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Sedentary behaviour in cardiovascular disease patients: Risk group identification and the impact of cardiac rehabilitation

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ABSTRACT

Background: Sedentary behaviour (SB) is potentially an important target to improve cardiovascular health. This study 1) compared SB between cardiovascular disease (CVD) patients and age-matched controls, 2) identified characteristics associated with high SB levels, and 3) determined the impact of contemporary cardiac rehabilitation (CR) on SB.

Methods: For objective 1, we recruited 131 CVD patients and 117 controls. All participants were asked about their general characteristics and medical history. SB was assessed by an objective accelerometer (activPAL3 micro). For objective 2, 2584 CVD patients were asked to fill in a questionnaire about their general characteristics, lifestyle, medical history and their SB. For objective 3, 131 CVD patients were followed over time and measured, pre-, directly post- and 2 months post-CR.

Results: Objective 1. CVD patients spent 10.4 h/day (Q25 9.5; Q75 11.2) sedentary which was higher compared to healthy controls (9.4 h/day [Q25 8.4; Q75 10.29]). *Objective 2*. CVD patients being male, single or divorced, employed, physically inactive, reporting high alcohol consumption, living in an urban environment, having comorbidities and cardiac anxiety demonstrated a greater odds for large amounts of SB. *Objective 3*. The CR program significantly reduced sedentary time (−0.4 h/day [95%CI -0.7; −0.1]), which remained lower at 2-months post-CR (−0.3 h/day [95%CI -0.6; −0.03]).

Conclusions: CVD patients had greater amounts of objectively measured sedentary time compared to healthy controls. Sedentarism was associated with personal- and lifestyle characteristics, and comorbidities. Participation in a contemporary CR program slightly reduced sedentary time, but tailored interventions are needed to target SB in CVD patients.

1. Introduction

A physically inactive lifestyle is increasingly common in the Western world [1] and is characterized by low levels of moderate-to-vigorous intensity physical activity (MVPA) and high levels of sedentary behaviour (SB; i.e. sitting, lying) [2]. Both low MVPA [3,4] and high SB [5–8] have been independently associated with an increased risk for cardiovascular morbidity and mortality. According to large meta-analyses [5–7] including >1,000,000 individuals, the detrimental health effects of an inactive lifestyle are largest for individuals with a combination of low MVPA and high SB.

Cardiovascular disease (CVD) patients typically report low MVPA levels [9], which increases the risk for disease progression and mortality [10–12]. Exercise training is the cornerstone in cardiac rehabilitation (CR) [13,14], but CR-induced increase in MVPA is often temporarily and most patients return to an inactive lifestyle within months [15]. Information about SB in patients with CVD is scarce. A recent study found

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[1] This author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

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high SB levels (9.7 ± 2.0 h/day) among acute coronary syndrome patients at 28 days post-discharge [16]. It is unknown how these SB characteristics differ from age-matched healthy controls, and which patient- and disease-characteristics are associated with high SB levels. Such information is necessary to develop and implement SB interventions for vulnerable patients with CVD. Moreover, CR-induced SB changes should be evaluated to determine the magnitude and sustainability of potential improvements in SB.

We aimed to 1) compare SB between patients with CVD and age-matched controls, 2) identify patient- and disease characteristics associated with high SB levels, and 3) determine the impact of CR on SB. We hypothesize that patients with CVD are more sedentary compared to controls. In addition, subject-, lifestyle- and health-related characteristics relate to high SB levels, and SB will not change after CR. Outcomes from this study can be used to identify high-risk patients with CVD and to optimize associated secondary prevention strategies.

2. Methods

2.1. Study population

To compare SB characteristics between patients with CVD and age-matched controls (objective 1), we recruited 131 patients with CVD from two different hospitals; Radboud University Medical Center (Nijmegen, the Netherlands) and Rijnstate Hospital (Arnhem, the Netherlands). Age-matched controls without a history of CVD or CVD risk factors (i.e. diabetes mellitus, hypertension and hypercholesterolemia) were recruited via social media advertisement and via friends and family of the patients with CVD ($n = 117$).

To identify patient- and disease characteristics associated with high levels of SB (objective 2), patients who participated in CR in the past 3 years within four hospitals in the Netherlands (i.e. Radboud University Medical Centre, Rijnstate Hospital, Jeroen Bosch Hospital and Isala clinic) were invited by mail or email to complete a questionnaire ($n = 7331$). In addition, patients with CVD were also recruited via social media channels of the Dutch Heart Foundation. Patients were included if they were diagnosed with CVD and were eligible for CR based on the American Heart Association [17] and European Society of Cardiology [18] guidelines. In total, 2584 patients with CVD were included. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki and the medical ethical committee of the Radboud University Medical Center approved the study (#2017–3315; objective 1 and 3, and #2018–4174; objective 2). All participants provided written informed consent.

