

# Traumatic Brain Injury in Spinal Cord Injury: Frequency and Risk Factors

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**Background:** The frequency of traumatic brain injury (TBI) co-occurring with traumatic spinal cord injury (tSCI) is unclear despite a number of past studies; as well, limited research has examined predictors of co-morbid TBI in tSCI patients. **Objectives:** (1a) To summarize past literature on comorbid diagnosis of TBI in tSCI in order to reexamine the frequency of dual diagnosis in a study designed to obviate past methodological limitations; (1b) to compare dual-diagnosis frequency with vs without the inclusion of diagnostically ambiguous cases; and (2) to measure risk factors for tSCI and comorbid TBI. **Methods:** Ninety-one of 135 eligible adults with tSCI, 3 to 6 months postinjury, were prospectively recruited from a tertiary inpatient tSCI rehabilitation program. TBI diagnosis was based on comprehensive, validated clinical neurological and neuroimaging measures. **Results:** Objective 1: 39.6% of the tSCI patients sustained a concomitant TBI, but when ambiguous cases were removed from analysis, frequency rose to 58.1%. Objective 2: Motor vehicle collisions were most likely to yield a comorbid TBI diagnosis, but 31.6% of falls also resulted in TBI. Patients with cervical and thoracic injuries showed a very similar frequency of comorbid TBI. **Conclusions:** Varied methodological approaches, particularly the decision to include/exclude ambiguous cases, likely explain disparate past estimates of TBI in tSCI. However, even this study's lower frequency estimate, at nearly 40%, is clinically important. The prevailing assumption that dual diagnosis is less common in thoracic than cervical spine injuries was not supported. Finally, while comorbid TBI most frequently occurred in motor vehicle collisions, nearly a third of tSCIs sustained in falls resulted in comorbid TBI in our sample. **Key words:** *computed tomography, dual diagnosis, magnetic resonance imaging, neuroimaging, neurological indices, neuropsychology, traumatic spinal cord injury, traumatic brain injury*

THE MOST COMMON causes of traumatic spinal cord injury (tSCI)—motor vehicle collisions (MVCs), falls, sport-related insults, and assaults—mirror those that typically cause traumatic brain injury (TBI),<sup>1–3</sup> leaving tSCI patients at elevated risk for a dual diagnosis.<sup>4</sup> Comorbid tSCI and TBI can yield complex and deleterious clinical consequences, with each diagnosis potentially compounding the other.<sup>3</sup> For example, several studies have found evidence of transneuronal degeneration of gray and white matter structures of the *brain* secondary to tSCI<sup>5–7</sup> (and with evidence of functional consequences<sup>8</sup>), and TBI can exacerbate

the effects of tSCI through damage to the sensory and motor systems of the brain.<sup>9,10</sup> Moreover, the cognitive and emotion dysregulation effects of TBI interfere with rehabilitation of tSCI.<sup>11</sup>

Understanding the frequency of TBI in patients with tSCI is important for clinical management and for furthering our scientific understanding of the problem. More than a dozen studies have investigated the frequency of TBI in patients with tSCI, but estimates have been wide ranging (from 10% to 74%)<sup>4,12–25</sup> (see Table 1). A number of factors may explain this disparity, and these include the following:

1. *Sensitivity and specificity of diagnostic measures.* All studies examining the prevalence of TBI are limited by the challenges of detecting mild TBIs,<sup>26</sup> which constitute the majority of all TBIs.<sup>27</sup> Milder TBIs are associated with subtle white matter changes that are not readily detectable by conventional computed tomography (CT) and magnetic resonance imaging (MRI).<sup>28,29</sup> As well, many tSCIs are unwitnessed. This impedes identification of TBI because potential findings on time-sensitive clinical neurological indices, such as the Glasgow Coma Scale (GCS)<sup>30</sup> and loss of consciousness (LOS), may be resolved by the time a

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**TABLE 1** Review of previous prevalence studies of traumatic brain injury in traumatic spinal cord injury

