BMJ Open

Lifestyle behaviour change for preventing the progression of chronic kidney disease: a systematic review

Nicole Evangelidis ,[1,2] Jonathan Craig,[2,3] Adrian Bauman,[1] Karine Manera,[1,2] Valeria Saglimbene,[1,2] Allison Tong[1,2]

To cite: Evangelidis N, Craig J, Bauman A, *et al*. Lifestyle behaviour change for preventing the progression of chronic kidney disease: a systematic review. *BMJ Open* 2019;**9**:e031625. doi:10.1136/bmjopen-2019-031625

► Prepublication history and additional material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2019-031625).

Received 13 May 2019
Revised 15 August 2019
Accepted 27 August 2019

[1]Sydney School of Public Health, University of Sydney, Sydney, New South Wales, Australia
[2]Centre for Kidney Research, The Children's Hospital at Westmead, Westmead, New South Wales, Australia
[3]College of Medicine and Public Health, Flinders University, Adelaide, South Australia, Australia

Correspondence to
Nicole Evangelidis;
nicole.evangelidis@sydney.edu.au

ABSTRACT

Objectives Modifying lifestyle can prevent the progression of chronic kidney disease (CKD) but the specific elements which lead to favourable behaviour change are not well understood. We aimed to identify and evaluate behaviour change techniques and functions in lifestyle interventions for preventing the progression of CKD.

Design Systematic review.

Data sources MEDLINE, EMBASE, CINAHL and PsycINFO.

Eligibility criteria Trials of lifestyle behaviour change interventions (including diet, physical activity, smoking and/or alcohol) published to September 2018 in adults with CKD stages 1–5.

Data extraction and synthesis Trial characteristics including population, sample size, study setting, intervention, comparator, outcomes and study duration, were extracted. Study quality was independently assessed by two reviewers using the Cochrane risk of bias tool. The Behaviour Change Technique Taxonomy v1 was used to identify behaviour change techniques (eg, goal setting) and the Health Behaviour Change Wheel was used to identify intervention functions (eg, education). Both were independently assessed by three reviewers.

Results In total, 26 studies involving 4263 participants were included. Risk of bias was high or unclear in most studies. Interventions involved diet (11), physical activity (8) or general lifestyle (7). Education was the most frequently used function (21 interventions), followed by enablement (18), training (12), persuasion (4), environmental restructuring (4), modelling (2) and incentivisation (2). The most common behaviour change techniques were behavioural instruction (23 interventions), social support (16), behavioural demonstration (13), feedback on behaviour (12) and behavioural practice/rehearsal (12). Eighteen studies (69%) showed a significant improvement in at least one primary outcome, all of which included education, persuasion, modelling and incentivisation.

Conclusion Lifestyle behaviour change interventions for CKD patients frequently used education, goal setting, feedback, monitoring and social support. The most promising interventions included education and used a variety of intervention functions (persuasion, modelling and incentivisation).

PROSPERO registration number CRD42019106053.

Strengths and limitations of this study

- We used comprehensive, evidence-based frameworks to identify and describe behaviour change techniques and intervention functions in lifestyle behavioural interventions for patients with chronic kidney disease.
- Coding of behaviour change techniques and intervention functions was systematically and independently conducted by three researchers, and risk of bias was assessed.
- Summary estimates could not be ascertained due to the heterogeneity of interventions and outcome measures.

INTRODUCTION

Preventing the progression of chronic kidney disease (CKD) is a high priority for patients and clinicians, to reduce the requirement for dialysis.[1–3] Lifestyle interventions which modify behavioural risk factors such as poor diet and low physical activity can prevent progression of CKD and life-threatening complications and improve quality of life and survival.[4–6] Addressing behaviour change is particularly relevant in CKD as lifestyle modification can be challenging. Poor adherence to diet, medication and other treatments is common in CKD.[7] Barriers to modifying lifestyle include low health literacy, conflicts with cultural norms, complicated nutritional requirements and safety concerns.[7–11]

Guidelines recommend the explicit use of behaviour change for addressing lifestyle risk factors when designing and reporting interventions for patients with CKD.[12 13] However, it is uncertain which aspects of lifestyle behaviour change interventions are the most effective, and reporting of behavioural components is often unclear, making implementation in practice problematic.

The Behaviour Change Technique Taxonomy v1 was developed to provide a comprehensive framework that integrates behaviour change techniques used in interventions.[14] The Taxonomy was further synthesised into a framework, the Health Behaviour

Change Wheel which describes the intervention functions necessary to change health behaviours.[15] The Health Behaviour Change Wheel provides a broad, overarching framework in which to characterise behaviour change interventions while the Taxonomy identifies specific techniques related to individual behaviours. The intervention functions described in the Health Behaviour Change Wheel can be delivered by a variety of behaviour change techniques. For example, the intervention function, 'education', outlined in the Wheel, can include the behaviour change techniques 'instruction on how to perform the behaviour' and 'information about antecedents', detailed in the Taxonomy. Similarly, the intervention function 'incentivisation' can incorporate techniques such as 'feedback on behaviour' and 'rewards'.

Behaviour change interventions using the Wheel and the Taxonomy can effectively change lifestyle behaviours. For example, a text-messaging and pedometer programme improved physical activity in people at high risk of type 2 diabetes,[16] a digital healthy eating programme increased consumption of fruit and vegetables and sustained this over a 6-month period[17] and a digital behaviour change programme achieved significant weight loss results in individuals at risk of type 2 diabetes.[18] The Taxonomy and the Wheel are recommended approaches to modify lifestyle risk factors for chronic disease prevention.[12 16 18] However, these frameworks have not been used in designing and reporting behaviour change strategies in lifestyle interventions for patients with CKD.

We aimed to identify and evaluate behaviour change techniques and intervention functions used in lifestyle interventions for preventing the progression of CKD. This may inform the development of effective and replicable behaviour change interventions for the prevention of CKD, leading to improvements in patient outcomes.

METHODS

We used the Preferred Reporting Items for Systematic Reviews and Meta-analyses Statement[19] and checklist to report this systematic review (online supplementary file S1).

Selection criteria

We included randomised trials of lifestyle behaviour change interventions (including, but not restricted to diet, physical activity, smoking and alcohol consumption) in adult patients (aged over 18 years) with CKD stages 1–5 and not requiring renal replacement therapy. We did not apply restrictions based on outcomes or language. Studies including a combination of pharmacological therapy and lifestyle were included but trials involving only pharmacological therapies were excluded.

Literature search

A comprehensive search was conducted in MEDLINE (1946 to 20 September 2018), EMBASE (1996 to 20 September 2018), CINAHL (1982 to 20 September 2018) and PsycINFO (1806 to 20 September 2018) using Medical Subject Heading (MeSH) terms relating to CKD, and lifestyle behaviour change interventions (online supplementary file S2), and reference lists of relevant articles and reviews. Author NE screened the studies by title and abstract and assessed full-text articles for eligibility. Those that did not meet the inclusion criteria were excluded.

Data extraction and critical appraisal

The trial characteristics relevant to the population, sample size and study setting as well as intervention (type, mode of delivery, use of theory, intervention functions (as described in the Health Behaviour Change Wheel[15] and behaviour change techniques (as described in the Behaviour Change Technique Taxonomy v1[14])), comparator, outcomes and study duration, were extracted and tabulated. We assessed the risk of bias using the Cochrane tool for randomised studies.[20] NE and KM assessed the risk of bias in each study independently and any differences were resolved by discussion.

We contacted the authors of the studies when it was necessary to gather additional information. Supplemental data was available in 12 of the 26 studies. In six studies with no supplemental data, sufficient information was available in the published article. Therefore, we contacted eight authors to request further information and received responses from two authors.

