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Cardiometabolic risk profiling during spinal cord injury rehabilitation: A longitudinal analysis from the Swiss Spinal Cord Injury (SwiSCI) cohort

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Abstract

Background: Early screening is important in individuals with spinal cord injury (SCI) as they are deemed high risk for cardiometabolic diseases. Few studies explored changes in cardiometabolic risk profile in the early phase of the injury. Thus it remains unclear how early the cardiometabolic status deteriorates after injury.

Objective: To determine the longitudinal changes in the cardiometabolic risk profile and examine the association between injury characteristics and cardiometabolic status in subacute SCI.

Setting: Multicenter Swiss Spinal Cord Injury Cohort.

Participants: Adults with traumatic SCI without a history of cardiovascular disease or type 2 diabetes.

Main Outcome Measures: Blood pressure (BP), lipid profile, fasting glucose, waist circumference (WC), weight, body mass index (BMI), and Framingham risk score (FRS) were compared across time and according to the injury characteristics.

Results: We analyzed the data of 258 individuals with traumatic SCI (110 tetraplegia and 148 paraplegia, 122 motor complete, and 136 incomplete). The median age was 50 years (interquartile range [IQR] 32-60), with 76.4% (n = 197) of the population being male. The median rehabilitation duration was 5.5 months (IQR 3.2-7.1). At admission to rehabilitation, fully adjusted linear regression models showed higher baseline weight (β 0.06, 95% confidence interval [CI] 0.005 to 0.11), systolic BP (β 0.05, 95% CI 0.008 to 0.09), diastolic BP (β 0.05, 95% CI 0.004 to 0.10), and triglycerides (β 0.27, 95% CI 0.13 to 0.42) in paraplegia than tetraplegia. Systolic BP, diastolic BP, high-density lipoprotein cholesterol (HDL-C) levels were higher in incomplete than complete injury. In our main analysis, we observed an increase in cholesterol and HDL-C and lipid ratio when comparing the beginning and end of rehabilitation. Individuals with paraplegia had a higher increase in BMI than individuals with tetraplegia, whereas no differences in other cardiometabolic risk factors were detected when comparing motor incomplete and complete injury. Trajectories of each participant showed that the majority of individuals with SCI decreased FRS score at follow-up compared to baseline and no significant changes in the prevalence of cardiometabolic syndrome were observed. At discharge, one third of study participants were classified as moderate to high risk of

cardiovascular disease (CVD), 64% were overweight, and 39.4% had cardiometabolic syndrome.

Conclusion: We observed a modest improvement in lipid profile and FRS during the first inpatient rehabilitation hospitalization. Injury characteristics, such as level and completeness, were not associated with changes in cardiometabolic risk factors in the subacute phase of the injury. Despite this, a significant proportion of study participants remained at risk of cardiometabolic disease at discharge, suggesting that early cardiometabolic preventive strategies may be initiated as early as during the first inpatient rehabilitation hospitalization.

INTRODUCTION

Cardiometabolic diseases (CMDs), comprising cardiovascular diseases (CVDs) and diabetes, are among the leading causes of morbidity and mortality in both able-bodied individuals (ABIs) and individuals with spinal cord injury (SCI).[1-6] Individuals with SCI experience these more frequently and with earlier disease onset,[1-3] which is attributed to the accumulation of cardiometabolic risk factors, namely hyperlipidemia, hypertension, glucose intolerance, and obesity,[7,8] which arise due to the impairments in the metabolic milieu, which occurs a few days or weeks following the injury and worsen thereafter. Specifically, the impairment of autonomic nervous system coupled with changes in body composition and limitations in physical activity can lead to derangements in lipid and glucose metabolism, and blood pressure dysregulation.[9-13] Despite the available evidence regarding the higher CVD risk in chronic SCI,[2,7,14] the early changes in CMD risk factors following the injury have been insufficiently explored.[15-18]

Previous studies have shown increasing fat accumulation as early as 3 to 6 months post-injury (during the first inpatient rehabilitation hospitalization).[18,19] One of the most comprehensive studies reported improvements in lipid profiles during inpatient rehabilitation hospitalization that worsened after discharge. An increase in the body mass index (BMI) is also associated with an unfavorable change in all lipid profiles.[15] These prior findings highlight the importance of maintaining a healthy body weight in diminishing the risk for unfavorable lipid profiles early post-injury. Furthermore, changes in CMD risk factors can depend on injury characteristics, which have not been accounted for in most studies conducted in the subacute phase of the injury. Individuals with tetraplegia and motor complete injuries may have poorer lipid profile and fat composition compared to individuals with paraplegia and motor incomplete injuries, respectively.[9,10] Understanding the early changes in CMD risk factors in individuals with SCI and whether these changes differ by injury characteristics can provide insight that might reduce the risks of CMD.

We aimed to contribute to the current body of the evidence by (1) assessing longitudinal changes in cardiometabolic risk factors over the subacute phase of traumatic SCI during first inpatient rehabilitation; and (2) exploring the influence of injury characteristics (such as injury level and completeness) on cardiometabolic risk profile by using a multicenter SCI cohort in Switzerland.

METHODOLOGY

Study population

The Swiss Spinal Cord Injury (SwiSCI) cohort was established to have a standardized reporting of individuals with SCI and form a database that can generate evidence on the care of this group. It is a collaboration of four major rehabilitation centers across Switzerland, namely, Spinal Cord Injury Center of the Balgrist University Hospital in Zurich, Centre for Spinal Cord Injury and Severe Head Injury in Basel, Clinique Romande de Readaptation in Sion, and the Swiss Paraplegic Centre in Nottwil. These four centers serve as regional catchment areas in Switzerland for individuals needing specialized care for the SCI.

The detailed information on the study design and collected data can be found in a previous publication.[20] In brief, each center prospectively enrolled newly diagnosed individuals with SCI who were admitted for their initial rehabilitation hospitalization. The study excluded individuals with congenital disorders, neurodegenerative disease, inflammatory diseases, and those having new-onset SCI under palliative care. The study collected clinical data compliant with the International Spinal Cord Society (ISCOS) data set, and included other questionnaires related to the overall well-being and functioning of an individual with SCI. The fixed time point for data collection was upon admission (2-4 weeks after the injury) and before discharge from respective rehabilitation centers. The overview of the study design can be found in Figure 1.

Inclusion and exclusion criteria

We included all adults (>18 years old) with SCI enrolled in Pathway 3 of the SwiSCI cohort who underwent inpatient rehabilitation from May 2013 to October 2020. We restricted our analysis to participants with traumatic injury and those without any known cardiovascular diseases or diabetes. We excluded participants with unknown etiology of SCI, those without injury classification, and those who