To determine the impact of CR on SB (objective 3), we examined all patients with CVD from objective 1 immediately after and 2 months after CR. Patients with CVD participating in a CR program with supervised exercise training sessions were eligible for participation. Patients who discontinued CR after the first session of the program were excluded from the analysis.

2.2. Objective 1: patients with CVD versus healthy controls

Patients and controls were asked to fill in a questionnaire about their general characteristics consisting of age, sex, education level, marital status and employment status. In patients with CVD, characteristics such as weight, height, smoking status, alcohol consumption, index diagnosis, medical treatment, comorbidities, and medication use were retrieved from the electronic patient files. In age-matched controls, characteristics such as weight, height, smoking status, alcohol consumption, comorbidities, and medication use were assessed at the research facility.

SB and PA characteristics (i.e. sedentary, standing and stepping time, and Metabolic Equivalent of Task [MET] values) were measured using the activPAL3 micro (PAL Technologies Ltd., Glasgow, UK). The waterproofed device was attached by trained staff on the midline, one third of the way down on the right thigh using a breathable hypoallergenic dressing. Participants were asked to wear the monitor 24-h/day over an 8-day period. Participants were asked to complete a diary with wake and sleep times. The monitors were initialized and downloaded using the activPAL software 7.2.38 (PAL Technologies Ltd., Glasgow, UK). The raw data was analysed by a modified version of the script of Winkler et al. [19] using the sleep/wake diaries. Sedentary time was defined as any waking behaviour characterized by an energy expenditure ≤1.5 MET [20] while in a seated, reclined or lying posture [21,22]. Light intensity physical activity (LIPA) was defined as standing time combined with stepping time with MET-values <3. Moderate-to-vigorous physical activity (MVPA) was defined as stepping time with MET-values ≥3 [23]. The accumulation of sedentary time was defined as short (<5 consecutive minutes), medium (5–29 consecutive minutes) and prolonged (≥30 consecutive minutes) sedentary bouts.

2.3. Objective 2: characteristics associated with high SB levels

Patients with CVD who participated in CR in the past 3 years were invited to complete a questionnaire. Patients who dropped out of CR were included in the analyses. The questionnaire inquired about age, sex, weight, height, marital status, education level, employment status, income, health, lifestyle factors, CR program characteristics, personality and living environment. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Health-related information contained self-reported CVD diagnosis, CVD treatment, medication use, comorbidities, pain and limitations of physical movement in daily life circumstances, and cardiac anxiety [24,25]. Cardiac anxiety was assessed with a validated questionnaire and contained heart-focused anxiety, which is the fear of cardiac-related stimuli and sensations because of their perceived negative consequences [24]. Lifestyle factors were the average number of sleeping hours per night, smoking status, alcohol consumption and motives for PA (i.e. doctor's advice, fitness, weight reduction, habit, health, pleasure, social contact and stress reduction) using a 5-point Likert scale. Heavy alcohol drinking was defined as >14 alcoholic drinks per week for men and > 7 for women [26]. Personality was determined on the big-five personality domains (i.e. extraverted, agreeable and warm, conscientious, emotionally stable, and open to new experiences) using the ten-item personality inventory (TIPI) [27]. Finally, patients were asked about their living environment (i.e. urban, transition or rural area) and their satisfaction about possibilities walking and cycling in the neighbourhood using a 5-point Likert scale.

Sedentary time was assessed in nine different settings using the Sedentary Behaviour Questionnaire [28,29]. The nine items were completed for weekdays and weekend days separately, and stratified into three domains; occupation, transportation and leisure time. Leisure time activities included domestic activities. The average amount of sedentary time per day was calculated by multiplying weekdays estimates by 5 and weekend days estimates by 2 and dividing this by 7. Since there are no evidence-based cut-off values for high levels of sedentary time, we dichotomized sedentary time based on the median value (8 h/day). High levels of sedentary time during transportation, occupation and leisure time sitting were based on the 75% percentile (i.e. 1 h/day, 3.5 h/day, and 8 h/day, respectively). PA volumes were determined for different domains (i.e. occupation, transportation, leisure and household) using the Short QUestionnaire to ASsess Health enhancing physical activity (SQUASH) questionnaire [30]. Weekly PA was converted into METs using the Adult Compendium of Physical Activities [31]. For each activity, the appropriate MET-score was selected (i.e. walking at 5.6 km/h [or 3.5 mph] = 4.3 METs or cycling at moderate effort = 8.0 METs) and multiplied by the number of minutes per week spent on the specific activity. The sum of all activities determined the total METs-minutes per week. These MET-minutes per week values were classified into four quartiles.