Analysis of intervention functions and behaviour change techniques

The Behaviour Change Technique Taxonomy v1 (the 'Taxonomy') and Health Behaviour Change Wheel (the 'Wheel') are comprehensive tools for identifying behavioural components in interventions and how frequently they occur.[14 15] The two frameworks are complementary and in addition to designing interventions, they have been used as a method for identifying behavioural components in public health interventions and clinical trials.[21] The tools have been used in previous systematic reviews to identify behaviour change techniques and functions in health interventions.[22–28]

Behaviour change techniques

The Behaviour Change Technique Taxonomy consists of 93 behaviour change techniques, such as goal-setting, self-monitoring, social support and re-structuring the physical environment (see online supplementary table S1 for the full taxonomy). The techniques are grouped into 16 domains: goals and planning, feedback and monitoring, social support, shaping knowledge, natural consequences, comparison of behaviour, associations, repetition and substitution, comparison of outcomes, reward and threat, regulation, antecedents, identity, scheduled consequences, self-belief and covert learning.

Intervention functions

There are nine intervention functions in the Wheel: education, persuasion, incentivisation, coercion, training, enablement, modelling, environmental restructuring and restrictions.[15] These are activities designed to change

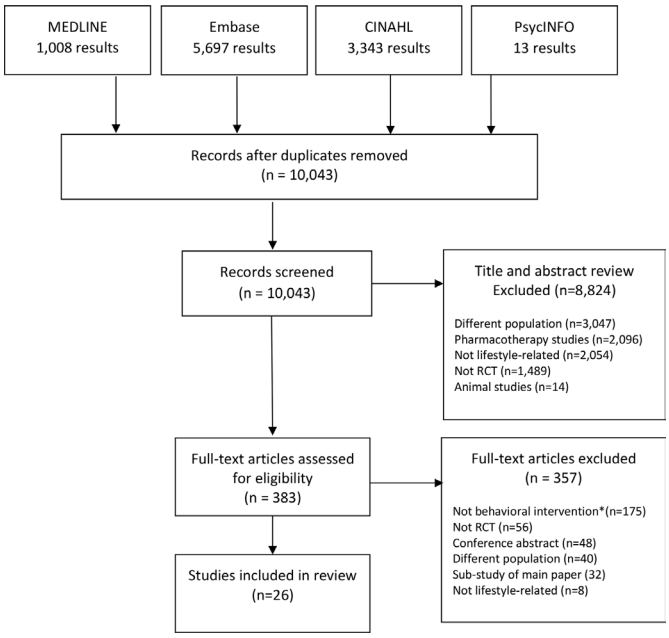

Figure 1 PRISMA flowchart of included/excluded studies. *A behavioural intervention explicitly describes a behaviour change technique which can be coded using the Behavior Change Technique Taxonomy v1. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses.

behaviours and include one or more behaviour change techniques. Definitions of each intervention function have been described by Michie *et al* and were used to inform decisions about what functions were present in each study.[15]

Authors NE and KM completed online training for interpreting the Wheel and the Taxonomy to ensure consistency and reliability of coding.[29] N.E, KM and VS independently read intervention descriptions line-by-line to locate text matching a definition of an intervention function[15] and the description of behaviour change techniques from the BCTTv1 coding frame (online supplementary table S1). Each of the 93 behaviour change techniques were indicated as either present or absent in a standardised data extraction form. A behaviour change technique had to be explicitly described to be coded and included in the analysis. The authors compared the codes and discussed discrepancies to reach consensus.

Patient and public involvement

No patient involved.

RESULTS

Literature search and study characteristics

The literature search yielded 10043 citations from which 26 studies (n=4263 participants) were eligible and included in the review (figure 1). Study characteristics are shown in table 1. The studies were conducted in 15 countries.

Risk of bias assessment

Overall, the reporting of studies was relatively incomplete, particularly for the blinding of participants and personnel which was missing or unclear in every study (figure 2). Allocation concealment was unclear or at high risk of bias in 20 (77%) studies. Blinding of outcome assessment was also poorly reported with 19 studies showing high or unclear risk of bias for this domain. Domains that performed better were selective reporting with low risk of bias in 21 studies, random sequence generation with low risk of bias in 17 studies and incomplete outcome data showing low risk of bias in 13 studies.

Characteristics of the interventions

Across the interventions assessed in the 26 studies included, 11 were dietary interventions, 8 involved physical activity and 7 used any combination of diet, physical activity, weight reduction and/or smoking cessation (lifestyle).

Five studies were informed by theory, three used the Trans-Theoretical Model,[30 31] one used self-regulation theory[32] and another was informed by contemporary behavioural theory, in particular the self-management approach.[33] Two studies used Motivational Interviewing,[34 35] a counselling approach which involves behaviour change strategies.[36]

Only three studies included family members, friends or partners in the intervention to facilitate participant's behaviour change (online supplementary table S2).[31 37]

Behaviour change techniques

Table 2 outlines the number of behaviour change techniques present in each lifestyle behaviour change intervention. The number of behaviour change techniques used across interventions ranged from two to 20.

The top five most frequently observed behaviour change techniques were instruction on how to perform the behaviour (23 interventions, 88%), social support (16, 62%), demonstration of the behaviour (13, 50%), feedback on behaviour (12, 46%) and behavioural practice/rehearsal (12, 46%). Of the 93 possible behaviour change techniques that could have been used, 12 techniques were used in more than 20% of trials, 27 were used at least once and 54 were never used. The mean number of behaviour change techniques was 5, the median was four and the range 2–20.

The two studies with the highest number of behaviour change techniques (20 and 18 in each study) were both informed by theory, with a particular focus on self-regulation and self-management.[32 33]

Intervention functions

Table 3 lists the intervention functions present in each study (education, enablement, training, persuasion, modelling, incentivisation, environmental restructuring, coercion and restrictions). The number of functions used across interventions ranged from one to seven.

Education

Education was used most frequently as an intervention function, present in 21 (81%) interventions (table 3). Examples of educational strategies were: nutritional label

Table 1 Characteristics of included studies

Study	N	CKD Stage	Age (years)	Country	Intervention	Comparator	Primary Outcomes	Study duration (months)
Dietary interventions								
Campbell *et al*[38]	56	CKD4–5	>18	Australia	Individualised nutritional counselling and regular follow-up	Usual care	Body composition	3
Clark *et al*[47]	590	CKD3	18–80	Canada	Coaching to increase water intake (drinking containers and water vouchers also provided)	Coaching to maintain usual fluid intake	Change in eGFR	12
De Brito-Ashurst *et al*[37]	56	eGFR <60 mL and BP >130/80 or taking BP medication; Bangladeshi origin	18–74	United Kingdom	Community cooking education sessions facilitated by Bengali workers	Usual care	Reduction in systolic/ diastolic BP	6
Dussol *et al*[61]	63	Type I/II diabetic nephropathy, eGFR60-100 mL	40–72	France	Low-protein diet with telephone calls every 6 weeks to help change dietary habits	Usual-protein diet	Decline GFR and 24-hour albumin excretion rate	24
MDRD Study (1995)*	840	eGFR 13–55 mL	18–70	United States	Low protein diet with dietician support	Moderate, low and very low protein diets compared	Decline eGFR, dietary satisfaction	45
Mekki *et al*[62]	40	eGFR 60–90 mL	47–75	Algeria	Nutritional advice based on Mediterranean diet	Usual care	Dyslipidaemia	3
Meuleman *et al* [32]	138	eGFR ≥20 mL	≥18	The Netherlands	Sodium restricted diet with self-management, education, motivational interviewing and self-monitoring	Usual care	Sodium excretion & BP	3
Paes-Barreto *et al*[46]	89	CKD3–5	≥18	Brazil	Intense counselling/education on low protein diet	Standard counselling	Change in protein intake	4
Pisani *et al*[42]	57	CKD3b–5	>18	Italy	Low protein, phosphate and sodium diet, '6-tips diet' checklist	Non-individualised, moderately low protein diet	Protein intake, metabolic parameters and adherence	6
Rosman *et al*[63]	247	CrCl 10–60 mL/min	15–73	The Netherlands	Dietary protein restriction and dietician visits every 3 months	Usual care	Adherence	24
Saran *et al*[64]	58	CKD3–4	>18	United States	Dietary sodium restriction (<2 g sodium per day)	Usual diet	Change in hydration status	1
Physical activity interventions								
Aoike *et al*[59]	29	CKD3–4	18–70	Brazil	Home-based moderate-intensity aerobic exercise programme	Usual care	Cardiopulmonary/ functional, BP, CrCl, eGFR	3
Barcellos *et al*[65]	150	CKD2–4	>18	Brazil	Aerobic and resistance training	Usual care	Change in eGFR	4
Greenwood *et al*[43]	20	CKD3–4	18–80	United Kingdom	Resistance and aerobic training (3 days per week)	Usual care	Change in eGFR	12

