
Supplementary information

Physical activity in kidney disease: evidence and implementation

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Supplementary table 1: Key randomised controlled trials of exercise interventions across the spectrum of CKD

Author, Year, Country (Data origin), Study name	Inclusion/Exclusion criteria	Sample size	Intervention	Main outcome(s) (Between group difference)
Haemodialysis				
Anding-Rost et al. 2023 Germany DiaTT ¹	Inclusion: Adults (>18 years) receiving haemodialysis for >4 weeks Exclusion: Planned kidney transplant <12 months, planned other dialysis <12 months, participation in other exercise during dialysis (≥1 session/week), unstable/uncontrolled conditions	1211 (578 exercise group, 633 control group)	Exercise: 12 months intradialytic exercise 3x/week (60 min). Endurance exercise, 30 min cycling. Resistance exercise, 30 mins exercise bands, balls, and dumbbells (8 exercises, 2 x 1 min sets 12-13 RPE) Control: usual care	↑STS-60 ↔TUAG ↔6MWT ↔Handgrip strength ↔SF36-PCS ↔SF36-MCS ↔SF-36 other domains
Graham-Brown et al. 2021 UK CYCLE-HD ²	Inclusion: Adults (>18 years) receiving maintenance haemodialysis for >3 months Exclusion: Unable to participate in exercise programme, unable to undergo MRI scan, unfit to exercise according to ACSM guidance	130 (65 exercise group, 65 control group)	Exercise: 6 months intradialytic cycling 3x/week. Aiming for 30 min continuous cycling at RPE 12-14. 1 month 'run-in' period Control: 6 months usual care	↓LVM ↓LVMi ↓LVM/LVEDV ↔LV ejection fraction ↓Global native T1 ↓aPWV ↔SBP ↔DBP ↔ISWT ↔SPPB ↔Daily steps ↔QoL ↔SF12-PCS ↔SF12-MCS
Greenwood et al. 2021	Inclusion:	335	Exercise: 6 months intradialytic cycling 3x/week. 2x/week lower	↔KDQoL-SF1.3 PCS ↔QoL

UK PEDAL ³	Adults (>18 years) receiving haemodialysis for >3 months Exclusion: Expected survival <6 months, clinically unstable, bilateral lower limb amputation, severe cognitive impairment, pregnancy	(175 exercise group, 160 control group)	extremity muscular conditioning (3 sets of 5 repetitions) Control: 6 months usual care	↔Energy/fatigue ↔burden of CKD ↔ $\dot{V}O_2$ peak ↔PWV ↔physical activity ↔Gait speed ↔STS-60 ↔Falls
Peritoneal dialysis				
Bennett et al. 2020 USA N/A ⁴	Inclusion: Receiving PD longer than 6 weeks. Exclusion: Major amputation Unable to ambulate independently Pregnancy	36 (18 exercise group, 18 control group)	Exercise: Monthly exercise physiologist consultation, exercise prescription (resistance and aerobic exercise program using exercise bands), and 4 support telephone calls over 12 weeks. Control: usual care	↔STS 30 ↑TUAG ↔Pinch strength London Evaluation of Illness: ↑ appetite component ↔ all other components
Luo et al. 2023 China N/A ⁵	Inclusion: Adults (18–70 years old) on continuous ambulatory peritoneal dialysis (≥ 3 months) Exclusion: simultaneously performing hemodialysis (HD) or kidney transplantation; unstable condition; acute infectious disease; haematological disease; malignant tumor; uncontrolled hypertension; severe anemia; symptomatic coronary artery disease or cerebrovascular disease within 3 months; severe heart failure; significant valvular heart disease, or other conditions not suitable for exercise; taking drugs that affect sleep or antidepressants or participating in other exercise programs in the last 3 months	120 (60 intervention group; 60 control group)	Intervention: Video based exercise programme, including stretching, core, and strengthening exercises, three times per week, 30–60 minutes each day, for 12 weeks. Control: Routine care without additional exercise intervention	At 12 weeks, per protocol: ↓ Depression (BDI) ↑ Subjective sleep quality ↓ Sleep latency ↑ Sleep duration ↑ Sleep efficiency ↓ Sleep disturbance ↔ Use of sleep medication ↓ Daytime dysfunction

