can be used to assess the impact of the quality assurance process on the referral of injured patients and consider improving the TRA system to become more efficient and enable the handling of the plethora of crash-related injuries in northern Thailand.

Methods

The TRA program

Severely injured patients are usually referred to tertiary hospitals from primary or secondary hospitals. However, according to the trauma audit program to review and improve the quality of managing the referral process, we found that some patients with slight or moderate injuries, which could be treated efficiently at a community hospital, were unnecessarily referred to Maharaj Nakorn Chiang Mai Hospital. This has resulted in overcrowding and delayed treatment. The TRA program is an intervention to improve the guidelines and procedures for injury-related referrals. It was established in Maharaj Nakorn Chiang Mai Hospital in May 2007 and completed in December 2010. In this program, staff in primary or secondary hospitals must evaluate the injury severity of patients, after which the referral center will communicate with the staff between two hospitals to decide whether the referral is appropriate according to the revised guidelines and criteria prior to referral (Fig. 1). The decision to refer is made based on the following nine criteria: airway, breathing, oxygen saturation monitoring, stop bleeding control, intravenous fluid resuscitation, EKG monitoring, external splint, pelvic splint, and C spine protection. The evaluators are the on-call physicians and well-trained staff in the emergency department who had completed advanced trauma life support (ATLS) training. The TRA program is reviewed and improved upon where appropriate every three months to maintain the quality of the program. The staff in Maharaj Nakorn Chiang Mai Hospital also provide feedback and training courses for the community hospital staff annually. The procedures for the quality improvement of the TRA are presented in Fig. 2.

Injury severity evaluation

The Injury Severity Score (ISS) is widely used as an indicator of the overall severity of multiple injuries to the body [23]. This score is calculated by summing the squares of the three highest values of an evaluation scale (the Abbreviated Injury Scale (AIS)) for the severity of trauma to individual body parts [24]. Major trauma is commonly defined using a standard ISS threshold score of 15. However, since we are interested in the need for referral to the Eds, we considered using a threshold score of 9, which is the suggested criterion for requiring ICU admission [25].

Study population

This retrospective study is based on the medical records of all patients referred to Maharaj Nakorn Chiang Mai Hospital, Thailand, between May 2007 and December 2017. The study period was categorized into "Pre" and "Post" periods according to the full implementation of the TRA process. The pre-full implementation TRA period (pre-TRA period) covers from 1 May 2007 to the end of December 2010 whereas the post-full implementation TRA period (post-TRA period) covers from 1 January 2011 to the end of December 2017.

Data collection

Demographic characteristics including sex, age, and occupation were obtained from the records. Occupation was categorized into six categories, including student, government officer, employee, agriculturist/trade, laborer, the elderly aged 60 years old and over, and unknown. Work-related injuries and behavioral characteristics (i.e., seat belt use, helmet use, and alcohol use) were also considered.

Information on trauma referral, such as the dates of admission and discharge, duration of the admission, the severity of the injury measured by using the injury severity score (ISS), the cause of injury, the pattern of injury, and the trauma referral group (inside or outside of Chiang Mai) were collated. The source of the injury was divided into six groups, including pedestrian, pedal cyclist, motorcycle crash, car occupant, fall, and others. The pattern of injury was reported as one of four categories: (1) the head; (2) the neck; (3) the thorax; and (4) the abdomen, lower back, lumbar spine, and pelvis.

The number of deaths (pre-hospital and in-hospital), the ISS after death, and the time of death after admission: (1) less than 48 h, (2) 48 h to 7 days, and (3) more than 1 week were retrieved from the records. Patients with ISS > 9 were considered as being severely injured and requiring ICU services [26].

Statistical analysis

The participants' demographic characteristics, as well as their behavior and information on trauma referral and mortality, were summarized by using descriptive analysis. The continuous variables are reported as the median and interquartile range (IQR) while the categorical variables are reported as the frequency and percentage.

Comparison of the patient characteristics between the pre- and post-implementation of TRA was performed using Chi-squared tests for categorical variables and Mann-Whitney U tests for continuous variables. The mortality rates of patients admitted to the Maharaj