2.4. Objective 3: impact of CR on SB characteristics

Patients with CVD enrolled in Objective 1 were followed over time to determine the impact of CR on SB characteristics and to assess whether potential changes were sustainable. The CR program contained a 6-week exercise program of two exercise sessions of 1 h per week optionally combined with 3 additional modules focussing on mental health and stress relief, social health and cardiovascular risk management. All patients followed the exercise program, but participation in the additional modules was based on individual needs and preferences. SB and PA data were collected at baseline (objective 1), directly after and 2 months after the CR program, resulting in a longitudinal database with 3 distinct measurement periods; pre-CR, post-CR and 2 months post-CR.

2.5. Statistical analyses

Baseline characteristics were summarized as mean for normally distributed continuous variables, as median (Q_{25} - Q_{75}) for not normally distributed continuous variables and as number (%) for categorical variables.

2.5.1. Objective 1

Differences in baseline characteristics between patients with CVD and age-matched controls were tested using a Student's *t*-test for normally distributed continuous variables, a Mann-Whitney *U* test for not normally distributed continuous variables, and a Chi-squared test for categorical variables. Differences in activity patterns (i.e. SB characteristics, MVPA, LIPA, and sleep time) were tested using a Mann-Whitney U test. To correct for potential confounding factors (i.e. age, sex, BMI, education level,employment status, smoking status and season), a multivariate linear regression model was used to examine the difference in sitting time and prolonged sitting bouts between patients with CVD and age-matched controls.

2.5.2. Objective 2

Univariate associations with age, sex, weight, height, marital status, education level, employment status, income, health, lifestyle factors, CR program characteristics, personality and living environment were determined using logistic regression analysis for total sedentary time and each domain of sedentary time. Variables with a *P-value* < 0.10 were included in the multivariate logistic regression model. Backward selection was used to finalize the multivariate logistic regression model.

2.5.3. Objective 3

Changes in activity patterns before and after CR were analysed with mixed model analyses using random intercepts. Time was described as categorical variables for pre-CR, post-CR and 2 months post-CR. In addition, multivariate mixed model analysis was performed to adjust for potential confounding factors (i.e. age, sex, BMI, education level, employment status, and disease characteristics).

All statistical tests were 2-sided, and significance was set at $P < 0.05$. All analyses were performed with R version 3.5.2 using packages ‘lme4’ [32] and ‘lmerTest’ [33].

3. Results

3.1. Patients with CVD versus healthy controls

In total, 131 patients with CVD and 117 individuals without a history of CVD or CVD risk factors were recruited (Supplemental Fig. 1). Median age of the patients with CVD was 63 years [Q_{25} 56; Q_{75} 69] and did not differ from controls (60 years [Q_{25} 54; Q_{75} 67]). Patients were more frequently male (75% vs 62%), had overweight or were obese (71% vs 44%), had a lower education level (18% vs 6%) and were more often unemployed (71% vs 38%) compared to controls (Table 1). Patients with CVD spent 10.4 h/day (Q_{25} 9.5; Q_{75} 11.2) sedentary, performed LIPA for 3.8 h/day (Q_{25} 3.0; Q_{75} 4.7), MVPA for 0.9 h/day (Q_{25} 0.7; Q_{75} 1.1) and slept for 8.9 h/day (Q_{25} 8.2; Q_{75} 9.6) (Fig. 1 and Supplemental Table 1). Healthy controls were less sedentary (9.4 h/day), more active (LIPA: 4.9 h/day, MVPA: 1.3 h/day, and slept less (8.3 h/day) compared to patients with CVD (Fig. 1 and Supplemental Table 1). After adjustment for potential confounders (i.e. age, sex, BMI, education level, employment status, smoking status and season), sedentary time remained higher in

Table 1
Baseline characteristics of patients ($n = 131$) participating in cardiac rehabilitation compared to healthy age-matched controls ($n = 117$).

