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Interval Versus Continuous Intradialytic Training on Muscle Quality Index and Functional Capacity in Hemodialysis Patients: a Prospective Randomized Clinical Study

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ABSTRACT

INTRODUCTION. Chronic kidney disease (CKD) is an important health well-being problem globally, with increasing incidence. That tends to create an "epidemic". Generalized muscle weakness in hemodialysis patients typically affects the lower limbs and proximal muscles. Patients experience impaired endurance and quality of life. Exercise is prescribed for these individuals to improve their physical health and prevent disease consequences.

AIM. To find out the effect of interval versus continuous intradialytic training on muscle quality index and functional capacity in Hemodialysis patients.

MATERIALS AND METHODS. Sixty men with chronic renal insufficiency grade 5 on hemodialysis aged from 45 to 55 years were divided into two groups using computerized block randomization: Groups (A) and (B) each containing 30 patients. They underwent 8-week program of high intensity interval training (HIIT), moderate intensity continuous training (MICT) intradialytic pedaling exercise plus hemodialysis three times per week. Pre-test and post-test evaluations have been carried out for 6-minute walk test (6MWT) and muscle quality index (MQI) of all patients.

RESULTS. Both groups had a significant positive improvement in MQI and 6MWT with different proportions, patients received high intensity interval intradialytic pedaling exercise had a slightly significant improvement in MQI compared to moderate intensity continuous training group. While, moderate intensity training group had a more significant improvement in 6MWT compared to high intensity training group.

CONCLUSION. Both HIIT and MICT are realistic and good options for individuals with CKD and have parallel profits on functional capability and, skeletal muscle quality and overall quality of life.

KEYWORDS: hemodialysis, intradialytic training, muscle quality index, 6MWT.

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Сравнение влияния интервальных и непрерывных физических тренировок на индекс качества мышц и функциональную способность у пациентов, находящихся на гемодиализе. Проспективное рандомизированное клиническое исследование

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РЕЗЮМЕ

ВВЕДЕНИЕ. Хроническая болезнь почек (ХБП) является важной проблемой здравоохранения во всем мире, заболеваемость которой растет. Это приводит к возникновению «эпидемии». Общая мышечная слабость у пациентов, находящихся на гемодиализе, обычно поражает нижние конечности и проксимальные мышцы. Пациенты испытывают снижение физической выносливости и качества жизни. Этим людям назначаются физические упражнения для улучшения их физического здоровья и предотвращения последствий заболеваний.

ЦЕЛЬ. Определить влияние интервальных и непрерывных физических тренировок на индекс качества мышц и функциональную способность у пациентов, находящихся на гемодиализе.

МАТЕРИАЛЫ И МЕТОДЫ. 60 мужчин с хронической почечной недостаточностью 5-й степени, находящихся на гемодиализе, в возрасте от 45 до 55 лет были разделены на две группы с использованием компьютерной блочной рандомизации: в группы (А) и (Б) вошли по 30 пациентов в каждой. Они прошли 8-недельную программу высокоинтенсивных интервальных тренировок (ВИИТ), непрерывных тренировок с вращением педалей средней интенсивности, а также гемодиализ три раза в неделю. Всем пациентам была проведена предварительная и последующая оценка теста на 6-минутную ходьбу (6ТШХ) и индекса качества мышц (ИКМ).

РЕЗУЛЬТАТЫ. В обеих группах наблюдалось значительное положительное улучшение показателей ИКМ и 6ТШХ с различными пропорциями, у пациентов, получавших ВИИТ с вращением педалей, наблюдалось незначительное улучшение показателей ИКМ по сравнению с группой непрерывных тренировок средней интенсивности. В группе тренировок средней интенсивности наблюдалось более значительное улучшение в 6ТШХ по сравнению с группой тренировок высокой интенсивности.

ЗАКЛЮЧЕНИЕ. Как ВИИТ, так и тренировки средней интенсивности являются практически применимыми хорошими вариантами для людей с ХБП и параллельно улучшают функциональные возможности, качество скелетных мышц и общее качество жизни.

КЛЮЧЕВЫЕ СЛОВА: гемодиализ, тренировка для диализных пациентов, индекс качества мышц, 6ТШХ.

