Clinical Kidney Journal, 2021, vol. 14, Suppl 2, ii3–ii14

doi: 10.1093/ckj/sfab012
CKJ Review

CKJ REVIEW

Exercise training in chronic kidney disease—effects, expectations and adherence

Naomi Clyne [1] and Kirsten Anding-Rost[2,3]

[1]Department of Nephrology, Faculty of Medicine, Institution of Clinical Sciences Lund, Lund University and Skåne University Hospital, Lund, Sweden, [2]KfH Kidney Center, Bischofswerda, Germany and [3]Department of Prevention, Rehabilitation and Sports Medicine, Klinikum Rechts der Isar der Technische Universität München, Munich, Germany

Correspondence to: Naomi Clyne; E-mail: Naomi.Clyne@med.lu.se

ABSTRACT

There is increasing evidence showing the health benefits of physical activity, such as better survival and possibly even a slower decline in kidney function, in people with chronic kidney disease (CKD). There is convincing evidence that exercise training improves physical function measured as aerobic capacity, muscle endurance strength and balance at all ages and all stages of CKD. In fact, long-term adherence to well-designed and adequately monitored exercise training programmes is high. In general, patients express interest in exercise training and are motivated to improve their physical function and health. A growing number of nephrologists regard physical activity and exercise training as beneficial to patients with CKD. However, many feel that they do not have the knowledge to prescribe exercise training and suppose that patients are not interested. Patients state that support from healthcare professionals is crucial to motivate them to participate in exercise training programmes and overcome medical, physical and psychological barriers such as frailty, fatigue, anxiety and fear. Equally important is the provision of funding by healthcare providers to ensure adequate prescription and follow-up by trained exercise physiologists for this important non-pharmacological treatment.

Keywords: adherence, barriers, chronic kidney disease, dialysis, exercise training, GFR, physical activity, physical function, mortality, motivators

INTRODUCTION

A growing number of nephrologists around the world regard physical activity and exercise training as an integral part of the care of patients with chronic kidney disease (CKD). The Kidney Disease: Improving Global Outcomes (KDIGO) 2012 Clinical Practice Guideline for the Management of CKD recommends that 'people with CKD be encouraged to undertake physical activity compatible with cardiovascular health and tolerance (1D)' [1]. For clinicians, level 1 means that 'most patients should receive the recommended course of action', for policymakers it means that 'the recommendation can be evaluated as a candidate for developing a policy or performance measure' and for patients it means 'most people in your situation would want the recommended course of action and only a small proportion would not'. However, the evidence rating was D, which is very low, implying 'the estimate of effect is very uncertain, and often will be far from the truth'.

Now, nearly 10 years later, there is more evidence, including several larger randomized controlled clinical trials and a number of meta-analyses. This overview will describe the effects of

Received: 6.11.2020; Editorial decision: 5.1.2021

exercise training on factors such as mortality, morbidity, progression of kidney disease and physical function in patients with CKD Stages 3–5D. It will also discuss adherence to exercise training programmes and facilitators and barriers that affect motivation.

MORTALITY AND SELF-REPORTED PHYSICAL ACTIVITY

Physical activity affects survival and health in the general population. There is similar evidence from observational studies in patients with CKD. Generally, people with CKD Stage ≥3 have lower levels of physical activity than their healthy counterparts [2]. In a recent systematic review studying non-dialysis-dependent (NDD) patients with CKD ranging from Stage 1 to 5 as well as renal transplant recipients, reduced physical activity was associated with higher mortality [3]. Observational studies comprising people with CKD at any stage have shown that higher levels of physical activity are associated with lower mortality [2, 4, 5]. In the Dialysis Outcomes and Practice Patterns Study, an exercise frequency of more than one session per week was associated with lower mortality risk [6].

MORTALITY AND MEASURED PHYSICAL FUNCTION

Recently a systematic review in NDD patients with CKD found that aerobic capacity and muscle endurance in the lower extremities, notably gait speed and ability to stand up from a chair, were associated with increased all-cause mortality [3]. Several studies have reported an association between lower gait speed and decreased muscular endurance in the legs and higher mortality in people with CKD Stages 2–5D [7, 8]. In one study in patients on haemodialysis (HD), the peak volume of oxygen (VO_2) was found to be a strong predictor of survival [9].

PHYSICAL FUNCTION AND PHYSICAL ACTIVITY DETERIORATE AS GLOMERULAR FILTRATION RATE (GFR) DECLINES

As GFR declines, physical function deteriorates. This relationship is consistent whichever measure of physical function is used. Several cross-sectional studies found significant negative relationships between GFR and maximal exercise capacity [10], walking distance [11], strength, balance and fine motor skills [12]. A recent large cross-sectional study in patients with CKD ranging from Stage 1 to 5D showed that self-reported physical inactivity is highly prevalent across all stages of CKD, with 66% reporting insufficient physical activity in Stages 1 and 2 to >90% of patients on dialysis [13].

RELATIONSHIP BETWEEN PHYSICAL FUNCTION, PHYSICAL ACTIVITY AND KIDNEY FUNCTION

Not only does physical function deteriorate as CKD progresses, but low physical function might also affect the rate of progression. One meta-analysis studied the effects of exercise training on GFR and found that exercise training improved estimated GFR (eGFR) by 2.16 mL/min/1.73 m^2 [14]. However, this improvement was driven by three studies comprising 8–14 patients exercising for 3–12 months; there were no within-group effects. Another meta-analysis showed that exercise increased eGFR by 2.62 mL/min/1.73 m^2; however, this increase was only found in studies with an observation period <3 months. In studies with an observation period of 3–12 months, there was no group effect of exercise training on eGFR [15]. The largest study included in the meta-analysis is the Landmark study, a randomized controlled trial (RCT) comprising 72 patients who completed the 12-month study period with unchanged eGFR in both the exercise and control arms [16]. The Renal Exercise (RENEXC) trial, a RCT with two active arms comprising 112 patients who completed 12 months of exercise training, reported a decline in measured GFR of 1.8 mL/min/1.73 m^2 in both groups with no between-group difference. Interestingly, the endurance and resistance group showed a significant reduction in the urine albumin:creatinine ratio compared with the endurance and balance group; there was a between-group difference [17].

Observational studies have found an association between higher levels of self-reported physical activity and a slower rate of eGFR decline [4, 18] as well as a dose-dependent relationship between the level of physical activity and loss of eGFR. A level of physical activity >150 min/week was related with the slowest decline in eGFR, while the highest degree of inactivity was related with the fastest decline [4, 18]. Measured physical function has also been found to be associated with a decline in eGFR. A higher fitness level in US veterans was associated with a lower risk of acquiring CKD [19]; handgrip strength (HGS) and the 1-min step test in the upper 50th percentile were associated with a slower progression to end-stage kidney disease (ESKD) [20].

To summarize, there are indications that exercise training slows the progression of GFR. However, for conclusive evidence, longitudinal prospective studies need to be performed. Moreover, GFR should be measured rather than estimated in order to eliminate a confounding effect of increased muscle mass. On the one hand, exercise can increase muscle mass, as has been shown in NDD CKD patients at Stages 3A–5 [21]; on the other hand, in observational studies, highly active people will have a higher muscle mass and may falsely be classified as having CKD based on eGFR. Finally, an observation period of at least 12 months is recommended.

