**1. Introduction**

Obesity is a well-established risk factor for coronary heart disease (CHD); a body mass index (BMI) [weight, kg/(height, m)2] ≥30 (obesity) leads to a moderate to severe increase in risk [1]. Body weight loss of ≥3% has been identified as beneficial to CHD risk factors [2].

Cardiac rehabilitation (CR) is a multi-component intervention delivered along a defined care pathway to aid recovery, slow the progression of disease and improve quality of life after diagnosis of heart disease [3]. Core CR provides a structured programme of education and activities to support psychological and physical recovery and aid the adoption of behaviours beneficial to health. CR guidelines recommend attaining a BMI of 18.5 to 24.9 kg/m2 with a 5-10% reduction in weight at 6 months [4].

The proportion of CR patients with obesity is high e.g. 30% in the UK [5]. However, mean weight loss is small in routine CR (0.4kg [6] to 1.7kg [7]). Meanwhile, individual variation in weight change is large; Gomadam and colleagues found 27% of patients lost ≥3% of body weight whilst 10% gained ≥3% [8].

Patient characteristics associated with increased weight loss in CR include:; initial body weight[8, 9]; height [10]; white ethnicity [8, 11]; higher levels of education [12]and low density lipoprotein cholesterol levels [9]. Characteristics associated with less weight loss during CR include: smoking at the time of the cardiac event [8, 13]; cardiac surgery [9] and a higher comorbidity score [14]. Age [12] and diabetes [8] have been reported to be associated with increased weight loss in CR in some studies, but decreased loss in others (age [8], diabetes [12]). Different CR settings (inpatient [12] versus free-living [10]) and analyses may play a role here.

Predictors of change in weight identified from behavioural weight management programmes include; gender [15, 16]; marital status [16]; employment status [17]; activity levels [18]; hypertension [19]; pain [20]; depression [19, 21]; anxiety [22] and mental health related quality of life [17]. McKee and colleagues found no significant predictors of BMI change in core CR using multivariate regression analysis on data from 66 patients including; gender, age, reason for referral, functional capacity and depression[6].

Many patient characteristics have been identified as associated with weight change in behavioural obesity-management programmes and CR. However, the size of the observational studies and quality of reporting of statistical outcomes is variable. Using a large dataset enables determination of the extent to which a variety of characteristics independently predict weight change in obese patients. The size of each predictors is useful to: determine clinically important differences in weight change; aid the setting of guidelines; identify patients most in need of weight loss support; and agree realistic goals with patients. To enable the valid comparison of weight loss outcomes in different CR programmes, account also needs to be taken of obese patients’ characteristics that significantly affect weight change. Hence our aim was to determine the extent to which obese patient characteristics predict weight change in routine cardiac rehabilitation using a large, registry-based dataset.

**2. Methods**

**2.1 Design and ethical considerations**

An observational, pre- and post-core CR study was undertaken of routine practice in the UK using the National Audit of Cardiac Rehabilitation (NACR) dataset. The CR was delivered in accordance with British Association for Cardiovascular Prevention and Rehabilitation (BACPR) guidelines and core components [23] which include the assessment of BMI, individual goal-setting, provision of personalised dietary advice and regular reviews of goals. Patient characteristics were determined pre-core CR and weight change was determined between pre- and post-core CR assessments. The NACR audit includes routinely collected data from medical records and patient NACR questionnaires completed at assessments before and after core CR [5]. General Data Protection Regulation (GDPR) requirements were met by approved members of clinical teams entering NACR data via NHS digital, a secure online environment authorised to hold individual patient-identifiable data and convey link-anonymised data electronically to the NACR database held at the University of York, UK. Under section 251 of the NHS Act 2006, the data governance processes eliminated the need for individual patients’ explicit consent for the use of routinely collected data for audit and service related research purposes. No further ethical approval was required. STROBE standards of reporting were utilised [24].

**2.2 Dataset**

The NACR audit dataset from 1st January 2012 to 31st December 2018 was used and processed in accordance with NACR reporting methodology and validation rules of the NACR data dictionary [25]. Male and female patients were included if they had a cardiac event that led to referral to CR from 1st January 2012; commenced core rehabilitation within a year of their cardiac event; completed core rehabilitation; and completed both pre-and post-core assessments before 1st January 2019. Patients with values for BMI ≥60 kg/m2 or weight change of >40% during CR were excluded, as deemed to include data entry errors (in line with Lopez-Jimenez and colleagues [10]). Patients with heart failure were excluded due to common complications of; changes in fluid status, which affects interpretation of changes in weight; and unintended weight loss [26].