Patient characteristics	Patients $N = 131$	Controls $N = 117$	*P*-value
Age	63 [56, 69]	60 [54, 67]	0.078
Sex (female)	33 (25%)	44 (38%)	0.049
Body mass index			<0.001
Normal	37 (29%)	73 (62%)	
Overweight	57 (45%)	36 (31%)	
Obesity	33 (26%)	8 (7%)	
Marital status (married)	89 (68%)	86 (74%)	0.412
Education level			<0.001
Low	24 (18%)	7 (6%)	
Middle	63 (48%)	44 (38%)	
High	44 (34%)	66 (56%)	
Current working status (employed)	38 (29%)	73 (62%)	<0.001
Cardiovascular disease			
Acute coronary syndrome			
STEMI	40 (31%)	Na	
NSTEMI	28 (22%)	Na	
Angina Pectoris	27 (21%)	Na	
Congenital heart disease	2 (2%)	Na	
Heart failure	5 (4%)	Na	
Heart rhythm disorder	6 (5%)	Na	
Heart valve disease	14 (11%)	Na	
Other cardiovascular diseases	6 (5%)	Na	
Medication use		Na	
ACE-inhibitor/Angiotensin receptor blockers	91 (70%)	Na	
Antiarrhythmic	14 (11%)	Na	
Anti-coagulants	26 (20%)	Na	
Beta-blocker	107 (82%)	Na	
Calcium-antagonists/nitrates/dihydropyridines	61 (47%)	Na	
Cholesterol lowering medication	101 (77%)	Na	
Diabetes medications and insulin therapy	18 (14%)	Na	
Diuretics	22 (17%)	Na	
Platelet aggregation inhibitors	107 (82%)	Na	
Treatment		Na	
CABG	30 (23%)	Na	
Electro cardioversion/ablation/mini-maze procedure	1 (1%)	Na	
Heart valve replacement	17 (13%)	Na	
Pacemaker or ICD implementation	9 (7%)	Na	
PCI	65 (51%)	Na	
Medication only	2 (2%)	Na	
Comorbidities			
Arthrosis	6 (5%)	Na	
COPD	5 (4%)	Na	
Diabetes mellitus	22 (18%)	Na	
Dyslipidemia	45 (38%)	Na	
Hypertension	59 (48%)	Na	
Rheumatoid arthritis	7 (6%)	Na	
Lifestyle			
High alcohol consumption	9 (8%)	9 (10%)	0.932
Smoking status			0.004
No, never smoked	10 (8%)	9 (8%)	
No, but in the past	86 (66%)	53 (46%)	
Yes, I currently smoke	35 (27%)	54 (47%)	

ACE-inhibitor, angiotensin-converting-enzyme inhibitors; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; ICD, implantable cardioverter-defibrillator; PCI, percutaneous coronary intervention; NSTEMI, non-ST-elevation myocardial infarction; STEMI, ST-elevation myocardial infarction; Na, not applicable.