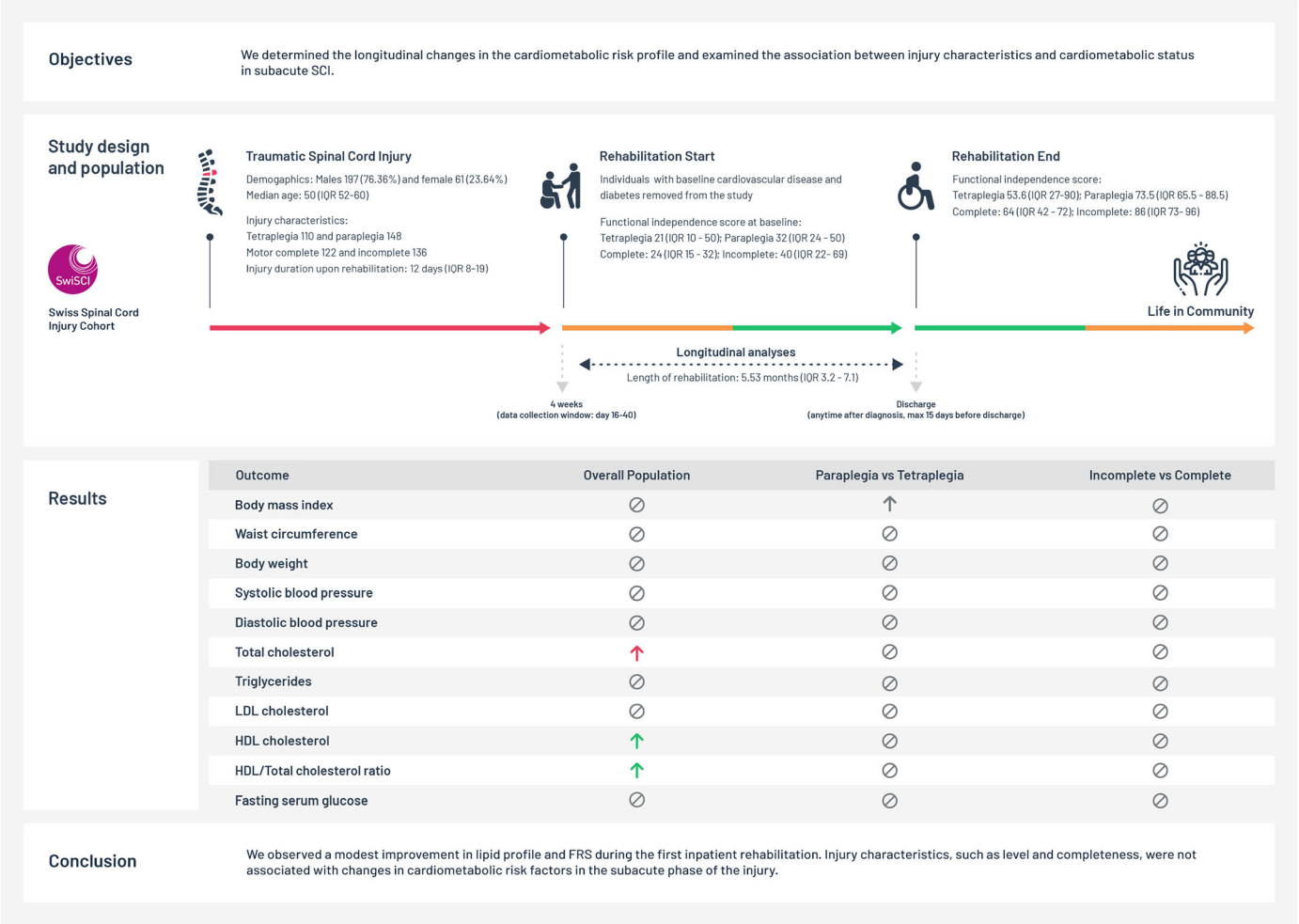

FIGURE 1 Graphical abstract. Abbreviations: FRS, Framingham risk score; IQR, interquartile range; LDL, low density lipprotein; HDL, high density lipoprotein; SCI, spinal cord injury.

did not provide consent for the study. We used the study records upon admission (baseline) and before discharge from the rehabilitation center.

Definition of exposure

The level of injury was classified as tetraplegia (at level C2-C8) and paraplegia (level T1-S5), and the completeness of injury into complete motor injury (AIS A and B) and incomplete (AIS C and D) based on the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI).[21]

Definition of outcomes (cardiometabolic risk factors, CVD risk, and cardiometabolic syndrome)

All anthropometric data were measured in the supine position. Waist circumference (WC) was measured after bowel care, at the end of normal expiration, approximately between the lower margin of the last palpable rib and the top of the iliac crest. It is measured using a pliable tape measure expressed with a precision of 0.5 cm. Weight was measured using an electric wheelchair scale. The total weight of the participant with the wheelchair was subtracted from the wheelchair's weight to determine the participant's weight expressed in kilograms (kg). Both WC and weight were measured once per assessment. Systolic and diastolic blood pressure (SBP and DBP) in mm Hg were measured with the patient in a 30° upright position (30°) after 10 minutes of rest using an automated blood pressure measurement device. The average of the last two of the three attempts was recorded. Body mass index (BMI) was computed using the standard formula: weight in kilograms/(height in meters)^2]. All anthropometric measurements for this study were obtained by trained hospital staff.

Venous blood samples were collected after overnight fasting. Serum fasting total cholesterol,

BOX 1 Criteria for Cardiometabolic Syndrome and Framingham Risk Score for estimating the 10-year risk of first cardiovascular event

Cardiometabolic Syndrome[a]

1. Body mass index greater than or equal to 22 kg/m^2, or waist circumference more than or equal to 86.5 cm
2. Fasting triglycerides: Greater than or equal to 1.7 mmol/L
3. Reduced high-density lipoprotein ("good") cholesterol:
   - Male— Less than or equal to 1.03 mmol/L
   - Female — Less than 1.29 mmol/L
4. Elevated blood pressure: Less than or equal to 130 mm Hg or use of medication for hypertension
5. Fasting glucose: Less than or equal to 5.6 mmol/L or use of medication for hyperglycemia

*Should have three of more

Framingham Risk Score (10-year risk for first cardiovascular event)[b]

Parameter	β	Parameter	β
Female	[So (10)=0.95012]	Male	[So (10)=0.88936]
Log of age	2.32888	Log of age	3.06117
Log of total cholesterol	1.20904	Log of total cholesterol	1.12370
Log of HDL cholesterol	−0.70833	Log of HDL cholesterol	−0.93263
Log of SBP if not treated	2.76157	Log of SBP if not treated	1.93303
Log of SBP if treated	2.82263	Log of SBP if treated	1.99881
Smoking	0.52873	Smoking	0.65451
Diabetes	0.69154	Diabetes	0.57367

[a]Grundy SM, Brewer HB, Jr., Cleeman JI, et al. Definition of metabolic syndrome: Report of the National Heart, Lung, and Blood Institute/American Heart Association conference on scientific issues related to definition. Circulation. 2004;109 (3):433-438; with SCI specific cutoff on body mass index and waist circumference based on Gill S, Sumrell RM, Sima A, Cifu DX, Gorgey AS (2020) Waist circumference cutoff identifying risks of obesity, metabolic syndrome, and cardiovascular disease in men with spinal cord injury. PLoS ONE 15 (7): e0236752. https://doi.org/10.1371/journal.pone.0236752.
[b]Indicates 10-year baseline survival; from D'Agostino RB, Sr., Vasan RS, Pencina MJ, Wolf PA, Cobain M, Massaro JM, et al. General cardiovascular risk profile for use in primary care: The Framingham Heart Study. Circulation. 2008; 117 (6):743-753.

triglycerides, high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and fasting serum glucose concentrations were measured by the laboratory of the respective participating center and reported using SI units. The lipid ratio was determined from HDL-C and total cholesterol (HDL-C/total cholesterol).

