Evaluating the effect of a digital health intervention to enhance physical activity in people with chronic kidney disease (Kidney BEAM): a multicentre, randomised controlled trial in the UK

Sharlene A Greenwood, Hannah M L Young, Juliet Briggs, Ellen M Castle, Christy Walklin, Lynda Haggis, Caitlin Balkin, Elham Asgari, Sunil Bhandari, James O Burton, Roseanne E Billany, Nicolette C Bishop, Kate Bramham, Jackie Campbell, Joseph Chilcot, Nicola J Cooper, Vashist Deelchand, Matthew M P Graham-Brown, Alexander Hamilton, Mark Jesky, Philip A Kalra, Pelagia Koufaki, Kieran McCafferty, Andrew C Nixon, Helen Noble, Zoe Saynor, Maarten W Taal, James Tollit, David C Wheeler, Thomas J Wilkinson, Hannah Worboys, Jamie H Macdonald

Summary

Background Remote digital health interventions to enhance physical activity provide a potential solution to improve the sedentary behaviour, physical inactivity, and poor health-related quality of life that are typical of chronic conditions, particularly for people with chronic kidney disease. However, there is a need for high-quality evidence to support implementation in clinical practice. The Kidney BEAM trial evaluated the clinical effect of a 12-week physical activity digital health intervention on health-related quality of life.

Methods In a single-blind, randomised controlled trial conducted at 11 centres in the UK, adult participants (aged ≥18 years) with chronic kidney disease were recruited and randomly assigned (1:1) to the Kidney BEAM physical activity digital health intervention or a waiting list control group. Randomisation was performed with a web-based system, in randomly permuted blocks of six. Outcome assessors were masked to treatment allocation. The primary outcome was the difference in the Kidney Disease Quality of Life Short Form version 1.3 Mental Component Summary (KDQoL-SF1.3 MCS) between baseline and 12 weeks. The trial was powered to detect a clinically meaningful difference of 3 arbitrary units (AU) in KDQoL-SF1.3 MCS. Outcomes were analysed by an intention-to-treat approach using an analysis of covariance model, with baseline measures and age as covariates. The trial was registered with ClinicalTrials.gov, NCT04872933.

Findings Between May 6, 2021, and Oct 30, 2022, 1102 individuals were assessed for eligibility, of whom 340 participants were enrolled and randomly assigned to the Kidney BEAM intervention group (n=173) or the waiting list control group (n=167). 268 participants completed the trial (112 in the Kidney BEAM group and 156 in the waiting list control group). All 340 randomly assigned participants were included in the intention-to treat population. At 12 weeks, there was a significant improvement in KDQoL-SF.13 MCS score in the Kidney BEAM group (from mean 44·6 AU [SD 10·8] at baseline to 47·0 AU [10·6] at 12 weeks) compared with the waiting list control group (from 46·1 AU [10·5] to 45·0 AU [10·1]; between-group difference of 3·1 AU [95% CI 1·8–4·4]; p<0·0001).

Interpretation The Kidney BEAM physical activity platform is an efficacious digital health intervention to improve mental health-related quality of life in patients with chronic kidney disease. These findings could facilitate the incorporation of remote digital health interventions into clinical practice and offer a potential intervention worthy of investigation in other chronic conditions.

Funding Kidney Research UK.

Lancet Digit Health 2023

Published Online November 13, 2023 https://doi.org/10.1016/S2589-7500(23)00204-2

Department of Renal Medicine, King's College Hospital NHS Trust, London, UK (S A Greenwood PhD, J Briggs BSc, C Walklin BSc, L Haggis BSc, C Balkin BSc); **Renal Sciences, Faculty of Life Sciences and Medicine, King's College London, London, UK** (S A Greenwood); **NIHR Leicester Biomedical Research Centre, Leicester, UK** (H M L Young PhD, Prof J O Burton MD, R E Billany MSc, M M P Graham-Brown PhD, T J Wilkinson PhD); **Leicester Diabetes Centre, University of Leicester, Leicester, UK** (H M L Young, T J Wilkinson); **Physiotherapy Department, University Hospitals of Leicester NHS Trust, Leicester, UK** (H M L Young); **School of Physiotherapy, Department of Health Sciences, Brunel University, London, UK** (E M Castle PhD); **Department of Renal Medicine, Guy's and St Thomas' NHS Trust, London, UK** (E Asgari MD); **Department of Renal Medicine, Hull University Teaching Hospitals NHS Trust, Hull, UK** (Prof S Bhandari PhD); **Department of Cardiovascular Sciences** (Prof J O Burton, R E Billany, M M P Graham-Brown) **and Department of Population Health Sciences** (Prof N J Cooper PhD, H Worboys PhD), **University of Leicester, Leicester, UK; School of Sport Exercise and Health Sciences, Loughborough**

Introduction

Globally, 28% of adults are insufficiently active.[1] Sedentary behaviour will lead to 500 million new cases of non-communicable disease before 2030,[1] and will continue to impact negatively on mental health and health-related quality of life (HRQoL).[2–4] Chronic kidney disease is common and affects more than 10% of the general population worldwide;[5] those affected are at particular risk of sedentarism and physical inactivity. In people with chronic kidney disease, physical inactivity exacerbates an already increased mortality risk,[6] accelerates disease progression,[7] and leads to poorer HRQoL. Of note, patient-reported outcomes, which include HRQoL and symptoms such as fatigue, have been highlighted by people with chronic kidney disease as being more important than clinical outcomes, such as mortality.[8]

University, Loughborough, UK (N C Bishop PhD); Women's Health (K Bramham PhD) and Institute of Psychiatry, Psychology & Neuroscience (J Chilcot PhD), King's College London, London, UK; Faculty of Health, Education and Society, University of Northampton, Northampton, UK (Prof J Campbell PhD); Department of Renal Medicine, Royal Free Hospital, London, UK (V Deelchand MBA); Royal Devon University Healthcare NHS Foundation Trust, Exeter, UK (A Hamilton PhD); Department of Renal Medicine, Nottingham NHS Trust, Nottingham, UK (M Jesky PhD); Salford Royal Hospital, Northern Care Alliance NHS Foundation Trust, Salford, UK (Prof P A Kalra MD, J Tollit PhD); Department of Renal Medicine, Queen Margaret University, Edinburgh, UK (P Koufaki PhD); Department of Renal Medicine, Barts Health NHS Trust, London, UK (K McCafferty PhD); Department of Renal Medicine, Lancashire Teaching Hospitals NHS Foundation Trust, Preston, UK (A C Nixon PhD); Division of Cardiovascular Sciences, University of Manchester, Manchester, UK (A C Nixon); School of Nursing and Midwifery, Queen's University, Belfast, UK (Prof H Noble PhD); School of Sport, Health and Exercise Science, University of Portsmouth, Portsmouth, UK (Z Saynor PhD); Centre for Kidney Research and Innovation, School of Medicine, University of Nottingham, Nottingham, UK (Prof M W Taal MD); Department of Renal Medicine, University College London, London, UK (Prof D C Wheeler MD); Institute for Applied Human Physiology, Bangor University, Bangor, UK (Prof J H Macdonald PhD)

Correspondence to: Dr Sharlene A Greenwood, Department of Renal Medicine, King's College Hospital NHS Trust, London SE5 9RS, UK
sharlene.greenwood@nhs.net

Research in context

Evidence before this study

Patient-reported outcomes, which include health-related quality of life (HRQoL) and symptoms such as fatigue, were highlighted by people with chronic kidney disease as being more important than clinical outcomes. Despite guidelines suggesting that all people with chronic kidney disease should be encouraged to do physical activity, people with chronic kidney disease remain too sedentary, and previous clinical trials of lifestyle interventions in people with chronic kidney disease have not often shown an impact of physical activity on HRQoL. We searched PubMed between Jan 1, 1990, and May 31, 2023, for original research or review articles published in English using the search terms "chronic kidney disease" AND "physical activity" OR "exercise' AND "digital health". The search returned 21 articles. After reviewing abstracts, we did not identify any original research articles evaluating a physical activity or exercise training digital health intervention for people living with chronic kidney disease. Although physical activity digital health interventions might provide a solution to the sedentary behaviour of people with chronic kidney disease, high-quality evidence is required before these can be implemented into clinical practice.

