

EFFECT OF PLYOMETRIC TRAINING ON MUSCLE STRENGTH AND BALANCE IN CHILDREN WITH CHRONIC KIDNEY DISEASE

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Abstract

Background: Physical inactivity reduces skeletal muscle strength, which in turn increases mortality risk in patients with chronic kidney disease (CKD). Purpose: to investigate the effect of plyometric training on balance and muscle strength in children with CKD.

Material and methods: Thirty six children with CKD (stages 2 and 3) ranging in age from 7 to 10 years were randomly allocated to two groups equally. Control group received traditional medical treatment and regular follow-up without change of their daily physical activity routine and Plyo-group received the same medical treatment given to the control group in addition to plyometric exercise 45 min, three times /week for 2 months. Balance and muscle strength were assessed by using Human Assessment Computer (HUMAC) Balance System and Lafayette manual muscle testing system, respectively.

Results: Study groups were comparable with respect to all outcome measures at entry ($P > 0.05$). With-in group comparison showed that there was no significant difference in control group post treatment compared with that pretreatment ($p > 0.001$), while there was a significant increase right and left hip flexors, abductors, knee flexors and extensors in Plyo-group ($p < 0.01$) as well as balance indices ($p < 0.05$). Further, between groups comparison revealed significant higher improvements ($P < 0.05$) in favor of the Plyo-group.

Conclusions: Two months plyometric training holds promise in enhancing balance and improving lower limb muscle strength. Clinicians and physical rehabilitation professionals can, therefore, integrate the plyometric training protocols for such a patient population to optimize their health and physical performance.

Keywords: CKD, Plyometric exercises, Balance, Strength exercises, conditioning exercises

Introduction

Chronic kidney disease (CKD) is considered a silent killer since it can lead to end-stage renal disease (ESRD) due to permanent kidney damage¹. The disorder can be classified into five stages based on the Schwartz formula. Stage 1 represents a renal injury, which is characterized by an estimated glomerular filtration rate (eGFR) of greater than 90 ml/min per 1.73 m². Stage 2 represents a mild injury, with an eGFR of 60-89 ml/min per 1.73 m². Stage 3 represents a moderate injury, with an eGFR of 30-59 ml/min per 1.73 m². Stage 4 represents a severe injury, with an eGFR of 15-29 ml/min per 1.73 m². Finally, stage 5 is end-stage renal disease, with an eGFR of below 15 ml/min per 1.73 m².

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Patients with CKD have poor health-related quality of life (HRQoL) peers, are less physically active, and struggle to perform occupational and daily living activities^{3,4}.

Patients with dialysis and predialytic CKD report much lower physical capacity⁵. Anemia and hypertension are the main causes of the lack of physical activity as well as decreased physical ability seen in children with CKD which linked to higher death rates in the general population⁶. Furthermore, children across all CKD stages experience physical dysfunction, limited confidence, and low motivation this leads to the need for tailored physical activity interventions to prevent the progressive decline in physical activity commonly observed in this population⁷.

Regular exercise has been found to maximize muscular strength, blood pressure management, lipid profile, glucose control, in addition to psychological profile also other benefits of exercise on bone health, HRQOL, and hospitalization rates in adults on dialysis have been well-documented, as well as in the general adult population^{5,8}.

Strength can be achieved through traditional training methods, using manual resistance and weights, or through functional training methods as plyometric training which add enjoyment and motivation to the children into their treatment by making strengthening exercises as play activities. Many plyometric movements actually similar to movements that are encountered in the normal play of children; no specific strength level is needed to begin such programs.

Plyometric training is safe and effective for children with average or above average motor competence in all phases of maturity when age-appropriate program design, gradual progression and qualified supervision are used⁹.

Plyometric training is one of the muscles strengthening exercises that individuals perform using their own body weight. It is easily performed by body weight without the necessity of any other weight¹⁰.

In the strengthening exercise known as plyometric, a muscle is contracted eccentrically and then quickly concentrically. It includes high-impact, high-velocity exercises like jumping, hopping, tossing and bounding¹¹. The eccentric contraction phase of plyometric exercises produces repetitive mechanoreceptor stimulation and rapid changes of trend muscular structures'

length and tension. Those effects may reduce the inhibitory effect of the Golgi tendon organs and increase the sensitivity of the muscle spindle especially of the antigravity muscles. Also, it may enhance the afferent contribution to the central nervous system regarding conscious awareness of joint position and movement¹². Plyometric exercises have the ability to enhance proprioceptive perception and re-establish functional movement patterns by stimulating motor units and enhancing neuromuscular efficiency in children with cerebral palsy (CP) 12 and juvenile dermatomyositis¹³.

According to Davies et al¹⁴ this kind of training is founded on several ideas that can help improve muscular performance, such as maximizing sarcomere length and stretch reflexes. Evidence from earlier research showed that plyometric exercises were safe and effective in improving children having neurofibromatosis type 1's throwing and jumping abilities as well as their postural control, weight-bearing symmetry, muscular strength, in addition to gross motor skills and balance in CP children^{12,15,16,17}. Previous studies used plyometric exercise as treatment method for children with disability as children with CP and Down syndrome⁹.