**2.3 Statistical Analysis**

Patient characteristics were included on the basis of previous literature on variables associated with weight change in CR or behavioural weight management programmes. The continuous variables age, weight and height were included. BMI was excluded due to collinearity with weight and its use as a cut off to define obesity affecting the assumptions of the planned regression analysis. For non-continuous variables, dichotomous variables were used: gender (male or female); relationship status (in permanent partnership or not); ethnicity (white or non-white); employment status (employed or not employed); cardiac treatment (surgical - coronary artery bypass graft and valve surgery; or non-surgical - myocardial infarction - MI; percutaneous coronary intervention - PCI; MI with PCI; angina; and other, excluding heart failure); comorbidities (present or absent); smoking status (stopped smoking since event or current smoker/ex-smoker/never smoked); activity (≥150mins moderate activity per week or less); pain (moderate to severe or less), and anxiety and depression assessed by the Hospital Anxiety and Depression Scales (HADS) (score ≥11 as indicative of the condition) [27]. Seven quality of life (QOL) measures from the Dartmouth Coop questionnaire [28], part of the NACR assessment questionnaire, were included in the analysis (normal QOL scores 1-3 or poor 4-5). Living in an area of deprivation is associated with a lower likelihood of taking part in CR [5] and obesity levels are higher in lower socioeconomic groups [29] . Area of residence by the England Index of Multiple Deprivation (IMD) (methodology previously described by Salman and Doherty [30]) was included in the analysis as a dichotomous variable (most deprived quintile or less deprived quintiles). The potential confounding factors; time from cardiac diagnosis to the start of core CR; and duration of core CR were included.

Descriptive statistics are reported as means and standard deviations (SD), medians and interquartile ranges (IQR) for non-normally distributed data, or percentages. Pre- and post-CR weight change was analysed by paired T tests and proportions of patients changing weight by ≥3% are presented, the cut off being that shown to have clinical effects on CHD risk factors [2].

Univariate analysis was by simple linear regression of change in body weight on individual continuous variables and by unpaired t tests for binary categorical variables.

Backward, stepwise, multiple linear regression was undertaken with entry at 5% significance following Bonferroni correction for multiple hypothesis testing. Variables were successively removed based on their significance value until only those significant at the 5% level were included. Only participants with values for all variables in the multiple linear regression were included; no imputation was used to account for missing data. All eligible patients were included in the analysis to avoid bias, enable generalisability and provide a valid sample for the regression analysis. Valid case analysis was utilised due to the use of routine data and not being able to back fill missing fields.

Model checking was performed to determine if assumptions were met. IBM SPSS version 25 was used.

**3. Results**

The reasons for exclusion of potentially eligible patients from the study sample are shown in **Figure 1.**

Overall, 29601 obese patients completed CR and pre- and post-assessments and form the study sample.

Of those who completed CR, 29% were obese at pre-CR assessment compared to 31% of patients who did not complete CR, indicating a slightly higher drop-out rate of obese patients compared to those with lower BMIs.

The characteristics of the study sample of obese patients at pre-CR assessment are shown in T**able 1 and Supplementary Information Tables S1 and S2**. The majority of the patients were male (74%), white (89%) and non-surgical (77%). Hypertension was the most common comorbidity (56%) followed by dyslipdaemia (35%) and diabetes (28%). Few patients reported being current smokers (7%) and 9% reported ceasing to smoke since their cardiac diagnosis.

The median time between the cardiac diagnosis and starting core CR was 6 weeks (IQR 4 to 10 weeks) and median duration of core CR was 10 weeks (IQR 7 to 13 weeks).

Mean weight change between pre and post CR assessments was -0.8kg (95% CI; -0.9, -0.8; p<0.001); -0.9kg (95% CI; 0.9, 1.0: p<0.001) in men and -0.5kg (95%CI; -0.6, -0.5; p<0.001) in women. Mean % weight change was -0.8% (SD 4.1); men -0.9% (SD 4.1) and women -0.6% (SD 4.3). 21% of the obese patients lost ≥3% of body weight during core CR and 11% gained ≥ 3% of body weight, whilst the remainder experienced weight change of <3%.