EFFICACY OF SUPERVISED EXERCISE TRAINING

Characteristics of the meta-analyses referred to and an overview of the reported effects of different exercise training regimes on various measures of physical function are given in Tables 1 and 2. The reviews comprise studies with in-centre group training, intradialytic (ID) training, home- or gym-based training, aerobic training only, resistance training only and a combination of both.

NDD CKD

We found three meta-analyses including NDD patients with CKD. Two of the reviews provided the number of patients in each study, comprising a total of 357 and 354 patients, respectively [14, 23]. All meta-analyses showed positive effects of exercise training on aerobic capacity measured as peak VO_2. One review analysed the effect of exercise training on the 6-min walk test (6MWT) and found no effect [22]. Two reviews showed positive effects on leg muscle strength [14, 22].

To date there are three larger RCTs comprising a total of 330 patients. The Landmark study, with a total of 72 patients exercising for 12 months [33], the study by Rossi *et al.*, with 107 patients exercising for 12 weeks, and the RENEXC trial, with 151 patients exercising for 12 months [17]. The Landmark study and

Table 1. Descriptive data of recent systematic reviews and meta-analyses of the effects of exercise training in patients with NDD CKD and ESKD

Meta-analyses	Studies, n	Participants, n (men/women)	Age (years), range[a]	ESKD Interdialytic exercise		ESKD ID exercise	NDD CKD exercise		Duration (months), range[b]
				At home	In-centre		At home	In-centre	
Vanden Wyngaert *et al.* [14]	11	362	51–72	NA	NA	NA	Yes	Yes	3–12
Heiwe and Jacobson [22]	41	NA	36–71	Yes	Yes	Yes	Yes	Yes	2–18
Barcellos *et al.* [23]	59	2665	NA	Yes	Yes	Yes	Yes	Yes	2–12
Andrade *et al.* [24]	7	243 (153/90)	NA	NA	NA	Yes	NA	NA	3–12
Bogataj *et al.* [25]	33	1274	40–70	Yes	Yes	Yes	NA	NA	2–10
Clarkson *et al.* [26]	27	1156	36–70	Yes	Yes	Yes	NA	NA	2–6
Ferrari *et al.* [27]	50	2062	NA	NA	NA	Yes	NA	NA	NA
Huang *et al.* [28]	20	677	30–70	Yes	Yes	Yes	NA	NA	2–12
Lu *et al.* [29]	21	898 (382/516)	45–71	Yes	Yes	Yes	NA	NA	NA
Pu *et al.* [30]	27	1215 (723/492)	53	NA	NA	Yes	NA	NA	2–12
Scapini *et al.* [31]	31	1251	NA	NA	Yes	Yes	NA	NA	2–12
Young *et al.* [32]	8	354	41–70	NA	NA	Yes	NA	NA	3.5

[a]Age, given as range, of participants in the individual studies of the meta-analysis (except in the review by Pu [30] where mean age was given). [b]Duration of exercise intervention in the individual studies of the meta-analysis (except in the review by Young *et al.* [32], where the mean duration of the exercise intervention was given). Interdialytic exercise: exercise on non-dialysis days; ID exercise: exercise during HD; NA: no data available or not studied.

Table 2. Overview of effects of exercise training in patients with NDD CKD and patients with ESKD (comprises HD and PD) from recent systematic reviews and meta-analyses

Meta-analyses	Type of exercise	Aerobic capacity: Peak VO_2 NDD CKD	Aerobic capacity: Peak VO_2 ESKD	Aerobic capacity: 6MWT ESKD	Muscular endurance STS ESKD	Muscle strength: Leg NDD CKD	Muscle strength: Leg ESKD	Muscle strength: HGS ESKD
Vanden Wyngaert *et al.* [14]	Aerobic	Increase	NA	NA	NA	NA	NA	NA
	Combined	Increase	NA	NA	NA	NA	NA	NA
Heiwe and Jacobson [22]	Aerobic	Increase	Increase	=	NA	Increase	Increase	NA
	Combined	Increase	Increase	=	NA	Increase	Increase	NA
	Resistance	Increase	Increase	=	NA	Increase	Increase	NA
Barcellos *et al.* [23]	Aerobic	Increase	Increase	NA	NA	Increase	Increase	NA
	Combined	Increase	Increase	NA	NA	Increase	Increase	NA
	Resistance	Increase	Increase	NA	NA	Increase	Increase	NA
Andrade *et al.* [24]	Aerobic	NA	Increase	NA	NA	NA	NA	NA
	Combined	NA	Increase	NA	NA	NA	NA	NA
Bogataj *et al.* [25]	Aerobic	NA	Increase	Increase	Increase	NA	NA	NA
	Combined	NA	Increase	Increase	Increase	NA	NA	NA
Clarkson *et al.* [26]	Aerobic	NA	NA	Increase	Increase	NA	NA	Increase
	Combined	NA	NA	=	Increase	NA	NA	NA
	Resistance	NA	NA	Increase	Increase	NA	NA	NA
Ferrari *et al.* [27]	Aerobic	NA	Increase	Increase	NA	NA	NA	NA
	Combined	NA	Increase	=	NA	NA	NA	NA
	Resistance	NA	NA	Increase	NA	NA	NA	NA
Huang *et al.* [28]	Aerobic	NA	Increase	Increase	NA	NA	NA	NA
	Combined	NA	NA	=	NA	NA	NA	NA
	Resistance	NA	Increase	=	NA	NA	NA	NA
Lu *et al.* [29]	Aerobic	NA	NA	Increase	Increase	NA	=	Increase
	Combined	NA	NA	=	Increase	NA	=	=
	Resistance	NA	NA	Increase	Increase	NA	Increase	Increase
Pu *et al.* [30]	Aerobic	NA	Increase	Increase	NA	NA	NA	NA
	Combined	NA	Increase	Increase	NA	NA	NA	NA
	Resistance	NA	Increase	Increase	NA	NA	NA	NA
Scapini *et al.* [31]	Aerobic	NA	Increase	NA	NA	NA	NA	NA
	Combined	NA	=	NA	NA	NA	NA	NA
	Resistance	NA	Increase	NA	NA	NA	NA	NA
Young *et al.* [32]	Aerobic	NA	=	Increase	NA	NA	NA	NA

Increase: statistically significant effect of exercise training; =: no effect of exercise training, NA: no data available or not studied.
In NDD CKD, there were no data available for aerobic capacity measured as 6MWT, except in Heiwe and Jacoobson's [22] review, where no effect was reported.
In NDD CKD, there were no data available for muscular endurance measured as STS, strength measured as HGS or balance.
In ESKD, there were no data available for balance except in Clarkson *et al.*'s [26] review, where no effect was reported.

Rossi *et al.* compared exercise training with standard care. The RENEXC trial had two active arms of intervention: endurance and resistance training or endurance and balance training. The study by Rossi *et al.* and the RENEXC trial were not included in the most recent meta-analysis by Vanden Wyngaert *et al.* [14]. The participants in these three studies had CKD Stages 3–5, with a mean age of 60–69 years. Only one study, the RENEXC trial, specified using intention-to-treat (ITT) analysis [17]. In the Landmark trial, the patients had 8 weeks of in-centre supervised training for 150 min/week, after which they were given individually adapted home-based programmes and were contacted regularly to monitor progress. In Rossi *et al.*'s study, patients had supervised in-centre exercise training twice a week. The RENEXC trial prescribed individually tailored gym- or home-based training for 150 min/week with regular telephone follow-up by the study physiotherapist every week for the first 3 months and every other week for the remaining study period. All studies showed an increase in the 6MWT. Rossi *et al.* and the RENEXC trial showed an improvement in the sit-to-stand (STS) test. The RENEXC trial showed improved muscle strength and endurance in the leg muscles, improved balance and improved fine motor skills, but no improvement in HGS. The Landmark trial showed an increase in metabolic equivalents (METs).