Added value of this study

To the best of our knowledge, the Kidney BEAM trial is the only robust clinical trial to evaluate a physical activity digital health intervention for people with chronic kidney disease. Our findings indicate that the Kidney BEAM intervention resulted in significant and clinically important effects on HRQoL when compared with usual care. Specifically, the Kidney BEAM intervention was effective for the primary outcome of mental health-related quality of life and the related secondary outcomes of physical function, symptom burden, social interaction, anxiety or depression, and patient activation. There was no significant change in physical health-related quality of life, physical activity levels, work and social adjustment scores, or clinical measures as a result of the intervention. Unlike previous lifestyle intervention trials in this population, the digital health intervention is practically implementable and successfully targets mental health.

Implications of all the available evidence

A physical activity digital health intervention provides more treatment options to improve HRQoL, enabling greater patient choice and reducing health inequality, while remaining aligned with prudent health-care principles. Our findings suggest that in people with chronic kidney disease, Kidney BEAM is a practically implementable lifestyle intervention that can improve the care of people living with chronic kidney disease, a population at particular risk of sedentarism and associated health risks. The intervention is also suitable for national and international scale-up, and therefore offers a viable model to be adapted for use globally in other chronic conditions associated with sedentarism and poor physical and mental health.

Consequently, interventions to enhance physical activity, mental health, and HRQoL are of global interest, and are even more crucial given the emotional distress and increased risk of poor mental health resulting from the COVID-19 pandemic.[9] The pandemic particularly affected people with chronic kidney disease, many of whom are clinically extremely vulnerable and were forced to self-isolate. The need to combat sedentarism and physical inactivity is recognised in disease-specific guidelines,[10–12] which recommend increasing physical activity levels for people with chronic kidney disease. However, unlike other long-term conditions, people with chronic kidney disease are not routinely counselled about physical activity as part of patient care,[13] and global policy-related barriers restrict access to exercise provision and exacerbate health inequality.[14]

Few large clinical trials have been published examining lifestyle interventions in chronic kidney disease populations.[10,15] Meta-analyses report that existing exercise studies have a high risk of bias and have uncertain effects on HRQoL, particularly mental health.[16] Furthermore, studies that have evaluated delivery of exercise interventions in outpatient settings have not demonstrated cost-effectiveness.[17] Encouragingly, when positive effects of exercise on HRQoL have been demonstrated, interventions have often included an at-home delivery model (as opposed to outpatient clinics).[18,19] Importantly, previous research suggests a need for patient choice within lifestyle interventions to facilitate good patient engagement.[17,20]

Remote digital health interventions that deliver evidence-based physical activity interventions provide a potential solution for the sedentary behaviour and physical inactivity of people with chronic kidney disease and can be offered to a diverse patient population at scale.[1] Despite increased interest in virtual chronic kidney disease care,[21] there is insufficient high-quality evidence for digital health interventions to guide clinical practice.[22,23] This is a major obstacle to improving the lives of people with chronic kidney disease and, without high-quality randomised controlled trials, digital health interventions will be difficult to implement. The Kidney BEAM multicentre randomised controlled trial investigated a novel digital health intervention delivery approach.[24] The findings are of particular importance for people with chronic kidney disease but might also be of relevance to those with other long-term conditions for which physical inactivity, poor mental health, and reduced HRQoL remain challenges.

Methods

Study design

Kidney BEAM was a multicentre, randomised, single-blind, controlled waiting list trial conducted to assess the

effectiveness of a physical activity digital health intervention on HRQoL in patients with chronic kidney disease recruited from 11 hospitals in the UK. The trial design, protocol, and baseline characteristics of the patients have been published previously.[24] The trial protocol was approved by the UK Bromley Research Ethics Committee at King's College Hospital NHS Trust (London, UK). The trial was designed and overseen by a trial steering committee and a data monitoring committee.

Participants

Adults (aged ≥18 years) with established chronic kidney disease (including those receiving kidney replacement therapy) who could access a digital health intervention (digital device and WiFi connectivity) were eligible for enrolment and were recruited from outpatient centres. Centres were selected to ensure the population was geographically representative of the chronic kidney disease population, with centres included from all regions of England, UK. Potential participants were screened by their clinical team, and clinical records reviewed to confirm eligibility. Suitable adults were approached in person during routine clinic visits, or via telephone, by trained research staff. Participants were excluded if they self-reported participation in a structured exercise programme or had used a physical activity digital health intervention platform within the previous 3 months; had persistent uncontrolled hypertension; had unstable angina; or had peripheral vascular or musculoskeletal disease that prevented them from undertaking a physical activity intervention. A complete list of the inclusion and exclusion criteria was published previously.[24] All participants provided written informed consent.

Randomisation and masking

Participants were randomly assigned in a 1:1 ratio to the Kidney BEAM intervention group or the waiting list control group (usual care). Randomisation was performed with the use of a web-based system, in randomly permuted blocks of six. Randomisation and treatment allocation were performed by an independent member of the research team and the allocation list was stored in a password-protected database. Given the nature of the intervention, it was not possible to mask the health-care professionals providing the programme or the participants. Outcome assessors were, however, masked to treatment allocation. The statistical analysis plan[24] was developed a priori by an independent statistician and approved by the trial steering committee. Data entry and quality assurance was undertaken by data entry clerks who were unaware of treatment allocation. Data cleaning and analysis of the primary outcome was conducted by the independent statistician who was unaware of treatment allocation.

Procedures

The trial interventions have been described in detail elsewhere.[24] In brief, the Kidney BEAM intervention is a digitally delivered physical activity intervention that was co-designed with people living with chronic kidney disease. The intervention comprises both live sessions and a pre-recorded, on-demand kidney rehabilitation programme, provided by specialist kidney physical therapists as a rolling 12-week programme. Each session includes a 10-min warm up and cool down, consisting of general upper and lower limb mobility and stretching, 20–30 min of moderate intensity aerobic and resistance exercise training, delivered in a standing and a seated position, and 15 min of disease-specific education on a weekly basis. Each participant was encouraged to accumulate 150 min per week of moderate intensity aerobic activity or 75 min per week of vigorous activity, and to do muscle resistance training on 2 days of the week. A physiotherapy assistant, trained in motivational interviewing, encouraged participants on a weekly basis via telephone or email to achieve these targets. Participants who were allocated to the waiting list control group did not participate in a structured exercise programme but were invited to use BEAM after their involvement in the trial. Usual care did not include routine delivery of any type of physical activity intervention. Adherence was recorded as the percentage of Kidney BEAM exercise sessions and percentage of education sessions completed out of the total prescribed for the 12-week follow-up period.