To assess the overall CVD risk, we used the Framingham risk score (FRS) to assess the 10-year risk for the first cardiovascular event.[22] Low risk for first CVD event at 10 years are those <10%, moderate risk for those ≥10% to <20%, and high risk for those ≥20%. We also identified individuals with cardiometabolic syndrome (or cardiometabolic dysfunction) using the criteria provided by the SCI-specific clinical guideline.[2] The variables used in computing FRS and the criteria for classifying cardiometabolic syndrome are provided in Box 1. Overweight was defined as those with BMI ≥22 kg/m^2 and/or WC ≥86.5 cm.[2,23]

Definition of covariates

Demographic and clinical data were collected using the prespecified data collection form by the SwiSCI study. Smoking history was classified into smoker or non-smoker/less than once per month. Alcoholic beverage consumption was classified as never or occasional/regular drinker. Diet was classified into those having a special diet and those under a regular diet. The regular diet was in accordance with the dietary plans by the respective centers and was not standardized across participating hospitals. Physical activity was measured based on the frequency (number per week) and length of time (hours per cycle), according to intensity (light, moderate, and vigorous).[24] We followed the recommendations from a previous study to determine active and sedentary participants. Active individuals were defined as having 30 minutes of moderate or vigorous activity three times a week (or 90 minutes total of moderate to vigorous activity per week).[25,26] Injury characteristics and classification followed the standardized reporting by the International Spinal Cord Injury Core data set (ISCoS).[27] Functional independence was assessed using the Spinal Cord Independence Measure III (SCIM III).[28]

Statistical analysis

We summarized the baseline findings of our study population using counts (with percentages), medians (interquartile range [IQR]) because of the skewed distribution, and means (standard deviation [SD]) as appropriate. We used signed-rank test or chi-square

test to determine differences between demographic and clinical profiles between comparison groups (tetraplegia vs. paraplegia and complete vs. incomplete). We used the Shapiro-Wilk test to determine the normality of the distribution of the outcomes. We log-transformed each outcome before regression analysis to approximate normality. We used multivariable linear regression to determine whether the cardiometabolic risk profiles were different between the comparison groups. Models were iterated as follows: (1) crude model; (2) basic model adjusted for age and sex; (3) further adjustment for smoking history (dichotomous), alcohol drinking (dichotomous), diet (dichotomous), physical activity (dichotomous), and time since injury (continuous); and (4) further correcting for completeness of injury (dichotomous, as complete and incomplete) or level of injury (dichotomous, as tetraplegia and paraplegia).

To determine the longitudinal changes of cardiovascular risk factors across the period of inpatient rehabilitation, we used a paired *t*-test and linear mixed models of baseline and discharge data of continuous outcomes. We also used the Sign test of matched pairs as appropriate. In addition, we used paired McNemar's test for dichotomous outcomes. For the linear mixed-model analysis, we used a random-slope analysis to account for changes of every participant within and across groups over time. Tetraplegia (injury level) and complete injury (injury completeness) were both used as the reference categories in the comparison. We iterated the same correction in the regression model, with the addition of rehabilitation duration and the interaction (factorial) of exposure (injury characteristics) and rehabilitation duration in the adjustment.

All analyses were performed using STATA 15.1 for Windows. All computations were completed using two-tailed tests, and a p value of <.05 was considered statistically significant.

Sensitivity analyses

We analyzed the baseline characteristics of individuals excluded from the analysis and compared them with our analysis group to detect selection bias. Details of the sensitivity analyses (age- and sex-specific analysis, correction for medication side effects, and correction for surrogates of obesity) can be found in the **Appendix.**

Ethical considerations

All clinical and laboratory data were transmitted by each participating center to the central data processing unit of the Swiss Paraplegic Research. The SwiSCI study is compliant with the Swiss Human Research Act (810.30 Federal Act of September 30, 2011, on Research involving Human Beings) and Federal Regulations on Data Protection (235.1 Federal Act of June 19, 1992, on Data Protection). Different regional ethical committees approved the study protocol before enrolling participants [Ethics Committee northwest/central Switzerland (EKNZ): PB_2016-00183, Ethics Committee Vaud (CEVD): 032/13 (CEVS), Ethics Committee Zurich (KEKZH): 2013-0249]. Written informed consent was obtained from each participant prior to data collection. The database is managed and stored in the secured servers of the Swiss Paraplegic Research Center.

RESULTS

Description of the study population

We included 258 individuals with traumatic SCI, 110 with tetraplegia (40 complete and 70 incomplete), and 148 with paraplegia (82 complete and 66 incomplete) **(**Table 1 **and** Figure 2**)**. The median age was 50 years (IQR 32-60); 76.4% (n = 197) of the participants were male. The most common causes of traumatic injury were falls (88, 34.1%), sports injuries (76, 29.5%), and vehicular accidents (62, 24.0%). Upon enrollment, the median injury duration was 12 days (8–19), and the median length of inpatient first rehabilitation hospitalization was 5.5 months (IQR 3.2-7.1, min 0.5, max 11.8). The median duration of rehabilitation was 6.6 months (IQR 3.7-8.9) for individuals with tetraplegia and 5.1 months (IQR 3.0-6.0) for individuals with paraplegia. Individuals with complete injury had a longer rehabilitation duration at 6.3 months (IQR 5.3-5.1) than those with incomplete at 3.7 months (IQR 2.3-5.9). Our first participant was enrolled on May 1, 2013, and our last participant was discharged on November 27, 2020. Functional independence measure (SCIM III score) was significantly higher in individuals with paraplegia than tetraplegia. The score was also higher in individuals with incomplete compared to those with complete injuries. At baseline, the 10-year risk for first cardiovascular event of the population was 5.47% (1.85-13.42) and 39.8% had cardiometabolic syndrome **(**Table 1**).**

Individuals with tetraplegia were older than those with paraplegia (tetraplegia 54 years vs. paraplegia 46 years, $p = .013$), and individuals with incomplete were older than those with complete injury (incomplete 51.5 years vs. complete 47 years). There was a higher proportion of males with complete injury than with incomplete injury (complete 82.8% vs. incomplete 70.6%). Smoking history, alcoholic beverage consumption, diet, and physical activity were similar among comparison groups (tetraplegia vs. paraplegia and complete vs. incomplete). The use of statins, antihypertensives, and systemic steroids was similar between

TABLE 1 Baseline characteristics (at T1)[a]

	Complete cohort N = 258	Tetraplegia N = 110	Paraplegia N = 148	*p* value	Complete N = 122	Incomplete N = 136	*p* value
Social and Lifestyle factors							
Age, years, median (IQR)	50 (32-60)	54 (35-63)	46 (30.5-56.5)	**.013**	47 (29-58)	51.5 (37-63)	**.029**
Age group, n (%)							
• 18-30	57 (22.1)	20 (18.2)	37 (25.0)	.221	35 (28.7)	22 (16.2)	.141
• 31-45	57 (22.1)	20 (18.2)	37 (25.0)		24 (19.7)	33 (24.3)	
• 46-60	80 (31.0)	36 (32.7)	44 (29.7)		38 (31.2)	42 (30.9)	
• 61-75	51 (19.8)	27 (24.6)	24 (16.2)		20 (16.4)	31 (22.8)	
• 76+	13 (5.0)	7 (6.4)	6 (4.0)		5 (4.1)	8 (5.9)	
Cause of trauma, n (%)							
• Vehicular	62 (24.0)	31 (28.2)	31 (21.0)	**.021**	23 (27.7)	39 (22.3)	.697
• Violence	2 (0.8)	2 (1.8)	0 (−)		1 (1.2)	1 (0.6)	
• Sports	76 (29.5)	22 (20.0)	54 (36.5)		27 (32.5)	49 (28.0)	
• Falls	88 (34.1)	44 (40.0)	44 (29.7)		25 (30.1)	63 (36.0)	
• Pedestrian	2 (0.8)	2 (1.8)	0 (−)		1 (1.2)	1 (0.6)	
• Medical complication	25 (9.7)	8 (7.3)	17 (11.5)		5 (6.0)	20 (11.4)	
• Others	2 (0.8)	1 (0.9)	1 (0.7)		1 (1.2)	1 (0.6)	
• Unknown	1 (0.4)	0 (−)	1 (0.9)		0 (−)	1 (0.6)	
Male, n (%)	197 (76.4)	85 (77.3)	112 (75.7)	.765	101 (82.8)	96 (70.6)	**.021**
Educational attainment, n (%)							
• Compulsory education (0-9 years)	15 (5.8)	10 (9.1)	5 (3.4)		8 (6.6)	7 (5.2)	
• Vocational school (10–12 years)	31 (12.0)	12 (10.9)	19 (12.8)	.084	14 (11.5)	17 (12.5)	.871
• Secondary education (13–16 years)	57 (22.1)	29 (26.4)	28 (18.9)		29 (23.8)	28 (20.6)	
• University education (≥17 years)	155 (60.1)	59 (53.6)	96 (64.9)		71 (58.2)	84 (61.8)	
Length of education, years, median (IQR)	13 (12-17)	13 (11-16)	13 (12-17)	.170	13 (12-17)	13 (12-17)	.965
Smoking history, n (%)							
• Never or <1/mo	98 (46.2)	38 (41.8)	60 (49.6)	.258	48 (47.6)	49 (45.0)	.702
• Smoker	114 (53.8)	53 (58.2)	61 (50.4)		54 (52.4)	60 (55.0)	
Alcoholic beverage use, n (%)							
• Never	28 (13.2)	14 (15.0)	14 (11.7)	.468	10 (9.7)	18 (16.4)	.151
• Drinker	185 (86.8)	79 (85.0)	106 (88.3)		93 (90.3)	92 (83.6)	
Diet, n (%)							
• Special diet	19 (8.9)	11 (11.8)	8 (6.7)	.190	9 (8.8)	10 (9.0)	.962
• Regular diet	194 (91.1)	82 (88.2)	112 (93.3)		93 (91.2)	101 (91.0)	