Study	Study characteristics									DD Prevalence, %
	n	Design	CT	MRI	LOC	PTA	GCS	NP	Val Clin Ind	
Maynard et al (1979) <sup>12</sup>	123	RS	...	...	X	...	...	...	...	10
Strubreither et al (1997) <sup>13</sup>	322	RS	...	...	...	...	...	X	...	20
Wagner and Stone (1983) <sup>14</sup>	167	RS	...	...	...	...	X	...	...	25
Harris (1968) <sup>15</sup>	150	RS	...	...	X	X	-	...	...	33
Iida et al (1999) <sup>16</sup>	188	RS	...	...	...	...	X	...	...	35
Davidoff et al (1985) <sup>17</sup>	101	RS	X	...	X	X	...	...	...	42
Hagen et al (2010) <sup>20</sup>	336	RS	a	a	X	X	X	...	...	47
Davidoff et al (1988) <sup>19</sup>	82	PS	...	...	X	X	...	...	...	49
Scheuneman and Morris (1982) <sup>21</sup>	35	RS	...	...	X	X	...	...	...	51
Pagni and Massaro, (1991) <sup>22</sup>	225	RS	...	...	X	...	...	...	...	54
Wilmot et al (1985) <sup>23</sup>	47	RS	...	...	X	...	...	X	...	56
Davidoff et al (1985) <sup>18</sup>	30	PS	...	...	...	...	...	X	...	57
Richards et al (1988) <sup>24</sup>	150	PS	...	...	X	...	...	X	...	59
Macciocchi et al (2008) <sup>25</sup>	198	PS	X	X	X	X	X	...	b	60
Tolonen et al (2007) <sup>4</sup>	31	PS	...	X	X	X	X	X	X	74

Abbreviations: CT, computed tomography; DD, dual diagnosis; GCS, Glasgow Coma Scale; LOC, loss of consciousness; MRI, magnetic resonance imaging; PTA, posttraumatic amnesia; NP, neuropsychological testing; PS, prospective study; RS, retrospective study; X, documented; . . . , not reported; Val Clin Ind, validation of clinical indices.

<sup>a</sup>Not completed for all participants.

<sup>b</sup>Controlled for intubation.

witness arrives at the scene of injury. Neuropsychological assessment also provides only limited sensitivity for the identification of milder TBIs.<sup>31,32</sup> Moreover, its specificity for identifying TBI is compromised in tSCI by documented overestimations of cognitive impairment in this population,<sup>33,34</sup> with regard to this overestimation, it is interesting to note that 4 of the 5 highest prevalence studies used neuropsychological assessment as one of the diagnostic measures (Table 1).

2. *Variability in type and number of diagnostic measures across studies.* The heterogeneity in type and number of diagnostic measures used across studies also likely contributes to the wide-ranging estimates of dual-diagnosis frequency. For example, Table 1 illustrates that of the 5 studies finding the lowest prevalence rates, 4 used only a single diagnostic measure and the 2 studies with the highest prevalence rates used the largest number of diagnostic measures. This relationship is not perfectly linear, with the fourth highest prevalence rate found using neuropsychological assessment alone. However, as noted earlier, neuropsychological assessment can inflate type II error rates, which may explain the high prevalence rate in this study.

3. *Validation of Clinical indices.* Confounds to clinical neurological indices of TBI (ie, PTA, GCS, LOC) include hypoxia, intoxication (alcohol/other), and intubation,<sup>26</sup> all of which occur with some frequency in tSCI. Psychoactive medications (eg, opioid narcotics) and neurological and developmental disorders can contaminate neuropsychological assessment.<sup>35</sup> Differences across studies in the identification of such potential confounds constitutes another probable contributing factor to the variability in findings across studies. To date, only the Tolonen et al<sup>4</sup> study has reported assessing comprehensively for confounds<sup>4</sup>; a second study by Macciocchi et al<sup>25</sup> controlled for intubation.<sup>25</sup>

4. *Management of ambiguous TBI cases in frequency calculation.* To classify a patient group with tSCI as TBI-negative, the null hypothesis must be accepted. The uncertainty of accepting the null hypothesis is elevated by the limited sensitivity and specificity of diagnostic tools for TBI, especially in cases when only a small number of measures with low sensitivity are available for a given patient (eg, CT and/or LOC alone<sup>36</sup>). Confounds can further increase uncertainty of diagnostic classification. For

example, a reduced GCS score in the presence of alcohol intoxication may represent either a TBI or altered consciousness secondary to intoxication. Whether such ambiguous cases are classified as TBI-positive, TBI-negative, or excluded altogether will affect prevalence rate estimation. To date, a direct comparison of dual-diagnosis frequency using differing approaches to management of ambiguous cases has yet to be undertaken.