To summarize, exercise training is effective in increasing aerobic capacity and muscle endurance and strength in the lower extremities. However, there are few large long-term studies. Few studies have employed ITT to evaluate their results.

Maintenance dialysis

We found 11 meta-analyses comprising 11 438 patients with ESKD; most of the patients were on HD, but some studies included patients on peritoneal dialysis (PD). It is important to note that many reviews include the same studies in their analysis, so the actual number of patients who have participated in exercise training studies is considerably less. All meta-analyses reviewed ID training, i.e. during HD, and seven reviews also included interdialytic training, i.e. on non-dialysis days.

All found that exercise training increased aerobic capacity, measured with peak VO_2 in eight reviews and the 6MWT in seven reviews. Three reviews reported positive effects of aerobic training only or combined training on peak VO_2 [27, 28, 31]; one review found no effect of resistance training only on peak VO_2 [31]. Three reviews found positive effects of aerobic only or resistance training only on the 6MWT [26, 27, 29]. Four reviews found no effect of combined training on the 6MWT [26–29]. Three reviews reported that all described exercise training modalities had a positive effect on muscle endurance measured with the STS test [25, 26, 29]. Two reviews reported an increase in leg muscle strength with all types of exercise training [22, 23], while one review found that only resistance training increased leg muscle strength [29].

Eighteen of the studies included in the meta-analyses comprised between 50 and 100 patients. We found four studies comprising >100 patients: Van Vilsteren *et al.* [35] with 103, Tao *et al.* [36] with 113, Manfredini *et al.* [37] with 296 and Bennett *et al.* [38] with 228. Van Vilsteren *et al.* [35] randomized 103 patients to strength training before the dialysis session followed by ID cycling two to three times a week for 12 weeks. Each patient also received four sessions of individual exercise counselling. They found significant improvements in muscle endurance measured with the STS test and leg muscle strength, but not in peak VO_2. Tao *et al.* [36] conducted a nurse-supervised case management programme with person-to-person counselling. A total of 113 patients were randomized to 6 weeks of biweekly exercise training before dialysis, followed by a 6-week observation period or 6 weeks of biweekly exercise training before dialysis and weekly health and exercise counselling for the first 6 weeks followed by 6 weeks of biweekly counselling. The patients in the counselling group improved their general endurance, measured as gait speed, and their muscle endurance, measured with the STS test. There was a significant group effect for gait speed. Results were analysed using ITT. Bennett *et al.* [38] randomized 228 patients in clinic clusters using a step-wedged design in which patients were their own controls. They were prescribed 12–36 weeks of individualized resistance training during HD three times a week, of which one session each week was supervised. Patients improved their muscle endurance as measured with the STS test and the timed-up-and-go test.

The hitherto largest study is the EXerCise Introduction To Enhance Performance in Dialysis (EXCITE) trial comprising 296 patients on either HD or PD. Patients were randomized to usual care or 6 months of a home-based exercise (HBE) training programme consisting of walking a predefined number of steps per minute as determined by a metronome, which was increased regularly according to each patient's capacity. Dialysis nurses were in daily contact with the patients to motivate them. The exercise group showed significant improvements in the 6MWT and STS test [37]. Results were analysed using ITT.

To summarize, most studies compared various forms of exercise training (in-centre or home-based, intra- or interdialytic) to a usual care control group. The meta-analyses report a positive effect of exercise training on aerobic capacity, muscle endurance and strength. There are a number of small studies with <20 participants and at least 16 studies with 50–80 patients. We found four studies with >100 patients. All studies showed positive effects on aerobic capacity irrespective of the test used. The largest studies measured muscle endurance and strength and found positive effects. Some studies analysed their data using ITT analysis, but most did not.

EFFICACY OF COUNSELLING

Several studies integrated some degree of counselling into their programmes. Tao *et al.* [36] showed significant effects of an integrated exercise prescription and counselling programme. An early study showed that patients with NDD CKD and ESKD increased their physical function with regular counselling by weekly telephone calls [39]. Both the RENEXC and EXCITE trials incorporated regular motivational contact by dedicated staff [17, 37].

EXERCISE TRAINING IN THE ELDERLY

One meta-analysis studied the effects of exercise training in people >60 years of age on dialysis, with inconclusive results [40]. An early study compared 12 weeks of in-centre individualized exercise training in patients with CKD Stages 4–5 and in healthy subjects with their respective sedentary counterparts; the average age was 75 years. Both the patients and the healthy subjects showed a similar increase in walking distance, muscle strength and endurance [41]. In a secondary analysis of the EXCITE trial comprising patients >65 years of age, 6 months of home-based walking improved the 6MWT and STS tests [42].

To summarize, older people with CKD Stages 4–5D benefit from individualized exercise training. In fact, for this group, exercise training can be especially important in order to preserve and increase functional ability and maintain personal autonomy.

EXERCISE TRAINING AND DIALYSIS EFFICACY

One meta-analysis showed increased dialysis efficacy as measured by K_t/V_{urea} after ID exercise [30]; another meta-analysis found this effect was specifically due to aerobic training [31].

WHERE AND WHEN TO EXERCISE?

To date, there are a large number of studies from around the world and from countries on every continent. For patients with NDD CKD, in-centre supervised exercise training has often been used initially to get patients accustomed to the training regime, after which individually tailored home-based training has been recommended. For patients with ESKD, ID training is most commonly prescribed, although interdialytic training, either in-centre or home based, is also recommended. There are several studies comprising 46–60 patients comparing ID with interdialytic in-centre or home-based training, with observation periods ranging from 4 to 6 months. Two of the studies found positive effects of exercise training on aerobic capacity in all groups [43, 44]; one study found no effect [45].

TYPE OF EXERCISE

The most common form of exercise training is aerobic training, such as cycling, walking and swimming. There are a few studies prescribing resistance training only, but many advocate a combination of endurance and resistance training using machines, weights or therabands. Balance in combination with aerobic training has been shown to be equally effective as a combination of resistance and aerobic training [17, 46]. Complemetary and alternative exercise for enhancing physical well-being has also been successfully employed in patients on HD. A RCT comprising 31 patients found that 12 weeks of yoga resulted in a non-significant improvement in self-assessed physical function [47]. A non-RCT comprising 172 patients found significantly less fatigue in the group practicing qigong compared with the control group after 6 months [48]. A systematic review studied the effects of inspiratory muscle training for a duration of 6–24 weeks in 134 patients and reported a significant improvement in the 6MWT [49].

DURATION AND DOSE OF EXERCISE

Most studies prescribed 20–60 min of exercise training two to three times a week. Some studies following the World Health Organization's recommendations prescribed a weekly exercise dose of 150 min of moderate-intensity activity with muscle-strengthening activities involving major muscle groups at least twice a week [50].

