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ARTICLE

Survival after non-traumatic spinal cord injury: evidence from a population-based rehabilitation cohort in Switzerland

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Abstract

Study design Observational cohort study.

Objective To investigate survival and life expectancy after NTSCI in Switzerland according to etiology.

Setting Specialized rehabilitation centers in Switzerland.

Methods Longitudinal data from the Swiss Spinal Cord Injury (SwiSCI) medical records study were used. Adjusted hazard ratios (HRs) and life expectancies were estimated using flexible parametric survival modeling.

Results One thousand four hundred and fifty individuals were admitted to first rehabilitation for NTSCI between 1990 and 2011, contributing 6137 cumulative person-years at risk and 528 deaths. With reference to persons with a degenerative disc disorder, the HR for mortality in individuals with NTSCIs from infections was 1.42 (95% CI 0.99–2.04), while risk in those with NTSCIs from vascular disorders was 1.28 (95% CI 0.97–1.68). Mortality risk was most pronounced in individuals with NTSCIs from malignant neoplasms (HR 6.32, 95% CI 4.79–8.34). Exemplified for males with an attained age of 60 years, a malignant etiology was associated with 1.7 life years remaining (LYR), as compared to 10.1 LYR for non-malignant etiologies. Males with an attained age of 60 years and a degenerative disc etiology were estimated to have 12.9 LYR.

Conclusions This study contributes an evidence base for risk factors of mortality after NTSCI, reducing a considerable knowledge gap in survival after NTSCI. Survival and life expectancy estimates were highly differential between etiological groups, indicating a need for a heterogeneous clinical approach and dynamic health-care provisions for this growing population.

Introduction

Non-traumatic spinal cord injuries (NTSCI) are a form of spinal cord injury (SCI) that originate from a distinct pathology (i.e., neoplasms, degenerative disc disorders, vascular disorders) and are associated with reduced long-term health, survival, and life expectancy [1, 2]. Furthermore, the underlying health conditions that precipitate NTSCI in combination with SCI-specific secondary health conditions induce complex health states and likely contribute to the reduced survival seen in this population. Therefore, identification of differential risk factors attributed to etiology are required to understand diminished survival within this diverse population [3].

The prevalence of NTSCI is expected to steadily rise with the shifting of demographics toward an older average age within the population, particularly in high-resource countries [4, 5]. This invokes a burgeoning need to bridge the knowledge gap in survival after NTSCI.

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Therefore, investigating survival outcomes and life expectancy is critical for this diverse community as to optimize individualized patient care and develop coordinated health-care systems for the NTSCI community [6]. Although, contemporary evidence on survival and risk factors for mortality after NTSCI is limited [7, 8], the recent development of a systematic reporting tool (The International Data Sets for NTSCI) has made feasible the comparability of survival analyses for this population [1, 9].

In order to contribute meaningful survival estimates for this community, survival and life expectancy must be conditioned on the health states that are precursory to NTSCI. Hence, the objective of this study is to estimate etiology-specific survival and mortality outcomes for individuals with NTSCI in a high-income setting. Hitherto, the only available Swiss-specific estimates of survival after SCI are for traumatic SCI [10]. The current study is a sequel that specifically focuses on NTSCI and aims to estimate overall survival, in addition to etiology-specific survival, and life expectancy.

Methods

Study description

This study employs data collected from the Swiss Spinal Cord Injury (SwiSCI) Medical Records study, which covers all specialized rehab centers for SCI in Switzerland [11].

Eligibility criteria for SwiSCI study inclusion were: individuals aged ≥16 years and residing in Switzerland at the time of SCI diagnosis. Cases due to congenital disorders (e.g., spina bifida) or progressive neurodegenerative disorders (e.g., multiple sclerosis) were excluded [11]. The study utilized all available retrospective medical records data of persons incurring a new NTSCI between 1990 and 2011. SwiSCI study data underwent ethical review and received approval from the ethical committees of the following Cantons: Lucerne, Basel, Valais, and Zürich (reference numbers: 1008 [Luzern]; 37/11 [Basel]; CCVEM 015/11 [Valais]; 2012–0049 [Zürich])

Vital status information

An extensive description of methodology to ascertain vital status of participants was described previously by Chamberlain et al [10]. For the present study, vital status information was updated until September 30, 2011. This administrative censoring date coincides with the start of the first community survey of SwiSCI [12] and was chosen because response to this survey confirmed vital status for a substantial proportion of individuals in the Medical Records study. Vital status of the remaining individuals who did not respond required a subsequent tracing effort via the respective rehabilitation clinics and through the successive communities of the last known residence.

