Comparison between center-based cardiac rehabilitation and home-based telerehabilitation regarding short-term health outcomes

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by

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Abstract

Introduction: Cardiovascular diseases (CVD) remain a leading cause of death globally. Both traditional center-based CR (cbCR) and cardiac telerehabilitation (teleCR) aim to educate and promote positive health behaviours, showing comparable outcomes in exercise capacity, mortality, cardiovascular (CV) risk factors, and quality of life. This study compares patient populations choosing cbCR or teleCR with regard to effectiveness for CV risk factors at a tertiary center in Switzerland, where CR is reimbursed by compulsory health insurance.

Method: This study compared two clinical cohorts using data from the Bern Rehab registry. It included cardiac patients enrolled in a 3-month ambulatory CR program at the Centre for Rehabilitation & Sports Medicine, University Hospital of Bern, between May 2022 and December 2023. Patients chose between ambulatory cbCR (three weekly exercise sessions at the center) and teleCR (one weekly session at the center and two at home). Patients had two visits, at the beginning and end of the program, where body composition, blood pressure, blood samples, and cardiopulmonary exercise testing (CPET) were conducted. Changes in outcome parameters with CR were compared between groups by linear mixed models adjusted for confounders.

Results: A total of 291 cbCR and 115 teleCR patients were included. TeleCR patients were younger by three years compared to cbCR patients and exhibited higher baseline peak VO_2, better quality of life, and less depression and anxiety. Adjusted models showed similar improvements in all outcome parameters over the CR period ($p > 0.05$). Compliance rates were similar across age groups and CR modalities. The proportion of patients meeting systolic blood pressure targets slightly decreased in both groups, while the percentage meeting low-density lipoprotein (LDL) targets improved considerably. However, LDL step I targets were only achieved in 69 % and 56 % in cbCR and teleCR patients, respectively.

Discussion and conclusion: TeleCR leads to equivalent results regarding CV risk factor profile as cbCR at a tertiary hospital in Switzerland. It is chosen by younger and fitter patients with higher quality of life and less depression and anxiety, with no difference between sexes.

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1 Introduction

1.1 Scientific background and initial status

Cardiovascular diseases (CVD) are leading non-communicable diseases (NCD) globally, responsible for approximately 17.5 million deaths each year (Al-Mawali, 2015). According to the World Health Organisation (n.d.), CVD encompasses a range of disorders affecting the heart and circulatory system, with four out of five CVD-related deaths attributed to heart attacks and strokes. Distinguishing between these conditions is crucial, as they impact physical performance differently, with strokes often significantly affecting future well-being. In this study we focused exclusively on heart diseases, excluding stroke from further consideration.

Myocardial infarctions (MI), commonly known as heart attacks, occur due to a disruption of blood flow in the coronary arteries, leading to decreased oxygen supply and myocardial damage. Recognizable symptoms include chest pain, fatigue, sweating, nausea, and irregular heartbeats (Lu et al., 2015). These clinical signs indicate myocardial ischemia, necessitating prompt diagnosis and intervention.

Another significant cardiovascular (CV) condition is chronic heart failure (CHF), characterized by either excessive stiffness or weakness of the heart, resulting in inadequate blood pumping and volume overload. CHF leads to blood accumulation in tissues and fluid retention in various compartments such as the lungs, abdomen, and legs. Clinical manifestations include dyspnea, weight gain due to water retention, and reduced energy levels (Baman & Ahmad, 2020). It is essential to note that CHF can be a consequence of CVD, sharing common risk factors such as physical inactivity, unhealthy diet, as well as tobacco and alcohol consumption, leading to conditions like obesity, hypertension, and elevated lipid levels (World Health Organisation, n.d.).

In Switzerland, CVD accounted for 27.5 % of the total 74,425 reported deaths in 2022. Despite a 17 % reduction in CVD-related mortality rates from 2002 to 2022, hospitalization rates increased by 12 % during the same period, reflecting complex factors influencing healthcare utilization (Federal Statistical Office, 2023a, 2023b; Swiss Health Obervatory, 2021).

Cardiac rehabilitation (CR) is a well-established, evidence-based and multidisciplinary intervention aimed at educating patients about their disease and promoting positive health behaviours such as smoking cessation, adopting a healthy diet, weight management, and regular physical activity to prevent future CV events (Batalik et al., 2020b; Wang et al., 2023). CR plays a crucial role in reducing both mortality and morbidity in individuals who have

experienced a cardiac event, improving their quality of life and psychological well-being (Shields et al., 2018).

Despite the proven benefits of CR, adherence rates remain suboptimal (Batalik et al., 2020b; Owen & O'Carroll, 2022; Ritchey et al., 2020). A study by Ritchey et al. (2020) found that in the U.S.A., only 24.4 % of eligible ambulatory patients engaged in CR, with even lower completion rates. Similarly, a Swiss study reported participation rate of only 35 % for ambulatory CR, with participation dropping to 23 % for patients aged 65 and older (Gonzalez-Jaramillo et al., 2022). To address low participation rates, home-based cardiac telerehabilitation (teleCR) has emerged as a promising alternative, leveraging technological advancements to deliver remote rehabilitation services (Batalik et al., 2020b; Hwang et al., 2023). Evidence suggests that both traditional center-based CR (cbCR) and teleCR yield comparable outcomes in terms of exercise capacity, mortality, CV risk factors, and quality of life among patients with CVD and/or CHF (Anderson et al., 2017; Batalik et al., 2020b).

1.2 Objective and specific question

At the Centre for Rehabilitation & Sports Medicine of the University Hospital of Bern, Switzerland, we have been offering a teleCR for almost two years. In contrast to most other developed countries, in Switzerland, CR is reimbursed by compulsory health insurance. The consequence of this universal reimbursement is that minorities are not underrepresented amongst CVD patients completing CR (Gonzalez-Jaramillo et al., 2022). In line with most developed countries, health costs are rising steeply necessitating the evaluation of cheaper therapy alternatives, such as teleCR. This study aimed to identify the patient populations choosing ambulatory cbCR or teleCR in Switzerland, where CR is accessible to all patients regardless of socioeconomic status, and to compare the health outcomes of these two CR modalities with each other. Chosen health outcomes were changes in cardiorespiratory fitness, body weight, blood pressure, lipid profile, self-reported quality of life, depression and anxiety.

2 Method

This study compared two clinical cohorts using data from the Bern Rehab registry (clinicaltrials.gov), established on 09.12.2020 in RedCap (REDCap, Version 14.0.24, Vanderbilt University, Nashville, USA). Data were prospectively collected, ensuring real-time event recording. Electronic health records from the hospital system (i-pdos_Prod_ODA, CompuGroup Medical, Koblenz, Germany) were also utilized. Approval for the registry study was obtained from the Ethics Committee of Bern.

2.1 Study Population

The study included consecutive cardiac patients who enrolled in a 3-month ambulatory CR program at the University Hospital of Bern, Switzerland, between May 2022 and December 2023. Patients could choose their preferred CR delivery as ambulatory cbCR or teleCR.

The inclusion criteria comprised in the least partial completion of the CR entry visit and provision of written general informed consent for the utilization of their medical data. Patients with diagnosis such as acute coronary syndrome (ACS) or chronic coronary syndrome (CCS), with or without percutaneous coronary intervention (PCI) or coronary artery bypass surgery (CABG), CHF, valve surgery or intervention, and adult congenital heart disease (ACHD) were included. The exclusion criteria encompassed the absence of general informed consent provision and/or failure to complete the CR entry examination. Furthermore, patients undergoing rehabilitation for cardio-oncologic, neurovascular, or diabetic conditions, alongside those with peripheral arterial disease (PAD) and large vessel intervention, were excluded from the study.

2.2 Patient assessments

Patients enrolling for CR were scheduled for an entry examination at the Center for Rehabilitation and Sports Medicine at the University Hospital of Bern. During this visit, the patients' CV risk factor profile, medical therapy and cardiorespiratory fitness were assessed. Based on the cardiopulmonary exercise test (CPET), the training zones for the rehabilitation endurance sessions were determined. The same examination was conducted during the conclusion visit shortly before or after completion of the 12-week CR program to evaluate the rehabilitation progress.

The two identical visits included a weight and body composition measurements using the InBody 770 device (InBody, Seoul, South Korea). Blood pressure was assessed three times on

the left arm in a seated position, and the average of the two last readings was recorded. Subsequently, blood samples were collected from the antecubital vein while patients were supine. Blood samples were analysed for total cholesterol, low-density lipoprotein (LDL), and high-density lipoprotein (HDL). Non-HDL-C was calculated as total cholesterol - HDL. Patients also completed questionnaires on quality of life (HeartQoL), depression (PHQ9), and anxiety (GAD7) and tobacco consumption (Fagerstöm).

Subsequently, a ten-second resting 12-lead electrocardiography (ECG) was conducted using the AMEDTEC ECGpro Cardiopart 12 Blue system (AMEDTEC Medizintechnik, Aue, Germany). Advanced practice nurses then auscultated patients for signs of lung edema and assessed jugular vein distention. Spirometry was performed before the CPET to assess forced vital capacity (FVC) and forced expiratory volume in one second (FEV1).

Ramp tests were conducted preferably on a cycle ergometer or on a treadmill, if cycling was contraindicated. ECG electrodes were repositioned to monitor heart rhythm during exercise. Participants were equipped with a respiratory facemask and blood pressure cuff, with manual blood pressure measurements conducted every 2 minutes during cycling and at the initiation and conclusion of treadmill tests. The ramp protocol was chosen based on participants' reported fitness levels, aiming for exhaustion within 8 to 12 minutes, with workload increments set at 5, 10, or 20 W/min for cycling, or 1.3 km/h and 2 % elevation every 3 minutes for treadmill tests. The CPET protocol began with a 3-minute resting phase followed by a 3-minute warm-up at low intensity. Subjects were instructed to maintain a cadence of 60 to 70 rpm during cycling. The test continued until exhaustion or was terminated by the supervising physician or advanced practice nurses due to clinical indications and followed by an active cool-down. Flows and O_2 and CO_2 concentrations were measured breath-by-breath using an open spirometric system (Quark, COSMED, Rome, Italy) and averaged over 8 breaths, with the system calibrated according to manufacturer guidelines before each CPET.