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INTRODUCTION

Chronic kidney disease (CKD) is characterized by persistent renal impairment, loss of kidney function, or both and can progress from early stages to more severe phases, necessitating renal replacement therapy. Despite considerable advances in prevention, diagnosis, and management, CKD remains a serious public health issue. The estimated global incidence of CKD is approximately 5–10 %, posing a high burden on patients with CKD-related disorders, primarily attributed to cardiovascular morbidity and mortality [1]. Moreover, CKD patients (pre-dialysis and end-stage renal diseases) may be more vulnerable to sarcopenia due to impairments in physical functioning, skeletal muscle mass, and performance [2].

Reduced kidney function leads to uremic solute retention, causing skeletal muscle failure by contributing to inflammatory disorders, oxidative stress, and insulin resistance. Kidney disease symptoms involve inflammation and catabolism, which diminish muscle power, physical performance, and health. Untreated skeletal muscle weakness may cause mobility limitation, loss of independence in daily life, and a higher susceptibility to significant sickness effects [3]. Hemodialysis (HD) stimulates protein and muscle breakdown all over the body. Lower limbs and proximal muscles are more commonly affected by generalized muscular weakness in these patients [4]. Muscle strength, size, oxygen extraction ability, and functional capacity have all been found to have strong positive associations in patients on HD, demonstrating that muscle loss also reduces physical functionality. Consequently, muscular atrophy detrimentally influences the quality of life (QOL) [5].

Mortality in patients on HD is considerably influenced by lower limb muscle strength. According to Matsuzawa R. et al. [6], patients with significantly reduced lower limb muscle power (≤ 40 %) had a 2.7-fold higher risk of dying than those with significantly higher lower limb muscle power

(≥ 40 %). Muscle Quality Index (MQI) is a technique used to quantify lower limb muscular power via anthropometric processes and time of sit-to-stand test. Low MQI is associated with poor physical performance and muscular strength [7]. A power index expressed in Watts (W) was calculated with MQI using a five times sit-to-stand (FTSTS) test, body mass, and leg length. The formula used to calculate the MQI [8] is as follows:

$$\text{MQI (Watts)} = \frac{((\text{Leg length} \times 0.4) \times \text{Body mass} \times \text{gravity} \times 10)}{\text{Time sit-to-stand.}}$$

This index considers the length of the limb (measurement between the lateral malleolus and the greater trochanter of the femur) in meters, the height of the chair during the sit-to-stand test (0.4 m), body mass in kilograms, acceleration due to gravity (9.81 m/ s2) and a constant of 10.

Physical exercise is a key therapeutic intervention in CKD patients as it can lower cardiovascular risk, improve cardiorespiratory, metabolic, neuromuscular, and cognitive functions, enhance physical function by increasing muscular soft tissue, and reduce the risk of functional loss, thereby improving QOL [9]. Physical exercise can increase lower limb strength, muscular growth, power, and motor function. Lower limb training improves endurance, muscular strength (isometric/isokinetic), lower limb fat-free mass, and exercise performance. This enhances functionality in FTSTS and three-min walk distance tests [10].

Aerobic exercise enhances cardiovascular health, muscular power, and everyday activities. Interval aerobic activity reverses muscle loss and enhances strength, endurance, motor performance, and subjective sensations of pain and tiredness in individuals with muscle wasting. Regular physical activity increases muscle fibers, mitochondria, and capillaries in patients on HD, preventing or curing muscle atrophy [11].

This study was conducted to determine the effect of high-intensity interval training (HIIT) versus moderate-intensity continuous training (MICT) intradialytic pedaling exercise on MQI and functional capacity in patients on HD.

AIM

To find out the effect of interval versus continuous intradialytic training on muscle quality index and functional capacity in Hemodialysis patients.

MATERIALS AND METHODS

Materials

The study enrolled 60 male renal failure patients on HD for around 1–3 years, aged 45–55 years, with a body mass index (BMI) of 25–34.9 kg/m2 from the National Institute of Urology and Nephrology's Hemodialysis unit. The training program was conducted from December 2022 to October 2023. The participants were directed by a physician and randomly allocated to two equal groups (n = 30) using computerized block randomization for an eight-week program, three sessions/week during the first two hours of the HD session, including group A: patients received aerobic exercise of HIIT intradialytic pedaling and group B: patients received aerobic exercise of MICT intradialytic pedaling. All the participants were medically and psychologically stable, receiving their pharmacotherapy regularly, and signed informed consent forms before the beginning of the study.