(Continues)

TABLE 1 (Continued)

	Complete cohort N = 258	Tetraplegia N = 110	Paraplegia N = 148	*p* value	Complete N = 122	Incomplete N = 136	*p* value
Physical activity, n (%)							
• Active	142 (97.3)	66 (98.5)	76 (96.2)	.395	9 (8.8)	10 (9.0)	.297
• Sedentary	4 (2.7)	4 (3.6)	4 (2.7)		93 (91.2)	101 (91.0)	
Use of lipid-lowering drugs, n (%)	8 (3.1)	2 (2.7)	4 (3.2)	.669	2 (1.6)	6 (4.4)	.200
Use of antihypertensive, n (%)	37 (14.3)	15 (13.6)	22 (14.9)	.781	14 (11.5)	23 (16.9)	.214
Use of systemic steroid, n (%)	14 (5.4)	8 (7.3)	6 (4.0)	.259	6 (4.9)	8 (5.9)	.733
Use of opioids, n (%)	114 (44.2)	**39 (35.4)**	**75 (50.7)**	**.015**	52 (42.6)	62 (45.6)	.632
Injury characteristics							
Time since injury, days, median (IQR)[b]	12 (8-19)	12.5 (8–20)	12 (7-19)	.495	11 (8–17)	13 (7-22)	.398
Length of rehabilitation, months,[b] median (IQR)	5.5 (3.2-7.1)	6.6 (3.7-8.9)	5.1 (3.0-6.0)	**<.001**	6.3 (5.3-5.1)	3.7 (2.3-5.9)	**<.001**
Level of injury, n (%)		n.a.	n.a.	n.a.			
• Tetraplegia	110 (42.6)				40 (36.4)	70 (63.6)	**.002**
• Paraplegia	148 (57.4)				82 (55.4)	66 (44.6)	
ISNCSCI Classification[d], n (%)					n.a.	n.a.	n.a.
• A	83 (32.2)	23 (23.9)	60 (40.5)	**.001**			
• B	39 (15.1)	17 (15.4)	22 (14.9)				
• C	38 (14.7)	19 (17.3)	19 (12.8)				
• D	98 (38.0)	51 (46.7)	47 (31.8)				
SCIM III score at baseline, median (IQR)[d]	29 (18-50)	21 (10-50)	32 (24-50)	**<.001**	24 (15-32)	40 (22-69)	**<.001**
Cardiometabolic risk factors at baseline							
Body mass index (kg/m^2)[c]	23.7 (21.1-26.5)	23.2 (20.8-26.2)	23.9 (20.9-27.01)	.231	23.9 (21.4-26.5)	23.0 (20.5-25.9)	.269
Waist circumference (cm)[c]	87.5 (79-95.5)	86 (78.5-94.5)	88 (79.5-97)	.588	89 (77-97)	86.5 (80-94.9)	.830
Weight (kg)[c]	71.9 (64.2-81)	70.1 (63.8-80)	73.8 (64.4-83)	.131	72.9 (66.6-82)	69.9 (62.4-79.9)	.106
Systolic blood pressure (mm Hg)[c]	115 (106-125)	112 (104-125)	116 (107-126)	.239	114 (105-122)	118 (107.5-130)	**.030**
Diastolic blood pressure (mm Hg)[c]	69 (60-77)	67 (60-79)	70 (62-77)	.212	67.5 (59-74)	70 (63–80)	**.006**
Total cholesterol (mmol/L)[c]	4.3 (3.84-5.1)	4.1 (3.7-4.8)	4.4 (5.3-3.9)	.105	4.3 (3.88-5.1)	4.36 (3.82-5.1)	.821
Triglycerides (mmol/L)[c]	1.43 (1.11-2.01)	1.26 (0.9-1.67)	1.55 (2.15-1.28)	**<.001**	1.38 (1.11-1.9)	1.5 (1.1-2.05)	.743
LDL cholesterol (mmol/L)[c]	2.80 (2.33-3.30)	2.74 (2.3-3.3)	2.86 (2.4-3.3)	.358	2.8 (2.4-3.3)	2.8 (2.3-3.3)	.413
HDL cholesterol (mmol/L)[c]	0.99 (0.80-1.20)	0.97 (0.81-1.20)	1.0 (0.8-1.2)	.741	0.9 (0.8-1.1)	1.0 (0.83-1.25)	**.002**
HDL/Total cholesterol ratio[c]	0.21 (0.18-0.26)	0.22 (0.18-0.29)	0.21 (0.18-0.26)	.717	0.19 (0.17-0.23)	0.22 (0.18-0.30)	**.005**
Fasting serum glucose (mmol/L)[c]	5.0 (4.6-5.5)	5.1 (4.7-5.85)	5.0 (4.6-5.4)	**.048**	5.1 (4.7-5.6)	5.0 (4.6-5.5)	.499
Overall risk at baseline							

(Continues)

TABLE 1 (Continued)

	Complete cohort N = 258	Tetraplegia N = 110	Paraplegia N = 148	*p* value	Complete N = 122	Incomplete N = 136	*p* value
10 year overall cardiovascular risk (Framingham risk score), median (IQR)[e]	5.47 (1.85-13.42)	5.9 (2.9-15.24)	5.9 (1.6-14.1)	.345	4.3 (1.4-11.5)	6.9 (2.9-16.7)	.055
mean (SD)	8.75 (8.91)	8.94 (8.66)	8.66 (9.08)		8.06 (9.07)	9.38 (8.77)	
Cardiometabolic syndrome (%)[f]	71 (52.59)	22 (50.00)	49 (53.85)	.675	35 (53.03)	36 (52.17)	.921

