Physical exercise improves arterial stiffness after spinal cord injury

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Objective/background: Aortic pulse wave velocity (PWV), the gold-standard assessment of central arterial stiffness, has prognostic value for cardiovascular disease risk in able-bodied individuals. The aim of this study was to compare aortic PWV in athletes and non-athletes with spinal cord injury (SCI).

Design: Cross-sectional comparison.

Methods: Aortic PWV was assessed in 20 individuals with motor-complete, chronic SCI (C2–T5; 18 ± 8 years post-injury) using applanation tonometry at the carotid and femoral arterial sites. Ten elite hand-cyclists were matched for sex to 10 non-athletes; age and time since injury were comparable between the groups. Heart rate and discrete brachial blood pressure measurements were collected throughout testing.

Outcome measures: Aortic PWV, blood pressure, heart rate.

Results: Aortic PWV was significantly lower in athletes vs. non-athletes (6.9 ± 1.0 vs. 8.7 ± 2.5 m/second, $P = 0.044$). There were no significant between-group differences in resting supine mean arterial blood pressure (91 ± 19 vs. 81 ± 10 mmHg) and heart rate (60 ± 10 vs. 58 ± 6 b.p.m.).

Conclusion: Athletes with SCI exhibited improved central arterial stiffness compared to non-athletes, which is in agreement with the previous able-bodied literature. This finding implies that chronic exercise training may improve arterial health and potentially lower cardiovascular disease risk in the SCI population.

Keywords: Cardiovascular diseases, Exercise, Pulse wave analysis, Spinal cord injuries, Vascular stiffness

Introduction

Individuals with spinal cord injury (SCI) are forced to extensive immobility due to paralysis and can experience a myriad of autonomic dysfunctions.¹ These two adverse alterations may predispose individuals with SCI to amplified risk factors for cardiovascular disease (CVD) relative to able-bodied individuals. In fact, CVD is a leading cause of mortality in the SCI population, with the incidence of CVD occurring at earlier ages compared to able-bodied individuals.²

Increased central arterial stiffness, as a non-traditional risk factor, has been shown to be a major contributor to CVD risk in able-bodied individuals.³ The gold-standard assessment of central arterial

stiffness is considered to be aortic pulse wave velocity (PWV),⁴ which has prognostic value of cardiovascular morbidity and all-cause mortality in the able-bodied population.³

There is a limited number of investigations on aortic PWV in individuals with SCI.^{5,6} To date, two investigations have demonstrated increased aortic PWV in SCI compared to able-bodied individuals, even when matched for age, sex, weight, height,⁵ and physical activity levels.⁶ The importance of physical exercise in the amelioration of arterial stiffness has been clearly demonstrated in able-bodied individuals.⁷ However, in the SCI population, the effect of high level of physical exercise training on aortic PWV has not been studied. This prompted us to test the hypothesis that high levels of physical exercise training improve central arterial stiffness in the SCI population.

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Methods

Participants

Twenty individuals with motor-complete traumatic SCI (C2–T5, 2–29 years post-injury) participated in this study. Ten of these individuals with SCI were elite hand-cyclists and sex matched to ten non-athletes, sedentary individuals with SCI (Table 1). Neurological level of lesion and American Spinal Injury Association Impairment Scale (AIS) classification was determined using the International Standards for Neurological Classification of SCI.⁸ Athletes were recruited and assessed at the Para-cycling World Championship in Baie-Comeau, Quebec, while non-athletes were

recruited from the Spinal Cord Injury Outpatient Program at Vancouver General Hospital.

All individuals with SCI were instructed to abstain from caffeine for 12 hours before aortic PWV testing. Furthermore, prior to testing individuals were asked to empty their bladder to minimize the influence of reflexive sympathetic activation on peripheral vascular tone. None of the individuals reported a history of smoking or CVD, such as coronary artery disease, pulmonary disease, diabetes mellitus, or metabolic syndrome. Each individual's current medication (Table 2) and amount of weekly physical activity (in hours, Table 1) were recorded. This study was approved by the local

Table 1 Subject characteristics and outcome parameters of athletes and non-athletes