Outcomes

The primary outcome was the difference in the Kidney Disease Quality of Life Short Form version 1.3 Mental Component Summary (KDQoL-SF1.3 MCS) between baseline and 12 weeks. This patient-reported outcome was selected after consultation with the trial's patient and public involvement panel, is supported more widely by the views of people with chronic kidney disease,[8] and is theoretically justified by the reported association between physical activity, mental health, and HRQoL.[2–4] Secondary outcomes were the difference between baseline and 12 weeks in: the KDQoL-SF1.3 Physical Component Score (PCS) and other subscales, European Quality of Life 5 Dimensions 5 Levels (EQ-5D-5L) questionnaire (converted to EQ-5D-3L to allow comparison with UK normative data),[25] physical function (60-s sit-to-stand test), fatigue (Chalder Fatigue Scale), patient activation (Patient Activation Measure-13, PAM-13), physical activity (Global Physical Activity Questionnaire), depression and anxiety (Patient Health Questionnaire-4, PHQ-4), impaired functioning (Work and Social Adjustment Score), body mass, haemoglobin, estimated glomerular filtration rate, and a qualitative exploration of participant experience. All outcome measures were chosen as valid and reliable tools to measure the primary and secondary outcomes in this patient population.[24] The 60-s sit-to-stand test outcome was assessed via video conference by a research assistant. All patient-reported outcome measures were completed via an online survey. Health economic data were also obtained to be evaluated at 6 months. The

For more on the **Kidney BEAM intervention** see www.kidneybeam.com

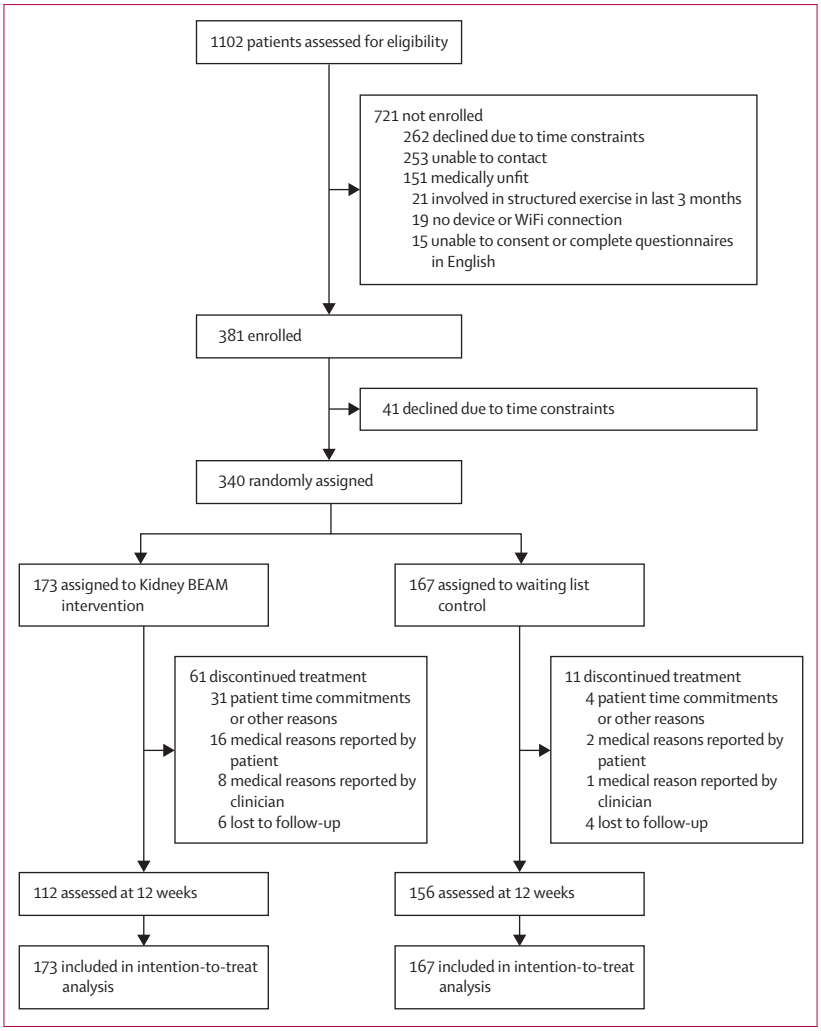

Figure 1: **Trial profile**

	Total (n=340)	Kidney BEAM group (n=173)	Waiting list control group (n=167)
Age, years	53·8 (13·5)	53·9 (13·6)	53·8 (13·5)
Sex			
Female	155 (46%)	77 (45%)	78 (47%)
Male	185 (54%)	96 (55%)	89 (53%)
Ethnicity			
n	339	173	166
Black	39 (11%)	20 (12%)	19 (11%)
White	254 (75%)	127 (73%)	127 (77%)
Asian	39 (11%)	22 (13%)	17 (10%)
Biracial	7 (2%)	4 (2%)	3 (2%)
BMI, kg/m²			
n	327	165	162
Median (IQR)	28·4 (24·8–33·3)	27·9 (24·7–33·4)	28·8 (24·9–33·0)
Smoking			
n	339	172	167
Current	16 (5%)	5 (3%)	11 (7%)
Former	130 (38%)	77 (45%)	53 (32%)
Never	193 (57%)	90 (52%)	103 (62%)
Alcohol consumption*			
n	339	172	167
More than recommended	26 (8%)	14 (8%)	12 (7%)
Less than recommended	174 (51%)	89 (52%)	85 (51%)
Non-drinker	139 (41%)	69 (40%)	70 (42%)
Blood pressure, mm Hg			
n	307	154	153
Systolic blood pressure	136·5 (18·4)	135·3 (19·3)	137·8 (17·5)
Diastolic blood pressure	79·7 (10·7)	78·6 (11·1)	80·7 (10·2)
Resting heart rate, beats per min			
n	207	103	104
Mean (SD)	77·6 (14·7)	77·8 (14·6)	77·3 (14·8)
Comorbidities			
Cerebrovascular accident	8 (2%)	8 (5%)	4 (2%)
Myocardial infarction	8 (2%)	3 (2%)	5 (3%)
Diabetes	76 (22%)	37 (21%)	39 (23%)
Hypertension	235 (69%)	115 (66%)	120 (72%)

(Table 1 continues in next column)

qualitative and health economic analyses are not included in this report. Safety outcomes were based on reporting of adverse events as per Medical Dictionary for Regulatory Activities (version 22.0) classification. An independent data monitoring committee oversaw trial safety.

Statistical analysis

The trial was designed to detect a clinically meaningful and statistically significant difference of 3 arbitrary units (AU) in KDQoL-SF1.3 MCS score between groups at 12 weeks.[26] An estimated sample size of 106 participants in each group (total n=212), based on an MCS with a mean of 45 AU (SD 10) and correlation between repeated measures of 0·7, would allow a clinically meaningful difference of 3 AU to be detected at 80% power and α of 5%. 340 patients were included to allow for 30% dropout and to ensure power for secondary outcomes. The baseline characteristics were described using summary statistics.[24] Primary and secondary outcomes were analysed with an analysis of covariance model, with baseline data and age as covariates. Independence of covariates and approximated normality of residuals were confirmed for all analyses. All analyses were performed in the intention-to-treat population using a last observation carried forward (LOCF) approach to missing data because this gives the most conservative result. The results from the LOCF analysis for the primary outcome were compared with those from a multiple imputation sensitivity analysis using pooled results from five linear regression imputations. Per-protocol analyses were also completed, in which only cases with observations at both baseline and week 12 were included, to assess efficacy under ideal conditions. Two-sided p values of less than 0·05