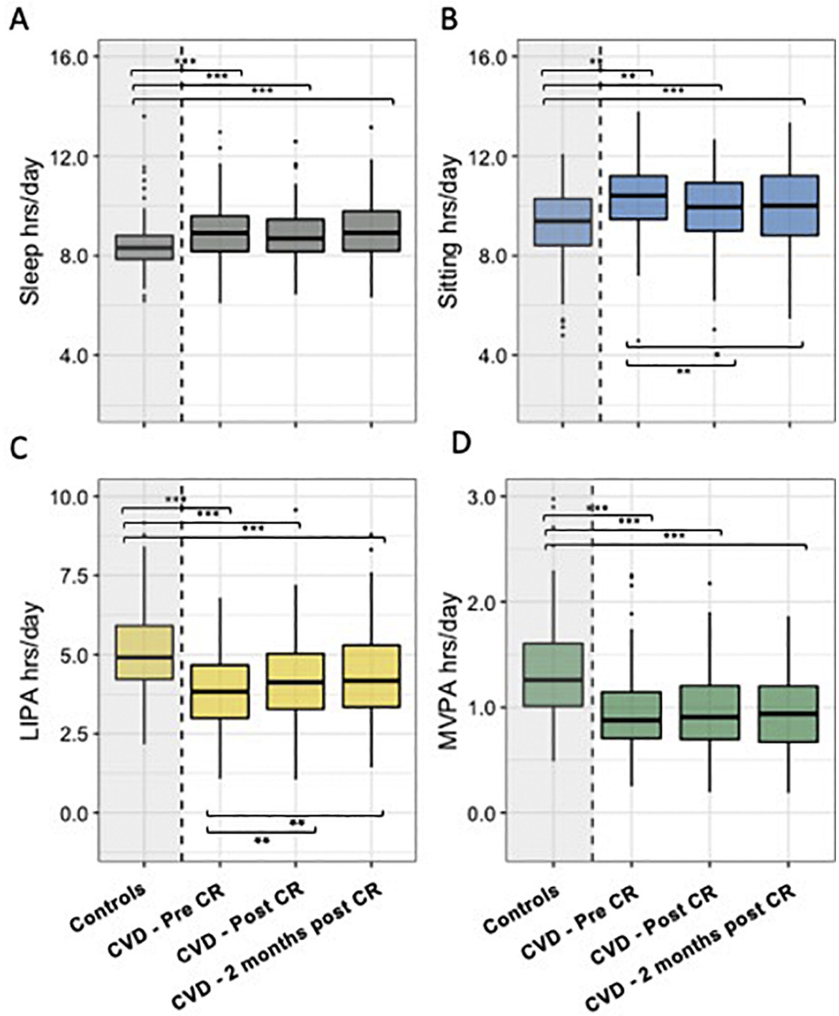

Fig. 1. Sleep time (A), sedentary time (B), light intensity physical activity (LIPA) time (C) and moderate-to-vigorous intensity physical activity (MVPA) time (D) in healthy controls and cardiac patients pre-, post- and 2 months post-cardiac rehabilitation. Data is presented as box plots. Statistically significant differences between healthy controls and patients with cardiovascular disease (CVD) are presented at the top of each panel, whereas cardiac rehabilitation induced changes among patients with CVD are located on the bottom of each panel. Patients with CVD spent more time sleeping and sedentary, but less time performing light and moderate-to-vigorous intensity physical activities compared to healthy controls at all time-points. Cardiac rehabilitation significantly reduced sitting time and increased LIPA, whereas no changes were found for sleeping or MVPA. * *p*-value <0.05, ** *p*-value <0.01, *** *p*-value <0.001.

patients with CVD compared to controls (+1.1 h/day; 95% CI: 0.6; 1.6, $P < 0.001$). Interestingly, patients with CVD had fewer short sedentary bouts (−4.2 bouts/day; 95% CI: −7.8; −0.5, $P = 0.02$), but more prolonged sedentary bouts (+1.0 bouts/day; 95% CI: 0.5; 1.61, $P < 0.001$) compared to controls (Supplemental Fig. 2). Finally, patients with CVD were less physically active at light and at a moderate-to-vigorous intensity compared to controls (LIPA −1.3 h/day [95% CI -1.8; −0.8] and MVPA −0.4 h/day [95% CI -0.6; −0.3]).

3.2. Characteristics associated with high SB levels

2923 Patients with CVD completed our questionnaire. After exclusion for duplicates ($n = 96$), individuals without CVD ($n = 16$), individuals not eligible for CR ($n = 67$) and invalid questionnaires ($n = 160$), 2584 patients with CVD were included for data analyses (Supplemental Fig. 3). Patients with CVD were 64 (SD 10) years of age and were more frequently male (72%), overweight or obese (69%), and unemployed (60%) (Table 2). Sedentary time was most prevalent during leisure time activities (Supplemental Fig. 4), such as watching TV and movies, eating and drinking and using the computer. Based on the multivariate logistic regression model, patients with CVD being male, single or divorced, employed, physically inactive, reporting high alcohol consumption, and living in an urban environment demonstrated a greater odds for high sedentary time (Fig. 2). Weight reduction as motive for PA was associated with lower sedentary time. Furthermore, the presence of comorbidities such as type 2 diabetes, hypercholesterolemia and rheumatoid arthritis and cardiac anxiety also were associated with high SB levels, but not the type of CVD diagnosis. Correlates for high levels of domain-specific SB were roughly comparable with total SB, but some general characteristics, comorbidities and lifestyle factors differed in magnitude and direction (Supplemental Figs. 5, 6 and 7).

3.3. Impact of CR on SB characteristics

Among the 131 patients measured at pre-CR, a total of 17 patients were lost to follow-up and 8 patients had a measurement failure (i.e. technical problems with device, early detachment, device lost in mail) during the post-CR measurements (Supplemental Fig. 1). Patients with CVD spend significantly less time sedentary following CR (−0.4 h/day [95% CI -0.7; −0.1], $P = 0.005$), which remained lower at 2-months post-CR (−0.3 h/day [95% CI -0.6; −0.03], $P = 0.03$) (Fig. 1B). Changes in sedentary time were independent of potential

Table 2
Characteristics of cardiovascular disease patients who completed a questionnaire about general, lifestyle and disease-related characteristics ($n = 2584$).