Data management

Etiological categories were based on recommendations from International SCI core data set and grouped at the second classification level [1, 9]. The following NTSCI categories were used: "degenerative disc disorders," "infection," "vascular disorders," "benign tumors," "malignant tumors," "unspecified tumors," and "other." The "other" category represented a mixed group of individuals with NTSCIs that developed from unclear origins, metabolic disorders, inflammatory diseases, and radiation-related causes. A category "unspecified tumors" was included, given that several participants had an NTSCI from neoplasms of an unknown origin. SCI-related characteristics included in the present study were: lesion level, lesion completeness, and SCI type. The International Standards for Neurological Classification of Spinal Cord Injury score, previously known as the American Spinal Injury Association Impairment Scale score, was included, although it was only systematically measured after the year 2000 in Switzerland. Data were collected at admission and discharge from first rehabilitation. Data from admission were used in instances of missing data at discharge. International Spinal Cord Society guidelines were followed in the grouping of all variables [13]. Cases of cauda equina were included within descriptive estimates and were measured separately for survival analyses.

Statistical analysis

All analyses were implemented using the Stata software version 14.1 for Windows (College Station, TX). Descriptive analyses include raw numbers and percentages Chi-square tests were used to evaluate differences between cohort effect or calendar periods (1990–2000, 2001–2011). The standard deviation and range were reported for continuous variables.

For all survival analyses, participants entered the study on date of admission to specialized rehabilitation, with time at risk beginning on the date of clinical diagnosis of SCI. Individual follow-up time was censored at the date of death, the date of last known clinic or study contact, or the date of administrative censoring (September 30, 2011), whichever came first. Individuals were considered lost to follow-up (LTFU) if their vital status could not be updated and their last known contact date was >18 months before administrative censoring. In line with the censoring recommendations by Lesko et al. [14], individuals LTFU were censored

when the 18-month criterion for loss to follow-up was met, implying the addition of 18 months of person-time.

Kaplan–Meier curves of crude survival according to etiology were estimated for the purpose of illustrating a non-parametric survival function of the population. Flexible parametric models (FPMs) were used to estimate hazard ratios (HRs) of risk factors for mortality, survival probabilities, and remaining life years [15]. This contemporary method for estimating survival was favored to more traditional methods (i.e., Cox regression) as it allowed for covariate-adjusted post-estimations of survival and life expectancy. Furthermore, FPMs utilize restricted cubic splines to fit a continuous function, where linearity is forced before the first knot and after the final knot, with the number of knots determining the flexibility, allowing for a well-fitted model. Akaike information criterion (AIC) values were used to determine the minimal number of knots in the model. When fitting the full FPM model (i.e., including all causes of NTSCI), AIC values indicated a model fit of 3 degrees of freedom (df), while 2 df were selected for best fit for models stratified by NTSCI etiological groups. Adjusted HRs were controlled for sociodemographic characteristics as well as SCI-specific factors. Likelihood ratio tests for identifying potential violations of the proportional hazards assumption indicated p values >0.05.

In the FPM survival models, time-splitting was used (with Stata's *stsplit* command) to account for age effects, which allocated quantities of follow-up time to the appropriate age categories [16]. Cohort effects were additionally accounted for by time-splitting on decade of injury, allowing participants to contribute time to different risk sets (i.e., 1990–2000, 2001–2011), during which they lived with their SCI. In survival models, inverse probability weights (IPW) were implemented to account for the biased representation of individual characteristics of those LTFU. IPWs were derived from propensity scores using logistic regression, with LTFU as the outcome, and age, sex, lesion level, completeness of lesion, and rehabilitation clinic as independent variables.

To estimate risk factors for mortality, etiological groups with similar overall mortality were combined. The major etiological categories were identified using a post hoc analysis of Bonferroni-corrected pairwise comparisons. The major groups identified were: "malignant tumors" and "non-malignant etiologies" (i.e., "degenerative disc disorders," "infection," "vascular disorders," "benign tumors," and "other"). "Degenerative disc disorders" were also analyzed separately, as it was the most frequently occurring etiological group within this population. In a separate analysis, the risk of mortality for individuals with NTSCIs from bacterial infections, which were grouped together with viral and unspecified infections due to low cell counts in the main analysis, was also evaluated.