Participants were excluded when they had dementia or speech issues, dysphasia, unstable coronary artery disease, uncontrolled irregular heartbeats, decompensated cardiac failure, elevated systolic or diastolic blood pressure (BP), severe case of pericarditis or myocarditis, serious infectious disease, malignancy, diabetes mellitus, lupus nephritis, chronic obstructive lung disease, restrictive lung disease or chronic chest infection, severe obesity (BMI > 35), chronic inflammatory orthopedic disorders, rheumatoid arthritis, muscle injuries, or neuromuscular disorders (muscular dystrophy, myasthenia gravis, myopathy, multiple sclerosis, and peripheral neuropathy).

Methods

Evaluative tools

- A pulse oximeter (MD300C29 SpO2 Simulator, China) was employed to determine oxygen saturation plus resting heart rate (RHR) for each patient before the session to calculate both the training heart rate (THR) per the Karvonen formula [12] THR = RHR + (HRmax – RHR) × % Intensity and maximum heart rate (HR max) using HRmax = 220 – Age [13].
- An electrical sphygmomanometer (BM26, No 652.28, Germany) was used to record the blood pressure before and after each therapy session.
- A standard scale (floor type, RGT-200, China) was utilized to measure body mass and height for computing the BMI (kg/m2) for all participants to meet inclusion criteria.
- The MQI measures muscle power and function using non-stretch anthropometric tape to measure leg length and a stopwatch to measure sit-to-stand time.
- A six-minute walk test (6MWT) assessed physical functional capacity (using a stopwatch and colored tape to mark the start and end lines of the corridor).

Intervention

A mini pedal exercise bike (TB-228, China) was used for intradialytic aerobic training. Group A performed leg cycling exercises in a high-intensity semi-recumbent position. The training session consists of three phases for 30 min, involving a 5-min warm-up phase (in the form of lower limb active exercise to increase heart rate and gradually prepare the skeletal muscles temperature and flexibility for the training phase), 20–30 min active training phase of three workout intervals lasting 3 min at an exercise force of 85–95 % of MHR equaling 15–17 on the Borg Rating of Perceived Exertion (RPE) measure. Each interval was divided by 4 min of active pauses at the force of 60–70 % of MHR and a 5-min cooling down phase (in the form of lower limbs active exercise, which helps heart rate to return to normal slowly and to get blood circulation freely back to the heart). Group B performed leg cycling exercises in a semi-recumbent position with moderate intensity. The session consisted of three phases for 30 min, involved a 5-min warm-up phase of lower limbs active exercise, a 20–30 min active training phase of pedaling at low-to-moderate exercise force of 50–60 % of MHR, the intensity was controlled using Borg scale representing 11–13 on it and a 5-min cooling down phase of lower limbs active exercise.

Statistical analysis

Data was analyzed using the SPSS Package software for Windows version 25 (SPSS, Inc., Chicago, IL). The quantitative data for clinical general features, MQI, and 6MWT are presented as the mean and standard deviation. Independent t-test was used to compare the clinical general characteristics parameters of patients in both groups. The MANOVA was utilized to contrast the tested primary variables of concern (MQI and 6MWT) across the tested classes and measuring times. The first independent factor (between subject parameters) was the tested group with two levels (high vs. moderate intensity) in a mixed design 2 × 2 MANOVA test. The second independent parameter (within the subject factor) measured time intervals with two distinct phases (pre- and post-treatment). The Bonferroni correction testing assessed pairwise within and among groups of the studied variables whose F was significant as determined by the MANOVA test. All statistical tests were significant at the 0.05 level of probability.

RESULTS

The patients clinical general demographic records (Table 1 and Figure 1) revealed that insignificant changes ($p > 0.05$) existed in age ($p = 0.823$), body mass ($p = 0.058$), BMI ($p = 0.814$), and dialysis duration ($p = 0.547$) between high and moderate intensity groups.