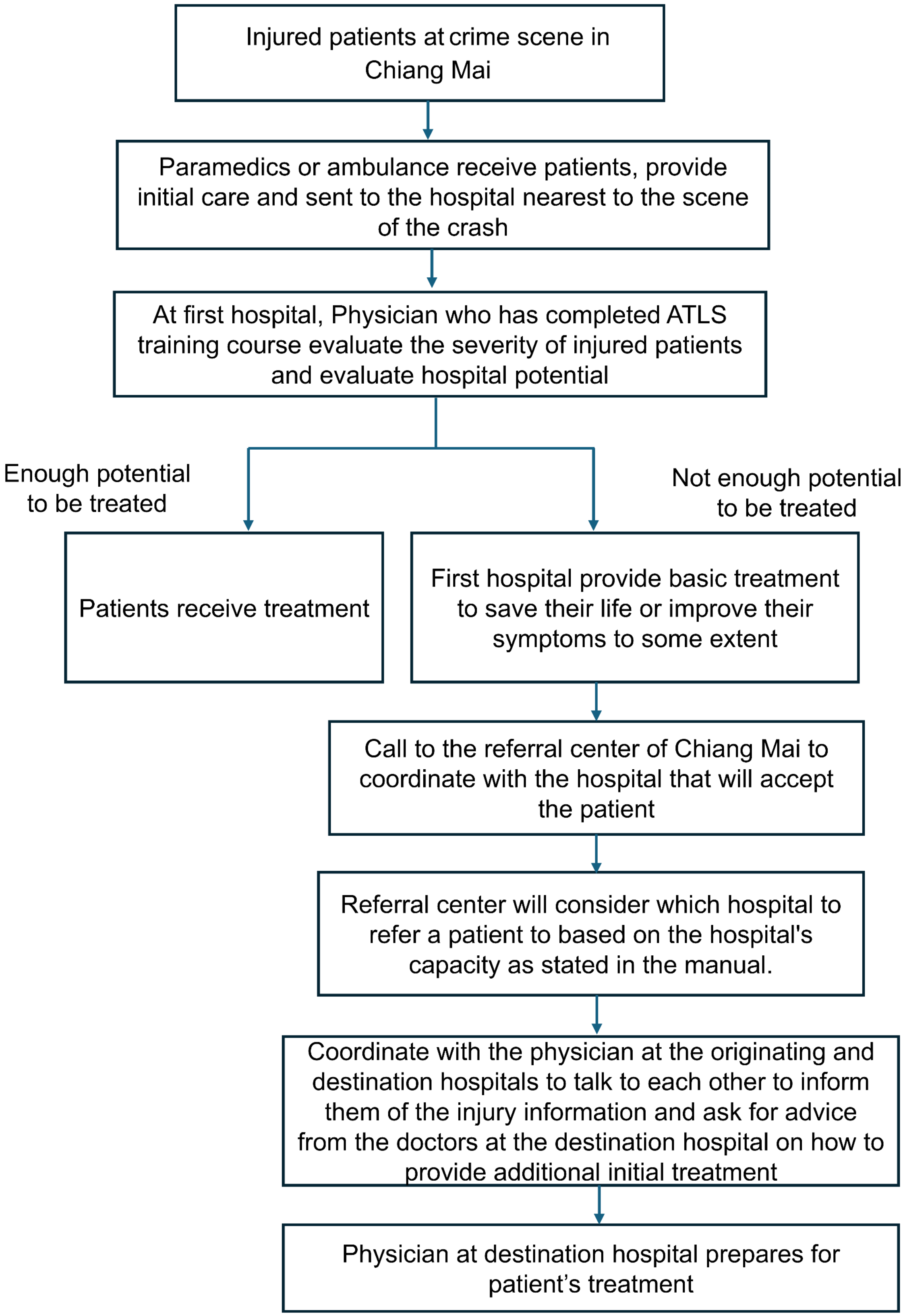

Fig. 1 The TRA program process

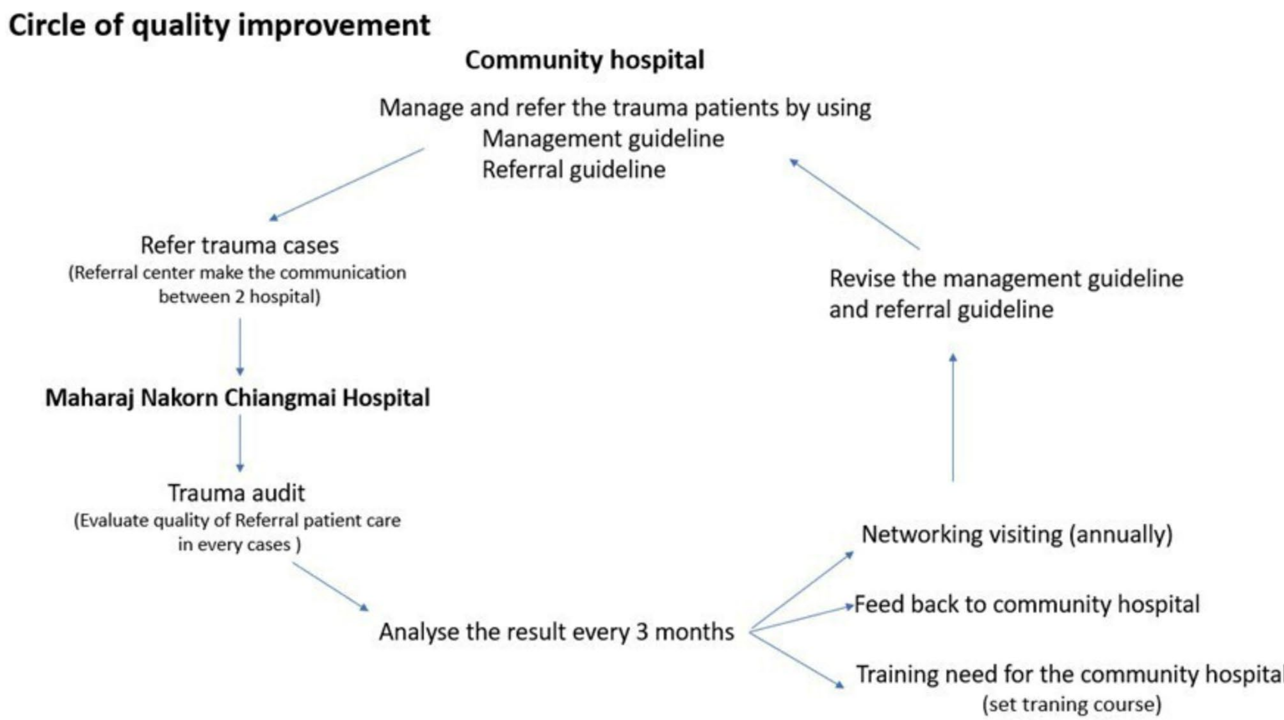

Fig. 2 The quality improvement cycle covered by the TRA

Nakorn Chiang Mai Hospital between 2007 and 2017 were considered both monthly and annually. The impact of the establishment of TRA was examined by using the trend of referrals and an interrupted time-series analysis of the monthly mortality of patients with severe injuries. All of the analyses were performed using Stata version 15 [StataCorp LLC, College Station, Texas, USA] [27].

Ethical approval and consent to participate

This study was approved by the Research Ethics Committee of the Faculty of Medicine at Chiang Mai University (No: 341/2022). Because the data were recorded anonymously, the requirements for written informed consent were waived by the Research Ethics Committee of the Faculty of Medicine at Chiang Mai University.

Results

Patients' characteristics

A total of 14,399 patients were included in the study, including 4,640 (32%) and 9,759 (68%) in the pre- and post-TRA full implementation periods, respectively. The median age in the post-TRA period was higher than that in the pre-TRA period (35 [IQR: 21–51] vs. 37 [22–54]; p-value < 0.001). The proportion of males in the pre-TRA period was significantly higher than in the post-TRA one (75.8% vs. 73.7%; p-value = 0.010). The number of elderly patients aged 60 years old or more was also higher in the post-TRA period (17.1% vs. 13.8%; p-value < 0.001). The most common cause of injury was motorcycle