When prescribing exercise dose and intensity it is important to acknowledge that many patients with CKD, both NDD and ESKD, can be severely deconditioned, weak and frail and might only be able to manage short sessions of physical activity consisting of up to 10 min/day to begin with. However, it is important to emphasize that even small doses of physical activity confer significant health benefits and that even 40 or 90 min of physical activity per week has been shown to reduce all-cause mortality in people with chronic conditions [51]. Moreover, inactive people can have the greatest benefit from low- to moderate-intensity physical activity [51]. Thus it is important to encourage patients to be physically active, but the dose and intensity of activity must be adjusted to their level of functional ability and physical function.

PARTICIPATION AND ADHERENCE

In order to be effective, an exercise training programme must attract a majority of available participants and must be constructed so that they are motivated to persevere. In this section, exercise training studies will be evaluated according to (i) the proportion of the total number of patients treated in the facility willing to participate; (ii) adherence to therapy, described as the number of possible sessions performed according to prescribed duration and intensity; and (iii) adherence to the programme, described as the number of patients who dropped out due to 'lack of interest'. An overview of these results is presented in Table 3 for patients with NDD CKD and Table 4 for patients with ESKD.

Proportion of patients willing to participate

There is a considerable range in the literature between the percentage of randomized patients and the number of patients screened or the source population (i.e. all CKD patients treated in the study facility; see Tables 3 and 4). The source population and number of screened patients are either equal [35, 44, 57], differ substantially [36, 37, 53] or the numbers are not provided. Moreover, whether patients who did not meet the inclusion/exclusion criteria were excluded before or after the screening procedure differs from study to study. In studies in dialysis patients, the proportion of randomized patients in the source population ranged from 15% [36] to 40% [37] to 80% [35]; when the entire source population was invited to participate, 48–80% agreed [35, 44, 57]. In studies screening patients with NDD CKD, the differences regarding participation are even more pronounced, ranging from 5% [63] to 16% [56] to 70% [17] to >90% [53]. In the studies with low participation rates, there is either a pre-selection of patients due to strict inclusion/exclusion criteria or a high percentage of patients who were not interested. In some studies, the number of screening failures, defined as patients declining participation due to a lack of interest, equals or exceeds the number of randomized patients [54–56, 58, 60]. However, there are a considerable number of studies with patients on dialysis as well as with NDD CKD characterized by a relatively high percentage of randomized patients compared with screened patients/source population and a low number of screening failures [17, 34, 35, 37, 38, 43, 44, 52, 53, 57, 61, 64, 65].

Adherence to prescribed therapy

The attendance rate to the prescribed exercise sessions and the quality of exercise, defined as being performed according to the prescribed duration and intensity, are important for the sustainability of an exercise programme. The percentage of possible training sessions completed in the studies is shown in Tables 3 and 4. Most long-term studies (>6 months) showed attendance rates of >60% [17, 33, 37, 57, 58].

The quality of exercise was rarely reported. In some studies it was self-reported using patient questionnaires. In centre-based training, objective measurements such as weekly training volume for strength training [55] or mean power per session for aerobic training [57] were reported; in home-based training, metronomes and/or pedometers were used [37, 66].

Adherence to the programme

Interestingly, the dropout rates were relatively low, especially if non-motivational dropouts due to death, transplantation (TX) or illness were excluded. In the latter case, adherence was often

Table 3. Participation and adherence to exercise training in recent studies in patients with NDD CKD

Studies	Study design	Type of exercise	Study duration (months)	Exercise location	Exercise duration (min) per week or per session and number of weekly sessions (*n*/week)	Number screened	Screening failures, *n*	Number randomized, *n* (men/women)	Number completed, *n* (men/women)	Possible sessions completed (%)[a]	Total dropouts, (dropouts due to death, TX, illness, moving)[a], *n*	Overall adherence(adherence excluding death, TX, illness)[a], (%)
Hellberg *et al.* [17]	RCT two treatment arms: (i) AE + RE (ii) AE + balance CKD 3–5	CE	12	HBE or CBE	AE: 60 min/week RE or balance: 90 min/week 3–5/week	217	NA	151 (98/53)	112 (NA)	66% of patients completed prescribed sessions	39 (NA)	74 (NA)
Howden *et al.* [31, 33]	RCT CKD 3 + 4	CE	12	CBE: 2 months HBE: 10 months	150 min/week NA	90	3	83 (52/31)	72 (NA)	70% in CBE 57% in HBE	6 (4)	86 (98)
Aoike *et al.* [52]	RCT three arms CKD 3 + 4	AE	6	HBE CBE	30–40 min/session 3/week	59	NA	45 (NA)	40 (27/13)	NA	5 (NA)	89 (NA)
Ikizler *et al.* [51, 53]	RCT four arms 2 × 2 factorial design, CKD3 + 4	AE	4	HBE	30 min/session 3/week	122	6	111 (64/47)	92 (NA)	85% of patients completed >50% of sessions, 49% completed >75% of sessions	19 (13)	82 (95)
Headley *et al.* [51, 54]	RCT CKD 3, only Diabetes or hypertension	AE	4	CBE	40 min/session 3/week	1116	86	51 (NA)	46 (30/16)	97%	5 (4)	90 (98)
Rossi *et al.* [32, 54]	RCT CKD 3 + 4	CE	3	CBE	AE: 60 min/session RE: 2/week	404	NA	119 (56/51)	94 (NA)	73% of patients completed 100% of sessions, 27% completed 50% of sessions	25 (5)	79 (83)
Kirkman *et al.* [32, 55]	RCT CKD 3–5	AE	3	CBE	45 min/session 3/week	384	196	36 (22/9) additional 27 individuals enrolled into a healthy control arm	31 (NA)	92%	5 (3)	86 (94)
Watson *et al.* [32, 54]	RCT CKD 3b–4	RE	2	CBE	NA 3/week	2349	365	38 (56/51)	33 (NA)	92%	5 (4)	87 (97)

Between 2010 and 2020, 11 RCT trials were conducted, from which 8 studies comprising ≥35 patients were selected. The studies are ranked according to study duration.
AE: aerobic exercise; RE: resistance exercise; CE: combined exercise; screening failures: patients declining participation due to a lack of interest.
[a]When not given, extracted and/or calculated from the data provided.

Table 4. Participation and adherence to exercise training in recent studies in patients on dialysis