Continued

Table 1 Continued

Study	N	CKD Stage	Age (years)	Country	Intervention	Comparator	Primary Outcomes	Study duration (months)
Kao *et al*[30]	94	eGFR ≥15 mL	≥39	Taiwan	Group education lecture; individual exercise programme Trans-Theoretical Model	Not specified	Exercise behaviour, depression, fatigue	3
Leehey *et al*[66]	32	CKD2–4	49–81	United States	Aerobic & resistance training, home exercise (plus dietary management)	Dietary management	Urine protein to creatinine ratio	12
Rossi *et al*[45]	107	CKD3–4	≥18	United States	Guided exercise twice a week plus usual care	Usual care	Physical function, quality of life	3
Tang *et al*[49]	90	CKD1–3	18–70	China	Individualised exercise programme (education and home-based aerobic exercise)	Usual care	Physical function, self-efficacy, anxiety, depression, quality of life	3
Van Craenenbroeck *et al*[34]	40	CKD3–4	≥18	Belgium	Home-based aerobic training programme (four daily cycling sessions, 10 min each)	Usual care	Peripheral endothelial function	3
Lifestyle interventions								
Flesher *et al*[39]	40	CKD3–4	18–80	Canada	Individual dietary counselling, group nutrition and cooking classes, exercise programme	Usual care	Composite eGFR, TC, urinary sodium, urinary protein and BP	12
Howden *et al*[40]	83	CKD3–4	18–75	Australia	Multi-disciplinary care, lifestyle and aerobic/resistance training	Usual care	Change in CRF	12
Ishani *et al*[41]	601	eGFR <60	>18	USA	Care by a multi-disciplinary team using a telehealth device	Usual care	Composite death, hospitalisation, emergency visits and admission to a nursing facility	20
Jiamjariyapon *et al*[67]	442	CKD3–4	18–70	Thailand	Integrated care by multi-disciplinary team and community care workers. Group counselling, home visits	Usual care	Change in eGFR	24
Joboshi and Oka[44]	65	Overt proteinuria and clinically diagnosed CKD	38–86	Japan	Self-management programme	Standard education	Self-efficacy and self-management behaviour	3
Patil *et al*[68]	76	Diabetic nephropathy	30–70	India	Low-calorie diet, physical activity and behaviour	ACE inhibitor therapy	24-hour urine protein BMI	6
Teng *et al*[31]	160	eGFR ≥30 mL/min/1.73 m^2	≥20	Taiwan	Lifestyle modification programme based on Trans-Theoretical Model	Standard education	Health behaviours, knowledge, physical function	12

*MDRD study described in two main articles: Gillis *et al*[33] and Coyne *et al*[48].
BMI, Body Mass Index; BP, blood pressure;CKD, chronic kidney disease; CrCl, creatinine clearance; CRF, cardiorespiratory fitness; eGFR, estimated glomerular filtration rate; MDRD, Modification of Diet in Renal Disease study; TC, total cholesterol.

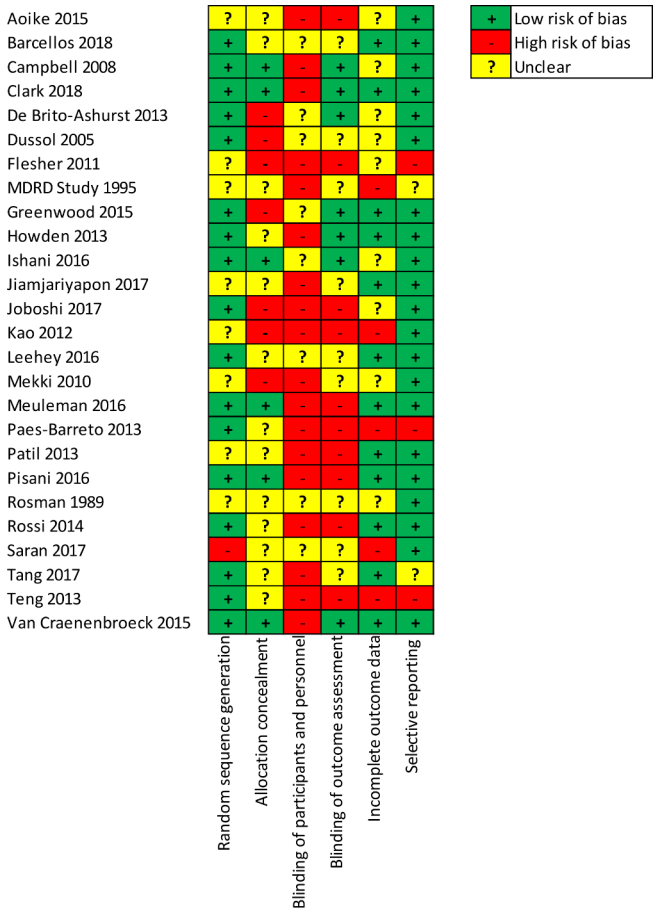

Figure 2 Risk of bias for individual studies (n=26). MDRD, Modification of Diet in Renal Disease study.

reading,[38 39] a resistance training booklet for home-based exercise,[40] a lecture/workshop about exercise recommendations with demonstrations,[30] online education modules on lifestyle modification[41] and a written 'six-tip diet' checklist.[42]

Enablement

Eighteen (69%) interventions used enablement. Examples include Motivational Interviewing to improve self-management of diet, lifestyle and physical activity,[32 43] supportive telephone calls matching stages of behaviour change,[30] self-management techniques to foster self-efficacy[38 39 44] and arranging support from friends and family members and 'buddy' visits.[31 33] Four interventions were specifically designed using a self-management approach and assessed self-efficacy as an outcome.[32 33 39 44]

Training

Twelve (46%) interventions included training as an intervention function. Training was used in every intervention targeting physical activity but only used in two dietary interventions and two lifestyle interventions. Examples of training include home-based exercise training, guided exercise training in a gym,[40] physical therapy or cardiac rehabilitation facility[45] or hospital[34] and interactive cooking classes.[39]

Persuasion

Four (15%) interventions used persuasion as an intervention function. A dietary intervention aimed to persuade participants about dietary salt intake by displaying test tubes of salt content alongside a range of high-salt food items.[46] In another dietary intervention, positive thinking was applied to participant's goals and dieticians praised progress and focused on positive results.[33] Similarly, a lifestyle intervention used positive reinforcement to increase confidence and celebrate successes related to behaviour change and also discussed lack of exercise, poor dietary habits, risks of not exercising and associated consequences.[31] Only one physical activity intervention used persuasion in designing and displaying printed health messages to promote exercise.[30]

Environmental re-structuring

Four (15%) interventions used environmental restructuring. Two involved placing exercise equipment in the home environment (exercise bicycle, Theraband, weights and Swiss ball)[40 43] and two included adding food products and equipment into the home environment (low sodium/protein meals and water bottles).[33 47]

Modelling

Two (8%) dietary interventions incorporated modelling as an intervention function. Educators used food models and household measuring utensils to model appropriate food portion sizes[46] and food tastings provided an example of low protein meals.[33]

Incentivisation

Two (8%) studies used incentivisation, one in the form of 'appreciation gifts' including certificates and mugs[33] and another included 'self-rewards' chosen by participants.[32]

Coercion and restrictions

These functions were not used in any of the interventions.

