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Self-reported disease management knowledge by cardiac rehabilitation use multinationally and its correlates

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ABSTRACT

Objectives: To multinationally investigate: (1) CVD management knowledge following CR, including variations by region, country income classification, as well as patient sociodemographic and clinical characteristics; (2) the association of post-CR knowledge with the number of CR sessions completed and setting of CR delivery; and (3) whether domain-specific knowledge post-CR is associated with corresponding health markers.
Methods: Secondary analysis of the International Council of Cardiovascular Prevention and Rehabilitation's International Cardiac Rehabilitation Registry (ICRR) data to December 2024 was conducted for this prospective observational study. Eligible patients were those receiving phase II outpatient CR, with pre-program assessment completed $\geq$ 6 months prior. Knowledge was assessed via patient report at follow-up/post-program in 9 domains (yes/no), as well as heart-health behaviors and work status. Programs reported CR use, functional capacity, and risk factors.
Results: 4309 patients from 17 programs in 11 countries were included, with 3359 (78.0%) having knowledge follow-up data. Total knowledge was high (8.1 $\pm$ 1.3), highest regarding return to life roles, cardiac medications, and care plans. In an adjusted regression model, knowledge varied by region, country income, work status, function, quality of life and CR completion. Knowledge in specific domains was associated with corresponding health markers, including nutrition ($p < 0.001$), medication adherence ($p < 0.001$), and stress ($p = 0.009$).
Conclusions: CR participants in diverse settings multinationally reported high disease management knowledge, with significant variation by regional, economic, and patient-level factors. Increased CR exposure, potentially in hybrid models, was associated with higher knowledge. This may be associated with improved health behaviors, and hence potentially better patient outcomes.
Practical implications: There is a need for tailored, evidence-based education strategies that address specific knowledge gaps and accommodate diverse patient populations.

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1. Introduction

Cardiovascular diseases (CVD) remain one of the leading causes of mortality and morbidity worldwide, with an increasing prevalence in low- and middle-income countries (LMICs) [1,2]. Advancements in acute CV care have improved survival rates, but left many patients managing chronic conditions, and suffering reduced quality of life [3]. Cardiac rehabilitation (CR) is an established, outpatient secondary prevention care model proven to reduce morbidity and mortality in these many patients living with CVD chronically [4].

In CR, internationally-agreed core components are delivered, including risk factor management, structured exercise, psychosocial counselling, and patient education [5]. With regard to the latter, indeed, disease management knowledge enables patients to understand their condition and ways to manage it, including pathophysiology, symptoms, risk factors, as well as needed secondary prevention and treatments [6]. This is necessary to support patient adoption of heart-healthy behaviors, and hence improve their outcomes. Indeed, rigorous reviews have shown that cardiac patients who receive structured education demonstrate better comprehension of risk factors, improved medication adherence, and have a greater likelihood of sustaining long-term behavior change [7]. This, in turn, results in fewer cardiovascular events and hospitalizations [8,9]. CR patient education is also a cost-effective secondary prevention strategy, particularly beneficial in addressing the burden of CVD in LMICs [10,11].

It has been established that CV patient information needs vary somewhat around the world [12]. Moreover and in some ways appropriately, there are variations in the delivery of patient education across CR programs worldwide, likely due to differences in risk factor burden, cultural norms, CR resource availability and healthcare infrastructure [13,14]. There is data on CV patient knowledge in high-income countries and some in LMICs [15], but to our knowledge there are no multinational studies exploring CVD management knowledge comparatively in lower-resource settings, nor are there examinations of the "real-world" impact of education in CR for patient knowledge. Therefore, the objectives of this study were to multinationally investigate: (1) CVD management knowledge following CR, including by region and country income class, and by key patient sociodemographic and clinical characteristics, (2) association of post-CR knowledge with number of CR sessions completed and setting of CR delivery in program completers, as well as (3) if disease management domain-specific knowledge post-CR among program-completing patients is associated with corresponding clinical indicators or behaviours, such as association with heart-health behaviors, CV risk factors, and functional capacity.

2. Methods

2.1. Design and procedure

Secondary analysis of data from the International Cardiac Rehabilitation Registry (ICRR) was undertaken [16]. The design was prospective and observational.

The study was approved centrally by the ethics review board of York University (e2020–147; Canada). Registry-participating centers also secured approvals from their respective institutions, securing written informed consent from participating patients in accordance with local requirements.

To be eligible to participate in ICRR, programs had to meet ICCPR's CR definition and be situated in a low-resource setting as defined by Heine et al [17]. This could relate to being situated in a low or middle-income country according to World Bank classification, or in a region within a high-income country where there is under-development of CR related to financial resources, lack of healthcare system resources, lack of patient and provider awareness, and/or patient disadvantage [e.g., limited social resources, geographic barriers]).

Programs entered data on phase II outpatient CR participants and were asked to do so consecutively from the point of on-boarding. As outlined elsewhere [18], participating programs enter data on consenting participants first pre-program. Patients were thereafter contacted for follow-up assessment, timed to correspond with the planned end of specific program. Programs were encouraged to follow-up with patients regardless of whether the patient completed the program or not, with some reporting difficulty reaching patient dropouts by phone where they were not on-site for a care appointment [19]. ICRR annual follow-up data were not considered in this study.