Note: BOLD for *p* values < .05.
Abbreviations: HDL, high density lipoprotein; LDL, low density lipoprotein.
[a]Physical activity was coded as active and sedentary based on the recommendation (30 min of moderate or vigorous activity 3 times per week, or 90 min cumulative for cardiometabolic health). Statin use was based on questionnaire collected data. For antihypertensive use, we used the past diagnosis of hypertension as surrogate. Time since injury was computed from the date of injury and admission date. We corrected the level of injury for completeness, and the completeness of injury for the level.
[b]Wilcoxon signed-rank test for statistical significance.
[c]Expressed as median and IQR. Log-transformation was done, then Student's *t*-test for statistical significance.
[d]ISNCSCI, International Standards for Neurological Classification of Spinal Cord Injury; SCIM III, Spinal Cord Independence Measure version III.
[e]Framingham risk score estimates the 10-year risk for the first cardiovascular event in individuals with no prior history of cardiovascular disease. (D'Agostino Circulation. 2008;117(6):743-753.).
[f]Cardiometabolic syndrome criteria as defined in Box 1.

comparison groups. Opioid use was higher in individuals with paraplegia and individuals with incomplete injury as compared to individuals with tetraplegia and complete injury, respectively. We observed no statistically significant differences in FRS and cardiometabolic syndrome prevalence across injury levels and completeness **(**Table 1**).**

Between-group differences at baseline (cross-sectional analysis)

Individuals with tetraplegia had a lower fasting serum triglyceride concentration (tetraplegia 1.26 mmol/L, 0.96-1.67 vs. paraplegia 1.55 mmol/L, 2.15-1.28; $p < .001$) and higher fasting serum glucose concentration (tetraplegia 5.1 mmol/L, 4.70-5.85 vs. paraplegia 5.0 mmol/L, 4.6-5.4; $p = .048$) than those with paraplegia. Individuals with complete injury had lower BP (SBP: complete 114 mm Hg, 105-122 vs. incomplete 118 mm Hg, 107.5-130; $p = .030$; and DBP: complete 67.5 mm Hg, 59-74 vs. incomplete 70 mm Hg, 63-80; $p = .006$) compared to individuals with incomplete injury. Individuals with complete injury had lower fasting serum HDL-C (complete 0.9 mmol/L, 0.8-1.1 vs. incomplete 1.0 mmol/L, 0.83-1.25; $p = .002$) and lower lipid ratio (complete 0.19, 0.17-0.23 vs. incomplete 0.22, 0.18-0.30) compared to incomplete injury. All other risk factors were comparable between the groups (Table 2).

In our basic model (age- and sex-adjusted) for injury level, individuals with paraplegia had higher BMI, higher weight, and higher triglyceride levels than individuals with tetraplegia. Using fully adjusted models (including correction for injury completeness), we observed higher weight (β 0.06, 95% confidence interval [CI] 0.005 to 0.11), higher SBP (β 0.05, 95% CI 0.008 to 0.09), higher DBP (β 0.05, 95% CI 0.004 to 0.10), and higher triglyceride levels (β 0.27, 95% CI 0.13 to 0.42) **(**Table 2**)** in individuals with paraplegia than individuals with tetraplegia.

In our basic model (age- and sex-adjusted) for injury completeness, individuals with incomplete injury had higher DBP, higher HDL-C, and a lower lipid ratio compared to those with complete injury. In fully adjusted models (including correction for injury level), we observed a higher SBP (β 0.05, 95% CI 0.005 to 0.09), higher DBP (β 0.06, 95% CI 0.01 to 0.11), higher HDL-C level (β 0.16, 19% CI 0.06 to 0.26), and a lower lipid ratio (β 0.18, 95% CI 0.07 to 0.28) in individuals with incomplete than in individuals with complete injury **(**Table 2**).**

Longitudinal changes in cardiometabolic risk factors

When exploring longitudinal changes in the overall population using paired *t*-test, the total cholesterol, HDL-C,

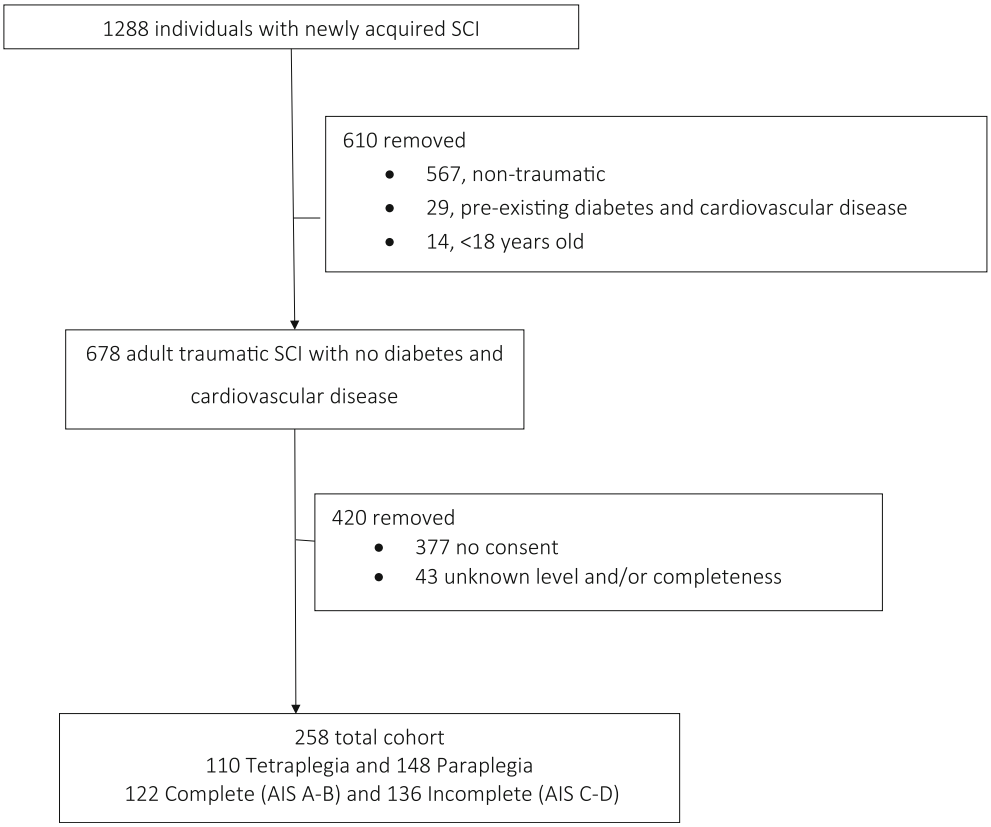

FIGURE 2 Flowchart of study participants. Abbreviation: SCI, spinal cord injury.

and lipid ratio increased from baseline to discharge **(**-Table 3**).** The results were also consistent in fully corrected analyses using linear mixed models (which accounts for within and between-group variance over time) with increasing total cholesterol (β 0.07, 95% CI 0.04 to 0.10), HDL-C (β 0.21, 95% CI 0.17 to 0.25), and HDL-C/total cholesterol ratio (β 0.18, 95% CI 0.07 to 0.28) when comparing baseline and discharge **(**Table 3**).**

In fully corrected linear-mixed models, we did not observe longitudinal changes in cardiometabolic risk factors when comparing among injury level and injury completeness **(**Table 4**),** except for one parameter. We observed a higher BMI increase in individuals with paraplegia compared to those with tetraplegia in the fully corrected model (β 0.15, 95% CI 0.03 to 0.26), comparing the changes within and between groups across time (baseline and discharge).

Longitudinal changes in cardiometabolic syndrome and FRS

Using a non-parametric test, we observed a decrease in FRS in the overall population **(**Table 3**).** We also observed a decrease in FRS in individuals with paraplegia and incomplete injury, whereas no significant changes were observed among individuals with tetraplegia and complete injury (Table S1). Figures 3 and S1(A),(B) depict individual trajectories in FRS change. At baseline, 34.0% (55/162) were classified as moderate to high risk, which decreased to 29.2% (49/168) at follow-up ($p < .001$) **(**Figure 3**).**

The overall proportion of cardiometabolic syndrome also decreased during rehabilitation from 43.1% (47/109) to 39.4% (43/109) but did not reach statistical significance. We observed no changes in cardiometabolic syndrome prevalence when stratifying our analyses based on injury characteristics (Table S1).