Anamnesis was conducted with a physician, medication discussed and adapted if necessary and available modes of rehabilitation presented (as detailed below).

2.3 Rehabilitation programs

The University Hospital of Bern provides two modalities for CR: cbCR and teleCR. Each program typically lasts 12 weeks, including three exercise training sessions per week.

A multidisciplinary team consisting of physicians, advanced practice nurses, physiotherapists, sports scientists, psychologists, and nutritionists supports the CR programs at the hospital. The healthcare team informs patients about the availability of psychological support, such as

assistance in smoking cessation or coping with the psychological aftermath of their cardiac event, provided by the cardiac psychology team. Additionally, patients can opt for nutritional assistance to manage risk factors like dyslipidemia and glycaemia, while maintaining a healthy diet.

During the CR program, each patient receives two telephone or on-site consultations by either a physician or an advanced practice nurse. The multi-disciplinary team also conducts group presentations/discussions covering topics such as CVD etiologies, risk factor management, and medication.

2.3.1 Ambulatory center-based cardiac rehabilitation

The physical training sessions of the cbCR lasting 90 minutes were conducted thrice weekly at the physiotherapy department of the University Hospital of Bern. Sessions accommodated up to 10 patients and included 40 minutes of ECG-monitored cycling on the cycle ergometers (ergoline GmbH, Bitz, Germany) and 45 minutes of strength training, gymnastics, relaxation, or outdoor Nordic walking.

2.3.2 Home-based cardiac telerehabilitation

In the teleCR patients were free to complete one to three trainings sessions at home, in a gym, or a location of their choice. TeleCR also included patients who chose a combination of cbCR and teleCR with 1-2 weekly training sessions at the center and the remaining sessions at home. Whichever combination they chose, patients were instructed to complete a total of three exercise sessions minimally to achieve at least 150 min/week of endurance training and two additional sessions of strength training. To objectively monitor patients' physical activity by daily steps, patients were equipped with a Fitbit watch (Inspire 2 or Charge 3; Fitbit Inc., San Francisco, USA). These watches were synchronized with the Fitbit smartphone application, enabling comprehensive parameter visualisation on the patients' phones. The EVITA electronic health record (Swisscom AG, Ittigen, Switzerland) facilitated data transmission to the hospital sport scientists.

Patients further received a Healer R3 biosensor vest (L.I.F.E. Italia s.r.l., Milano, Italy) which they were instructed to wear during their exercise training sessions. From this, data from 6-lead ECG, strain gauges measuring thorax movement by breathing, and accelerometry were transmitted by SIM card to a platform. Filtered signals and calculated data such as HR, breathing rate and number of steps were monitored by the sports scientist and discussed with the patients on a weekly basis. During these weekly 15 to 30-minute phone calls, sport scientist

provided personalized feedback to completed training sessions, offered training guidance regarding type of exercise, volume and intensity of training, and discussed potential barriers to training and methods to overcome these barriers. The aim of the calls was to help the patient in adopting exercise training of their chosen sports that could be accommodated in their daily schedules and sustained beyond the CR program. Upon request, additional devices such as scales and blood pressure monitors were supplied, which automatically transmitted relevant parameters to the EVITA platform. Whenever necessary, patients were directed to the cardiac psychology or nutrition team for specialized assistance.

2.4 Data curation and statistical analysis

Data from the Bern Rehab registry, LookinBody120 (InBody, Seoul, South Korea), COSMED and AMEDTEC were downloaded as csv files. Missing data and outliers amongst the data from the Bern Rehab Registry were retrieved or verified and corrected with data extracted manually from the hospital information system. Thresholds for systolic blood pressure, LDL, glycated haemoglobin (HbA1c) and weight changes were used to calculate the percentage of patients satisfying target values. For systolic blood pressure, step I target was set at < 140 mmHg and step II at < 130 mmHg. For LDL the threshold for step I was set at < 1.8 mmol/l and at < 1.4 mmol/l for step II. For HbA1c of non-diabetic patients the target value was 5.7 % and for diabetic patients it was 7.0 % (Marx et al., 2023; Visseren et al., 2022). Weight change targets were set at ≥ 5 % for patients with BMI ≥ 28. Changes between entry and completion tests were calculated for all outcome parameters. If testing modality of the CPET at entry and conclusion visit was not congruent, changes between time points were not calculated for peak exercise values. Also, if ramp duration of CPET was < 4 min, peak values were not utilized. Power was only measured for cycling tests. Further, proportions of patients meeting target values for CVD risk factors were calculated for the two CR modalities separately. Compliance was calculated for center-based (cb) training sessions, whereby teleCR patients had one prescribed weekly cb session, and cbCR patients had 3 weekly cb sessions for patients aged < 65 years and 2 sessions for patients aged ≥ 65 years. Baseline characteristics were tested between groups of different CR modalities using Kruskal-Wallis test and post hoc pairwise Wilcoxon rank-sum test with continuity correction and the Benjamini-Hochberg adjustment. Chi-square tests were used for categorical (dichotomous) data. Analysis were performed with RStudio (Posit, Version 2021.09.2, Boston, USA). Between-group differences in changes from baseline to 12 weeks were conducted using linear mixed models with fixed factors group and visit as well as their interaction, random factor patient and adjusted for baseline age, sex, height and weight

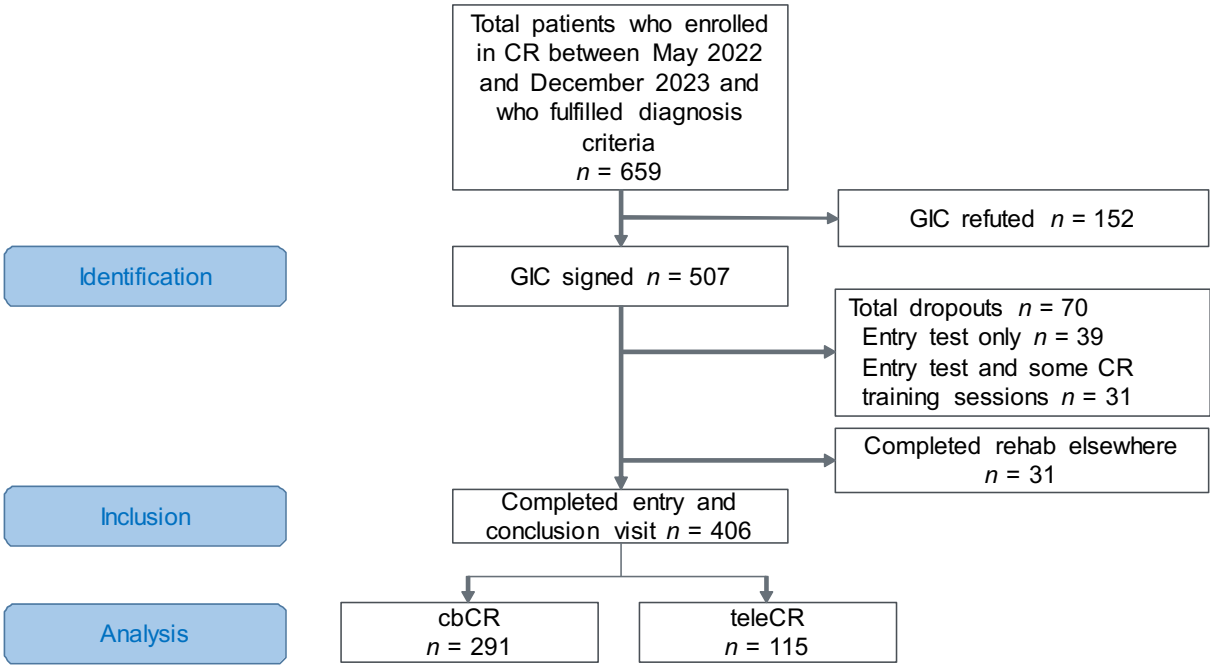
(packages “lme4” and “lmer”). For non-parametric questionnaire data, the dependent variable was transformed to achieve normal distribution of residuals as visually inspected. Statistical significance was determined at a threshold of $p < 0.05$.

3 Results

Of the 659 patients meeting primary diagnosis criteria, 507 had consented for further data usage and of these, 406 completed CR at the University Hospital of Bern, either as cbCR or teleCR (Figure 1). Seventy patients were dropouts because they neither completed CR nor a conclusion visit. Thirty-one patients completed CR in another, mostly stationary centre. Of the two latter groups only baseline data were analysed. Of the 406 patients who completed CR as well as a conclusion visit, 291 patients completed cbCR and 115 teleCR.

Figure 1

Study flowchart



Note. Patients were included if they had a CR entry visit and provided written general informed consent. Further indicated are patients who did not complete the CR conclusion visit or completed CR at a different centre.

cbCR, center-based cardiac rehabilitation; CR, cardiac rehabilitation; GIC, general informed consent; teleCR, cardiac telerehabilitation.