This type of training has safely and effectively been used in children with low motor competencies to help them make progress with their long-term motor skills. Despite the prior favourable impact of plyometric training in children with impairments, there is a limited research scope on its effect on patients with CKD. Therefore, the scope of the current study was to evaluate the efficacy of plyometric exercises on balance and lower limb muscle strength in children suffering from CKD. We hypothesized that; plyometric exercises can be an effective method to enhance balance and lower limb muscle strength among this population.

Materials and Methods

Participants

This study included 36 children with CKD They were between the ages of 7 and 10, they were male or female, and they were stage 2 and 3 with a GFR between 30 and 89 ml/min per 1.73 m².

If a child has any of the following conditions: a recent heart attack, severe uncontrolled diabetes, a neurological or cognitive impairment, or peripheral arterial disease, they were eliminated from the study.

Ethical considerations

This randomized controlled clinical study was conducted at the Outpatient Clinics of Nephrology Unit, Abo-Elresh Hospital, and Cairo University. It was allowed and approved by the Research Ethical Committee at the Faculty of Physical Therapy, Cairo University with NO: P.T.REC/012/004083 and the Research Ethical Committee at the Faculty of Medicine, Cairo University with NO: N-237-2024. Additionally, the study protocol has been submitted retrospectively; with a clinical trial registration number was NCT05657236. The study complied with the ethical standards outlined in the Declaration of Helsinki concerning human experimental studies. All parents and guardians provided written consent prior to data collection.

Sample size calculation

The sample size was calculated using G*POWER statistical software (version 3.1.9.2; Franz Faul, Universität Kiel, Germany), based on pilot study data from 5 subjects in each group. The mean $\pm$ SD of knee extensor strength was 4.56 ± 2.38 in the control group and 7.25 ± 2.75 in the study group. Using an independent t-test with a significance level (α) of 0.05, power of 80%, and an effect size of 1.05, the required sample size was determined to be 16 participants per group. To accommodate a potential dropout rate of 10%, the sample size was increased to 18 participants per group.

Randomization

A total 54 children with CKD were evaluated for eligibility and only thirty-six children complete the study at stages 2 and 3 of CKD. The children were given a number between one and thirty-six in a sequential manner after the baseline measurements. After that, 18 children were randomly divided up between the two groups using an online version of Graph Pad Software. The registration clerk and all of the children were unaware that they were being randomly assigned as represented in figure 1. The children in the control group, which consisted of ten girls and eight boys, continued with their usual activities and got usual medical care. The Plyo-group, on the other hand, consisted of 12 girls and 6 boys who, for two months in a row, received plyometric training three times per week in addition to their usual medical care. The usual medical care for the two groups included regular biochemical lab analysis with providing supplements (as vitamin D and iron) when necessary (Figure 1).

Outcome measures

Assessment of anthropometric measurements

Medical interviews, physical examinations, and precise record-keeping of hospital records were utilized to record the ages, weights, and heights of children.

Assessment of biochemical measurements

Findings of the child's hemoglobin and GFR were documented from their most recent medical records.

Assessment of balance

The HUMAC, developed by commuter sports medicine, Inc. of Stoughton, MA, was a computerized dynamic post urography platform utilized in the present study. It is distinct technology used for postural control evaluation and treatment. This widely available, reasonably priced force plate offers both numerical data and visual feedback to the patient and examiner. With eight programs to select from, the system offers a number of reporting choices with unbiased, educational data to give medical professionals knowledge regarding the patient's improvement. This information is utilized for both baseline and follow-up analysis^{18,19}.

For the current investigation, the centre of pressure test (COP), the modified clinical test of sensory integration of balance test (mCTSIB), and limit of stability test (LOS) were conducted.

- Limit of Stability test: As a measure of the participant's capacity to maintain balance in various positions relative to their neutral position, a higher score indicates greater performance. The subjects' percentage of time holding their COP within each of the eight flashing targets is given in a clockwise manner, following the distribution of weight from right to left as well as anterior to posterior. Each of the eight spots serves as a target; while the player is on target, the target will light up green; when he is off target, it will light up yellow. As the participant approaches the end of the hold period, the HUMAC system notifies them that it is time to go on to the new target.
- The center of pressure test: This test measures the static balance