The challenge of accurately determining dual-diagnosis rates is illustrated by the rate of missed TBI diagnoses in acute care. In a recent study by our group, we found that nearly 60% of TBIs were missed in patients with tSCI in emergency/acute care.<sup>35</sup> We speculated that one further impediment to the diagnosis of TBI in tSCI might concern assumptions about the predictors of comorbid TBI in patients with tSCI. While recent studies have found that cervical injuries are more highly associated with comorbid TBI than subcervical injuries,<sup>25,40</sup> an early study by the Davidoff group<sup>19</sup> in 82 patients found no such relationship. Assumptions about this relationship could influence whether or not a patient is comprehensively assessed for TBI; therefore, further research into the association between level of injury and presence of TBI is warranted. Mechanism of injury may also contribute to potential biases, for example, with MVCs assumed to be associated with dual diagnosis and other types of injuries (eg, falls) potentially overlooked. Thus, a better understanding of the risk factors for TBI in tSCI patients could help to reduce missed diagnoses of TBI while improving our understanding of this dual diagnosis.

Therefore, the main objectives of this study were 2-fold: The first was to utilize the review of the literature above to design a study that built on past strengths and obviated methodological limitations. The methodologically strongest study, by Tolonen et al<sup>4</sup> employed comprehensive diagnostic measures for TBI and assessed the validity of all diagnostic indices. However, the sample size of this study was  $N = 31$  and it was conducted in a European setting. Thus, objective 1a entailed the measurement of frequency of TBI in tSCI, incorporating the strengths of the Tolonen et al<sup>4</sup> study but employing a larger sample and investigating a North American population to examine the generalizability of findings. A further question yet to be examined was how the frequency of dual diagnosis might be affected by differing management strategies for diagnostically ambiguous cases, as discussed above. Therefore, Objective 1b entailed the examination of frequency of TBI in tSCI with all ambiguous cases removed as compared to the the frequency of dual diagnosis with ambiguous cases included (Objective 1a). The second main objective was to examine the clinical correlates of dual diagnosis within this experimental design.

## METHODS

The research ethics board at Toronto Rehabilitation Institute, now part of the University Health Network, approved this study. All procedures were conducted in accordance with the guidelines and standards of this research ethics board. Informed consent was received from all study participants upon enrollment. All participants were fully competent to respond to the consent forms.

### Participants

The final sample comprised 91 patients, selected from an eligible sample of 135. The first 105 patients admitted to a tertiary spinal cord rehabilitation program from 2007 to 2011 in an urban center who met the inclusion and exclusion criteria of the study, who agreed to be approached by research, and who gave their informed consent comprised the initial cohort. The majority of these patients were referred from local urban teaching hospitals with a neurotrauma unit, but the program has a larger catchment area of all acute care hospitals throughout Ontario. Inclusion criteria for the study were as follows: clinical diagnosis of tSCI (cervical 1-lumbar 2; American Spinal Injury Association Impairment Scale [AIS] A-D); 3 to 6 months postinjury; and aged 18 to 55 years. Subjects were excluded from the study if they had a history of neurological and/or psychotic disorder due to risk of positive MRI findings secondary to conditions unrelated to TBI.

Of the initial 135, a total of 30 eligible participants declined to participate in research, leaving a potential sample of 105. Fourteen patients were excluded from the analysis because of either withdrawal from the study ( $n = 8$ ) or unavailability of at least 3 clinical neurological and/or MRI variables ( $n = 6$ ), leaving the final sample of 91 participants. All participants were classified into 1 of 3 groups: definitively positive for TBI diagnosis; definitively negative for TBI diagnosis; and ambiguous for TBI diagnosis.

### Research design

Objective 1a used descriptive statistics and 1b used a within-subjects design. The dependent variable was diagnostic classification of positive, ambiguous or negative TBI. For objective 1a, the frequency of dual diagnosis was calculated with all TBI-positive cases in the numerator and *all* TBI-positive plus TBI-negative plus ambiguous cases in the denominator (ratio 1). For objective 1b, this frequency was compared with a second equation that *excluded* the ambiguous cases. Here, the numerator was all TBI-positive cases and the denominator comprised only TBI-positive plus TBI-negative cases (ratio 2).