	Lesion level	AIS	Lesion duration (years)	Height (m)	Weight (kg)	Sex	Age (years)	SBP/DBP (mmHg)	MAP (mmHg)	HR (b.p.m.)	aPWV (m/second)	Physical exercise (hours/week)
Athletes												
SCI_01	C2	A	29	1.73	62	M	48	101/57	72	50	6.3	12
SCI_02	C4	B	23	1.76	70	M	42	104/62	76	53	7.8	18
SCI_03	C4	B	24	1.69	55	F	42	95/52	66	53	5.9	12
SCI_04	C5	A	17	1.81	62	M	37	112/66	82	49	6.0	14
SCI_05	C5	B	18	1.78	80	M	38	116/63	81	61	6.5	15
SCI_06	C7	A	14	1.92	71	M	54	132/80	97	63	8.0	21
SCI_07	C7	A	14	1.80	74	M	38	116/60	78	66	7.3	15
SCI_08	T2	A	12	1.80	66	M	32	111/54	73	63	5.8	21
SCI_09	T4	A	25	1.78	59	F	41	125/75	92	62	8.5	21
SCI_10	T5	A	17	1.72	60	M	37	125/72	90	62	6.6	24
mean ± SD			19 ± 6	1.78 ± 0.06	66 ± 8		41 ± 6	114/64 ± 12/9	81 ± 10	58 ± 6	6.9 ± 1.0	17 ± 4
Non-athletes												
SCI_11	C4	A	16	1.93	95	M	43	104/59	74	71	6.0	0
SCI_12	C4	A	3	1.86	88	M	58	174/102	131	58	14.5	0
SCI_13	C4	A	26	1.88	88	M	55	148/92	111	77	9.5	0
SCI_14	C4	A	2	1.65	47	F	23	92/61	71	51	7.1	5
SCI_15	C4	B	26	1.58	68	M	42	93/59	70	60	6.4	0
SCI_16	C4	B	25	1.83	67	M	43	135/85	102	59	10.6	0
SCI_17	C5	A	25	1.93	98	M	46	126/78	93	61	7.5	0
SCI_18	T2	A	5	1.73	91	M	33	114/71	85	65	8.1	3
SCI_19	T3	A	10	1.78	60	M	30	106/62	90	50	8.1	2
SCI_20	T3	A	28	1.60	72	F	46	109/66	84	43	9.1	2
mean ± SD			17 ± 11	1.78 ± 0.13	77 ± 17		42 ± 11	120/73 ± 26/15	91 ± 19	60 ± 10	8.7 ± 2.5	1 ± 2

AIS, American Spinal Injury Association Impairment Scale; aPWV, aortic pulse wave velocity; C, cervical; DBP, diastolic blood pressure; HR, heart rate; MAP, mean arterial pressure; SBP, systolic blood pressure T, thoracic.

Table 2 Medication of athletes and non-athletes with SCI

Athletes		Non-athletes	
SCI_01	–	SCI_11	–
SCI_02	–	SCI_12	Amitriptyline, Nortriptyline, Pregabalin
SCI_03	Softlax, Dulcolax	SCI_13	Gabapentin
SCI_04	Baclofen	SCI_14	Pregabalin, Amitriptyline
SCI_05	Baclofen, Pregabalin	SCI_15	Baclofen, Gabapentin
SCI_06	Acetan	SCI_16	Venlafaxine, Zopiclone
SCI_07	–	SCI_17	–
SCI_08	Detrusitol	SCI_18	Ditropan
SCI_09	Baclofen, Ditropan, Nitrofurantoin, Citalopram, Cefadroxil	SCI_19	Ditropan
SCI_10	Ditropan, Nitrofurantoin	SCI_20	Methadone

ethics board and is in accordance to the Declaration of Helsinki. In addition, all individuals provided written informed consent prior to data collection.

PWV assessment

Following 10 minutes of rest in the supine position, measurements of arterial pressure waveforms were captured using applanation tonometry according to the most recent guidelines.⁴ A trained rater collected pulse pressure waveforms at the left carotid, and femoral arteries for a minimum of 30 seconds using a handheld tonometer (Model SPT-301; Millar Instruments Inc., Houston, TX, USA), as previously described.⁹ Aortic PWV was calculated using the equation, $PWV = (0.8 \times D) / \Delta t$ where D is the distance between the carotid and femoral arterial sites measured along the body surface using anthropometric measuring tape held parallel to the body, and Δt is the pulse transit time between those sites.⁴ Arterial pressure waveforms were bandpass filtered (2–30 Hz), and the arrival of the waveform at each site was identified as the minimum value of the filtered signal. PWV was calculated as the average of two, 10-second samples. If the difference between the values for these two samples was >0.5 m/second, a third 10-second sample was calculated and the median of the three values was reported as the aortic PWV.⁴ Throughout the PWV assessment, discrete brachial blood pressure (BP) measurements and heart rates (HR) were collected every minute on the left arm using an automated device (Carescape™ V100; GE Healthcare, Milwaukee, WI, USA). Supine brachial BP and HR values are reported as the average values recorded during the PWV measurements.

