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The association between economic indicators and the incidence of tetraplegia from traumatic spinal cord injury in Taiwan

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Abstract

Background: Economic performance may affect public health parameters. This study aimed to determine the time trend of incidence of traumatic spinal cord injury (SCI) and its association with income, presented by GDP (gross domestic product) per capita.

Methods: This study was a retrospective observational study in Taiwan. Newly diagnosed SCI patients with moderate to severe disability from 2002 to 2015 were identified from the reimbursement database of the National Health Insurance (NHI) system (1998–2015). CIR_{16–99} (cumulative incidence rate, aged 16–99 years, per 10³ person-years) and CIR_{16–59} (aged 16–59 years) of SCI from 2002 to 2015 were measured.

Results: There were 5048 newly diagnosed SCI patients during the study period. After controlling the factors of sex, urbanization level, literacy, income inequality, and global financial crisis (mixed effects models), the CIR_{16–99} of SCI, traumatic SCI, motor vehicle (MV)-related SCI, fall-related SCI, tetraplegia, traumatic tetraplegia, MV-related tetraplegia, and fall-related tetraplegia were inversely associated with GDP per capita; the β coefficients ranged from -4.85 (95% confidence interval -7.09 to -2.6) for total SCI to -0.8 (-1.3 to -0.29) for fall-related tetraplegia. We restricted our comparison to Taipei City and the 4 lowest densely populated counties, which also corroborated with the above results. The income elasticity analysis revealed when GDP per capita increased by 1%, the total SCI decreased by 1.39%; which was also associated with a decrease of 1.34%, 1.55%, 1.36%, 1.46%, 1.54%, 1.54%, and 1.62% for traumatic SCI, MV-related SCI, fall-related SCI, tetraplegia, traumatic tetraplegia, MV-related tetraplegia, and fall-related tetraplegia respectively. The β coefficients show that the compared areas of urbanization level were also inversely correlated with CIR_{16–59} in the SCI population.

Conclusions: We conclude that the incidence of tetraplegia of traumatic SCI in Taiwan decreases with good economic performance, which may be resulted from the provision of public goods and services, possibly through improvements in the infrastructure of transportation and construction.

Keywords: Incidence, Spinal cord injuries, Tetraplegia, Gross domestic product, Income elasticity, Motor vehicle injury

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Background

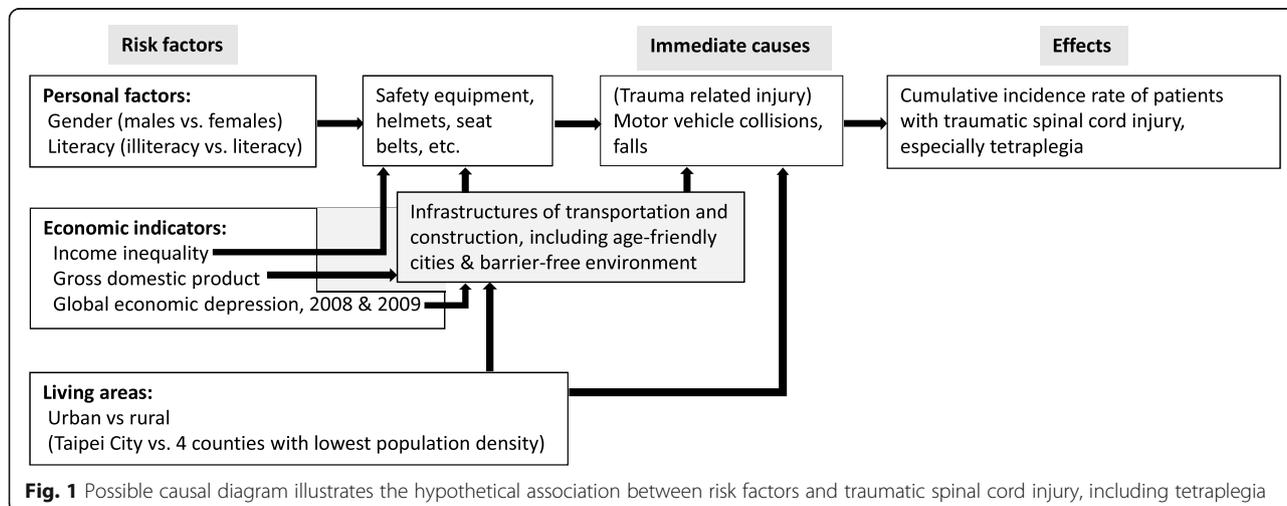
Traumatic spinal cord injury (SCI) has profound physical, social, and economic impacts for the individual and society [1]. Although neurorestorative strategies, for example cytotherapy, have been shown to be beneficial, there is no effective treatment to restore neurological impairments after SCI [2]. The findings of epidemiological studies of SCI over time across regions have revealed dissimilar results. In Galicia, Spain, the overall incidence rate (IR) of traumatic SCI was 23.4 per 1 million people in 1995 and dropped down to 1.4 in 2014 [3]. In the United States (US), the incidence rate of traumatic SCI was 53 per 1 million people in 1993 and slightly went up to 54 per 1 million people in 2012 [4]. In Taiwan, the annual IR of SCI was 24.5 per 1 million people in 1993 and dropped down to 17.2 in 1996 [5].