Objective 2 involved a between-subjects design. The dependent variable was group membership (TBI-positive or TBI-negative group). The independent variables were neurological level (cervical vs subcervical), mechanism of injury (MVC vs other), neurological category (incomplete vs complete), functional motor performance (AIS score: A/B vs C/D), age, and education. The independent variables were further subdivided and descriptive statistics reported to determine the relative contribution for each of the following: (1) neurological level (cervical, thoracic, lumbar, and multi-level), (2) mechanism of injury (MVC, falls, sports, blunt force, and assault), (3) neurological category (tetraplegic complete, tetraplegic incomplete, paraplegic complete, and paraplegic incomplete), and (4) functional motor performance (AIS scores A-D).

Data collection was carried out both retrospectively and prospectively. The former was conducted by medical record review, in which each patient's record was reviewed by a trained psychometrist/research coordinator. Here, the variables of interest were obtained along with any additional information associated with the variable that could be used to assess the validity of the measurement. All record information was additionally reviewed by a supervising clinical neuropsychologist who evaluated collateral information for potential variable confounds such as intoxication, intubation, sedation, and hypoxia.

#### *Outcome measures: Retrospective*

##### **Clinical neurological indices of brain injury**

Information on 3 clinical indices of brain injury was retrieved from medical records: (1) GCS score; (2) presence and length of PTA; and (3) presence of LOC.

##### **CT reports**

Emergency department CT scan reports were obtained from medical records.

#### *Outcome measures: Prospective*

##### **Structural MRI: MRI data acquisition**

Acquisition parameters were tailored to maximize TBI detection. All patients were scanned using a GE 3 Tesla MRI scanner equipped with an 8-channel head-coil. Subjects underwent an MRI protocol including T<sub>1</sub>-weighted spin-echo, T<sub>2</sub>-weighted spin-echo, T<sub>2</sub>\*-weighted gradient-echo, and fluid-attenuated inversion recovery.

#### **Procedures**

Magnetic resonance images were collected prospectively. All other measures were collected from medical records retrospectively. A neuroradiologist from a large

urban medical center with extensive experience in TBI evaluated MRIs. The neuroradiologist was blinded to all clinical findings, and MRIs were quantitatively evaluated for all subjects. This evaluation included classification of all visible lesions based on their signal characteristics.

On all outcome measures, our threshold for TBI was deliberately biased away from false-positives to keep our frequency estimate conservative. This results in an increased risk of type II errors; we also note that assessment of patients with tSCI outside of the acute care window in itself may have reduced our ability to detect some TBI cases due to symptom resolution, resulting in an increased risk of type II errors.

All patients with tSCI who comprised the final sample were classified with respect to a TBI diagnosis as definite positive, definite negative, or ambiguous, as follows: *Definite positive*: (i) 2 or more positive and unfounded clinical neurological indices for TBI (ie, presence of PTA, presence of LOC, GCS score of  $\leq 14$ ) or (ii) 1 (or more) unambiguously positive neuroimaging findings (ie, a neuroradiology conclusion of definite TBI on CT scan or MRI). *Definite negative*: 3 or more negative indices with other variables either invalid or not available (clinical neurological) or ambiguous (imaging—ie, positive findings, but *without* a diagnosis of TBI). *Ambiguous*: (i) 1 positive *clinical neurological* indicator with all other variables negative, invalid, or unavailable; (ii) 1 or 2 negative clinical neurological or imaging indicators, with all other variables invalid or unavailable.

For objective 1a, the frequency was calculated using ratio 1, as follows: Ratio 1 = (TBI positive)/(TBI positive + TBI negative + ambiguous cases). For objective 1b, the frequency was calculated using ratio 2, as follows: Ratio 2 = (TBI positive)/(TBI positive + TBI negative). For objective 1b, ratio 1 and ratio 2 were compared. As indicated earlier, the equations differed only on the inclusion (ratio 1) versus exclusion (ratio 2) of ambiguous cases in the denominator.

#### *Data analysis*

Statistical analyses were performed with SPSS version 20 (SPSS Inc, Chicago, Illinois). The significance was set at  $\alpha$  less than .05 for all analyses. The correlates of dual diagnosis in the tSCI population were determined via binary logistic regression using categorical and continuous predictors. Following the review of the diagnostic statistics (ie, <1% of the cases had standardized residuals with an absolute value of  $>2$ ; Cook's distance of each case was  $<1$ ), no missing data, nor outliers that could be identified as influential, were identified. The variables were selected on the basis of prior information and the forced entry method was used. The backward method was used to account for potential

suppressor effects. Variables whose deletion resulted in the smallest, nonsignificant change in the dual-diagnosis accuracy were deleted. The sensitivity analyses, testing the assumptions using forward forced and stepwise methods, yielded the same, overall conclusions.