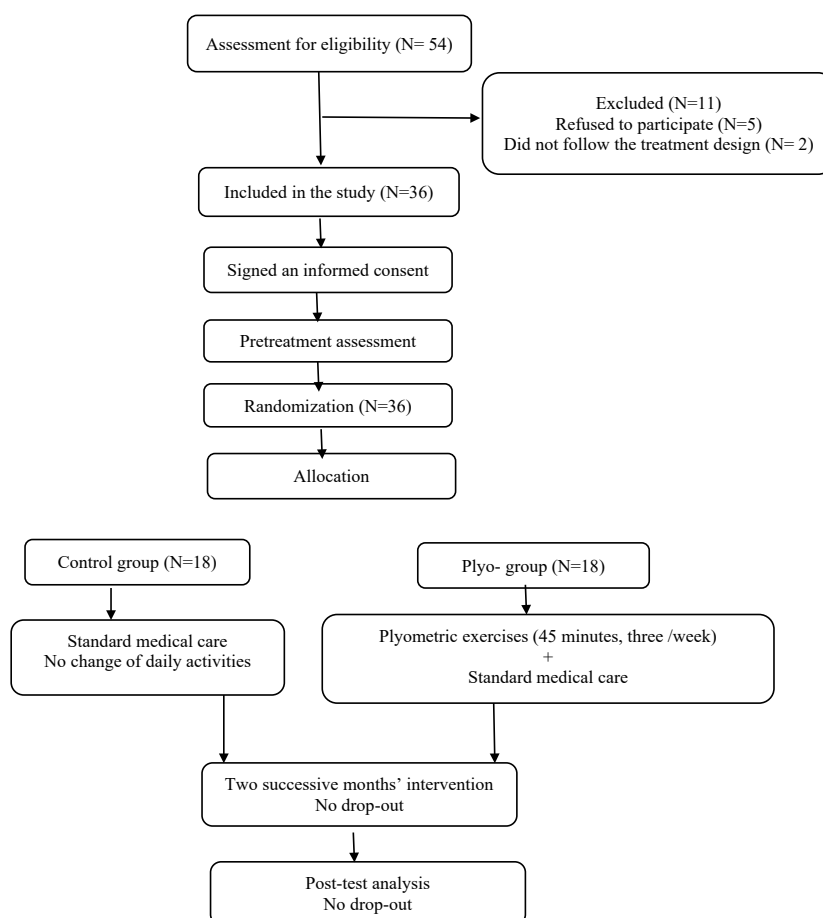


Figure 1. Flow chart demonstrates the experimental design of the study.

ability of the child. The child was asked to stand on the platform and after determining the foot position the child was taught that the purple point on the screen shows the movement of his body and he is asked to maintain this point fixed at the center by stopping his body movement and remain as balanced as possible. The test lasts for 30 seconds, and repeated for three times and the highest value was taken in the form of percent of stability in each trial¹⁷.

- The modified clinical test of sensory integration of balance test: The purpose of this test was to evaluate the child's ability to maintain balance while their eyes were both open and closed. The tests were: eyes open foam surface (EOFS), eyes closed foam surface (ECFS), eyes open stable surface (EOSS), and eyes closed stable surface (ECSS). The procedure began with the child standing on a platform. Once the therapist determined the child's foot positions and established the anatomical zero, the child was asked to keep looking at a target upon the wall at their level of vision for thirty seconds. Following that, they were told to close their eyes for another 30 seconds on a firm surface. After that, they were asked to repeat the process on a foam surface, switching between open and closed eyes for an additional thirty seconds²⁰.

Assessment of muscle strength

For the purpose of objectively assessing muscular strength, the Lafayette manual muscle testing Hand Held Dynamometer (HHD) (model 01163 USA) is utilized. The purpose of the test is to have a practitioner apply force on the patient's resistant limb. It gives consistent, repeatable readings of muscle strength that are consistent with the results of the majority of manual muscle testing protocols by recording the peak force as well as the time it takes to accomplish the break. Data storage, test duration, and force thresholds are just a few of the many customizable aspects of the HHD.

The Lafayette manual muscle testing device was used to assess the maximal isometric force (MIF) prior to and following the treatment period. Four sets of lower extremity muscles, including the flexors and abductors of the hips as well as the flexors and extensors of the knees, will be evaluated. An accommodative isometric "make" test was used to evaluate the MIF. In this test, children were asked to hold a constant stance while applying maximal force against the clinician. Using a gravity-neutralized stance, we evaluated each muscle group. Children completed three sets of five-second contractions for each muscle group after completing a minimum of one familiarization trial. Then thirty seconds of rest was done following each round of contractions along with five minutes between sets. For every muscle, we calculated the average force over all three trials. Throughout the assessment, the examiner reminded the children to do their best standardized methods was used to apply the testing postures as well as dynamometer placement¹³.

- The hip flexors were tested while the subject was lying supine on a testing table with their legs supported up by the researcher. On the front of the thigh, close to the knee joint, was where the dynamometer was positioned.
- The hip abductors were examined when the subjects were lying supine, with the leg that was being tested fully extended and 10 degrees abducted at the hip. The dynamometer was placed on the side of the shank close to the ankle joint.
- Knee extensors as well as flexors were tested while subjects are in a

sitting position with their hips and knees at 90° flexion. The dynamometer was placed on the front of the shank to measure the knee extensors and on the back of the shank to measure the knee flexors; it was placed above the ankle joint for both assessments.

