Trends of epidemiological characteristics of traumatic spinal cord injury in China, 2009–2018

Dingjun Hao1 · Jinpeng Du1 · Liang Yan1 · Baorong He1 · Xiao Qi2 · Shicheng Yu2 · Jiaojiao Zhang2 · Wenjing Zheng3 · Rongqiang Zhang3 · Da-Geng Huang1 · Junsong Yang1 · Ming Zhu1 · Jiawei Ouyang1 · He Zhao1 · Keyuan Ding1 · Haodong Shi1 · Yang Cao1 · Ying Zhang1 · Qinghua Tang1 · Yuan Liu1 · Zilong Zhang1 · Yuhang Wang1 · Ye Tian1 · Hao Chen1 · Lulu Bai1 · Heng Li1 · Chenchen Mu1 · Youhan Wang1 · Xiaohui Wang1 · Chao Jiang1 · Jianhua Lin4 · Bin Lin5 · Shunwu Fan6 · Lin Nie7 · Jiefu Song8 · Xun Ma9 · Zengwu Shao10 · Yanzheng Gao11 · Zhong Guan12 · Yueming Song13 · Weihu Ma14 · Qixin Chen15

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Abstract
Objective We focus on providing the first comprehensive national dataset on the incidence, injury aetiology and mortality of TSCI in China.

Methods A multi-stage stratified cluster sampling method was used. We included TSCI cases from all hospitals in three regions, nine provinces and 27 cities in China via search of electronic medical records and retrospectively analysed the characteristics of TSCI in China from 2009 to 2018. We estimated the incidence of TSCI in the total population and subgroups.

Results There were 5954 actual cases in 2009, corresponding to a total estimated TSCI incidence of 45.1 cases per million population (95% CI, 44.0–46.3). There were 10,074 actual cases in 2018, corresponding to a total estimated TSCI incidence of 66.5 cases per million population (95% CI, 65.2–67.8) (P < 0.001; annual average percentage change (AAPC), 4.4%). From 2009 to 2018, the incidence of almost all sex/age groups showed an increasing trend over time (P < 0.001; AAPC, 0.7–8.8%). The elderly population (aged 65–74) displayed the highest incidence of TSCI (with an average annual incidence of 127.1 cases per million [95% CI, 119.8–134.3]).

Conclusions The TSCI incidence increased significantly from 2009 to 2018. The incidence in the elderly populations was consistently high and continues to increase over time. The mortality of TSCI patients in hospitals is relatively low and continues to decrease each year, but elderly individuals remain at a high risk of hospital death.

Keywords Epidemiology · Incidence · Mortality · Spinal cord injury · China

Introduction
Traumatic spinal cord injury (TSCI) is a highly disabling condition. It places a heavy burden on individuals, families and society as a whole because of its labour loss, long-term rehabilitation, occupation of large medical resources and expensive medical costs [1, 2]. Due to the imperfections of the national registration system, the national epidemiology of TSCI in China remains unknown and has only been reported in particular cities [3, 4]. The reported incidences vary widely, and there is significant error when extrapolating the characteristics of national TSCI cases from survey data reported from a single region. Throughout the world, developed countries have identified the epidemic characteristics of TSCI through domestic large-scale epidemiological investigations [5–9] and then taken corresponding preventive and first-aid measures. We designed the Chinese TSCI Epidemiological Survey to create the first comprehensive and up-to-date national dataset of the incidence, injury aetiology, mortality and other epidemiological characteristics of TSCI in China.


Materials and methods

Study design and participants

This retrospective survey uses a multi-stage stratified cluster sampling method of the medical records of TSCI patients who were admitted to the hospital. According to the expected incidence rate reported in a previous literature review [10], the required sample size was calculated, and the number of sampling layers at all levels was determined. In the main sampling stage, the 32 provinces (autonomous regions) of China were divided into three regions (East, Central and West) according to their socio-economic development and geographical location, which is the same classification method often used by the China Bureau of Statistics. In the stratified random sampling stage, three provinces were randomly selected from each region for a total of nine provinces (Qinghai, Gansu, Shaanxi, Shanxi, Hubei, Sichuan, Shandong, Zhejiang and Fujian). Three cities were randomly selected from each province. The eligible TSCI cases in all hospitals in the sample cities were investigated. Similar to previous studies, our study did not take into account those who died at the scene of the injury or in the emergency department [7, 8]. The ethics committee of Xi’an Honghui Hospital and the participating centres approved the study, and given the retrospective nature of the study, the requirement for informed consent was waived.

Data collection

To identify the rationality and comprehensiveness of the contents of the questionnaire, two cities were selected for pilot projects in Shaanxi Province in the pre-survey stage. After repeated argumentation and revision, the following survey indicators were finally confirmed: 1. general patient data (name, age, sex, occupation, urbanization, education level, medical insurance); 2. spinal cord injury index (cause of injury, injury level, severity of injury); 3. treatment measures (operation or rehabilitation treatment, operation procedure); 4. complications; and 5. death.

The investigators searched all cases in the digital archive of each target hospital (Qualified to treat patients with TSCI) from 2009 to 2018 that were diagnosed with TSCI as defined by the International Classification of Diseases, 10th edition (ICD-10) code (see Appendix). The ICD code for TCSI includes cauda equina injury but does not include spinal root and spinal plexus injury. The investigators initially searched for qualified cases in the digital archives and then referred to the patients’ electronic medical records after the initial screening to extract the relevant data. We classified the causes of TSCI into traffic injury, falling object injury, low falls (height < 1 m), high falls (height > 1 m), and other, as well as the classification of complications and surgical methods, which are often used in Chinese clinical practice and national health service surveys.

Select trained investigation team members participated in this data collection. The relevant personnel were trained repeatedly before data collection and data entry and were provided detailed questionnaire management instructions. During the investigation stage, two members comprised an investigation team and performed the data collection and verification for each data site. We created nine quality control teams (one for each province), and all the questionnaires collected were checked for omissions and errors by the quality control team. The data in the medical records were independently interpreted by the attending physician to ensure the accuracy of the original data.