Outcomes

A description of primary outcomes and results reported in studies is included in table 4. Primary outcomes of studies in this review were diverse and were mainly physiological metrics (for example, eGFR, blood pressure, peak VO_2 and sodium or albumin excretion). Only six studies included patient-reported and/or behavioural primary outcomes such as quality of life, fatigue, knowledge, self-efficacy, self-management, exercise and health behaviours.[30 31 44 45 48 49]

Eighteen studies (69%) showed a significant improvement in at least one primary outcome and all of these studies included education, persuasion, modelling and incentivisation as an intervention function (see online supplementary table S3). A meta-analysis of the data was not possible due to heterogeneity of outcome measures across the included studies. The heterogeneity of outcomes also meant we could not link outcomes with specific behaviour change techniques. Many studies are likely to be underpowered to detect modest effects, and

Table 2 Cross matrix of behaviour change techniques and lifestyle behaviour change trials

	Meuleman *et al*[32]	MDRD Study (1995)*	De Brito-Ashurst *et al*[37]	Paes-Barreto *et al*[46]	Campbell *et al*[38]	Rosman *et al*[63]	Dussol *et al*[61]	Pisani *et al*[42]	Saran *et al*[64]	Clark *et al*[47]	Mekki *et al*[62]	Tang *et al*[49]	Kao *et al*[30]	Greenwood *et al*[43]	Rossi *et al*[45]	Aoike *et al*[59]	Barcellos *et al*[65]	Van Craenenbroeck *et al*[34]	Leehey *et al*[66]	Howden *et al*[40]	Ishani *et al*[41]	Joboshi and Oka[44]	Teng *et al*[31]	Flesher *et al*[39]	Jiamjariyaponet *al*[67]	Patil *et al*[68]
	Diet											Physical Activity								Lifestyle						
1.Goals and planning																										
1.1. Goal setting (behaviour)	■	■	■		■							■	■		■					■						
1.2. Problem solving	■	■			■							■								■		■	■			
1.3. Goal setting (outcome)	■																				■	■	■	■		
1.4. Action planning	■											■	■		■											
1.5. Review behaviour goal(s)	■				■							■											■			
1.7. Review outcome goal(s)	■	■	■			■								■		■					■	■				
1.8. Behavioural contract	■	■										■	■													
1.9. Commitment		■																								
2.Feedback and monitoring																										
2.1. Monitoring of behaviour by others without feedback							■	■			■										■					■
2.2. Feedback on behaviour		■	■	■	■	■			■			■	■			■					■	■			■	
2.3. Self-monitoring of behaviour	■	■										■	■	■						■	■	■				
2.4. Self-monitoring of outcome(s) of behaviour	■	■																						■		
2.6. Biofeedback	■	■																								
2.7. Feedback on outcome(s) of behaviour	■																									
3. Social support																										
3.1. Social support (unspecified)	■		■	■	■		■					■	■			■	■	■	■		■	■	■	■	■	
3.2. Social support (practical)						■														■						
3.3. Social support (emotional)	■	■							■					■												
4. Shaping knowledge																										
4.1. Instruction on behaviour	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■			■	■	■
4.4. Behavioural experiments			■																							
5.Natural consequences																										
5.1. Information about health consequences	■		■		■				■			■	■										■			
5.2. Salience of consequences				■																						
5.4. Monitoring of emotional consequences												■														
6.Comparison of behaviour																										
6.1. Demonstration of the behaviour		■	■	■								■	■	■	■	■	■	■		■				■	■	
6.2. Social comparison	■																									
7.Associations																										
7.1. Prompts/cues	■																									
8.Repetition and substitution																										
8.1. Behavioural practice/rehearsal		■	■	■								■	■	■	■	■	■	■		■				■		
8.2. Behaviour substitution			■	■		■	■	■																		■
8.4. Habit reversal			■	■		■		■																		■
8.6. Generalisation of target behaviour														■	■					■						
8.7. Graded tasks	■		■							■		■		■	■		■					■				
9.Comparison of outcomes																										
9.2. Pros and cons				■									■										■			
10.Reward and threat																										
10.3. Non-specific reward	■																									
10.4. Social reward		■																								
10.10. Reward (outcome)		■																								
11.Regulation																										

Continued

Table 2 Continued

	Meuleman *et al*[32]	MDRD Study (1995)*	De Brito-Ashurst *et al*[37]	Paes-Barreto *et al*[46]	Campbell *et al*[38]	Rosman *et al*[63]	Dussol *et al*[61]	Pisani *et al*[42]	Saran *et al*[64]	Clark *et al*[47]	Mekki *et al*[62]	Tang *et al*[49]	Kao *et al*[30]	Greenwood *et al*[43]	Rossi *et al*[45]	Aoike *et al*[69]	Barcellos *et al*[65]	Van Craenenbroeck *et al*[34]	Leehey *et al*[66]	Howden *et al*[40]	Ishani *et al*[41]	Joboshi and Oka[44]	Teng *et al*[31]	Flesher *et al*[39]	Jiamjariyapon *et al*[67]	Patil *et al*[68]
	Diet											Physical Activity								Lifestyle						
11.2. Reduce negative emotions																										
11.3. Conserving mental resources																										
12.Antecedents																										
12.5. Adding objects to the environment																										
15.Self-belief																										
15.1. Verbal persuasion capability																										
15.3. Focus on past success																										
Number of BCTs	20	18	12	9	7	6	4	4	4	2	2	14	11	9	7	6	6	4	2	9	7	7	7	6	4	4

*MDRD study described in two main articles: Gillis *et al*[33] and Coyne *et al*[48].
BCT, Behaviour Change Technique.

so the absence of a statistically significant effect should not be regarded as evidence of no effect.

DISCUSSION

Behaviour change interventions in trials in patients with CKD mostly focused on diet and physical activity. The primary outcomes of the trials were diverse and most were biochemical outcomes (eg, eGFR, blood pressure, peak VO_2 and sodium or albumin excretion), with few clinical or patient-reported and/or behavioural outcomes such as quality of life, fatigue, knowledge, self-efficacy and self-management.[30 31 38 39 44 45] Only five interventions were underpinned by theory. The most frequently used intervention function was education, followed by enablement and training. Persuasion, environmental restructuring, modelling and incentivisation were used less frequently. Coercion and restrictions (which includes regulation) were not used in any of the studies. The top five most common behaviour change techniques were instruction on how to perform the behaviour, social support, demonstration of the behaviour, feedback on behaviour and behavioural practice/rehearsal. Identity, scheduled consequences and covert learning were not used in any of the studies. No association between frequency of functions or behaviour change techniques and the effect of interventions on outcomes could be identified.

The use of multiple behaviour change techniques does not necessarily lead to better outcomes and some evidence suggests that fewer techniques and the right combinations of techniques suited to the context are more effective.[50–52] Education was the most frequent intervention function used across the studies, which may be because it has been consistently shown that patients with CKD lack awareness about lifestyle risk factors and have low health literacy.[10 11 53] Specifically, the behaviour change technique, 'instruction on how to perform the behaviour', was the most frequently reported technique, used in all interventions except two. We suggest this is highly applicable because dietary interventions can involve complex dietary restrictions of sodium, protein, potassium and phosphate. Patients have sought practical advice about how to implement these restrictions.[54] However, most educational strategies used a didactic approach, with health professionals verbally conveying information or providing written materials. Patients with CKD prefer multiple problem-solving and collaborative approaches, in partnership with health professionals.[54] Also, written materials for patients with CKD have a reading grade of 9 (age 14–15 years), which is higher than the recommended level (grade 5).[10]

The intervention function 'training' was used in every study targeting physical activity but was only used in two dietary interventions. Patients with CKD are overwhelmed by dietary information which can be complex, restrictive and insensitive to cultural norms.[54] A recent review of educational interventions for CKD patients found that including practical skills and workshops was associated with better outcomes.[55] For example, a low-salt programme for Bangladeshi patients with CKD in the United Kingdom included cooking and educational sessions facilitated by Bengali workers in a community kitchen. It targeted both patients and family members who cooked their own low-salt version of Bangladeshi recipes and led to a reduction in salt intake and reduced blood pressure for participants.[37] Approaches to enabling and training patients for behaviour change incorporating hands-on training may be more effective.