Intervention

Children allocated to the Plyo-group were given the same medical treatment provided to the control group along with plyometric exercise. Table 1 shows the plyometric program that was designed with the assistance of the National Strength and Conditioning Association's standards for children strength training¹². Strengthening results from the following: (1) single and multipoint exercises incorporated together with concentric and eccentric contractions; (2) progressive resistance exercise sessions consisting of 1 to 3 sets of 6 to 15 repetitions; a training frequency of 3 times per week; (4) a duration of resistance training of at least 12 weeks; (5) a 5- to 10-minute warm-up period, and 1-minute rest intervals; (6) increasing strength gradually by 5% to 10% when the child performs the number of exercises more easily and using the correct form; and (7) participants should be at least 7 years of age, as well as the guidelines of the American Academy of Pediatrics and the American College of Sports Medicine. There was a 5-minute warming up of stretching as well as active range of motion exercises at the beginning of each session. Then, for 20-30 minutes, children did a set of ten plyometric exercises aimed at the lower body. Progression of exercise was done progressively by raising the number of sets and repetitions in two blocks, with each one lasting a month. Finally, there was a cooling down for 5 minutes, involving five minutes of walking at their regular speed and stretching the main muscle groups statically. Children are instructed to wear well cushioned sport shoes and comfort clothes, take from 1-2-minute rest between sets and if they fell any sign of fatigue (e.g. shortness of breath, headache, soreness, dizziness) stop the exercise and they followed the instructions and there was no adverse event occurred. The exercises were conducted as individualized training for more safety and close observation for any possible drawbacks (Table 1).

Statistical analysis

To compare the subject characteristics among the groups, an independent t-test was used. The distribution of sexes among the groups was compared using a chi-squared test. The data was examined for normal distribution utilizing the Shapiro-Wilk test. The homogeneity of variances among groups was tested using Levene's test. To compare the chemical profiles, strength, and balance measurements between groups, an independent t test. To compare each group's baseline and post-treatment data, we used a dependent test. A significance criterion of $p < 0.05$ was established for all statistical tests. For this study, we used SPSS 25 for Windows (IBM SPSS, Chicago, IL, USA) to perform all of our statistical analysis.

Results

Subject characteristics

Thirty-six children with CKD participated in the study. The characteristics of the subjects in both the control and Plyo groups are displayed in Table 2. Age, weight, height, body mass index, and gender distribution did not differ significantly ($p > 0.05$) across the groups (Table 2).

Table 1. Plyometric training program.

Exercise	Description	Repetitions in 1 st Mo.	Repetitions in 2 nd Mo.
Horizontal training paradigm			
Bounding	Exaggerated foot to foot forward movement	1set / 10 R	1set / 15 R
Forward jumping	Double-footed forward jump to maximum achievable distance preceded arm swing	1set / 5 R	1set / 10 R
Forward hopping	Hop forward as far as possible between marked points without pause in both directions	1set (5 RT and 5 LT) / 5 R	1set (5 RT and 5 LT) / 10 R
jumping	Double-footed side to side jump as far as possible	1set / 5 R	1set / 10 R
Lateral leaping	Stretch out one side and hop off the other in a lateral motion landing on one foot	1set / 5 R	1set / 10 R
Vertical training paradigm			
Stride jumping	From stride stance, interchangeably move each foot forward between jumps	1set / 5 R	1set / 10 R
Squat jumping	Squat down and spring upward as high as achievable	1set / 5 R	1set / 10 R
ck jumping	Jump high moving knees toward the chest	1set / 5 R	1set / 10 R
Step jumping	Stand behind a step, jump up onto and down a step and switch RT and LT feet.	1set / 10 RT and 10 LT	1set / 15 RT and 15 LT
Step hopping	While facing a step, hop up and down and switch RT and LT feet	1set / 10 RT and 10 LT	1set / 15 RT and 15 LT
- Children were instructed to perform consecutive repetitions without pausing and were encouraged to exert their maximum efforts during each exercise. - The number of repetitions in the 1st month was set based on observation of children's performance at the baseline. - Children were given 1-2 minutes' rest between exercises. - The standard step height is 5 inches. - Abbreviations: R, repetitions; RT, right; LT, left.			

Table 2. Comparison of subject characteristics between control and study groups.

	Control group	Plyo-group	t-value	p-value
	Mean $\pm$ SD	Mean $\pm$ SD		
Age (years)	8.44 $\pm$ 1.38	8.16 $\pm$ 1.09	0.66	0.5
Weight (kg)	26.72 $\pm$ 7.06	28.83 $\pm$ 9.36	-0.76	0.45
Height (cm)	118.66 $\pm$ 13.40	120.83 $\pm$ 11.92	-0.51	0.61
BMI (Kg/m ²)	18.74 $\pm$ 2.59	19.09 $\pm$ 3.97	-0.31	0.75
Sex, N (%)				
Girls	8 (45%)	6 (33%)	$\chi^2 = 0.46$	0.49
Boys	10 (55%)	12 (67%)		

SD, Standard deviation; χ^2 : Chi squared value; p value, Probability value

Treatment Compliance

The PLYO-group participants found the training tolerable, and were able to complete all of the exercises each session without experiencing any adverse effects. The PLYO-group showed compliance to treatment rate (i.e., the proportion of scheduled training sessions that participants actually attended out of the 24 over the sessions of 8-week period) ($p = 0.51$). For the PLYO-group it was 95.87% (92.36–100%).