Sensitivity analyses

We excluded 377 individuals with no consent and 43 with unknown injury classification (level and/or completeness) **(**Figure 2**).** The excluded participants (n = 420) were older (53.5 y, IQR 35-69 vs. 50 y, IQR 32-60), had longer injury duration (16 days, IQR 9-35 vs. 12 days, IQR 8-19), had lower independent functioning score (22.5, IQR 11-44 vs. 29, IQR 18-50) and had a lower proportion of alcohol consumers (71.4% vs. 86.8%) compared to individuals included in the analysis (Table S2). Details of sex- and age-specific analyses, adjustments for medication side-effects, and surrogates of obesity can be found in the Appendix (-Tables S3–S7). The results of the sensitivity analyses were aligned with the main results.

TABLE 2 Baseline cardiometabolic profile of participants (cross-sectional analysis)

	Injury level comparison (tetraplegia vs. paraplegia)				Injury completeness comparison (motor complete vs. incomplete)			
	β (95% CI) Basic model (TP Ref)[a]	*p*	β (95% CI) Adjusted model (TP Ref)[b]	*p*	β (95% CI) Basic model (COM Ref)[a]	*p*	β (95% CI) Adjusted model (COM Ref)[b]	*p*
Body mass index	**0.04* [0.0004, 0.08]**	**.048**	0.04 [−0.01, 0.08]	.132	−0.04 [−0.08, 0.005]	.083	−0.03 [−0.08, 0.02]	.249
Waist circumference	0.03 [−0.009, 0.08]	.126	0.04 [−0.01, 0.09]	.153	−0.01 [−0.05, 0.03]	.580	−0.001 [−0.05, 0.05]	.961
Weight	**0.05* [0.007, 0.09]**	**.023**	**0.06* [0.005, 0.11]**	**.033**	−0.03 [−0.07, 0.02]	.210	−0.02 [−0.07, 0.03]	.486
Systolic blood pressure	0.03 [−0.008, 0.06]	.126	**0.05* [0.008, 0.09]**	**.019**	0.03 [−0.001, 0.07]	.059	**0.05* [0.005, 0.09]**	**.028**
Diastolic blood pressure	0.03 [−0.01, 0.07]	.151	**0.05* [0.004, 0.10]**	**.035**	**0.06* [0.02, 0.10]**	**.008**	**0.06* [0.01, 0.11]**	**.015**
Total cholesterol	0.06 [−0.008, 0.12]	.091	0.05 [−0.03, 0.12]	.231	−0.005 [−0.07, 0.06]	.888	−0.004 [−0.08, 0.07]	.925
Triglycerides	**0.26* [0.13, 0.38]**	**<.001**	**0.27* [0.13, 0.42]**	**<.001**	−0.02 [−0.15, 0.11]	.802	0.01 [−0.14, 0.16]	.872
LDL cholesterol	0.04 [−0.05, 0.14]	.363	0.04 [−0.06, 0.15]	.432	−0.04 [−0.13, 0.05]	.416	−0.03 [−0.14, 0.07]	.543
HDL cholesterol	−0.008 [−0.10, 0.08]	.858	−0.008 [−0.11, 0.09]	.870	**0.11* [0.03, 0.19]**	**.011**	**0.16* [0.06, 0.26]**	**.002**
HDL-C/Total cholesterol ratio	−0.07 [−0.17, 0.03]	.186	−0.06 [−0.16, 0.06]	.324	**0.12* [0.02, 0.21]**	**.001**	**0.18* [0.07, 0.28]**	**.001**
Fasting serum glucose	−0.05 [−0.11, 0.008]	.090	−0.04 [−0.11, 0.03]	.220	−0.03 [−0.09, 0.03]	.295	−0.02 [−0.09, 0.05]	.591

Note: **BOLD** for *p* values <.05.

Abbreviations: HDL, high density lipoprotein; LDL, low density lipoprotein.

[a]Basic model adjusted for age and sex.

[b]Fully adjusted for age, sex, medications, smoking status, alcohol intake, time since injury, medications (statins for lipid profile and antihypertensives for blood pressure), and injury characteristics. Crude values were log-transformed before regression analysis.

TABLE 3 Cardiovascular risk comparing baseline (T1) and follow-up (T4) (Longitudinal analysis)

	Baseline	Discharge	*p* value[a]	β (95% CI) Fully corrected[b] (Baseline Ref)	*p* value
Cardiovascular risk factors					
Body mass index, kg/m^2, median (IQR)	23.7 (20.9-26.5)	23.5 (21.1-26.5)	.762	−0.007 [−0.02, 0.004]	.221
Waist circumference, cm, median (IQR)	87.5 (79-95.5)	87 (78-96)	.816	−0.003 [−0.02, 0.01]	.749
Weight, kg, median (IQR)	71.95 (64.2-81)	73.95 (65.6-82.2)	.488	−0.004 [−0.02, 0.007]	.469
Systolic blood pressure, mmHg, median (IQR)	115 (106-125)	119 (110-130)	.084	0.01 [−0.009, 0.03]	.297
Diastolic blood pressure, mmHg, median (IQR)	69 (60-77)	70 (63.5-80)	.055	0.02 [−0.008, 0.04]	.183
Total cholesterol, mmol/L, median (IQR)	4.3 (3.84-5.1)	4.7 (4.1-5.36)	**<.001***	**0.07* [0.04, 0.10]**	**<.001**
Triglycerides, mmol/L, median (IQR)	1.43 (1.11-2.01)	1.36 (0.84-1.96)	.794	−0.04 [−0.12, 0.03]	.252
HDL cholesterol, mmol/L, median (IQR)	0.99 (0.8-1.2)	1.17 (0.99-1.4)	**<.001***	**0.21* [0.17, 0.25]**	**<.001**
LDL cholesterol, mmol/L, median (IQR)	2.8 (2.33-3.3)	2.8 (2.28-3.4)	.517	−0.03 [−0.14, 0.07]	.543
HDL-C/Total cholesterol ratio	0.21 (0.18-0.26)	0.25 (0.20-0.32)	**<.001***	**0.18* [0.07, 0.28]**	**.001**
Fasting serum glucose, mmol/L, median (IQR)	5.0 (4.6-5.5)	5.0 (4.5-5.5)	.164	−0.02 [−0.05, 0.01]	.224
Overall risk (paired samples)					
10-year overall cardiovascular risk (Framingham risk score), median (IQR)[c]	5.8 (2.1-14.3)	6.4 (1.9-13.2)	**.011***	n.a.	n.a.
mean (SD)[c]	8.99 (9.05)	8.11 (7.75)			
Cardiometabolic syndrome, n (%)[d]	47/109 (43.12)	43/109 (39.45)	.458	n.a.	n.a.

Abbreviations: HDL, high density lipoprotein; LDL, low density lipoprotein.
[a]Values were log-transformed prior to statistical testing. Paired *t*-test with *p* value <.05 considered statistically significant.
[b]Linear mixed modeling using individual as cluster and time as predictor variable (baseline values as reference) to determine the change from baseline to discharge. *p* values <.05 are considered statistically significant. Fully adjusted model included age, sex, smoking history, alcohol use, time since injury, medications (statins and antihypertensives), length of rehabilitation, and injury characteristics. Crude values were log-transformed before regression analysis.
[c]Framingham risk score estimates the 10-year risk for the first cardiovascular event in individuals with no prior history of cardiovascular disease. (D'Agostino Circulation. 2008;117 (6):743-753.) **BOLD** for *p* values <.05 using signed-rank test for matched pairs.
[d]Cardiometabolic syndrome criteria as defined in Box 1, only those with repeated measures. *p*-value computed using McNemar's test for repeated measures.