Watanabe et al. 2021 Japan N/A ⁶	Inclusion: PD therapy for more than 3 months combined therapy (PD + HD) also included although study focuses on PD population Exclusion: Unstable hypertension; recent myocardialinfarction or unstable angina; congestive heart failure; arthritic or orthopedic problems that limit exercise and require assistance during walking; cognitive disorders; change in hemodialysis type.	71 (36 exercise group, 35 control group)	Exercise: Home-based exercise for 6 months, including walking, resistance and stretching. Participants walked for 20–30 min, 3–5 times per week. and increased 500–1000 steps every month, depending on their ability. The intensity of aerobic and resistance exercises was a Borg scale score of 11–13. Control: Low-frequency,low- intensity upper and lower body stretching for 6 months, alongside usual care.	At six months, per protocol: ↔BMD ↔Grip strength ↑STS30 ↑6MWT ↑Average daily steps ↑Number of moderate intensity steps ↑Average daily energy expenditure ↑ Average daily moderate activity time
Uchiyama et al. 2019 Japan N/A ⁷	Inclusion: Adults (aged 20–90 years) who have undergone PD for at least 3 months Exclusion: Uncontrolled hypertension; severe anemia; active and proliferative diabetic retinopathy; symptomatic coronary artery disease or cerebrovascular disease within 3 months; current heart failure; symptomatic and fatal arrhythmia, signifcant valvular heart disease, and difficulty walking without a walking aid owing to orthopedic problems; cerebrovascular disease; peripheral artery disease	47 (24 exercise group, 23 control group)	Exercise: Unsupervised walking thrice weekly for 12 weeks. 40– 60% of the peak heart rate, as determined during the ISWT, with a rating of 11–13 on the Borg Rating of Perceived Exertion scale. 20-30 min/session. Resistance exercise was prescribed at 70% of one repetition maximum (RM). Participants trained a variety of upper and lower body muscle groups using resistance bands. Control: Usual care and advice to maintain their lifestyles.	↑ISWT ↔Handgrip ↔Quads Strength QOL: ↑KDCS ↔PCS ↔MCS ↑RCS ↔Anthropometrics ↑Serum albumin ↔HDL ↔Cholesterol ↔HbA1C ↔HOMA-IR ↔ Kt/V ↔CRP ↔hANP

				↔baPWV ↔blood pressure ↔hemoglobin levels ↔parameters of CKD–mineral bone disorder
Haemodialysis and peritoneal dialysis				
Manfredini et al. 2017 Italy EXCITE ⁸	Inclusion: Adults (>18 years) on haemodialysis (>6 months) Exclusion: Physical or clinical limitations to deambulation	296 (151 exercise group, 145 control group)	Exercise: 6 months individualised, home-based, low-intensity personalised program of walking exercise. Based on 6MWT performance and gradually increased throughout Control: usual care	↑6MWT ↑STS-5 ↑KDQOL-SF cognitive function ↑KDQOL-SF quality of social interaction ↔ KDQOL-SF all other domains
Kidney Transplant Recipients				
Greenwood et al. 2015 UK ExeRT ⁹	Inclusion: Adult (≥18 years) Kidney transplant <12 months Exclusion: Pregnancy Ambulatory support <50m Unstable conditions Structured exercise participation <6 months prior Psychiatric illness	60 (20 aerobic group [AT], 20 resistance group [RT], 20 control group [C])	Exercise: 12 weeks of AT or RT 3x/week. AT consisted of stationary bike, treadmill and elliptical trainer, 80% HR maximum, RPE 13-15. Duration was progressed to 60 min per session. RT intensity set at 80% 1-RM for both upper and lower body exercises. Frequency built to 3 sets of 8-10 repetitions ((bench press, latissimus pulldown, bicep curl, triceps pull down, leg press, knee extension, hamstring curl, and calf raises). AT group were provided with a HR monitor and the RT were provided with Therabands, ankle weights and free weights	↑PWV ↑VO ₂ peak ↑ Lower limb strength (RT group only) ↑STS-60 (RT group only) ↑DASI ↔SF36 ↔eGFR ↔BMI ↑ Weight ↔ Resting HR ↔SBP ↔ DBP ↔CRP ↔IL-6 ↔TNF-α ↔TNFR-1 ↔TNFR-2