Statistical analysis

We included TSCI cases from all hospitals in the sample cities and calculated the total incidence of TSCI per 1 million population based on the sum of population estimate data given by the Bureau of Statistics in each sample city. Then, we calculated the stratified incidence rate according to region, sex/age, urbanization and education level. The standardized incidence rates overall and by regional and sex/age stratifications were then calculated using the World Health Organization’s world standard population through a direct standardized method so that the results could be compared. The estimated number of cases in each stratification was then calculated. Additionally, we calculated the average annual incidence of each stratification by dividing the average number of cases from 2009 to 2018 by each stratification by the average population at the corresponding level in 2009–2018. All incidence rates are shown with a 95% confidence interval (CI).

We calculated the proportion of the internal composition of aetiology, hospital complications, hospital mortality and other clinical and demographic characteristics of the included TSCI patients for 10 consecutive years; the unweighted calculation did not provide a nationally representative estimate. The CI of the internal composition ratio is calculated by using the asymptotic normal distribution of large samples. The trend analysis of the incidence and internal constituent ratio was analysed with the Cochran–Armitage trend test. $P < 0.05$ was considered statistically significant. If the trend test indicates that the incidence displays a changing trend over time, it is assumed that the trend is linear. In that case, the time term linear regression model is used for linear fitting, and the slope represents the speed of change, which can be simply used to compare the difference.
between linear trends. Simultaneously, the annual average percentage change (AAPC) of each stratification was calculated to assist in the assessment of changes in incidence over the past 10 years.

We used Epidata software (version 3.1) for data entry and management and used Microsoft Office Excel 2019 to check and save the data. Analyses were performed with SAS (version 9.1).

Result

Incidence

This study included a total of 78,061 patients with TSCI from 2009 to 2018 who were admitted to 200 hospitals (with the ability to treat TSCI) in 27 sample cities. The general data are detailed in the appendix. The number of cases in the dataset increased from 5954 in 2009 to 10,074 in 2018 (AAPC, 6.0%). The incidence rates in 2009 and 2018 were estimated at 45.1 (95% CI, 44.0–46.3) and 66.5 (95% CI, 65.2–67.8) cases per million population (P < 0.001; AAPC, 4.4%), respectively. The stratified incidence of each region showed an increasing trend (P < 0.001, for all trends; AAPC: East, 2.5; Central, 4.4; West, 8.3%), with the highest annual average incidence rate of 49.4 cases (95% CI, 49.3–49.6) per million population in the eastern region (standardized) and the lowest annual incidence rate of 34.2 cases (95% CI, 34.0–34.3) per million population in the western region (standardized); however, the incidence rate has increased the fastest over time in the western region (slope, 3.0; $R^2$, 0.9). See Fig. 1 and Appendix for details.

As shown in Table 1, except for the < 14-year-old age group of males, the incidence rates of the other sex/age groups increased over time (P < 0.001) (for example, the adolescent male age group [15–24 years old] [AAPC, 5.8%] increased from 17.5 cases/million people [202 cases] in 2009 to 29.0 cases/million people [255 cases] in 2018). The incidence rate of males was higher than that of females (standardized annual average incidence rate, males: 66.4 cases/million people [95% CI, 66.2–66.7]; females: 23.6 cases/million people [95% CI, 23.4–23.8]). Among the male and female populations, the incidence of TSCI in the elderly population remained high from 2009 to 2018 (for example, the male 65–74 age group [AAPC, 2.55%] increased from 158.1 cases/million people [612 cases] in 2009 to 197.1 cases/million people [1125 cases] in 2018, with an average annual incidence of 184.4/million people [95% CI, 172.1–196.8]).