crashes at 48.5% (50.2% and 47.7% for pre- and post-TRA, respectively). The percentage of referrals within Chiang Mai in the post-TRA period was higher than in the pre-TRA period (83.4% vs. 77.2%; p-value < 0.001). The proportion of patients arriving during the post-TRA period was significantly higher (25.5% vs. 13.2%; p-value < 0.001). Conversely, the proportion of patients wearing fastened seatbelts during the post-TRA period was significantly lower than the pre-TRA period (11.3% vs. 27.7%; p-value < 0.001). Patients who came during the post-TRA period had a longer stay in the hospital than patients during the pre-TRA period (8 [4–17] vs. 9 [4–19]; p-value < 0.001). Moreover, 56.6% of patients who came during the post-TRA period stayed in the hospital for more than 1 week (Table 1).

Injury severity

The ISS evaluation in this setting has been available since 2010. The ISSs of the patients who attended the hospital during the post-TRA period were significantly higher than those who attended during the pre-TRA period (Fig. 3a). The number of patients with severe injury (ISS > 9) who required ICU services in the post-TRA period was also higher (49.2% vs. 44.6%; p-value = 0.003) (Table 1). When considering the ISSs per year, the median ISS of the patients in 2010 was 9 [4–18] and slightly increased to the highest score of 16 [8–25] in 2017 (Table 2). The proportion of patients with

Table 1 Patient demographics, information related to injuries before and after the full establishment of the TRA and injury severity and mortality by year