Table 1

Baseline characteristics of groups according to CR modality and completion

	cbCR ***n*** **=291**	**teleCR** ***n*** **=115**	**CR elsewhere** ***n*** **= 31**	**Dropouts** ***n*** **= 70**	***p*-value**
Age [years ± SD]	61.3 ± 12.4	58.3 ± 13.2	65.8 ± 11.7	61.5 ± 13.1	**0.025**
Sex					
Male	229 (78.7)	93 (80.9)	22 (71.0)	54 (77.1)	0.681
Female	62 (21.3)	22 (19.1)	9 (29.0)	16 (22.9)	
Migration status					
None (or third generation +)	218 (74.9)	92 (80.0)	29 (93.5)	51 (72.9)	**0.028**
First generation	66 (22.7)	16 (13.9)	2 (6.5)	15 (21.4)	
Second generation	4 (1.4)	6 (5.2)	0 (0)	1 (1.4)	
Missing data	3 (1.0)	1 (0.9)	0 (0)	3 (4.3)	
Marital status					
Single	50 (17.2)	20 (17.4)	4 (12.9)	14 (20.0)	0.564
Married	185 (63.6)	71 (61.7)	20 (64.5)	38 (54.3)	
Divorced	43 (14.8)	22 (19.1)	4 (12.9)	15 (21.4)	
Widowed	13 (4.5)	2 (1.7)	3 (9.7)	3 (4.3)	
Primary diagnosis					
ACS	170 (58.4)	73 (63.5)	22 (71.0)	35 (50.0)	0.639
CCS	45 (15.5)	18 (15.7)	3 (9.7)	14 (20.0)	
Valve	26 (8.9)	5 (4.3)	3 (9.7)	9 (12.9)	
CHF	37 (12.7)	14 (12.2)	3 (9.7)	10 (14.3)	
ACHD	13 (4.5)	5 (4.3)	0 (0)	2 (2.9)	
Hypertension	166 (57.0)	58 (50.4)	17 (54.8)	38 (54.3)	0.688
Diabetes mellitus	58 (19.9)	13 (11.3)	6 (19.4)	20 (28.6)	**0.034**
Obesity	89 (30.6)	32 (27.8)	11 (35.5)	25 (35.7)	0.663
Dyslipidemia	179 (61.5)	69 (60.0)	17 (54.8)	43 (61.4)	0.904
Atrial fibrillation					
None	261 (89.7)	100 (87.0)	28 (90.3)	62 (88.6)	0.641
Paroxysmal	22 (7.6)	15 (13.0)	2 (6.5)	7 (10.0)	
Persistent	7 (2.4)	0 (0)	1 (3.2)	1 (1.4)	
Permanent	1 (0.3)	0 (0)	0 (0)	0 (0)	
Smoking					
Never	98 (33.7)	51 (44.3)	9 (29.0)	12 (17.1)	**0.041**
Former smoker, stop > 6 months	95 (32.6)	30 (26.1)	12 (38.7)	28 (40.0)	
Former smoker, stop < 6 months	46 (15.8)	13 (11.3)	3 (9.7)	5 (7.1)	
Currently smoking occasionally	6 (2.1)	3 (2.6)	1 (3.2)	2 (2.9)	
Currently smoking daily	44 (15.1)	17 (14.8)	5 (16.1)	18 (25.7)	
Missing	2 (0.7)	1 (0.9)	1 (3.2)	5 (7.1)	

Note. The results are presented as both absolute patient counts and corresponding percentages of the respective CR modality if not indicated otherwise.

ACHD, adult congenital heart disease; ACS, acute coronary syndrome; cbCR, center-based cardiac rehabilitation; CR, cardiac rehabilitation; CCS, chronic coronary syndrome; CHF, chronic heart failure; teleCR, cardiac telerehabilitation; Valve, valve surgery or intervention.

A comprehensive overview of patients' baseline characteristics is provided by groups according to whether and where they performed CR (Table 1). Age differed between the four patient groups with the teleCR patients being 7.5 years younger than the CR elsewhere and 3 years younger than cbCR patients ($p = 0.025$). Dropout patients exhibited the lowest percentage of none or third-generation migration background (73 %), the highest prevalence of diabetes mellitus (29 %), and the lowest proportion of non-smokers (17 %), with 26 % still smoking daily after hospitalization.

Measurements quantifying the CV risk profile at the CR entry visit as well as changes thereof between entry and conclusion visit were compared between cbCR and teleCR patients (Table 2). At baseline, there were no differences between cbCR and teleCR patients in body composition and LDL levels. However, teleCR had higher total cholesterol ($p = 0.034$) and HDL ($p = 0.027$), but lower HbA1c ($p = 0.016$). Systolic blood pressure tended to be higher ($p = 0.062$) in teleCR patients. Variables of cardiorespiratory fitness were not available in 26 patients (18 cbCR and 8 teleCR) who did not complete a CPET at either entry or conclusion visit. Further, in 6 cbCR and 8 teleCR patients the testing modality was disparate (e.g. treadmill test at entry and cycling test at conclusion), so that changes from entry to conclusion visit could not be calculated and in 2 cbCR patients, ramp duration was < 4 min, which is why values measured at peak exercise were discarded and changes between visits not calculated. CPET parameters at peak exercise were all higher in the teleCR patients (all $p \leq 0.002$), except for respiratory exchange ratio (RER) and breathing frequency (BF). The ventilation to carbon dioxide production slope (VE/VCO_2 slope) was lower in the teleCR patients ($p = 0.042$). CPET resting values showed lower BF ($p = 0.012$), higher FVC ($p = 0.005$) and higher FEV1 ($p = 0.003$) in teleCR patients. Furthermore, teleCR patients had higher quality of life ($p < 0.001$), were less depressed ($p = 0.017$) and less anxious ($p = 0.055$) than cbCR patients.

From entry to conclusion visit, cbCR patients had a 3.5 % greater improvement in peak VO_2 of predicted (11.8 % vs. 8.3 % in teleCR patients ($p = 0.029$). Likewise, $PETCO_2$ increased more in cbCR patients compared to teleCR patients ($p = 0.011$). Missing data and corresponding percentages are detailed in Table 1 of the Appendix. The linear mixed models for relative (to body weight) peak VO_2 adjusted for age, sex, height, weight at baseline resulted in 17 % higher peak VO_2 in the teleCR patients at baseline ($p < 0.001$) but comparable increases to conclusion visit ($p = 0.234$ for interaction effect). Compliance with cb training sessions was 80.8 % for cbCR patients under 65 years and 86.3 % for those over 65 years. Amongst teleCR patients, compliance rates were 81.1 % for individuals under 65 years and 85.9 % for those over 65 years.

Table 2

Baseline values and changes between entry and conclusion visit of cbCR and teleCR groups

	Baseline values			Changes from entry to conclusion visit		
	cbCR ***n*** **= 291**	**teleCR** ***n*** **= 115**	***p*-value**	**cbCR** ***n*** **= 291**	**teleCR** ***n*** **= 115**	***p*-value**
Body composition						
BMI [kg/m^2]	26.7 ± 4.71	26.7 ± 4.41	0.726	0.136 ± 1.25	0.054 ± 1.26	0.236
Weight [kg]	79.9 ± 15.6	81.2 ± 14.1	0.305	0.41 ± 3.77	0.16 ± 3.86	0.221
Skeletal muscle mass [kg]	32.0 ± 6.12	33.1 ± 5.34	0.096	0.09 ± 1.34	0.07 ± 1.05	0.698
Skeletal muscle mass index [kg/m^2]	10.6 ± 1.38	10.8 ± 1.13	0.116	0.04 ± 0.42	0.02 ± 0.34	0.633
Body fat mass [kg]	22.6 ± 10.5	21.8 ± 9.72	0.562	0.34 ± 3.32	-0.04 ± 2.76	0.212
Body fat mass [%]	27.4 ± 9.25	26.1 ± 8.91	0.202	0.37 ± 3.21	-0.07 ± 2.55	0.435
Blood pressure						
Systolic BP [mmHg]	123 ± 15.6	126 ± 15.4	0.062	1.64 ± 16.9	1.11 ± 15.5	0.748
Diastolic BP [mmHg]	70.0 ± 9.95	72.9 ± 10.7	**0.016**	-0.52 ± 11.1	-0.31 ± 11.1	0.865
Lipid and glycaemic profile						
Total cholesterol [mmol/l] [a]	3.80 ± 1.09	4.01 ± 1.09	**0.034**	-0.42 ± 1.00	-0.43 ± 0.97	0.588
HDL [mmol/l] [a]	1.17 ± 0.31	1.26 ± 0.32	**0.027**	0.10 ± 0.23	0.07 ± 0.21	0.283
LDL [mmol/l] [a]	2.14 ± 0.986	2.23 ± 1.01	0.390	-0.50 ± 0.93	-0.44 ± 0.89	0.253
HbA1c [%]	5.90 ± 0.861	5.71 ± 0.692	**0.016**	0.03 ± 0.51	0.06 ± 0.37	0.963
CPET rest						
VE [l/min]	14.4 ± 3.33	14.1 ± 3.17	0.408	-0.26 ± 3.07	0.05 ± 3.22	0.393
BF [cpm]	17.1 ± 4.10	15.9 ± 3.59	**0.012**	-0.34 ± 3.36	-0.28 ± 3.24	0.880
VT [l]	0.88 ± 0.26	0.92 ± 0.27	0.219	-0.00 ± 0.25	0.02 ± 0.29	0.625
$PETCO_2$ [mmHg]	26.8 ± 3.63	27.5 ± 3.50	0.075	0.69 ± 3.10	0.81 ± 2.74	0.708
FVC [l]	3.87 ± 1.02	4.18 ± 0.936	**0.005**	0.18 ± 0.54	0.22 ± 0.46	0.260
FEV1 [l/min]	2.94 ± 0.81	3.21 ± 0.762	0.003	0.07 ± 0.44	0.13 ± 0.34	0.254
CPET exercise [b]						
Peak VO_2 [ml/min]	1600 ± 515	1930 ± 601	**< 0.001**	243 ± 362	178 ± 360	0.056
Peak VO_2 [ml/min/kg]	20.1 ± 5.63	23.9 ± 7.19	**< 0.001**	2.91 ± 4.49	2.41 ± 4.59	0.167
Predicted peak $\dot{V}O_2$ [%]	80.0 ± 19.9	91.1 ± 23.8	**< 0.001**	11.8 ± 16.6	8.3 ± 15.7	**0.029**
Peak power [W] [c]	133 ± 52.8	162 ± 57.6	**< 0.001**	23.3 ± 26.8	21.2± 27.1	0.254
Peak power [W/kg] [c]	1.67 ± 0.61	2.02 ± 0.73	**< 0.001**	0.28 ± 0.34	0.27 ± 0.34	0.531
VE [l/min]	70.2 ± 23.4	80.1 ± 26.6	**0.002**	5.21 ± 13.9	7.10 ± 17.5	0.600
BF [cpm]	33.4 ± 7.00	33.2 ± 7.18	0.924	0.44 ± 5.13	1.81 ± 5.84	0.107
VT [l]	2.12 ± 0.61	2.42 ± 0.64	**< 0.001**	0.12 ± 0.31	0.07 ± 0.30	0.157
$PETCO_2$ [mmHg]	30.7 ± 5.07	32.6 ± 5.18	**0.002**	1.77 ± 3.72	0.50 ± 3.27	**0.011**
HR [bpm]	128 ± 23.7	138 ± 23.0	**< 0.001**	3.58 ± 18.9	2.89 ± 16.7	0.631
RER	1.14 ± 0.14	1.14 ± 0.13	0.813	-0.01 ± 0.16	0.02 ± 0.14	0.081
VE/VCO_2 slope	35.6 ± 7.87	33.8 ± 6.85	**0.042**	-2.18 ± 6.43	-1.67 ± 4.78	0.942
Psychological well-being						
HeartQoL score	2.09 ± 0.63	2.32 ± 0.59	**< 0.001**	0.37 ± 0.55	0.33 ± 0.47	0.462
PHQ9 score	5.29 ± 4.45	4.12 ± 3.69	**0.017**	-1.57 ± 3.63	-1.28 ± 3.00	0.548
GAD7 score	3.50 ± 3.67	2.90 ± 3.43	0.055	-0.87 ± 2.78	-1.03 ± 2.21	0.490

Note. The results are presented as mean ± SD.

