



Pulse Wave Velocity for Assessment of Arterial Stiffness Among People With Spinal Cord Injury: A Pilot Study

Masae Miyatani, PhD^{1,2}; Kei Masani, PhD^{1,2}; Paul I. Oh, MD^{3,4}; Motohiko Miyachi, PhD⁵; Milos R. Popovic, PhD²; B. Cathy Craven, MD, FRCPC, MSc⁴

¹Lyndhurst Center, Toronto Rehab Institute, Toronto, Ontario, Canada; ²Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, Ontario, Canada; ³Cardiac Rehabilitation and Secondary Prevention Program, Toronto, Ontario, Canada; ⁴Department of Medicine, University of Toronto, Toronto, Ontario, Canada; ⁵Division of Health Promotion, National Institute of Health and Nutrition, Tokyo, Japan

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Abstract

Background/Objective: The most significant complication and leading cause of death for people with spinal cord injury (SCI) is coronary artery disease (CAD). It has been confirmed that aortic pulse wave velocity (PWV) is an emerging CAD predictor among able-bodied individuals. No prior study has described PWV values among people with SCI. The objective of this study was to compare aortic (the common carotid to femoral artery) PWV, arm (the brachial to radial artery) PWV, and leg (the femoral to posterior tibial artery) PWV in people with SCI (SCI group) to able-bodied controls (non-SCI group).

Methods: Participants included 12 men with SCI and 9 non-SCI controls matched for age, sex, height, and weight. Participants with a history of CAD or current metabolic syndrome were excluded. Aortic, arm, and leg PWV was measured using the echo Doppler method.

Results: Aortic PWV (mean \pm SD) in the SCI group ($1,274 \pm 369$ cm/s) was significantly higher ($P < 0.05$) than in the non-SCI group (948 ± 110 cm/s). There were no significant between-group differences in mean arm PWV (SCI: $1,152 \pm 193$ cm/s, non-SCI: $1,237 \pm 193$ cm/s) or mean leg PWV (SCI: $1,096 \pm 173$ cm/s, non-SCI: 994 ± 178 cm/s) values.

Conclusions: Aortic PWV was higher among the SCI group compared with the non-SCI group. The higher mean aortic PWV values among the SCI group compared with the non-SCI group indicated a higher risk of CAD among people with SCI in the absence of metabolic syndrome.

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Key Words: Arterial stiffness; Pulse wave velocity; Spinal cord injuries; Doppler ultrasound; Coronary artery disease; Risk factors

INTRODUCTION

Coronary artery disease (CAD) is the most significant complication and leading cause of mortality after spinal cord injury (SCI) (1). Individuals with chronic SCI have higher cardiovascular mortality rates and cardiovascular mortality occurs at earlier ages compared with the able-bodied population (2-4). Stiffening of the central or cardiothoracic arteries is a significant independent risk factor for CAD in able-bodied people (5-7). Decreases in the elastic properties of arteries reduce their buffering

capacity, leading to increased pulse pressure, aortic impedance, and left ventricular wall tension, all of which augment the workload of the heart, thereby increasing CAD risk. Several indices have been used to quantify the stiffness of the peripheral and cardiothoracic arteries. These include (a) measuring pulse wave velocity (PWV); (b) relating changes in arterial diameter to distending pressure; and (c) assessing arterial pressure wave forms. Of the above indirect methods for measuring arterial stiffness, PWV is the most widely accepted technique (8). PWV has been a useful noninvasive measure to assess arterial stiffness and severity of CAD among able-bodied people in a number of previous studies (9-11).

PWV is the velocity of the blood pressure wave as it travels a known distance between 2 anatomic sites within the arterial system; it is determined by the elasticity and other properties of the artery (12). PWV values positively

Please address correspondence to Masae Miyatani, PhD, Lyndhurst Center, Toronto Rehabilitation Institute, 520 Sutherland Drive, Toronto, Ontario, Canada M4G 3V9; p: 416 597 3422; f: 416 425 9923 (e-mail: miyatani.masae@torontorehab.on.ca).