2.2. Participants

Heart disease patients who are indicated for CR based on clinical guidelines (e.g., acute coronary syndrome +/- revascularization, heart failure, stable coronary artery disease +/- valve or rhythm conditions) [20] are included in the registry; there are some exclusions to CR eligibility such as inability to ambulate [21]. Patients who were not capable of providing informed consent for cognitive, mental or literacy-related reasons were excluded.

Patient data from ICRR inception in October 2021 to December 2024 were analyzed. Only those patients with at least six months of follow-up at the time of pulling the data were included to enable time for follow-up assessments (which reduces bias related to loss to follow-up).

2.3. Measures

ICRR-interested programs complete a program survey on their characteristics, based on ICCPR's Global Audit [13]. They state their country, which was categorized by World Health Organization (WHO) region [22] and World Bank country income classification [2]. Items from the survey were used to describe their characteristics relevant to patient education.

At the patient-level, there are program and patient-reported variables, some of which are assessed at both pre-CR and follow-up assessment points. The latter are primarily administered interview style in person or on the phone by CR staff. Local translation was undertaken were needed. The rigorous, stepwise process to develop the variables as well as data definitions for each are available elsewhere [18]. Sociodemographic (e.g., age, sex education level, work status) and clinical (e.g., referral indication, comorbidities, peak metabolic equivalents of task [METs] from exercise test) characteristics of participants reported in the pre-CR assessment were used to characterize the population. They were also used for regression model adjustment where applicable.

Knowledge – the dependent variable of interest - was assessed at follow-up using patient report. There are nine knowledge domains assessed, pertaining to heart-health behaviours, risk factor management, symptom control, care continuity and return to life roles. Response options are 'yes' or 'no'.

Also in the follow-up assessment, programs reported number of sessions attended, whether any sessions were unsupervised (e.g., home-based or hybrid model), and whether the patient completed the program [18]. The latter was defined as participating in the prescribed components of the CR intervention near the planned end of the program and attending a follow-up assessment [23]. Programs also reported clinical outcomes such as functional capacity as well as risk factor levels such as blood pressure and body mass index. Patients were asked to report their exercise behavior (i.e., minutes of at least moderate-intensity activity per week), nutrition habits (i.e., number of servings of fruits and vegetables per day), and medication adherence (Likert-scale reverse-scored from 5 'never' to 1 'all the time'), and quality of life (0−10) [24].

2.4. Statistical analysis

SPSS v29 was used. A descriptive examination of program characteristics was performed (frequency and percentage; median [Q1-Q3]). Participant pre-CR sociodemographic and clinical characteristics were

similarly described, with means ± standard deviations or medians [Q1–Q3] as appropriate.

A descriptive examination of each of the 9 knowledge domains was performed, and missingness scrutinized. Available individual domain responses were used for analyses reporting knowledge at the item level. Where more than 80% of the nine items were completed, the sum of 'yes' responses was calculated as a total knowledge score, and prorated to a 9-item scale when one item was missing. The distribution of the total knowledge score was examined for skewness and kurtosis.

T-tests and chi-square analyses were used as applicable to ascertain retention bias in the sample between participants who had any knowledge data at follow-up versus those who did not. The association of total knowledge with participant characteristics, CR completion, session dose and mode of delivery were tested using Kruskal-Wallis test, Mann-Whitney *U* test, or Spearman's rank correlation, as applicable, given the non-normal distribution of the knowledge score and/or ordinal predictor variables.

Although participants were nested within CR programs and programs within countries/regions, we did not use multi-level modeling. The number of programs (n = 17) and countries (n = 11) is small relative to what is typically required for stable estimation of random effects, particularly with multiple predictors and uneven cluster sizes. Additionally, our primary research question concerned patient-level correlates of knowledge rather than program-level variance or cross-level interactions. Consequently, we used a single-level multiple linear regression model and interpret the results at the overall sample level, acknowledging that within-program and within-region / income class correlation may not be fully accounted for. Associations should be interpreted at the overall sample level, with caution regarding within-program correlation.

Given the number of independent variables of interest, multiple comparisons would be required, which inflates error. Therefore, an adjusted regression model of the association of characteristics of interest with total knowledge was planned. Assumptions for the multiple linear regression model were investigated, including linearity, homoscedasticity, normality of residuals, and multicollinearity. Variable selection for the multiple linear regression model was guided by bivariate screening ($p < .10$) and retention-status differences. This approach was chosen to: (a) reduce the risk of over-fitting and unstable coefficient estimates while preserving important predictors, (b) adjust for factors associated with attrition bias, as retained participants differed systematically from those lost to follow-up, and (c) facilitate multicollinearity assessment prior to model fitting. Candidate variables were tested for multicollinearity using variance inflation factors (VIF); non-collinear variables were entered into the final model. This strategy balances model parsimony, stability, and adjustment for key sources of bias in this observational study.

Finally, the bivariate association of specific knowledge domains with associated and assessed health behaviours and clinical markers were investigated with independent samples *t*-tests. For example, the association of nutrition knowledge with fruit and vegetable intake at follow-up was tested.

