


Original Article

Disaster-related carbon monoxide poisoning after the Great East Japan Earthquake, 2011: a nationwide observational study

Mikio Nakajima,^{1,2}  Shotaro Aso,¹ Hiroki Matsui,¹ Kiyohide Fushimi,³ Yoshihiro Yamaguchi,² and Hideo Yasunaga¹

¹Department of Clinical Epidemiology and Health Economics, School of Public Health, The University of Tokyo,

²Department of Trauma and Critical Care Medicine, Kyorin University School of Medicine, and ³Department of Health Policy and Informatics, Tokyo Medical and Dental University Graduate School of Medicine, Tokyo, Japan

Aim: To investigate disaster-related carbon monoxide (CO) poisoning after the Great East Japan Earthquake using a nationwide inpatient database in Japan.

Methods: This was a retrospective cohort study. We identified adult patients with CO poisoning who were registered in the Japanese Diagnosis Procedure Combination inpatient database from 2010 to 2017. We evaluated trends in the numbers of patients with CO poisoning each month from disaster (Tohoku region) and non-disaster areas. In the disaster area, we compared the numbers of patients with CO poisoning during pre- and post-earthquake periods. We also compared the numbers of CO poisonings after the earthquake (<30 days) and 1 year later.

Results: Eligible patients ($n = 7,814$) were categorized into disaster area ($n = 988$) and non-disaster area ($n = 6,826$) groups. The numbers of CO-poisoned patients in the non-disaster area showed a seasonal variation, and there was a significant peak registered on March 11 in the disaster area. In the disaster area, the number of patients with CO poisoning in the post-earthquake period was significantly higher than that in the pre-earthquake period (135 versus 18; odds ratio, 7.50; 95% confidence interval, 4.59–12.3). The number of patients in the post-earthquake period was also significantly higher than that on April 9, 2012, which was one month after the annual follow-up (135 versus 10; odds ratio, 13.5; 95% confidence interval, 7.10–25.7).

Conclusion: This study showed that CO poisoning significantly increased in the affected area after the Great East Japan Earthquake, underlining the importance of providing information regarding the hazard of earthquake-related CO poisoning.

Key words: toxicology/poisoning, disaster medicine, carbon monoxide, earthquake, Great East Japan Earthquake

INTRODUCTION

CARBON MONOXIDE (CO) is a leading cause of death from poisoning worldwide.^{1,2} Carbon monoxide poisoning can promote neuropsychological disturbances, some of which could be permanent.³ Unintentional CO poisoning has both seasonal and regional variation,^{4,5} and is

most common during winter in cold climates.⁵ In addition, CO poisoning occurs in the immediate aftermath of hurricanes^{6–8} and snowstorms.^{9,10} Disaster-related CO poisoning can occur with improper indoor use of charcoal grills, heating devices, and portable generators during a power outage.⁷

Japan often encounters natural disasters including earthquakes, tsunamis, typhoons, volcanic eruptions, and landslides. Recently, after the Hokkaido Eastern Iburi earthquake in 2018, the media reported sporadic cases of CO poisoning, which reignited the concern of why CO poisoning continues to occur in post-disaster situations in Japan. While active debates regarding the issue are taking place, the general agreement is that further public health and medical education regarding the risk of CO poisoning in the aftermath of an earthquake is warranted.

Carbon monoxide poisoning after an earthquake has not been widely investigated. The aim of this study was to

Corresponding: Mikio Nakajima, MD, Department of Clinical Epidemiology and Health Economics, School of Public Health, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. E-mail: mikioh@ks.kyorin-u.ac.jp.

Received 17 Dec, 2018; accepted 14 Mar, 2019; online publication 5 Apr, 2019

Funding information

This work was supported by grants from the Ministry of Health, Labour and Welfare, Japan (H30-Policy-Designated-004 and H29-ICT-General-004) and the Ministry of Education, Culture, Sports, Science and Technology, Japan (17H04141).

evaluate CO poisoning after the Great East Japan Earthquake, 2011, using a nationwide inpatient database.