	Total (n=340)	Kidney BEAM group (n=173)	Waiting list control group (n=167)
(Continued from previous column)			
Cause of kidney disease			
Diabetic nephropathy	31 (9%)	13 (8%)	18 (11%)
Hypertension	38 (11%)	21 (12%)	17 (10%)
Nephrosclerosis	1 (<1%)	1 (1%)	0
IgA nephropathy	39 (11%)	18 (10%)	21 (13%)
Tubulointerstitial nephritis	5 (1%)	2 (1%)	3 (2%)
Polycystic kidney disease	60 (18%)	31 (18%)	29 (17%)
Obstructive nephropathy	7 (2%)	2 (1%)	5 (3%)
Medullary sponge kidney disease	0	0	0
Membranous nephropathy	5 (1%)	5 (3%)	0
Lupus nephritis	5 (1%)	4 (2%)	1 (1%)
Unknown	65 (19%)	33 (19%)	32 (19%)
Other	84 (25%)	43 (25%)	41 (25%)
Chronic kidney disease stage			
n	339	172	167
2	55 (16%)	27 (16%)	28 (17%)
3A	62 (18%)	29 (17%)	33 (20%)
3B	76 (22%)	45 (26%)	31 (19%)
4	67 (20%)	34 (20%)	33 (20%)
5	79 (23%)	37 (22%)	42 (25%)
Treatment modality			
Non-dialysis dependent kidney disease	160 (47%)	75 (43%)	85 (51%)
Kidney transplant recipient	118 (35%)	65 (38%)	53 (32%)
Dialysis therapy	62 (18%)	33 (19%)	29 (17%)
HbA_{1c}, mmol/mol			
n	124	64	60
Median (IQR)	39 (35–48)	39 (34–50)	39 (36–47)
Creatinine, µmol/L			
n	332	170	162
Median (IQR)	159 (106–293)	159 (109–279)	161 (106–330)
C-reactive protein, mg/L			
n	169	92	77
Median (IQR)	4 (2–9)	3·9 (2–10)	4 (2–9)

Data are mean (SD), n (%), or median (IQR). HbA_{1c}=glycated haemoglobin.
*Recommended limit is 14 units per week.

Table 1: **Baseline demographic data**

were considered to indicate statistical significance. Analyses were performed with SPSS (version 28). The trial was registered with ClinicalTrials.gov, NCT04872933.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

	n	Baseline, mean (SD)	Week 12, mean (SD)	Mean adjusted difference in change between groups (Kidney BEAM – waiting list control), mean (95% CI)	p value
Primary outcome					
KDQoL-SF1.3 MCS, AU					
Kidney BEAM group	172	44·6 (10·8)	47·0 (10·6)	3·1 (1·8 to 4·4)	<0·0001
Waiting list control group	166	46·1 (10·5)	45·0(10·1)	..	..
Secondary outcomes					
KDQoL-SF1.3 PCS, AU					
Kidney BEAM group	172	40·0 (11·7)	41·1 (11·4)	–0·7 (–2·0 to 0·7)	0·35
Waiting list control group	166	41·3 (11·2)	42·9 (11·8)	..	..
Chalder Fatigue Scale score					
Kidney BEAM group	173	16·2 (6·1)	14·4 (6·3)	–0·5 (–1·5 to 0·5)	0·33
Waiting list control group	167	15·3 (6·4)	14·3 (6·6)	..	..
60-s sit-to-stand test, repetitions					
Kidney BEAM group	173	22·9 (8·8)	26·3 (10·7)	3·8 (2·6 to 4·9)	<0·0001
Waiting list control group	167	23·9 (8·9)	23·5 (9·3)	..	..
PAM-13 score					
Kidney BEAM group	173	63·9 (16·4)	68·2 (17·3)	6·9 (4·9 to 8·8)	<0·0001
Waiting list control group	166	67·4 (17·7)	64·2 (16·4)	..	..
EQ-5D-5L utility score					
Kidney BEAM group	172	0·65 (0·25)	0·67 (0·26)	0·01 (–0·02 to 0·04)	0·64
Waiting list control group	167	0·73 (0·23)	0·72 (0·24)	..	..
PHQ-4 score					
Kidney BEAM group	173	3·2 (3·3)	2·7 (3·1)	–0·4 (–0·8 to 0·5)	0·082
Waiting list control group	167	2·4 (2·8)	2·4 (2·9)	..	..
Work and Social Adjustment Score					
Kidney BEAM group	162	12·6 (10·9)	11·7 (10·7)	0·4 (0·8 to 1·7)	0·49
Waiting list control group	160	10·2 (10·4)	9·3 (10·5)	..	..
GPAQ, MET min per week					
Kidney BEAM group	111	3403 (5267)	3136 (4875)	393 (–334 to 1120)	0·29
Waiting list control group	120	3256 (4902)	2676 (3959)	..	..
GPAQ, physical activity min per day					
Kidney BEAM group	111	121·5 (188·1)	112·0 (174·1)	14·0 (–11·9 to 40·0)	0·29
Waiting list control group	120	116·3 (175·0)	95·6 (141·4)	..	..
KDQoL-SF1.3 burden of kidney disease score, AU					
Kidney BEAM group	172	54·9 (31·2)	60·5 (30·9)	3·2 (0·0 to 6·4)	0·049
Waiting list control group	167	64·7 (30·5)	65·8 (30·3)	..	..
KDQoL-SF1.3 general health score, AU					
Kidney BEAM group	171	40·4 (21·7)	42·0 (21·9)	–0·8 (–3·4 to 1·8)	0·56
Waiting list control group	166	42·6 (21·7)	44·7 (22·8)	..	..
KDQoL-SF1.3 social function score, AU					
Kidney BEAM group	172	51·5 (27·7)	67·0 (27·5)	4·4 (0·9 to 7·8)	0·013
Waiting list control group	166	64·2 (30·4)	64·8 (28·7)	..	..
KDQoL-SF1.3 energy or fatigue score, AU					
Kidney BEAM group	171	42·5 (21·5)	47·8 (21·7)	7·0 (4·6 to 9·5)	<0·0001
Waiting list control group	166	45·0 (23·2)	42·9 (22·7)	..	..
eGFR, mL/min per 1·73 m^2					
Kidney BEAM group	165	39·1 (24·1)	38·7 (24·5)	–0·2 (–1·3 to 0·9)	0·72
Waiting list control group	158	38·2 (25·0)	38·7 (26·1)	..	..

(Table 2 continues on next page)

	n	Baseline, mean (SD)	Week 12, mean (SD)	Mean adjusted difference in change between groups (Kidney BEAM – waiting list control), mean (95% CI)	p value
(Continued from previous page)					
Haemoglobin, d/L					
Kidney BEAM group	165	12·5 (2·0)	13·3 (1·1)	0·8 (–0·7 to 2·4)	0·30
Waiting list control group	161	12·2 (1·8)	12·3 (2·0)	..	..
Body mass, kg					
Kidney BEAM group	169	85·4 (20·1)	85·6 (19·5)	0·1 (–0·4 to 0·7)	0·61
Waiting list control group	163	84·4 (19·1)	84·5 (18·9)	..	..

Data are mean (SD) or mean (95% CI) ANCOVA-adjusted scores. KDQoL-SF1.3=Kidney Disease Quality of Life Short Form version 1.3. MCS=Mental Component Summary. AU=arbitrary units. PCS=Physical Component Summary. PAM-13=Patient Activation Measure-13. EQ-5D-5L=European Quality of Life 5 Dimensions 5 Levels. PHQ-4=Patient Health Questionnaire-4. GPAQ=Global Physical Activity Questionnaire. MET=metabolic equivalent. eGFR=estimated glomerular filtration rate.