3. Results

3.1. Program and participant characteristics

At the time of study, there were 17 programs with included data (Fig. 1), from the following countries (income class and region): Brazil (upper-middle income; Americas; n = 2 programs), Colombia (upper-middle income; Americas; n = 1), Czech Republic (high income; Europe; n = 1), India (lower-middle income; South-East Asia; n = 3), Iran (upper-middle income; Eastern Mediterranean; n = 1), Malaysia (upper-middle income; Western Pacific; n = 1), Mexico (upper-middle income; Americas; n = 1), Pakistan (lower-middle income; South-East Asia; n = 3), Qatar (high income; Eastern Mediterranean; n = 1), Senegal (lower-middle income; Africa; n = 2), and Taiwan (high income; Western Pacific; n = 1). These programs had a median of 4.5 (Q1-Q3: 3.5–6.0) staff members (0.5 denotes part-time), such that education could be delivered by multiple disciplines. Median program duration was 10.0 (Q1-Q3: 5.3–12.0) weeks, and they offered a median of 3.5 (Q1-Q3: 3.0–7.0) education sessions to program completers. By site, the lowest total mean

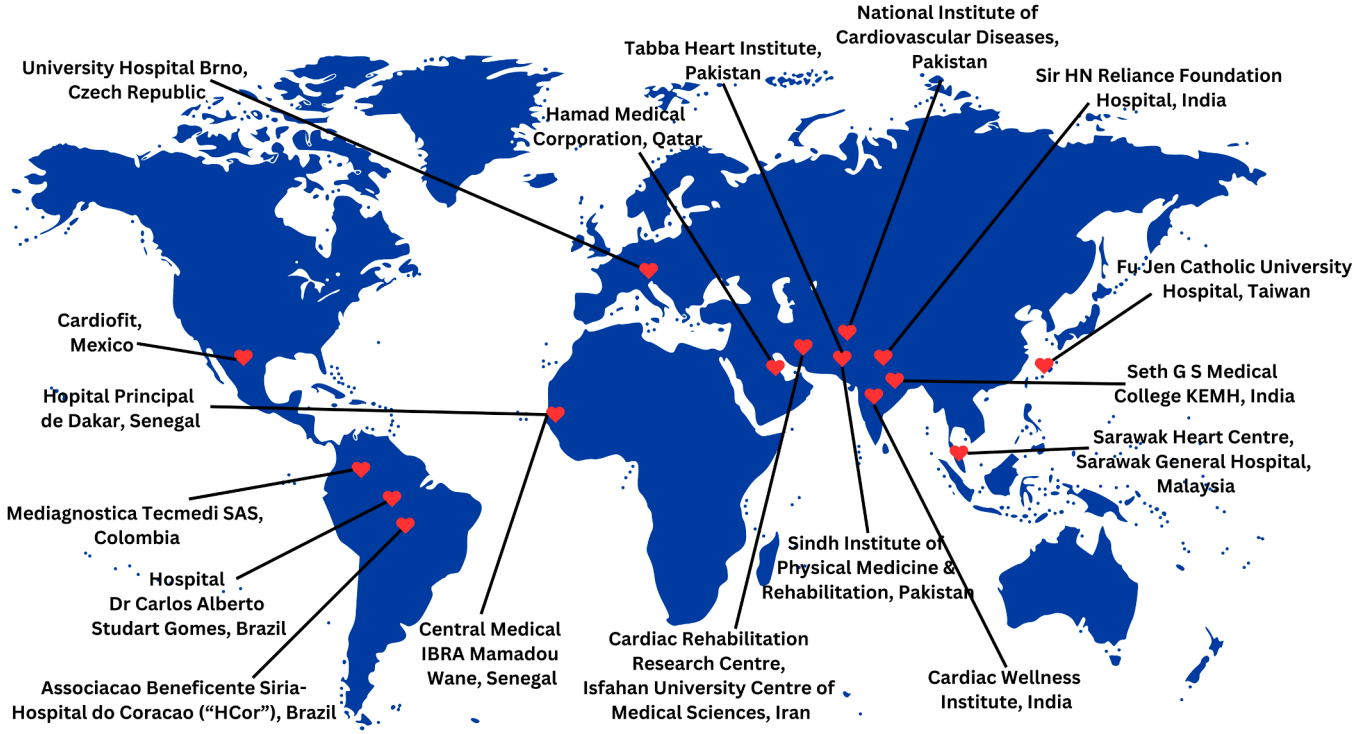

Fig. 1. Map of included cardiac rehabilitation programs in the ICRR at the time of study, ICRR, international Cardiac Rehabilitation Registry.

knowledge score was 6.9/9.0 and the highest was 8.8/9.0.

Participant characteristics are shown in Table 1. There were 4309 participants, from 6 of the 6 WHO regions (many in the Eastern Mediterranean), mostly from lower-middle income countries and none from low-income. Most were middle-aged males, with moderate education, who were not working. Most patients initiated CR following acute coronary syndrome and/or percutaneous coronary intervention (PCI). Diabetes was the most common comorbidity. Health behaviours were not at target.

Table 1
Participant Pre-CR characteristics, and bivariate association with total knowledge at follow-up, N = 4309.

