ORIGINAL ARTICLE

Preserved Cardiac Function After Chronic Spinal Cord Injury

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ABSTRACT. de Groot PC, van Dijk A, Dijk E, Hopman MT. Preserved cardiac function after chronic spinal cord injury. Arch Phys Med Rehabil 2006;87:1195-200.

Objective: To assess the effect of chronic deconditioning on cardiac dimensions and function in subjects with high-level spinal cord injury (SCI), who represent a human in-vivo model of extreme inactivity.

Design: Cross-sectional study.

Setting: University medical center.

Participants: Seven men with tetraplegia and 7 able-bodied controls.

Interventions: Not applicable.

Main Outcome Measures: Echocardiographic measurements of resting cardiac dimensions, systolic function, and global and long-axis diastolic function.

Results: Left ventricular mass index was significantly lower in the subjects with SCI than in the controls ($90.8\pm26 g/m^2$ vs $122\pm28.9 g/m^2$; $P=.05$). In addition, dimensions of left ventricle, left atrium, and vena cava inferior were all significantly reduced in the subjects with SCI compared with controls ($P<.05$). There were no differences between the groups for any of the parameters reflecting systolic and global and long-axis diastolic function.

Conclusions: Tetraplegia is associated with a reduction in cardiac mass and dimensions. Resting diastolic and systolic function is not altered with continued exposure to inactivity, however, which suggests a remodeling of the heart as a physiologic adaptive process.

Key Words: Atrophy; Cardiovascular deconditioning; Echocardiography; Rehabilitation.

CHANGES IN PHYSICAL ACTIVITY lead to marked changes in cardiac structure, ranging from the "physiologic hypertrophy" of the endurance-trained athlete,[1] to the "physiologic atrophy" of chronically deconditioned patients. For example, decreases in cardiac volumes, dimensions, and/or left ventricular (LV) mass in humans have been observed after a period of bedrest (2–12wk),[2,3] after space flight by astronauts,[4] and after spinal cord injury (SCI).[5-8] Similar changes in LV dimensions[9] and cardiac mass[9,10] were seen in adult rats after simulated microgravity by hindlimb unloading.

SCI results in sublesional motor dysfunction, which is more substantial in patients with cervical SCI.[11] Consequently, these people have a wheelchair-bound, inactive lifestyle, which is illustrated by maximal oxygen uptake values averaging approximately 0.7L/min[12] or $12 mL\cdot kg^{-1}\cdot min^{-1}$.[13] Hence, the most extreme degree of inactivity possible is experienced by tetraplegic subjects who are otherwise healthy.

Previous studies using echocardiography found a significant reduction in cardiac dimensions and mass in subjects with tetraplegia.[5-8]

Although changes in cardiac dimensions with different modes of inactivity seem to be well described, the effect of inactivity on cardiac function has rarely been investigated.

Impairment of diastolic function has been recognized as an important component of heart failure and changes in diastolic filling associated with physical inactivity may be a specific risk factor in the development of heart failure.[14,15] Only a few studies have reported that cardiac output was reduced after periods of inactivity induced by bedrest or SCI,[7,16] whereas the effect of inactivity on diastolic function remains obscure. Levine et al[3] found a reduction in LV distensibility and impaired cardiac function due to reduced filling after 2 weeks of bedrest,[3] whereas Eysmann et al[8] reported no changes in diastolic filling in a group of subjects with SCI who were compared with age-matched controls.

Our main objective in this study was to assess the effect of chronic deconditioning on cardiac dimensions and function in a group of subjects with cervical SCI, who serve as a natural model for extreme inactivity. We hypothesized that tetraplegia is associated with reductions in both cardiac dimension and function, as compared with able-bodied persons. In addition to more traditional measurements for cardiac dimension and function, we used innovative echocardiography techniques to measure diastolic and systolic function.

METHODS

Participants

Seven men with SCI who were between the ages of 28 and 48 years, and 7 able-bodied male controls who were between the ages of 27 and 48 years, volunteered to participate in the study. The SCI subjects had motor complete neurologically stable spinal cord lesions of traumatic origin at levels C5-6 (American Spinal Injury Association grade A)[11]; time since injury varied between 4 and 30 years (mean, 17.7 ± 9.6y). Inclusion criteria for both groups included age less than 50 years, with no known coronary artery, cardiac, or pulmonary disease or other chronic medical problems—including cancer, diabetes, and hypertension—that required regular medical therapy. Five subjects with SCI used medication to suppress spasms, while 2 also used medicine for their bowel function. At the time of the study, the control subjects were low to moderately active, with their activity ranging from routine daily activities to walking and/or cycling 2 to 3 hours a week. All participants with SCI used electric wheelchairs for locomotion. The ethics committee of the Radboud University Medical Centre Nijmegen approved the study and all subjects provided written, informed consent before participating.