Variable	Overall (*N* = 14,399)	Pre-TRA period (*n* = 4,640)	Post-TRA period (*n* = 9,759)	*p*-value
Age (years old), median [IQR]	37 [22–53]	35 [21–51]	37 [22–54]	< 0.001
Male, n (%)	10,706 (74.4)	3,518 (75.8)	7,188 (73.7)	0.010
Occupation, n (%)				< 0.001
Student	1,901 (13.2)	656 (14.1)	1,245 (12.8)	
Government officer	595 (4.1)	211 (4.6)	384 (3.9)	
Employee	490 (3.4)	187 (4.0)	303 (3.1)	
Agriculturist / Trade	558 (3.9)	255 (5.5)	303 (3.1)	
Laborer	6,493 (45.1)	1,810 (39.0)	4,683 (48.0)	
Elderly (≥ 60 years old)	2,303 (16.0)	638 (13.8)	1,665 (17.1)	
Unknown	2,059 (14.3)	883 (19.0)	1,176 (12.1)	
Injury circumstances, n (%)				< 0.001
Pedestrian	348 (2.4)	127 (2.7)	221 (2.3)	
Pedal cyclist	262 (1.8)	76 (1.6)	186 (1.9)	
Motorcycle	6,981 (48.5)	2,330 (50.2)	4,651 (47.7)	
Car occupant	878 (6.1)	246 (5.3)	632 (6.5)	
Fall	2,593 (18.0)	723 (15.6)	1,870 (19.2)	
Other	3,337 (23.2)	1,138 (24.5)	2,199 (22.5)	
Work-related accident, n (%)	1,563 (10.9)	479 (10.3)	1,084 (11.1)	0.160
Referral, n (%)				< 0.001
Within Chiang Mai	11,721 (81.4)	3,581 (77.2)	8,140 (83.4)	
Outside of Chiang Mai	2,678 (18.6)	1,059 (22.8)	1,619 (16.6)	
Injured body part, n (%)				
Head	7,151 (49.7)	2,396 (51.6)	4,755 (48.7)	0.001
Neck	1,173 (8.2)	356 (7.7)	817 (8.4)	0.150
Thorax	2,061 (14.3)	589 (12.7)	1,472 (15.1)	< 0.001
Abdomen, lower back, lumbar spine, and/or pelvis	1,980 (13.8)	583 (12.6)	1,397 (14.3)	0.004
Injured body part combinations, n(%)				
Head and neck	659 (4.6)	158 (3.4)	501 (5.1)	< 0.001
Head and thorax	1,248 (8.7)	335 (7.2)	913 (9.4)	< 0.001
Head and abdomen, lower back, lumbar spine, and/or pelvis	943 (6.6)	251 (5.4)	692 (7.1)	< 0.001
Neck and thorax	360 (2.5)	97 (2.1)	263 (2.7)	0.030
Neck and abdomen, lower back, lumbar spine, and/or pelvis	165 (1.2)	38 (0.8)	127 (1.3)	0.010
Thorax and abdomen, lower back, lumbar spine, and/or pelvis injuries	732 (5.1)	184 (4.0)	548 (5.6)	< 0.001
ISS, median [IQR]	9 [4–20]	9 [4–18]	9 [4–21]	< 0.001
ISS > 9, n (%) (*n* = 7,807)	3,785 (48.5)	560 (44.6)	3,225 (49.2)	0.003
Alcohol consumption, n (%)	2,413 (16.8)	760 (16.4)	1,653 (16.9)	0.140
Wearing a helmet, n (%) (*n* = 5,308)	1,132 (21.3)	237 (13.2)	895 (25.5)	< 0.001
Fastened seat belt, n (%) (*n* = 1,168)	157 (13.4)	43 (27.7)	114 (11.3)	< 0.001
Length of stay (days), median [IQR]	9 [4–18]	8 [4–17]	9 [4–19]	< 0.001
Length of stay (discrete), n (%) (*n* = 10,755)				< 0.001
< 48 hours	1,666 (15.5)	705 (17.6)	961 (4.2)	
> 48 h to 7 days	3,173 (29.5)	1,198 (30.0)	1,975 (29.2)	
> 1 week	5,916 (55.0)	2,095 (52.4)	3,821 (56.6)	
Number of deaths, n (%)	861 (6.0)	253 (5.5)	608 (6.2)	0.070
Number of deaths by location, n (%)				
Pre-hospital	64 (7.4)	19 (7.5)	45 (7.4)	0.960
In-hospital	797 (92.6)	234 (92.5)	563 (92.6)	
ISS after death, median [IQR]	26 [25–34]	28 [25–36]	25 [24–34]	0.080
In-hospital stay duration before death (days), median (IQR)	1 [1–4]	2 [1–5]	1 [1–4]	0.004
< 48 hours	481 (55.9)	125 (49.4)	356 (58.6)	0.040
> 48 h to 7 days	257 (29.9)	89 (35.2)	168 (27.6)	

Table 1 (continued)

Variable	Overall (*N* = 14,399)	Pre-TRA period (*n* = 4,640)	Post-TRA period (*n* = 9,759)	*p*-value
> 1 week	123 (14.3)	39 (15.4)	84 (13.8)	

Year	Number of referrals (n)	Number of deaths	Mortality rate per 100 persons-year	Motorcycle and car crash referrals	ISS median	ISS interquartile ranges	
						P_{25}	P_{75}
2007	832	56	6.73	437	NA	NA	NA
2008	1,212	75	6.19	646	NA	NA	NA
2009	970	44	4.54	574	NA	NA	NA
2010	1,626	78	4.80	919	9	4	18
2011	1,571	75	4.77	850	9	4	20
2012	1,522	97	6.37	810	9	4	20
2013	1,515	96	6.34	775	9	4	20
2014	1,384	81	5.85	752	9	4	21
2015	1,385	84	6.06	760	13	4	22
2016	1,276	91	7.13	721	13	4	25
2017	1,106	84	7.59	615	16	8	25

ISS: Injury Severity Score, pre-TRA period: pre-full implementation TRA period, post-TRA period: post-full implementation TRA period