METHODS

Data source

WE UNDERTOOK A retrospective cohort study using the Diagnosis Procedure Combination database, which has been described in detail in previous reports.^{11–13} The database includes discharge abstracts and administrative claims data from more than 1,200 acute care hospitals and covers approximately 90% of all tertiary care emergency hospitals in Japan. The database includes the following information for each patient: dates of admission and discharge, age, sex, main and subcategorized secondary diagnosis, and pre-existing comorbidities at admission recorded using the International Classification of Diseases, 10th Revision (ICD-10) codes and text data entered in Japanese. The database also provides consciousness level on admission, burn index,¹² medical procedures, daily records for drugs, devices used, and discharge status (e.g., discharge to home, discharge to other facility, and in-hospital death). Consciousness level on admission was evaluated by the Japan Coma Scale score: 0, alert consciousness; 1–3, awake without any stimuli; 10–30, aroused by some stimuli; and 100–300, coma. Assessments by the Japan Coma Scale and Glasgow Coma Scale were reported to be well correlated.^{14,15}

Patient selection

We extracted data on patients with the main diagnosis of CO poisoning discharged from April 2010 to March 2017, using ICD-10 code T58. We excluded patients who were readmitted to the hospital. Patients with CO poisoning were divided into two categories: patients who lived in the area affected by the Great East Japan Earthquake, which occurred on March 11, 2011 (disaster area); and patients who lived in other regions (non-disaster area) (Fig. 1). We defined the disaster area as the Tohoku region including Aomori, Iwate, Miyagi, Akita, Yamagata, and Fukushima prefectures. We divided the period into two categories: (i) pre-earthquake period (30 days prior to the earthquake: February 9, 2011–March 10, 2011), (ii) post-earthquake period (within 30 days after the earthquake: March 11, 2011–April 9, 2011).

Outcome comparison

The outcome of this study was the number of patients with CO poisoning. We detailed the characteristics of patients

who lived in the disaster area in the post-earthquake period (earthquake-related CO poisoning). Additionally, patients who lived in the disaster area outside of the post-earthquake period and patients who lived in the non-disaster area (non-earthquake-related CO poisoning) were also characterized. We next specified the numbers of patients with CO poisoning in the full cohort of the study in each month during the study period. We then evaluated them in accordance with residential sites (disaster and non-disaster areas).

In the disaster area, we compared the number of patients with CO poisoning during pre-earthquake and post-earthquake periods to account for annual variation. We also compared the number of patients with CO poisoning in the disaster area between March 11 to April 9, 2011, and March 11 to April 9, 2012 (1 year beyond the post-earthquake period), to account for seasonal and climatic variation.

Statistical analysis

We undertook two analyses in the disaster area. First, we compared the numbers of patients in the post-earthquake period with those in the pre-earthquake period. Next, we analyzed the numbers of patients between March 11 to April 9, 2011, and March 11 to April 9, 2012. We used a binomial test to evaluate the numbers of patients with CO poisoning,^{16,17} and calculated odds ratios and their 95% confidence interval (CI) for the outcomes.^{16,17} Continuous variables were reported using medians and interquartile ranges, and categorical variables were reported using numbers and percentages. Continuous variables were compared using Wilcoxon rank-sum tests, and categorical variables were compared using χ^2 -tests. Two-sided *P*-values of <0.05 were considered significant. All analyses were carried out using Stata/MP 15 (Stata, College Station, TX, USA).

RESULTS

WE IDENTIFIED 7,814 eligible patients during the study period, including 988 in the disaster area and 6,826 in the non-disaster area (Fig. 1). In the disaster area, there were 18 patients in the pre-earthquake period and 135 in the post-earthquake period.

Table 1 shows the patients' characteristics. Patients with earthquake-related CO poisoning had a significantly lower percentage of inhalation injury, burn, ambulance use, teaching hospital admission, intensive care unit admission, disturbance of consciousness, requirement of vasopressor, and mechanical ventilation compared with those with non-earthquake-related CO poisoning. In-hospital mortality was significantly lower in patients with earthquake-related CO