Table 2: **Primary and secondary outcomes in the intention-to-treat population**

See Online for appendix

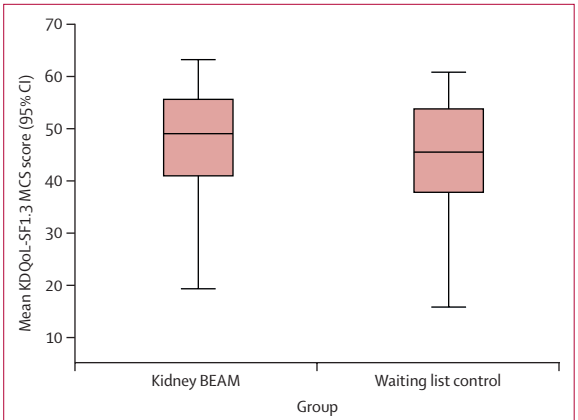

Figure 2: **KDQoL-SF1.3 MCS score at 12 weeks**
KDQoL-SF1.3 MCS=Kidney Disease Quality of Life Short Form version 1.3 Mental Component Summary.

Results

Between May 6, 2021, and Oct 30, 2022, we assessed 1102 patients for eligibility. 721 (65%) patients were not enrolled, mainly due to time constraints or not being contactable (figure 1). 381 (35%) patients provided consent, of whom 340 (31%) patients from 11 centres were assessed at baseline and randomly assigned; 173 (51%) patients were assigned to the Kidney BEAM intervention group, and 167 (49%) patients were assigned to the waiting list control group. Of these patients, 268 (78%) patients completed the trial, including 112 (42%) participants in the intervention group and 156 (58%) participants in the waiting list control group. All 340 participants were included in the intention-to-treat population. Only 338 participants were included when analysing the primary outcome because two participants (one in each group) were missing both baseline and 12-week data.

Overall, the two groups were well balanced with respect to baseline characteristics (table 1). The proportion of participants in the intervention group who had a PAM-13 score of 1 (disengaged and overwhelmed; 30 [17%] of 166) was higher than in the control group (22 [13%] of 173; appendix), and the mean PAM-13 score was lower at baseline in the intervention group (63·9 [SD 16·4]) than in the control group (67·4 [17·7]). The mean EQ-5D-5L utility scores were lower in the intervention group (0·65 [0·25]) than in the control group (0·73 [0·23]), and the mean PHQ-4 scores for the intervention group were higher (3·2 [3·3]) and classified as within the mild category for anxiety and depression, whereas mean PHQ-4 scores for the control group (2·4 [2·8]) corresponded to the normal category for anxiety and depression. There was a higher self-reported burden of kidney disease in the intervention group than in the control group (mean KDQoL-SF1.3 burden of kidney disease score 54·9 [31·2] *vs* 64·7 [30·5]; table 2).

A median of 15 (IQR 9–22) of the recommended 24 sessions of structured physical activity were completed by participants in the Kidney BEAM intervention group, representing a median adherence rate of 63% (IQR 38–92). Participants completed a median of 529 min (IQR 283–814) of structured physical activity, which is the equivalent of 44 min per week. A median of six (IQR 1–10) of the recommended 12 sessions of education were completed, representing a median adherence rate of 50% (8–83).

There was a clinically important and statistically significant improvement in the primary outcome of KDQoL-SF1.3 MCS score after 12 weeks in the Kidney BEAM group compared with the control group (difference of 3·1 AU [95% CI 1·8–4·4]; p<0·0001; table 2, figure 2). This was due in part to significant mean between-group improvements in the individual components of the KDQoL-SF1.3 questionnaire, including social function (4·4 AU [0·9–7·8]; p=0·013), energy or fatigue (7·0 AU [4·6–9·5]; p<0·0001), and burden of kidney disease (3·2 AU [0·0–6·4]; p=0·049; table 2). Although the intention-to-treat analysis of the primary outcome (KDQoL-SF1.3 MCS) showed statistical differences in favour of the intervention group using the most conservative LOCF approach, 69 (33%) observations were missing at week 12 for the primary outcome. A sensitivity analysis using multiple imputation of the week 12 missing values was performed using five iterations of linear regression imputation and the analysis of covariance was repeated using the pooled imputations. This analysis also showed a significant improvement in the primary outcome in the intervention group compared with the control group (pooled mean difference of 3·9 AU [2·0–5·9]; p<0·0001).

Analysis of secondary outcomes showed a significant improvement at 12 weeks in PAM-13 patient activation score (p<0·0001) and the 60-s sit-to-stand test of physical function (p<0·0001) in the Kidney BEAM group compared with the control group (table 2). The mean between-group difference in the KDQoL-SF1.3 PCS at

12 weeks was not significant, and there were no significant between-group differences at 12 weeks for body mass, haemoglobin concentration, Work and Social Adjustment Score, EQ-5D-5L clinical utility score, or Global Physical Activity Questionnaire measures. The mean between-group differences in fatigue (Chalder Fatigue Scale score) and anxiety and depression (PHQ-4 score) at 12 weeks were non-significant; however, in the per-protocol analysis, Chalder Fatigue Scale score (p=0·014) and PHQ-4 score (p=0·0031) were improved in the Kidney BEAM group compared with the control group (table 3).

Eight serious adverse events unrelated to study treatment were recorded in a total of 340 participants, with a similar incidence across groups: three (2%) of eight in the Kidney BEAM group and five (3%) of eight in the control group (table 4). There were no expected related or unrelated serious adverse events recorded in either group during the trial.

There were no obvious differences in characteristics between participants who completed the 12-week outcome assessment and participants who did not (table 5). 47 (77%) of 61 participants who did not complete the trial in the intervention group withdrew within the first week post baseline assessment due to time constraints.

	n	Baseline, mean (SD)	Week 12, mean (SD)	Mean adjusted difference in change between groups (Kidney BEAM – waiting list control), mean (95% CI)	p value
KDQoL-SF1.3 MCS, AU					
Kidney BEAM group	103	46·1 (10·5)	50·1 (9·2)	4·98 (3·35 to 6·61)	<0·0001
Waiting list control group	156	46·3 (10·3)	45·1 (10·0)	..	..
KDQoL-SF1.3 PCS, AU					
Kidney BEAM group	103	40·8 (12·0)	42·7 (11·3)	0·17 (–1·64 to 1·99)	0·85
Waiting list control group	156	41·1 (11·0)	42·8 (11·7)	..	..
KDQoL-SF1.3 general health score, AU					
Kidney BEAM group	97	43·8 (21·2)	46·6 (22·1)	0·73 (–2·75 to 4·20)	0·68
Waiting list control group	156	42·9 (21·3)	45·1 (22·4)	..	..
Chalder Fatigue Scale score					
Kidney BEAM group	101	15·8 (6·1)	12·9 (5·9)	–1·58 (–2·84 to –0·32)	0·014
Waiting list control group	153	15·1 (6·3)	14·1 (6·4)	..	..
EQ-5D-5L utility score					
Kidney BEAM group	103	0·7 (0·2)	0·7 (0·2)	0·03 (–0·01 to 0·07)	0·22
Waiting list control group	157	0·7 (0·2)	0·7 (0·2)	..	..
PHQ-4 score					
Kidney BEAM group	101	2·8 (3·1)	1·8 (2·4)	–0·80 (–1·33 to -0·27)	0·0031
Waiting list control group	154	2·3 (2·8)	2·4 (2·9)	..	..
Work and Social Adjustment Score					
Kidney BEAM group	89	10·5 (9·8)	9·0 (9·0)	–1·09 (–3·53 to 1·36)	0·38
Waiting list control group	145	10·1 (10·1)	9·7 (14·5)	..	..
GPAQ, MET min per week					
Kidney BEAM group	76	3081·0 (4739·1)	2690·8 (4039·3)	~~211·6 (–654·2 to 1077·5)~~	0·63
Waiting list control group	109	3259·7 (5069·2)	2620·9 (4057·2)	..	..
GPAQ, physical activity min per day					
Kidney BEAM group	76	110·0 (169·2)	96·1 (144·2)	7·6 (–23·7 to 38·5)	0·63
Waiting list control group	109	116·4 (181·0)	93·6 (144·9)	..	..
eGFR, mL/min per 1·73 m²					
Kidney BEAM group	85	39·5 (23·0)	38·9 (23·9)	–0·34 (–2·08 to 1·40)	0·70
Waiting list control group	126	36·5 (24·5)	36·4 (24·5)	..	..
Haemoglobin, d/L					
Kidney BEAM group	88	12·5 (1·7)	12·5 (1·8)	–0·1 (–4·27 to 2·17)	0·52
Waiting list control group	134	12·2 (1·9)	12·3 (1·8)	..	..
Body mass, kg					
Kidney BEAM group	87	83·8 (18·9)	83·9 (18·2)	0·16 (–0·73 to 1·06)	0·72
Waiting list control group	130	84·8 (19·2)	84·7 (19·0)	..	..