Fig. 1 Traumatic spinal cord injury incidence rate per 1 million people by Region in China, 2009–2018
| Year | ≤ 14 | 15–24 | 25–34 | 35–44 | 45–54 | 55–64 | 65–74 | ≥ 75 |
|------|------|-------|-------|-------|-------|-------|-------|------|
| Male |
| 2009 | 3.2 (2.2–4.2) | 17.5 (15.1–20.0) | 51.6 (47.1–56.1) | 57.4 (53.0–61.8) | 132.5 (125.3–139.8) | 144.8 (135.9–153.6) | 158.1 (145.5–170.6) | 70.5 (59.0–82.0) |
| 2010 | 2.9 (1.9–3.9) | 18.7 (16.3–21.9) | 45.1 (40.9–51.2) | 52.1 (48.0–56.1) | 132.7 (125.7–139.8) | 143.8 (126.7–143.0) | 152.6 (140.5–164.6) | 62.9 (52.3–73.5) |
| 2011 | 3.5 (2.5–4.6) | 14.9 (12.8–17.1) | 41.2 (37.4–45.1) | 56.6 (52.3–60.9) | 150.5 (142.8–158.1) | 158.3 (149.4–167.2) | 173.1 (160.1–184.6) | 70.3 (59.3–81.4) |
| 2012 | 3.3 (2.3–4.3) | 14.8 (12.6–17.1) | 41.7 (37.8–45.5) | 58.6 (54.2–63.0) | 148.0 (140.4–155.5) | 147.6 (139.2–156.0) | 169.0 (156.6–181.5) | 71.6 (60.6–82.5) |
| 2013 | 3.4 (2.4–4.4) | 18.0 (15.5–20.1) | 41.6 (37.8–45.4) | 65.7 (61.0–70.4) | 152.3 (144.8–159.7) | 153.2 (144.8–161.6) | 172.3 (160.1–184.6) | 74.7 (63.9–85.6) |
| 2014 | 4.1 (2.9–5.2) | 21.9 (19.0–24.8) | 47.5 (43.5–51.5) | 79.4 (74.3–84.6) | 189.7 (181.2–194.8) | 186.2 (177.0–195.4) | 198.0 (185.2–201.9) | 93.3 (81.3–105.2) |
| 2015 | 3.4 (2.4–4.5) | 22.3 (19.3–25.3) | 42.8 (39.1–45.8) | 77.5 (72.3–82.6) | 154.1 (146.9–161.3) | 183.5 (174.3–192.6) | 190.3 (177.9–202.6) | 78.8 (68.0–89.7) |
| 2016 | 4.0 (2.9–5.0) | 29.6 (26.1–33.1) | 56.9 (52.7–61.2) | 94.4 (88.7–100.1) | 172.5 (165.1–179.9) | 210.7 (200.9–220.4) | 209.7 (197.2–222.2) | 84.1 (73.3–94.9) |
| 2017 | 3.7 (2.6–4.7) | 30.0 (26.4–33.7) | 55.4 (51.2–59.6) | 95.5 (89.7–101.2) | 171.3 (164.0–178.6) | 210.2 (200.6–219.9) | 202.5 (190.4–214.5) | 94.2 (82.8–105.6) |
| 2018 | 4.0 (3.0–5.1) | 29.0 (24.5–30.6) | 55.0 (51.0–59.5) | 93.0 (87.4–98.6) | 171.2 (164.0–175.8) | 206.5 (197.3–215.8) | 197.1 (185.6–208.6) | 92.3 (81.3–103.4) |
| Annual Average | 3.6 (2.5–4.6) | 21.0 (18.2–23.8) | 48.1 (44.1–52.2) | 72.7 (67.7–77.6) | 158.3 (150.8–165.8) | 175.1 (160.0–184.1) | 184.4 (172.1–196.8) | 80.3 (69.1–91.5) |
| Female* |
| 2009 | 8.0 (6.2–9.9) | 6.7 (5.2–8.3) | 15.1 (12.7–17.6) | 18.2 (15.8–20.7) | 35.7 (31.9–39.4) | 46.2 (41.1–51.3) | 60.3 (52.7–67.9) | 24.9 (18.9–30.8) |
| 2010 | 7.1 (5.4–8.8) | 6.6 (5.1–8.1) | 13.5 (11.2–15.7) | 17.5 (15.1–19.8) | 34.4 (30.7–38.0) | 40.8 (36.3–45.3) | 59.6 (52.1–67.2) | 30.3 (23.8–36.8) |
| 2011 | 8.8 (6.9–10.6) | 5.9 (4.4–7.3) | 13.8 (11.5–16.0) | 19.1 (16.6–21.6) | 44.7 (40.5–48.9) | 44.4 (39.7–49.1) | 69.7 (61.5–78.0) | 30.2 (23.8–36.6) |
| 2012 | 8.7 (6.9–10.5) | 6.8 (5.2–8.4) | 12.0 (9.9–14.0) | 18.9 (16.4–21.4) | 42.5 (38.4–46.5) | 42.8 (38.3–47.3) | 65.7 (57.9–73.4) | 31.6 (25.2–38.1) |
| 2013 | 8.9 (7.1–10.7) | 8.6 (6.7–10.5) | 13.5 (11.3–15.6) | 21.1 (18.4–23.8) | 41.7 (37.8–45.6) | 46.3 (41.6–50.9) | 65.7 (58.1–73.3) | 34.2 (27.6–40.7) |
| 2014 | 10.3 (8.4–12.3) | 9.5 (7.5–11.5) | 14.9 (12.7–17.2) | 25.8 (22.8–28.8) | 47.3 (43.2–51.4) | 53.2 (48.3–58.1) | 78.8 (70.7–86.9) | 36.6 (30.0–43.3) |
| 2015 | 9.3 (7.5–11.2) | 9.9 (7.8–12.0) | 15.4 (13.2–17.6) | 24.4 (21.5–27.3) | 45.9 (41.9–49.8) | 54.4 (49.4–59.4) | 72.5 (64.9–80.0) | 38.1 (31.4–44.8) |
The incidence rate in the male 55–64 age group increased the fastest over time (from 144.8 cases/million people [1025 cases] in 2009 to 206.5 cases/million people [1914 cases] in 2018; [AAPC, 4.0%]; slope, 9.0; \( R^2, 0.9 \)). The number of cases stratified by age-sex in the database and the corresponding case estimates are shown in the appendix.

The TSCI incidence stratified by urbanization and education level shows an increasing trend linearly related to the time series (Fig. 2) (\( P < 0.001 \); for all trend). The incidence rate in the rural population was higher than that of the urban population (annual average IRR, 1.9 [95% CI, 1.8–2.0]), but the incidence rate in the urban population has increased faster over time (slope, 4.0; \( R^2, 0.9 \)). The incidence of the low-educated population (junior high school and below) was slightly higher than that in the higher educated population (senior high school and above) (annual average IRR, 1.1 [95% CI, 1.1–1.2]), and the incidence rate in low-educated population has increased faster over the past 10 years (slope, 3.2; \( R^2, 0.9 \)). Additionally, the incidence of urbanization and education showed a significant difference after regional stratification (appendix). For example, the incidence of the rural population in the eastern region shows a downward trend over time (\( P = 0.04 \); AAPC, −1.0%; slope, −0.5, \( R^2, 0.1 \)), whereas the incidence in the urban population increased faster in the eastern region than in other regions (AAPC, 9.0%; slope, 5.4, \( R^2, 0.8 \)). The incidence rate in the rural population in the western region has increased faster than that in the other regions over time (AAPC, 11.8%; slope, 7.2, \( R^2, 0.9 \)), whereas the increase in incidence in the urban population was the slowest in the western region (AAPC, 4.2%; Slope, 1.4, \( R^2, 0.6 \)). In addition, the incidence rate of the higher educated population in the eastern region has increased faster than that of the other regions (AAPC, 4.1%; slope, 4.7, \( R^2, 0.7 \)), and the incidence rate of the low-educated population in the western region has increased faster than that in the other regions (AAPC, 11.3%; slope, 5.1, \( R^2, 0.9 \)).