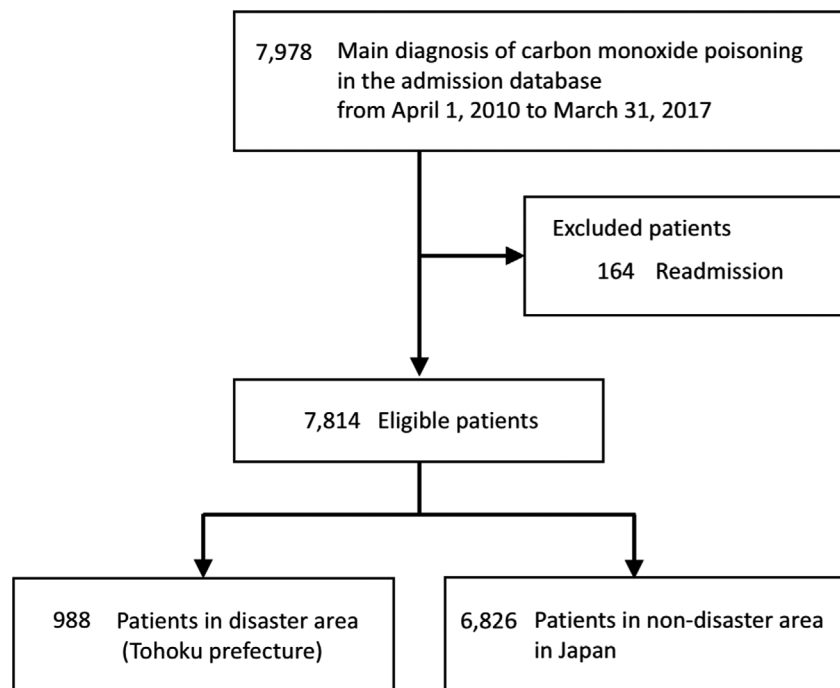


Fig. 1. Selection of patients with carbon monoxide poisoning related/unrelated to the Great East Japan Earthquake, March 11, 2011.

poisoning than in those with non-earthquake-related CO poisoning.

Figure 2 presents a histogram of patients with CO poisoning each month from the full cohort, which shows seasonal variations with peaks during winter. Figures 3 and 4 show the numbers of patients with CO poisoning for each area (disaster and non-disaster areas). Whereas the non-disaster area showed only seasonal variation, there was a significant peak in March 2011 in the disaster area.

In the disaster area, the number of patients with CO poisoning in the post-earthquake period was significantly higher than that in the pre-earthquake period (135 versus 18; odds ratio, 7.50; 95% CI, 4.59–12.3). The number of patients in the post-earthquake period was also significantly higher than that on March 11 to April 9, 2012, 1 year after the post-earthquake period (135 versus 10; odds ratio, 13.5; 95% CI, 7.10–25.7).

DISCUSSION

IN THE PRESENT study, we found that the number of patients with CO poisoning significantly increased after the Great East Japan Earthquake in the disaster area. Taking the rough estimation of the population of the Tohoku region as 9 million in 2011, the prevalence of CO poisoning would be at least 1.5 in 100,000 in the post-earthquake period (within 30 days of the earthquake).

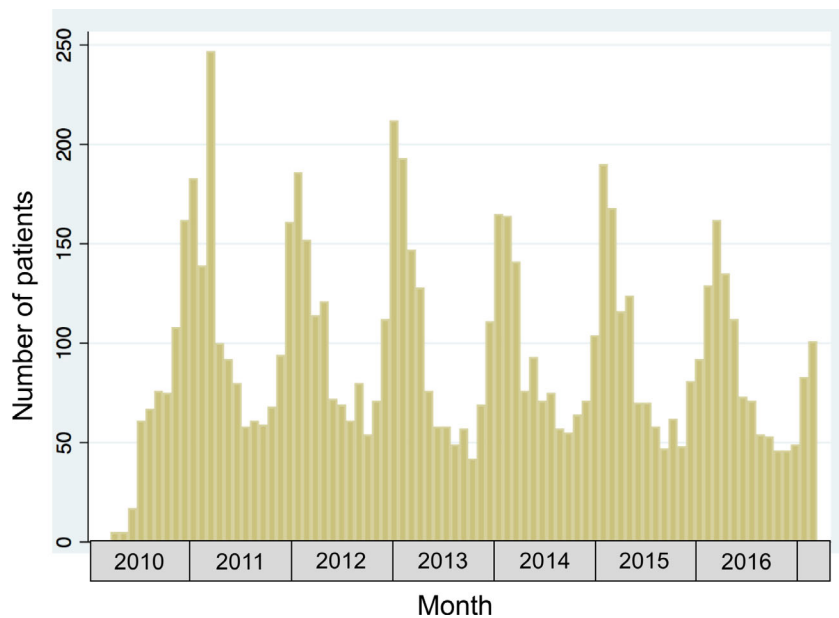
There were over 4.4 million power outages in the affected area in almost all areas of the Tohoku region, which persisted for a prolonged time in some areas. The mean temperature of six prefectural capitals in Tohoku was 1.0–3.8°C in March 2011. Although sporadic power outages were observed in non-disaster areas (i.e., Kanto, including Tokyo metropolitan where over 13 million people live), no outstanding peaks in the number of CO poisonings were observed during the post-earthquake period. The mean temperature in Tokyo was 8°C during this period. It should be noted, however, that the power outage in Tokyo occurred in a limited area and time-frame and was scheduled (pre-announced). The combination of widespread and prolonged power outages and low temperatures led people to use alternative power sources, placing many persons at risk for CO poisoning.⁷