Variable	n (%[a]), mean ± SD	Association with Total Knowledge[b]
Sociodemographic		
WHO Region		< 0.001
Americas	816 (18.9%)	
Africa	112 (2.6%)	
South-East Asia	622 (14.4%)	
Western Pacific	259 (6.0%)	
Europe	86 (2.0%)	
Eastern Mediterranean	2414 (56.0%)	
Country Income Classification		< 0.001
High	688 (16.0%)	
Upper-Middle	1197 (27.8%)	
Lower-Middle	2424 (56.3%)	
Sex		0.63
Male	3395 (78.8%)	
Female	912 (21.2%)	
Age	59.8 ± 11.7	0.35
Less than 65 years old	2760 (64.1%)	
65 years old or older	1549 (35.9%)	
Education (years)	12.7 ± 5.6	< 0.001
Work Status		< 0.001
Full or part-time	1278 (30.1%)	
Other	2969 (69.9%)	
Financial Insecurity		< 0.001
None	1828 (43.0%)	
Some	1815 (42.7%)	
A lot	610 (14.3%)	
Clinical		
Referral Diagnosis/es		
ACS /CAD	3297 (84.2%)	0.07
HF	181 (4.6%)	< 0.001
Other	437 (11.2%)	0.60
Referral Intervention(s)		
PCI	2174 (53.6%)	< 0.001
CABG	1061 (26.2%)	< 0.001
Other	445 (11.0%)	0.71
None	375 (9.2%)	0.07
Functional Capacity (peak METs)	4.5 ± 2.8	< 0.001
Body Mass Index (kg/m^2)	27.0 ± 4.7	0.86
Quality of Life (/10)	6.2 ± 1.8	0.42
Comorbidities		
Diabetes	1669 (38.7%)	0.48
MSK issues	426 (9.9%)	0.42
Mental health issues	328 (7.6%)	0.30
Kidney disease	185 (4.3%)	0.06
Lung disease	169 (3.9%)	0.91
Stroke or TIA	156 (3.6%)	0.72
Cognitive issues	26 (0.6%)	0.59
Total (/15)	0.8 ± 0.8	0.21
Nutrition (# servings fruit and vegetables / day)	2.8 ± 1.7	< 0.001
Exercise (minutes ≥ moderate intensity / week)	83.9 ± 97.9	0.05
Medication adherence (/5[c])	1.7 ± 0.9	< 0.001

ACS, acute coronary syndrome; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CR, cardiac rehabilitation; HF, heart failure; METs, metabolic equivalents of task; MSK, musculoskeletal; PCI, percutaneous coronary intervention; SD, standard deviation; TIA, transient ischemic attack; WHO, World Health Organization.

[a] Valid percentages are reported.

[b] p-value for the chi-square test, Mann-Whitney *U* test, and Spearman's rank correlation, as applicable.

[c] lower scores indicate better adherence

Overall, 3359 (78.0%) participants had any follow-up self-report knowledge data (Supplemental Table 1). These retained participants were significantly more often from the Eastern Mediterranean and less often from the Americas, as well as less often from high-income but more often from lower-middle income countries. They were more often male, with greater educational attainment, and more financially secure. They more often had acute coronary syndrome and less often heart failure or another indication, and more commonly had coronary bypass surgery (and had less interventions overall than those lost to follow-up). Retained participants also had significantly better functional capacity, higher body mass index, lower quality of life, more often had diabetes, and less often had mental health issues. They also reported higher weekly exercise as well as fruit and vegetable intake than those lost to follow-up. Additionally, they were more likely to have completed CR. No other differences were observed. Total knowledge score was computed in 3352 participants.

3.2. Cardiac rehabilitation participant self-reported disease management knowledge and its' correlates

Participant knowledge by domain and total knowledge in the overall sample are shown in Table 2. As shown, total scores were very high, with highest scores observed for return to life roles (98%) as well as cardiac medications and sharing of the care plan with primary care (both 97%); scores were lowest regarding stress management (73%) and lipid control (87%).

Knowledge by WHO region is shown in Fig. 2, and there was significant variation (Table 1). Specifically, participants in Africa (caution is warranted as there were few participants) and the Eastern Mediterranean reported lower knowledge compared to other regions, with higher knowledge in the Western Pacific (similarly there are few participants in Europe, so those data should not be over-interpreted). Knowledge by income class is shown in Fig. 3, and there was significant variation (Table 1). Specifically, knowledge was generally high in most domains in upper-middle income countries and moderately high in high-income countries. There was notable variation across domains among participants in lower-middle-income countries, with particularly low knowledge regarding stress management.

As shown in Supplemental Table 1, approximately four in five participants with any knowledge data had completed CR. Participants completed an average of 14.8 sessions (standard deviation [SD] = 10.5), and as shown in Tables 2, 15.5% of these had any home-based or hybrid delivery. As also shown in this Table, CR completers had greater total knowledge (8.5/9), with significantly higher knowledge across most domains. Knowledge regarding stress management techniques and exercise (more sessions) and that their primary care clinician was informed of their secondary prevention plan and return to life roles (fewer sessions) were significantly associated with the number of CR sessions attended. Knowledge overall and across almost all domains was significantly higher among the low proportion of participants who received any home-based or hybrid CR (Table 2; hence caution is warranted in over-interpretation).

Associations of total knowledge with pre-CR sociodemographic and clinical characteristics are shown in Table 1. In addition to variation by region and income class as outlined above, knowledge was also greater in participants with higher levels of education, those who were employed, and those with lower levels of financial insecurity. Participants with a history of heart failure, PCI and/or coronary artery bypass graft (CABG) had higher knowledge levels, as did those with better functional capacity. Additionally, participants with greater daily servings of fruit and vegetables, and better medication adherence had significantly higher levels of knowledge than their counterparts.

Upon testing for multicollinearity of these variables as well as those identified as significantly associated with retention in Supplemental

Table 2
Participant knowledge[a] at follow-up, and association with cardiac rehabilitation use.