Motor vehicle (MV) traffic accidents were the primary etiology of traumatic SCI among developed countries (43–57.3%), including the US and some OECD (Organization for Economic Co-operation and Development) countries, such as Japan, the United Kingdom (UK), Portugal, Australia, and Italy [6–11]. In Fiji, Romania, and Russia, falls were the primary cause of SCI [12–14]. In other countries, falls were usually the second major cause of SCI [15]. MV accidents and falls frequently resulted in tetraplegia [16]. In California, the incidence rate of MV-related SCI gradually decreased during 1996–2008, which may be associated with the improvements in public health campaigns and road traffic safety [17]. In Taiwan, motor vehicle traffic accidents were also the primary etiology of SCI cases, and about half of them (49.9%) had cervical injury [5]. In Australia, the proportion of tetraplegia among SCI was 57.7% [9]. Tetraplegia resulted in higher loss of life expectancy, especially in young and middle-aged adults [18], and affected quality of life to a greater extent [19].

Economic development usually leads to improvements in health parameters which has been shown in population-based studies [20, 21]. According to the World Bank Country and Lending Groups, the overall incidence rate of traumatic spinal injury in high income countries, such as the US, Sweden, Canada, Finland, Australia, Spain, Japan, and Taiwan, seemed to be lower in comparison with low and middle income countries, such as Turkey, Nigeria, Nepal, Malaysia, India, Brazil, Iran, China, South Africa, and Mexico [22]. Gross domestic product (GDP) exhibits the market value of the aggregate goods and services produced within a country in a given time period and is similar to a barometer of a nation’s economy. GDP per capita measures an individual’s living standard and could provide us with past trends, current patterns, and future predictions. Previous studies revealed that illiteracy [23] and income inequality [24], old age [25], and residing in rural area [26] were related to fatal traumatic injuries, indicating the need for control of these confounding factors, as illustrated in Fig. 1. However, to the best of our knowledge, no study has explored the association between the IRs of SCI and living standard, presented by GDP per capita, longitudinally. Therefore, the objectives of this study were to assess the trends of etiology in IRs, the association between IRs and GDP per capita, and the influence of rural-urban disparity in tetraplegia of acute traumatic SCI from 2002 to 2015 in Taiwan.

Methods

This study was first approved by the Institutional Review Board of National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University before commencement (Approval No.: B-ER-105-386). Because this study analyzed national reimbursement data plus related secondary data, of which all personal identification information was fully encrypted, it did not



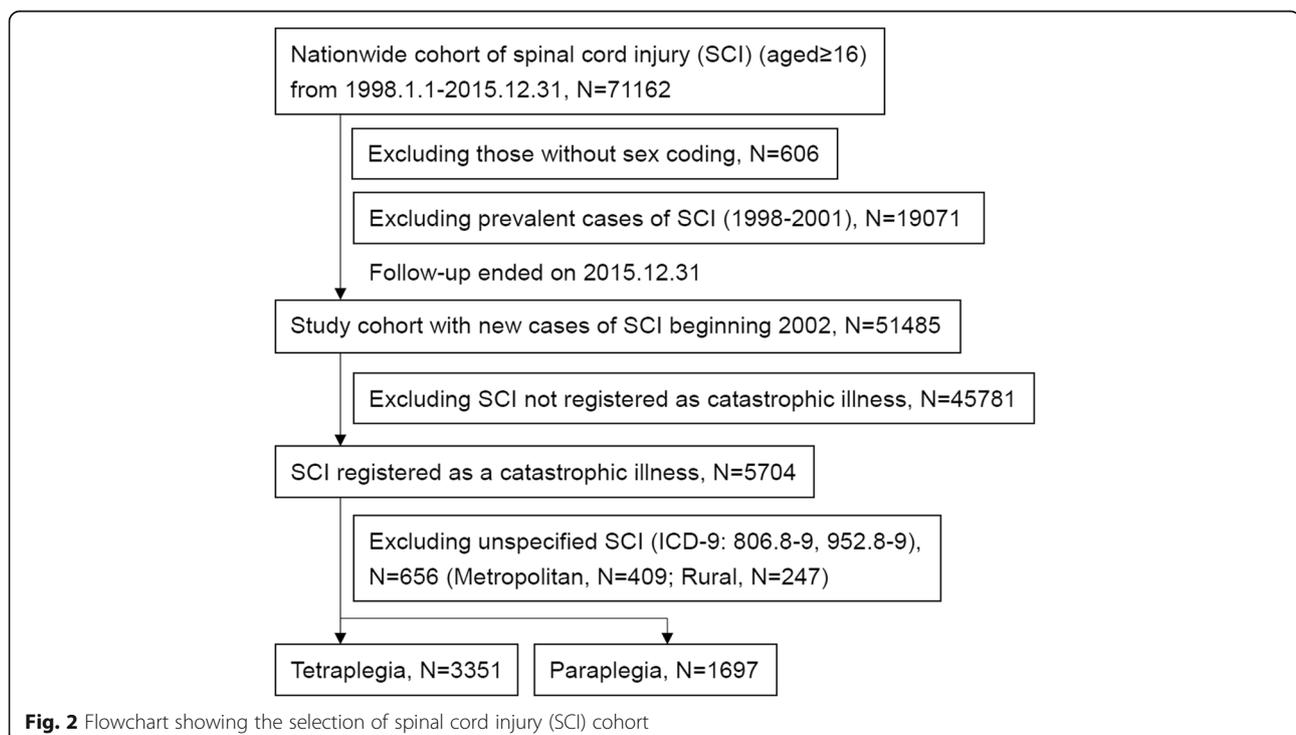
require patient's informed consent according to our national regulation of Personal Data Protection Act (<https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=I0050021>).