## RESULTS

### Representativeness of the sample

Table 2 provides demographic and injury variables. The entire tSCI sample was classified into TBI-positive ( $n = 36$ ) and TBI-negative ( $n = 55$ ). Of the 55 TBI-negative cases, 29 cases were ambiguous. The mean lowest GCS score for the full sample, for which 54 of 91 GCS scores were available, was 13.0. When GCS scores of questionable validity were removed, there were 46 cases available, and the mean lowest GCS score was 13.8.

Our study sample was demographically a fairly typical sample of adults with tSCI with respect to age, sex, and years of education.<sup>25,37</sup> As well, as compared with the Model Systems database of tSCI,<sup>38</sup> our neurorehabilitation sample presented with comparable proportions of different neurological injury levels (ie, cervical, thoracic, lumbar, and sacral) with cervical level injuries the most common level of injury among both populations of patients with tSCI (see Table 3).

### Objective 1a: Frequency of TBI in patients with tSCI (all participants included)

When all TBI-positive and TBI-negative patients were included along with ambiguous cases (ie, ratio 1), the frequency of TBI was 39.6%; this frequency of tSCI-TBI falls toward the lower to midrange of past studies. Figure 1 presents this value in the context of all other prior prevalence studies.

### Objective 1b: Frequency of TBI in patients with tSCI (ambiguous cases removed)

When ambiguous cases were excluded from the equation (ie, ratio 2), the proportion of tSCI patients with TBI was 58.1%. Thus, a disparity of 18.5% was observed between these 2 ratios (see Fig 1).

### Objective 2: Correlates of dual diagnosis

#### Ratio 1

All ambiguous cases were included in the first set of analyses, and all 6 variables were entered at the first step, followed by backward logistic regression. For ratio 1, 67.0% of all the cases were correctly classified. This included mechanism of injury, neurological category, and age at injury variables. The Hosmer and Lemeshow

test was not significant ( $\chi^2_8 = 4.46$ ,  $P = .813$ ), indicating a good fit between the observed and predicted TBI-positive cases. Patients with tSCI who were in an MVC were 3.80 times more likely to sustain a comorbid TBI than those who suffered another type of accident (ie, a fall, sports injury, blunt object, or assault;  $W_1 = 7.43$ ,  $P = .006$ ). However, it is important to note that a third (31.6%) of the patients with tSCI who were injured because of a fall also sustained a TBI. Neurological category ( $W_1 = 5.73$ ,  $P = .017$ ) significantly predicted TBI-positive or TBI-negative diagnosis among patients with tSCI, but age did not ( $W_1 = 1.56$ ,  $P = .212$ ).

Interestingly, higher level of injury (ie, cervical) was *not* associated with a higher likelihood of sustaining a comorbid TBI than lower level of injury (ie, thoracic + lumbar). Of the 50 cervical cases, 36.0% sustained a concomitant TBI whereas of the 41 subcervical cases, 43.9% sustained a concomitant TBI. Within the subcervical group, 41.9% of the patients with thoracic level injury, 28.6% of the patients with lumbar level injury, and all patients with multilevel injury sustained a concomitant TBI. Finally, functional motor performance and education did not differentiate between TBI-positive and TBI-negative patients.

#### Ratio 2

The aforementioned analyses were rerun using the definite TBI-positive cases and definite TBI-negative cases, but removing the 29 ambiguous TBI-negative cases. All 6 variables were entered at the first step, followed by backward logistic regression. Overall, the findings were similar. Using ratio 2, 75.8% of all the cases were correctly classified. The included variables, again, were mechanism of injury, neurological category, and age at injury variables. The Hosmer and Lemeshow test was not significant ( $\chi^2_8 = 7.00$ ,  $P = .537$ ), indicating a good fit between the observed and predicted TBI-positive cases. Patients with tSCI who were in an MVC were 8.99 times more likely to sustain a comorbid TBI than those who suffered another type of accident (ie, a fall, sports injury, blunt object, or assault;  $W_1 = 9.06$ ,  $P = .003$ ). Even more of the patients with tSCI who were injured because of a fall sustained a TBI, namely, 57.1%. Older patients ( $W_1 = 9.34$ ,  $P = .002$ ) and, surprisingly, those with incomplete tSCI ( $W_1 = 4.14$ ,  $P = .042$ ) were more likely to sustain a TBI in our sample.