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correlate with arterial distensibility and stiffness. Three locations for the measurement of PWV have been proposed: (a) trunk (aortic PWV); (b) arm (arm PWV); and (c) leg (leg PWV). Aortic PWV is the established index for measuring arterial stiffness.

Aortic PWV values have been directly linked with cardiovascular mortality, fatal and nonfatal coronary events, and fatal strokes in patients with low and high levels of traditional CAD risk factors (9–11,13–15). For example, aortic PWV values of at least 1,300 cm/s are a strong predictor of cardiac mortality among patients with hypertension (13). Among people with hypertension, a 500-cm/s increment in aortic PWV is an independent predictor of both cardiovascular mortality (odds ratio = 1.34) and all-cause mortality (odds ratio = 1.51) (14). Although leg PWV and arm PWV have not been studied to the same extent, it has been suggested that these peripheral PWV measures are insensitive to physical activity levels and/or aging compared with aortic PWV in able-bodied people (16,17).

Several CAD risk factors have been identified as determinants of PWV in the able-bodied population including obesity (18–20), diabetes mellitus (21,22), hypercholesterolemia (23) and hypertension (9,24), poor cardiorespiratory fitness (25,26), and low physical activity (27). These same CAD risk factors are common among people with SCI (28–32). In addition, people with SCI above the splanchnic outflow (T6) have autonomic dysfunction, which may contribute to disordered cardiac regulation and abnormalities of the vascular system. Thus, it was hypothesized that people with chronic SCI will have an increased risk of adverse vascular health and increased arterial stiffness as measured by PWV.

The purpose of this study was to compare aortic PWV in people with chronic SCI (SCI group) to that of age-, sex-, height-, and weight-matched able-bodied controls (non-SCI group) and to compare arm PWV and leg PWV in these same groups to determine whether differences exist in the values obtained.

METHODS

The SCI group was made up of 15 individuals with SCI (C3–T10, ASIA A, B, and C). The non-SCI group was made up of 11 sedentary able-bodied controls matched for age, height, and weight. Individuals with SCI were recruited by a poster campaign from Toronto Rehab's Lyndhurst Centre. Non-SCI participants were recruited from the staff and friends of the authors affiliated with the Lyndhurst Centre. Participants in this study did not participate in any regular exercise or endurance-type wheelchair exercise beyond their normal activities of daily living for 6 months before enrollment. All participants were nonsmokers for at least 1 year before the study. No participants reported a prior history of CAD, pulmonary disease, diabetes mellitus, or metabolic syndrome. Each participant's current medications were recorded. No

participants were taking medications known to interfere with the cardiovascular system.

A 12-lead ECG was done to screen for signs of arrhythmia or prior myocardial infarction. Fasting serum blood sugar, glycosylated hemoglobin (HbA1C), total cholesterol (TC), high-density lipoproteins (HDL), low-density lipoproteins (LDL), triglycerides (TG), C-reactive protein (CRP), and apolipoprotein (A and B) levels, resting blood pressure (BP), and waist circumference were measured to screen for metabolic syndrome. Heart rate and BP were recorded from the right antecubital fossa using a stethoscope and hand-held dynamometer. Metabolic syndrome was defined as per the American Heart Association Guidelines as at least 3 or more of the following criteria: abdominal obesity (waist circumference ≥ 102 cm for men); dyslipidemia (TC/HDL > 4 or LDL > 2.5); glucose intolerance (fasting blood sugar > 7 mmol/L); elevated CRP (> 3 mg/dL); or hypertension (BP $> 140/90$ mmHg).

Fifteen people with SCI and 11 people without SCI were screened for enrollment in the study. Five individuals' data were excluded from the analysis; 3 individuals had metabolic syndrome; 1 individual had an arrhythmia (atrial fibrillation) that interfered with PWV measurement; and 1 individual had an incomplete assessment. In total, 12 individuals with SCI and 9 controls were included in the study. The study protocol was approved by the Toronto Rehab Research Ethics Board.