Study design and identification of patients with traumatic SCI

In Taiwan, the coverage of health insurance and access to healthcare are prevalent and boundless for every citizen, and provided by the governmental agency of NHI (National Health Insurance) Administration. Because diagnostic accuracy is usually a consideration with claim data sets, the NHI Administration adopts regular evaluation of medical records to make certain of the information. Deceitful recording will result in heavy penalties and audits are conducted for both hospitals and physicians involved. In this study, we used ICD-9-CM diagnosis codes of SCI with fracture of vertebral column (coding 806) and SCI without evidence of spinal bone injury (coding 952) to represent the SCI population in nationwide health insurance claims data from 1998 to 2015 [27]. These two ICD-9-CM codes (806 and 952) were applied for identifying traumatic SCI based on the "Uniform Data Systems Cases Definition" suggested by the US Centers for Disease Control and Prevention [28]. All patients ≥ 16 years of age with newly diagnosed SCI were included. The index date was the date of the first hospitalization due to SCI within the period from January 1, 2002 to December 31, 2015. The levels of

injury were divided into cervical (806.0–1, 952.0), thoracic (806.2–3, 952.1), lumbar (806.4–5, 952.2), and sacral (including cauda equine syndrome), excluding unspecified levels (806.8–9, and 952.8–9). Due to the sparse number of cases, cervical SCI was designated as tetraplegia, and the latter three (i.e. thoracic, lumbar, and sacral levels) were combined for analysis and categorized as paraplegia and/or cauda equine syndrome [27]. The archives of catastrophic illness patients collated by the NHI Administration were used to represent patients with SCI resulting in moderate and severe disability ($N = 5704$). Because all patients successfully registered in this registry are waived from all copayment, the NHI Administration requires two specialists to validate the persistent functional disability after SCI [29]. Six hundred and fifty six patients with injury at unspecified levels were excluded as mentioned above. Among the 5048 patients with SCI, 3351 patients were recorded as tetraplegia (Fig. 2) and external codes were further abstracted to identify the mechanisms of injury. The E-codes (external cause of injury) included in our review were E810–E819 (MV traffic accidents), fall (E880–E888), and others (the rest of the E-codes). Urbanization levels of acute admissions were divided into metropolitan areas with satellite cities and rural areas [30]. Thus, we stratified all patients with SCI and tetraplegia by gender, age, E-code, and urbanization level.

Since patients successfully registered on the list of catastrophic illnesses can be waived from co-payment,



every patient is required to be validated by two physicians to prevent abuse. The only chance of miscalculation of the incidence rate of disabled patients with SCI was if an event happened before 1996 or prior to the establishment of the reimbursement database on January 1, 1998. To avoid including prevalent cases, a previous study documents that at least a 36-month prevalence period should be allowed to exclude previously diagnosed patients [31]. We thus excluded data from the first 4 years (1998–2001) to assure that all included cases were incident cases.

We also abstracted the following major comorbidities: including stroke (ICD-9-CM: 430–437), acute myocardial infarction (AMI, ICD-9-CM: 410), chronic obstructive pulmonary disease (COPD, ICD-9-CM: 491–492), liver cirrhosis (ICD-9-CM: 571.2, 571.5, 571.6), end-stage renal disease (ESRD, ICD-9-CM: 585), and cancer (ICD-9-CM: 140–208). Then, the Charlson Comorbidity Index (CCI) [32] was calculated to explore if there were any specific trends in patients with SCI.

Estimating the cumulative incidence rates (CIRs) of SCI

In general, the peak ages for SCI were 16–30 years and 45–59 years, during their working age [15, 33], and the majority of fall-related traumatic SCI occurred in elderly people. We therefore used two age ranges 16–99 and 16–59 for every consecutive calendar year between 2002 and 2015 to determine if both were associated with the economic indicators. The CIR per 10^3 person-years was calculated from 16 to 99 year-old patients to estimate the CIR_{16-99} of all SCI, and also from 16 to 59 year-old patients to estimate the CIR_{16-59} of young and middle-aged patients with SCI [11, 34].

Mixed effects model for nationwide data of SCI

GDP per capita (US dollars in 2011) [35] in natural logarithm form ($\ln(\text{GDP per capita})$) was the independent variable for presenting the changes of income or the economic growth rate. Taking into account the global financial crisis between 2008 and 2009, a dummy year was used, whereby the calendar years 2008 and 2009 were individually designated as 1, and other years as 0. Moreover, we applied the literacy rate at 20–64 years (LR_{20-64}) [36] and the ratio of the average income of the richest 20% to the poorest 20% ($P80/P20$) [37], to account for potential confounding of literacy and income inequality. We used mixed effects models to analyze the association between the CIRs of SCI and $\ln(\text{GDP per capita})$ for nationwide patients with SCI (Y_n ; $n = 1-8$; $Y_1 = \text{total SCI}$, $Y_2 = \text{traumatic SCI}$, $Y_3 = \text{MV-related SCI}$, $Y_4 = \text{fall-related SCI}$, $Y_5 = \text{tetraplegia}$, $Y_6 = \text{traumatic tetraplegia}$, $Y_7 = \text{MV-related tetraplegia}$, $Y_8 = \text{fall-related tetraplegia}$), where β_0 is constant, β_s ($s = 1-7$) are

coefficients to adjacent variables, and ε is the approximation error.