Univariate analysis was undertaken on 39 patient characteristics and 2 programme-related factors and identified 17 patient characteristics at pre-CR assessment and 1 programme-related factor which significantly predicted weight change during core CR after application of the Bonferroni correction factor (p≤0.001). These were: age; height; weight; BMI; gender; cardiac surgery; white ethnicity; being employed; being in a permanent relationship; living in the most deprived quintile of IMD; stopping smoking since the cardiac diagnosis; fitness allowing only light or very light activities; HADS Anxiety score ≥11; HADS Depression score ≥11; moderate to severe bodily pain; much difficulty or unable to do daily activities; diabetes; and time from the cardiac event to commencing core CR. With the planned omission of BMI, the remaining 17 variables were entered into the backward stepwise multiple linear regression **Table 2**.

The standardized coefficients suggest that body weight at pre-CR assessment was the strongest independent predictor of greater weight loss; a mean 0.05kg per kg body weight (95% CI; 0.04, 0.06). Increasing age and being employed also independently predicted increased weight loss. Ceasing to smoke since the cardiac diagnosis predicted 1.2kg (95% CI; 0.9, 1.5) less weight loss during core CR compared to those with any other smoking status. Having cardiac surgery, living in an area of high deprivation, having diabetes, being female and only being able to undertake light activities also independently predicted sizably diminished weight loss, compared to comparator groups and mean weight change.

**4. Discussion**

We aimed to determine the extent to which obese patient’s characteristics predicted weight loss in CR. Smoking cessation predicted a large, detrimental reduction in weight loss. Cardiac surgery, diabetes, living in a deprived area and being female also predicted less weight loss whilst low initial fitness levels and pain predicted smaller diminutions in weight loss. Higher initial body weight, increasing age and being employed predicted greater weight loss.

Mean weight loss of 0.8kg during CR with a median duration of 10 weeks was small, in line with losses reported in other studies of routine CR (0.4kg [6] to 1.7kg [7]). The proportions of patients who changed % body weight by ≥3% were also broadly similar to those previously reported [8]; a fifth of patients achieved clinically meaningful weight loss during core CR.

4.1 Characteristics Predicting Less Weight Loss

Smoking cessation since cardiac diagnosis independently predicted less weight loss by 1.2kg during core CR. Aubin and colleagues’ systematic review of smoking cessation identified mean weight gain of 2.9kg at 3 months [31]. Our findings are limited to the time window of core CR commencing a median of 6 weeks after cardiac diagnosis, but also predict a negative effect of smoking cessation on weight loss during the first few months of smoking cessation. A Cochrane review of interventions to prevent weight gain following smoking cessation, identified that personalized weight management, with individualized energy prescription and feedback on personal goals, may reduce weight gain without reducing smoking abstinence [32]. However, weight management education did not reduce weight gain and may reduce smoking cessation [32]. An individualized approach to weight control in CR may be particularly important in those ceasing to smoke.

Cardiac surgery independently predicted less weight loss by 0.9kg during core CR, compared to non-surgical treatments. This is in line with the findings of Savage and colleagues [9] who, through also weighing CR patients at the time of hospitalization, were additionally able to identify more weight loss in surgical patients prior to commencing core CR and similar overall weight loss by surgical and non-surgical patients by the end of cardiac rehabilitation.

Having diabetes independently predicted less weight loss by 0.5kg during CR which is in agreement with Gondoni and colleagues [12] in inpatient CR. On the contrary, Gomadam and colleagues reported diabetes as an independent predictor of greater weight loss in CR [8] and it is unclear why there are conflicting findings. Karlsen and colleagues [17] found diabetes predicted less weight loss at 3 months in a behavioural weight loss programme, in agreement with our findings. Some drug treatments for diabetes, e.g. insulin and sulphoylureas, can promote weight gain. Unfortunately, we were unable to investigate the potential effects of diabetes medications. Previous repeated unsuccessful attempts at weight loss are associated with poorer weight loss outcomes [33] and may also play a role in obese, diabetic CR patients.

Living in a deprived area independently predicted less weight loss by 0.5kg. The reasons that obesity is related to low socio-economic status in the developed world are multifactorial and complex. These reasons may include both environmental factors (such as a lack of access to affordable fresh foods) and psychological aspects (such as the effects of low socio-economic status on self-efficacy and overeating in response to emotional pressures)[34]. With increased barriers to healthy eating in those living in deprived areas, it is unsurprising that they are predicted to lose less weight in CR.