PWV was measured from the foot; blood flow waves were recorded at 2 points along the path of the arterial pulse wave. PWV was calculated from the measured wave latency and the distance traveled between the 2 arterial recording sites (Figure 1) (10,15,17,33,34). Two identical transcutaneous Doppler flowmeters (Smartdop50, Hade-co, Kanagawa, Japan) were used to obtain the PWV values at 3 locations: (a) between the carotid and the femoral arteries (aortic PWV); (b) between the femoral and posterior tibial arteries (leg PWV); and (c) between the brachial and radial arteries (arm PWV; Figure 1B). Distance traveled by the pulse was measured over the surface of the body with a tape measure as the distance (D) between recording sites (cm). A minimum of 20 sequentially recorded wave forms were analyzed and averaged. All PWV data were obtained by 2 trained technicians between 10:00 AM and 1:00 PM to avoid circadian changes in PWV values. Measurement of PWV was conducted after abstinence from caffeine and an overnight fast of at least 8 hours. Flow measurements were obtained sequentially in the arm, aorta, and leg over a 40-minute period. Arterial pulse waves were digitized for off-line analysis with signal-processing software (Chart 5.5.5, AD Instruments, New South Wales, Australia). PWV was determined over the 3 arterial segments as $PWV = D/\Delta t$ (cm/s), where Δt was determined from time delay between the proximal and the distal foot of the wave form (Figure 1A). The foot of the wave was identified as the start of the sharp systolic

Table 1. Participant Characteristics

	SCI Group	Non-SCI Group
N	12	9
Age (y)	45.9 ± 7.8	44.1 ± 10.9
Height (cm)	177.6 ± 7.0	174.5 ± 8.2
Weight (kg)	81.1 ± 20.6	73.7 ± 11.5
Body mass index (kg/m ²)	25.5 ± 5.7	24.1 ± 1.9
Systolic blood pressure (mmHg)	121.0 ± 9.5	116.2 ± 11.4
Diastolic blood pressure (mmHg)	74.8 ± 9.3	71.2 ± 6.5
Heart rate (beats/min)	64.3 ± 10.5	65.4 ± 8.0

Data are means ± SD.

upstroke. All analyses were performed by a trained technician blinded to the participant's group assignment (SCI or non-SCI).

The test-retest variability of PWV measures in our laboratory was established by sequential measurement of 9 able-bodied men (21–39 years) on 2 separate days. The intraclass correlation coefficients for test-retest reliability were 0.730 to 0.972 for each PWV value. The mean PWV combined for the 3 sites was 1,095 ± 238 vs 1,057 ± 210 cm/s for Trial 1 vs Trial 2 (not significant).

Statistical analyses were performed using StatView (Version 5.0) software. Demographic, anthropometric, and PWV data are expressed as mean ± SD. Participants with and without SCI were compared by the nonparametric Mann-Whitney *U* test because of the small group size. A 2-sided *P* < 0.05 was considered significant.