The regression model is as follows:

$$Y_n = \beta_0 + \beta_1 \text{sex} + \beta_2 \text{urbanization} + \beta_3 \text{year2008} + \beta_4 \text{year2009} + \beta_5 \ln(\text{GDP per capita}) + \beta_6 LR_{20-64} + \beta_7 P80/P20 + \varepsilon \quad (1)$$

Mixed effects model of SCI in Taipei City and the 4 counties with the lowest population density (Taitung County, Yilan County, Hualien County, and Nantou County)

There were 4 counties with a population density lower than $220/\text{km}^2$ from 2002 to 2015 in Taiwan, namely Taitung County, Yilan County, Hualien County, and Nantou County. We constructed mixed effects models using the same equation as Eq. (1) to analyze the association between the CIRs of SCI and $\ln(\text{GDP per capita})$ for patients with SCI in Taipei City (the capital and a special municipality of Taiwan with a population density above $9500/\text{km}^2$) in contrast to the 4 counties with the lowest population density as a cluster to corroborate the robustness of our models.

The measurement of income elasticity

The income elasticity of SCI was estimated according to Eq. 2, as shown by Newhouse in the 1970s [38].

$$\frac{\partial CIR_{16-99}}{\partial \ln(\text{GDP per capita})} \times \frac{1}{CIR_{16-99}} \quad (2)$$

Statistical analyses

We used mixed-effects models to examine the relationship between CIR and $\ln(\text{GDP per capita})$ in SCI and tetraplegia. Differences between the characteristics of tetraplegia and traumatic tetraplegia were evaluated utilizing an independent t test for continuous variables and the χ^2 test for nominal variables. β coefficient, 95% confidence interval (CI), and p value were calculated in the mixed effects model. A p value of < 0.05 was regarded as indicating statistical significance. All statistical analyses were completed using the statistical package SAS (Version 9.3, SAS Institute, Cary, NC).

Results

In total, 5048 newly diagnosed patients with SCI from 2002 to 2015 were included in this study, with 3351 tetraplegia and 2182 traumatic tetraplegia patients. The mean ages of all SCI patients, tetraplegia, and traumatic tetraplegia were 50.3 (95% CI 49.8 to 50.8), 52.4 (51.9 to 52.9), and 52.2 (51.5 to 52.9) years, respectively. About four-fifths were males. Among all patients with SCI,

19.0% were in the dependent insurance group; 30.1% had yearly income less than the median level (640 US dollars), and 50.9% had yearly income greater than the median level. 49.4% of the SCI incidents and 51.4% of the tetraplegia incidents occurred in rural areas. Among all patients with SCI, about 56.7% scored 0 on the CCI [32], 17.9% scored 1, and the remaining 25.4% scored > 1. The proportion of patients with chronic obstructive pulmonary disease was higher in tetraplegia than in traumatic tetraplegia. The proportion of multiple comorbidities (CCI > 1) was higher in tetraplegia than in traumatic tetraplegia (Table 1).

Figure 3 shows the trends for the various types of SCI incidence and GDP per capita in natural logarithm form. The majority of external causes of injury were MV collisions followed by falls during 2002–2011. Beginning

2012, however, the CIR_{16–99} of MV-related SCI decreased rapidly and appeared close to those of fall-related SCI and tetraplegia in 2015.

After controlling for sex, urbanization level, global financial crisis (year 2008, 2009), literacy rate, and income inequality (mixed effects model), we found the CIR_{16–99} of SCI, traumatic SCI, MV-related SCI, fall-related SCI, tetraplegia, traumatic tetraplegia, MV-related tetraplegia, and fall-related tetraplegia were all inversely correlated with Ln (GDP per capita); the β coefficients ranged from -4.85 (95% CI -7.09 to -2.6) for total SCI to -0.8 (-1.3 to -0.29) for fall-related tetraplegia (Table 2). The mixed effects models constructed for Taipei City and the 4 least densely populated counties in Taiwan showed similar results of consistent inverse correlations between CIR and Ln (GDP per capita), with β coefficients ranging

Table 1 Background characteristics for total spinal cord injury (SCI), tetraplegia and traumatic tetraplegia cases in Taiwan, 2002–2015