Patient characteristics	$N = 2584$
Sex (female)	722 (28%)
Age	64 (10)
Body mass index	
Normal	794 (31%)
Overweight	1231 (48%)
Obesity	553 (22%)
Marital status	
Unmarried	345 (17%)
Married	1958 (76%)
Widow(er)	125 (5%)
Living together	145 (6%)
Education level	
Low	435 (17%)
Middle	1206 (47%)
High	934 (36%)
Current work status	
Employed	1025 (40%)
Unemployed	(60%)
Health problems	197 (8%)
Retired	1143 (45%)
Other	1535 (8%)
Income	
≤1000 euro	78 (3%)
1000–1500 euro	252 (10%)
1500–2500 euro	872 (35%)
≥2500 euro	1265 (51%)
Cardiovascular disease	
Acute coronary syndrome	1380 (53%)
Angina pectoris	707 (27%)
Congenital heart defect	25 (1%)
Heart failure	343 (13%)
Heart rhythm disorder	537 (21%)
Heart valve disease	332 (13%)
Other cardiovascular diseases	151 (6%)
Medication use	
ACE-inhibitor/Angiotensin receptor blockers	1617 (59%)
Antiarrhythmic	201 (7%)
Anti-coagulants	561 (20%)
Beta-blocker	1670 (61%)
Calcium-antagonists/nitrates/dihydropyridines	710 (26%)
Cholesterol lowering medication	2013 (73%)
Antidiabetic agents and insulin therapy	300 (11%)
Diuretics	618 (23%)
Platelet aggregation inhibitors	1952 (71%)
Treatment	
CABG	673 (26%)
Electrical cardioversion/ablation/mini-maze procedure	209 (8%)
Heart valve replacement	331 (13%)
Medication only	312 (12%)
Pacemaker or ICD implantation	255 (10%)
PCI	1499 (58%)
Other cardiothoracic surgery	14 (1%)
Comorbidities	
Asthma/bronchitis/COPD	304 (12%)
Arthrosis	315 (12%)
Cancer	239 (9%)
Depression	189 (7%)
Diabetes mellitus	
Type 1	28 (1%)
Type 2	326 (13%)
Hypercholesterolemia	896 (35%)
Hypertension	1043 (40%)
Osteoporosis	86 (3%)
Rheumatoid arthritis	99 (4%)
Thyroid disorder	128 (5%)
Transient ischemic attack or stroke	143 (6%)
Lifestyle	
Sleeping (hrs/day)	7.4 (1.2)
Smoking status	
No, never smoked	784 (30%)
No, but in the past	1617 (63%)
Yes, I currently smoke	173 (7%)
Packyears	21.43 [0.00, 64.29]
High alcohol consumption	253 (10%)
Physical activity	
Days/week 30 min physically active	5.00 [4.00, 7.00]
MET-minutes per week	3447 [1608, 6165]
MET-minutes per week, leisure	2591 [1200, 4854]
MET-minutes per week, non-leisure	0 [0, 800]
Cardiac rehabilitation	
Participation CR	
Currently following CR	84 (3%)
Followed CR less than 6 months ago	398 (15%)
Followed CR more than 6 months ago	1784 (70%)
Never followed CR	302 (12%)
Completed CR (no)	113 (5%)
Contribution of CR to recovery	113 (5%)
None	109 (5%)
Little	232 (10%)
Moderate	775 (34%)
High	1142 (51%)
Cardiac anxiety score	18 [12, 25]

ACE-inhibitor, angiotensin-converting-enzyme inhibitors; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; CR, cardiac rehabilitation; ICD, implantable cardioverter-defibrillator; PCI, percutaneous coronary intervention.

confounders at baseline. No changes in short sedentary bouts were observed following CR. Although prolonged sedentary bouts decreased significantly post-CR (−0.4 bouts/day [95% CI -0.7; −0.1]), values normalized to baseline values within 2-monts post-CR (−0.2 bouts/day [95% CI -0.5; 0.1], $P = 0.2$) (Supplemental Fig. 2C). LIPA increased significantly following CR (0.3 h/day [95% CI 0.1; 0.6], $P = 0.005$) and remained higher 2-months post-CR (0.4 h/day [95% CI 0.1; 0.6], $P = 0.002$). Finally, MVPA and sleep time did not change following CR or 2-months post-CR. Stratified analyses for weekdays and weekend days revealed similar outcomes of changes in sedentary time, prolonged sedentary bouts, LIPA and MVPA (Supplemental Figs. 8 and 9).

4. Discussion

This study presents novel findings related to the prevalence, correlates and CR-induced changes of sedentary behaviour of patients with CVD. First, patients with CVD show significantly higher sedentary time and lower levels of PA compared to healthy, age-matched controls. Especially the greater accumulation of prolonged, uninterrupted sedentary bouts contributed to higher SB time spent by patients with CVD. Second, general characteristics (i.e. sex, marital status, employment status), lifestyle characteristics (i.e. physical inactivity, alcohol consumption, living environment, motives for PA) and presence of comorbidities (i.e. type 2 diabetes, hypercholesterolemia, rheumatoid arthritis, and cardiac anxiety), but not the type of CVD diagnosis, were associated with higher levels of sedentary time among patients with CVD. Third, patients with CVD demonstrated a small, but significant reduction in sedentary time following a 6-weeks CR program with supervised exercise training sessions. Sedentary time was mostly replaced by LIPA, whereas no changes in MVPA were observed. Taken together, these results highlight the high prevalence of SB in patients with CVD, and provide novel and important information on factors that are related to SB. These insights are relevant in the development of new strategies to stimulate patients with CVD to move more and sit less as CR programs only have small-to-modest effects on SB.