[a] Lipid profile was only analysed for patients with ACS and CCS; [b] CPET data only from 278 cbCR patients and 104 teleCR patients excluding patients with disparent testing modalities;

Table 2

(Continued)

[c] data from 276 cbCR patients and 103 teleCR patients who performed cycling tests

ACS, acute coronary syndrome; BF, breathing frequency; BMI, body mass index; BP, blood pressure; cbCR, center-based cardiac rehabilitation; CCS, chronic coronary syndrome; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; GAD7, generalized anxiety disorder; HbA1c, glycated haemoglobin; HDL, high-density lipoprotein; HeartQoL, health-related quality of life; HR, heart rate; LDL, low-density lipoprotein; $PETCO_2$, partial pressure of end-tidal carbon dioxide; PHQ9, patient health questionnaire; teleCR, cardiac telerehabilitation; VE, ventilation; VE/VCO_2, ratio of minute ventilation to carbon dioxide production; peak VO_2, peak oxygen uptake; VT, tidal volume.

Changes in CVD risk profile outcomes were also assessed by models adjusted for age, sex, height and weight (Table 3). Normal distribution of residuals of the models for PHQ9 and GAD7 was achieved by transforming the dependent variable by the power of 0.33. According to these models, patients of the teleCR group had a 3.3 ml/min/kg higher peak VO_2, and 4.0 mmHg higher systolic blood pressure ($p = 0.017$) at baseline. Further, teleCR patients had higher quality of life ($p < 0.001$) and less depression ($p = 0.002$) and had less anxiety ($p = 0.020$) at baseline. None of the changes in CVD risk profile outcomes differed between groups (group x conclusion visit interactions, Table 3). From entry to conclusion visit, peak VO_2 increased by 3.0 ml/min/kg ($p < 0.001$), LDL and non-HDL-C decreased by -0.5 mmol/l ($p < 0.001$), quality of life increased by 0.4 points ($p < 0.001$), depression decreased by -1.6 points ($p < 0.001$) and anxiety decreased by -0.9 points ($p < 0.001$).

Female sex was associated with a -3.4 ml/min/kg lower peak VO_2, a 0.4 mmol/l higher LDL ($p = 0.003$) and non-HDL-C ($p = 0.004$), and -0.3 % lower HbA1c ($p = 0.016$). They had lower quality of life (-0.3 points, $p < 0.001$), and had higher depression (1.5 points, $p = 0.022$). Per decade of older age, peak VO_2 decreased by -1.5 ml/min/kg, systolic blood pressure increased by 3.1 mmHg, LDL and non-HDL-C decreased by -0.1 mmol/l, and HbA1c increased by 0.1 % (all $p \leq 0.004$). Older age was associated with higher quality of life ($p = 0.004$), and less depression and anxiety (both $p < 0.001$). Increased weight was associated with lower quality of life ($p = 0.004$) and greater anxiety ($p = 0.012$).

Table 3

Results from linear mixed models for parameters of cardiovascular risk factor profile with CR modes and visit (incl. interaction), adjusted for sex, age, height, and weight

Dependent variable	Predictor	Estimate	95 % CI	*p*-value
Peak VO_2 [ml/min] [a]	Intercept	-1408.67	-2561.51 – -255.83	**0.017**
	TeleCR group	264.96	160.72 – 369.21	**<0.001**
	Conclusion visit	242.85	201.26 – 284.44	**<0.001**
	Female sex	-253.63	-387.44 – -119.82	**<0.001**
	Age [years]	-11.73	-15.13 – -8.34	**<0.001**
	Height [cm]	17.18	10.48 – 23.87	**<0.001**
	Weight [kg]	9.98	6.84 – 13.12	**<0.001**
	Group [teleCR] x Conclusion visit interaction	-66.75	-146.50 – 13.01	0.102
Peak VO_2 [ml/min/kg] [a]	Intercept	5.89	-8.61 – 20.38	0.427
	TeleCR group	3.31	1.99 – 4.62	**<0.001**
	Conclusion visit	3.02	2.49 – 3.56	**<0.001**
	Female sex	-3.38	-5.06 – -1.69	**<0.001**
	Age [years]	-0.15	-0.19 – -0.11	**<0.001**
	Height [cm]	0.20	0.11 – 0.28	**<0.001**
	Weight [kg]	-0.13	-0.17 – -0.09	**<0.001**
	Group [teleCR] x Conclusion visit interaction	-0.62	-1.64 – 0.40	0.234
Weight [kg]	Intercept	-52.57	-86.95 – -18.19	**0.003**
	TeleCR group	-0.07	-2.99 – 2.86	0.965
	Conclusion visit	0.41	-0.02 – 0.85	0.065
	Female sex	1.17	-2.83 – 5.17	0.566
	Age [years]	-0.08	-0.18 – 0.03	0.144
	Height [cm]	0.79	0.60 – 0.98	**<0.001**
	Group [teleCR] x Conclusion visit interaction	-0.25	-1.07 – 0.57	0.545
Systolic BP [mmHg]	Intercept	128.89	95.20 – 162.58	**<0.001**
	TeleCR group	4.04	0.73 – 7.35	**0.017**
	Conclusion visit	1.59	-0.28 – 3.46	0.098
	Female sex	-2.36	-6.23 – 1.52	0.235
	Age [years]	0.31	0.21 – 0.41	**<0.001**
	Height [cm]	-0.28	-0.48 – -0.09	**0.005**
	Weight [kg]	0.30	0.21 – 0.40	**<0.001**
	Group [teleCR] x Conclusion visit interaction	-0.52	-4.03 – 2.99	0.771
LDL [mmol/l] [b]	Intercept	1.34	-0.91 – 3.59	0.245
	TeleCR group	0.07	-0.14 – 0.27	0.516
	Conclusion visit	-0.50	-0.62 – -0.37	**<0.001**
	Female sex	0.39	0.13 – 0.64	**0.003**
	Age [years]	-0.01	-0.02 – -0.00	**0.004**
	Height [cm]	0.01	-0.00 – 0.02	0.197
	Weight [kg]	0.00	-0.01 – 0.01	0.947
	Group [teleCR] x Conclusion visit interaction	0.05	-0.17 – 0.28	0.645
Non-HDL-C [mmol/l] [b]	Intercept	2.47	0.02 – 4.92	**0.049**
	TeleCR group	0.11	-0.12 – 0.33	0.355
	Conclusion visit	-0.52	-0.65 – -0.38	**<0.001**
	Female sex	0.41	0.13 – 0.68	**0.004**
	Age [years]	-0.01	-0.02 – -0.00	**0.006**
	Height [cm]	0.00	-0.01 – 0.02	0.652
	Weight [kg]	0.00	-0.00 – 0.01	0.342

Table 3

(Continued)

Dependent variable	Predictor	Estimate	95 % CI	*p*-value
Non-HDL-C [mmol/l] [b]	Group [teleCR] x Conclusion visit interaction	0.01	-0.24 – 0.25	0.964
HbA1c [%]	Intercept	7.95	6.15 – 9.75	**<0.001**
	TeleCR group	-0.15	-0.31 – 0.00	0.059
	Conclusion visit	0.03	-0.02 – 0.08	0.291
	Female sex	-0.26	-0.46 – -0.05	**0.016**
	Age [years]	0.01	0.00 – 0.01	**0.003**
	Height [cm]	-0.02	-0.03 – -0.01	**<0.001**
	Weight [kg]	0.01	0.01 – 0.02	**<0.001**
	Group [teleCR] x Conclusion visit interaction	0.03	-0.07 – 0.13	0.597
HeartQoL score	Intercept	1.05	-0.17 – 2.27	0.092
	TeleCR group	0.24	0.12 – 0.35	**<0.001**
	Conclusion visit	0.38	0.31 – 0.44	**<0.001**
	Female sex	-0.30	-0.43 – -0.16	**<0.001**
	Age [years]	0.01	0.00 – 0.01	**0.004**
	Height [cm]	0.01	-0.00 – 0.01	0.056
	Weight [kg]	-0.01	-0.01 – -0.00	**0.002**
	Group [teleCR] x Conclusion visit interaction	-0.04	-0.16 – 0.07	0.446
PHQ9 score [c]	Intercept	2.51	1.61 – 3.41	**<0.001**
	TeleCR group	-0.14	-0.22 – -0.05	**0.002**
	Conclusion visit	-0.17	-0.21 – -0.13	**<0.001**
	Female sex	0.12	0.02 – 0.22	**0.022**
	Age [years]	-0.01	-0.01 – -0.00	**<0.001**
	Height [cm]	0.00	-0.01 – 0.00	0.259
	Weight [kg]	0.00	-0.00 – 0.00	0.290
	Group [teleCR] x Conclusion visit interaction	0.03	-0.05 – 0.10	0.493
GAD7 score [c]	Intercept	2.79	1.88 – 3.70	**<0.001**
	TeleCR group	-0.10	-0.18 – -0.02	**0.020**
	Conclusion visit	-0.11	-0.15 – -0.08	**<0.001**
	Female sex	0.02	-0.08 – 0.13	0.677
	Age [years]	-0.01	-0.01 – -0.00	**<0.001**
	Height [cm]	-0.01	-0.01 – -0.00	**0.018**
	Weight [kg]	0.00	0.00 – 0.01	**0.009**
	Group [teleCR] x Conclusion visit interaction	-0.02	-0.08 – 0.05	0.639

Note. [a] data only from 278 cbCR patients and 104 teleCR patients with available CPET data; [b] data only from ACS and CCS patients (215 cbCR and 91 teleCR); [c] PHQ9 and GAD7 were transferred as follows to achieve normal distribution of residuals: (x+1)^0.33.