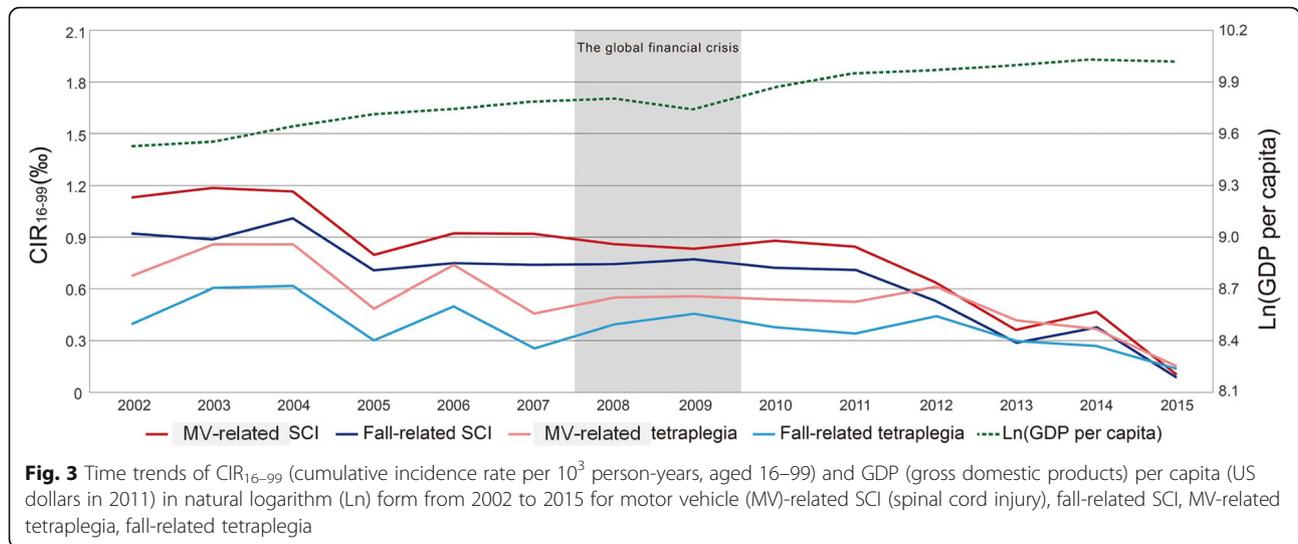
Characteristic	SCI, N (%)	Tetraplegia, N (%)	Traumatic tetraplegia, N (%)
Total number of subjects	5048 (100%)	3351 (100%)	2182 (100%)
Age, mean (range), years ^a	50.3 (range 16–96)	52.4 (range 16–96)	52.2 (range 16–94)
Age group ^b			
16–39	1328 (26.3%)	704 (21.0%)	457 (20.9%)
40–59	2198 (43.5%)	1501 (44.8%)	995 (45.6%)
60–99	1522 (30.2%)	1146 (34.2%)	730 (33.5%)
Sex ^b			
Male	3927 (77.8%)	2738 (81.7%)	1786 (81.9%)
Female	1121 (22.2%)	613 (18.3%)	396 (18.1%)
Degree of urbanization ^b			
Metropolitan areas including satellite cities	2556 (50.6%)	1629 (48.6%)	1017 (46.6%)
Rural areas	2492 (49.4%)	1722 (51.4%)	1165 (53.4%)
Monthly insured salary (US dollar) ^b			
Dependent	961 (19.0%)	840 (25.1%)	380 (17.4%)
< 640 US dollars	1517 (30.1%)	824 (24.6%)	627 (28.7%)
≥ 640 US dollars	2570 (50.9%)	1687 (50.3%)	1175 (53.9%)
Major comorbidities			
Stroke (ICD-9-CM: 430–437) ^b	315 (6.2%)	218 (6.5%)	115 (5.3%)
Acute myocardial infarction (ICD-9-CM: 410) ^b	25 (0.5%)	17 (0.5%)	6 (0.3%)
COPD (ICD-9-CM: 491–492) ^{*b}	179 (3.6%)	119 (3.6%)	55 (2.5%)
Liver cirrhosis (ICD-9-CM: 571.2, 571.5, 571.6) ^b	80 (1.6%)	58 (1.7%)	39 (1.8%)
ESRD (ICD-9-CM: 585) ^b	86 (1.7%)	49 (1.5%)	25 (1.2%)
Cancer (ICD-9-CM: 140–208) ^b	116 (2.3%)	80 (2.4%)	47 (2.2%)
Charlson Comorbidity Index ^{*b}			
0	2863 (56.7%)	1989 (59.4%)	1355 (62.1%)
1	905 (17.9%)	655 (19.6%)	429 (19.7%)
> 1	1280 (25.4%)	707 (21.1%)	398 (18.2%)

CI confidence interval, ICD-9-CM International Classification of Disease, Ninth Revision, Clinical Modification, COPD chronic obstructive pulmonary disease, ESRD end-stage renal disease

* $p < 0.05$, comparison between tetraplegia and traumatic tetraplegia

^aThe independent t test

^bThe χ^2 test



from -7.23 (95% CI -11.2 to -3.26) for total SCI to -1.91 (-3.37 to -0.45) for MV-related tetraplegia, as summarized in Table 2. We additionally tested the robustness of the above association between the CIR of those aged 16–59 and Ln (GDP per capita); the β coefficients of the areas of acute admission were also inversely correlated with CIR₁₆₋₅₉ in all SCI populations (Supplementary Table 1).

The incidence of SCI in Taiwan decreased from 5‰ in 2002 to 1‰ in 2015. GDP per capita grew steadily about 63% over this period, as Fig. 3 presents. This brief deviation in various SCI suggests that incidence rates turn out to be strongly connected to GDP per capita. The extent of the changes in SCI decreases with GDP per capita. Based on the mean of CIR₁₆₋₉₉ of total SCI in Table 2 and Eq. (2), the income elasticity of total SCI related to GDP per capita is -1.39. Namely, when GDP per capita grows by 1%, total SCI decreases by 1.39‰. Similarly, as GDP per capita increases by 1%, the incidence rates of traumatic SCI, MV-related SCI, fall-related SCI, tetraplegia, traumatic tetraplegia, MV-related tetraplegia, and fall-related

tetraplegia decrease by 1.34‰, 1.55‰, 1.36‰, 1.46‰, 1.54‰, 1.54‰, and 1.62‰, respectively (Supplementary Table 2).