Survival probabilities with 95% confidence intervals (CIs) were estimated using Stata's *predict* command, specifying *meansurv* to calculate the mean survival [17]. This approach allows calculation of point estimates using flexible parametric survival models adjusted for sex, age, cohort, and SCI characteristics. Successive estimates were conditional on having survived to that time point. Estimates of life years remaining (LYR) were measured using Stata's *rmst* command by calculating the restricted mean survival time [17]. This method allows for comparative evaluation of mean survival time across etiological groups and at a specific attained ages by measuring the area under the survival curve up to the specified attained age [18]. An attained age of 60 years was chosen, as it was the average age at onset for individuals within this population.

Multiple imputation was used to account for bias due to missing data for estimating HRs, with the assumption that data were missing at random [19]. As part of a sensitivity analysis, HRs estimated with multiple imputed data were compared with complete-case estimates, in line with STROBE guidelines.

Results

Participant characteristics

The present study includes 1450 persons diagnosed with an NTSCI between January 1, 1990 and September 30, 2011, resulting in a total cumulative person-time of 6137 person-years and 528 deaths (Supplementary Table S1). In the current study, 101 individuals (7%) were considered LTFU. The population was 59% male, with 65.3% of participants having a paraplegia, and 87.2% having incomplete spinal cord lesions. NTSCIs from degenerative disc disorders were most often reported (28.3%). Differences in sociodemographic and SCI-specific factors were reported between the decades (1990–1999 and 2000–2011). In the more recent decade, the average age at onset increased by 3 years, with almost a 7% proportional increase in degenerative disc disorders, while the proportion of NTSCIs due to malignant neoplasms declined in the latter decade from 22.6% to 18.3% (Table 1). The overall crude death rate within the study population was 86.0 per 1000 individuals (S1).

Mortality risk

Kaplan–Meier curves (Fig. 1) depict strong differences according to etiology, with malignant and unspecified tumors indicating the steepest declines in survival. All other etiological groups exhibited roughly similar survival trajectories within the first 5 years of diagnosis. HRs were

Table 1 Characteristics of study participants overall and by SCI decade of injury ($n = 1450$)

Characteristics [missing][a]	Overall, *n* (%) $n = 1450$	1990–1999, *n* (%) $n = 359$	2000–2011, *n* (%) $n = 1091$	*p*
Sex [0]				0.74
Female	595 (41.0)	150 (41.8)	445 (40.8)	
Male	855 (59.0)	209 (58.2)	646 (59.2)	
Age at injury [0]				0.02
16–30	82 (5.7)	31 (8.6)	51 (4.7)	
31–45	223 (15.4)	61 (17.0)	162 (14.9)	
46–60	372 (25.7)	96 (26.7)	276 (25.3)	
61–75	523 (36.1)	121 (33.7)	402 (36.9)	
76+	250 (17.2)	50 (13.9)	200 (18.3)	
SCI type [7]				0.78
Para	942 (65.3)	227 (63.8)	715 (65.8)	
Tetra	368 (25.5)	94 (26.4)	274 (25.2)	
Cauda equina	133 (9.2)	35 (9.8)	98 (9.0)	
Completeness [74]				0.08
Incomplete	1,200 (87.2)	288 (84.5)	912 (88.1)	
Complete	176 (12.8)	53 (15.5)	123 (11.9)	
SCI severity [82]				0.22
Para, incomplete	768 (56.1)	174 (51.2)	594 (57.8)	
Para, complete	139 (10.2)	44 (12.9)	95 (9.2)	
Tetra, incomplete	325 (23.8)	83 (24.4)	242 (23.5)	
Tetra, complete	25 (1.8)	7 (2.1)	18 (1.8)	
Cauda equina, incomplete	101 (7.4)	30 (8.8)	71 (6.9)	
Cauda equina, complete	10 (0.7)	2 (0.6)	8 (0.8)	
Neurological classification [222]				n.a
A	–	–	103 (9.4)	
B	–	–	93 (8.5)	
C	–	–	186 (17.1)	
D	–	–	487 (44.6)	
Etiology [0]				0.10
Degenerative disc disorder	410 (28.3)	83 (23.1)	327 (30.0)	
Infection	126 (8.7)	39 (10.9)	87 (8.0)	
Vascular	363 (25.0)	93 (25.9)	270 (24.8)	
Other	98 (6.8)	20 (5.6)	78 (7.2)	
Tumor-benign	122 (8.4)	31 (8.6)	91 (8.3)	
Tumor-unspecified	50 (3.5)	12 (3.3)	38 (3.5)	
Tumor-malignant	281 (19.4)	81 (22.6)	200 (18.3)	
Continuous variable [missing]	Mean (SD); median (IQR)	Mean (SD); median (IQR)	Mean (SD); median (IQR)	*p*
Age at injury, years	59.5 (16.2); 62.0 (48–72)	56.9 (17.0); 60.0 (44–70)	60.3 (15.8); 63.0 (50–73)	<0.001
Length of stay, months	3.5 (4.5); 2.8 (1–5)	4.3 (5.3); 3.5 (2–6)	3.3 (4.2); 2.7 (1–5)	<0.001