### Cause of injury

From 2009 to 2018, the three leading causes of injury included traffic injuries, low falls and high falls (Fig. 3). Over the past 10 years, the largest proportion of TSCIs has always been caused by traffic injuries (from 2009 [30.7%; 95% CI, 29.5–31.9%] to 2018 [32.4%; 95% CI, 31.5–33.3%]), and the overall trend has remained stable (\( P = 0.071 \)). The proportion of TSCIs caused by low falls was correlated with the time series (\( P = 0.015 \)) and ranged from 27.8% (95% CI, 26.7–29.0%) in 2009 to 26.6% (95% CI, 25.8–27.5%) in 2018. The proportion of TSCIs caused by high falls tended to increase over time (\( P < 0.001 \)), from 2009 [23.0%; 95% CI, 22.0–24.1%] to 2018 [25.8%; 95% CI, 24.9–26.6%]. After stratifying by region, the

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**Appendix**

### Table 1 (continued)

| Year | ≤ 14 | 15–24 | 25–34 | 35–44 | 45–54 | 55–64 | 65–74 | ≥ 75 |
|------|------|-------|-------|-------|-------|-------|-------|------|
| 2016 | 9.9 (8.1–11.8) | 13.7 (11.2–16.3) | 17.4 (15.0–19.8) | 21.0 (18.5–23.6) | 34.3 (31.4–37.0) | 78.9 (71.3–86.5) | 17.5 (15.0–19.9) | 27.8 (27.6–27.9) |
| 2017 | 10.1 (8.3–12.0) | 13.6 (11.1–16.2) | 17.5 (15.1–19.8) | 21.0 (18.5–23.5) | 34.2 (31.3–37.0) | 78.5 (71.1–86.5) | 17.4 (15.0–19.9) | 27.7 (27.5–27.8) |
| 2018 | 10.2 (8.4–12.1) | 13.7 (11.2–16.3) | 17.5 (15.1–19.8) | 21.0 (18.5–23.5) | 34.2 (31.3–37.0) | 78.5 (71.1–86.5) | 17.4 (15.0–19.9) | 27.7 (27.5–27.8) |

**Annual Average**

| ≤ 14 | 15–24 | 25–34 | 35–44 | 45–54 | 55–64 | 65–74 | ≥ 75 |
|------|-------|-------|-------|-------|-------|-------|------|
| 9.2 (7.2–11.0) | 14.4 (11.7–17.1) | 13.7 (11.2–16.3) | 17.5 (15.1–19.8) | 34.2 (31.3–37.0) | 78.5 (71.1–86.5) | 17.4 (15.0–19.9) | 27.7 (27.5–27.8) |

*Rates standardized for age by the direct method using the WHO World Standard Population; data are incidence (95%CI), unless stated otherwise*
proportion of TSCIs caused by traffic injuries was always the highest in the eastern region and increased linearly along the time series (P < 0.001) whereas it decreased linearly along the time series in the central region (P < 0.015); however, traffic injuries were still the main cause of injury in the central region. The proportion of TSCIs caused by high falls decreased linearly along the time series in the eastern region (P < 0.022) but increased linearly along the time series in the central and western regions (P < 0.001, for all trends). High falls have always been the main cause of injury in patients with TSCIs in the western region. Detailed data are given in Appendix.

Results of general clinical indicators

The proportions of these clinical indexes such as cervical spinal cord injury, complete spinal cord injury, rehabilitation treatment, surgical treatment, and complications showed a linear increasing trend over time (P < 0.05) (Table 2). However, the proportion of patients with bedsores decreased over time (P < 0.001). Most TSCI patients received decompression and fixation fusion; this proportion increased from 60.3% (95% CI, 58.9–61.8%) in 2009 to 63.4% (95% CI, 62.3–64.5%) in 2018 (P < 0.001). Detailed data for more indicators are given in Appendix.
Table 2 Details of selected secondary outcomes in included inpatient samples with traumatic spinal cord injury in China, 2009–2018