Our findings are similar to recent reviews of behavioural interventions for other conditions (cardiovascular

Table 3 Cross matrix of intervention functions and lifestyle behaviour change trials

		Intervention functions						
Studies	**Type of intervention**	**Education**	**Enablement**	**Training**	**Persuasion**	**Environmental restructuring**	**Modelling**	**Incentivisation**
Campbell *et al*[38]	**Diet**	■	■					
Clark *et al*[47]			■			■		
De Brito-Ashurst *et al*[37]		■		■				
Dussol *et al*[61]		■	■					
MDRD Study (1995)*		■	■	■	■	■	■	■
Mekki *et al*[62]		■						
Meuleman *et al*[32]		■	■					■
Paes-Barreto *et al*[46]		■			■		■	
Pisani *et al*[42]		■						
Rosman *et al*[63]		■	■					
Saran *et al*[64]		■	■					
Aoike *et al*[59]	**Physical Activity**	■	■	■				
Barcellos *et al*[65]			■	■				
Greenwood *et al*[43]			■	■		■		
Kao *et al*[30]		■	■	■	■			
Leehey *et al*[66]				■				
Rossi *et al*[45]		■		■				
Tang *et al*[49]		■	■	■				
Van Craenenbroeck *et al*[34]				■				
Flesher *et al*[39]	**Lifestyle**	■	■	■				
Howden *et al*[40]		■	■	■		■		
Ishani *et al*[41]		■	■					
Jiamjariyapon *et al*[67]		■	■					
Joboshi[44]		■	■					
Patil *et al*[68]		■						
Teng *et al*[31]		■	■		■			
Total		**21**	**18**	**12**	**4**	**4**	**2**	**2**

*MDRD study described in two main articles: Gillis *et al*[33] and Coyne *et al*.[48]

disease, obesity, rheumatoid arthritis, prostate cancer and diabetes), which also found that behavioural interventions are not well-reported, not informed by theory and have diverse outcomes and modes of delivery.[25–27 51 56] The behaviour change techniques associated with goals and planning, feedback and monitoring and social support have also been frequently used in behaviour changes interventions in patients with other chronic conditions. These techniques are proven strategies for behaviour change and in line with evidence-based recommendations for lifestyle modification.[12 13 57]

We identified and described the behaviour change techniques and intervention functions in lifestyle behavioural interventions for patients with CKD with comprehensive evidence-based frameworks. Coding of behaviour change techniques and intervention functions was systematically and independently conducted by three researchers, and risk of bias was assessed. Potential limitations relate to poor reporting. Some interventions may have used behaviour change techniques or intervention functions in their study but did not report them, or details of techniques were unclear. We contacted authors and examined all associated supplementary materials and papers to collect more information.

Lifestyle behaviour change interventions for patients with CKD appear to integrate recommended and proven behaviour change techniques and intervention functions. These techniques such as goals and planning and self-monitoring are important but focus on individual agency rather than external factors. Interventions could be improved by considering the context of behaviour change and the social and physical environment of participants. For example, most of the interventions for physical activity focused on structured exercise programme and a reliance on equipment (eg, exercise bikes). Patients with CKD need to be able to integrate physical activity in to their daily lifestyle.[58] However, only one intervention for physical activity gave instructions on how to incorporate physical activity to fit in with daily activities and in environments easily accessible to patients, without the use of equipment.[59] This study reported improvements in cardiopulmonary and functional capacities of overweight patients with CKD.

Table 4 Effects of the behaviour change interventions on the primary outcome(s)

Study	Primary outcome/s	Measures	Intervention (n)	Control (n)	Intervention*	Control*	Mean difference (95% CI)	P value
Dietary interventions								
Campbell *et al* [38]	Body composition	Body cell mass, %	29	27	2.0 (1.9 to 5.9)†	1.5 (5.5 to 2.5)†	3.5 (2.1 to 9.1)	0.2
		Body cell mass, kg			0.5 (1.8 to 0.8)†	0.5 (0.7 to 1.8)†	1.1 (0.7 to 2.9)	0.2
Clark *et al*[47]	Change in eGFR	Change eGFR, mL/min/1.73 m^2	311	308	−2.2 (−3.3 to −1.1)†	−1.9 (−2.9 to −0.9)†	−0.3 (−1.8 to 1.2)	0.74
De Brito-Ashurst *et al*[37]	Change in BP	Reduction systolic/diastolic BP	25	23	–	–	−8 mm Hg (−11 to −5)/2 (−4 to −2)	<0.001
Dussol *et al*[61]	Decrease in eGFR	Decrease eGFR, mL/min/1.73 m^2	25	22	−7±11	−5±15	–	–
	24-hour albumin excretion rate	Microalbuminuria, mg/d			+114±364	+156±486	–	–
MDRD‡ Study 1 (1995)	Dietary satisfaction (Study A: GFR 25–55 mL/min. 1.73m^2)	Dietary satisfaction score	220	221	3.6±1.0	3.8±1.0	–	<0.05
	Dietary satisfaction (Study B: GFR 13–24 mL/min. 1.73m^2	Dietary satisfaction score	65	59	3.1±0.9	3.6±0.9	–	<0.01
MDRD‡ Study 2 (1996)	Decline eGFR (Study A: GFR 25–55 mL/min. 1.73m2)	Decline eGFR, baseline to 3 years	291	394	–	–	3.8 (4.2)§	–
	Decline eGFR (Study B: GFR 13–24 mL/min. 1.73m2)	Decline eGFR, baseline to 3 years	126	129	–	–	4.0 (3.1)§	–
Mekki *et al*[62]	Total cholesterol (TC)	TC/mmol L-1	20	20	4.1±0.5	5.4±0.4	–	<0.05
	Triacylglycerols (TG)	TG/mmol L-1			2.9±0.1	3.9±0.1	–	<0.05
Meuleman *et al* [32]	Blood pressure	Office systolic BP, mmHg	67	71	–	–	−7.3 (−12.7 to −1.9)¶	<0.01
		Office diastolic BP, mmHg			–	–	−3.8 (-6.9 to -0.6)¶	<0.05
	Sodium excretion	Sodium excretion rate, mmol/24 hours			–	–	2.9 (−21.6 to 27.3)¶	
Paes-Barreto *et al*[46]	Change in protein intake	Change protein intake, g/day	43	46	−20.7 (−30.9%)††	−10.5 (−15.1%)¶††	–	0.04
Pisani *et al*[42]	Protein intake	Change protein intake, g/kg/day	27	27	−0.1 (−0.17 to −0.03)†	−0.2 (−0.28 to −0.13)†	–	0.04
	UUN excretion	Change UUN, g/day			−1.3 (−2.1 to −0.5)†	−2.8 (−3.6 to −2)†	–	0.008
	SUN	Change SUN, mg/dL			2.96 (−7.71 to 13.64)†	−16.63 (−27.3 to −5.96)†	–	0.012
	Urinary phosphate excretion	Change phosphate excretion, mg/day			−27.6 (−93.7 to 38.4)†	−165.3 (−231.3 to −99.2)†	–	0.005
	Serum phosphate concentration	Change serum phosphate, mg/dL			0.2 (0 to 0.4)†	−0.1 (−0.3 to 0.2)†	–	0.093
	Adherence	Met criteria, n, %			19 (70%)‡‡	11 (44%)‡‡	–	–
Rosman *et al*[63]	Adherence (Group A1 & B: CrCl >30)	Median 24-hour urea excretion mmol/24 hours	45	47	–	–	–	<0.01