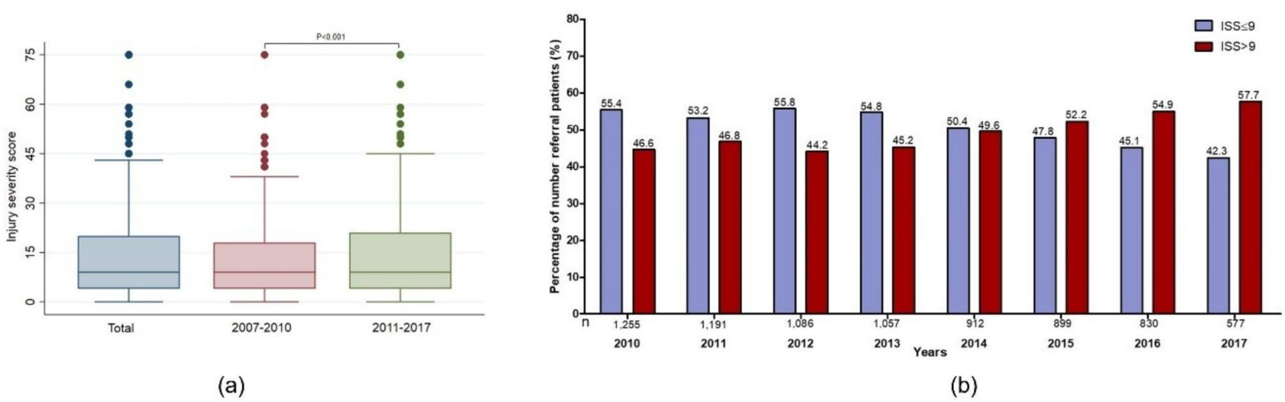

Fig. 3 Comparison of the injury severity score (ISS) between pre- and post- TRA period and the percentage of referrals by injury severity score (ISS) ≤ or > 9

less severe injuries (ISS ≤ 9) decreased after the implementation of TRA (from 55.4% in 2010 to 42.3% in 2017) (Fig. 3b).

Mortality

The overall mortality in this study was 6%, of which the in-hospital mortality accounted for 92.6%. Although the median ISS at death was no different in both periods (28 [25–36] vs. 25 [24–34]; *p*-value = 0.08), the median time of death in-hospital during the pre-TRA period was higher than post-TRA (2 [1–5] vs. 1 [1–4]; *p*-value = 0.004) (Table 1).

The mortality rate continued to decline between 2007 and 2010 whereas the mortality rate tended to increase after 2010 (4.77% in 2011 to 7.59 in 2017). Meanwhile, the number of referred patients and the number of motorcycle and car crashes were higher post-TRA implementation after 2010 (Fig. 4a). Although the trend in mortality appears to be different between the pre- and post-implementation periods (Fig. 4a), it was not by much when considering only patients with severe injuries (Fig. 4b).

Overall, the monthly mortality rate of patients was estimated as 7.22% [95% confidence interval (CI): 5.89–8.56%] (7.58% [95% CI: 6.41–8.76%] and 5.85% [95% CI: 4.29–7.42%] for referrals from hospitals within and outside Chiang Mai, respectively). The mortality rate in the post-TRA implementation period appeared to significantly increase by 1.57% [95% CI: 0.16–2.98%] and in the annual trend of 0.11% [95% CI: 0.05–0.16%]. The level and trend of mortality rate among referrals from hospitals within Chiang Mai also tended to increase after the implementation of TRA (1.56 [95% CI: 0.05–3.07%] vs. 0.11 [0.06–0.16%]) whereas only the trend in mortality rate tended to increase by 0.11% [95% CI: 0.02–0.20%] among patients referred from hospitals outside of Chiang Mai (Table 2).

Table 2 Interrupted time-series analysis of monthly mortality by referral group

Parameters	Total				Within Chiang Mai				Outside of Chiang Mai			
	Coef.	***p*-value**	**95% CI**		**Coef.**	***p*-value**	**95% CI**		**Coef.**	***p*-value**	**95% CI**	
All patients												
Intercept (β_0)	7.22	**< 0.001**	5.89	8.56	7.58	**< 0.001**	6.41	8.76	5.85	**< 0.001**	4.29	7.42
Trend (β_1)	-0.08	**0.001**	-0.13	-0.03	-0.09	**< 0.001**	-0.14	-0.04	-0.07	0.100	-0.15	0.01
Level change after December 2010 (β_2)	1.57	**0.030**	0.16	2.98	1.56	**0.040**	0.06	3.07	2.04	0.240	-1.35	5.43
Trend change after December 2010 (β_3)	0.11	**< 0.001**	0.05	0.16	0.11	**< 0.001**	0.06	0.16	0.11	**0.020**	0.02	0.20
Patients with ISS > 9												
Intercept (β_0)	10.70	**< 0.001**	6.22	15.18	11.43	**< 0.001**	6.70	16.17	4.95	0.130	-1.54	11.44
Trend (β_1)	-0.15	0.590	-0.69	0.39	0.02	0.940	-0.64	0.69	-0.20	0.680	-1.14	0.75
Level change after December 2010 (β_2)	3.02	0.120	-0.78	6.82	2.00	0.470	-3.48	7.47	4.71	0.210	-2.72	12.15
Trend change after December 2010 (β_3)	0.21	0.450	-0.34	0.75	0.01	0.970	-0.65	0.68	0.32	0.500	-0.63	1.27

When considering patients with severe injury, the monthly mortality rate was estimated as 10.70% [95% CI: 6.22–15.18%] (11.43% [95% CI: 6.70–16.17%] and 4.95% [95% CI: -1.54–11.44%] for referrals from within and outside of Chiang Mai, respectively). There was no significant change in either the level (3.02 [95% CI: -0.78 to 6.82]; p-value = 0.120) or trend (0.21 [95% CI: -0.34 to 0.75]; p-value = 0.450) in the mortality rate after TRA implementation (Table 2). The level and trend of mortality were not significantly different between the pre- and post-TRA implementation periods for referrals from within and outside Chiang Mai (Fig. 5).