Studies	Study design	Type of exercise	Study duration (months)	Exercise location	Session duration (min), number of weekly sessions	Number screened (source population), *n*	Screening failures, *n*	Number randomized (men/women), *n*	Number completed (men/women), *n*	Possible sessions complete[a] (%)	Total dropouts (dropout due to death, TX, illness, moving)[a], *n*	Overall adherence (adherence excluding death, TX, illness)[a] (%)
Anding *et al.* [32, 57]	Clinical trial, no control group	CE	12 (5 years)	CBE-ID	AE: 30 min RE: 30 min 2/week	72 (72)	26	Patients starting with exercise: 46 (24/22)	1 year: 36 5 years : 20 (NA)	87/71/39 (high/moderate /low adherence)	1 year: 10 (8) 5 years: 26 (23)	1 year: 78 (96) 5 years: 43 (93)
Jeong *et al.* [32, 58]	RCT Two intervention arms, one control: (i) Exercise + Protein supplement (ii) Protein supplement (iii) Control	AE	12	CBE-ID	40 min 3/week	337	109	138 (80/58)	101 (NA)	79	37 (28) Exercise + protein: 20 (13) Protein and control: 17 (15)	73 (95) Exercise + protein: 59 (86)
Bennett *et al.* [32, 38]	RCT, stepped-wedge cluster	RE	3, 6 and 9	CBE-ID	Duration: NA 3/week	304 (NA)	9	228 (NA)	113 (NA)	>33	115 (73)	50 (82)
Manfredini *et al.* [32, 37]	RCT HD and PD	AE	6	HBE	20 min (2 × 10 min) 3/week	497 (714)	196	296 (NA)	227 (151/76)	83	69 (32)	77 (89)
Bohm *et al.* [32, 45]	RCT Two intervention arms: (i) AE, CBE-ID (ii) AE, HBE	AE	6	CBE-ID HBE	CBE-ID: 52–130 min HBE: NA 3/week	191 (NA)	107	60 (40/20)	43 (NA)	CBE-ID: 53 HBE: 58	17 (10)	72 (88)
Konstantinidou *et al.* [32, 44]	RCT Three intervention arms, one control: (i) CE, HBE (ii) CE, CBE-ID (iii) AE, HBE (iv) Control group	CE	6	CBE-NDD CBE-ID HBE	60 min 3/week	120 (120)	NA	58 (NA)	48 (NA)	NA	10 (2)	83 (97)
Ortega-Perez de Villar *et al.* [32, 43]	RCT Two intervention arms: (i) CE, CBE-ID (ii) CE, HBE	CE	4	CBE-ID HBE	60 min 3/week	63	NA	46 (29/17)	23 (NA)	CBE-ID: 81 HBE: 53	23 (18)	50 (89)
Tao *et al.* [32, 36]	RCT Two intervention arms: (i) CE (ii) RE	CE	3	CBE-BD + HE	CBE-BD: 20 min 2/week HE: 2–3/week	466 (750)	76	113 (59/54)	107 (NA)	NA	6 (4)	95 (98)

(continued)

Table 4. (continued)

Studies	Study design	Type of exercise	Study duration (months)	Exercise location	Session duration (min), number of weekly sessions	Number screened (source population), n	Screening failures, n	Number randomized (men/women), n	Number completed (men/women), n	Possible sessions complete[a] (%)	Total dropouts (dropout due to death, TX, illness, moving)[a], n	Overall adherence (adherence excluding death, TX, illness)[a] (%)
van Vilsteren *et al.* [32, 35]	RCT	CE	3	CBE-ID + CBE-BD	AE: 50 min RE: 20 min 2–3/week	128 (128)	7	103 (NA)	96 (64/32)	AE: 91 RE: 62	7 (2)	93 (95)
Abdelaal *et al.* [46]	RCT Two intervention arms one control group: (i) AE (ii)RE (iii)control	AE, RE	3	CBE-NDD	AE : 30–45 min RE : 30 min 3/week	87 (NA)	6	66 (36/30)	66 (NA)	NA	0 (0)	100 (100)
Cheema *et al.* [44, 59]	RCT	RE	3	CBE-ID	3/week	77 (142)	28	49 (34/15)	44 (NA)	85	5 (4)	90 (98)
Greenwood *et al.* [60]	Uncontrolled cohort study HD, CKD 3–4, TX	CE	3	CBE-NDD + HBE	60 min 3/week	263	132	131 (NA)	77 (NA)	>50	54 (NA)	59 (NA)
Uchiyama *et al.* [61]	RCT PD	CE	3	HBE	AE: 30 min, 3/week RE: ≈30 min 2/week	68	7	47 (35/12)	44 (NA)	AE: 52 RE: 76	3 (3)	94 (94)
Wu *et al.* [62]	RCT Two intervention arms: (i) AE (ii) Stretching	AE	3	CBE-ID	15 min 3/week	NA (NA)	NA	69 (NA)	65 (55/10)	NA	4 (3)	94 (99)

The studies are ranked according to study duration. Studies selected were prospective interventional studies with a duration ≥3 months. Only studies with ≥45 randomized patients were included. Eleven of the studies were conducted between 2010 and 2020. Three older studies from 2002, 2005 and 2007 were included, as they fulfilled the selection criteria.

RCT= randomized controlled trial; HD= hemodialysis; PD= peritoneal dialyis; TX= transplantation, AE= aerobic exercise; RE= resistance exercise; CE= combined exercise; CBE-BD = centre-based exercise before dialysis; CBE-NDD: centre-based exercise on nondialysis days; CBE-ID= centre-based exercise intradialytic that is during hemodialysis; HBE= home-based exercise.Source population: number of all patients on dialysis in study dialysis units; screening failures: patients declining participation due to a lack of interest.

[a] when not given extracted and/or calculated from the data provided.

>80% (>60% without any exclusions), even for studies running >6 months [17, 33, 45, 57, 58, 67]. The EXCITE trial, which had broad inclusion criteria for HBE in patients on dialysis, reported an adherence of 89% (77% without exclusions) [37]. In short-term studies in patients on dialysis there was a tendency towards higher dropout rates with exercise on non-dialysis days for home-based as well as for centre-based training [44, 60]. In NDD CKD patients, however, both home-based training and a mixture of home- and centre-based exercise [17, 33] showed high adherence rates.

The proportion of men in the studies was higher than women, ranging from 65% to 85%, as seen in Tables 3 and 4 [17, 60]. The studies screened in the present review did not present data enabling an analysis of whether the study participants' sex influenced the impact of and adherence to exercise training.

BARRIERS AND FACILITATORS TO EXERCISE TRAINING

Already in 1991 investigators described a high adherence rate to self-care and medical management, as well as having a support group encouraging exercise, as important factors for high adherence to exercise training in patients with ESKD. Negative factors were long-term inactivity and weakness due to old age, coupled with a belief that exercise would not help [68]. Figure 1 depicts barriers and facilitators of exercise training.

Disease acceptance and positive expectations

Recent studies confirm that patients with high levels of disease acceptance and higher expectations concerning the outcome of exercise were more prone to adhere to the prescription of physical activity [69, 70]. One qualitative study reported that a majority of patients with CKD felt that exercise would make them feel better and have a positive impact on their health [71]. These findings were corroborated in a large quantitative study comprising patients on HD and PD in which the top two desired benefits from exercise training were improved energy and strength [72]. Older patients' top priority was maintaining independence, while longevity and transplant candidacy were the most important motivators for younger patients [72]. A recent study in patients with ESKD participating in a pedometer intervention showed improved physical function was their prime motivator [73].

Support

Support from family, friends, peers and from healthcare professionals has been identified as a main motivating factor [74–76]. In facilities providing an exercise physiologist, she/he is perceived as a primary source of support. Patients' sense of physical ability, body confidence and self-esteem was enhanced by the technical competence, caring and esteem conveyed by the exercise physiologist [77]. Of great importance is that a lack of advice and support from the nephrologist, as well as from the dialysis nurses, is experienced as a major barrier [74, 77]. This experience is corroborated by attitudes expressed by nephrologists and dialysis nurses stating that they did not have time to discuss exercise with patients, did not believe that it was their role to provide advice on exercise training, did not have the knowledge to prescribe exercise or did not believe that exercise was important [77–80]. Some expressed a firm belief that patients lacked interest in exercise and that their compliance to exercise would be low [78, 80]. These attitudes resulted in the healthcare professionals not even asking patients about their exercise patterns [79].