Continued

Table 4 Continued

Study	Primary outcome/s	Measures	Intervention (n)	Control (n)	Intervention*	Control*	Mean difference (95% CI)	P value
	Adherence (Group A2 & C: CrCl ≤30)	Median 24-hour urea excretion mmol/24 hours	23	17	–	–	–	<0.01
Saran et al[64]	Change hydration status	Extracellular Volume, L	29	29	–	–	−1.02 (−1.48 to 0.56)	<0.001
		Intracellular Volume, L			–	–	−0.06 (−0.12 to 0.01)	0.02
Physical activity interventions								
Aoike *et al*[59]	Cardiopulmonary	Maximal ventilation, L/min	14	15	90.7±28.1	76.6±23.3	–	0.003
	parameters	Ventilatory threshold, VO_2 peak, ml/kg/min			26.1±7.0	24.2±7.1	–	0.302
		VO_2 in respiratory compensation point, ml/kg/min			21.7±5.5	19.0±5.6	–	0.073
		Speed in respiratory compensation point, Km/h			6.8±1.1	5.8±1.0	–	<0.001
	Functional capacity	6MWT, minutes			583.1±85.2	561.2±91.2	–	0.028
		Time up/go test, seconds			5.82±1.39	6.42±1.11	–	0.001
		Arm curl test, repetitions			22.8±4.8	18.1±3.1	–	<0.001
		STST, repetitions			24.0±7.1	18.3±4.8	–	<0.001
		2-minute step test, steps			219.3±36.7	179.9±36.3	–	<0.001
		Back scratch test, cm			6.4±6.6	12.6±9.9	–	0.05
	Systolic and diastolic BP	Systolic BP, mm Hg			118.7±7.3	126.8±6.7	–	0.012
		Diastolic BP, mm HgP			76.1±4.4	81.0±3.7	–	0.038
	Renal function	Serum creatinine, mg/dL			2.6±1.1	3.2±1.4	–	0.215
		eGFR, mL/min/1.73 m^2			31.9±13.7	23.9±12.2	–	0.046
Barcellos *et al*[65]	Mean change in eGFR	Change eGFR, mL/min/1.73 m^2	76	74	61.5 (57.0 to 66.1)†	59.0 (54.2 to 63.8)†	0.7 (−4.0 to 5.4)	–
Greenwood *et al*[43]	Mean change in eGFR	Change eGFR, mL/min/1.73 m^2	8	10	−3.8±2.8	−8.5±6.4	7.8±3.0 (1.1 to 13.5)	0.02
Kao *et al*[30]	Depression	Change depression (Beck Depression Inventory-II scale)	45	49	−3.71§§	1.33§§	–	<0.01
	Fatigue	Change fatigue			−4.74§§	1.91§§	–	<0.001
	Exercise behaviour	Change weekly exercise			4.28§§	−1.24§§	–	<0.001
Leehey et al[66]	UPCR ratio	UPCR (mg/g) at 52 wks	14	18	405 (225 to 1038)†††	618 (323 to 1155)†††	–	0.39
Rossi *et al*[45]	Physical function	6MWT, minutes	59	48	210.4±266	−10±219.9	–	<0.001
		STST, seconds			26.9%±27% age prediction***	0.7%±12.1% age prediction***	–	<0.001
		Gait speed, cm			9.5 (−36.4 to 34)†††	0 (−9 to 13)†††	–	0.76

Continued

Table 4 Continued

Study	Primary outcome/s	Measures	Intervention (n)	Control (n)	Intervention*	Control*	Mean difference (95% CI)	P value
	QoL (RAND SF-36),	Role functioning/physical			19.0±31.7	−8.9±38.4	–	<0.001
	mean change from	Physical functioning			11.1±19.3	−0.7±18.7	–	0.004
	baseline	Energy/fatigue			9.8±17.6	0.5±18.0	–	0.01
		General health			4.9±15.3	−1.2±11.5	–	0.03
		Pain			5.7±20.0	−3.8±24.4	–	0.04
		Emotional well-being			4.2±16.9	−0.4±17.1	–	0.2
		Social functioning			4.2±20.8	1.6±22.6	–	0.57
		Role functioning/emotional			6.9±24.5	1.9±29.2	–	0.38
Tang *et al*[49]	Physical function	Change 6MWT, minutes	42	42	41.93±14.57	−5.05±14.81	–	<0.001
		Change STST, seconds			−2.68±1.95	0.49±2.07	–	<0.001
	Self-efficacy	Change self-efficacy score			6.64±6.92	−3.72±6.80	–	<0.001
	Anxiety	Change HAD-A score			−1.02±1.47	0.21±2.17	–	0.003
	Depression	Change HAD-D score			−0.76±1.32	0.31±1.84	–	0.003
	QoL (KDQOL-SF),	Symptom/problem list			2.49±4.81	0.38±6.97	–	0.007
	mean change from	Effects of kidney disease			1.90±5.22	−1.56±9.64	–	0.005
	baseline	Burden of kidney disease			−0.45±15.27	−15.3±18.11	–	<0.001
		SF-12 PCS			1.08±3.60	−0.74±4.55	–	0.045
		SF-12 MCS			1.87±5.69	−0.73±4.53	–	0.002
Van Craenenbroeck *et al*[34]	Peripheral endothelial function	Flow mediated dilation of brachial artery	19	21	4.6±3.0	5.3±3.1	0.32 (−1.88 to 2.53)	0.9
Lifestyle interventions								
Flesher *et al*[39]	Composite of eGFR, TC, US, UP, BP	Number of improved endpoints	23	17	83	30		0.028
Howden *et al*[40]	Change in CRF	VO_2, ml/kg/min	36	36	2.8±0.7	0.3±0.9	–	0.004
Ishani *et al*[41]	Composite death, hospitalisation, emergency visits, admission nursing facility	Occurrence of primary outcome/HR	451	150	208 (46.2%)	70 (46.7%)	–	0.9
Jiamjariyapon *et al*[67]	Mean change in eGFR	Change eGFR, mL/min/1.73 m^2	234	208	42.4±1.5	39.9±2.8	2.74 (0.60 to 4.50)	0.009
Joboshi and Oka[44]	Perceived behaviour	Self-efficacy	32	29	r=0.27, U=318.5**	–	–	0.035
		Self-management			r=0.29, U=310.0**	–	–	0.026
Patil *et al*[68]	24-hour urine protein	24-hour urine protein, g/d	23 (B)	22 (A),31 (C)	1284.74±1079.94	A: 1079.27±1269.20; C: 1187.61±756.92	–	–

Continued

Table 4 Continued

Study	Primary outcome/s	Measures	Intervention (n)	Control (n)	Intervention*	Control*	Mean difference (95% CI)	P value
	BMI	Change in BMI (paired t-test)			−1.95±1.10	A: −0.15±0.38 (p=0.069); C: −2.56±0.68 (p=0.000)	–	0.000
Teng *et al*[31]	Health-promotion lifestyle	Stress management	45	45	–	–	2.76	0.10
	behaviours (HPLP-IIC)	Interpersonal relations			–	–	3.88	0.05
		Health responsibility			–	–	13.63	0.001
		Physical activity			–	–	7.50	0.01
		Spiritual growth			–	–	2.79	0.10
		Nutrition			–	–	2.62	0.11
	Renal function protection knowledge	Knowledge renal function, Chinese herbs and CKD diet			–	–	No data	0.001
	Physical function	6MWT, minutes	45	45	420.4±81.2	368.5±99.7	–	0.04

*Unless otherwise indicated, values are shown as mean+/-SD.
†Mean change (95% CI).
‡Modification of Diet in Renal Disease (MDRD) study (Gillis *et al*[33], Coyne *et al*[48]).
§Mean decline +/-SD.
¶Mean change from baseline after 6 months.
**Effect size (r) Median, Mann-Whitney's U Test.
††Mean change and % reduction from baseline values.
‡‡ Number of participants who met adherence criteria (n,%).
§§Paired T test.
¶¶ p-value calculated as p<0.05 x group interaction (Aoike 2015).
***STST results standardized as a percentage of age-predicted value using prediction formulas (Rossi 2014).
†††Median (IQR)
BMI, Body Mass Index; BP, blood pressure;CrCl, Creatinine clearance; CRF, Cardiorespiratory fitness; eGFR, estimated glomerular filtration rate; HAD-A/HAD-D, Hospital Anxiety & Depression Scale; HPLP-IIC, Health Promoting Lifestyle Profile-II Chinese version (questionnaire); KDQOL-SF, Kidney Disease & Quality of Life Short Form; 6MWT, 6 min Walk Test; SF-12 PCS/MCS, Physical and Mental Health Composite Scores; QoL, Quality of life; RAND SF-36, 36-Item Short Form Survey; STST, Sit to Stand Test; SUN, Serum urea nitrogen; UP, Urinary protein; UPCR, Urine protein to creatinine ratio; US, Urinary sodium; UUN, urinary urea nitrogen.