DISCUSSION

We observed modest changes in lipid profiles among individuals with traumatic SCI and without a history of CVD or diabetes during the first inpatient rehabilitation. We did not observe differences in the risk factor changes according to injury level and completeness, except for the higher increase in BMI in paraplegia as compared to tetraplegia. Our results did not change materially after age- and sex-stratified analyses. The FRS decreased over the rehabilitation period in the overall population and among individuals with paraplegia and incomplete injury. Nevertheless, one third of study participants remained classified as moderate to high risk of CVD (29.2% had FRS ≥10%), 64.1% were overweight (51.5% had BMI >22 kg/m^2, and 36.1% had WC >86.5 cm), and 39.4% had cardiometabolic syndrome upon discharge. These findings are based on a study population recruited within health care facilities, which precludes the generalization of our findings to individuals with subacute SCI living in the community. A summary of our findings can be found in Figure 1.

Longitudinal assessments of cardiometabolic risk factor changes in the SCI population are scarce and based predominantly on data from a multicenter study from The Netherlands.[15,17,29-31] In line with our results, this multicenter longitudinal study reported increased HDL-C and lipid ratio, or an improvement of lipid profile, during the first rehabilitation.[15] In addition, the authors reported that individuals with incomplete injury, as compared to complete, had a higher HDL-C and lipid ratio.[15] Over time, they saw unchanged SBP, but DBP increased yet remained within normal limits.[16] All these findings were based on changes in CVD risk factors among 180 participants with traumatic and non-traumatic SCI when comparing baseline (3 months after injury) and discharge (10 months after injury) from rehabilitation.[15-17] The previous studies used an analytical framework in estimating the difference across time (linear mixed model) similar to ours, although we used two time points. We think that the disparities in the results on the effect of injury characteristics could be due to different participant inclusion (i.e., the prior assessment included both traumatic and non-traumatic injury of lower mean age and included those with baseline cardiovascular diseases and diabetes).

During acute injury, individuals with SCI are in a high catabolic state due to stress, inflammation, and acute denervation.[32] They experience drastic loss in lean mass and total body water.[33] Consequently, it also

TABLE 4 Incremental changes in cardiometabolic risk factors over time (longitudinal analysis)

	Injury level comparison (tetraplegia vs. paraplegia)				Injury completeness comparison (motor complete vs. incomplete)			
	β (95% CI) Basic model (TP Ref)[a]	*p*	β (95% CI) Adjusted model (TP Ref)[b]	*p*	β (95% CI) Basic model (COM Ref)[a]	*p*	β (95% CI) Adjusted model (COM Ref)[b]	*p*
Δ Body mass index	0.09 [−0.002, 0.18]	.054	**0.15* [0.03, 0.26]**	**.013**	0.01 [−0.10, 0.12]	.853	0.01 [−0.13, 0.16]	.852
Δ Waist circumference	0.06 [−0.02, 0.15]	.142	0.10 [−0.003, 0.21]	.057	0.05 [−0.04, 0.15]	.281	0.05 [−0.07, 0.17]	.425
Δ Weight	0.07 [−0.03, 0.17]	.187	0.11 [−0.02, 0.24]	.088	0.01 [−0.10, 0.13]	.816	0.04 [−0.11, 0.19]	.624
Δ Systolic blood pressure	−0.002 [−0.07, 0.07]	.952	0.006 [−0.08, 0.09]	.895	0.02 [−0.06, 0.10]	.587	0.03 [−0.07, 0.13]	.516
Δ Diastolic blood pressure	−0.01 [−0.09, 0.07]	.773	0.0001 [−0.11, 0.11]	.998	0.08 [−0.02, 0.17]	.103	0.12 [−0.005, 0.24]	.061
Δ Total cholesterol	0.03 [−0.10, 0.16]	.643	0.07 [−0.09, 0.23]	.372	−0.01 [−0.16, 0.14]	.867	0.03 [−0.15, 0.21]	.739
Δ Triglycerides	0.10 [−0.19, 0.39]	.501	0.13 [−0.22, 0.49]	.468	−0.031 [−0.38, 0.31]	.858	0.05 [−0.36, 0.45]	.824
Δ LDL cholesterol	0.01 [−0.17, 0.20]	.894	0.07 [−0.15, 0.28]	.552	−0.10 [−0.32, 0.11]	.343	−0.09 [−0.34, 0.16]	.466
Δ HDL cholesterol	−0.002 [−0.20, 0.18]	.980	−0.002 [−0.22, 0.22]	.985	0.13 [−0.08, 0.34]	.219	0.23 [−0.03, 0.48]	.084
Δ HDL-C/ Total cholesterol ratio	0.10 [−0.30, 0.50]	.623	−0.06 [−0.31, 0.19]	.645	0.16 [−0.08, 0.40]	.192	0.23 [−0.07, 0.53]	.129
Δ Fasting serum glucose	−0.005 [−0.12, 0.11]	.930	0.08 [−0.07, 0.22]	.291	−0.08 [−0.22, 0.06]	.249	−0.06 [−0.23, 0.11]	.481

Abbreviations: HDL, high density lipoprotein; LDL, low density lipoprotein.

[a]Basic model adjusted for age and sex.

[b]Fully adjusted model included age, sex, smoking history, alcohol use, time since injury, medications (statins and antihypertensives), length of rehabilitation, and injury characteristics. Crude values were log-transformed before regression analysis.

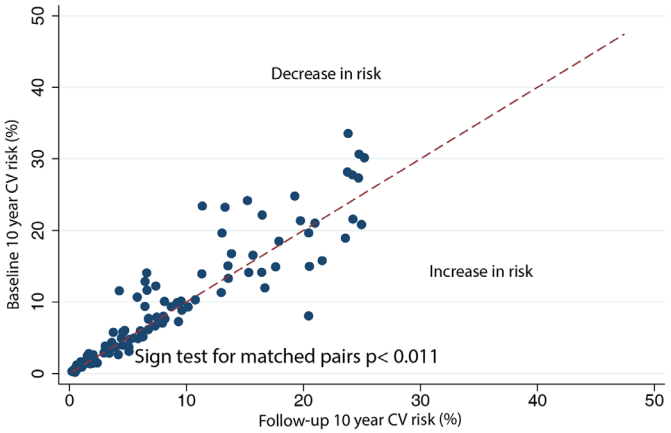

FIGURE 3 Framingham risk score at baseline and follow-up (10-year risk for first cardiovascular [CV] event). This graph shows the trajectory of each individual (dot) by plotting the baseline (x-axis) and follow-up (y-axis) values. Individuals (dots) on the line mean there is no change across time. Individuals above the line represent an increased 10-year risk (Framingham score), whereas those below the line represent a decreased 10-year risk (Framingham score). *p* value is measured through Sign test for matched pairs.