| Injury level                  | Years | 2009       | 2010       | 2011       | 2012       | 2013       | 2014       | 2015       | 2016       | 2017       | 2018       | P value*     |
|-------------------------------|-------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|--------------|
| Cervical spinal cord          |       | 3729       | 3856       | 4101       | 4139       | 4625       | 5428       | 5450       | 6428       | 6699       | 6946       | <0.001       |
| Thoracic spinal cord          |       | 785        | 755        | 945        | 825        | 885        | 1032       | 993        | 1081       | 1182       | 1208       | <0.001       |
| Lumbar spinal cord            |       | 1440       | 1334       | 1491       | 1571       | 1926       | 1694       | 2163       | 1915       | 1920       |            | <0.001       |
| Severity of injury, Complete SCI |     | 1015       | 1179       | 1107       | 1285       | 1577       | 1614       | 1998       | 2372       | 2721       | 2763       | <0.001       |
| Rehabilitation, Yes           |       | 1073       | 1181       | 1707       | 1783       | 2070       | 2973       | 3802       | 4742       | 5808       | 6322       | <0.001       |
| Surgery, Yes                  |       | 4246       | 4240       | 4653       | 4657       | 5005       | 6008       | 5866       | 6979       | 7079       | 7258       | 0.022        |
| Surgical procedures           |       |            |            |            |            |            |            |            |            |            |            |              |
| Simple spinal cord decompression |     | 256        | 224        | 267        | 252        | 275        | 315        | 311        | 374        | 362        | 382        | 0.067        |
| Decompression and fixation    |       | 1183       | 1217       | 1262       | 1303       | 1388       | 1623       | 1621       | 1872       | 1857       | 1900       | 0.001        |
| Decompression, fixation and fusion |   | 2562       | 2565       | 2865       | 2845       | 3089       | 3773       | 3639       | 4364       | 4500       | 4604       | <0.001       |
| Other                         |       | 60.3       | 60.5       | 61.6       | 61.1       | 61.7       | 62.8       | 62.0       | 62.5       | 63.2       | 63.6       | 0.001        |
| Complications, Yes            |       | 245        | 234        | 259        | 257        | 253        | 297        | 295        | 369        | 360        | 372        | 0.050        |
| Urinary system                |       | 446        | 404        | 435        | 462        | 553        | 557        | 644        | 669        | 674        | 739        | 0.798        |
| Years | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|-------|------|------|------|------|------|------|------|------|------|------|
| Respiratory system | 614 (9.5–11.1) | 9.0 (8.2–9.7) | 10.9 (10.1–11.6) | 10.7 (9.9–11.4) | 10.3 (9.6–11.0) | 9.3 (8.6–9.9) | 11.4 (10.7–12.1) | 11.5 (10.8–12.1) | 11.1 (10.5–11.7) | 11.8 (11.2–12.4) | <0.001 |
| Electrolyte disorder | 6.0 (5.4–6.6) | 5.9 (5.3–6.5) | 6.0 (5.4–6.6) | 6.4 (5.8–7.0) | 6.6 (6.0–7.2) | 6.9 (6.3–7.4) | 6.7 (6.1–7.2) | 6.3 (5.9–6.8) | 6.5 (6.1–7.0) | 5.8 (5.3–6.2) | 0.592 |
| Bedsore | 261 | 246 | 266 | 244 | 269 | 361 | 325 | 355 | 352 | 340 |
| Venous thrombosis | 4.4 (3.9–4.9) | 4.1 (3.6–4.6) | 4.1 (3.6–4.5) | 3.7 (3.3–4.2) | 3.8 (3.4–4.3) | 4.3 (3.9–4.7) | 4.0 (3.6–4.4) | 3.7 (3.3–4.0) | 3.6 (3.2–4.0) | 3.4 (3.0–3.7) | <0.001 |
| Infection, Yes | 2.3 (1.9–2.6) | 2.1 (1.8–2.5) | 2.6 (2.2–3.0) | 2.5 (2.1–2.8) | 2.6 (2.3–3.0) | 2.7 (2.4–3.1) | 2.5 (2.1–2.8) | 2.8 (2.5–3.1) | 2.4 (2.1–2.7) | 2.9 (2.6–3.2) | 0.011 |
| Upper respiratory tract | 14.7 (13.8–15.6) | 14.5 (13.6–15.3) | 14.9 (14.0–15.7) | 15.5 (14.7–16.4) | 14.9 (14.2–15.7) | 16.0 (15.2–16.8) | 14.9 (14.1–15.6) | 15.5 (14.7–16.2) | 15.2 (14.5–15.9) | 0.028 |
| Lower respiratory tract | 36 | 34 | 34 | 33 | 43 | 48 | 52 | 63 | 72 | 64 |
| Urinary system | 0.6 (0.4–0.8) | 0.6 (0.4–0.8) | 0.5 (0.3–0.7) | 0.6 (0.4–0.8) | 0.6 (0.4–0.8) | 0.6 (0.5–0.8) | 0.7 (0.5–0.8) | 0.7 (0.6–0.9) | 0.6 (0.5–0.8) | 0.111 |
| Respiratory system | 10.9 (10.1–11.6) | 10.7 (9.9–11.4) | 10.3 (9.6–11.0) | 9.3 (8.6–9.9) | 11.4 (10.7–12.1) | 11.5 (10.8–12.1) | 11.1 (10.5–11.7) | 11.8 (11.2–12.4) | 11.0 (10.2–11.8) | 0.001 |
| Venous thrombosis | 134 | 126 | 169 | 161 | 186 | 227 | 202 | 272 | 232 | 292 |
| Infection, Yes | 848 | 875 | 947 | 1092 | 1253 | 1305 | 1437 | 1514 | 1528 | 1528 |
| Upper respiratory tract | 14.7 (13.8–15.6) | 14.5 (13.6–15.3) | 14.9 (14.0–15.7) | 15.5 (14.7–16.4) | 14.9 (14.2–15.7) | 16.0 (15.2–16.8) | 14.9 (14.1–15.6) | 15.5 (14.7–16.2) | 15.2 (14.5–15.9) | 0.028 |
| Lower respiratory tract | 36 | 34 | 34 | 33 | 43 | 48 | 52 | 63 | 72 | 64 |
| Urinary system | 0.6 (0.4–0.8) | 0.6 (0.4–0.8) | 0.5 (0.3–0.7) | 0.6 (0.4–0.8) | 0.6 (0.5–0.8) | 0.7 (0.5–0.8) | 0.7 (0.6–0.9) | 0.6 (0.5–0.8) | 0.111 |

Data are n or % (95%CI), unless stated otherwise; *P value for Cochran–Armitage trend test. SCI means spinal cord injury

Bold means that the internal constituent ratio of secondary results shows a linear trend over time.
Mortality

The hospital mortality rates in 2009 and 2018 were 2.5% (95% CI, 2.1–2.9%) and 1.9% (95% CI, 1.6–2.1%) ($P < 0.001$), respectively. Although the mortality rate increased with age (Table 3), among people 55 or older, it tended to decrease over time. For example, in the age group ≥75, the mortality rate decreased from 6.2% (95% CI, 2.9–9.4%) in 2009 to 3.9% (95% CI, 2.0–5.7%) in 2018 ($P = 0.032$).