Optimising the social environment and arranging support from friends, family and the community may also improve lifestyle behaviour change interventions for patients with CKD. Family support was used rarely in interventions in this review and only included in two studies.[31 37] However, informal caregivers play an important role in the management of CKD and are often required to change their own lifestyle behaviours to support patients with CKD.[60] Characteristics of effective educational interventions for patients with CKD involved the patient's family.[55]

The quality of the design and reporting of lifestyle behaviour change interventions for patients with CKD requires explicit description of behavioural strategies to ensure interventions are generalisable and replicable. There are numerous evidence-based guidelines that recommend the explicit use of behaviour change techniques for addressing lifestyle risk factors in chronic disease prevention and these may be better used when designing and reporting interventions for patients with CKD. Recently the National Institute of Health and Care Excellence in the UK published comprehensive guidelines specific to behavioural interventions and lifestyle modification.[12] The WHO's recommendations on behaviour change support this and further reinforce the need to consider the social and environmental determinants of health in changing lifestyle behaviours.[57]

CONCLUSION

Lifestyle interventions in trials conducted in patients with CKD mostly focus on goals and planning, feedback and monitoring and education. However, we suggest that interventions may be improved by using interactive and tailored training, and strategies to help patients incorporate lifestyle modification in their daily activities, and physical and social environments. Explicit application of behaviour change taxonomies may help to increase the effect of lifestyle behaviour change interventions for improved health outcomes in patients with CKD.

Contributors Research idea and study design: NE, AT, JC; data acquisition: NE, KM, VS; data analysis/interpretation: NE, AT, JC, AB, KM, VS; statistical analysis: NE; supervision or mentorship: AT, JC, AB.

Funding This work was supported by a Postgraduate Research Scholarship and a National Health and Medical Research Grant (NHMRC: 1098815).

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information.

ORCID iD

Nicole Evangelidis http://orcid.org/0000-0001-9184-680X

REFERENCES

1 Hemmelgarn BR, Pannu N, Ahmed SB, *et al*. Determining the research priorities for patients with chronic kidney disease not on dialysis. *Nephrol Dial Transplant* 2017;32:847–54.
2 Tong A, Crowe S, Chando S, *et al*. Research priorities in CKD: report of a national workshop conducted in Australia. *Am J Kidney Dis* 2015;66:212–22.
3 Urquhart-Secord R, Craig JC, Hemmelgarn B, *et al*. Patient and caregiver priorities for outcomes in hemodialysis: an international nominal group technique study. *Am J Kidney Dis* 2016;68:444–54.
4 Couser WG, Remuzzi G, Mendis S, *et al*. The contribution of chronic kidney disease to the global burden of major noncommunicable diseases. *Kidney Int* 2011;80:1258–70.
5 Dunkler D, Kohl M, Teo KK, *et al*. Population-Attributable Fractions of Modifiable Lifestyle Factors for CKD and Mortality in Individuals With Type 2 Diabetes: A Cohort Study. *Am J Kidney Dis* 2016;68:29–40.
6 Ricardo AC, Anderson CA, Yang W, *et al*. Healthy lifestyle and risk of kidney disease progression, atherosclerotic events, and death in CKD: findings from the chronic renal insufficiency cohort (CRIC) study. *Am J Kidney Dis* 2015;65:412–24.
7 Beto JA, Schury KA, Bansal VK. Strategies to promote adherence to nutritional advice in patients with chronic kidney disease: a narrative review and commentary. *Int J Nephrol Renovasc Dis* 2016;9:21–33.
8 Clarke AL, Young HML, Hull KL, *et al*. Motivations and barriers to exercise in chronic kidney disease: a qualitative study. *Nephrol Dial Transplant* 2015;30:1885–92.
9 de Brito-Ashurst I, Perry L, Sanders TAB, *et al*. Barriers and facilitators of dietary sodium restriction amongst Bangladeshi chronic kidney disease patients. *J Hum Nutr Diet* 2011;24:86–95.
10 Morony S, Flynn M, McCaffery KJ, *et al*. Readability of written materials for CKD patients: a systematic review. *Am J Kidney Dis* 2015;65:842–50.
11 Taylor DM, Fraser SDS, Bradley JA, *et al*. A systematic review of the prevalence and associations of limited health literacy in CKD. *Clin J Am Soc Nephrol* 2017;12:1070–84.
12 National Institute for Health and Care Excellence. Behaviour change: individual approaches. *NICE guidelines [PH49]*, 2014. Available: https://www.nice.org.uk/guidance/ph49 [Accessed 26 Aug 2018].
13 The Royal Australian College of General Practitioners. *Guidelines for preventive activities in general practice*. 9th edn, 2016. https://www.racgp.org.au/your-practice/guidelines/redbook/
14 Michie S, Richardson M, Johnston M, *et al*. The behavior change technique taxonomy (V1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Ann Behav Med* 2013;46:81–95.
15 Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implementation Sci* 2011;6:1–12.
16 Morton K, Sutton S, Hardeman W, *et al*. A Text-Messaging and Pedometer program to promote physical activity in people at high risk of type 2 diabetes: the development of the propels follow-on support program. *JMIR Mhealth Uhealth* 2015;3:e105.
17 Tapper K, Jiga-Boy G, Maio GR, *et al*. Development and preliminary evaluation of an Internet-based healthy eating program: randomized controlled trial. *J Med Internet Res* 2014;16:e231.
18 Hampton J, Allen E, Edson C. Service evaluation of a digital behavioural change programme. *Future Hosp J* 2017;4:173–7.
19 Moher D, Liberati A, Tetzlaff J, *et al*. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;6:e1000097.
20 Higgins JPT, Altman DG, Gøtzsche PC, *et al*. The Cochrane collaboration's tool for assessing risk of bias in randomised trials. *BMJ* 2011;343.
21 Sallis A, Bunten A, Bonus A, *et al*. The effectiveness of an enhanced invitation letter on uptake of national health service health checks in primary care: a pragmatic quasi-randomised controlled trial. *BMC Fam Pract* 2016;17:1–8.
22 Garnett CV, Crane D, Brown J, *et al*. Behavior change techniques used in digital behavior change interventions to reduce excessive alcohol consumption: a meta-regression. *Ann Behav Med* 2018;52:530–43.
23 Alageel S, Gulliford MC, McDermott L, *et al*. Multiple health behaviour change interventions for primary prevention of cardiovascular disease in primary care: systematic review and meta-analysis. *BMJ Open* 2017;7:e015375.
24 Gardner B, Smith L, Lorencatto F, *et al*. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. *Health Psychol Rev* 2016;10:89–112.