Impact of treatment on chemical profile, strength and balance

Within group comparison

No significant difference was observed in chemical profile regarding Creatinine, GFR, Calcium and Phosphorus post treatment in both groups compared to that at baseline ($p > 0.05$) while a significant improvement was observed in haemoglobin post treatment in both groups compared to that baseline ($p < 0.05$; Table 3).

No significant difference was observed in strength regarding right and left side hip flexors, abductors, knee flexors and extensors in control group after treatment compared with baseline ($p > 0.05$) while a significant improvement was observed in right and left hip flexors, abductors, knee flexors and extensors in Plyo-group after treatment compared with pretreatment ($p < 0.01$; Table 4,5).

The control group's EOSS, ECSS, EOFS, ECFS, and COP did not differ significantly after treatment compared to baseline ($p > 0.001$), but the limit of stability increased significantly ($p < 0.01$) after treatment. After treatment, the Plyo-group showed significant improvements in EOSS, ECSS, EOFS, ECFS, limit of stability, as well as COP when compared to before treatment ($p < 0.05$). Table 6.

Between group comparison

No significant difference was noted in chemical profile among group post treatment ($p > 0.05$; Table 3).

A significant increase was noted in strength of right and left sides of hip flexors, abductors, knee flexors and extensors of Plyo-group compared to that of control group post treatment ($p < 0.01$). Tables 4,5.

After treatment, the Plyo-group's EOSS, ECSS, limit of stability, as well as COP were not significantly different from the control group's ($p > 0.05$). The post treatment EOFS as well as ECFS of the study group were significantly higher than those of the control group ($p < 0.01$). Table 6 (Table 3-6).

Discussion

This study was done to examine the potential benefits of plyometric exercises on muscle strength as well as balance in children suffering from CKD. The prescribed designed physical rehabilitation program and plyometric exercises training were appropriate and well tolerated by the study participants with no complain after performing the intervention. It appears to be the first attempt to assess the effectiveness of plyometric activities on children with CKD. As a result, it is challenging to compare the current outcome with those of other comparable studies. In addition to regular medical care, the study's key findings indicate that plyometric exercises three times a week may significantly enhance muscle strength and balance in children suffering from CKD. It is possible that the therapeutic effects of plyometric exercises are responsible for the improvements in muscular strength and balance seen in the Plyo-group. A number of researches have studied into how strengthening activities affect CKD patients. Since physical activity is thought to directly affect overall health, using planned, structured, repetitive, and tailored body movements can enhance mental and physical functioning in addition to quality of life (QOL).

The findings of the study by Koufaki et al.²² conducted on people with CKD, which shown beneficial benefits of exercise on both physical along with emotional elements of QOL and academic achievement, corroborate our

findings. However, there are a number of previous investigations that indicate the positive effects of lower limb plyometric exercises in children with multiple sclerosis²³, juvenile dermatomyositis¹³ unilateral CP^{11,12,15,17}, and healthy individuals²⁴. The findings of the current study on the effectiveness of plyometric training for children with multiple sclerosis, dermatomyositis, and unilateral CP were almost supported by the reported findings, which generally indicated that plyometric exercises performed for two months had positive impacts with notable enhancement in muscle power, functional performance, in addition to postural stability.

It has been found that plyometric exercises can help children with neuromuscular diseases improve their motor skills and increase their muscle strength, therefore these exercises have become increasingly popular in their rehabilitation. Performing plyometric exercises can increase neuromuscular efficiency as well as functional activities. This could be because these types of exercises activate a large number of motor units, restore functional movement patterns, and additionally enhance proprioceptive awareness^{12,13,25}.

The improvement of the co-contraction ratio and motor activation patterns between the agonist along with antagonist muscles, that influenced motor control approaches, is thought to be the cause of the substantial improvements in the outcome measures that were found following plyometric exercises. According to earlier research, plyometric workouts increase force production and improve muscular strength by inducing and activating higher motor units and reinforcing neuronal frequency^{11,13,17}.

Because of their nature, plyometric exercises have plausible mechanisms that can explain how they enhance lower limb muscle strength and balance. According to previous studies, these dynamic exercises include a short cycle of stretching and shortening that activates the stretch reflex, leading to increased afferent proprioceptive inputs, fast muscle contraction, and agonist-antagonist co-activation^{26,27}. Additionally, this form of training makes use of suitable biomechanics to swiftly shift the contraction phase of the muscle from eccentric towards concentric. Musculotendinous structures undergo a quick change in length and tension (mostly during the eccentric phase) due to desensitization of the Golgi tendon organs; this, in turn, increases the sensitivity of the muscle spindle, which in turn amplifies the force of muscular contraction^{12,14}.