			Control: usual care not referred to any exercise pathway	↔Fetuin
Knobbe et al. 2024 Netherlands ACT ¹⁰	Inclusion: Adult KTR >18 years Exclusion: Multi-organ transplantations and who had physical or clinical limitations (eg, too ill to follow the exercise protocol)	221 (77 exercise, 74 control, 70 exercise + diet)	Exercise: 3 months 2x/week supervised exercise (30 min dynamic resistance exercise, 30 min aerobic exercise, 30 min supervised sports) + Lifestyle counselling (5 sessions across 15 months) Control: Standard post-op care (15 months) Exercise + diet: Exercise above + lifestyle counselling above + 15 months diet intervention	At 15 months (exercise only): ↔SF-36 domain physical functioning ↔SF-36 physical and mental component scores ↔QoL ↑Muscle strength, Z score ↑VO ₂ peak ↑Peak power output ↔Daily steps ↔Physical activity ↔Weight ↔BMI ↔% Body fat ↓Waist size ↑HDL ↔SBP and DBP ↔LDL ↔Glucose
Painter et al. 2002 USA N/A ¹¹	Inclusion: Received kidney transplant <2 months Exclusion: Transplant rejection Psychiatric or neurological disorder Orthopaedic/other limitations to exercise Contraindications to exercise in line with ACSM guidelines	167 97 completed follow-up (54 exercise group, 43 control group)	Exercise: 12 months home-based aerobic exercise that consisted of walking/cycling 4x/week for at least 30 min (intensity set at 60-65% maximum HR, progressed up to 75-80%) Control: 12 months usual care	↑VO ₂ peak ↑Lower body strength ↔Body mass ↔BMI ↔Fat mass ↔Lean mass, ↔BMD (total) ↔ SF-36 ↔Creatinine ↔BUN ↑Haematocrit ↑Haemoglobin

Zhang et al. 2023 China N/A¹²	Inclusion: Adults >18 years Undergoing first kidney transplant Smartphone access No experience of resistance exercise Participating in no other research Exclusion: Cognitive or mental disability Skeletal muscle issues hindering exercise Transplant rejection Haemodynamic instability	108 (54 exercise group, 54 control group)	Exercise: 6 months total nurse led programme. Pre and post discharge. Non-ambulatory to ambulatory (after passing TUAG test). Daily combined aerobic and resistance exercise. Once discharged participants sent daily video to nurse. Dumbbells for resistance exercise	↓ Fatigue ↔ QoL ↔ HR ↔ BMI ↔ Glucose ↔ Creatinine ↔ Triglycerides ↑ 6MWT ↔ SF-36 ↓ Anxiety ↓ Depression ↔ % Body fat ↔ Fat free mass
All CKD stages				
Greenwood et al. 2024 UK Kidney BEAM¹³	Inclusion: Adults (aged ≥18 years) with established CKD (including those receiving KRT) who could access a digital health intervention (digital device and WiFi connectivity) Exclusion: Self-reported participation in a structured exercise programme; used a physical activity digital health intervention platform within the previous 3 months; persistent uncontrolled hypertension; unstable angina; peripheral vascular or musculoskeletal disease that prevented them from undertaking a physical activity intervention	340 (173 intervention, 167 wait-list control)	Intervention: 12-week digitally delivered physical activity intervention; live sessions and a pre-recorded, on-demand kidney rehabilitation programme. 20-30 min of moderate intensity aerobic and resistance exercise, delivered in a standing and a seated position, and 15 min of disease-specific education on a weekly basis. Participants encouraged to accumulate 150 min of moderate intensity exercise/week or 75 min/week of vigorous intensity activity and 2 resistance exercise sessions/week Control: Usual care followed by the option to use Kidney BEAM	Difference in change between groups: ↑ KDQoL-SF1.3 MCS ↔ KDQoL-SF1.3 PCS ↑ STS-60 ↑ PAM score ↔ Fatigue ↔ QoL ↔ Physical activity ↔ Body mass ↔ Haemoglobin ↔ eGFR