Interestingly, the physicians' and nursing staff's own patterns of physical activity affect whether they recommend

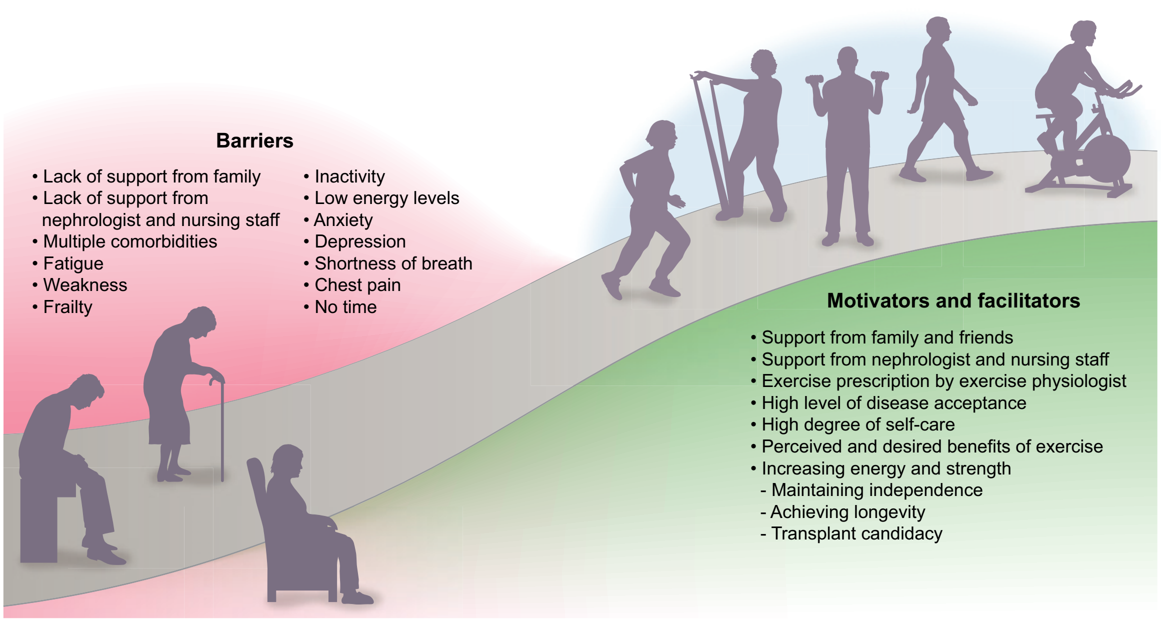

FIGURE 1: Barriers, facilitators and motivators affecting interest and willingness to engage in exercise training.

exercise to their patients. One study reported a highly significant relationship between CKD primary care physicians' own level of physical activity and their readiness to recommend exercise training to their patients [81].

Medical, physical, psychological and temporal barriers

Many patients experience having too many medical problems as a barrier to physical activity [72, 74, 78, 79]. Predominant physical barriers comprise fatigue, tiredness, low energy levels, weakness, shortness of breath and chest pain [72, 74, 78, 79]. Frailty and a low level of physical function, often in combination with old age, are also perceived to be significant barriers. These patients risk being housebound and thus are physically inactive [69]. External conditions such as cold weather, hot weather and unsafe neighbourhoods are other barriers [74, 82]. Psychological and existential barriers are lack of motivation, sadness, depression, anxiety, feeling of helplessness and a fear of getting hurt [78–80, 83]. Another important barrier is the time consumed by maintenance dialysis [78].

PREFERRED TYPE OF EXERCISE AND LOCATION

One study reported that patients, irrespective of age or dialysis modality, preferred a combination of aerobic and strength exercises [72]. Despite the focus on ID exercise in most studies, a recent study found that 73% of the patients stated that their preferred exercise location was their home, followed by their neighbourhood or the gym. Less than one in four preferred to exercise at their HD unit [72]. Being able to exercise close to home was identified as a facilitator in another study [75].

CONCLUSION

There is growing and convincing evidence that physical activity affects mortality and that exercise training improves physical function in patients with CKD. Many studies show a high adherence rate to exercise training programmes. Patients are increasingly aware of the beneficial effects of exercise training but express the need for support. This safe and efficacious non-pharmacological treatment modality requires the involvement of nephrologists and nurses. The structural support of healthcare providers is necessary in order to provide on-site exercise physiologists to prescribe and monitor individualized exercise training programmes.

ACKNOWLEDGEMENTS

We would like to thank research librarian Matthias Bank at the Faculty of Medicine, Lund University for excellent help in searching for articles for this overview.

CONFLICT OF INTEREST STATEMENT

Neither author has any financial interests or connections, direct or indirect, or other situations that might raise the question of bias in the work reported or the conclusions, implications or opinions stated including pertinent commercial or other sources of funding for the individual authors or for the associated departments or organizations, personal relationships, or direct academic competition.

REFERENCES

1. Kidney Disease: Improving Global Outcomes CKD Work Group. KDIGO 2012 clinical practice guideline for the evaluation and management of chronic kidney disease. *Kidney Int Suppl* 2013; 3: 1–150
2. Beddhu S, Baird BC, Zitterkoph J *et al.* Physical activity and mortality in chronic kidney disease (NHANES III). *Clin J Am Soc Nephrol* 2009; 4: 1901–1906
3. MacKinnon HJ, Wilkinson TJ, Clarke AL *et al.* The association of physical function and physical activity with all-cause mortality and adverse clinical outcomes in nondialysis chronic kidney disease: a systematic review. *Ther Adv Chronic Dis* 2018; 9: 209–226
4. Chen IR, Wang SM, Liang CC *et al.* Association of walking with survival and RRT among patients with CKD stages 3–5. *Clin J Am Soc Nephrol* 2014; 9: 1183–1189
5. Clarke AL, Zaccardi F, Gould DW *et al.* Association of self-reported physical function with survival in patients with chronic kidney disease. *Clin Kidney J* 2019; 12: 122–128
6. Tentori F, Elder SJ, Thumma J *et al.* Physical exercise among participants in the Dialysis Outcomes and Practice Patterns Study (DOPPS): correlates and associated outcomes. *Nephrol Dial Transplant* 2010; 25: 3050–3062
7. Roshanravan B, Robinson-Cohen C, Patel KV *et al.* Association between physical performance and all-cause mortality in CKD. *J Am Soc Nephrol* 2013; 24: 822–830
8. Hellberg M, Wiberg EM, Simonsen O *et al.* Small distal muscles and balance predict survival in end-stage renal disease. *Nephron Clin Pract* 2014; 126: 116–123
9. Sietsema KE, Amato A, Adler SG *et al.* Exercise capacity as a predictor of survival among ambulatory patients with end-stage renal disease. *Kidney Int* 2004; 65: 719–724
10. Clyne N, Jogestrand T, Lins LE *et al.* Factors limiting physical working capacity in predialytic uraemic patients. *Acta Med Scand* 2009; 222: 183–190
11. Roshanravan B, Patel KV, Robinson-Cohen C *et al.* Creatinine clearance, walking speed, and muscle atrophy: a cohort study. *Am J Kidney Dis* 2015; 65: 737–747
12. Hellberg M, Höglund P, Svensson P *et al.* Decline in measured glomerular filtration rate is associated with a decrease in endurance, strength, balance and fine motor skills. *Nephrology (Carlton)* 2017; 22: 513–519
13. Wilkinson TJ, Clarke AL, Nixon DGD *et al.* Prevalence and correlates of physical activity across kidney disease stages: an observational multicentre study. *Nephrol Dial Transplant* 2019; doi: 10.1093/ndt/gfz235
14. Vanden Wyngaert K, Van Craenenbroeck AH, Van Biesen W *et al.* The effects of aerobic exercise on eGFR, blood pressure and VO_2peak in patients with chronic kidney disease stages 3–4: a systematic review and meta-analysis. *PLoS One* 2018; 13: e0203662
15. Zhang L, Wang Y, Xiong L *et al.* Exercise therapy improves eGFR, and reduces blood pressure and BMI in non-dialysis CKD patients: evidence from a meta-analysis. *BMC Nephrol* 2019; 20: 398
16. 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: 1494–1501
17. Hellberg M, Höglund P, Svensson P *et al.* Randomized controlled trial of exercise in CKD—the RENEXC study. *Kidney Int Rep* 2019; 4: 963–976