Knowledge domain		CR completion[b]		CR sessions attended[c]		Any unsupervised CR/Hybrid[d]	
	Overall n = 3359	Yes (n = 2267, 75.8%)	No (n = 723, 24.2%)	Those with knowledge in domain area (mean±SD)	Those without knowledge (mean ±SD)	Yes (n = 521, 15.5%)	No (n = 2838, 84.5%)
Know primary care clinician informed of secondary prevention plan	3256 (96.9%)	2181 (96.2%)[b]	714 (98.8%)	15.4 ± 10.5	25.7 ± 10.8[c]	509 (97.7%)	2687 (94.7%)
Cardiac medications	3250 (96.8%)	2204 (97.2%)[b]	691 (95.6%)	15.6 ± 10.6	16.8 ± 11.8	497 (95.4%)	2701 (95.2%)
Stress management	2446 (72.8%)	1980 (87.3%)[b]	349 (48.3%)	16.8 ± 10.8[c]	11.4 ± 9.1	441 (84.6%)[d]	1963 (69.2%)
Exercise	3121 (92.9%)	2196 (96.9%)[b]	633 (87.6%)	15.7 ± 10.5[c]	14.6 ± 13.4	500 (96.0%)[d]	2584 (91.1%)
Nutrition	3229 (96.1%)	2208 (97.4%)[b]	688 (95.2%)	15.6 ± 10.7	15.5 ± 10.8	509 (97.7%)	2682 (94.5%)
Blood pressure control	3090 (92.0%)	2156 (95.1%)[b]	647 (89.5%)	15.6 ± 10.6	16.3 ± 11.5	508 (97.5%)[d]	2541 (89.5%)
Lipid control	2670 (87.0%)	1977 (87.2%)[b]	502 (69.4%)	15.6 ± 10.4	15.9 ± 11.7	484 (92.9%)[d]	2155 (75.9%)
Chest pain response	2936 (87.4%)	2089 (92.1%)[b]	605 (83.7%)	15.7 ± 10.8	15.1 ± 9.9	509 (97.7%)[d]	2384 (84.0%)
Return to life roles	3303 (98.3%)	2233 (98.5%)[b]	711 (98.3%)	15.6 ± 10.7	18.8 ± 12.9[c]	512 (98.3%)	2731 (96.2%)
TOTAL (/9)	8.1 ± 1.3	8.5 ± 1.1[b]	7.7 ± 1.3	-	-	8.6 ± 0.9[d]	8.1 ± 1.3

Note: number of symbols corresponds to degree of significance: one symbol, $p < .05$, two symbols, $p < .01$; three symbols, $p < 0.001$.
CR, cardiac rehabilitation; SD, standard deviation.
[a] n (%) yes reporting sufficient knowledge. Note that percentages are based on available data for each cell; the number of participants with available data for each knowledge domain and CR use indicator variable therefore varies because of item-level and variable-specific missing data. Moreover, consequently, subgroup counts may not sum to the overall total.
[b] $p < .05$ for association of knowledge with CR completion
[c] $p < .05$ for association of knowledge with CR session dose. Note the number of sessions prescribed varies by program
[d] $p < .05$ for association of knowledge with CR delivery mode.

WHO Region	Knowledge by Domain (%)									
	Know care plan sent to primary care	Cardiac medications	Stress management	Exercise	Nutrition	Blood pressure control	Lipid control	Chest pain response	Return to life roles	**Regional Average**
Americas (n=536; 16.0%)	96	96	96	94	98	96	83	96	98	**95**
Africa (n=104; 3.1%)	96	83	85	67	65	71	57	65	98	**76**
South-East Asia (n=462; 13.8%)	95	98	94	98	99	97	94	97	97	**97**
Western Pacific (n=200; 6.0%)	97	99	96	97	98	99	99	99	100	**98**
Europe (n=72; 2.1%)	79	82	81	90	89	81	69	92	93	**84**
Eastern Mediterranean (n=1985; 59.1%)	99	98	59	92	97	91	75	83	98	**88**
Global (N=3359)	**97**	**97**	**73**	**93**	**96**	**92**	**80**	**87**	**98**	**90**

Lowest Knowledge — Highest Knowledge

Fig. 2. Heat map of cardiac knowledge by domain by WHO region, WHO, World Health Organization. *Average total knowledge (i.e., across all knowledge domains) for each WHO Region.

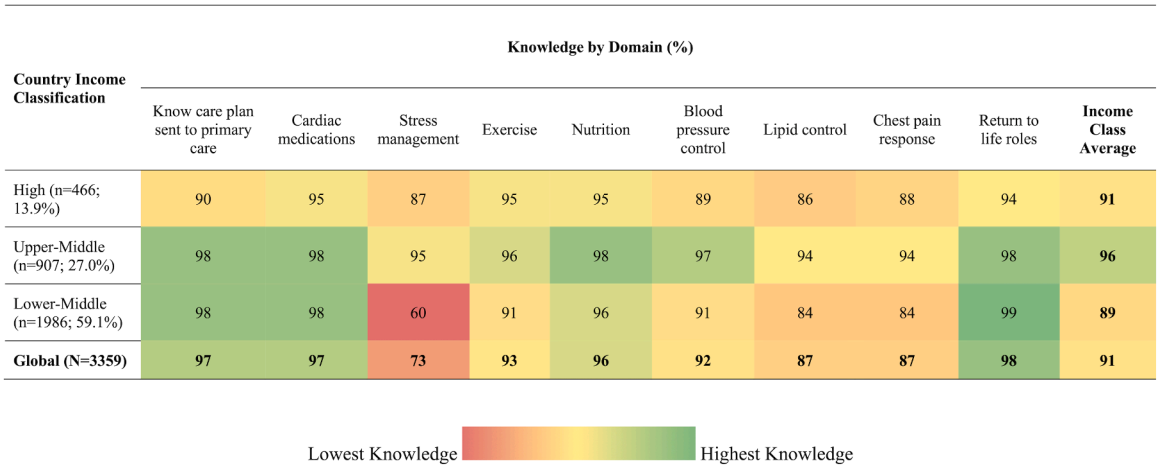

Fig. 3. Heat map of knowledge by domain by country income classification. *Average total knowledge (i.e., across all knowledge domains) for each income class.