BP, blood pressure; CI, confidence interval; CR, cardiac rehabilitation; GAD7, generalized anxiety disorder; LDL, low-density lipoprotein; non-HDL-C, total cholesterol - high density lipoprotein; HbA1c, glycated haemoglobin; HeartQoL, health-related quality of life; PHQ9, patient health questionnaire; teleCR, cardiac telerehabilitation; peak VO_2, peak oxygen uptake.

Percentage of patients meeting target values for CV risk factors according to CR modality are shown in Table 4. The proportion of patients meeting target values for systolic blood pressure decreased slightly in both CR modality groups, while the percentages of patients meeting LDL targets improved considerably. Changes in patients meeting target levels of HbA1c were small, however, for non-diabetic patients in the cbCR group, the percentage meeting target HbA1c values dropped from 54 % to 41 %.

Table 4

Proportion of patients meeting target values for CV risk factors

Variable	cbCR		teleCR	
	Entry in %	Conclusion in %	Entry in %	Conclusion in %
Systolic BP < 140 mmHg	83.1	81.8	83.5	83.5
Systolic BP < 130 mmHg	69.3	64.3	60.9	57.4
LDL < 1.8 mmol/l [a]	42.3	69.3	36.3	56.0
LDL < 1.4 mmol/l [a]	22.3	40.9	20.9	29.7
HbA1c < 7.0 % [b]	58.6	63.8	53.9	61.54
HbA1c < 5.7 % [c]	53.7	40.9	59.8	61.6
Body weight loss > 5 % [d]		14.3		3.1

Note. The results are presented as percentages.

[a] Data only from ACS and CCS patients (215 cbCR and 91 teleCR); [b] Data only from diabetic patients (58 cbCR and 13 teleCR); [c] Data only from non-diabetic or pre-diabetic patients (233 cbCR and 102 teleCR); [d] Data only from patients with BMI > 28 at entry visit (91 cbCR and 32 teleCR);

ACS, acute coronary syndrome; BMI, body mass index; BP, blood pressure; cbCR, center-based cardiac rehabilitation; CCS, chronic coronary syndrome; CV, cardiovascular; HbA1c, glycated haemoglobin; LDL, low-density lipoprotein; teleCR, cardiac telerehabilitation.

An age disparity was evident across the four primary diagnosis groups: ACS/CCS patients averaged 61.9 ± 10.6 years, CHF patients 57.5 ± 14.5 years, valve patients 62.3 ± 14.7 years, and ACHD patients 40.2 ± 18.1 years (Table 5). Systolic blood pressure increased significantly in patients after valve surgery, while it did not change in the other groups (Figure 2). HbA1c increased significantly in patients after valve surgery and by trend in patients with ACHD (who mostly completed CR following a surgical intervention). LDL levels decreased significantly in patients with ACS/CCS by -0.48 mmol/l, while it did not change in the other groups. The largest increases in peak VO_2 were found in patients after valve surgery or intervention with 5.43 ± 5.33 ml/min/kg and in patients with ACHD with 4.24 ± 6.53 ml/min/kg, while in patients with

ACS/CCS and those with CHF it was 2.4 and 2.7 ml/min/kg, respectively (Table 5). Parameters with highest number of missing data, mostly for data from bioimpedance measurements, were 7.8 % in patients with ACS/CCS, 13.7 % in patients with CHF, 3.2 % in patients with valve surgery, and 5.6 % in patients with congenital heart disease (Table 2 in the Appendix).

Table 5

Diagnosis-specific changes of body composition, cardiorespiratory fitness and parameters of cardiovascular risk from entry to conclusion visit of cardiac rehabilitation period

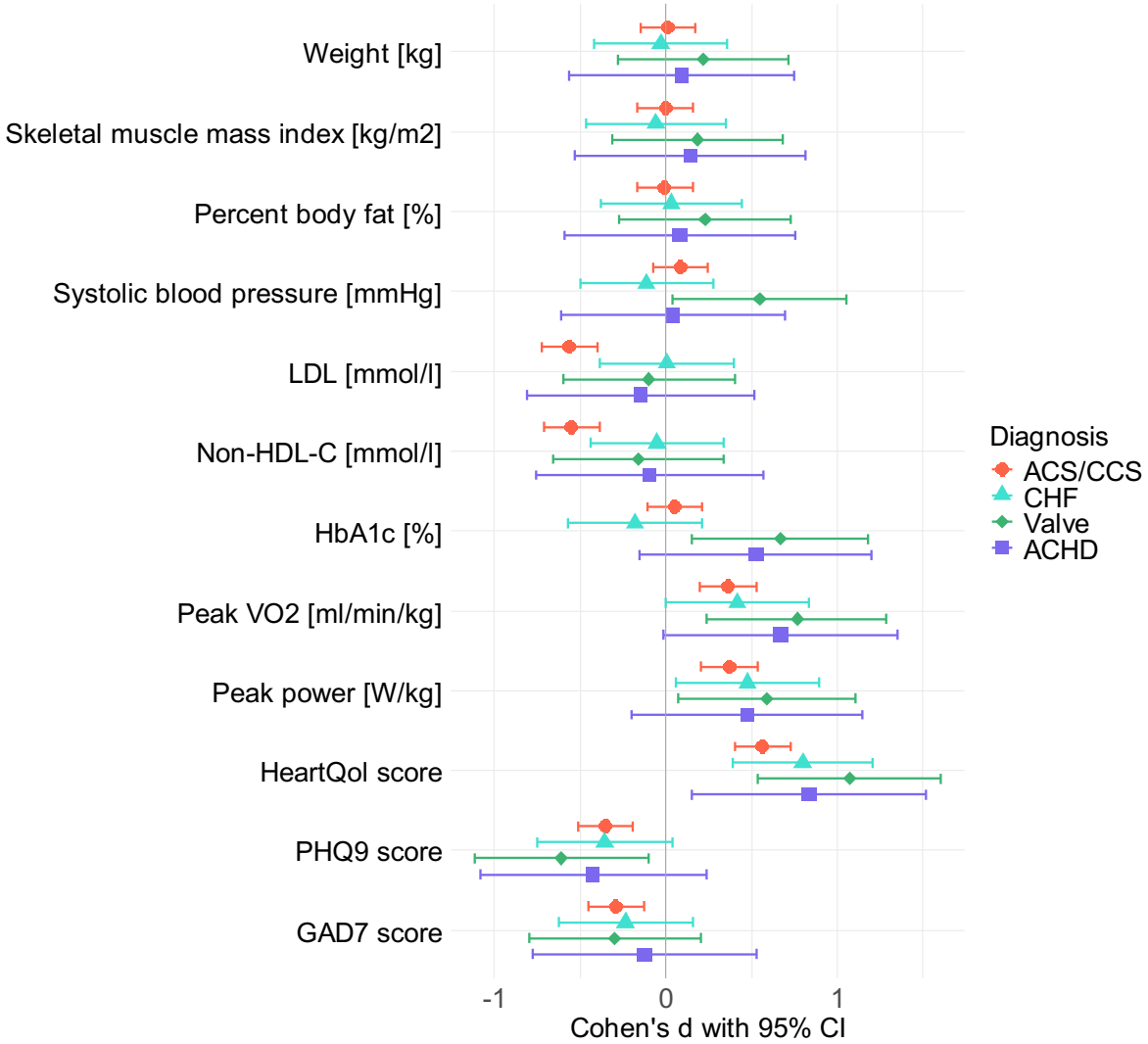
Changes in	**ACS/CCS** ***n* = 306**	**CHF** ***n* = 51**	**Valve** ***n* = 31**	**ACHD** ***n* = 18**
Age [years]	61.9 ± 10.6	57.5 ± 14.5	62.3 ± 14.7	40.2 ± 18.1
Weight [kg]	0.16 ± 3.78	-0.56 ± 3.29	2.80 ± 3.95	1.74 ± 3.32
Skeletal muscle mass [kg]	0.06 ± 1.19	-0.30 ± 1.41	0.58 ± 1.63	0.61 ± 0.97
Skeletal muscle mass index [kg/m^2]	0.027 ± 0.374	-0.097 ± 0.446	0.204 ± 0.511	0.197 ± 0.324
Percent body fat [%]	0.02 ± 3.08	0.29 ± 2.61	1.92 ± 3.06	0.94 ± 2.52
Systolic BP [mmHg]	1.28 ± 16.2	-1.84 ± 17.1	9.55 ± 19.2	0.56 ± 9.69
LDL [mmol/l]	-0.48 ± 0.92	0.01 ± 0.61	-0.08 ± 0.71	-0.12 ± 0.66
Non-HDL-C [mmol/l]	-0.51 ± 0.99	-0.06 ± 0.65	-0.15 ± 0.75	-0.09 ± 0.76
HbA1c [%]	0.03 ± 0.46	-0.13 ± 0.53	0.31 ± 0.41	0.18 ± 0.31
Peak VO_2 [ml/min]	192 ± 323	213 ± 433	472 ± 401	371 ± 509
Peak VO_2 [ml/min/kg]	2.42 ± 4.14	2.66 ± 4.76	5.43 ± 5.33	4.24 ± 6.53
Peak power [W]	20.2 ± 24.5	24.5 ± 27.8	39.0 ± 31.5	31.9 ± 41.0
Peak power [W/kg]	0.25 ± 0.31	0.31 ± 0.33	0.46 ± 0.44	0.36 ± 0.57
HeartQoL score	0.31 ± 0.49	0.48 ± 0.55	0.61 ± 0.61	0.49 ± 0.69
PHQ9 score	-1.32 ± 3.26	-1.76 ± 3.58	-2.26 ± 3.71	-2.06 ± 5.36
GAD7score	-0.93 ± 2.56	-1.00 ± 2.68	-0.84 ± 2.08	-0.61 ± 4.15

Note. The results are presented as mean ± SD. Data show mean age at the beginning of the CR and the changes during CR for different diagnosis in cbCR and teleCR patients.