Discussion

The objectives of this study were to explore the associations between economic indicators and occurrence of SCI. Although we found a consistent inverse correlation between the CIR₁₆₋₉₉ of various types of SCI and Ln (GDP per capita), it does not necessarily indicate that it is causally related. We have presented, however, the following arguments to corroborate the above hypothesis: First, this is a longitudinal nation-wide cohort study, which involved an unbiased participant selection process and accurately assessed the incidence rates of SCI based on all new cases in the catastrophic registry. Since the registry of every patient requires a board-certified physician to provide sufficient evidence plus another physician assigned by the NHI Administration to validate it, we are confident that the diagnosis is accurate to avoid any abuse of waiving copayment. Second, since we have comprehensively controlled the major risk factors for

Table 2 The CIR₁₆₋₉₉ (cumulative incidence rate per 10³ person-years, aged 16–99) of spinal cord injury (SCI) and major risk factors in Taiwan from 2002 to 2015

Characteristic	SCI	Tetraplegia	Traumatic tetraplegia
CIR ₁₆₋₉₉ , mean (95% CI), ‰ ^a	3.5 (2.9 to 4.2)	2.5 (2.0 to 2.9)	1.6 (1.3 to 1.9)
Literacy rate, %	99.4 (99.2 to 99.6)		
P80/P20 ^b	7.57 (7.45 to 7.7)		
GDP ^b , mean (95% CI), US dollars	18,447 (16,862 to 20,032)		
Ln (GDP ^b per capita), mean (95% CI), US dollars	9.8 (9.7 to 9.9)		

CI confidence interval

^ap < 0.05, comparison between tetraplegia and traumatic tetraplegia

^bThe independent t test

^bP80/P20: the ratio of the average income of the richest 20% to the poorest 20%; GDP: gross domestic product

the occurrence of SCI (Fig. 1), including age, sex, urban-rural disparity, literacy rate, income inequality, and years with major economic depression (the global financial crisis) in the construction of mixed effects models, plus we stratified the patients into different injury levels and external causes, these factors cannot be explanatory to the independent association between improved economic performance and decreased occurrence of SCI. Third, we have tested the robustness of these models by restrictive comparison between Taipei City and the 4 counties with the lowest population density, which still corroborates our hypothesis. Therefore, we tentatively conclude that the inverse association between GDP per capita and incidence of SCI (Fig. 3) might be causal and deserves attention.

The β coefficients of Ln (GDP) were higher in the 16–99 year age group of all SCI than in the 16–59 year age group. Increases in GDP per capita also seemed to have preventive effects on old people for the occurrence of SCI. In addition, residing in metropolitan areas also showed a preventive effect in lowering the occurrence of all SCI, but such an effect appeared to be diminished in the occurrence of fall-related tetraplegia among young and middle aged people. This may be due to the different mechanisms of fall-related tetraplegia in old versus young to middle aged populations, as the latter often occurs due to occupational or sport-related injuries [39].

Our results corroborate previous studies that show MV accidents are the most prevalent etiology of SCI [40]. The inverse association between incidence rate of MV-related SCI and GDP per capita in Taiwan could be resulted from improvements in both transportation infrastructure and accessibility of public transportation in urban regions. Economies with higher GDP per capita accumulate more tax revenue to be able to establish better public transportation systems than those with lower GDP per capita. Among them, South Korea is one of these examples, which shows a high association between increase in GDP and increase in capital of the transportation sector [41]. Moreover, our study found that urbanization was an independent factor for reduction in the occurrence of SCI (Table 3). In fact, the increased usage of public transportation from 16.3% in 2009 to 18.0% in 2015 may have contributed to the lower occurrence of SCI in Taiwan [42]. The public transportation system in urban regions of Taiwan is predominated by bus and railway systems, and Taipei City's transportation system is superior to those of all other areas in Taiwan. Taipei City established the first medium-capacity metro line in March 1996 and the system quickly expanded to cover the whole metropolitan area [43]. Public transport usage rate in Taipei City was 40% in contrast to below 10% for the 4 counties with the lowest population density (Yilan County, Taitung County, Hualien County, and

Nantou County) during 2009–2015 [42]. Moreover, the number of heavy-type motorcycles per 100 people in Taipei City was much lower compared to those of the 4 counties with the lowest population density during 2002–2015 [44]. Motorcycle accidents are also a growing hazard of a cervical cord injury [26], which may be why the occurrences of traumatic SCI, tetraplegia, and traumatic tetraplegia in urbanized Taipei City versus the 4 counties are about 1.5–2 times lower than those of the whole country (Table 3). Simultaneously, the potential effect of income inequality in Taipei City has become less significant, probably due to the high accessibility of convenient public transportation and excellent enforcement on safety regulations, such as penalties for drink driving and other traffic offences.

Previous studies revealed that poor residential or construction infrastructure was correlated with falls and fall-related injuries [45]. In Taiwan, the fact that more than 30% of patients with SCI were over 60 years of age (Table 1), of which the incidence rate would be higher because of a smaller denominator, deserves our attention. In fact, Taiwan government began to establish the first age-friendly city in Chia-Yi City in 2010 and has continued such efforts to build barrier-free environments in Taiwan at one of the fastest rates in the world [46]. The program might also contribute to the inverse association between incidence rate and fall-related SCI and GDP per capita in Taiwan (Table 3).

The global financial crisis between 2008 and 2009 was inversely associated with the occurrence of SCI, especially in 2009, because tourism activities probably declined over the recession period. In Greece, the mortality rate of MV accidents also fell by 45% in 2009 [47]. In this study, we also found that income inequality was positively associated with the occurrence of SCI, which corroborated with the results of previous studies [48]. The association was stronger in MV-related SCI than fall-related SCI, probably because a more equal distribution of income would improve citizen's capability to purchase safety equipment for transportation (Fig. 1). Thus, reduction of income inequality through fiscal tools should also be included as a strategy to prevent SCI.