Statistics

Statistical analyses were performed using SPSS (Version 20.0; IBM Corporation, Armonk, NY, USA). Differences in aortic PWV, resting hemodynamic indices, and demographic parameters between athletes and non-athletes were determined using independent-samples *t*-tests. Data are presented as mean $\pm$ SD, with the significance level set at $P < 0.05$.

Results

There was no significant difference in age ($P = 0.793$), time since injury ($P = 0.499$), weight ($P = 0.072$), or height ($P = 0.966$) between athletes and non-athletes (Table 1). The amount of physical exercise, measured as self-reported hours of exercise per week, was as expected significantly ($P < 0.001$) higher in athletes compared to non-athletes (17 ± 4 vs. 1 ± 2 hours/week).

Figure 1 Aortic PWV in athletes and non-athletes with SCI. Dashed line indicates the clinical cut-off value for increased CVD risk.⁴ * $P < 0.05$

Resting supine hemodynamic parameters are presented in Table 1. There were no significant differences in systolic BP ($P = 0.484$), diastolic BP ($P = 0.108$), mean arterial pressure ($P = 0.139$), and HR ($P = 0.827$) between athletes and non-athletes.

Fig. 1 depicts the difference in aortic PWV assessments between athletes and non-athletes. Aortic PWV was significantly ($P = 0.044$) lower in athletes as compared with non-athletes (6.9 ± 1.0 vs. 8.7 ± 2.5 m/second).

Discussion

Our study is the first to investigate the influence of a high physical exercise training level in individuals with SCI on aortic PWV, a prognostic index of CVD risk in the able-bodied population. We report significantly lower aortic PWV in athletes with high level of physical exercise training (mean 17 hours/week) compared to sex-matched non-athletes with SCI of comparable age and time since injury. This finding is in line with previous reports in the able-bodied literature comparing trained vs. untrained individuals.¹⁰ The difference in aortic PWV between athletes and non-athletes with SCI was 1.8 m/second. The lower central arterial stiffness in athletes might be interpreted as clinically relevant, since it has been shown that a 1.0 m/second change in aortic PWV translates into a 15% increased risk of CVD mortality in the able-bodied population.³ On the other hand, both of our assessed groups are still below the clinical cut-off value for aortic PWV of 10 m/second, with values above this indicating an increased risk for CVD in able-bodied individuals.⁴

To date, aortic PWV in the SCI population has only been investigated by two studies.^{5,6} Applying the PWV equation used in our investigation, the first study

demonstrated an average aortic PWV for their middle-aged (46 ± 8 years) individuals with SCI of 10.2 m/second,⁵ whereas the second study reported an average aortic PWV of 5.8 m/second for its younger (30 ± 7 years) and physically active SCI sample.⁶ The average aortic PWV for our middle-aged non-athletic sample was 8.7 m/second lying in between the former investigations, whereas aortic PWV in our middle-aged athletic group was 6.9 m/second. While it is difficult to draw conclusions on the values obtained in our SCI groups based on the limited and varied evidence on aortic PWV in SCI, it is important to note that aortic PWV of elite hand-cycling athletes is even lower than the reference value of 7.2 ± 2.6 m/second of able-bodied normotensive individuals (40–49 years old).¹¹

It has been shown that transient changes in BP can alter PWV.¹² However, our reported hemodynamic indices were not significantly different between athletes and non-athletes and were therefore unlikely to account for group differences in aortic PWV.

In conclusion, this study suggests for the first time that a high level of physical exercise training in individuals with SCI attenuates arterial stiffness measured as aortic PWV and might reduce CVD risk in this population. However, the value of aortic PWV as a predictor for CVD risk in the SCI population still needs to be established.

Disclaimer statements

Contributors MH is the primary author and was responsible for study conception, data collection, data analyses, data interpretation, and drafting of the manuscript. KDC was responsible for study design, data collection, data analyses, data interpretation, and drafting of the manuscript. CRW was responsible for data collection and drafting of the manuscript. CMG was responsible for participant recruitment and drafting of the manuscript. AVK is the senior author and was responsible for study conception, data interpretation, drafting of the manuscript, and final approval of the manuscript.

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Conflicts of interest None.

Ethics approval Research Ethics Board of University of British Columbia.

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