ACHD, adult congenital heart disease; ACS, acute coronary syndrome; BP, blood pressure; cbCR, center-based cardiac rehabilitation; CCS, chronic coronary syndrome; CHF, chronic heart failure; CR, cardiac rehabilitation; GAD7, generalized anxiety disorder; HbA1c, glycated haemoglobin; HeartQoL, health-related quality of life; LDL, low-density lipoprotein; non-HDL-C, total cholesterol - high density lipoprotein; PHQ9, patient health questionnaire; teleCR, cardiac telerehabilitation; Valve, valve surgery or intervention; peak VO_2, peak oxygen uptake.

Figure 2

Forest plot depicting effect sizes of CVD risk factors for patient groups according to diagnosis



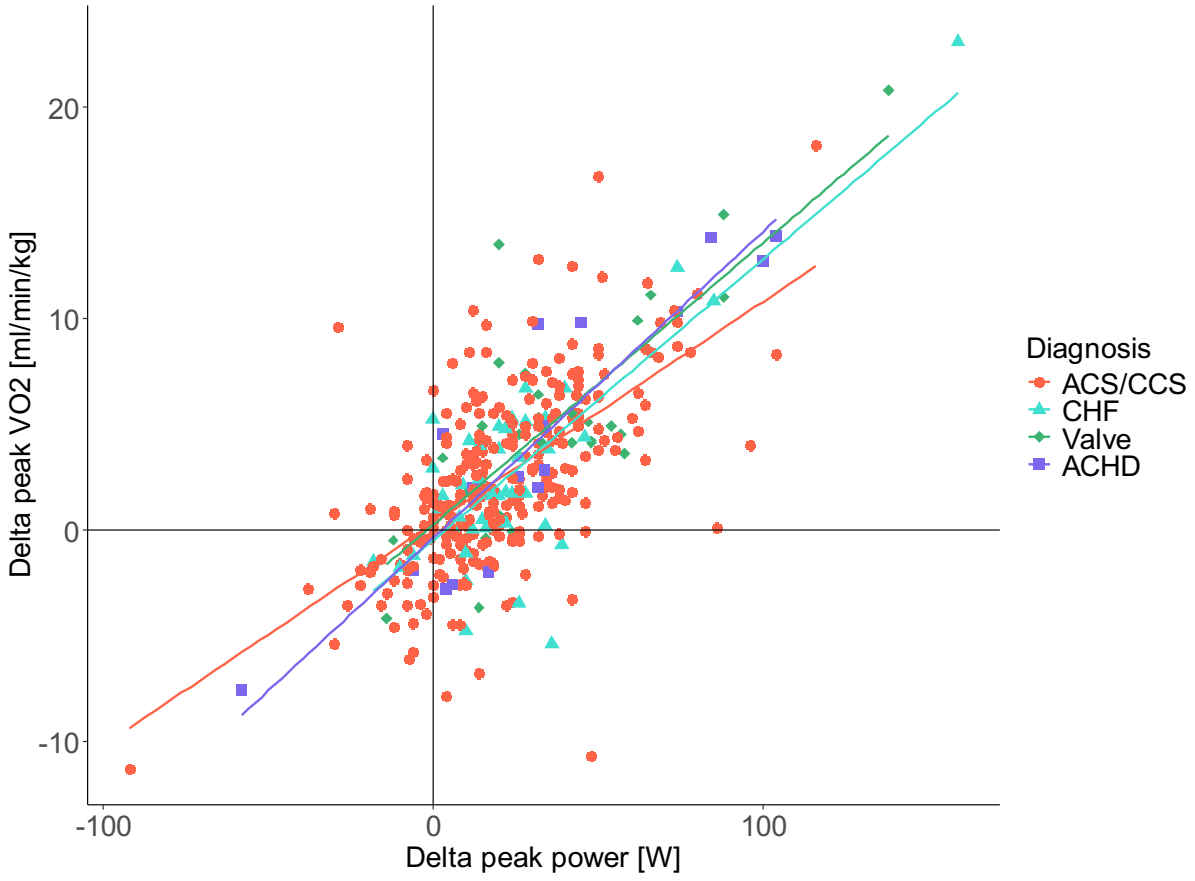
Note. The figure shows the effect sizes for the groups with different diagnoses. Patients completing cbCR and teleCR were pooled for this analysis.

ACHD, adult congenital heart disease; ACS, acute coronary syndrome; CCS, chronic coronary syndrome; CHF, chronic heart failure; CI, confidence interval; CR, cardiac rehabilitation; GAD7, generalized anxiety disorder; HbA1c, glycated haemoglobin; HeartQoL, health-related quality of life; LDL, low-density lipoprotein; PHQ9, patient health questionnaire; Valve, valve surgery or intervention; peak VO_2, peak oxygen uptake.

A total of 96 patients experienced a decrease in peak VO_2 during CR, with 65 (23.4 %) from the cbCR group and 31 (29.8 %) from the teleCR group (Figure 3). However, in 56 (58.3 %) of these patients, there was an increase in power output between entry and conclusion visit with a concomitant decrease in peak VO_2 (lower right quadrant of Figure 3).

Figure 3

Correlation between changes in peak VO_2 versus peak power according to the four diagnosis groups



Note. Scatter plot of changes in peak VO_2 from entry to conclusion of CR versus changes in peak power according to diagnosis as indicated in different colours and symbols of 379 patients with cycling tests in both visits.

ACHD, adult congenital heart disease; ACS, acute coronary syndrome; CCS, chronic coronary syndrome; CHF, chronic heart failure; Valve, valve surgery or intervention; peak VO_2, peak oxygen uptake.

4 Discussion

This study, utilizing prospectively collected data from 406 cardiac patients at a tertiary centre in Switzerland, aimed to compare changes in CVD risk factor profiles between patients completing ambulatory cbCR and those completing teleCR. The findings revealed that patients choosing teleCR were younger, fitter, had higher systolic blood pressure, higher quality of life and less depression and anxiety than patients choosing cbCR. When adjusted for age, sex, height and weight, changes in outcomes between the two rehabilitation modalities were not different. Specifically, both cbCR and teleCR demonstrated the same increase in peak VO_2 and peak power, and the same decrease in LDL and non-HDL-C. Questionnaire assessments also indicated the same improvements in quality of life, depression and anxiety amongst the cbCR and teleCR patients. Compliance rates with the cardiac rehabilitation program were not different between the two groups. The targets for LDL in both step I and step II were not sufficiently achieved by the end of CR and need to be addressed more aggressively.

4.1 Exercise capacity

Given its relevance for cardiovascular health and prognosis (Coeckelberghs et al., 2016; Hung et al., 2014; Vanhees et al., 1994), peak VO_2 was selected as the primary outcome measure in this study. Our findings indicate that both cbCR and teleCR led to improvements in peak VO_2, with increases of 2.9 ml/min/kg and 2.4 ml/min/kg, respectively. These results align with previous studies by Batalik et al. (2020a), Maddison et al. (2019), Li et al. (2023) and Prescott et al. (2020), which also demonstrated similar improvements in peak VO_2 over comparable cbCR durations. Uddin et al. (2016) conducted a meta-analysis comparing cbCR to no CR in patients with CAD and CHF, concluding that structured CR programs resulted in an average improvement in peak VO_2 by 3.3 ml/min/kg. We showed that average increases in cardiorespiratory fitness with CR were double in patients after valve surgery (5.4 ml/min/kg) than in patients with ACS or CCS or HF (2.7 ml/min/kg). This is in line with previous studies finding improvements in exercise capacity with and without CR due to an improved cardiac function after valve surgery (Bagur et al., 2011; Sibilitz et al., 2022; Vitez et al., 2023). An increase of one metabolic equivalent of task (MET, 1 MET = 3.5 VO_2 ml/min/kg) may, according to Uddin et al. (2016) translate into enhanced functional capacity, enabling patients to perform daily activities more effectively and maintaining independence for longer.

Notably, while these studies were randomized controlled trials (RCTs), our study was observational, which is why we adjusted for the younger age and higher fitness of the teleCR

patients at baseline. Nevertheless, even after adjusting for age, sex, height and weight, teleCR patients had a 3.3 ml/min/kg higher peak VO_2 at baseline. Their adjusted increase in peak VO_2 was 0.6 ml/min/kg smaller than the increase of the cbCR group, which was most likely based on their higher baseline values. Self-selected teleCR participation was also found to be favoured by younger and fitter patients in a study by Brouwers et al. (2022). In contrast to our results, they found teleCR to be less favoured by females but more favoured by patients with diabetes mellitus.

Exercise capacity, as measured by peak VO_2, is known to decline by approximately 10 % per decade after the age of 30, largely influenced by genetic factors (Pimentel et al., 2003). In our patient group, the age related decrease was approximately 7 % per decade. However, regular endurance training has been shown to mitigate this decline, with potential improvements of 15 % to 20 % across all age groups, leading to reduced all-cause mortality with each 1 ml/min/kg gained (Bacon et al., 2013; Keteyian et al., 2008).

There is conflicting evidence in the literature regarding the possibility of a learning effect in performing CPETs influencing changes in peak VO_2. While some studies have reported no significant learning effects in patients with CHF (Bensimhon et al., 2008; Russell et al., 1998), others have observed improvements in peak VO_2 following repeated testing in patients with CHF (Jakovljevic et al., 2012). No studies assessing such learning effects have been conducted in patients with CAD, highlighting the need for research to elucidate the role of learning effects in peak VO_2 improvements in these patients. The absence of a control group not conducting CR makes it impossible for us to quantify a potential learning effect of the CPET in our patients.

A small fraction of patients (24 %) showed a reduction in peak VO_2. However, 58 % of these "non-responders to CR" had an increase in power, meaning that they consumed less oxygen for the same power output. The higher energy efficiency in these patients may be explained by a reduced energy demand of muscles other than the leg muscles involved in cycling, namely the respiratory muscles. Exercise training may have failed to increase energy production of the legs but led to more efficient energy utilisation of supporting muscles such as the respiratory muscles. A decrease in power output was present only in 11 % of our patients, indicating that a true deterioration of cardiorespiratory fitness was present in a very small fraction.