Table 1 using VIFs (<5 indicating acceptable collinearity), the regression model was adjusted for the variables shown in Table 3. The overall multiple linear regression model was statistically significant (F=33.75, $p < 0.001$). The model explained 12.8% of the variance in total disease-related knowledge at follow-up (adjusted R^2). Standardized β coefficients are also reported in Table 3. In addition to differences by region and country income class, being employed, higher functional capacity (peak METs), higher quality of life and CR completion were significantly associated with greater knowledge.

Finally, as shown in Table 4, some domains of knowledge were statistically associated with behavior post-program among completers in unadjusted comparisons. Specifically, higher stress management knowledge was associated with better quality of life, higher self-reported nutrition knowledge was associated with greater fruit and vegetable intake, and finally, higher medication knowledge was associated with greater medication adherence. There was a trend for exercise, but no other differences were observed.

Table 3
Adjusted regression model assessing correlates of greater total disease-related knowledge at follow-up (N = 2537).

Predictor	B	Standardized β	95% CI for B	p
WHO region[a]	-0.048	−0.079	-0.075 to −0.022	< 0.001
Country income classification[a]	0.154	0.098	0.072–0.236	< 0.001
Sex (male)	-0.019	-0.006	-0.133–0.095	0.746
Education (years)	0.006	0.029	-0.002–0.015	0.150
Work status (not employed)	-0.229	-0.092	-0.340 to −0.119	< 0.001
Financial insecurity	-0.028	-0.017	-0.091–0.035	0.379
Heart failure	0.043	0.008	-0.171–0.257	0.695
Coronary artery bypass grafting	0.073	0.028	-0.027–0.174	0.153
Functional capacity (peak METs)	0.042	0.108	0.022–0.061	< 0.001
Quality of life	-0.031	-0.049	-0.055 to −0.006	0.013
CR completion status[b] (yes)	-0.676	-0.254	-0.789 to −0.563	< 0.001

Acronyms: CI = confidence interval; CR = cardiac rehabilitation; METs = metabolic equivalents; WHO = World Health Organization.
WHO region: 1 = Americas, 2 = Africa, 3 = South-East Asia, 4 = Western Pacific, 5 = Europe, 6 = Eastern Mediterranean. Country income classification: 1 = high, 2 = upper-middle, 3 = lower-middle income.
[a] WHO region and country income classification were entered as single numerical predictors using the codes listed as follows, rather than as sets of indicator variables. Consequently, their coefficients represent the modelled change in the outcome per one-unit increase in the assigned code and should not be interpreted as comparisons between individual regions or income groups. Figs. 2 and 3 display unadjusted knowledge scores by these categories.
[b] this variable only assessed at follow-up.

Table 4
Unadjusted association of disease-related knowledge with disease management at follow-up in CR completers, N = 2267.

Knowledge domain	Disease management	p
Stress Management[a]		0.009
Yes (n = 1980)	7.9 ± 1.4	
No (n = 285)	7.6 ± 1.5	
Nutrition[b]		< 0.001
Yes (n = 2208)	4.3 ± 2.6	
No (n = 58)	3.0 ± 2.0	
Nutrition[c]		0.54
Yes (n = 2208)	26.9 ± 4.5	
No (n = 58)	26.3 ± 5.2	
Exercise[d]		0.08
Yes (n = 2196)	219.2 ± 127.1	
No (n = 70)	191.3 ± 97.3	
Exercise[e]		0.77
Yes (n = 2196)	6.3 ± 3.7	
No (n = 70)	6.1 ± 2.7	
Medication[f]		< 0.001
Yes (n = 2204)	1.2 ± 0.5	
No (n = 58)	1.5 ± 0.8	
Medication[h]		0.26
Yes (n = 2204)	118.4 ± 14.7	
No (n = 58)	115.9 ± 13.9	
Lipid control[g]		0.31
Yes (n = 1977)	79.2 ± 36.1	
No (n = 287)	85.8 ± 38.3	
Blood pressure control[h]		0.77
Yes (n = 2156)	118.3 ± 14.8	
No (n = 111)	117.8 ± 12.5	

[a] mean quality of life (/10, higher scores better)
[b] mean number of fruits and vegetables per day
[c] body mass index
[d] minutes ≥moderate-intensity / week
[e] functional capacity (peak METs)
[f] with lower scores indicating greater cardiac medication adherence
[g] low-density lipoprotein (mg/dl)
[h] systolic blood pressure (mmHg)

4. Discussion and conclusion

4.1. Discussion

There have been no studies on degree of self-reported disease

management knowledge in larger real-world populations of CR patients to our knowledge. This study is the first to assess CVD management knowledge among CR participants multinationally, in lower-resource settings and with strong representation from middle-income countries in the Americas and Eastern Mediterranean. Leveraging ICCPR's international registry ICRR, overall knowledge levels were established to be high. While, as outlined above, scores may be inflated by selective retention of participants who were healthier, more educated, and more likely to complete CR, significant regional variations were also observed, as were economic ones. These disparities in outpatient knowledge are concerning, especially given the poorer CVD outcomes in lower-middle-income countries as well as in Africa and the Eastern Mediterranean [1], where healthcare resources and access to rehabilitation services is often inadequate [25]. Furthermore, the observed association between CR completion and knowledge, while positive, reveals the pressing need for continued investment in strengthening CR availability to ensure that patients receive not only the physical rehabilitation needed but also the knowledge essential for sustained, effective self-management of their cardiovascular health.