Neurological classification refers to the ISNCSCI score = International standards for neurological classification of spinal cord injury (also known as the AISA score), which was only systematically measured after the year 2000 in Switzerland. *p* Values were derived from Chi-squared tests for categorical variables or *T* tests for continuous variables.

[a]Missing data, percentages exclude missing values

highly differential between NTSCI-specific etiologies (Table 2). For example, malignant and unspecified tumors were associated with a greater risk of mortality in comparison to degenerative disc disorders, with an HR of 6.32 (95% CI 4.79–8.34) in malignant tumors and with an HR of 2.57 (95% CI 1.56–4.23) in unspecified tumors, adjusted for sociodemographic and SCI-specific characteristics. Furthermore, results from a post hoc analysis suggested that malignant tumors and unspecified tumors differed greatly with reference to other etiologies ($p < 0.0001$). Group-level differences are indicated by letters A–C in Table 2. HRs from complete cases showed similar results (S2). A separate analysis restricted to bacterial infections (excluding viral and unspecified infections) observed an adjusted HR of 1.65 (95% CI 1.12–2.45).

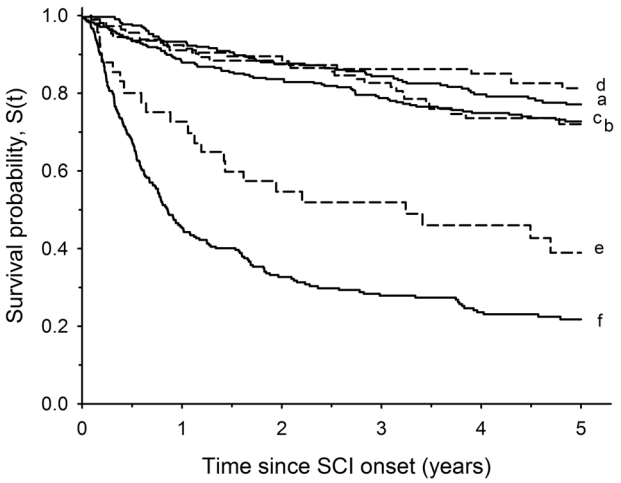

Fig. 1 Kaplan–Meier survival curve for NTSCI by etiological group. Letters a–f indicate survival curves by specific etiological category. a: Degenerative disc disorder, b: Infection, c: Vascular, d: Tumor-benign, e: Tumor-unspecified, f: Tumor-malignant

Determinants of mortality differed between malignant and non-malignant etiological groups (Table 3). For non-malignant etiologies, higher attained age was associated with an increased risk of mortality. In contrast, attained age was less strongly associated with mortality risk among individuals with a malignant etiology. In particular, individuals with an attained age of ≥76 years had an 11 times greater risk of mortality in non-malignant cases (HR 11.02, 95% CI 6.08–19.98) in comparison to malignant cases (HR 1.41, 95% CI 0.88–2.37). For both malignant and non-malignant etiologies, complete lesions were associated with about a doubled risk of mortality. In degenerative disc disorders, tetraplegia was associated with having a higher risk of mortality (HR 1.67, 95% CI 1.04–2.67). In a separate analysis including individuals with cauda equina, a lower mortality risk for individuals with a malignant etiology was observed (HR 0.16, 95% CI 0.05–0.60) $p = 0.01$. Results from stratified estimates of mortality were comparable in complete cases (S3).