This study has the following limitations that must be acknowledged: First, since our NHI (National Health Insurance) claim data do not contain clinical details of AIS (ASIA (American Spinal Injury Association) Impairment Scale), we are unable to differentiate whether a patient is a complete or incomplete SCI. However, our registry of catastrophic illnesses stipulates that these patients must present with moderate to severe permanent functional disability to be eligible for this registry. Namely, we expected that all patients with complete SCI from severing trauma would be included. But our estimations cannot be generalized to SCI patients with mild or temporary

Table 3 Estimation results of constructed mixed-effects model with CIR₁₆₋₉₉^a of spinal cord injury (SCI) as the dependent variable and major risk factors as fixed effects

	SCI	Traumatic SCI	MV ^b -related SCI	Fall-related SCI	Tetraplegia	Traumatic tetraplegia	MV ^b -related tetraplegia	Fall-related tetraplegia
National data								
Sex (Male/Female)	1.85*** (1.59 to 2.1)	1.21*** (1.01 to 1.4)	0.62*** (0.5 to 0.73)	0.37*** (0.29 to 0.44)	1.56*** (1.35 to 1.77)	1.01*** (0.85 to 1.18)	0.55*** (0.44 to 0.65)	0.29*** (0.23 to 0.34)
Ln (GDP ^a per capita), USD	-4.85*** (-7.09 to -2.6)	-3.07*** (-4.78 to -1.36)	-1.55** (-2.56 to -0.55)	-1.09*** (-1.69 to -0.48)	-3.64*** (-5.51 to -1.78)	-2.46** (-3.9 to -1.02)	-1.23* (-2.15 to -0.31)	-0.8*** (-1.3 to -0.29)
Urbanization level (Metropolitan/Rural)	-0.65*** (-0.9 to -0.39)	-0.56*** (-0.76 to -0.37)	-0.31*** (-0.42 to -0.2)	-0.14*** (-0.21 to -0.07)	-0.49*** (-0.7 to -0.28)	-0.46*** (-0.62 to -0.29)	-0.29*** (-0.39 to -0.18)	-0.1*** (-0.16 to -0.04)
Year 2008 (Yes/No)	-0.34 (-0.91 to 0.23)	-0.32 (-0.75 to 0.11)	-0.1 (-0.35 to 0.16)	-0.13 (-0.29 to 0.02)	-0.24 (-0.72 to 0.23)	-0.22 (-0.58 to 0.15)	-0.08 (-0.31 to 0.16)	-0.1 (-0.23 to 0.03)
Year 2009 (Yes/No)	-1.49*** (-2.47 to -0.52)	-1.13** (-1.87 to -0.38)	-0.54* (-0.98 to -0.1)	-0.3* (-0.57 to -0.03)	-1.13** (-1.94 to -0.31)	-0.77* (-1.39 to -0.14)	-0.43* (-0.83 to -0.03)	-0.16 (-0.38 to 0.06)
LR ₂₀₋₆₄ ^a	0.53 (-0.4 to 1.46)	0.38 (-0.33 to 1.08)	0.2 (-0.22 to 0.61)	0.16 (-0.1 to 0.42)	0.55 (-0.22 to 1.32)	0.42 (-0.18 to 1.01)	0.17 (-0.21 to 0.55)	0.17 (-0.04 to 0.38)
P80/P20 ^a	1.54** (0.5 to 2.59)	1.2** (0.4 to 1.99)	0.49* (0.03 to 0.96)	0.32* (0.03 to 0.61)	1.24** (0.37 to 2.11)	0.85* (0.17 to 1.52)	0.45* (0.02 to 0.88)	0.18 (-0.05 to 0.42)
Taipei versus 4 counties ^b								
Sex (Male/Female)	2.38*** (1.93 to 2.83)	1.49*** (1.14 to 1.84)	0.71*** (0.53 to 0.9)	0.45*** (0.31 to 0.6)	2.07*** (1.69 to 2.44)	1.33*** (1.02 to 1.64)	0.64*** (0.48 to 0.81)	0.41*** (0.28 to 0.54)
Ln (GDP ^a per capita), USD	-7.23*** (-11.2 to -3.26)	-4.61** (-7.69 to -1.52)	-2.07* (-3.7 to -0.45)	-2.47*** (-3.7 to -1.23)	-6.65*** (-9.98 to -3.32)	-4.52** (-7.26 to -1.78)	-1.91* (-3.37 to -0.45)	-2.26*** (-3.39 to -1.12)
Urbanization level (Taipei City/4 counties ^b)	-1.12*** (-1.57 to -0.67)	-1.16*** (-1.5 to -0.81)	-0.49*** (-0.68 to -0.31)	-0.35*** (-0.5 to -0.21)	-1.01*** (-1.38 to -0.63)	-1.02*** (-1.33 to -0.71)	-0.51*** (-0.68 to -0.35)	-0.26*** (-0.39 to -0.13)
Year 2008 (Yes/No)	-0.29 (-1.29 to 0.72)	-0.37 (-1.15 to 0.41)	-0.01 (-0.42 to 0.4)	-0.29 (-0.61 to 0.03)	-0.25 (-1.09 to 0.59)	-0.2 (-0.89 to 0.49)	-0.01 (-0.38 to 0.36)	-0.21 (-0.5 to 0.08)
Year 2009 (Yes/No)	-2.12* (-3.85 to -0.39)	-1.25 (-2.59 to 0.09)	-0.65 (-1.36 to 0.06)	-0.6* (-1.16 to -0.04)	-1.83* (-3.28 to -0.38)	-0.99 (-2.18 to 0.2)	-0.51 (-1.15 to 0.12)	-0.5* (-1 to -0.01)
LR ₂₀₋₆₄ ^a	1.32 (-0.33 to 2.96)	0.85 (-0.42 to 2.13)	0.47 (-0.2 to 1.15)	0.62* (0.09 to 1.15)	1.51* (0.13 to 2.89)	1.14 (0 to 2.27)	0.49 (-0.11 to 1.09)	0.69* (0.22 to 1.16)
P80/P20 ^a	1.98* (0.13 to 3.83)	1.41 (-0.03 to 2.85)	0.74 (-0.01 to 1.5)	0.48 (-0.11 to 1.07)	1.58* (0.03 to 3.13)	0.93 (-0.35 to 2.2)	0.63 (-0.05 to 1.31)	0.32 (-0.21 to 0.85)