Data are mean (SD) or mean (95% CI) ANCOVA-adjusted scores. KDQoL-SF1.3=Kidney Disease Quality of Life Short Form version 1.3. MCS=Mental Component Summary. AU=arbitrary units. PCS=Physical Component Summary. PAM-13=Patient Activation Measure-13. EQ-5D-5L=European Quality of Life 5 Dimensions 5 Levels. PHQ-4=Patient Health Questionnaire-4. GPAQ=Global Physical Activity Questionnaire. MET=metabolic equivalent. eGFR=estimated glomerular filtration rate.

Table 3: **Outcomes in the per-protocol population**

Discussion

Our results demonstrate that the Kidney BEAM physical activity digital health intervention innovation enhances health-related quality of life in people with chronic kidney disease. To our knowledge, this is the first randomised controlled trial to report improvements in the mental health-related quality of life of people with chronic kidney disease as a direct result of a physical activity digital health intervention. The Kidney BEAM platform therefore offers a scalable innovation to enhance mental health in this patient population and also offers a potential intervention to improve mental health and HRQoL in other chronic conditions characterised by sedentarism.

Numerous neurophysiological, psychological, and social mechanisms could explain the beneficial effects of physical activity on mental health.[27] As has been observed in previous studies,[27] a combination of these is likely to be responsible for the improvements seen in our primary outcome of mental health-related quality of life. However, the results from both the intention-to-treat and per-protocol analyses of secondary outcomes would suggest reductions in symptom burden (particularly fatigue, anxiety, and depression), improvements in social functioning, increased patient activation, and enhanced physical function could have been most important and are thus worthy of further discussion.

The Kidney BEAM physical activity digital health intervention was developed with rigorous application of the behaviour change wheel method,[28] employing co-design principles including lived experience and expert health-care providers, and adhering to the Medical Research Council framework for developing and evaluating complex interventions.[29] The behaviour change wheel method[28] was specifically used to identify the common physical, social, and psychological barriers and motivators to physical activity in the chronic kidney disease patient population, and thereby identify crucial intervention functions to facilitate behaviour change and

	Total (n=340)	Kidney BEAM group (n=173)	Waiting list control group (n=167)
Number of patients with any event	8 (2%)	3 (2%)	5 (3%)
Gastrointestinal disorders	2 (1%)	1 (1%)	1 (1%)
Infections and infestations	4 (1%)	2 (1%)	2 (1%)
Injury, poisoning, and procedural complications	1 (<1%)	0	1 (1%)
Renal and urinary disorders	1 (<1%)	0	1 (1%)

Data are n (%). MedDRA=Medical Dictionary for Regulatory Activities.

Table 4: **Number of patients with at least one serious adverse event during the Kidney BEAM trial by MedDRA system organ class**

	Participants with complete data		Participants who were lost to follow-up or withdrew	
	Kidney BEAM (n=112)	Waiting list control (n=156)	Kidney BEAM (n=61)	Waiting list control (n=11)
Sex				
Male	59 (52%)	71 (46%)	37 (62%)	4 (36%)
Female	53 (47%)	85 (55%)	24 (39%)	7 (64%)
Age, years	55 (14)	54 14)	53 (13)	49 (13)
Ethnicity				
Black	16 (14%)	19 (12%)	4 (7%)	0
White	82 (73%)	117 (75%)	45 (74%)	10 (91%)
Asian	11 (10%)	16 (10%)	11 (18%)	1 (9%)
Biracial	3 (3%)	3 (2%)	1 (2%)	0
Chronic kidney disease stage				
2	18 (16%)	27 (17%)	9 (15%)	1 (9%)
3A	19 (17%)	30 (19%)	10 (16%)	3 (27%)
3B	31 (27%)	28 (18%)	14 (23%)	3 (27%)
4	23 (20%)	32 (21%)	11 (18%)	1 (9%)
5	20 (18%)	39 (25%)	17 (28%)	3 (27%)
Comorbidities				
Cardiovascular accident	2 (2%)	4 (3%)	6 (10%)	0
Myocardial infarction	2 (2%)	5 (3%)	1 (2%)	0
Diabetes	23 (20%)	39 (25%)	14 (23%)	0
Hypertension	76 (67%)	109 (70%)	44 (72%)	6 (55%)

Data are n (%) or mean (SD).

Table 5: **Comparison of participants with complete data and participants with missing data at 12 weeks due to loss to follow-up or withdrawal**

engagement with the intervention.[28] The significant improvements we report in the KDQoL mental component scale and improvements in secondary outcomes of social function and fatigue or energy scales, as well as the improvement in physical function, support the importance of targeting discrete behaviours with independent and interdependent mechanisms of action, which are common within a patient population with recognised complex health needs. Lower patient activation levels are associated with a higher symptom burden and reduced HRQoL across the trajectory of chronic kidney disease stages and treatment modalities,[30] and there is a need to prioritise the promotion of patient activation in kidney care management.[31] The improvement in patient activation observed in the Kidney BEAM intervention group suggests that participation in this type of physical activity digital health intervention could improve patient self-management behaviours, and directly impact health-related quality of life.[32]

Our findings are consistent with those from an umbrella systematic review from 2023 regarding the effectiveness of physical activity interventions for improving symptoms of mental health in adult patients.[33] Physical activity was effective at reducing symptoms of depression and anxiety across all clinical conditions, with a larger magnitude of effect size observed in those people with chronic disease, and specifically people with chronic kidney disease. This finding was postulated to be due to the above-average symptoms of depression and anxiety and low physical activity levels inherent in this patient population, which allows for a greater scope for improvement.[33] The improvement in mental health-related quality of life determinants as a result of the Kidney BEAM intervention, as observed by the increase in the KDQoL-SF1.3 MCS scores in the intention-to-treat population, was accompanied by a reduction in symptoms of anxiety and depression in those participants who completed the Kidney BEAM programme. Mean PHQ-4 scores in the intervention group reduced (p=0·08 in the intention-to-treat analysis; p=0·03 in the per-protocol analysis) from a score within the mild category for symptoms of depression and anxiety to a score within the normal category. Similarly, the Kidney BEAM intervention appeared to be efficacious in the reduction of patient-reported fatigue levels (with significant improvements to KDQoL-SF1.3 energy or fatigue scores in the intention-to-treat analysis and to Chalder Fatigue Scale score in the per-protocol analysis). Fatigue improved with physical activity in previous small trials in people with chronic kidney disease,[34] and the results from our trial support the growing evidence for physical activity interventions to be used as a means to improve this common and burdensome symptom for people with chronic kidney disease.[35]