4.2 Body composition and systolic blood pressure

We found an increase (by trend, $p = 0.065$) in body weight by 0.4 kg and 0.2 kg in the cbCR and teleCR group, respectively. This aligns with findings from previous research, indicating that while CR programs improve cardiorespiratory fitness and cardiovascular risk profiles, they

may often not result in weight loss (Avila et al., 2020; Dorje et al., 2019; Maddison et al., 2019). It is possible that dietary habits and other lifestyle factors not directly addressed by the CR programs played a role in maintaining body weight. In 35,000 patients with a mean BMI of 30 it was found that intentional weight loss improved outcome by 1/3 (Pack et al., 2014). Our patients were with a mean BMI of 27 and only 21 % and 19 % obesity in cbCR and teleCR, respectively, relatively slim. Weight control as a target of CR, however, may be questionable. A recent meta-analysis confirmed the "obesity paradox" in CAD patients after revascularisation (Ma et al., 2018) by showing that not only overweight but also obese and severely obese patients had lower all-cause mortality than normal weight patients. The relationship between BMI and cardiovascular outcomes appears to be complex and varies with the type of disease (Dwivedi et al., 2020).

Similarly, no significant changes were observed in systolic blood pressure in either CR modality. This is in contrast to a meta-analysis that found systolic blood pressure decreased by -5 mmHg with CR (Mamataz et al., 2022). Comparable improvements in systolic blood pressure by teleCR and cbCR were found by a meta-analysis that included 26 trials with over 6000 patients (Jin et al., 2019). The absence of a decrease in our study may be attributed to the already relatively well-controlled blood pressure levels at baseline due to prior medical management with over 80 % of patients achieving step I target. Our teleCR patients had higher systolic blood pressure than cbCR patients at baseline and CR conclusion. Nevertheless, the importance of regular monitoring and managing systolic blood pressure remains critical, as elevated blood pressure is a well-established risk factor for cardiovascular events (Fuchs & Whelton, 2020). Future CR programs might benefit from integrating more targeted interventions aimed at further reducing systolic blood pressure through lifestyle modifications and optimized pharmacotherapy.

4.3 Lipid and glycaemic profile

In patients with ACS or CCS, LDL was decreased by -0.5 mmol/l with CR with no difference between CR modality groups. The smaller percentage of patients reaching step I target of LDL < 1.8 mmol/l at conclusion of CR in the teleCR group (56 %) compared to cbCR (69 %) likely reflects the slightly higher mean LDL at baseline and a slightly smaller decrease with CR in the teleCR group. The decrease found in our study is 2-fold the decrease found in a meta-analysis by Wu et al. (2022), and 5-fold the decrease that was found in a European study in elderly CAD patients (Prescott et al., 2020), however, fraction of patients reaching step I target at the end of CR was similar. The study by Maddison et al. (2019) also found no difference between teleCR

and cbCR with regard to changes in LDL, however, they reported a small increase in LDL. Likewise, the decrease in total cholesterol of -0.4 mmol/l found in our patients with ACS or CCS is 3-fold the decrease found in the meta-analysis Wu et al. (2022). It seems that insufficient lipid control in CAD patients with CR is a common problem and increased focus needs to put on more frequent measuring of lipid status during CR and more aggressive lipid lowering therapy.

4.4 Psychological well-being

Quality of life plays a pivotal role in the prognosis of cardiac patients, with higher quality of life scores associated with reduced rates of rehospitalization and mortality among those with CAD and CHF (Rodríguez-Artalejo et al., 2005; Westin et al., 2005). Our findings demonstrated a significant increase in HeartQoL scores and a decrease in PHQ9 and GAD7 scores indicating an overall improvement in patient well-being.

These results are consistent with those of other studies (Campo et al., 2020; Dorje et al., 2019; Kraal et al., 2017; Li et al., 2023), although not all studies employed the same questionnaires as used in our study to assess quality of life, depression and anxiety. Moreover, Molloy et al. (2023) conducted a meta-analysis comparing no CR with three CR modalities (cbCR, teleCR and hybrid teleCR), in CHF patients. All three modalities demonstrated clinically significant improvements in HeartQoL in both the short and long term (≥ 12 months), regardless of the CR delivery setting. Similarly, Ramachandran et al. (2022) conducted a meta-analysis, which concluded that teleCR led to significant improvements in quality of life and depression (assessed using various questionnaires, including PHQ9) compared to no CR, but no significant differences observed compared to cbCR. In our study quality of life was reduced in females but improved with age, the former being in line with a study by Dąbek et al. (2024) while the latter was in contrast with Dabek's study.

Both, teleCR and cbCR similarly reduced anxiety and depression. This is in line with several previous studies (Kraal et al., 2017; Spindler et al., 2019). Also supported by previous studies in CAD patients (Lam et al., 2019; Shanmugasegaram et al., 2012), we found female patients to be more depressed, a finding that may be attributed to hormonal differences to men and particularly changes during menopause (Albert, 2015). Further, depression and anxiety decreased with advancing age, which is also in line with previous studies (Olsen et al., 2018).

4.5 Strengths and limitations

Our observational study compared effectiveness of teleCR and cbCR based on patients' own choice. Consequently, our results reflect the real clinical situation and respect patients' individual needs and circumstances. It is not possible to recruit an unbiased control group in a randomised control trial with a lifestyle or training intervention because interested study participants who cannot be blinded to group allocation mostly have a group preference, which will lead to poor compliance in those with non-preferred group allocation. The non-randomised study design resulted in age and fitness differences, which we adjusted for in the models. Nevertheless, we may have overestimated the effect of CR on some improvements, as they may have (partly) been attributed to the natural recovery process after a cardiac event, which has been suggested to take approximately two months (Cleveland Clinic, 2022). Another limitation is the relatively high rate of patients (23 %) who did not provide general informed consent for further use of their health data. We do not know whether our study results also reflect the characteristics of the patients who did not provide consent.

5 Conclusion

In conclusion, patients choosing teleCR at a tertiary hospital in Switzerland had comparable improvements of their CVD risk factor profile as patients completing cbCR. In line with previous studies, patients choosing teleCR were younger, fitter, and less depressed and anxious than those choosing cbCR.

These findings suggest that teleCR is a valuable alternative or adjunct to traditional cbCR, particularly for patients who may face barriers to accessing center-based programs. Given that patients completing teleCR become familiar with exercise training at home or near their home, we anticipate better outcomes at 1 year follow-up, which we will analyse in the near future. The thorough work-up of our Bern Rehab Registry data has made us aware that we need to improve lipid and blood pressure management of our patients in both, cbCR and teleCR modalities, and that a special focus needs to be put on treating depression in female patients.

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Appendix

Table 1

Baseline values and changes between entry and conclusion visit of cbCR and teleCR groups with missing data

	Baseline			Changes from entry to conclusion visit		
	cbCR ***n*** **= 291**	**teleCR** ***n*** **= 115**	***p*-value**	**cbCR** ***n*** **= 291**	**teleCR** ***n*** **= 115**	***p*-value**
Body composition						
Weight [kg]	79.9 ± 15.6	81.2 ± 14.1	0.305	0.413 ± 3.77	0.159 ± 3.86	0.221
Skeletal muscle mass [kg]	32.0 ± 6.12	33.1 ± 5.34	0.096	0.0945 ± 1.34	0.0713 ± 1.05	0.698
Missing	9 (3.1)	4 (3.5)		18 (6.2)	7 (6.1)	
Skeletal muscle mass index [kg/m^2]	10.6 ± 1.38	10.8 ± 1.13	0.116	0.0392 ± 0.420	0.0220 ± 0.339	0.633
Missing	9 (3.1)	4 (3.5)		18 (6.2)	7 (6.1)	
Body fat mass [kg]	22.6 ± 10.5	21.8 ± 9.72	0.562	0.342 ± 3.32	-0.0389 ± 2.76	0.212
Missing	9 (3.1)	4 (3.5)		18 (6.2)	7 (6.1)	
Body fat mass [%]	27.4 ± 9.25	26.1 ± 8.91	0.202	0.366 ± 3.21	-0.0657 ± 2.55	0.435
Missing	9 (3.1)	4 (3.5)		18 (6.2)	7 (6.1)	
Blood pressure						
Systolic BP [mmHg]	123 ± 15.6	126 ± 15.4	0.062	1.64 ± 16.9	1.11 ± 15.5	0.748
Missing	1 (0.3)	0 (0)		1 (0.3)	0 (0)	
Diastolic BP [mmHg]	70.0 ± 9.95	72.9 ± 10.7	0.016	-0.521 ± 11.1	-0.313 ± 11.1	0.865
Missing	1 (0.3)	0 (0)		1 (0.3)	0 (0)	
Lipid and glycaemic profile						
Total cholesterol [a] [mmol/l]	3.80 ± 1.09	4.01 ± 1.09	0.034	-0.419 ± 1.00	-0.427 ± 0.973	0.588
Missing	77 (26.5)	25 (21.7)		77 (26.5)	25 (21.7)	
HDL [a] [mmol/l]	1.17 ± 0.312	1.26 ± 0.324	0.027	0.0966 ± 0.230	0.0733 ± 0.212	0.283
Missing	77 (26.5)	24 (20.9)		77 (26.5)	24 (20.9)	
LDL [a] [mmol/l]	2.14 ± 0.986	2.23 ± 1.01	0.390	-0.497 ± 0.926	-0.444 ± 0.893	0.253
Missing	76 (26.1)	24 (20.9)		76 (26.1)	24 (20.9)	
HbA1c [%]	5.90 ± 0.861	5.71 ± 0.692	0.016	0.0340 ± 0.506	0.0571 ± 0.374	0.963
Missing	0 (0)	0 (0)		3 (1.0)	3 (2.6)	
CPET rest						
VE [l/min]	14.4 ± 3.33	14.1 ± 3.17	0.408	-0.264 ± 3.07	0.0464 ± 3.22	0.393
Missing	7 (2.4)	4 (3.5)		15 (5.2)	7 (6.1)	
BF [cpm]	17.1 ± 4.10	15.9 ± 3.59	0.012	-0.340 ± 3.36	-0.284 ± 3.24	0.880
Missing	7 (2.4)	4 (3.5)		15 (5.2)	7 (6.1)	
VT [l]	0.883 ± 0.262	0.921 ± 0.269	0.219	-0.0000362 ± 0.248	0.0199 ± 0.287	0.625
Missing	7 (2.4)	4 (3.5)		15 (5.2)	7 (6.1)	
$PETCO_2$ [mmHg]	26.8 ± 3.63	27.5 ± 3.50	0.075	0.690 ± 3.10	0.811 ± 2.74	0.708
Missing	7 (2.4)	4 (3.5)		15 (5.2)	7 (6.1)	
FVC [l]	3.87 ± 1.02	4.18 ± 0.936	0.005	0.184 ± 0.544	0.218 ± 0.460	0.260
Missing	8 (2.7)	5 (4.3)		17 (5.8)	8 (7.0)	
FEV1 [l/min]	2.94 ± 0.806	3.21 ± 0.762	0.003	0.0668 ± 0.443	0.126 ± 0.339	0.254
Missing	8 (2.7)	5 (4.3)		17 (5.8)	8 (7.0)	