As found for ratio 1, a higher level of injury was not associated with a higher likelihood of sustaining a comorbid TBI. Of the 31 patients with cervical level injury, 58.1% sustained a concomitant TBI whereas of the 31 patients with subcervical level injury, an equal proportion (58.1%) sustained a concomitant TBI. Within the subcervical group, 56.5% of the patients with thoracic level injury, 40.0% of the patients with

**TABLE 2** Demographic and injury variables of all tSCI participants, TBI-positive tSCI participants, and TBI-negative tSCI participants<sup>a</sup>

Demographic	Dual-diagnosis per subgroup			All subjects (N = 91)			TBI-positive (n = 36)			TBI-negative (n = 55)		
	n	%		n	%		n	%		n	%	
Age, median (range), y				37.0 (18-55)			38.5 (19-55)			36.0 (18-55)		
Age, interquartile range, y				26-46			27-46			23-46		
Sex (% male)				67 (73.6)			24 (66.7)			43 (78.2)		
Education, mean (SD), y				12.9 (2.4)			13.0 (2.5)			12.8 (2.4)		
Valid GCS score, mean (range)				13.8 (3-15)			12.1 (3-15)			15 (15-15)		
Injury mechanism												
Motor vehicle crash	19/33	57.6		33	36.3		19	52.8		14	25.5	
Bike related	3/4	75		4	4.4		3	8.3		1	1.8	
Car/truck related	14/24	58.3		24	26.4		14	38.9		10	18.2	
Motorcycle related	1/3	33.3		3	3.3		1	2.8		2	3.6	
Pedestrian hit by car	1/1	100		1	1.1		1	2.8		0	0	
Fall	12/38	31.6		38	41.8		12	33.3		26	47.3	
Sports	4/15	26.7		15	16.5		4	11.1		11	20.0	
Struck by/against object	1/4	25.0		4	4.4		1	2.8		3	5.5	
Assault	0/1	0		1	1.1		0	0		1	1.8	
Neurological level												
Cervical	18/50	36.0		50	54.9		18	50.0		32	58.2	
Thoracic	13/31	41.9		31	34.1		13	36.1		18	32.7	
Lumbar	2/7	28.6		7	7.7		2	5.6		5	9.1	
Multilevel	3/3	100		3	3.3		3	8.3		0	0	
Functional motor performance												
AIS A	16/28	57.1		28	30.8		16	44.4		12	21.8	
AIS B	2/11	18.2		11	12.1		2	5.6		9	16.4	
AIS C	8/19	42.1		19	20.9		8	22.2		11	20.0	
AIS D	10/33	30.3		33	36.3		10	27.8		23	41.8	
Neurological category												
Tetraplegic complete	8/13	61.5		13	14.3		8	22.2		5	9.1	
Tetraplegic incomplete	10/34	29.4		34	37.4		10	27.8		24	43.6	
Paraplegic complete	8/15	53.3		15	16.5		8	22.2		7	12.7	
Paraplegic incomplete	10/29	34.5		29	31.9		10	27.8		19	34.5	

Abbreviations: AIS, the American Spinal Injury Association's motor and sensory scores for spinal cord injury; GCS, Glasgow Coma Scale; TBI, traumatic brain injury; tSCI, traumatic spinal cord injury.

<sup>a</sup>Completeness is defined according to the American Spinal Injury Association Impairment Scale.

**TABLE 3** Base rates in Model Systems database of traumatic spinal cord injury × level of injury versus current sample

	Neurological level, %				Neurological category, %			
	Cervical	Thoracic	Lumbar	Sacral	TC	TI	PC	PI
Model Systems <sup>a</sup>	54.9	34.1	7.7	0.0	14.3	37.4	16.5	31.9
TRI sample <sup>b</sup>	54.7	33.7	8.1	0.0	15.1	39.5	17.4	27.9

Abbreviations: PC, paraplegic complete; PI, paraplegic incomplete; TC, tetraplegic complete; TI, tetraplegic incomplete.