Our trial showed an improvement in objectively measured physical function. In a patient population for whom a decline in physical function, and resultant disability, is associated with poor health outcomes,[36] and for whom the longer-term effects of the COVID-19 pandemic have resulted in deconditioning and an increased risk of falls,[37] the effect of our physical activity digital health intervention on physical function is encouraging and important. However, like other physical activity clinical trials for people with chronic kidney disease,[38–40] our trial did not report improvements in HRQoL self-reported physical health scores. The KDQoL-SF1.3 PCS score might be less sensitive to change than the other subscales in the KDQoL-SF1.3 questionnaire.[41,42] Additionally, the structured exercise dose, which averaged at 44 min per week and was sufficient to confer mental health improvements in our patient population, might have been insufficient to improve

perceptions of improved physical health. Improvements to mental health despite only modest increases in physical activity have been observed previously,[33] and have been suggested to be due to shorter periods of weekly physical activity being less burdensome for patients and, consequently, having less negative psychological impact.

Our trial was initiated in response to the COVID-19 pandemic and is an example of agile research activity. The trial and intervention were conducted remotely, which has lasting implications for both research and clinical delivery of lifestyle interventions. Additional strengths of the trial include its size, and the small number of exclusion criteria that allowed for the enrolment of a cohort of people representative of those seen in routine clinical practice, providing reassurance regarding the potential external validity and generalisability of the results. A limitation of the trial was the restriction of the trial sites to a single country and that we delivered the research trial and intervention only in English. Thus, the generalisability of the trial findings to chronic kidney disease populations worldwide will require further evaluation. The primary outcome, and some secondary outcomes, were self-reported and because participants were not masked to the allocated treatment, this method will have introduced bias. A number of secondary outcomes in the trial were assessed without any control of the overall type I error rate and therefore the risk of at least one type I error is inflated. We also could not mask the supporting physiotherapy assistants. However, the assessors for the clinical effectiveness and statisticians were masked. There was an expected dropout rate of 30% from the intervention group, which required data to be imputed and could have added imprecision to estimates. There was no obvious difference in participant characteristics between groups for complete and incomplete cases and more than 75% of the dropouts were within the first week of the trial. The LOCF approach to missing data offers a conservative estimate of the patient's outcome trajectory in a study,[43] and the sample size for the study allowed for the expectant dropout rate. More than half of the dropouts from the study were due to patient time constraints, with a larger proportion evident in the intervention group in which extra time was needed to complete the intervention. The inclusion of numerous intervention components and behaviour change techniques within the Kidney BEAM digital health intervention also meant that it was not possible to determine their independent effects. A formal mediation analysis was also not completed to determine mechanisms of the observed change in the primary outcome.

Future research should investigate the Kidney BEAM physical activity digital health intervention in other countries and investigate this clinically implementable intervention in other chronic health conditions. Cost-effectiveness and follow-up results will be determined at 6 months, and a qualitative evaluation of intervention, trial acceptability, and participant experience, as well as subgroup analyses of the primary and key secondary outcomes, will be presented separately. Chronic kidney disease disproportionately affects under-resourced individuals, and we acknowledge that this might have affected the opportunity for some individuals to partake in a digital health trial.[44] Sub-studies will report the impact of enhanced digital health skills training and provision of devices or WiFi connectivity, and will investigate the impact of the intervention in different stages of the chronic kidney disease pathway.

Overall, these results demonstrate that the Kidney BEAM physical activity platform is an effective digital health intervention to improve mental health and HRQoL in people with chronic kidney disease, in part via positive effects on physical function, symptom burden, social interaction, anxiety or depression, and patient activation. The results from this clinical trial will facilitate implementation of current guidelines on physical activity in people with chronic kidney disease and thus inform future national and potentially international clinical practice.

Contributors

SAG, HMLY, REB, NCB, JB, EMC, ZS, HN, AH, KB, ACN, MMPG-B, TJW, and JHM were responsible for the conception and design of the project and prepared the manuscript. SAG, HMLY, REB, NCB, JB, EMC, AH, VD, HN, ACN, TJW, NCB, JCa, JCh, NJC, HW, SB, JOB, PK, PAK, DCW, JT, MJ, MWT, EA, KM, ZS, MMPG-B, CW, LH, CB, and JHM contributed to the design of the study, provided methodological input, wrote the manuscript, and prepared tables 1–3. All authors reviewed the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication. SAG, JHM, CW, and JCa verified the data.

Declaration of interests

King's College Hospital NHS Trust and SAG were involved in the conception and development of Kidney BEAM. SB is a trustee of Kidney Research UK. DCW has an ongoing consultancy contract with AstraZeneca and has received honoraria or consultancy fees from Astellas, Boehringer Ingelheim, Bayer, Eledon, Galderma, GlaxoSmithKline, Gilead, Janssen, Mundipharma, ProKidney, Tricida, Vifor, and Zydus for activities related to education and clinical trials. All other authors declare no competing interests.

Data sharing

Data collected during the study, including de-identified participant data, will be made available on reasonable request, and following trial steering committee approval, by contacting the corresponding author. The study protocol, statistical analysis plan, and other study forms were published previously.[24]

Acknowledgments

This study was funded by a grant from Kidney Research UK (SP/BEAM/2020). HMLY, JB, REB, NCB, NJC, MMPG-B, TJW, and HW are supported by the National Institute for Health Research (NIHR) Leicester Biomedical Research Centre. HW is funded by the NIHR Applied Research Collaboration East Midlands. The views expressed are those of the authors and not necessarily those of the UK National Health Service, the NIHR, or the Department of Health and Social Care.

References

1 WHO. Global status report on physical activity 2022. Geneva: World Health Organization, 2022.
2 Rejeski WJ, Brawley LR, Shumaker SA. Physical activity and health-related quality of life. *Exerc Sport Sci Rev* 1996; **24:** 71–108.
3 Marquez DX, Aguiñaga S, Vásquez PM, et al. A systematic review of physical activity and quality of life and well-being. *Transl Behav Med* 2020; **10:** 1098–109.

4 Anokye NK, Trueman P, Green C, Pavey TG, Taylor RS. Physical activity and health related quality of life. *BMC Public Health* 2012; **12:** 624.

5 Kovesdy CP. Epidemiology of chronic kidney disease: an update 2022. *Kidney Int Suppl (2011)* 2022; **12:** 7–11.

6 Rampersad C, Brar R, Connelly K, et al. Association of physical activity and poor health outcomes in patients with advanced CKD. *Am J Kidney Dis* 2021; **78:** 391–98.

7 Oh TR, Choi HS, Kim CS, et al. Association between health related quality of life and progression of chronic kidney disease. *Sci Rep* 2019; **9:** 19595.

8 Morton RL, Tong A, Howard K, Snelling P, Webster AC. The views of patients and carers in treatment decision making for chronic kidney disease: systematic review and thematic synthesis of qualitative studies. *BMJ* 2010; **340:** c112.