Table 1. Patient clinical general characteristics between groups

Items	Groups		p-value
	High-intensity group ($n = 30$)	Moderate intensity group ($n = 30$)	
Age, year	50.00 ± 2.91	49.83 ± 2.82	0.823
Body mass, kg	76.96 ±7.22	74.85 ± 7.78	0.058
BMI, kg/m^2	27.96 ± 1.34	27.08 ± 1.61	0.814
Duration of dialysis, years	2.11 ± 0.77	2.00 ± 0.71	0.547

Note: *Data are reported as mean ± standard deviation and compared by t-independent test. Qualitative data (gender) are expressed as numbers (percentage) and compared by the chi-square test. p-value: probability value and NS: non-significant.*

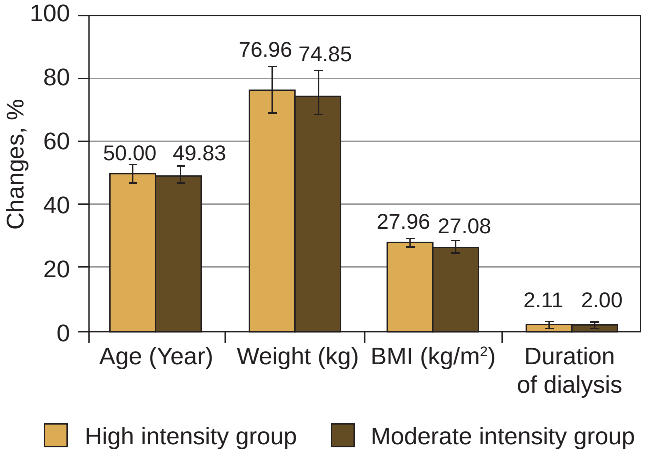

Fig. 1. Patient clinical general characteristics in both groups

Statistical multiple pairwise comparison tests (time effect) for 6MWT and MQI variables within each group revealed that 6MWT (Table 2 and Figure 2) was significantly increased ($p > 0.05$) after treatment compared with before treatment within the high- ($p = 0.003$) and moderate-intensity groups ($p = 0.001$). The 6MWT improvement percentage was more favorable for the moderate-intensity group (74.47 % and 22.02 %) than the high-intensity group (65.10 % and 17.63 %). The MQI (Table 2 and Figure 3) significantly ($p < 0.05$) increased after treatment compared with before treatment within the high- ($p = 0.0001$) and moderate-intensity groups ($p = 0.0001$). The MQI improvement percentage was more favorable for the high-intensity group (8148.21 % and 66.95 %) than the moderate-intensity group (7546.70 % and 65.14 %).

Numerous pairwise comparison examinations (group effect) for 6MWT and MQI variables between both groups (Table 2) indicated insignificant differences ($p > 0.05$) before and after treatment for 6MWT ($p = 0.151$ and $p = 0.315$, respectively) and MQI ($p = 0.692$ and 0.422, respectively).

Statistical significance and effect size should be employed together. Our results were statistically significant; therefore, we assessed the effect size to determine whether it was practically important. The effect sizes within each group (Table 2) showed that both high- and moderate-intensity groups had large effect sizes on 6MWT and MQI from pre-treatment to after-treatment.

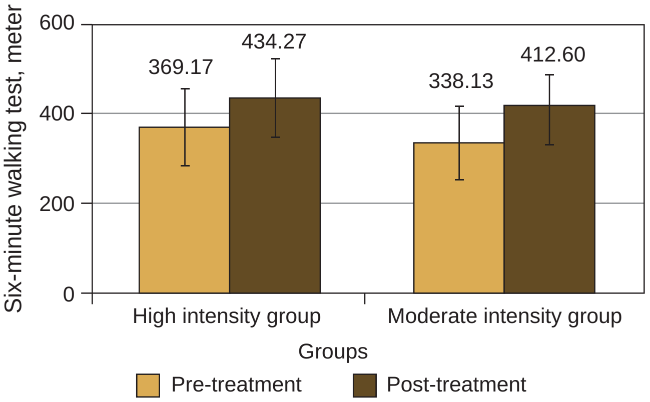

Fig. 2. Mean values of 6MWT at pre- and post-training in both groups

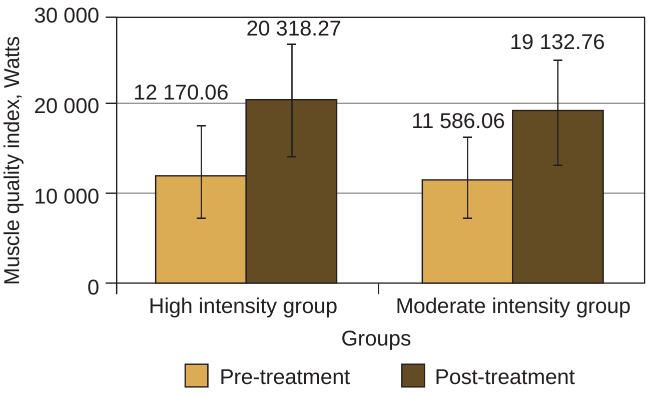

Fig. 3. Mean values of MQI at pre- and post-training in both groups

Discussion

This study was conducted to determine the influence of intradialytic HIIT versus MICT on MQI and 6MWT in HD patients.