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Protocol

All measurements were performed in a quiet, temperature-controlled room (range, 22°–24°C) at the Department of Cardiology of the Radboud University Hospital Nijmegen. Blood pressure was measured manually at the brachial artery with a sphygmomanometer.[a] Body mass in SCI was measured using a specialized sitting scale,[b] while body mass of controls and height in both groups were taken from a medical questionnaire. Echocardiographic measurements, using standard views and formulas as recommended by the American Society of Echocardiography,[17-19] were obtained by a single cardiologist using the Vingmed System Five.[c] Echocardiography using the 2-dimensional, M-mode, Doppler of mitral inflow and pulmonary venous velocities, and tissue Doppler imaging modalities of both the septum and lateral wall at the mitral annulus were performed with the subjects placed in the left lateral position. Images were obtained in multiple cross-sectional planes using second harmonic imaging with a phased-array transducer (range, 1.7–3.5MHz) in standard positions. An electrocardiographic signal was recorded simultaneously with the echo images. Raw data were stored digitally for off-line analysis using EchoPAC PC.[c] In all measurements, 3 beats were averaged, with the subject pausing during the respiratory cycle at end expiration. Clear, 2-dimensional, echocardiographic images were obtained from all subjects. Cardiac dimensions and cardiac output were corrected for body surface area using the formula of Dubois and Dubois.[20]

Measurements: Dimensions

From the M-mode echocardiogram, we measured the diameter of the aorta, left atrium, left ventricle at end-diastole (LVED) and at end-systole (LVES), end-diastolic wall thickness of the intraventricular septum (IVS), and left ventricular posterior wall (LVPW) in the parasternal long-axis view. From the 2-dimensional echocardiogram, we measured length and width from the left atrium, and diameter of the vena cava inferior at end expiration in the apical 4-chamber and subcostal view, respectively. LV mass was calculated using a geometric cube formula[21]: $(1.04\times[(\text{LVED}+\text{LVPW}+\text{IVS})^3-\text{LVED}^3]\times 0.8+0.6)/1000$. We used the ratio of LVED mass/volume to evaluate the degree of adaptation of wall thickness to changes in chamber size.

Measurements: Function

Systolic function. We measured the ejection fraction using the formula: (LVEDV–LVESV/LVEDV)×100, where left ventricular end-diastolic volume (LVEDV) and left ventricular end-systolic volume (LVESV) from 2-dimensional echocardiograms in the apical 4-chamber view were determined using the single-plane Simpson rule method.[22]

Cardiac output was calculated by Doppler-derived stroke volume by heart rate. Therefore, stroke volume was measured using the formula: $¼\times\pi\times(\text{LVOT}_{\text{diameter}})^2\times\text{LVOT}_{\text{VTI}}$, where LVOT is left ventricular outflow tract and VTI is velocity time integral. A measure of systolic performance corrected for afterload was calculated as the peak systolic pressure/end systolic volume (PSP/ESV) ratio.

Diastolic function. Parameters reflecting global diastolic function were measured with the echo-Doppler technique and color M-mode. To measure filling velocities, we obtained standard LV inflow pulsed-wave Doppler measurements at the mitral leaflet tips, including peak flow velocity of the early rapid filling wave (E[-wave]), peak flow velocity of the late filling wave due to atrial contraction (A[-wave]), the E/A ratio, (early deceleration time), and isovolumetric relaxation time. In addition, left atrium inflow pulsed-wave Doppler measurements were obtained, including pulmonary venous flow velocities in both diastole (D) and systole (S), and the S/D ratio. To quantify diastolic suction, color M-mode measurements at the center of the mitral inflow region were obtained, including early diastolic flow propagation velocity (v_p).

Parameters reflecting long-axis diastolic function were measured with the tissue Doppler imaging (TDI) technique. To measure myocardial relaxation, we obtained pulsed-wave TDI measurements at the septal and lateral mitral annulus, including early LV systolic myocardial tissue contraction velocity (S_m[-wave]), peak early LV diastolic myocardial tissue filling velocity (E_m[-wave]), and peak late LV diastolic myocardial tissue filling velocity during atrial contraction (A_m[-wave]).

Statistical Analysis

Statistical analyses were performed using the Statistical Package for Social Sciences.[d] All data are expressed as mean ± standard deviation (SD). Differences in physical and echocardiographic measurements between the 2 groups were analyzed using an unpaired Student *t* test. Two-tailed significance levels were used throughout. For all statistics, a *P* value of .05 or less was considered statistically significant.

RESULTS

Baseline Characteristics

Both groups were well matched for age, sex, height, body mass, and body surface area. Subjects with SCI had significantly lower values of systolic and diastolic blood pressure than with the controls.

Heart rate and stroke volume did not differ between the groups (table 1).

Echocardiography: Dimensions

Because body surface area values did not differ between groups, data corrected for body surface area, with the exception of LV mass, was not considered, and only absolute values are presented (table 2). LV dimensions were significantly smaller in the subjects with SCI compared with the controls, which is indicated by a 12% reduction in LVED and a 14% reduction in LVES. LV mass index was significantly reduced (26%) in SCI subjects compared with controls. In addition, left atrium size (21%) and the diameter of the vena cava inferior (28%) were significantly smaller in the SCI subjects. No differences between groups were observed for aorta diameter, IVS, LVPW, LVEDV, and LVESV, although a trend toward a decrease in

Table 1: Subject Characteristics

Characteristics	SCI (n=7)	Controls (n=7)	*P*
Age (y)	38±8	37±8	.83
Height (cm)	180±6	178±7	.90
Weight (kg)	72±14	72±7	.66
BSA (m^2)	1.9±0.2	1.9±0.1	.93
SBP (mmHg)	97±10	125±6	<.01*
DBP (mmHg)	61±4	79±10	<.01*
Heart rate (bpm)	53±8	58±10	.32
Stroke volume (mL)	73±20	88±34	.34

NOTE. Values are mean ± SD.
Abbreviations: BSA, body surface area; DBP, diastolic blood pressure; SBP, systolic blood pressure.
*Significantly different, subjects with SCI versus controls.