Discussion

We assessed the national trends in the incidence, aetiology, general clinical indicators and mortality of TSCI in China as reflected by hospitalized patients from 2009 to 2018. Our data show that the incidence of TSCI in China increased rapidly from 2009 to 2018 (that is, from 45.1 cases per million population in 2009 to 66.5 cases per million population in 2018). There were an estimated 59,685 and 92,841 cases in China in 2009 and 2018, respectively (Appendix). The incidence in the western region was lower than that in other areas. In the past 10 years, the incidence of TSCIs in the elderly population has always been high and continues to increase. The incidence in the rural population was higher than that in the urban population, but the incidence in the urban population is increasing faster over time. The incidence in the low-educated population was slightly higher than that of the high-educated population, and the incidence in low-educated people has increased faster over time. The hospital mortality rate of TSCI in China is low and continues to decline (from 2.5% in 2009 to 1.9% in 2018), particularly among patients aged 55 and older.

This is the first time that we have reported the results of an epidemiological survey of TSCIs at the national level. The annual incidence of TSCI in the world is estimated to range from 10.4 to 83.0 cases per 1 million people [11, 12]. The incidence of TSCI is 20.7–83.0 cases per 1 million in North America, 8.0–130.6 cases per 1 million in Europe [13, 14], and 14.0 cases per 1 million people in Australia [6]. A review of studies focusing on developing countries found that the incidence of TSCI was 25.5 cases per 1 million people [15]. The USA has a similar reported incidence (crude incidence rate of 54 cases/million people) of TSCI compared to that of China (crude incidence rate of 55.3 cases/million people, standardized incidence rate of 44.9 cases/million people) [8].

We identified significant differences in the characteristics and trends of the TSCI incidence among the eastern, central and western regions. The incidence in the western region was significantly lower than that in the other areas (the standardized annual average incidence rate was 34.2 cases/million people). The imbalance of regional economic development may be the main reason for this difference [2]. Previous literature has made it clear that the difference in the level of socio-economic development between developed and developing countries is a potential factor for differences in the incidence of TSCI [12, 16]. The economic development of the three regions in China is not coordinated, and the economic level of the western region has always lagged far behind that of the eastern and central regions. The rapid increase in the incidence in the western region may be related to the continuous strong governmental support of the economy of the western region in recent years.

We found that elderly individuals (65–74 age group) had the highest incidence of TSCI (with an average annual incidence of 127.1 cases/million people) and that the incidence increased slightly over time (AAPC, 2.3%); moreover, the incidence of TSCI in people aged 55–64 increased significantly over time (AAPC, 3.8%; with an AAPC of 9.0% for men). The peak age at which TSCI occurs in Beijing, Shanghai, Tianjin and other cities is 40–60 years old [3, 4, 17], but the time range of the report is earlier (2002–2010), indicating that with the ageing of the population in recent years, the proportion of cases of TSCI in elderly individuals is increasing. The results of studies from many countries indicate that young people are the second most vulnerable population to TSCI; thus, the age of TSCI patients shows a bimodal distribution [6, 7, 18]. However, our study found that the incidence in young people was much lower than that in elderly individuals (unimodal distribution). In addition, countries such as the USA and Australia [6, 8] have found that the incidence of TSCI among young people has decreased significantly over time. Conversely, the incidence of TSCI in young people aged 15–24 in China has increased significantly over time, which may be due to the relative lag in public education, the improvement of motor vehicle safety functions, traffic safety laws and their enforcement despite the rapid development of the economy.

The incidence of TSCI can also vary with the progress of urbanization and the education level. We found that the incidence was higher in the rural population, but the incidence in the urban population has increased each year. The summary study by Yuan et al. [19] classified the occupations of TSCI patients in China and found that farmers, workers and unemployed people had a significantly higher risk of TSCI. In China, these occupations are mainly concentrated in the rural population, and the educational level is generally low. However, with the acceleration of urbanization, these people gradually gather to work or even settle in cities. As a result, the incidence in the urban population and the incidence in the low-educated population increased significantly with the passage of time. Migrant workers are more likely to gather in the eastern and central economically developed regions, which may be responsible for the large differences in the
### Table 3: Temporal trends in mortality of traumatic spinal cord injury in China