In general, CO poisoning is often underdiagnosed or misdiagnosed because of its non-specific symptoms, for example, flu-like symptoms such as fatigue, headache, dizziness, nausea, vomiting, and confusion.⁵ These would also be common symptoms in patients without CO poisoning in the post-disaster period. However, characteristics of earthquake-related CO poisoning were less severe than in non-earthquake-related CO poisoning according to our data. This suggests that physicians who worked in the disaster areas would have known the risk of CO poisoning after the earthquake and were able to diagnose those patients with lesser CO-related effects.

Table 1. Characteristics of patients with carbon monoxide (CO) poisoning related/unrelated to the Great East Japan Earthquake, March 11, 2011

	Patients with CO poisoning		P-value
	Earthquake-related CO poisoning (n = 135)	Non-earthquake-related CO poisoning (n = 7,679)	
Age, years; median (IQR)	56 (26, 74)	50 (34, 67)	0.840
Male, n (%)	55 (40.7)	4,782 (62.3)	<0.001
Inhalation injury, n (%)	1 (0.7)	644 (8.4)	<0.001
Burn, n (%)	1 (0.7)	332 (4.3)	0.031
Suicide attempt, n (%)	0 (0)	149 (1.9)	0.190
Ambulance use, n (%)	70 (51.9)	6,474 (84.3)	<0.001
Teaching hospital admission, n (%)	122 (90.4)	6,452 (84.0)	0.044
Intensive care unit admission, n (%)	6 (4.4)	1,667 (21.7)	<0.001
Japan Coma Scale, n (%)			
0 (alert)	104 (77.0)	3,558 (46.3)	<0.001
1–3	21 (15.6)	1,858 (24.2)	
10–30	6 (4.4)	816 (10.6)	
100–300 (coma)	4 (3.0)	1,447 (18.8)	
Procedure during hospitalization			
Vasopressor use, n (%)	0 (0)	525 (6.8)	<0.001
Renal replacement therapy, n (%)	0 (0)	30 (0.4)	1.000
Mechanical ventilation, n (%)	2 (1.5)	1,243 (16.2)	<0.001
In-hospital mortality, n (%)	1 (0.7)	539 (7.0)	0.002

Earthquake-related CO poisoning, patients who lived in the disaster area in the post-earthquake period; Non-earthquake-related CO poisoning, patients who lived in the disaster area except in the post-earthquake period or patients who lived in the non-disaster area.

**Fig. 2.** Trend of the number of patients in the full cohort with carbon monoxide poisoning in Japan, April 2010 to March 2016.

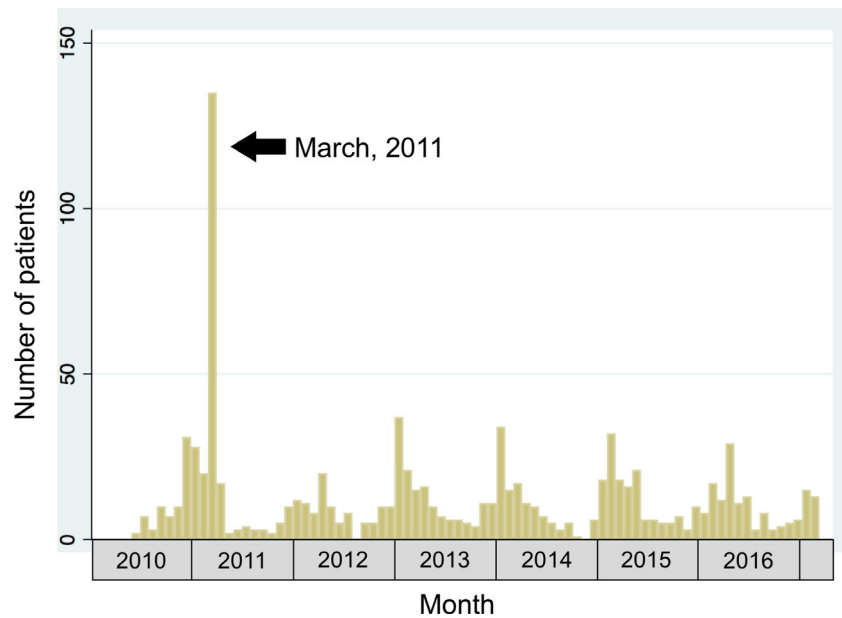


Fig. 3. Trend of the number of patients with carbon monoxide poisoning in the Great East Japan Earthquake disaster area (Tohoku region), April 2010 to March 2016.