9 Pfefferbaum B, North CS. Mental health and the Covid-19 pandemic. *N Engl J Med* 2020; **383:** 510–12.

10 Baker LA, March DS, Wilkinson TJ, et al. Clinical practice guideline exercise and lifestyle in chronic kidney disease. *BMC Nephrol* 2022; **23:** 75.

11 Levin A, Stevens PE, Bilous R, et al. KDIGO 2012 clinical practice guideline for the evaluation and management of chronic kidney disease. *Kidney Int Suppl* 2013; **3:** 1–150.

12 Bennett PN, Bohm C, Harasemiw O, et al. Physical activity and exercise in peritoneal dialysis: International Society for Peritoneal Dialysis and the Global Renal Exercise Network practice recommendations. *Perit Dial Int* 2022; **42:** 8–24.

13 Greenwood SA, Koufaki P, Rush R, Macdougall IC, Mercer TH. Exercise counselling practices for patients with chronic kidney disease in the UK: a renal multidisciplinary team perspective. *Nephron Clin Pract* 2014; **128:** 67–72.

14 Bennett PN, Kohzuki M, Bohm C, et al. Global policy barriers and enablers to exercise and physical activity in kidney care. *J Ren Nutr* 2022; **32:** 441–49.

15 Heiwe S, Jacobson SH. Exercise training in adults with CKD: a systematic review and meta-analysis. *Am J Kidney Dis* 2014; **64:** 383–93.

16 Bernier-Jean A, Beruni NA, Bondonno NP, et al. Exercise training for adults undergoing maintenance dialysis. *Cochrane Database Syst Rev* 2022; **1:** CD014653.

17 Greenwood SA, Koufaki P, Macdonald JH, et al. Randomized trial—prescription of intradialytic exercise to improve quality of life in patients receiving hemodialysis. *Kidney Int Rep* 2021; **6:** 2159–70.

18 Zhang F, Bai Y, Zhao X, et al. Therapeutic effects of exercise interventions for patients with chronic kidney disease: an umbrella review of systematic reviews and meta-analyses. *BMJ Open* 2022; **12:** e054887.

19 Salhab N, Karavetian M, Kooman J, Fiaccadori E, El Khoury CF. Effects of intradialytic aerobic exercise on hemodialysis patients: a systematic review and meta-analysis. *J Nephrol* 2019; **32:** 549–66.

20 Graham-Brown MPM, March DS, Young R, et al. A randomized controlled trial to investigate the effects of intra-dialytic cycling on left ventricular mass. *Kidney Int* 2021; **99:** 1478–86.

21 Hull SA, Rajabzadeh V, Thomas N, et al. Do virtual renal clinics improve access to kidney care? A preliminary impact evaluation of a virtual clinic in East London. *BMC Nephrol* 2020; **21:** 10.

22 Stevenson JK, Campbell ZC, Webster AC, et al. eHealth interventions for people with chronic kidney disease. *Cochrane Database Syst Rev* 2019; **8:** CD012379.

23 Clarkson P, Stephenson A, Grimmett C, et al. Digital tools to support the maintenance of physical activity in people with long-term conditions: a scoping review. *Digit Health* 2022; **8:** 20552076221089778.

24 Walklin CG, Young HML, Asghari E, et al. The effect of a novel, digital physical activity and emotional well-being intervention on health-related quality of life in people with chronic kidney disease: trial design and baseline data from a multicentre prospective, wait-list randomised controlled trial (Kidney BEAM). *BMC Nephrol* 2023; **24:** 122.

25 Hernández Alava M, Pudney S, Wailoo A. Estimating the relationship between EQ-5D-5L and EQ-5D-3L: results from a UK population study. *PharmacoEconomics* 2023; **41:** 199–207.

26 Maruish ME. User's manual for the SF-36v2 health survey, 3rd edn. Lincoln, RI: QualityMetric, 2011.

27 Arent SM, Walker AJ, Arent MA. The effects of exercise on anxiety and depression. In: Genenbaum G, Eklund RC, Boiangin N, eds. Handbook of sport psychology: exercise, methodologies, & special topics. New York, NY: John Wiley & Sons, 2020: 872–90.

28 Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement Sci* 2011; **6:** 42.

29 Skivington K, Matthews L, Simpson SA, et al. A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. *BMJ* 2021; **374:** n2061.

30 Magadi W, Lightfoot CJ, Memory KE, et al. Patient activation and its association with symptom burden and quality of life across the spectrum of chronic kidney disease stages in England. *BMC Nephrol* 2022; **23:** 45.

31 Nair D, Cavanaugh KL. Measuring patient activation as part of kidney disease policy: are we there yet? *J Am Soc Nephrol* 2020; **31:** 1435–43.

32 Hibbard JH, Mahoney ER, Stock R, Tusler M. Do increases in patient activation result in improved self-management behaviors? *Health Serv Res* 2007; **42:** 1443–63.

33 Singh B, Olds T, Curtis R, et al. Effectiveness of physical activity interventions for improving depression, anxiety and distress: an overview of systematic reviews. *Br J Sports Med* 2023; **57:** 1203–09.

34 Gregg LP, Bossola M, Ostrosky-Frid M, Hedayati SS. Fatigue in CKD: epidemiology, pathophysiology, and treatment. *Clin J Am Soc Nephrol* 2021; **16:** 1445–55.

35 Weisbord SD, Fried LF, Arnold RM, et al. Prevalence, severity, and importance of physical and emotional symptoms in chronic hemodialysis patients. *J Am Soc Nephrol* 2005; **16:** 2487–94.

36 McAdams-Demarco MA, Law A, Garonzik-Wang JM, et al. Activity of daily living disability and dialysis mortality: better prediction using metrics of aging. *J Am Geriatr Soc* 2012; **60:** 1981–82.

37 Antoun J, Brown DJ, Jones DJW, et al. Understanding the impact of initial COVID-19 restrictions on physical activity, wellbeing and quality of life in shielding adults with end-stage renal disease in the United Kingdom dialysing at home versus in-centre and their experiences with telemedicine. *Int J Environ Res Public Health* 2021; **18:** 3144.

38 Chung YC, Yeh ML, Liu YM. Effects of intradialytic exercise on the physical function, depression and quality of life for haemodialysis patients: a systematic review and meta-analysis of randomised controlled trials. *J Clin Nurs* 2017; **26:** 1801–13.

39 Clarkson MJ, Bennett PN, Fraser SF, Warmington SA. Exercise interventions for improving objective physical function in patients with end-stage kidney disease on dialysis: a systematic review and meta-analysis. *Am J Physiol Renal Physiol* 2019; **316:** F856–72.

40 Hannan M, Bronas UG. Barriers to exercise for patients with renal disease: an integrative review. *J Nephrol* 2017; **30:** 729–41.

41 Ware JE. SF-36 physical and mental health summary scales: a user's manual. Boston, MA: New England Medical Center Hospital Health Institute, 1994.

42 Weng LC, Dai YT, Huang HL, Chiang YJ. Self-efficacy, self-care behaviours and quality of life of kidney transplant recipients. *J Adv Nurs* 2010; **66:** 828–38.

43 Liu X. Methods for handling missing data. In: Liu X, ed. Methods and applications of longitudinal data analysis. Oxford: Academic Press, 2016: 441–73.

44 Graham-Brown MPM, Smith AC, Greenwood SA. Digital health interventions in chronic kidney disease: levelling the playing field? *Clin Kidney J* 2022; **16:** 763–67.