Non-dialysis CKD				
Hellberg et al. 2019 Sweden RENEXC ¹⁴	Inclusion: CKD stages 3 to 5 ≥18 years No contraindication for regular exercise Exclusion: Severe orthopaedic or neurologic disorders, unstable CVD, uncontrolled hypertension, severe anaemia, severe electrolyte disturbances, inability to communicate in Swedish, inability to understand oral instructions, expectation to start KRT <1 year	151 (76 strength group; 75 balance group)	Both groups: 150 min/week of self-administered exercise for an intervention period of 12 months In both groups, 60 min of endurance exercise was part of the prescription and was combined with 90 min of either strength or balance exercise	↔6MWT ↔Climbing capacity ↔Muscular endurance ↔Balance ↔Handgrip strength ↔Lower limb strength
Lightfoot et al. 2024 UK SMILE ¹⁵	Inclusion: Adults (≥18 years) with CKD stages 3–4 (eGFR 15–59 ml/min/1.73m²) and were assessed as having a kidney condition that was likely to progress Exclusion: Receiving kidney replacement therapy or eGFR >60 ml/min/1.73m²	420 (280 intervention group; 140 control group)	Intervention: Access to My Kidneys & Me (MK&M) a digital self-management intervention for people with non-dialysis CKD; a structured 10 week programme with tailored, interactive information and support. Control: Usual clinical care	At 20 weeks, per protocol: ↑PAM ↑kidney health awareness ↑STS-60 ↑Diet score ↔Medication adherence ↔SARC-F score ↔Symptoms ↔Self-management behaviours
Weiner et al. 2023 USA AWARD ¹⁶	Inclusion: Adults ≥55 years with CKD eGFR 15–<45 mL/min/1.73² Exclusion: >185 min/week exercise, prior disabling stroke, severe anemia (hemoglobin <9 g/dL), uncontrolled diabetes (glycated hemoglobin >10%), vascular claudication impairing physical functioning, dementia or severe cognitive impairment, NYHA class III/IV	99 (49 exercise group; 50 control group)	Exercise: 3x/week in-centre for 6 months. 1/3 sessions at home for the second 6 months Progressive aerobic exercise starting with 20 min at 50-60% heart rate reserve progressing to 40 min at 70-80%. Two 10 min strength routines per week Control: Group-based educational sessions modeled after the	At 12 months: ↔$\dot{V}O_2$peak ↑6MWT ↑TUAG ↔SPPB ↔eGFR ↔SBP ↔DBP ↔BMI ↔HbA1c

	heart failure, and acute cardiovascular event (stroke, myocardial infarction, decompensated heart failure, or coronary revascularisation) <6 months		successful aging intervention in the LIFE (Lifestyle Interventions and Independence for Elders) clinical trial in older adults. Weekly for 6 months and month for the second 6 months	
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Abbreviations: ACSM, American College of Sports Medicine; baPWV, Brachial-ankle pulse wave velocity; BDI, Beck Depression Index; BMI, body mass index; BUN, blood urea nitrogen; CKD, chronic kidney disease; CRP, C-reactive protein; CVD, cardiovascular disease; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; hANP, Human atrial natriuretic peptide; HbA1c, hemoglobin A1C; HDL, high-density lipoprotein; HOMA-IR, Homeostasis model assessment of insulin resistance; HR, heart rate; IL-6, Interleukin 6; KDCS, kidney disease component summary score; KRT, kidney replacement therapy; KTR, kidney transplant recipient; LDL, low-density lipoprotein; MCS, mental component score; MRI, magnetic resonance imaging; NYHA, New York Heart Association; PA, physical activity; PCS, physical component score; QoL, quality of life; RCT, randomised controlled trial; RPE, rating of perceived exertion; SARC-F, Strength, Assistance in walking, Rise from a chair, Climb stairs, and Falls; SBP, systolic blood pressure; SCr, serum creatinine; SPPB, short physical performance battery; STS, sit-to-stand; TC, total cholesterol; TUAG, timed up and go; U-ACR, urine albumin-creatinine ratio; $\dot{V}O_2$ peak, peak oxygen uptake; 6MWT, 6-minute walk test. $\uparrow$ = significantly higher; $\leftrightarrow$ = no significant difference; $\downarrow$ = significantly lower.