accords higher metabolic rate as a physiologic response. The subacute phase is a critical period of transition that occurs after physiologic and injury stabilization. In this phase, there is a shift from a catabolic state (muscle and water loss) to anabolic processes (muscle and fat gain). It is also in this phase when basal metabolic rate begins to decline, albeit with an unchanged diet and lifestyle. Thus the body starts gaining muscle and fat mass, depending on their energy balance. The adiposity pattern in the early phase of the injury could provide a link on the early lipid changes in this group.[32,33] The improvement in lipid profile is linked to lower adiposity and higher muscle mass as a result of the rehabilitation regimen.[13,32,33] Body composition in SCI is then considered to have a mediating effect on the cardiometabolic profile[13,32,33]; however, it is worth mentioning that this complex relationship of fat and lean mass changes across time may not be reflected in the BMI.[17,33,34] Thus it may be challenging to interpret our changes in BMI in the context of cardiometabolic risk. The increase in BMI in tetraplegia, albeit lower, may be more toward fat accumulation rather than lean mass,[35] perhaps due to an unchanged diet and lifestyle aggravated by physical activity limitations. This is compatible with a review paper showing differences in fat composition between tetraplegia and paraplegia, although mainly based on chronic injury.[9] This is also compatible with another analysis done on a Dutch cohort showing differences in cardiometabolic profile (i.e., lipid profile and blood pressure) according to adiposity surrogate.[17]

Finally, the mean FRS in our study was 8.99% at baseline and 8.11% at follow-up, suggesting that during the rehabilitation period, the majority of our study population remained at low risk for developing first CVD in the next 10 years (mean FRS <10%). The decreasing CVD risk scores (FRS) across time may indicate that the rehabilitation period, aside from promoting cardiorespiratory fitness, also contributes to the improvement of cardiometabolic risk profile. This is compatible with a previous study in a rehabilitation center that showed that cardiorespiratory fitness had been associated with a lower risk of diabetes and hypertension.[36] Although some studies devalue the FRS as the most widely used CVD risk stratification tool in this group, its use is still deemed important in delineating the high from low CVD risk in the SCI population.[37-39] A recent study reported acceptable accuracy of the FRS to identify individuals with increased risk of future CVD events, whereas adding the characteristics of the SCI (injury level and completeness) and lifestyle factors (such as engagement in sports before injury) did not improve the level of discrimination.[37] Nevertheless, further optimization of traditional cardiovascular risk stratification tools is needed to improve the accuracy.

Strengths and limitations

This is one of the few studies evaluating the longitudinal changes in cardiometabolic risk factors during the first inpatient rehabilitation hospitalization in patients with SCI. We employed a longitudinal analysis framework, which is more robust as compared to methods used in previous studies. In particular, most of the previous evidence was based on crude analysis that did not consider individual differences and did not adjust for known confounding factors. Our analysis accounted for individual and group variations in CVD risk factors, included the interaction of the exposure with observation points, and adjusted for potential confounding factors. Second, we have selected a more homogenous study population (without history of CVD and diabetes) that could help us detect the influence of injury characteristics on cardiometabolic risk factors. Finally, we obtained our data from all four specialized SCI rehabilitation centers across Switzerland, making our data representative of the SCI population in the country. The majority of the data on cardiometabolic health come from North America, comprising a younger study population, army veterans, and study participants who may be prone to follow lifestyle choices different from those of Europeans. We believe that our findings contribute to filling in the literature gap and provide findings that are generalizable to Europeans.

Our study has some limitations that should be considered when interpreting the findings. First, we analyzed only traditional cardiometabolic risk markers, whereas information on inflammatory biomarkers (e.g., high sensitivity C-reactive protein) or body composition were not routinely collected within the SwiSCI

cohort. In addition, our findings on fasting glucose should be interpreted with caution, considering that information on fasting insulin and glycated hemoglobin was not available in our cohort. Second, our laboratory data were based on hospital records, and there was no standardization of assays within the consortium (e.g., there is no central laboratory that processed all the blood specimens). This may result in variability of results among different centers. Third, females, the elderly, and individuals with lower functional independence were less likely to participate in the study.[40] This group may have been preoccupied with more physical challenges and adaptation difficulties, which precluded them from participation in the study.[41] Older individuals and individuals with lower functional independence may have a higher cardiometabolic risk profile that we failed to capture in our study population. Fourth, longitudinal changes in FRS and cardiometabolic syndrome were assessed using McNemar's test and signed-rank tests, and did not adjust for other factors. Finally, although the number of missing paired samples was less frequent for routinely obtained clinical data (such as weight, BP, and BMI), the number of available paired samples was lowest for LDL-C (127, 49.2%), HDL-C, and lipid ratio (144, 55.8%) (Table S4).

Clinical implications and future outlook

During the first inpatient rehabilitation hospitalization, we observed a modest improvement in cardiometabolic risk profile (i.e., lipid profile and FRS) and no association between injury level/completeness and cardiometabolic risk factors. For clinicians, this could mean that the dietary and activity regimens in a hospital setting are compatible with promoting cardiometabolic health. This could be indirect evidence showing that lifestyle factors (e.g., physical limitations in participation in physical activity as a consequence of injury level) rather than the neurologic injury/impairment may be crucial in developing cardiometabolic complications. Thus future studies should focus on the changes in cardiometabolic risks profile upon discharge and reintegration into the community. The community life (compared to the hospital setting) is an uncontrolled and unmonitored environment for which diet, physical activity, and other lifestyle factors can be investigated.

Furthermore, in individuals with chronic SCI, the level of injury was suggested as a potential non-modifiable cardiovascular risk factor, implying higher risks in individuals with tetraplegia. However, similar to our findings, a recent study reported that adding characteristics of the SCI (injury level and completeness) did not improve the performance of FRS in SCI; therefore, this merits exploration in future studies with longer follow-up.[37]

Finally, future research should also focus on validating or developing other body indices that better reflect adiposity in this group.[23,34,42] In contrast with the general population, BMI cannot be used to classify individuals with SCI as obese/overweight with certainty.[9] The current clinical guidelines adopted 22 kg/m^2 for overweight (from 25 kg/m^2 in ABI), and 25 kg/m^2 for obesity (from 30 kg/m^2 in ABI).[43,44] Another study has validated an SCI-specific cutoff for waist circumference, with ≥86.5 cm classified as high risk.[23] Yet, the studies to explore the accuracy of adjusted cutoff in predicting future cardiovascular events are missing, and this merits further investigation. This is crucial in screening those at risk more accurately.[45]

CONCLUSION

We observed a modest improvement in lipid profile during the first inpatient rehabilitation that was independent of injury characteristics. Despite this, approximately one third of individuals with SCI remained at moderate to high risk of developing the first CVD in 10 years. More than two thirds were classified as overweight/obese, and more than 40% had cardiometabolic syndrome. Our findings suggest that targeted preventive strategies should be initiated as early as during first inpatient rehabilitation. More studies should be done on subacute injury or after rehabilitation discharge to determine the optimal time for cardiovascular prevention and to explore the effect of modifiable risk factors such as diet and exercise. Furthermore, there is a need to explore novel CVD biomarkers to detect early changes in cardiometabolic risk profile and engage large collaborative population-based cohorts to correlate these findings with incident cardiovascular diseases, diabetes, and obesity in subacute and chronic phases of the injury.

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DISCLOSURES

None.

ETHICS

SwiSCI study is compliant with the Swiss Human Research Act (810.30 Federal Act of September 30, 2011, on Research involving Human Beings) and Federal Regulations on Data Protection (235.1 Federal Act of June 19, 1992, on Data Protection). Different regional ethical committees cleared the study protocol before enrolling participants [Ethics Committee northwest/central Switzerland (EKNZ): PB-2016-00183, Ethics Committee Vaud (CEVD): 032/13 (CEVS), Ethics Committee Zurich (KEKZH): 2013-0249].

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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CME Question

Which is a finding from this longitudinal study profiling cardiometabolic risk during spinal cord injury (SCI) rehabilitation in a Swiss SCI Cohort?

A. Increase in body mass index in tetraplegia more than paraplegia
B. Decrease in Framingham Risk Score in the overall population
C. Increase in the overall proportion of cardiometabolic syndrome
D. Decrease in high density lipoprotein cholesterol and lipid ratio

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