While these data cannot be readily compared or contrasted with existing literature (although there is some around the importance of health literacy in secondary prevention of chronic disease) [26,27], several important associations were observed that have key implications for the field. First, the lower lipid control knowledge should be better understood. It is a 'silent' risk factor, yet lipid testing is validated and recommended, and treatments to successfully control lipids well-established [28]. This might be explained by lack of healthcare coverage in these settings, particularly for lipid testing in addition to lipid-lowering medications [29]. WHO calls for universal healthcare coverage could overcome this barrier [30].

Second was the association between knowledge of their secondary prevention plan and that it had been received by the patient's primary care provider being associated with less CR session attendance. While it could be argued that continuity of secondary preventive care recommendations post-CR is not necessarily a knowledge domain, this association is likely owing to reverse causality or a third variable. For instance, patients without primary care may leverage CR long-term to compensate for the lack of a long-term clinician to support secondary prevention and disease management.

Third, one of the areas with lower knowledge was stress management. This is concerning given the association between mental distress and prognosis [31]. Indeed, many programs in LMICs offer lower dose or fewer sessions due to resource constraints [32]. Often the component that suffers is psychosocial counselling, including stress management [13]. Indeed, results showed that attendance at more CR sessions was associated with greater self-reported knowledge in this domain, suggesting that where patients can get sufficient education, delivery comprehensiveness may increase. This, in turn, supports patients, as evidenced by the results herein of an observed association between knowledge and better quality of life.

Fourth, the observed association of greater knowledge with receipt of hybrid delivery may be explained by a third variable. To explore this, the association of receipt of any unsupervised CR delivery with work status ($p = 0.03$) and educational attainment ($p = 0.01$) were assessed. These post-hoc analyses suggest that patients who return to work – and hence likely have more cognitive and technical skills – may also be able to learn what they need to optimize their CVD secondary prevention and access more flexible hybrid CR services, where education is potentially available on-demand asynchronously or delivered one-on-one.

Finally, while knowledge was associated with several favourable health behaviours, these associations were generally weak or non-significant for clinical indicators associated with targeted health behavior changes (e.g., BMI, peak METs, blood pressure and lipid control), suggesting limited predictive validity of the current binary self-reported knowledge measure for clinical manifestations. These relationships are likely influenced by unmeasured confounding factors, including socioeconomic status (including access to medicines), food environment, and educational attainment, which are known to independently affect both knowledge and health behaviours.

4.2. Limitations

Caution is warranted in interpreting these results. The following key and other limitations are expounded below, chiefly: (a) selection bias, in that participating programs were those able to join the registry, and patients were those able to enroll in CR, so the sample may over-represent better-resourced settings and more advantaged patients; (b) attrition/retention bias in that only 78% had follow-up knowledge data, and retained participants were systematically different from those lost to follow-up, which may have inflated knowledge estimates; (c) information bias in that knowledge was self-reported, binary, and collected by staff interview, so social desirability and limited measurement sensitivity are plausible; as well as (d) confounding, in that associations between knowledge and behaviors / clinical indicators may reflect unmeasured factors such as access to medications, food environment, education, and primary care continuity. On a related note, these comparisons were unadjusted, and the clinical relevance of any observed differences is not known.

First, while this is the first multinational study on CR participant knowledge, generalizability is limited to phase II outpatient programs that are resourced to participate in a registry and patients in low-resource settings with sufficient resources to attend CR programs. These findings are generalizable to CR patients from the 17 registry-participating programs, primarily in the Eastern Mediterranean (56% of participants), with additional representation from the Americas (19%), South-East Asia (14%), Western Pacific (6%), Africa (3%), and Europe (2%), across upper-middle, lower-middle, and only three high-income countries; generalizability to low-income countries, programs unable to participate in a registry, and patients unable to enroll in or complete CR is unknown. However, given the real-world nature of registry data and the variation in participating program characteristics, caution can be tempered.

Second, there was retention bias, as CR program non-completers were less likely to complete the follow-up assessment, and therefore contribute knowledge data. Retained participants were generally more educated, economically advantaged, and had higher functional capacity than those lost to follow-up. These systematic differences suggest that the analytic sample may represent a higher-functioning subgroup of CR participants, which may have led to an over-estimation of knowledge.

Third, due to the nature of the design, causal conclusions cannot be drawn, nor can inferences be drawn about any changes in knowledge being due to CR, given knowledge was not assessed pre-program. Because knowledge was assessed only at follow-up, whether knowledge was acquired during CR, whether more knowledgeable patients were more likely to complete CR, or whether retained participants simply differed systematically from those not retained cannot be determined.