Discussion

This study was conducted on the data from the records of 14,399 injured patients referred to Maharaj Nakorn Chiang Mai Hospital between 2007 and 2017 to examine the impact of the TRA fully implemented at the end of 2010: 4,640 (32%) patients from the pre-TRA full implementation period (2007–2010) and 9,759 (68%) patients from the post-TRA full implementation period (2011–2017). The ISSs of referred patients tended to increase from the median score of 9 points in 2010 to 16 points in 2017. The proportion of patients with ISS ≤ 9 points also decreased every year (from 55.4 to 42.3%). This means that following the implementation of the TRA program, only severely injured patients were referred to tertiary hospitals. This infers that since the full implementation of the TRA program, primary and secondary hospitals could provide appropriate healthcare services efficiently to slightly or moderately injured patients.

The percentage of injured patients referred from hospitals outside of Chiang Mai decreased from 22.8% in the pre-TRA period to 16.6% in the post-TRA period. This is the result of streamlining the national emergency medical system based on a master plan outlining the standards for various components of the system, such as service, transportation, staff training courses, financial support, research, and the development of ED services. Moreover, this reflects the success of efforts to expand the basic infrastructure to provide ED services, including pre-hospital care, patient transfer, and disaster management to all of the provinces in the country. From 2008 to 2012 [28], although hospitals located outside of Chiang Mai provided healthcare to severely injured trauma patients and only referred those with a very high ISS for treatment at Maharaj Nakorn Chiang Mai Hospital [29], the number of referrals from hospitals within Chiang Mai increased.

Although there was no significant difference in the percentage of patient deaths between the pre-TRA (5.5%) and post-TRA (6.2%) periods, the mortality rate increased from 4.77% in 2011 to over 7% in 2016–2017. According to the interrupted time-series analysis, the level and