Table 2. Mixed MANOVA within and between Groups comparison for 6MWT and MQI

Variables	Items	Groups (Mean ± SD)		Change	*p*-value
		High-intensity group (*n* = 30)	Moderate-intensity group (*n* = 30)		
6MWT (Meter)	Pre-treatment	369.17 ± 84.02	338.13 ± 83.04	31.04	0.151
	Post-treatment	434.27 ± 86.46	412.60 ± 79.20	21.67	0.315
	Change (MD)	65.10	74.47	—	—
	Improvement, %	17.63 %	22.02 %	—	—
	95 % CI	22.53–107.66	31.90–117.02	—	—
	Effect size	0.82	0.94	—	—
	p-value	0.003*	0.001*	—	—
MQI (Watts)	Pre-treatment	12170.06 ± 5295.75	11586.06 ± 4417.29	584.00	0.692
	Post-treatment	20318.27 ± 6620.60	19132.76 ± 6209.68	11185.51	0.422
	Change (MD)	8148.21	7546.70	—	—
	Improvement, %	66.95 %	65.14 %	—	—
	95 % CI	5233.36–11063.05	4631.85–10461.54	—	—
	Effect size	0.92	0.85	—	—
	p-value	0.0001*	0.0001*	—	—

The 6MWT is more appropriate in the clinical setting to assess physical fitness in subjects with low functional capacity, such as End Stage Renal Diseases (ESRD) patients. The significant increase in distance walking is of fundamental interest because walking capacity is considered a better indicator than physiological exercise capacity, as it assesses capability and fitness and reflects the ability to perform activities of daily life [14]. Our outcomes revealed that both groups had significantly improved 6MWT with different proportions, as the moderate-intensity exercise group had a more significant effect than the high-intensity exercise group, with improvement percentages of 22.02 % and 17.63 %, respectively. These results are supported by several meta-analyses and systematic reviews by Young H.M. et al. [15], who indicated significant increases in physical performance and aerobic fitness (6MWT and gait acceleration) after three-six months of several intensities of intradialytic biking aerobic training.

Consistent with the meta-analysis of Song Y. et al. [16], moderate intensity was the most effective in improving 6MWT. This could reflect the ability to perform daily activities and enhance global exercise responses.

This result coincided with Yeh M.L. et al. [17], demonstrating that moderate-intensity intradialytic cycling exercise increased the 6MWT by 49 m at week 12. The longer the exercise period, the higher the physical functional performance improves as the exercise increases muscle fiber protein synthesis and reduces muscle protein breakdown, thereby increasing physical functional performance.

In addition, Manfredini F. et al. [18] proved that individuals who engaged in light to moderate-intensity exercise for 20 min three times per week had an increase in 6MWT distance and a decrease in time required to complete the 5FSTS testing to half. These improvements were explained by neural adjustments, which better increased muscular power by enhancing the recruitment of motor neurons and skeletal muscle fibers and diminishing co-activation.

Our results coincided with Bae Y.H. et al. [19], who demonstrated that the overall distance taken in the 6MWT and preservation of skeletal muscle mass was significantly increased at the end of an aerobic moderate-intensity intradialytic activity plan for 30 min three times per week for twelve weeks.

Consistent with Henrique D.M. et al. [20], the moderate intensity intradialytic cycling exercise contributes to the improvement of 6MWT and physical capacity due to the significant increase in 6MWT distance of 509 ± 91.9 m in the pre-exercise to 555 ± 105.8 m at the end of exercise corresponding to an increase of about 10 %.

Despite a study by Nilsson B.B. et al. [21], who proved that HIIT improves 6MWT results and functional capacity in patients on HD, they cannot conclude whether HIIT is superior to MICT due to the small sample size.

Although Rouchon M.I. et al. [22], who were the first to demonstrate that a three-month HIIT program is effective in patients on peritoneal dialysis to improve 6MWT and physical functioning and could be proposed as an alternative to the classical MICT, they recommend studying its effect in patients on HD.