18. Robinson-Cohen C, Littman AJ, Duncan GE *et al*. Physical activity and change in estimated GFR among persons with CKD. *J Am Soc Nephrol* 2014; 25: 399–406
19. Kokkinos P, Faselis C, Myers J *et al*. Exercise capacity and risk of chronic kidney disease in US veterans: a cohort study. *Mayo Clin Proc* 2015; 90: 461–468
20. Tsai YC, Chen HM, Hsiao SM *et al*. Association of physical activity with cardiovascular and renal outcomes and quality of life in chronic kidney disease. *PLoS One* 2017; 12: e0183642
21. Zhou Y, Hellberg M, Hellmark T *et al*. Sarcopenia, muscle mass and plasma myostatin after 12 months of exercise training in patients with CKD: a sub-study of RENEXC—a randomized controlled trial. *Nephrol Dial Transplant* 2019; 34: a183
22. Heiwe S, Jacobson SH. Exercise training in adults with CKD: a systematic review and meta-analysis. *Am J Kidney Dis* 2014; 64: 383–393
23. Barcellos FC, Santos IS, Umpierre D *et al*. Effects of exercise in the whole spectrum of chronic kidney disease: a systematic review. *Clin Kidney J* 2015; 8: 753–765
24. Andrade FP, Rezende PdS, Ferreira TdS *et al*.. Effects of intradialytic exercise on cardiopulmonary capacity in chronic kidney disease: systematic review and meta-analysis of randomized clinical trials. *Sci Rep* 2019; 9: 18470
25. Bogataj Š, Pajek M, Pajek J *et al*. Exercise-based interventions in hemodialysis patients: a systematic review with a meta-analysis of randomized controlled trials. *J Clin Med* 2019; 9: 43
26. Clarkson MJ, Bennett PN, Fraser SF *et al*. 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–F872
27. Ferrari F, Helal L, Dipp T *et al*. Intradialytic training in patients with end-stage renal disease: a systematic review and meta-analysis of randomized clinical trials assessing the effects of five different training interventions. *J Nephrol* 2020; 33: 251–266
28. Huang M, Lv A, Wang J *et al*. Exercise training and outcomes in hemodialysis patients: systematic review and meta-analysis. *Am J Nephrol* 2019; 50: 240–254
29. Lu Y, Wang Y, Lu Q. Effects of exercise on muscle fitness in dialysis patients: a systematic review and meta-analysis. *Am J Nephrol* 2019; 50: 291–302
30. Pu J, Jiang Z, Wu W *et al*. Efficacy and safety of intradialytic exercise in haemodialysis patients: a systematic review and meta-analysis. *BMJ Open* 2019; 9: e020633
31. Scapini KB, Bohlke M, Moraes OA *et al*. Combined training is the most effective training modality to improve aerobic capacity and blood pressure control in people requiring haemodialysis for end-stage renal disease: systematic review and network meta-analysis. *J Physiother* 2019; 65: 4–15
32. Young HML, March DS, Graham-Brown MPM *et al*.. Effects of intradialytic cycling exercise on exercise capacity, quality of life, physical function and cardiovascular measures in adult haemodialysis patients: a systematic review and meta-analysis. Nephrol Dial Transplant 2018; 33: 1436–1445
33. Howden EJ, Coombes JS, Strand H *et al*. Exercise training in CKD: efficacy, adherence, and safety. *Am J Kidney Dis* 2015; 65: 583–591
34. 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: 2052–2058
35. van Vilsteren MCBA, de Greef MHG, Huisman RM. The effects of a low-to-moderate intensity pre-conditioning exercise programme linked with exercise counselling for sedentary haemodialysis patients in The Netherlands: results of a randomized clinical trial. *Nephrol Dial Transplant* 2005; 20: 141–146
36. Tao X, Chow SK, Wong FK. A nurse-led case management program on home exercise training for hemodialysis patients: a randomized controlled trial. *Int J Nurs Stud* 2015; 52: 1029–1041
37. Manfredini F, Mallamaci F, D'Arrigo G *et al*. Exercise in patients on dialysis: a multicenter, randomized clinical trial. *J Am Soc Nephrol* 2017; 28: 1259–1268
38. Bennett PN, Fraser S, Barnard R *et al*. Effects of an intradialytic resistance training programme on physical function: a prospective stepped-wedge randomized controlled trial. *Nephrol Dial Transplant* 2016; 31: 1302–1309
39. Fitts SS, Guthrie MR, Blagg CR. Exercise coaching and rehabilitation counseling improve quality of life for predialysis and dialysis patients. *Nephron* 1999; 82: 115–121
40. Matsuzawa R, Hoshi K, Yoneki K *et al*. Exercise training in elderly people undergoing hemodialysis: a systematic review and meta-analysis. *Kidney Int Rep* 2017; 2: 1096–1110
41. Heiwe S, Tollbäck A, Clyne N. Twelve weeks of exercise training increases muscle function and walking capacity in elderly predialysis patients and healthy subjects. *Nephron* 2001; 88: 48–56
42. Baggetta R, D'Arrigo G, Torino C et al. Effect of a home based, low intensity, physical exercise program in older adults dialysis patients: a secondary analysis of the EXCITE trial. *BMC Geriatr* 2018; 18: 248
43. Ortega-Pérez de Villar L, Martínez-Olmos FJ, Pérez-Domínguez FB *et al*. Comparison of intradialytic versus home-based exercise programs on physical functioning, physical activity level, adherence, and health-related quality of life: pilot study. *Sci Rep* 2020; 10: 8302
44. Konstantinidou E, Koukouvou G, Kouidi E *et al*. Exercise training in patients with end-stage renal disease on hemodialysis: comparison of three rehabilitation programs. *J Rehabil Med* 2002; 34: 40–45
45. Bohm C, Stewart K, Onyskie-Marcus J *et al*. Effects of intradialytic cycling compared with pedometry on physical function in chronic outpatient hemodialysis: a prospective randomized trial. *Nephrol Dial Transplant* 2014; 29: 1947–1955
46. Abdelaal AAM, Abdulaziz EM. Effect of exercise therapy on physical performance and functional balance in patients on maintenance renal hemodialysis: randomized controlled study. *J Exerc Rehabil* 2019; 15: 472–480
47. Birdee GS, Rothman RL, Sohl SJ *et al*. Feasibility and safety of intradialysis yoga and education in maintenance hemodialysis patients. *J Ren Nutr* 2015; 25: 445–453
48. Wu CY, Han HM, Huang MC *et al*. Effect of qigong training on fatigue in haemodialysis patients: a non-randomized controlled trial. *Complement Ther Med* 2014; 22: 244–250
49. de Medeiros AIC, Fuzari HKB, Rattesa C *et al*. Inspiratory muscle training imprives respiratory muscle strength, functional capacity and quality of life in patients with chronic kidney disease: a systematic review. *J Physiother* 2017; 63: 76–83
50. World Health Organization. Physical activity. https://www.who.int/news-room/fact-sheets/detail/physical-activity (23 February 2018, date last accessed)
51. Warburton DE, Bredin SS. Reflections on physical activity and health: what should we recommend? *Can J Cardiol* 2016; 32: 495–504