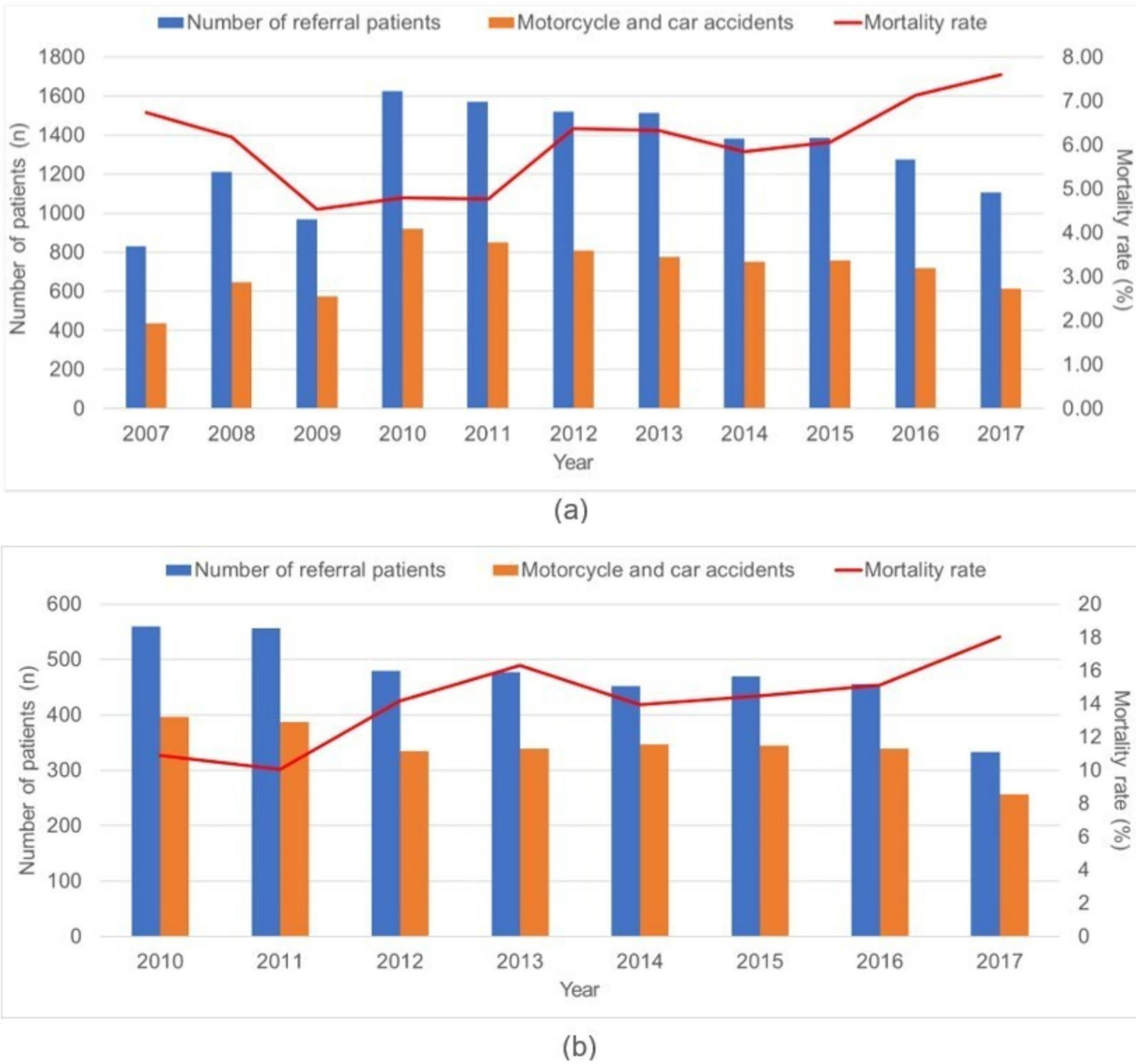

Fig. 4 Overall referrals, motorcycle and car crash victim referrals, and the overall mortality rate by year

trend of the monthly mortality rate increased after the full implementation of the TRA program. However, when considering severely injured patients only (ISS > 9 points), the level and trend of the monthly mortality rate were no different between the pre- and post-TRA periods. This indicates that even though the TRA program helped to reduce patient overcrowding and unnecessarily increased the workload of healthcare workers, it did not result in a reduction in the mortality rate. This is in contrast with the findings from a previous study on the trauma audit program at Songkhla Nakarin Hospital in 2009, which indicate that the mortality rate decreased from 66.7 to 46.3% [22]. The difference between the findings might be related to several issues, such as the criteria or guidelines for the program, behavioral factors, and/or the time of examination. Therefore, revising referral and in-hospital care guidelines to account for different scenarios and related factors might lead to a reduction in mortality.

The prevalence of patients referred to Maharaj Nakorn Chiang Mai Hospital with an increased risk of mortality due to the high severity of their injuries could be related to age. Although the proportion of deaths between the pre- and post-TRA periods was not different across all age subgroups, that in the post-TRA period tended to increase with age (3.9%, 5.6%, 6.6%, 5.8%, 6.6%, and 8.8% among patients aged < 20, 20–29, 30–39, 40–49, 50–51, and ≥ 60 years old, respectively). These findings are consistent with those reported by Wongweerakit et al. [30], who demonstrated that age has a significant impact on mortality rates in trauma patients (odds ratio = 1.05; 95%