Survival probabilities

Among cases of malignant etiologies, completeness of lesion had the largest impact on survival (Table 4). For example, the 1-year survival probability for an individual with a complete paraplegia due to a malignant etiology was 29.0%, which then dropped to 9.2% after 5 years. In comparison, individuals with a complete paraplegia from a non-malignant etiology had a survival probability of 69.9% after 1 year, which diminished to 45.6% after 5 years.

Life expectancy having attained the age of 60 years

Estimated LYR for individuals with an attained age of 60 years are presented in Fig. 2. Men with an attained age of

Table 2 Relative risk of mortality in relation to personal demographics and SCI-specific conditions[a]

Characteristics	Univariable estimates		Multivariable estimates		Group-level differences[b]
	Hazard ratio, 95% CI	*p*	Hazard ratio, 95% CI	*p*	
Etiology		<0.0001		<0.0001	
Degenerative disc disorders	Ref.		Ref.		A
Infection[c]	1.29 (0.89–1.87)		1.42 (0.99–2.04)		A
Vascular	1.51 (1.14–1.99)		1.28 (0.97–1.68)		A
Other	1.38 (0.91–2.10)		1.62 (1.09–2.41)		A
Tumor-benign	0.89 (0.58–1.36)		1.05 (0.69–1.60)		A
Tumor-unspecified	3.09 (1.92–4.98)		2.57 (1.56–4.23)		B
Tumor-malignant	6.41 (4.90–8.38)		6.32 (4.79–8.34)		C

[a]Multivariable model is adjusting for sex, age, decade, lesion level, and lesion completeness

[b]Letters A–C indicate group-level differences present in the study population based on Bonferroni-corrected pairwise comparisons in a post hoc analysis

[c]Owing to low cell counts, viral infections (15 cases), bacterial infections (83 cases), and unspecified infections (28 cases) were combined into one group. The adjusted hazard ratio of bacterial infections only was 1.65 (95% CI 1.12–2.45).

Table 3 Multivariate analysis of determinants of mortality between major NTSCI-specific etiological groups

Characteristics	Malignant tumors		All non-malignant etiologies[a]		Only degenerative disc disorders	
	Hazard ratio (95% CI)	*p*	Hazard ratio (95% CI)	*p*	Hazard ratio (95% CI)	*p*
Sex		0.94		<0.01		0.21
Female	Ref.		Ref.		Ref.	
Male	0.99 (0.70–1.38)		1.48 (1.17–1.88)		1.36 (0.84–2.21)	
Attained age at injury		0.03		<0.0001		<0.0001
16–30	0.44 (0.13–1.45)		1.67 (0.62–4.50)		–	
31–45	Ref.		Ref.		Ref.	
46–60	0.98 (0.62–1.55)		2.21 (1.16–4.20)		3.04 (0.35–26.67)	
61–75	1.55 (1.02–2.37)		4.26 (2.32–7.80)		14.85 (1.97–112.10)	
76+	1.44 (0.88–2.37)		11.02 (6.08–19.98)		28.68 (3.88–211.83)	
SCI decade		0.47		0.09		0.39
1990–2000	Ref.		Ref.		Ref.	
2000–2011	0.88 (0.63–1.24)		0.73 (0.50–1.05)		0.70 (0.31–1.59)	
SCI type		0.16		0.75		0.03
Paraplegia[b]	Ref.		Ref.		Ref.	
Tetraplegia	0.70 (0.42–1.16)		1.04 (0.81–1.34)		1.67 (1.04–2.67)	
Lesion completeness		<0.0001		<0.0001		0.42
Incomplete	Ref.		Ref.		Ref.	
Complete	1.91 (1.40–2.62)		2.01 (1.46–2.77)		1.90 (0.39–9.15)	

Hazard ratios are from multivariable regression modeling using Wald tests to measure significance

[a]A composite group of all etiologies excluding malignant tumors and unspecified tumors

[b]The adjusted HR of cauda equina lesion level with reference to "Paraplegia" was 0.16 (95% CI 0.05–0.60), $p = 0.01$ in malignant tumors, 0.82 (95% CI 0.56–1.18), $p = 0.47$ in the non-malignant groups, and 1.32 (95% CI 0.79–2.19), $p = 0.11$ within degenerative disc disorders

Table 4 Marginally adjusted survival probabilities (percent) according to time since injury[a]