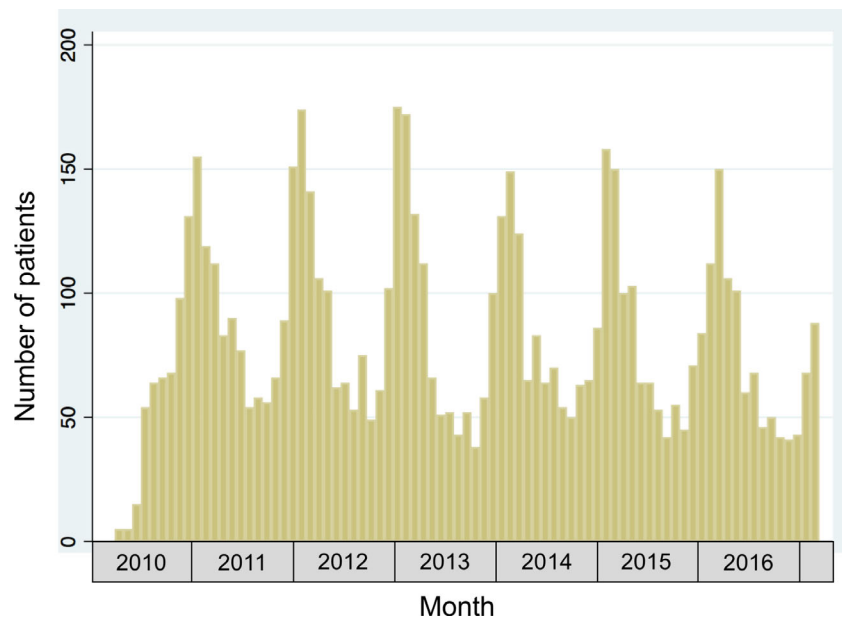


Fig. 4. Trend of the number of patients with carbon monoxide poisoning in the non-disaster area (not affected by the Great East Japan Earthquake), April 2010 to March 2016.

Our study suggests the importance of providing information to the populace regarding prevention of CO poisoning. Despite extensive public health messaging about the hazards of CO exposure, it continues to occur in post-disaster situations.^{4,10,18–20} Although previous reports suggest that

receiving health information on CO poisoning before, during, and after a disaster could lead to safer health practices, information is at times not widely received by affected populations.²⁰ Once a disaster occurs, residents in the primary disaster areas cannot obtain information regarding the risk

of disaster-related CO poisoning due to power outages. Public service announcements and general medical education on the dangers of disaster-related CO poisoning using electronic devices (e.g., television) should be actively disseminated before a disaster strikes. Additionally, this type of warning should be highlighted in schools or at local events. In the immediate aftermath of a disaster, the ability to reach a broader audience using electronic means of communication becomes severely restricted and therefore means of communication that are independent of constant power supply (i.e., radio broadcasting; social media such as Twitter or Facebook; flyers and posters in shelters/supply areas).

Several limitations of the present study should be noted. First, the database lacks information on the causes of CO poisoning. As shown in Table 1, there were few patients with burns in the disaster area during the post-earthquake period. This could mean that there were few fire-related CO poisonings in the post-earthquake situation. Additionally, we documented the number of suicide attempts among patients, which were obtained from diagnosis text data entered in Japanese. These data have not been validated. Intentional CO poisoning (disaster-related suicide attempts) could thus be included among the documented patients with CO poisoning. Second, our data might underestimate the prevalence of CO poisoning in the disaster area. In particular, we could not obtain annual data for 2011 from hospitals in Fukushima Prefecture. These hospitals did not submit inpatient claim data in 2011 because of the Fukushima nuclear power plant accident. Finally, we can only extract patient data for those who were admitted to hospital. We were unable to detect patients with CO poisoning who died at the scene or those who were not admitted to hospital.

CONCLUSIONS

THIS STUDY INDICATES that the number of CO poisoning cases significantly increased after the Great East Japan Earthquake in the affected area. For this reason, we must continue to provide information to the population regarding the hazard of earthquake-related CO poisoning.

DISCLOSURE

Research protocol: This study was approved by the Institutional Review Board at The University of Tokyo (No. 3501).