Numerous researches have shown that strengthening activities are thought to improve muscular strength, endurance, mass, and cardiopulmonary efficiency in those with CKD. Other advantages include improved body image, social wellbeing, and confidence. It is thought that these factors, along with improved psychological well-being and physical functioning, improve physical activities along with QOL¹.

Likewise, 50 adult haemodialysis patients participated in a randomized pilot study by Chen et al.²⁸. According to their study's findings, strength training significantly increased muscular strength, recreational physical activity, self-reported physical function, in addition to daily living activities. They reported a notable improvement in both their physical fitness and quality of life. They came to the conclusion that including moderate resistance training into a daily therapy routine can help those with CKD.

Plyometric exercise is a resisting exercise it has been reported in previous studies that exercise provides many benefits for CKD patient like increase muscle mass, reduced cardiovascular risk and systemic inflammation and improve quality of life. Both aerobic and resisted exercise may confer systemic anti-inflammatory benefits in pre-dialysis children with CKD. This comes in consistence with the study conducted by Watson et al.²⁹. They investigated the effects of an 8-week progressive resistance training program on adults with stages 3b-4 CKD. They discovered notable gains in exercise capacity muscle volume and strength, and muscle anatomical cross-sectional area. Additionally, they said that this kind of exercise has significant therapeutic advantages and is well tolerated by CKD patients. Moreover, they concluded that, unaccustomed exercise creates a large inflammatory response within the muscle, which is no longer present following a period of training. This indicates that resistance

Table 3. Mean chemical profile pre and post treatment of the groups .

Chemical profile	Pre-treatment	Post-treatment	MD	% of change	t- value	p value
	Mean $\pm$ SD	Mean $\pm$ SD				
Creatinine (mg/dl).						
Control group	0.68 $\pm$ 0.31	0.67 $\pm$ 0.26	0.01	1.47	0.24	0.81
Study group	0.78 $\pm$ 0.57	0.76 $\pm$ 0.43	0.02	2.56	0.46	0.64
MD	-0.1	0.09				
t-value	-0.61	-0.69				
	p = 0.54	p = 0.49				
		d = 0.25				
GFR (ml/min)						
Control group	55.65 $\pm$ 17.81	61.67 $\pm$ 13.24	-6.02	10.81	-1.51	0.14
Study group	62.65 $\pm$ 20.04	59.00 $\pm$ 16.58	3.65	5.82	0.85	0.4
MD	-7	2.67				
t-value	-1.1	0.53				
	p = 0.27	p = 0.59				
		d = 0.18				
Calcium (mg/dl).						
Control group	9.90 $\pm$ 0.31	9.67 $\pm$ 0.53	0.23	2.32	1.64	0.11
Study group	9.99 $\pm$ 0.55	9.84 $\pm$ 0.49	0.15	1.5	0.79	0.43
MD	-0.09	-0.17				
t-value	-0.59	-1				
	p = 0.55	p = 0.32				
		d = 0.33				
Hemoglobin (g/dl)						
Control group	11.91 $\pm$ 0.90	12.08 $\pm$ 1.00	-0.17	1.42	-2.43	0.02
Study group	11.95 $\pm$ 0.94	12.35 $\pm$ 0.93	-0.4	3.34	-2.67	0.01
MD	-0.04	-0.27				
t-value	-0.14	-0.81				
	p = 0.88	p = 0.42				
		d = 0.28				
Phosphorus (mg/dl).						
Control group	4.84 $\pm$ 1.00	5.03 $\pm$ 1.08	-0.19	3.92	-1.51	0.14
Study group	4.73 $\pm$ 0.74	5.06 $\pm$ 1.09	-0.33	6.97	-0.97	0.34
MD	0.11	-0.03				
t-value	0.37	-0.07				
	p = 0.70	p = 0.94				
		d = 0.03				

SD, Standard deviation; MD, Mean difference; p value, Probability value; d, Effect size

exercise does not provoke a detrimental on-going inflammatory response within the muscle.

Additionally, Headley et al.³⁰ examined the effect of resistance training for 12 weeks on haemodialysis patients suffering from CKD. According to their findings, CKD patients' muscle wasting was slowed down and their strength, endurance, and exercise tolerance were improved.

Kajbafvala et al.³¹ conducted a systematic review and meta-analysis on the effect of exercise training on functional capacity, muscle strength, exercise capacity, dialysis efficacy and quality of life in children and adolescents with CKD. They concluded that, exercise training could benefit children and adolescents with CKD by increasing their strength. Longer exercise interventions may be beneficial for improving functional capacity and QOL. Future well-designed RCTs should overcome the existing limitations using adequate sample sizes and longer exercise durations.