<sup>a</sup>From USA SCI 2012 NSCISC Annual Statistical Report.<sup>38</sup>

<sup>b</sup>Toronto Rehabilitation Institute neurorehabilitation sample.

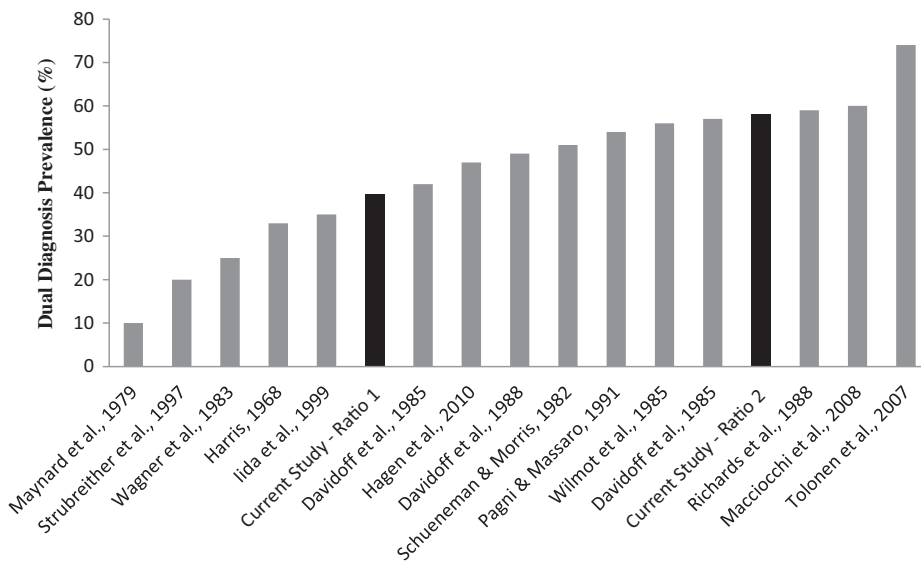
lumbar level injury, and all patients with multilevel injury sustained a concomitant TBI. Finally, functional motor performance and education did not significantly differentiate between TBI-positive and TBI-negative patients. Findings, for both ratios, are summarized in Table 4.

**DISCUSSION**

Our article provides a brief review of previous dual-diagnosis studies with a discussion of probable explanations for the marked disparity in frequency of dual-diagnosis across studies. Our study was designed to obviate problems of past studies by using comprehensive diagnostic measures with careful validation of each variable. We highlighted that a limitation of past research was an absence of explanation of how ambiguous TBI-negative cases were managed, and we provided 2 frequencies of dual diagnosis in the current study, one including and one excluding ambiguous cases. For

the purpose of better identification of patients with tSCI at risk for TBI, we also examined correlates of dual diagnosis.

We found the minimum frequency of TBI among patients with tSCI to be 39.6%. Excluding ambiguous cases, the rate climbed to 58.1%. Therefore, the findings clearly underscore a clinically concerning rate of TBI in patients with tSCI, regardless of how ambiguous cases are addressed. As our 2 different approaches to managing ambiguous cases resulted in a difference in prevalence rates of nearly 20%, the findings also underscore a probable contributor to the differing prevalence rates across past studies. However, other factors such as variability in the type and number of screening tools and the handling of confounds also necessarily contribute to this disparity. Our methods and our findings (with ambiguous cases excluded) most closely align with those of Macciocchi et al (60%),<sup>25</sup> who used identical diagnostic measures in a prospective study, and controlled for intubation (though not other variables).<sup>25</sup> Our frequency



**Figure 1.** Frequency of TBI among patients with tSCI in our study—in black are ratios 1 and 2, respectively contrasted with dual-diagnosis incidence of past studies.