Informed consent: Because of the anonymous nature of the data, the requirement for informed consent was waived.

Registry and registration no. of the study/trial: N/A.

Conflict of interest: None declared.

REFERENCES

- Hampson NB, Piantadosi CA, Thom SR, Weaver LK. Practice recommendations in the diagnosis, management, and prevention of carbon monoxide poisoning. *Am. J. Respir. Crit. Care Med.* 2012; 186: 1095–101.
- Hampson NB. U.S. Mortality due to carbon monoxide poisoning, 1999–2014. Accidental and intentional deaths. *Ann. Am. Thorac. Soc.* 2016; 13: 1768–74.
- Annane D, Chadda K, Gajdos P, Jars-Guincestre MC, Chevrete S, Raphael JC. Hyperbaric oxygen therapy for acute domestic carbon monoxide poisoning: two randomized controlled trials. *Intensive Care Med.* 2011; 37: 486–92.
- Centers for Disease Control and Prevention (CDC). Unintentional non-fire-related carbon monoxide exposures—United States, 2001–2003. *MMWR Morb. Mortal. Wkly Rep.* 2005; 54: 36–9.
- Centers for Disease Control and Prevention (CDC). Nonfatal, unintentional, non-fire-related carbon monoxide exposures—United States, 2004–2006. *MMWR Morb. Mortal. Wkly Rep.* 2008; 57: 896–9.
- Centers for Disease Control and Prevention (CDC). Notes from the field: carbon monoxide exposures reported to poison centers and related to Hurricane Sandy—Northeastern United States, 2012. *MMWR Morb. Mortal. Wkly Rep.* 2012; 61: 905.
- Schnall A, Law R, Heinzerling A *et al.* Characterization of carbon monoxide exposure during Hurricane Sandy and subsequent nor'easter. *Disaster Med. Public Health Prep.* 2017; 11: 562–7.
- Falise AM, Griffin I, Fernandez D *et al.* Carbon monoxide poisoning in Miami-Dade County following Hurricane Irma in 2017. *Disaster Med. Public Health Prep.* 2018; 13: 94–6.
- Lutterloh EC, Iqbal S, Clower JH *et al.* Carbon monoxide poisoning after an ice storm in Kentucky, 2009. *Public Health Rep.* 2011; 126(Suppl. 1): 108–15.
- Johnson-Arbor KK, Quental AS, Li D. A comparison of carbon monoxide exposures after snowstorms and power outages. *Am. J. Prev. Med.* 2014; 46: 481–6.
- Yamana H, Moriwaki M, Horiguchi H, Kodan M, Fushimi K, Yasunaga H. Validity of diagnoses, procedures, and laboratory data in Japanese administrative data. *J. Epidemiol.* 2017; 27: 476–82.
- Tagami T, Matsui H, Fushimi K, Yasunaga H. Validation of the prognostic burn index: a nationwide retrospective study. *Burns* 2015; 41: 1169–75.
- Nakajima M, Aso S, Matsui H, Fushimi K, Yasunaga H. Clinical features and outcomes of tetanus: analysis using a National Inpatient Database in Japan. *J. Crit. Care* 2018; 44: 388–91.
- Shigematsu K, Nakano H, Watanabe Y. The eye response test alone is sufficient to predict stroke outcome—reintroduction

- of Japan Coma Scale: a cohort study. *BMJ Open* 2013; 3: e002736.
- 15 Ono K, Wada K, Takahara T, Shirotani T. Indications for computed tomography in patients with mild head injury. *Neurol. Med. Chir. (Tokyo)* 2007; 47: 291–7. discussion 297–8.
 - 16 Redelmeier DA, Yarnell CJ. Can tax deadlines cause fatal mistakes? *Chance* 2013; 26: 8–14.
 - 17 Redelmeier DA, Shafir E. The full moon and motorcycle related mortality: population based double control study. *BMJ* 2017; 359: j5367.
 - 18 Hampson NB, Stock AL. Storm-related carbon monoxide poisoning: lessons learned from recent epidemics. *Undersea Hyperb. Med.* 2006; 33: 257–63.
 - 19 Cukor J, Restuccia M. Carbon monoxide poisoning during natural disasters: the Hurricane Rita experience. *J. Emerg. Med.* 2007; 33: 261–4.
 - 20 Iqbal S, Clower JH, Hernandez SA, Damon SA, Yip FY. A review of disaster-related carbon monoxide poisoning: surveillance, epidemiology, and opportunities for prevention. *Am. J. Public Health* 2012; 102: 1957–63.