The nature of the plyometric exercise led to displacement of the body's center-of-mass in different directions which presents balance challenges resulting in neuromuscular adaptations that reinforced balance abilities also contributed to enhanced balance by increasing the kinaesthetic awareness. The repeated stimulation of the mechanical receptors and rapid change in muscles' length and tension during training could have increased the proprioceptive feedback to the central nervous system, which is highly needed for promoting balance competencies. Additionally, performing Plyo training led to significant improvement in selective motor control (i.e., motor unit recruitment) and consequently muscle strength, which may have contributed to enhanced

balance capabilities. This come in consistence with our results regarding improved balance in the plyometric group¹⁵.

Results of this study showed significant improvement in muscle strength and balance for the study group. This comes in consistent with other studies found improvement in muscle strength and static and dynamic balance in youth with CP³².

According to another study, showed that participating in a community-based high intensity exercise program for 12 weeks despite a high missing rate can improve cardiorespiratory fitness and muscle strength among the Pediatric patients with end stage renal disease. Moreover, resistance training can increase muscle strength, muscle endurance and improves the capacity of O₂ carrying and following that, exercise tolerance in CKD³³.

The improvements recorded in balance can be attributed to the effect of the training exercises in the form of plyometric training which was conducted in progressive amount. This is supported by several studies which have demonstrated the positive effects of progressive resistance training in patients with CKD undergoing hemodialysis. Significant improvements were reported in physical fitness and quality of life after 12 weeks of training, suggesting its integration into routine care. Similarly, it was found that high-intensity resistance training during dialysis led to notable gains in muscle strength, attenuation, and cross-sectional area. Also there was observed improvements in strength, endurance, exercise tolerance, and a slowing of muscle wasting. Overall, strengthening exercises in CKD patients are shown to enhance muscle mass, endurance, cardiopulmonary efficiency, and physical strength, while

Table 4. Mean right side strength pre and post treatment of the study groups.

Strength (kg)	Pre treatment	Post treatment	MD	% of change	t- value	p value
	Mean $\pm$ SD	Mean $\pm$ SD				
Right hip flexors						
Control group	5.67 $\pm$ 1.23	5.99 $\pm$ 3.02	-0.32	5.64	-0.49	0.62
Study group	6.33 $\pm$ 1.41	8.77 $\pm$ 2.38	-2.44	38.54	-4.61	0.001
MD	-0.66	-2.78				
t-value	-1.49	-3.05				
	p = 0.14	p = 0.004				
		d = 1.02				
Right hip abductors						
Control group	4.16 $\pm$ 0.85	4.80 $\pm$ 2.16	0.64	15.38	-1.21	0.24
Study group	4.29 $\pm$ 1.24	7.11 $\pm$ 2.27	-2.82	65.73	-4.71	0.001
MD	-0.13	-2.31				
t-value	-0.37	-3.12				
	p = 0.71	p = 0.004				
		d = 1.04				
Right knee flexors						
Control group	5.02 $\pm$ 1.14	5.62 $\pm$ 1.02	-0.6	11.95	-1.58	0.13
Study group	5.57 $\pm$ 1.35	7.43 $\pm$ 1.77	-1.86	33.39	-5.06	0.001
MD	-0.55	-1.81				
t-value	-1.31	-3.74				
	p = 0.19	p = 0.001				
		d = 1.25				
Right knee extensors						
Control group	5.08 $\pm$ 0.90	5.35 $\pm$ 0.80	-0.27	5.31	-1.6	0.12
Study group	5.12 $\pm$ 1.22	7.63 $\pm$ 1.28	-2.51	49.02	-10.05	0.001
MD	-0.04	-2.28				
t-value	-0.09	-6.36				
	p = 0.92	p = 0.001				
		d = 2.14				

Table 5. Mean left strength pre and post treatment of control and study groups.

Strength (kg)	Pre treatment	Post treatment	MD	% of change	t- value	p value
	Mean $\pm$ SD	Mean $\pm$ SD				
Left hip flexors						
Control group	5.22 $\pm$ 1.11	6.06 $\pm$ 2.18	-0.84	16.09	-1.57	0.13
Study group	5.31 $\pm$ 1.11	8.80 $\pm$ 2.58	-3.49	65.72	-5.35	0.001
MD	-0.09	-2.74				
t-value	-0.24	-3.44				
	p = 0.81	p = 0.002				
		d = 1.15				
Left hip abductors						
Control group	4.38 $\pm$ 0.92	4.19 $\pm$ 1.06	0.19	4.33	1.42	0.17
Study group	4.90 $\pm$ 1.30	6.23 $\pm$ 1.46	-1.33	27.14	-3.11	0.006
MD	-0.52	-2.04				
t-value	-1.37	-4.79				
	p = 0.18	p = 0.001				
		d = 1.61				
Left knee flexors						
Control group	4.72 $\pm$ 0.84	5.15 $\pm$ 1.45	-0.43	9.11	-1.1	0.28
Study group	5.31 $\pm$ 1.35	6.72 $\pm$ 2.26	-1.41	26.55	-3.4	0.003
MD	-0.59	-1.57				
t-value	-1.54	-2.48				
	p = 0.13	p = 0.01				
		d = 0.83				
Left knee extensors						
Control group	5.01 $\pm$ 0.99	5.37 $\pm$ 1.93	-0.36	7.18	-0.95	0.35
Study group	5.41 $\pm$ 1.01	9.17 $\pm$ 2.45	-3.76	69.5	-6.34	0.001
MD	-0.4	-3.8				
t-value	-1.17	-5.16				
	p = 0.24	p = 0.001				
		d = 1.73				

Table 6. Mean balance pre and post treatment of control and study groups.