		Non-malignant etiology groups	
	Malignant tumors	All non-malignant etiologies[b]	Only degenerative disc disorders
Paraplegia, incomplete			
1 year	49.3 (42.5–57.2)	82.1 (79.8–84.5)	95.7 (93.6–97.9)
5 years	24.4 (18.8–31.5)	64.3 (61.1–67.6)	84.5 (79.0–90.3)
10 years	14.8 (10.1–21.6)	51.9 (48.3–55.8)	76.1 (68.4–84.5)
Paraplegia, complete			
1 year	29.0 (20.6–40.9)	69.9 (64.4–75.7)	–
5 years	9.2 (4.8–17.4)	45.6 (38.7 – 53.7)	–
10 years	4.3 (1.8–10.5)	31.9 (25.4–40.0)	–
Tetraplegia, incomplete			
1 year	64.9 (50.6–83.1)	86.8 (84.4–89.3)	93.0 (90.0–96.1)
5 years	41.6 (25.7–67.4)	72.5 (68.4–76.9)	76.3 (69.9–83.2)
10 years	30.0 (15.6–57.8)	61.8 (56.7–67.4)	65.2 (58.0–73.3)
Tetraplegia, complete			
1 year	14.6 (1.9–100.0)	64.9 (51.9–81.2)	50.2 (37.8–66.7)
5 years	–	39.2 (25.0–61.6)	22.2 (11.9–41.4)
10 years	–	25.9 (13.9–48.3)	14.8 (5.7–38.8)

[a]The model is adjusted for age, sex, decade of injury, and lesion severity

[b]Includes all non-malignant etiologies including "degenerative disc disorders"

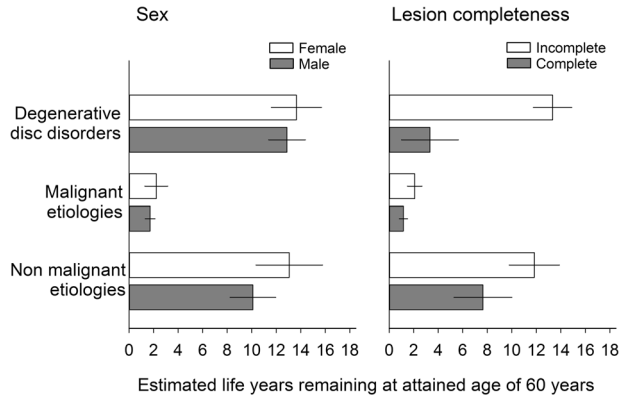

Fig. 2 Estimated life years remaining (LYR) with 95% confidence intervals for individuals having the attained age of 60 years. All figures are adjusted for sex, decade of onset, completeness of lesion, and SCI type, and compares LYR between sexes and between incomplete and complete lesions. The category "non-malignant etiologies" includes all etiologies except malignant and unspecified tumors. All values of mean survival time were significant at $p < 0.0001$. Footnote: When excluding the etiological group "degenerative disc disorders" from the "non-malignant etiologies" composite group, estimates of LYR would indicate 13.1 LYR (CI 10–16) for females, 10.1 LYR (CI 8–12) for males, 11.8 LYR (CI 10–14) in cases of incomplete lesions, and 7.6 LYR (CI 5–10) in cases of complete lesions

60 years and an NTSCI due to a malignant neoplasm were estimated to have only 1.7 (95% CI 1.3–2.1) LYR, in comparison with 10.1 years (95% CI 8.2–12.0) for those with a non-malignant etiology. Women with a degenerative disc disorder and an attained age of 60 years had the highest estimated LYR, with 13.6 years (95% CI 11.6–15.7).

Discussion

This study identified a heterogeneous population with diverse survival outcomes following NTSCI. Survival differences identified between etiological groups suggest that underlying health conditions precipitating NTSCI are strong predictors of mortality, identifying a need for individualized patient management for optimized treatment of this community [20, 21]. Furthermore, comparable estimates of survival and life expectancy are still greatly needed for this community as to establish a formal evidence base that allows for targeted improvement of strategies of SCI treatment, rehabilitation, and overall management [22], particularly within etiological groups.

Determinants of survival

Disparities observed in mortality risk due to malignant etiologies compared to individuals with a non-malignant NTSCI present a strong argument that malignant tumors should be analyzed separately to prevent misinterpretation or skewed survival estimates. Inclusion of cases with NTSCIs resulting from a malignant etiology could result in the underestimation of life expectancy, given the strong force of mortality imposed by the tumors. The higher risk of mortality observed for individuals with unspecified neoplasms is potentially resultant of the advanced tumor stage at the time of diagnosis. However, despite the reduced survival observed in individuals with NTSCI due to malignant tumors, evidence from recent literature suggest that these individuals can realize functional gains from specialized rehabilitation for SCI [20, 23].