52. Aoike DT, Baria F, Kamimura MA *et al.* Home-based versus center-based aerobic exercise on cardiopulmonary performance, physical function, quality of life and quality of sleep of overweight patients with chronic kidney disease. *Clin Exp Nephrol* 2018; 22: 87–98
53. Alp Ikizler T, Robinson-Cohen C, Ellis C *et al.* Metabolic effects of diet and exercise in patients with moderate to severe CKD: a randomized clinical trial. *J Am Soc Nephrol* 2018; 29: 250–259
54. Headley S, Germain M, Wood R *et al.* Short-term aerobic exercise and vascular function in CKD stage 3: a randomized controlled trial. *Am J Kidney Dis* 2014; 64: 222–229
55. Kirkman DL, Mullins P, Junglee NA *et al.* Anabolic exercise in haemodialysis patients: a randomised controlled pilot study. *J Cachexia Sarcopenia Muscle* 2014; 5: 199–207
56. Watson EL, Greening NJ, Viana JL *et al.* Progressive resistance exercise training in CKD: a feasibility study. *Am J Kidney Dis* 2015; 66: 249–257
57. Anding K, Bär T, Trojniak-Hennig J *et al.* A structured exercise programme during haemodialysis for patients with chronic kidney disease: clinical benefit and long-term adherence. *BMJ Open* 2015; 5: e008709
58. Jeong JH, Biruete A, Tomayko EJ *et al.* Results from the randomized controlled IHOPE trial suggest no effects of oral protein supplementation and exercise training on physical function in hemodialysis patients. *Kidney Int* 2019; 96: 777–786
59. Cheema B, Abas H, Smith B *et al.* Randomized controlled trial of intradialytic resistance training to target muscle wasting in ESRD: the Progressive Exercise for Anabolism in Kidney Disease (PEAK) study. *Am J Kidney Dis* 2007; 50: 574–584
60. Greenwood SA, Lindup H, Taylor K *et al.* Evaluation of a pragmatic exercise rehabilitation programme in chronic kidney disease. *Nephrol Dial Transplant* 2012; 27: iii126–iii34
61. Uchiyama K, Washida N, Morimoto K *et al.* Home-based aerobic exercise and resistance training in peritoneal dialysis patients: a randomized controlled. *Sci Rep* 2019; 9: 2632
62. Wu Y, He Q, Yin X *et al.* Effect of individualized exercise during maintenance haemodialysis on exercise capacity and health-related quality of life in patients with uraemia. *J Int Med Res* 2014; 42: 718–727
63. Headley S, Germain M, Milch C *et al.* Exercise training improves HR responses and VO_{2peak} in predialysis kidney patients. *Med Sci Sports Exerc* 2012; 44: 2392–2399
64. Bogataj Š, Pajek J, Buturović Ponikvar J *et al.* Kinesiologist-guided functional exercise in addition to intradialytic cycling program in end-stage kidney disease patients: a randomised controlled trial. *Sci Rep* 2020; 10: 5717
65. Howden EJ, Coombes JS, Leano R *et al.* Effect of exercise and lifestyle intervention on left ventricular and vascular function in patients with chronic kidney disease: a randomised controlled trial. *Eur Heart J* 2012; 33: 515
66. Sheshadri A, Kittiskulnam P, Lazar AA *et al.* A walking intervention to increase weekly steps in dialysis patients: a pilot randomized controlled trial. *Am J Kidney Dis* 2020; 75: 488–496
67. 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: 359–367
68. Williams A, Stephens R, McKnight T *et al.* Factors affecting adherence of end-stage renal disease patients to an exercise programme. *Br J Sports Med* 1991; 25: 90–93
69. Hornik B, Duława J. Frailty, quality of life, anxiety, and other factors affecting adherence to physical activity recommendations by hemodialysis patients. *Int J Environ Res Public Health* 2019; 16: 1827
70. Bogataj Š, Pajek M, Ponikvar JB *et al.* Outcome expectations for exercise and decisional balance questionnaires predict adherence and efficacy of exercise programs in dialysis patients. *Int J Environ Res Public Health* 2020; 17: 3175
71. Clarke AL, Young HM, Hull KL *et al.* Motivations and barriers to exercise in chronic kidney disease: a qualitative study. *Nephrol Dial Transplant* 2015; 30: 1885–1892
72. Moorman D, Suri R, Hiremath S *et al.* Benefits and barriers to and desired outcomes with exercise in patients with ESKD. *Clin J Am Soc Nephrol* 2019; 14: 268–276
73. Sheshadri A, Kittiskulnam P, Delgado C *et al.* Association of motivations and barriers with participation and performance in a pedometer-based intervention. *Nephrol Dial Transplant* 2020; 35: 1405–1411
74. Kendrick J, Ritchie M, Andrews E. Exercise in individuals with CKD: a focus group study exploring patient attitudes, motivations, and barriers to exercise. *Kidney Med* 2019; 1: 131–138
75. Parsons TL, Bohm C, Poser K. “A learned soul to guide me”: the voices of those living with kidney disease inform physical activity programming. *Physiother Can* 2018; 70: 289–295
76. Zhang J, Bennett P. The perception of people with chronic kidney disease towards exercise and physical activity: a literature review. *Renal Soc Aust J* 2019; 15: 97–104
77. Thompson S, Tonelli M, Klarenbach S *et al.* A qualitative study to explore patient and staff perceptions of intradialytic exercise. *Clin J Am Soc Nephrol* 2016; 11: 1024–1033
78. Fiaccadori E, Sabatino A, Schito F *et al.* Barriers to physical activity in chronic hemodialysis patients: a single-center pilot study in an Italian dialysis facility. *Kidney Blood Press Res* 2014; 39: 169–175
79. Regolisti G, Maggiore U, Sabatino A et al. Interaction of healthcare staff’s attitude with barriers to physical activity in hemodialysis patients: a quantitative assessment. *PLoS One* 2018; 13: e0196313
80. Michou V, Kouidi E, Liakopoulos V *et al.* Attitudes of hemodialysis patients, medical and nursing staff towards patients’s physical activity. *Int Urol Nephrol* 2019; 51: 1249–1260
81. Morishita Y, Numata A, Miki A *et al.* Primary care physicians’ own exercise habits influence exercise counseling for patients with chronic kidney disease: a cross-sectional study. *BMC Nephrol* 2014; 15: 48
82. Han M, Ye X, Preciado P *et al.* Relationships between neighborhood walkability and objectively measured physical activity levels in hemodialysis patients. *Blood Purif* 2018; 45: 236–244
83. Delgado C, Johansen KL. Barriers to exercise participation among dialysis patients. *Nephrol Dial Transplant* 2012; 27: 1152–1157