Women undertaking CR were predicted to lose 0.4kg less than men, having taken account of other factors within the analysis, including initial weight, height, age, smoking cessation and fitness levels. The direction of difference in weight loss with gender is in agreement with Gondoni and colleagues [12] in CR and behavioural weight management programmes [15, 16].

Women [5], patients with diabetes [35] and those living in deprived areas [5] are also less likely to take up CR. Poor CR uptake combined with evidence of lower weight loss in these groups indicates that continued efforts are needed to develop inclusive CR programmes, engage these groups in CR and meet their weight management needs.

Being able to undertake only light activities when commencing CR independently predicted less weight loss by 0.3kg. Ades and colleagues [36] reported that those with low fitness levels were unable to tolerate high energy expenditure activities to promote weight loss. Obese CR patients with low initial fitness may need additional weight management support if they are unable to increase activity levels to the same extent as other patients. Meanwhile, pain predicted less mean weight loss by 0.2kg. In behavioural weight management, Maseb and colleagues [20] also reported those in pain losing less weight. Good pain control may be helpful to aid weight loss.

4.2 Characteristics Predicting More Weight Loss

Higher initial body weight is a well-recognized predictor of greater weight loss in behavioural weight management [37] and CR [8, 38] and was the largest independent predictor of weight change in our study (mean 0.05kg weight loss per kg body weight). Increasing age independently predicted greater weight loss by 0 03kg per year of age, in agreement with Lopez-Jimenez and colleagues in CR in free-living individuals [10] and a number of weight management studies[10, 17-19, 39]. Gondoni and colleagues identified less weight loss during inpatient CR in older patients, divided into tertiles by age. Their study population comprised patients referred for inpatient CR and predominantly those with a history of multiple dietary failures [12] which may have particularly adversely affected weight loss with age. Our sample included all those undertaking routine core CR post-discharge. Our sample was also older, 62.8 years (range 18-100) versus 60.3 years (range 27-80) and we accounted for a wider range of characteristics using a continuous analysis. It is unknown whether the different study populations, CR setting or analysis accounts for the different findings compared to Gondoni and colleagues. The reasons for the finding of increased weight loss with age, or the fat and lean composition of that loss, is unknown. Lower attrition is also evident in older patients [40] which may indicate a group more able to engage with CR.

Being employed independently predicted greater mean weight loss of 0.4kg; also noted in a behavioural weight loss study [17]. Employment may improve general activity levels, self-efficacy and limit the time over which food is available. Initial body weight, age and employment status could be considered when agreeing realistic weight loss goals with patients.

4.3 Limitations

Although the BACPR standards[23] include the recommendation of individualized dietary advice to enable a cardio-protective diet to be followed, it was unknown whether weight loss was a specific behaviour-change goal for individual obese participants. The EUROASPIRE V study found that, amongst obese cardiac patients, a quarter reported not being told they were overweight and a half had not attempted to lose weight 6 months or more following their cardiac event[41]. From the national audit data used in this study, we were also unable to determine the details of the dietary advice and support for weight control given at the multiple sites. The multiple regression analysis was limited to CR in England due to inclusion of the English Index of Multiple Deprivation. However, the generalizability of the findings is mostly supported by the similarity in weight change, and characteristics affecting it, to those reported in international literature. Weight change during core CR is a small time-window and in practice, weight at the time of cardiac diagnosis is key to setting realistic weight loss goals in CR. Longer term weight monitoring is required to evaluate weight management success. We had insufficient quantity and coverage of longer term follow up to be confident to include this in the analysis.

**5. Conclusions**

This study examined the extent to which a wide range of factors independently predict weight change in obese patients during CR using a large, registry-based dataset. A fifth of obese patients achieved clinically meaningful weight loss during core CR. Smoking cessation predicted the largest reduction in weight loss; being female, having cardiac surgery, having diabetes and living in deprived areas also predicted less weight loss in core CR. Meanwhile, higher initial body weight, employment and older age predicted greater weight loss. The current study identifies groups of obese patients who may need further support to aid weight loss and helps inform CR guidelines and realistic goals for patients with particular characteristics. It also identifies characteristics that need to be accounted for when comparing weight loss outcomes between different CR programmes.

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**Author contributions statement**

**Jacqueline Wilkinson:** Conceptualization, Methodology, Formal Analysis, Writing – original draft, Visualization. **Alexander Harrison:** Conceptualization, Methodology, Formal Analysis, Data curation, Writing – review and editing. **Patrick Doherty:** Conceptualization, Methodology, Writing – review and editing, Supervision. All gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

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