4.1. Patients with CVD versus controls

In line with our hypothesis, patients with CVD demonstrated a significantly higher SB and lower PA compared to age-matched controls, making them vulnerable to adverse outcomes [5]. In addition to total

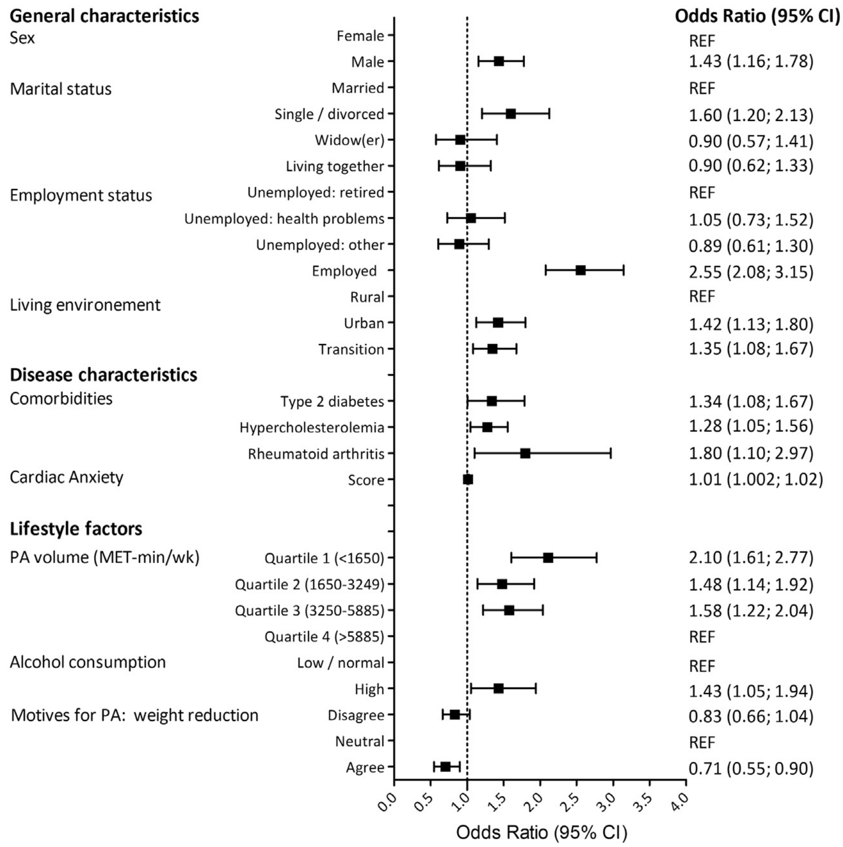

Fig. 2. Characteristics associated with high levels of sedentary time (≥8 h/day) in 2584 patients with cardiovascular disease. Data is presented as odds ratios with 95% confidence intervals. Sex, marital status, employment status, comorbidities, physical activity, alcohol consumption, cardiac anxiety, motives for physical activity and living environment were significantly associated with high levels of sedentary time.

sedentary time, previous work reported that the pattern of accumulation of sedentary time importantly contributes to the risk for cardiovascular events and mortality [13,34]. We found that patients with CVD demonstrated significantly more prolonged uninterrupted sedentary bouts compared to controls. These prolonged bouts have previously been linked to acute detrimental effects on vascular function, blood pressure and lipids [35], which may contribute to disease progression and long-term outcomes. Given the high prevalence of SB and prolonged uninterrupted sedentary bouts among patients with CVD, identification of factors associated with this unhealthy behaviour facilitates early recognition of individuals at risk.

4.2. Characteristics associated with high SB levels

We found that general characteristics (i.e. sex, marital status, employment status, living environment) and lifestyle-related characteristics (i.e. physical inactivity, alcohol consumption, motives for physical activity) were associated with total sedentary time of patients with CVD. It is interesting to note that these factors largely align with predictors of high SB levels in the general population [36,37], suggesting that SB may be independent of underlying disease. To support this hypothesis, the type of CVD diagnosis was not related to total sedentary time. On the other hand, patients with CVD with type 2 diabetes, hypercholesterolemia, and/or rheumatoid arthritis had higher odds of high SB levels. These findings suggest that existing comorbidities and cardiac anxiety, but not type of CVD diagnosis, impact SB levels of patients with CVD.