^aCIR₁₆₋₉₉ cumulative incidence rate per 10³ person-years, aged 16-99, GDP gross domestic product, MV motor vehicle, LR₂₀₋₆₄ literacy rate at age of 20-64 years, P80/P20 income inequality based on the ratio of the average income of the richest 20% to the poorest 20%

^bThe 4 counties with the lowest population density: Taitung County, Yilan County, Hualien County, and Nantou County

Figures in parentheses are 95% confidence interval

Significant at *, **, and *** indicate significance at p < 0.05, 0.01, and 0.001, respectively

functional impairment. Second, the promotion of age-friendly cities in Taiwan is generally based on the principle of aging in place and trying to adapt to heterogeneous local cultures. From 2013, the Ministry of Interior began to evaluate the quality of pedestrian barrier-free environment in every city every 2 years [49]. By assuming the trend of this score could be linearly extrapolated to 2002–2012, we added the new indicator into the original mixed-effects model. Although the score of pedestrian environment showed a consistent inverse effect on injury occurrences of tetraplegia, fall-related tetraplegia, and fall related SCI, it was statistically significant on CIR_{16–99} of tetraplegia alone (Supplementary Table 3), and we were unable to draw any strong inference. Future studies are needed to corroborate this hypothesis. Third, although this study brings attention to the importance of GDP per capita and infrastructures of transportation and construction, we have not explored the pathophysiology of individual SCI cases in details. More studies are warranted to develop effective prevention strategies for SCI occurrence on macro- and micro-levels to elevate economic performance, decrease income inequality, and improve infrastructures of transportation and construction, including age-friendly cities, barrier-free environment, and health literacy to adhere to safety regulations (Fig. 1).

Conclusions

In conclusion, this study offers a comprehensive exploration of the trends and incidence rates of patients with tetraplegia of traumatic SCI in Taiwan. The associations between increased GDP per capita & reduced income inequality and reduced SCI incidence in Taiwan seem to have resulted from the provision of public goods and services, especially improvements in the infrastructure of transportation and construction, plus improved health literacy to adhere to regulations and individual financial ability to obtain safety equipment. In the coming years, we recommend that the government continues to improve infrastructure and enforce traffic regulations in rural regions of Taiwan to reduce the urban-rural disparity and decrease income inequality in the prevention of tetraplegia of traumatic SCI.

Abbreviations

SCI: Spinal cord injury; IR: Incidence rate; MV: Motor vehicle; US: United States; OECD: Organization for Economic Co-operation and Development; UK: United Kingdom; GDP: Gross domestic product; Ln (GDP per capita): Gross domestic product per capita in natural logarithm form; NHI: National Health Insurance; AMI: Acute myocardial infarction; COPD: Chronic obstructive pulmonary disease; ESRD: End-stage renal disease; CCI: Charlson Comorbidity Index; LR_{20–64}: The literacy rate at 20–64 years; P80/P20: The ratio of the average income of the 20% richest to the 20% poorest; CIR_{16–99}: Cumulative incidence rate per 10³ person-years, aged 16–99; CIR_{16–59}: Cumulative incidence rate per 10³ person-years, aged 16–59;

CI: Confidence interval; ICD-9-CM: International Classification of Disease, Ninth Revision, Clinical Modification

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12883-021-02141-8>.

Additional file 1: Supplementary Table 1. Estimation results of constructed mixed-effects model with CIR_{16–99}† of spinal cord injury (SCI) as the dependent variable and major risk factors as fixed effects.

Additional file 2: Supplementary Table 2. Income effects of total spinal cord injury (SCI), traumatic SCI, motor vehicle (MV)-related SCI, fall-related SCI, tetraplegia, traumatic tetraplegia, MV-related tetraplegia, and fall-related tetraplegia in Taiwan.

Additional file 3: Supplementary Table 3 Estimation results of mixed-effects model with CIR_{16–99}† of spinal cord injury (SCI) as the dependent variable and major risk factors as fixed effects. The major risk factors in this mixed-effects model include one more indicator, the evaluation scores of pedestrian environment (SPE), to represent the quality of barrier-free environment.

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Authors' contributions

WCL, WMW, JDW, and FW designed the study protocols. WCL, WMW, JDW, and FW collected the data. Data analysis and interpretation were performed by WCL, WMW, JDW, and FW. WCL wrote the manuscript under the supervision of JDW and FW. WCL, WMW, JDW, and FW contributed significantly to revising the manuscript. All authors have read and approved the final manuscript.

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Availability of data and materials

The Institutional Review Board (IRB) of National Cheng Kung University Hospital (NCKUH) are entitled and have full rights to oversee all activities, including the data of this study of each researcher, to comply with the Personal Data Protection Act. Anyone who is interested in analyzing the same dataset must write a formal proposal approved by the IRB of a university, institution, medical center, or a formal organization. Accompanied with the approval letter of the IRB of the researcher's institution and the research proposal, the researcher can email the application to the Collaboration Center of Health Information Application, Ministry of Health and Welfare for access to the data.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University before commencement (Approval No.: B-ER-105-386). This study was performed without patient involvement.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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