25 Hallward L, Patel N, Duncan LR. Behaviour change techniques in physical activity interventions for men with prostate cancer: a systematic review. *J Health Psychol* 2018;1359105318756501.
26 Heron N, Kee F, Donnelly M, *et al*. Behaviour change techniques in home-based cardiac rehabilitation: a systematic review. *Br J Gen Pract* 2016;66:e747–57.
27 Larkin L, Gallagher S, Cramp F, *et al*. Behaviour change interventions to promote physical activity in rheumatoid arthritis: a systematic review. *Rheumatol Int* 2015;35:1631–40.
28 Laba T-L, Bleasel J, Brien J-A, *et al*. Strategies to improve adherence to medications for cardiovascular diseases in socioeconomically disadvantaged populations: a systematic review. *Int J Cardiol* 2013;167:2430–40.
29 University College London Centre for Behaviour Change. BCT taxonomy V1 online training, 2018. Available: http://www.bct-taxonomy.com/ [Accessed 5 Aug 2018].
30 Kao Yu-Hsiu, Huang Yi-Ching, Chen Pei-Ying, *et al*. The effects of exercise education intervention on the exercise behaviour, depression, and fatigue status of chronic kidney disease patients. *Health Educ* 2012;112:472–84.
31 Teng H-L, Yen M, Fetzer S, *et al*. Effects of targeted interventions on lifestyle modifications of chronic kidney disease patients: randomized controlled trial. *West J Nurs Res* 2013;35:1107–27.
32 Meuleman Y, Hoekstra T, Dekker FW, *et al*. Sodium restriction in patients with CKD: a randomized controlled trial of self-management support. *Am J Kidney Dis* 2017;69:576–86.
33 Gillis BP, Caggiula AW, Chiavacci AT, *et al*. Nutrition intervention program of the modification of diet in renal disease study: a self-management approach. *J Am Diet Assoc* 1995;95:1288–94.
34 Van Craenenbroeck AH, Van Craenenbroeck EM, Van Ackeren K, *et al*. Effect of moderate aerobic exercise training on endothelial function and arterial stiffness in CKD stages 3-4: a randomized controlled trial. *Am J Kidney Dis* 2015;66:285–96.
35 van Zuilen AD, Bots ML, Dulger A, *et al*. Multifactorial intervention with nurse practitioners does not change cardiovascular outcomes in patients with chronic kidney disease. *Kidney Int* 2012;82:710–7.
36 Miller WR, Rollnick S. *Motivational interviewing: preparing people to change addictive behavior*. New York: Guilford Press, 1991.
37 de Brito-Ashurst I, Perry L, Sanders TAB, *et al*. The role of salt intake and salt sensitivity in the management of hypertension in South Asian people with chronic kidney disease: a randomised controlled trial. *Heart* 2013;99:1256–60.
38 Campbell KL, Ash S, Davies PSW, *et al*. Randomized controlled trial of nutritional counseling on body composition and dietary intake in severe CKD. *Am J Kidney Dis* 2008;51:748–58.
39 Flesher M, Woo P, Chiu A, *et al*. Self-Management and biomedical outcomes of a cooking, and exercise program for patients with chronic kidney disease. *J Ren Nutr* 2011;21:188–95.
40 Howden EJ, Leano R, Petchey W, *et al*. Effects of exercise and lifestyle intervention on cardiovascular function in CKD. *Clin J Am Soc Nephrol* 2013;8:1494–501.
41 Ishani A, Christopher J, Palmer D, *et al*. Telehealth by an Interprofessional Team in Patients With CKD: A Randomized Controlled Trial. *Am J Kidney Dis* 2016;68:41–9.
42 Pisani A, Riccio E, Bellizzi V, *et al*. 6-tips diet: a simplified dietary approach in patients with chronic renal disease. A clinical randomized trial. *Clin Exp Nephrol* 2016;20:433–42.
43 Greenwood SA, Koufaki P, Mercer TH, *et al*. Effect of exercise training on estimated GFR, vascular health, and cardiorespiratory fitness in patients with CKD: a pilot randomized controlled trial. *Am J Kidney Dis* 2015;65:425–34.
44 Joboshi H, Oka M. Effectiveness of an educational intervention (the encourage autonomous Self-Enrichment program) in patients with chronic kidney disease: a randomized controlled trial. *Int J Nurs Stud* 2017;67:51–8.
45 Rossi AP, Burris DD, Lucas FL, *et al*. Effects of a renal rehabilitation exercise program in patients with CKD: a randomized, controlled trial. *Clin J Am Soc Nephrol* 2014;9:2052–8.
46 Paes-Barreto JG, Silva MIB, Qureshi AR, *et al*. Can renal nutrition education improve adherence to a low-protein diet in patients with stages 3 to 5 chronic kidney disease? *J Ren Nutr* 2013;23:164–71.
47 Clark WF, Sontrop JM, Huang S-H, *et al*. Effect of coaching to increase water intake on kidney function decline in adults with chronic kidney disease: the CKD wit randomized clinical trial. *JAMA* 2018;319:1870–9.
48 Coyne T, Olson M, Bradham K, *et al*. Dietary satisfaction correlated with adherence in the modification of diet in renal disease study. *J Am Diet Assoc* 1995;95:1301–6.
49 Tang Q, Yang B, Fan F, *et al*. Effects of individualized exercise program on physical function, psychological dimensions, and health-related quality of life in patients with chronic kidney disease: a randomized controlled trial in China. *Int J Nurs Pract* 2017;23:e12519.
50 Berdal G, Bo I, Dager TN, *et al*. Structured goal planning and supportive telephone followup in rheumatology care: results from a pragmatic stepped-wedge cluster-randomized trial. *Arthritis Care Res* 2018.
51 Dombrowski SU, Sniehotta FF, Avenell A, *et al*. Identifying active ingredients in complex behavioural interventions for obese adults with obesity-related co-morbidities or additional risk factors for co-morbidities: a systematic review. *Health Psychol Rev* 2012;6:7–32.
52 Michie S, Abraham C, Whittington C, *et al*. Effective techniques in healthy eating and physical activity interventions: a meta-regression. *Health Psychol* 2009;28:690–701.
53 Lopez-Vargas PA, Tong A, Howell M, *et al*. Patient awareness and beliefs about the risk factors and comorbidities associated with chronic kidney disease : A mixed-methods study. *Nephrology* 2017;22:374–81.
54 Palmer SC, Hanson CS, Craig JC, *et al*. Dietary and fluid restrictions in CKD: a thematic synthesis of patient views from qualitative studies. *Am J Kidney Dis* 2015;65:559–73.
55 Lopez-Vargas PA, Tong A, Howell M, *et al*. Educational Interventions for Patients With CKD: A Systematic Review. *Am J Kidney Dis* 2016;68:353–70.
56 Cradock KA, ÓLaighin G, Finucane FM, *et al*. Behaviour change techniques targeting both diet and physical activity in type 2 diabetes: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act* 2017;14.
57 World Health Organisation, World Health Organisation. Behaviour change strategies and health: the role of health systems. *Paper presented at Regional Committee for Europe: Fifty-eighth session Georgia*, 2008.
58 Tong A, Sainsbury P, Carter SM, *et al*. Patients' priorities for health research: focus group study of patients with chronic kidney disease. *Nephrology Dialysis Transplantation* 2008;23:3206–14.
59 Aoike DT, Baria F, Kamimura MA, *et al*. Impact of home-based aerobic exercise on the physical capacity of overweight patients with chronic kidney disease. *Int Urol Nephrol* 2015;47:359–67.
60 Tong A, Sainsbury P, Craig JC. Support interventions for caregivers of people with chronic kidney disease: a systematic review. *Nephrology Dialysis Transplantation* 2008;23:3960–5.
61 Dussol B, Iovanna C, Raccah D, *et al*. A randomized trial of low-protein diet in type 1 and in type 2 diabetes mellitus patients with incipient and overt nephropathy. *J Ren Nutr* 2005;15:398–406.
62 Mekki K, Bouzidi-bekada N, Kaddous A, *et al*. Mediterranean diet improves dyslipidemia and biomarkers in chronic renal failure patients. *Food Funct* 2010;1:110–5.
63 Rosman JB, Langer K, Brandl M, *et al*. Protein-restricted diets in chronic renal failure: a four year follow-up shows limited indications. *Kidney Int Suppl* 1989;27:S96–102.
64 Saran R, Padilla RL, Gillespie BW, *et al*. A randomized crossover trial of dietary sodium restriction in stage 3-4 CKD. *Clin J Am Soc Nephrol* 2017;12:399–407.
65 Barcellos FC, Del Vecchio FB, Reges A, *et al*. Exercise in patients with hypertension and chronic kidney disease: a randomized controlled trial. *J Hum Hypertens* 2018;32:397–407.
66 Leehey DJ, Collins E, Kramer HJ, *et al*. Structured exercise in obese diabetic patients with chronic kidney disease: a randomized controlled trial. *Am J Nephrol* 2016;44:54–62.
67 Jiamjariyapon T, Ingsathit A, Pongpirul K, *et al*. Effectiveness of integrated care on delaying progression of stage 3-4 chronic kidney disease in rural communities of Thailand (escort study): a cluster randomized controlled trial. *BMC Nephrol* 2017;18:83.
68 Patil MR, Mishra A, Jain N, *et al*. Weight loss for reduction of proteinuria in diabetic nephropathy: comparison with angiotensin-converting enzyme inhibitor therapy. *Indian J Nephrol* 2013;23:108–13.