Insight into correlates of SB is important to identify patients with CVD with the highest SB levels, whereas it also facilitates development of interventions specifically targeting SB in patients with CVD. For example, modifiable factors as habitual physical activity levels, alcohol consumption, motives for physical activity, cardiac anxiety and optimal therapy for comorbidities should be considered when developing SB interventions. Furthermore, sedentary time was primarily spent during leisure time (Supplemental Fig. 4), suggesting that leisure time sedentary activities should be specifically targeted to achieve the largest reductions in total sedentary time.

4.3. Impact of CR on SB characteristics

CR programs are multidisciplinary, including both supervised exercise training and lifestyle modification, but SB is hardly addressed. Hence, it was no surprise that sedentary time was high and reduced only with 0.4 h/day following CR. A recent meta-analysis of observational studies showed that an objectively measured sedentary time ≥ 9.5 h/day was associated with an increased risk of all-cause mortality [6]. These findings suggest that ±75% of our patients with CVD (pre-CR sedentary time: 10.4 h/day [Q_{25} 9.5; Q_{75} 11.2]) are at risk for the detrimental health effects of SB, making these individuals highly vulnerable for recurrent cardiovascular events and premature death. We also found that the reduction in sedentary time was mainly replaced by LIPA, whereas no changes in MVPA were found post-CR. These results are in line with a recent meta-analysis [38] of randomized clinical trials suggesting no change in both LIPA and MVPA after CR. Although the changes in LIPA and sedentary time were small in our study, replacing sedentary time by LIPA aligns with the contemporary recommendation to 'move more and sit less' [39]. It is important to emphasise that these behavioural changes occurred in a CR program focusing on increasing PA levels, rather than reducing SB. This highlights the potency for interventions specifically targeting SB in CR programs, as replacement of

30 min sedentary time by 30 min of LIPA is associated with a 17% risk reduction of all-cause mortality [40]. Moreover, it is recommended to frequently break-up prolonged sedentary bouts [13,34,41], but currently no changes in this SB characteristic were observed following CR. In further understanding the role of SR, future should evaluate whether CR-induced changes in other cardiovascular risk factors (e.g. weight, fitness levels, cholesterol levels, blood pressure, medication use) are related to changes in SB. In addition, it would be interesting to explore whether tailoring CR to maximize changes in (long-term) SB could improve CR efficacy to reduce CVD morbidity and mortality.

Taken together, more attention in CR programs is needed to target high SB levels and prolonged uninterrupted sedentary bouts of patients with CVD. In this non-exercising population of patients with CVD, such lifestyle improvements may be more feasible and sustainable compared to MVPA interventions.

4.4. Strengths and limitations

The strengths of this study include the assessment of both objective and subjectively measured SB among two relatively large and independent cohorts of patients with CVD. Furthermore, longitudinal measurements were performed to assess the impact of CR on SB, LIPA and MVPA. Limitations of our study include the lack of a control group of patients with CVD not participating in CR and the limited follow-up time post-CR. Normalization of SB and LIPA may occur across longer time periods, limiting the generalizability of our findings to patients with chronic CVD. In addition, assessment of SB for objective 2 was based on self-reported data, which may result in an underestimation of SB. However, questionnaires provide domain-specific SB which is not available using objectively measured SB.

5. Conclusion

Patients with CVD demonstrate significantly higher amounts of SB compared to healthy controls, which may largely be explained through a more frequent engagement in prolonged, uninterrupted sedentary bouts. SB was most prevalent during leisure time and characteristics associated with high levels of SB in patients with CVD largely overlapped with the general population, except for comorbidities and cardiac anxiety. Furthermore, we found low engagement in MVPA in patients with CVD, which did not change following a CR program with supervised exercise training sessions. Therefore, adding interventions specifically aimed at reducing SB seems an important and feasible target to improve health in patients with CVD. Since reductions of SB will be replaced by LIPA and MVPA, our work enforces the health message to ‘sit less and move more’ in patients with CVD.

Author statement

Bakker contributed to conception, design, methodology, data curation, data analyses, data interpretation, data visualization, drafted the manuscript and critically revised the manuscript. Van Bakel contributed to conception, design, methodology, data curation, interpretation, and critically revised the manuscript. Thijssen and Eijsvogels contributed to conception, design, methodology, data interpretation, project administration and supervision, critically revised the manuscript, and acquired funding and resources. Aengevaeren, Meindersma, Snoek, Waskowsky, van Kuijk, Jacobs and Hopman contributed to the design, interpretation and critically revised the manuscript.

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Declaration of Competing Interest

The Authors declare that there is no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2020.11.014.

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