Balance	Pre treatment	Post treatment	MD	% of change	t- value	p value
	Mean $\pm$ SD	Mean $\pm$ SD				
EOSS						
Control group	85.38 $\pm$ 7.51	82.44 $\pm$ 8.59	2.94	3.44	1.56	0.13
Study group	84.22 $\pm$ 4.82	85.94 $\pm$ 5.26	-1.72	2.04	-2.64	0.01
MD	1.16	-3.5				
t-value	0.55	-1.47				
	p = 0.58	p = 0.15				
		d = 0.49				
ECSS						
Control group	79.22 $\pm$ 11.59	79.16 $\pm$ 13.04	0.06	0.07	0.01	0.98
Study group	77.05 $\pm$ 8.82	81.22 $\pm$ 9.51	-4.17	5.41	-2.23	0.03
MD	2.17	-2.06				
t-value	0.63	-0.54				
	p = 0.53	p = 0.59				
		d = 0.18				
EOFS						
Control group	75.61 $\pm$ 8.67	73.16 $\pm$ 5.80	2.45	3.24	1.14	2.66
Study group	75.33 $\pm$ 6.05	78.11 $\pm$ 5.58	-2.78	3.69	-2.68	0.01
MD	0.28	-4.95				
t-value	0.11	-2.6				
	p = 0.91	p = 0.01				
		d = 0.87				
ECFS						
Control group	62.44 $\pm$ 11.30	64.88 $\pm$ 8.96	-2.44	3.9	-0.91	0.37
Study group	60.22 $\pm$ 10.00	71.61 $\pm$ 7.00	-11.39	18.91	-4.01	0.001
MD	2.22	-6.73				
t-value	0.62	-2.5				
	p = 0.53	p = 0.01				
		d = 0.84				
Limit of stability						
Control group	29.44 $\pm$ 8.42	37.27 $\pm$ 8.39	-7.83	26.59	-3.74	0.002
Study group	28.27 $\pm$ 7.97	41.27 $\pm$ 7.94	-13	45.98	-6.75	0.001
MD	1.17	-4				
t-value	0.42	-1.46				
	p = 0.67	p = 0.15				
		d = 0.49				
COP						
Control group	82.27 $\pm$ 8.72	84.55 $\pm$ 9.41	-2.28	2.77	-0.85	0.4
Study group	79.33 $\pm$ 7.44	87.66 $\pm$ 5.74	-8.33	10.5	-5.91	0.001
MD	2.94	-3.11				
t-value	1.08	-1.19				
	p = 0.28	p = 0.24				
		d = 0.40				

SD, Standard deviation MD, Mean difference p-value, Probability value; d, Effect size

EOSS, eyes open stable surface EOFS, eyes open foam surface

ECSS, eyes closed stable surface (ECSS) ECFS, eyes closed foam surface

COP, center of pressure test

also boosting confidence, social well-being, body image, and psychological health—contributing to improved physical activity and QoL^{1,28-30, 34}.

Strengths and limitations

This study has a number of advantages. This is the first randomized controlled trial to examine the effect of strength and conditioning training on functional performance in children with stage 2 and 3 of CKD. The findings indicate that plyometric exercise is a type of strength and conditioning training non-invasive method that can improve muscle strength and balance in children with chronic kidney disease.

The study also has some limitations. Firstly, the sample was rather small, and is restricted to a particular age range and stage 2 and 3 of CKD; as such, it may

not accurately reflect the general population with CKD. Furthermore, the brief follow-up period might not adequately reflect the long-term impact of therapy. Therefore, we recommend carrying out additional research with larger sample sizes and a wider range of age groups. Also, we recommend further research to compare the effect of plyometric exercise between boys and girls.

Conclusions

Plyometric exercises are an efficient therapeutic approach for enhancing strength as well as balance in children suffering from with CKD. It is recommended that physical therapists and other health professionals should consider the effect of implementing plyometric exercises for rehabilitation program for children with CKD. However, this type of exercises should be conducted according to individual's abilities and must be introduced

progressively while monitoring the child's response to the exercises.

Recommendations

Rigorous studies are necessary to assess the impact of the proposed program across various age groups, children with End Stage Renal Disease ESRD, those undergoing hemodialysis or peritoneal dialysis, and children who have received kidney transplants. Subsequent studies are advised to examine whether the program can produce additional enhancements in QoL and functional capacity as well as other medical and psychological benefits. Finally, it is recommended to compare the effect of plyometric exercises compared with other types of exercise training.

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