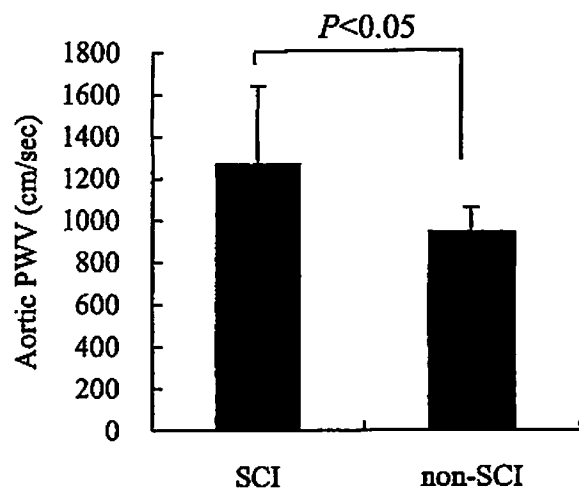
RESULTS

There were no significant differences between groups in the baseline demographic or anthropometric parameters including age, height, weight, heart rate, and BP (Table 1). The mean duration of injury of the participants with SCI was 20 ± 13 years (SD). Mean aortic PWV in the SCI group (1,274 ± 369 cm/s) was significantly higher (*P* < 0.05) than that of the non-SCI group (948 ± 110 cm/s; Figure 2A). There were no statistically significant differences between the SCI group and the non-SCI group (Figure 2B and C) in either arm PWV (SCI: 1,152 ± 193 cm/s, non-SCI: 1,237 ± 193 cm/s; *P* = 0.434) or leg PWV (SCI: 1,096 ± 173 cm/s, non-SCI: 994 ± 178 cm/s) values (*P* = 0.145).

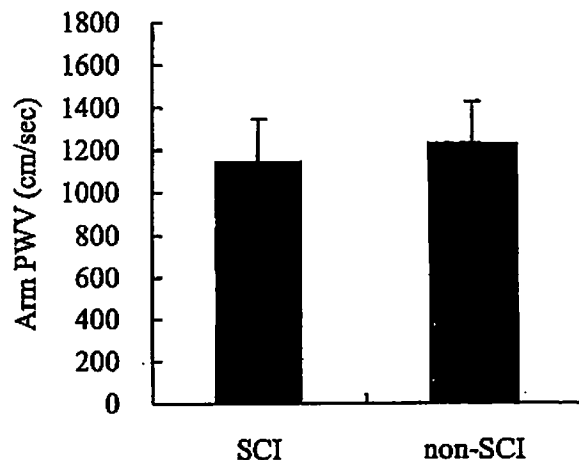
DISCUSSION

Aortic PWV values in the SCI group were higher than those of able-bodied controls (non-SCI group), whereas there were no significant differences between the SCI and non-SCI groups in arm PWV and leg PWV values. Recently reported aortic PWV values in healthy able-bodied individuals 24 to 62 years of age ranged from 600 to 1,000 cm/s (8). Among hypertensive study participants, aortic PWV values ranged from 1,100 to 1,500 cm/s (8).

A



B



C

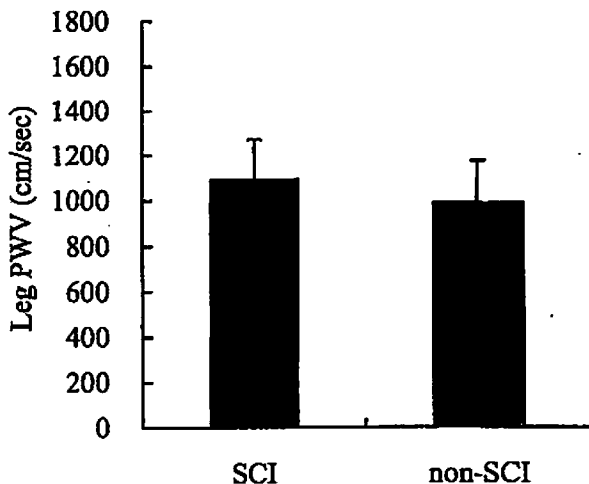


Figure 2. Aortic PWV (A), arm PWV (B), and leg PWV (C) in participants with SCI and able-bodied controls (non-SCI).

Arm and leg PWV values in healthy able-bodied individuals ranged from 840 to 1,200 and from 920 to 1,050 cm/s, respectively (8). The values for PWV documented herein are comparable with those previous-

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ly reported for able-bodied individuals within the same age range.

Additionally, we found that aortic PWV values among healthy SCI participants were higher than those of the age-matched non-SCI participants. Aortic PWV values in the SCI group were equally high compared with the values ($>1,300$ cm/s) associated with an increased risk of developing CAD in the report of Blacher et al (13). These results suggest that the SCI group has a high risk of CAD. Screening protocols to diagnose and prevent CAD related mortality are urgently needed.