| Age group (year) | Years       | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   |  \( P \) value*  \\
|-----------------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------------|
| 15–24 ≤ 14     | No. died/total | 1/114 | 1/103  | 0/131  | 0/126  | 2/132  | 3/159  | 3/144  | 1/162  | 2/159  | 1/177  | 0.633          \\
|                 | % (95%CI)    | 0.9 (−0.8–2.6) | 1.0 (−0.9–2.9) | 0     | 0     | 1.5 (−0.6–3.6) | 1.9 (−0.2–4.0) | 2.1 (−0.2–4.4) | 0.6 (−0.6–1.8) | 1.3 (−0.5–3.0) | 0.6 (−0.5–1.7) |             \\
| 15–24 25–34    | No. died/total | 5/274 | 2/292  | 2/246  | 2/240  | 4/274  | 3/307  | 4/295  | 6/375  | 5/364  | 3/365  | 0.948          \\
|                 | % (95%CI)    | 1.8 (0.2–3.4) | 0.7 (−0.3–1.6) | 0.8 (−0.3–1.9) | 0.8 (−0.3–2.0) | 1.5 (0.0–2.9) | 1.0 (−0.1–2.1) | 1.4 (0.0–2.7) | 1.6 (0.3–2.9) | 1.4 (0.2–2.6) | 0.8 (−0.1–1.7) |             \\
| 25–34 35–44    | No. died/total | 12/652 | 7/590 | 6/586  | 7/582  | 10/609 | 6/715  | 9/703  | 14/902 | 12/891 | 15/934 | 0.982          \\
|                 | % (95%CI)    | 1.8 (0.8–2.9) | 1.2 (0.3–2.1) | 1.0 (0.2–1.8) | 1.2 (0.3–2.1) | 1.6 (0.6–2.7) | 0.8 (0.2–1.5) | 1.3 (0.4–2.1) | 1.6 (0.7–2.4) | 1.3 (0.6–2.1) | 1.6 (0.8–2.4) |             \\
| 35–44 45–54    | No. died/total | 11/872 | 14/835 | 12/899 | 15/914 | 11/994 | 14/1203 | 15/1136 | 18/1395 | 16/1386 | 18/1394 | 0.503          \\
|                 | % (95%CI)    | 1.3 (0.5–2.0) | 1.7 (0.8–2.5) | 1.3 (0.6–2.1) | 1.6 (0.8–2.5) | 1.6 (0.5–1.8) | 1.2 (0.6–1.8) | 1.3 (0.7–2.0) | 1.3 (0.7–1.9) | 1.2 (0.6–1.7) | 1.3 (0.7–1.9) |             \\
| 45–54 55–64    | No. died/total | 26/1633 | 26/1685 | 24/1922 | 35/1903 | 36/2024 | 35/2358 | 32/2274 | 34/2659 | 39/2688 | 41/2752 | 0.511          \\
|                 | % (95%CI)    | 1.6 (1.0–2.2) | 1.5 (1.0–2.1) | 1.2 (0.8–1.7) | 1.8 (1.2–2.4) | 1.8 (1.2–2.4) | 1.5 (1.0–2.0) | 1.4 (0.9–1.9) | 1.3 (0.9–1.7) | 1.5 (1.0–1.9) | 1.5 (1.0–1.9) |             \\
| 55–64 65–74    | No. died/total | 44/1345 | 48/1372 | 45/1558 | 43/1538 | 51/1667 | 47/2020 | 47/1994 | 49/2317 | 53/2377 | 50/2489 | <0.001         \\
|                 | % (95%CI)    | 3.3 (2.3–4.2) | 3.5 (2.5–4.5) | 2.9 (2.1–3.7) | 2.8 (2.0–3.6) | 3.1 (2.2–3.9) | 2.3 (1.7–3.0) | 2.4 (1.7–3.0) | 2.1 (1.5–2.7) | 2.2 (1.6–2.8) | 2.0 (1.5–2.6) |             \\
| 65–74 ≥ 75     | No. died/total | 39/854  | 42/850 | 37/954 | 41/976 | 43/1039 | 41/1274 | 44/1265 | 40/1489 | 45/1522 | 44/1548 | <0.001         \\
|                 | % (95%CI)    | 4.6 (3.2–6.0) | 4.9 (3.5–6.4) | 3.9 (2.7–5.1) | 4.2 (2.9–5.5) | 4.1 (2.9–5.3) | 3.2 (2.2–4.2) | 3.5 (2.5–4.5) | 2.7 (1.9–3.5) | 3.0 (2.1–3.8) | 2.8 (2.0–3.7) |             \\
| ≥ 75 Overall   | No. died/total | 13/210  | 14/218 | 14/241 | 12/256 | 16/286 | 14/350 | 15/327 | 15/373 | 18/409 | 16/415 | 0.032          \\
|                 | % (95%CI)    | 6.2 (2.9–9.4) | 6.4 (3.2–9.7) | 5.8 (2.9–8.8) | 4.7 (2.1–7.3) | 5.6 (2.9–8.3) | 4.0 (1.9–6.1) | 4.6 (2.3–6.9) | 4.0 (2.0–6.0) | 4.4 (2.4–6.4) | 3.9 (2.0–5.7) | <0.001         \\
| Overall        | No. died/total | 151/5954 | 154/5945 | 140/6537 | 155/6535 | 173/7025 | 163/8386 | 169/8137 | 177/9672 | 190/9796 | 188/10074 | <0.001         \\
|                 | % (95%CI)    | 2.5 (2.1–2.9) | 2.6 (2.2–3.0) | 2.1 (1.8–2.5) | 2.4 (2.0–2.7) | 2.5 (2.1–2.8) | 1.9 (1.6–2.2) | 2.1 (1.8–2.4) | 1.8 (1.6–2.1) | 1.9 (1.7–2.2) | 1.9 (1.6–2.1) |             \\

Data are \( n \) or % (95%CI), unless stated otherwise; *\( P \) value for Cochran–Armitage trend test

Bold means that the mortality of age subgroup shows a linear trend over time
The changes of population ageing, economic development, urbanization and education level that we mentioned earlier affect the incidence of TSCI in China. However, we cannot ignore the impact of utilization/accessibility of healthcare on the changing trend of the incidence of TSCI in China, because with the significant expansion of health care in China over the decade, utilization/accessibility of healthcare continues to improve. For example, it is possible that 10 years ago, many patients with TSCI gave up treatment before hospitalization because of the limited medical resources and heavy financial burden. At present, due to the comprehensive coverage of China’s medical insurance and rich medical resources, the hospitalization rate of patients with TSCI is higher than that of 10 years ago, which may be a confounding factor contributing to the increase in the incidence of TSCI over the decade. However, we believe that economic development and so on are the main factors.

In developed countries, traffic accidents and falls are the main causes of SCIs [8, 20, 21]. Traffic injuries are also the main cause of SCIs in China, particularly in the eastern and central regions. With the rapid development of China’s economy, most people own private cars, which has led to a significant increase in car accidents. In the western region, the proportion of SCIs caused by high-altitude falls remains high and has increased over time. In recent years, the acceleration of urbanization and infrastructure construction in the western region with the support of the government may be potential factors for this increase. The government must formulate corresponding prevention strategies according to the aetiological characteristics of injuries in different regions. For example, the eastern and central regions must further standardize driver behaviour, improve road conditions, strengthen the crackdown on drunk driving, etc. High falls are more likely to occur in construction sites. When vigorously developing infrastructure construction in the western region, construction units must be required to strengthen personal safety awareness and focus on supervising work safety.

The increasing proportions of cervical spinal cord injuries and complete spinal cord injuries may be related to the increase in traffic injuries and high falls. With the expansion and upgrading of Chinese medical institutions and the full implementation of the medical insurance policy, the proportion of patients receiving rehabilitation treatment and surgical treatment continues to increase each year. Despite the obvious improvement in medical conditions and the rapid improvement in the treatment level in China in recent years, the proportion of hospitalized complications and infection in TSCI patients reported in our study still increased over time. Previous studies have shown that patients with cervical spinal cord injury and complete spinal cord injury have a higher probability of complications and infection [22], which should be the most reasonable explanation.