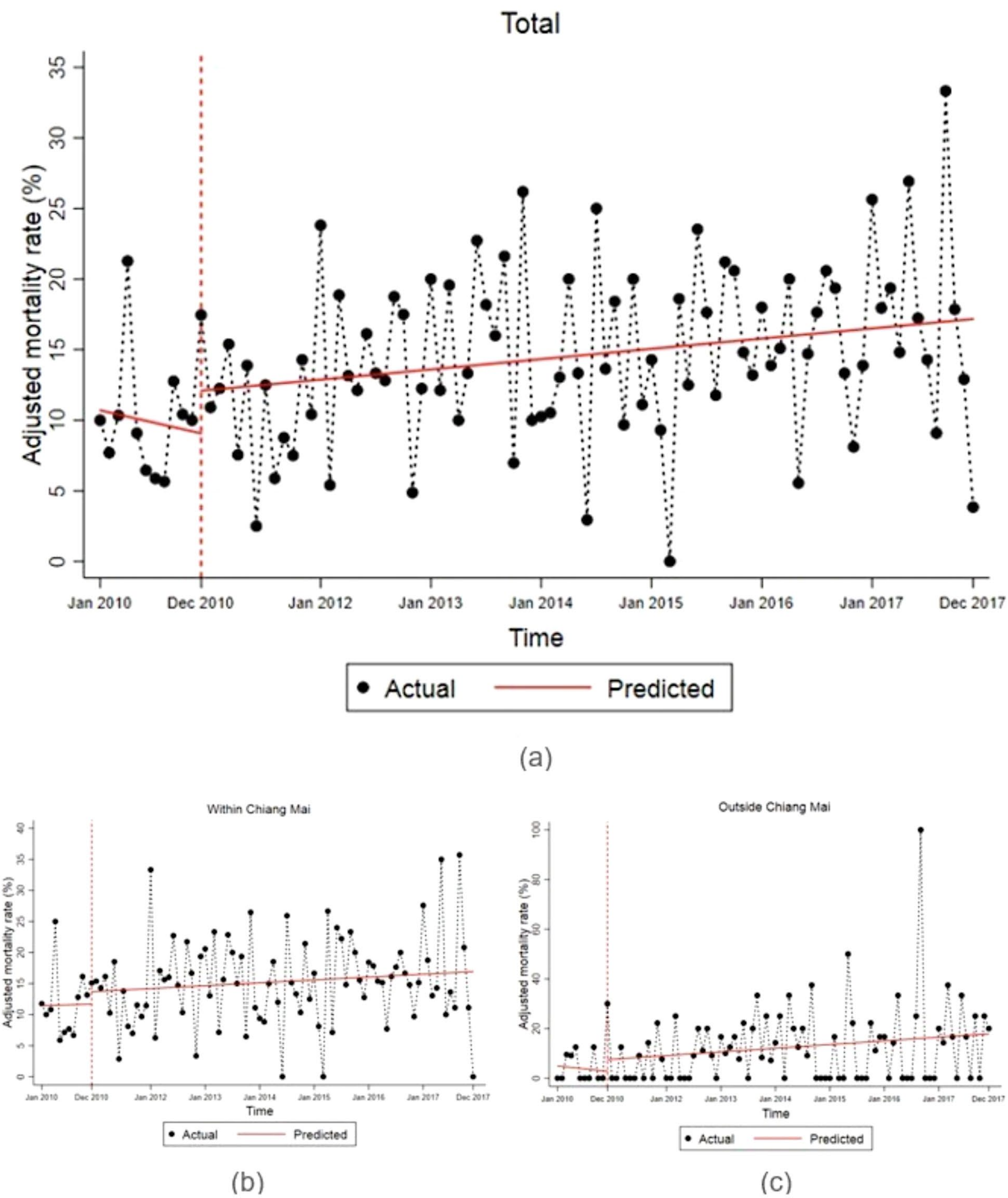

Fig. 5 Interrupted time-series analysis of monthly adjusted mortality among patients requiring ICU pre- and post- TRA periods

CI = [1.02–1.07]; p-value < 0.001). In a previous study in the US [31], the authors suggested a relationship between the pre-hospital scene time, pre-hospital transport time, and ISS with the mortality of motor vehicle trauma patients. They found that ISS was a statistically significant predictor of hospital mortality whereas the pre-hospital scene time and transport time were not.

In our study, the proportions of patients wearing helmets and fastening seat belts were very low (21.3% and 13.4% respectively). Furthermore, following the implementation of the post-TRA program, although the number of car crashes increased, there was a significant reduction in the percentage of injured individuals wearing seat belts. Meanwhile, there was an observed rise in motorcycle crashes and an increase in helmet usage. This suggests a possible correlation between non-compliance with safety regulations and the severity of patient injuries. Therefore, a comprehensive public awareness campaign promoting helmet wearing and seat belt usage is necessary to reduce the crash rate and the severity of injuries sustained in crashes [32–34].

The strength of this study is the availability of significant data on hospital referrals in northern Thailand over a decade (from 2007 to 2017), which was useful for examining the long-term efficacy of the TRA program. Another strength is that the preparation of the TRA program was developed over several years prior to its establishment; drafting revisions of the management and referral guidelines to be appropriate for several situations was extremely useful. However, there are also some limitations in this study. First, the ISS was only available from 2010 onward, which might have limited exploration of the prior trend in mortality among severely injured patients. Second, assessing pre-hospital deaths and ISSs was difficult. The findings from previous studies suggest that in addition to predicting the mortality rate, the ISS could be useful for predicting the need for and the length of stay in the ICU [26]. The ISS information should be addressed clearly in the criteria for the referral process. Third, we only considered injuries to four anatomical areas, which does not correspond with the AIS encoding systems. Considering the body areas according to the standard system might provide more insightful findings and enable comparison with other studies. Next, data on the ISSs and mortality rates at primary and secondary hospitals were not available. Comparing the trends in the ISS and the mortality rate between these groups of hospitals after the full implementation of the TRA program could be useful for determining the efficacy of the TRA program from other perspectives. Advances in trauma care during the study period might have influenced the efficiency of the program. Further investigation should take this into account and compare the changes in the guidelines for the program. Finally, there were some potential associated factors with injury severity and mortality, such as abnormal respiration rate, abnormal pulse rate, abnormal blood pressure, or transportation issues, that were not included in this study. These factors should be included in the analysis in a future study.

Conclusions

In conclusion, although the TRA program could reduce overcrowding in EDs and the workload of healthcare workers in tertiary hospitals, it did not reduce the mortality rate. A high ISS should be accounted for in the referral and in-hospital care processes and its influence on the mortality rate examined in a future investigation.

Abbreviations

CI	Confidence interval
EDs	Emergency departments
ICU	Intensive Care Unit
IQR	Interquartile range
ISS	Injury Severity Score
post-TRA period	Post-full implementation TRA period
pre-TRA period	Pre-full implementation TRA period
TRA	Trauma referral audit
WHO	World Health Organization

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Author contributions
P.T. and N.C. contributed to the Conceptualization. P.T. and P.S. contributed to the formal analysis. A.K., K.C., Kam.C., and N.C. contributed to the resources and data curation. P.T., P.S., C.N., and N.C. contributed to writing—original draft preparation and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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