In contrast to the aortic PWV result, there were no significant differences between the SCI and non-SCI groups in either arm PWV or leg PWV. These results concur with a prior study reporting that aortic PWV is sensitive to daily activity and aging, whereas leg and arm PWV values are not (16,17). This sensitivity of the PWV of central vs peripheral arteries may be related to their distinct roles in hemodynamic regulation. Compared with the central arteries whose cushioning function damps fluctuations in flow, the peripheral arteries do not exhibit the same extent of pulsatile changes in diameter (35) and, as such, may not undergo the adaptations leading to a loss of elasticity. However, previous studies, which investigated femoral arterial stiffness by augmentation index (AI) (36) and arterial compliance (37,38) among people with SCI, showed that stiffness of the femoral artery in people with SCI was higher than that of able-bodied people. The reasons for this discrepancy is not clear; however, the use of the PWV methodology as opposed to the AI and arterial compliance to assess arterial stiffness may in part explain the discrepancy between our finding of normal leg PWV values and prior publications reporting elevated femoral AI and decreased arterial compliance values among patients with SCI. The PWV method measures pulse wave latency over the femoral and posterior tibial arteries as opposed to the femoral artery alone when assessing AI or arterial compliance.

Although there are no prior studies determining PWV in people with SCI, 3 previous studies investigated arterial stiffness using other measures of arterial stiffness: the AI (36) and arterial compliance (37,38) and compared them with those of able-bodied controls. de Groot et al (37) and Schmidt-Trucksass et al (38) reported that arterial compliance of the superficial femoral and carotid artery were significantly lower in people with SCI compared with people without SCI. Wecht et al (36) reported that arterial stiffness evaluated by AI was high in a group of people with paraplegia compared with an able-bodied group. Moreover, premature and advanced coronary atherosclerosis was found in persons with SCI compared with able-bodied people using electron beam tomography (39). Our observation of increased aortic arterial stiffness supports prior reports of premature CAD in the SCI population.

Mechanisms that may potentially account for higher aortic PWV among people with SCI include (a) structural changes in the vessel as a result of long-term sympathectomy and increased collagen content in the vascular wall (40) or (b) functional changes in the endothelium caused by decreased regional blood flow. Decreased regional blood flow as a result of inactivity impedes endothelium function and subsequently inhibits NO production, which is a mediator of endothelium dilatation (38). Although the relative importance of structural and functional changes in vascular tone is unknown, these may relate to both disordered cardiac regulation and inactive lifestyles after SCI. The mechanism(s) that account for these results are unknown.

This study has limitations that require caution when interpreting and generalizing the findings reported herein. First, the reliability of PWV values for people with SCI has not been reported. Second, this pilot study had a small sample size. Third, adjustments for confounding variables including the participant's injury level, duration of injury, and physical activity levels, which impact CAD risk, were not done. Future studies may want to use validated measures such as the Physical Activity Recall Assessment for People with SCI (PARA-SCI) (31) to quantify activity and explore the relationship between PWV and activity. Last, it is uncertain if the high PWV values reported reflect the presence of CAD among the subjects' in this study. Further studies with larger representative samples of participants with SCI are needed to determine the relationship between the increased arterial stiffness and the development/onset of atherosclerotic and asymptomatic CAD among people with SCI.

CONCLUSION

To our knowledge, this is the first study describing aortic PWV in people with SCI. High aortic PWV values were found in study participants with SCI compared to age-, sex-, height-, and weight-matched able-bodied participants, indicating a higher risk of CAD among individuals with SCI. Arm PWV and Leg PWV were found to be insensitive to the differences between the 2 groups. PWV is potentially a good screening test to assess CAD risk among people with chronic SCI. However, this pilot study merely measured PWV among people with SCI. Further study is needed to confirm the reproducibility of PWV measures among people with SCI. Further study of the PWV method's reliability, validity, and responsiveness while considering the potential confounding effects of: age, duration of injury, impairment, and physical activity on PWV among individuals with SCI are needed.

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