The hospital mortality rate of TSCI reported in the USA is very high and has increased from 6.6% in 1993–1996 to 7.5% in 2010–2012 [8]. The standardized mortality rate of TSCI reported in Australia increased from 2.34 per million people in 2002 to 3.57 per million people [17]. Although we reported that the hospital mortality of TSCI patients is low and has decreased over time, in fact, we only reported the proportion of hospital deaths. Recently, through a survey of the China Disease Surveillance Points system covering 161 surveillance sites in China, Li et al. [23] found that the mortality of TSCI increased from 1.9 cases/million people in 2006 to 3.4 cases/million people in 2016. Many pre-hospital deaths can be monitored by using the system, which may be a potential cause of the difference in incidence trends.

**Conclusions**

The incidence of TSCI increased significantly from 2009 to 2018, particularly in the western region. The incidence in the elderly population was always high and has continued to increase over time. The incidence is higher in the rural population, but the incidence in the urban population has increased significantly in recent years. The incidence in the low-educated population is slightly higher than that in the high-educated population, and the incidence of the low-educated population has increased rapidly in recent years. TSCI caused by traffic accidents is the focus of prevention work in the future, but the proportion of high falls is the highest in the western region, so it is necessary to formulate corresponding preventive measures according to the characteristics of regional injury causes. The death rate of TSCI patients in the hospital is relatively low and continues to decrease over time, but elderly individuals are still at a high risk of hospital death.

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**Authors’ contributions** DH, JD, and LY searched the literature, conceived the study, designed the study, analysed the data, interpreted the results, and drafted the report. QX, SY, JZ, and WZ designed the methods of the study and analysed the data. D-GH, JY, MZ, JO, HZ, KD, HS, YC, YZ, QT, YL, ZZ, YW, YT, HC, LB, HL, CM, YW, XW, and CJ collected the data. RZ, JL, BL, SF, LN, JS, XM, ZS, YG, ZG, YS, WM, and QC revised the report. DH, JD, LY, and BH obtained funding. DH and BH conceived the study, organized, and supervised the study, interpreted the results, and revised the report.

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**Declarations**

**Conflict of interest** The authors declare that there are no conflicts of interest.

**Ethical approval** The study was approved by the appropriate institutional review board for each study site, and given the retrospective nature of the study, the requirement for informed consent was waived.

**Availability of data and materials** Except for the personal data of all included patients with spinal cord injury such as ID number and place of residence cannot be displayed because of privacy protection, the epidemiological raw data of other key variables (cause of injury, injury level, severity of injury) and supplementary materials used to calculate the results are published on Figshare (https://doi.org/10.6084/m9.figshare.12782834) and can be obtained.

**Standard statement** We have no personal or institutional financial interest in drugs, materials, or devices described in our submissions.

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Authors and Affiliations

Dingjun Hao¹ · Jinpeng Du¹ · Liang Yan¹ · Baorong He¹ · Xiao Qi² · Shicheng Yu² · Jiaojiao Zhang² · Wenjing Zheng² · Rongqiang Zhang³ · Da-Geng Huang¹ · Junsong Yang¹ · Ming Zhu¹ · Jiawei Ouyang¹ · He Zhao¹ · Keyuan Ding¹ · Haodong Shi¹ · Yang Cao¹ · Ying Zhang¹ · Qinghua Tang¹ · Yuan Liu¹ · Zilong Zhang¹ · Yuhang Wang¹ · Ye Tian¹ · Hao Chen¹ · Lulu Bai¹ · Heng Li¹ · Chenchen Mu¹ · Youhan Wang¹ · Xiaohui Wang¹ · Chao Jiang¹ · Jianhua Lin⁴ · Bin Lin⁵ · Shunwu Fan⁶ · Lin Nie⁷ · Jiefu Song⁸ · Xun Ma⁹ · Zengwu Shao¹⁰ · Yanzheng Gao¹¹ · Zhong Guan¹² · Yueming Song¹³ · Weihu Ma¹⁴ · Qixin Chen¹⁵

¹ Department of Spine Surgery, Honghui Hospital, Xi’an Jiao Tong University, Youyidong Road, Xi’an 710000, Shaanxi Province, China
² Office of Epidemiology, Chinese Center for Disease Control and Prevention, Beijing, China
³ Office of Epidemiology, School of Public Health, Shaanxi University of Traditional Chinese Medicine, Xianyang, China
⁴ Department of Spine Surgery, The First Affiliated Hospital of Fujian Medical University, Fujian, China
⁵ Department of Orthopaedic, The No. 909 Hospital of the People’s Liberation Army, Zhangzhou, China
⁶ Department of Orthopaedic, Sir Run Run Shaw Hospital, Zhejiang University School of Medicine, Zhejiang, China
⁷ Department of Spine Surgery, Qilu Hospital of Shandong University, Shandong, China
⁸ Department of Orthopaedic, Shanxi Provincial People’s Hospital, Taiyuan, China
⁹ Department of Orthopaedic, Shanxi Bethune Hospital, Taiyuan, China
¹⁰ Department of Orthopaedic, Union Hospital, Tongji Medical College of Huazhong University of Science and Technology, Wuhan, China
¹¹ Department of Orthopaedic, Henan Provincial People’s Hospital, Zhengzhou, China
¹² Department of Spine Surgery, Qinghai University Affiliated Hospital, Xining, China
¹³ Department of Spine Surgery, West China Hospital of Sichuan University, Chengdu, China
¹⁴ Department of Spine Surgery, Ningbo No. 6 Hospital, Ningbo, China
¹⁵ Department of Orthopaedic, The Second Affiliated Hospital of Zhejiang University School of Medicine, Hangzhou, China