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**TABLE 4** Binary logistic regression (forced backward method) results for ratio 1 (includes all cases) and ratio 2 (excludes ambiguous cases)

	B (SE)	Wald	df	P	95% CI for exp b		
					Lower	exp b	Upper
Ratio 1							
Mechanism of injury	1.34 (0.49)	7.43	1	.006	1.46	3.80	9.93
Neurological category	− 1.22 (0.51)	5.73	1	.017	0.11	0.29	0.80
Age at injury	0.027 (0.022)	1.56	1	.212	0.99	1.03	1.07
Ratio 2							
Mechanism of injury	2.20 (0.73)	9.06	1	.003	2.15	8.98	37.54
Neurological category	− 1.49 (0.73)	4.14	1	.042	0.054	0.23	0.95
Age at injury	0.11 (0.035)	9.34	1	.002	1.04	1.11	1.19

Abbreviation: CI, confidence interval.

of dual diagnosis was not as high as that of Tolonen et al (74%);<sup>4</sup> however, our sample was more than twice the size of theirs (see Table 1) and conducted in a North American setting both of which might have contributed to differences in frequency estimations.

A small number of studies have examined correlates of dual diagnosis.<sup>16,25,39</sup> We found that MVCs were the most common cause of tSCI that leads to dual diagnosis, consistent with previous findings.<sup>25</sup> However, other injuries, particularly falls, are an important risk factor as well, with a frequency of 31.6%; this frequency was commensurate with, but slightly higher than that of, other studies (eg, 26%).<sup>25</sup>

Departing from the findings of the majority of recent<sup>25,40</sup> and older literature,<sup>16</sup> we found that patients with cervical and thoracic level injuries were at similarly high risk for dual diagnosis. Our finding is consistent with the 1988 prospective study by Davidoff and colleagues in 82 patients with tSCI.<sup>19</sup> Although our sample is smaller than many, given the comprehensiveness of our diagnostic measures and the careful approach to verifying validity of diagnostic information, we suggest that the current findings underscore the clinical need to consider for dual diagnosis *all* patients with tSCI, including those with subcervical injuries and those who sustain a tSCI in a fall. Functional disability and education were not associated significantly with the presence of comorbid TBI; age, on the other hand, was a very significant risk factor in our cleaner sample (ie, ratio 2), consistent with the findings of Davidoff and colleagues.<sup>19</sup>

A motivation for examining these clinical correlates was our previous research revealing that many TBI diagnoses are missed in acute care.<sup>35</sup> Given the necessary clinical focus in acute care on life-threatening crush injuries and management of the SCI itself, TBIs without overt need for neurosurgical or pharmacological intervention are at risk of being overlooked, especially because TBI symptoms (eg, emotional dysregulation,

reduced attention) are easily misattributed to the emotional sequelae of sustaining SCI or to psychoactive medications such as opioids.<sup>11</sup> Therefore, the current findings emphasize the importance of considering dual diagnosis in tSCI with both cervical and subcervical injuries and in non-MVC mechanisms of injury, falls in particular.<sup>36</sup> Patients with any suspicion of TBI could be flagged for later follow-up.

It is important to note that no single acute or subacute diagnostic investigation (ie, conventional CT or MRI, neuropsychological assessment) has high sensitivity and specificity for the milder TBIs that are often sustained in the context of tSCI. The strongest diagnostic information comes from clinical neurological indices (GCS score,<sup>41</sup> PTA,<sup>42</sup> LOC<sup>43</sup>) taken at the scene of the accident and at the emergency department.<sup>44</sup> In the past, researchers have noted a scarcity of these essential data.<sup>36,45</sup> In the current study, the presence of ambiguous cases of dual diagnosis was frequently due to a lack of such clinical indices or to the questionable validity of the indices. Thus, not only is there a need for wider and more reliable collection of this information, but there is also a strong need for collateral information to be consistently recorded in medical records that would help users of the records ascertain the validity of measures, or lack thereof (eg, the timing of collection with respect to intubation, the administration of psychoactive medication, etc.).

Finally, the findings of our study—with a wide disparity in frequency depending upon the handling of ambiguous cases—point to the need for still further research to determine the true rate of comorbid TBI in tSCI. The ambiguity of classifications in our study was based in large part on missing or incomplete data and, in particular, missing data for clinical neurological indices. Thus, a well-powered, prospective study commencing in the emergency department in which diagnostic measures—and collateral information to permit their

validation—are recorded consistently and completely at the time of injury is still needed. Sufficient power to stratify by a more fine-grained level of injury (eg, C1-C4, C5-C8) and mechanism of injury (eg, driver vs passenger injury, high- vs low-velocity injury) would

help gain risk factor information to better target high risk individuals for early screening. Given the compounding impact of TBI on tSCI, improved diagnosis (permitting improved management) could improve the clinical outcomes of this highly vulnerable population.

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