Table 1

(Continued)

	Baseline			Changes from entry to conclusion visit		
	cbCR *n* = 291	**teleCR *n* = 115**	***p*-value**	**cbCR *n* = 291**	**teleCR *n* = 115**	***p*-value**
CPET exercise [b]						
Peak $\dot{V}O_2$ [ml/min]	1600 ± 515	1930 ± 601	< 0.001	243 ± 362	178 ± 360	0.056
Missing	0 (0)	0 (0)		6 (2.2)	3 (2.9)	
Peak $\dot{V}O_2$ [ml/min/kg]	20.1 ± 5.63	23.9 ± 7.19	< 0.001	2.91 ± 4.49	2.41 ± 4.59	0.167
Missing	0 (0)	0 (0)		6 (2.2)	3 (2.9)	
Predicted peak $\dot{V}O_2$ [%]	80.0 ± 19.9	91.1 ± 23.8	< 0.001	11.8 ± 16.6	8.26 ± 15.7	0.029
Missing	0 (0)	0 (0)		6 (2.2)	3 (2.9)	
Peak power [c] [watt]	133 ± 52.8	162 ± 57.6	< 0.001	23.3 ± 26.8	21.2 ± 27.1	0.254
Missing	2 (0.7)	1 (1.0)		2 (0.7)	1 (1.0)	
Peak power [c] [watt/kg]	1.67 ± 0.606	2.02 ± 0.731	< 0.001	0.284 ± 0.344	0.269 ± 0.342	0.531
Missing	2 (0.7)	1 (1.0)		2 (0.7)	1 (1.0)	
VE [l/min]	70.2 ± 23.4	80.1 ± 26.6	0.002	5.21 ± 13.9	7.10 ± 17.5	0.600
Missing	0 (0)	2 (1.9)		9 (3.2)	5 (4.8)	
BF [cpm]	33.4 ± 7.00	33.2 ± 7.18	0.924	0.437 ± 5.13	1.81 ± 5.84	0.107
Missing	0 (0)	2 (1.9)		9 (3.2)	5 (4.8)	
VT [l]	2.12 ± 0.613	2.42 ± 0.638	< 0.001	0.123 ± 0.309	0.0665 ± 0.298	0.157
Missing	0 (0)	2 (1.9)		9 (3.2)	5 (4.8)	
$PETCO_2$ [mmHg]	30.7 ± 5.07	32.6 ± 5.18	0.002	1.77 ± 3.72	0.501 ± 3.27	0.011
Missing	0 (0)	2 (1.9)		9 (3.2)	5 (4.8)	
HR [bpm]	128 ± 23.7	138 ± 23.0	< 0.001	3.58 ± 18.9	2.89 ± 16.7	0.631
Missing	0 (0)	0 (0)		6 (2.2)	3 (2.9)	
RER	1.14 ± 0.143	1.14 ± 0.129	0.813	-0.00864 ± 0.155	0.0190 ± 0.140	0.081
Missing	0 (0)	0 (0)		6 (2.2)	3 (2.9)	
VE/VCO_2 slope	35.6 ± 7.87	33.8 ± 6.85	0.042	-2.18 ± 6.43	-1.67 ± 4.78	0.942
Missing	1 (0.4)	0 (0)		9 (3.2)	5 (4.8)	
Psychological well-being						
HeartQoL score	2.09 ± 0.633	2.32 ± 0.587	< 0.001	0.373 ± 0.550	0.330 ± 0.468	0.462
Missing	5 (1.7)	0 (0)		12 (4.1)	0 (0)	
PHQ9 score	5.29 ± 4.45	4.12 ± 3.69	0.017	-1.57 ± 3.63	-1.28 ± 3.00	0.548
Missing	6 (2.1)	0 (0)		11 (3.8)	0 (0)	
GAD7 score	3.50 ± 3.67	2.90 ± 3.43	0.055	-0.868 ± 2.78	-1.03 ± 2.21	0.490
Missing	6 (2.1)	0 (0)		11 (3.8)	0 (0)	

Note. The results are presented as mean ± SD. Missing data is indicated as frequencies (percent).
[a] Lipid profile was only analysed for patients with ACS and CCS; [b] CPET data only from 278 cbCR patients and 104 teleCR patients excluding patients with disparent testing modalities; [c] data from 276 cbCR patients and 103 teleCR patients who performed cycling tests.

ACS, acute coronary syndrome; BF, breathing frequency; BP, blood pressure; cbCR, center-based cardiac rehabilitation; CCS, chronic coronary syndrome; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; GAD7, generalized anxiety disorder; HbA1c, glycated haemoglobin; HDL, high-density lipoprotein; HeartQoL, health-related

Table 1

(Continued)

quality of life; HR, heart rate; LDL, low-density lipoprotein; $PETCO_2$, partial pressure of end-tidal carbon dioxide; PHQ9, patient health questionnaire; teleCR, cardiac telerehabilitation; VE, ventilation; VE/VCO_2, ratio of minute ventilation to carbon dioxide production; peak VO_2, peak oxygen uptake; VT, tidal volume.

Table 2

Diagnosis-specific changes of body composition, cardiorespiratory fitness and parameters of cardiovascular risk from entry to conclusion visit of cardiac rehabilitation period with missing data

Changes in indicated variables from entry to conclusion and number of patients with missing data	ACS.CCS n = 306	CHF n = 51	Valve n = 31	ACHD n = 18
Age [years]	61.9 ± 10.6	57.5 ± 14.5	62.3 ± 14.7	40.2 ± 18.1
Weight [kg]	0.16 ± 3.78	-0.555 ± 3.29	2.80 ± 3.95	1.74 ± 3.32
Skeletal muscle mass [kg]	0.064 ± 1.19	-0.302 ± 1.41	0.577 ± 1.63	0.612 ± 0.965
Missing	17 (5.6)	7 (13.7)	0 (0)	1 (5.6)
Skeletal muscle mass index [kg/m^2]	0.027 ± 0.374	-0.097 ± 0.446	0.204 ± 0.511	0.197 ± 0.324
Missing	17 (5.6)	7 (13.7)	0 (0)	1 (5.6)
Body fat mass [%]	0.016 ± 3.08	0.291 ± 2.61	1.92 ± 3.06	0.935 ± 2.52
Missing	17 (5.6)	7 (13.7)	0 (0)	1 (5.6)
Systolic blood pressure [mmHg]	1.28 ± 16.2	-1.84 ± 17.1	9.55 ± 19.2	0.556 ± 9.69
Missing	1 (0.3)	0 (0)	0 (0)	0 (0)
LDL [mmol/l]	-0.482 ± 0.915	0.013 ± 0.608	-0.085 ± 0.712	-0.115 ± 0.662
Missing	0 (0)	1 (2.0)	0 (0)	1 (5.6)
Non-HDL-C [mmol/l]	-0.512 ± 0.994	-0.062 ± 0.652	-0.146 ± 0.746	-0.086 ± 0.761
Missing	2 (0.7)	1 (2.0)	0 (0)	1 (5.6)
HbA1c [%]	0.033 ± 0.463	-0.132 ± 0.528	0.310 ± 0.413	0.182 ± 0.305
Missing	4 (1.3)	1 (2.0)	0 (0)	1 (5.6)
Peak VO2 [ml/min]	192 ± 323	213 ± 433	472 ± 401	371 ± 509
Missing	24 (7.8)	7 (13.7)	1 (3.2)	1 (5.6)
Peak VO2 [ml/min/kg]	2.42 ± 4.14	2.66 ± 4.76	5.43 ± 5.33	4.24 ± 6.53
Missing	24 (7.8)	7 (13.7)	1 (3.2)	1 (5.6)
Peak power [W]	20.2 ± 24.5	24.5 ± 27.8	39.0 ± 31.5	31.9 ± 41.0
Missing	20 (6.5)	5 (9.8)	1 (3.2)	1 (5.6)
Peak power [W/kg]	0.251 ± 0.311	0.313 ± 0.328	0.457 ± 0.439	0.360 ± 0.568
Missing	20 (6.5)	5 (9.8)	1 (3.2)	1 (5.6)
HeartQoL score	0.306 ± 0.493	0.480 ± 0.548	0.605 ± 0.611	0.491 ± 0.689
Missing	11 (3.6)	1 (2.0)	0 (0)	0 (0)
PHQ9 score	-1.32 ± 3.26	-1.76 ± 3.58	-2.26 ± 3.71	-2.06 ± 5.36
Missing	10 (3.3)	1 (2.0)	0 (0)	0 (0)
GAD7 score	-0.926 ± 2.56	-1.00 ± 2.68	-0.839 ± 2.08	-0.611 ± 4.15
Missing	10 (3.3)	1 (2.0)	0 (0)	0 (0)

Note. The results are presented as mean ± SD. Data show changes during CR for different diagnosis in cbCR and teleCR patients.

ACHD, adult congenital heart disease; ACS, acute coronary syndrome; cbCR, center-based cardiac rehabilitation; CCS, chronic coronary syndrome; CHF, heart failure; CR, cardiac rehabilitation; GAD7, generalized anxiety disorder; HbA1c, glycated haemoglobin; HeartQoL, health-related quality of life; LDL, low-density lipoprotein; PHQ9, patient health questionnaire; teleCR, cardiac telerehabilitation; Valve, valve surgery or intervention; peak VO_2, peak oxygen uptake.