- 1 Anding-Rost, K. *et al.* Exercise during hemodialysis in patients with chronic kidney failure. *NEJM evidence* **2**, EVIDoA2300057 (2023).
- 2 Graham-Brown, M. P. *et al.* A randomized controlled trial to investigate the effects of intra-dialytic cycling on left ventricular mass. *Kidney international* **99**, 1478-1486 (2021).
- 3 Greenwood, S. A. *et al.* Randomized trial—prescription of intradialytic exercise to improve quality of life in patients receiving hemodialysis. *Kidney International Reports* **6**, 2159-2170 (2021).
- 4 Bennett, P. N. *et al.* An exercise program for peritoneal dialysis patients in the United States: a feasibility study. *Kidney medicine* **2**, 267-275 (2020).
- 5 Luo, Y., Yang, Z., Chen, X. & Huang, Y. Effect of a video-based exercise intervention on depression and sleep conditions of peritoneal dialysis patients. *Clinical Nephrology* **99**, 58 (2023).
- 6 Watanabe, K. *et al.* Home-based exercise and bone mineral density in peritoneal dialysis patients: a randomized pilot study. *BMC nephrology* **22**, 1-9 (2021).
- 7 Uchiyama, K. *et al.* Home-based aerobic exercise and resistance training in peritoneal dialysis patients: a randomized controlled trial. *Scientific reports* **9**, 2632 (2019).
- 8 Manfredini, F. *et al.* Exercise in patients on dialysis: a multicenter, randomized clinical trial. *Journal of the American Society of Nephrology* **28**, 1259-1268 (2017).

- 9 Greenwood, S. A. *et al.* Aerobic or resistance training and pulse wave velocity in kidney transplant recipients: a 12-week pilot randomized controlled trial (the Exercise in Renal Transplant [ExeRT] Trial). *American Journal of Kidney Diseases* **66**, 689-698 (2015).
- 10 Knobbe, T. J. *et al.* Effect of an exercise intervention or combined exercise and diet intervention on health-related quality of life-physical functioning after kidney transplantation: the Active Care after Transplantation (ACT) multicentre randomised controlled trial. *The Lancet Healthy Longevity* **5** (2024).
- 11 Painter, P. L. *et al.* A randomized trial of exercise training after renal transplantation. *Transplantation* **74**, 42-48 (2002).
- 12 Zhang, P. *et al.* The effects of a physical exercise program in Chinese kidney transplant recipients: a prospective randomised controlled trial. *Clinical Kidney Journal* **16**, 1316-1329 (2023).
- 13 Greenwood, S. A. *et al.* 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. *The Lancet Digital Health* **6**, e23-e32 (2024).
- 14 Hellberg, M., Höglund, P., Svensson, P. & Clyne, N. Randomized controlled trial of exercise in CKD—the RENEXC study. *Kidney international reports* **4**, 963-976 (2019).
- 15 Lightfoot CJ, W. T., Sohansoha GK, Gillies CL, Vadaszy N, Ford EC, Davies MJ, Yate T, Smith AC, Graham-Brown MPM. 2024. . The effects of a digital health intervention on patient activation in chronic kidney disease. . *npj Digital Medicine* (2024).
- 16 Weiner, D. E. *et al.* Effect of long-term exercise training on physical performance and cardiorespiratory function in adults with CKD: a randomized controlled trial. *American Journal of Kidney Diseases* **81**, 59-66 (2023).