Fourth, with regard to measurement, the knowledge variable reflects self-reported awareness of selected secondary prevention concepts rather than objectively verified or performance-based knowledge. As such, it should be interpreted as perceived understanding rather than true knowledge. Knowledge was assessed via only 9 self-report items with 'yes' or 'no' responses, and has not been validated. While items were developed following a rigorous, stepwise process [18] and were piloted [19], this limits variation capture, and reliability and validity of the items are not known. Because the items were administered interview style by CR staff, socially desirable responding may be at play. These factors may have culminated in the relatively high knowledge scores observed. With a mean total score of 8.1 out of 9 and several individual items endorsed by 96–98% of participants, the instrument shows a marked ceiling effect. In practice, that raises the possibility that the variable is capturing perceived preparedness, acquiescence, or social

desirability as much as true disease-management knowledge. Moreover, some programs translated the items, and due to resource constraints, this was not done with a professional translator; this may further limit reliability and validity.

Fifth, with regard to analytic approach, multi-level analyses were not used, which limits the ability to account for between-program and between-country variability, including differences among programs and countries within regions and income classifications. Instead, a multiple linear regression model was applied to examine overall group-level relationships, focusing was on how total knowledge was associated with various patient-level correlates. A multi-level approach may have provided additional insights but was not feasible due to constraints such as the smaller number of clusters at higher levels, uneven cluster sizes, as well as model convergence issues due to the number of correlates and their multiple categories. Consequently, differences in program characteristics, including educational practices, staffing, resources, patient populations, and approaches to knowledge assessment, may have contributed to observed differences in knowledge but could not be fully accounted for in the present analysis. In particular, findings concerning differences by WHO region and country income classification should be interpreted cautiously, as these characteristics may partly reflect differences between the programs and countries represented in the registry rather than regional or income-related effects per se.

Relatedly, CR completion should not be interpreted as a clean, exogenous predictor of follow-up knowledge. It is conceptually and methodologically intertwined with exposure to education, program engagement, and follow-up assessment participation. Patients who complete CR are more likely to receive the full education dose, remain in contact with the program, and participate in the knowledge assessment. Thus, the association between completion and knowledge likely reflects education exposure, engagement, and selection factors rather than a purely causal effect. Completion should therefore be viewed as a marker of greater program exposure and engagement, and the association described cautiously without causal interpretation.

Overall, readers are cautioned that findings are based on self-reported rather than verified knowledge, and given the registry design, causal conclusions cannot be drawn. Moreover, given biases in the sample, the CR participant self-report of knowledge may represent a somewhat optimistic estimate at a global level.

4.3. Practical implications

These findings suggest that while patient participation in CR programs in low-resource settings is associated with high levels of self-reported disease management knowledge, important gaps and inequities remain that have direct implications for patient education practice. Programs should prioritize targeted strengthening of lower-scoring domains, particularly stress management and lipid control, while recognizing that knowledge as assessed herein reflects perceived rather than verified understanding. The observed associations between CR completion and higher knowledge underscore the importance of supporting patient retention and completion; however, causality cannot be assumed, and strategies to enhance engagement should be sensitive to structural barriers such as socioeconomic constraints and access to care. Given regional and income-related disparities, education should be culturally-adapted and responsive to local resource contexts, rather than uniformly applied. The weak and inconsistent associations between knowledge and clinical indicators further suggest that education alone is insufficient to drive risk factor control, and should be integrated with broader supports addressing access to medications, healthy food environments, and continuity of care. Finally, the potential advantages observed with hybrid delivery models warrant cautious exploration, as these may reflect differences in patient characteristics rather than intervention effects. Routine, validated assessment of both baseline and post-program knowledge, alongside behavioral and clinical outcomes, is recommended to better tailor education and evaluate its true impact.

4.4. Conclusion

While self-reported and with apparent selection bias, post-CR knowledge in this diverse multinational sample was quite high, with significant variation by region, income classification (although these differences should be interpreted cautiously as the study design as well as the clustering of participants within programs and countries does not allow for these differences to be disentangled from program- and country-level characteristics), and by several patient characteristics; these findings pinpoint inequities potentially requiring amelioration. Moreover, more than mere session attendance, CR completion was associated with greater post-program self-reported knowledge across most domains, yet patients who did not know their CR summary would be transitioned to primary care had attended significantly more sessions. Overall, these findings highlight the need for tailored, evidence-based education strategies that address specific knowledge gaps and accommodate diverse patient populations.

CRediT authorship contribution statement

Sheikh S. Shaubnaum: Writing – original draft, Investigation, Formal analysis, Data curation. **Sherry L. Grace:** Writing – original draft, Supervision, Methodology, Investigation, Conceptualization. **Maria S.Q. Farias:** Writing – review & editing, Investigation, Data curation. **Priya Chockalingam:** Writing – review & editing, Investigation, Data curation. **Ladislav Batalik:** Writing – review & editing, Investigation, Data curation. **Ariany Marques Vieira:** Writing – review & editing, Investigation, Data curation. **Ssu-Yuan Chen:** Writing – review & editing. **Francisco Lopez-Jimenez:** Writing – review & editing, Conceptualization. **Gabriela L.M. Ghisi:** Writing – original draft, Visualization, Supervision, Investigation, Formal analysis, Conceptualization.

Ethics declaration

Written informed consent to take part in the study and to publish the article has been obtained from all participants or their legal representatives. The privacy rights of participants have been observed.

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place. This study was approved by the York University. (Approval No. e2020-147)

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.pec.2026.110366.

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