Differential diagnosis

The complex health states that individuals with NTSCI develop are most likely attributable to the multimorbid nature of the disease [24], likely contributing to reduced survival in comparison to TSCI [10]. Contemporary chronic disease management models are thus necessary to facilitate provision of adequate care [22]. Furthermore, survival differences in etiology observed in this study reveal the need for individualized patient management for this population. For instance, the prognosis of a middle-aged person with an NTSCI from a malignant origin (i.e., metastasized cancer) has disparate expected outcomes in comparison with an elderly person diagnosed with a degenerative disorder (i.e., spinal stenosis). Considering the differential impact of SCI-specific factors on survival (i.e., lesion level), the development of disease frameworks could identify individuals with the greatest need. The next steps of improving life expectancy in this population would require the development and implementation of specified treatment and individual outcome plans [5].

Health systems planning

In addition to informing on elements of personalized rehabilitation, evidence from this analysis can serve as a benchmark for guiding health-care systems and evidence-based policy. Changes within the NTSCI population between decades suggest that there are potentially altering trends in the NTSCI patient profile, stemming from an increasing prevalence of NTSCIs due to degenerative disc disorders. Considering that degenerative disc disorders are attributed to older age, these findings correspond to studies which indicate that the increase in prevalence of NTSCI is due to the growing aging population [22]. Furthermore, long-term treatment needs vary greatly within etiological groups and should be taken into consideration for estimating the volume of long-term care [25].

Strengths and Limitations

A major strength of the SwiSCI study is the clear sampling frame of people who receive specialized rehabilitation. In addition to traditional Kaplan–Meier crude estimates of survival, contemporary methodological approaches were implemented to estimate mortality. However, selection biases related to receiving admission to specialized rehab could have impacted survival estimates [26]. For example, individuals with NTSCI are often undiagnosed or misdiagnosed for lengths of time before they are admitted to specialized care [5, 22, 25] (i.e., their time at risk may often begin before they have an SCI diagnosis), which would result in estimates of survival and life expectancy lower than reality. This bias could potentially explain the lower HRs observed in individuals with tetraplegia compared to paraplegia. Furthermore, survivor bias may skew results, as individuals who experience an early mortality after NTSCI forgo specialized rehabilitation, particularly the elderly and those with the most terminal diagnoses [20, 27]. Currently, Switzerland has a limited ability to identify the prevalence and outcomes of individuals with NTSCI before rehabilitation. Evidence from other countries suggest that a considerable proportion of individuals with NTSCI receive health care outside the sphere of SCI-specific rehabilitation [5, 22]. Findings from an administrative data study in context to SwiSCI has similarly suggested that many individuals with TSCI do not receive a referral to specialized SCI rehabilitation [26]. Another limitation in the present study concerns potential bias due to LTFU. To account for this bias, inverse probability weights were implemented, based on the individual's probability of survival, given the pre-specified covariates [28].

Conclusion

This study contributes a comprehensive evidence base for risk factors of mortality after NTSCI, moving toward narrowing a considerable knowledge gap in survival after NTSCI. Disparities in survival between etiological groups indicate a need for a dynamic clinical approach in addition to focused research on optimal rehabilitation strategies for the specific needs of individuals according to etiology. Research investigating survival outcomes in comparison to TSCI could identify the impact that underlying health conditions attributed to NTSCI have on the risk of mortality. Further research that emphasizes cause-specific survival, social factors, and quality of care in NTSCI is essential for the development of prognostic models, measuring treatment progress, and estimating service demands.

Data archiving

Owing to our commitment to SwiSCI study participants and their privacy, datasets generated during the current study are not made publicly available. The SwiSCI study center requires, on behalf of the SwiSCI Study Group, contact prior to any planned data usage (contact@swisci.ch).

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Author contributions AB and MWGB were responsible for designing and planning the conceptual framework of the present study. MWGP and JDC further provided statistical support in addition to contributing critical feedback on the manuscript. HPG, KH, XJ, and MS provided clinical support, feedback on the manuscript, and support in data collection at their respective clinics. AB was responsible for data analysis, interpretation, and development of the present manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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