Concerning MQI outcomes, we revealed that both groups significantly improved but with different proportions. The high intensity exercise group positively affected MQI more than the moderate intensity exercise group, with improvement percentages (66.95 % and 65.14 %) respectively.

This is inconsistent with Beetham K.S. et al. [23], whose pilot study demonstrated that HIIT is a feasible and safe option for CKD patients. They exist similar benefits of HIIT and MICT on exercise capacity and skeletal muscle protein synthesis, and recommend a larger trial to evaluate the effectiveness of HIIT further.

Besides, our results are supported by Larsen S. et al. [24], showing that HIIT positively enhances skeletal muscle oxidative capacity after six weeks of aerobic cycling exercise. This was explained by increased VO2peak, mitochondrial content, and mitochondrial oxidative phosphorylation (OXPHOS) capacity in skeletal muscle.

Li J. et al. [25] conclude that HIIT leads to more significant improvements in skeletal muscle metabolic adaptations, cardiorespiratory fitness, vascular function, and body composition than MICT and is more time efficient. Within skeletal muscle, HIIT is associated with great adaptations in mitochondrial biogenesis and angiogenesis in a muscle fiber type-specific manner. Moreover, it provides physiological stimuli for mitochondrial biogenesis, which reduces glycogen use and lactate production, increases the lactate threshold, and allows individuals to exercise longer at a given intensity.

The result came in coincidence with Storer T.W. et al. [26], indicating that nine weeks of intradialytic high-intensity leg-cycling three times per week improves cardiopulmonary fitness and endurance and lowers extremity muscle strength, power, fatigability, and physical function compared with decrease in the untrained group. The marked muscle weakness of patients on HD might explain this. Accordingly, aerobic exercise training may provide adequate resistance to improve muscle function in patients on HD.

A 24-week clinical research conducted by Liu Q. et al. [27] on the muscle atrophy population demonstrated that high-intensity interval aerobic activity enhances muscular strength and motor abilities in these subjects. By regulating the development of Forkhead box proteins class O (FOXO3a) and its subsequent goals, aerobics optimizes AMPK and skeletal muscle degeneration by lowering the rate of the protein breakdown system and encouraging the regaining of muscle loss.

Moreover, Fyfe J.J. et al. [28] stated that HIIT has comprehensive effects on exercise capacity and skeletal muscle metabolism as it induces significant growth of muscle, prevents skeletal muscle atrophy, and improves motor function via promoting significant phosphorylation of mTOR and rps6 and induces the expression of transcriptional co-activator peroxisome proliferator-activated receptor γ co-activator 1α (PGC-1α), which is crucial for mitochondrial biogenesis.

Results coincide with Caparrós-Manosalva C. et al. [29], who showed that 12 weeks of HIIT promotes increased lean mass, maximal strength, and lower limb muscle power.

Conversely, Ballesta-Garcia I. et al. [30] assessed functional lower extremity muscle power using the 30-second STS test and discovered that HIIT was inferior to MICT regarding performance improvement.

CONCLUSION

Our results revealed that intradialytic aerobic cycling exercise implementation is vital for patients on HD since it increases muscle power and improves the ability to complete the 6MWT. Therefore, these exercises significantly affect both physical function and muscle loss in patients on HD.

ADDITIONAL INFORMATION

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Author Contributions. All authors confirm their authorship according to the international ICMJE criteria (all authors contributed significantly to the conception, study design and preparation of the article, read and approved the final version before publication). Special contributions: Mansour H.S. and Ezz Eldeen H.M. — development of the study design; Mansour H.S., Ahmed T.F., Sharabash A.M. — data collection; Elnahas N.G., Ezz Eldeen H.M. and Mansour H.S. — data interpretation; Mansour H.S. — writing; Elnahas N.G., Ezz Eldeen H.M., Ahmed T.F., Mansour H.S. and Sharabash A.M. — supervision.

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Ethics Approval. The authors declare that all procedures used in this article are in accordance with the ethical standards of the institutions that conducted the study and are consistent with the 2013 Declaration of Helsinki. Study was approved by the Ethics Committee of faculty of physical therapy Cairo University, Egypt, Protocol No P.T.REC/012/004299 dated December 11, 2022.

Data Access Statement. The data that support the findings of this study are available on reasonable request from the corresponding author.

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