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Virtual reality-based exercises' effects on pulmonary functions, cardiopulmonary capacity, functional performance, and quality of life in children with repaired congenital diaphragmatic hernia

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Abstract. – OBJECTIVE: The long-term consequences of congenital diaphragmatic hernia (CDH), which include altered lung functions and compromised cardiopulmonary capacity, impact functional performance and quality of life. This study investigates the effects of virtual reality-based exercise programs on pulmonary functions, cardiopulmonary capacity, functional performance, and quality of life in children with repaired CDH.

PATIENTS AND METHODS: A randomized controlled clinical trial was performed. Fifty-two children with repaired CDH (aged 6-10 years) were enrolled and randomly allocated to virtual reality-based exercises plus traditional physical therapy (VR-EX group, n = 26) or traditional physical therapy alone (control group, n = 26). Interventions were conducted three times a week for 12 weeks. Pulmonary functions, cardiopulmonary capacity, functional performance, and quality of life were assessed before and after the intervention.

RESULTS: The VR-EX group demonstrated significantly enhanced post-treatment pulmonary functions and cardiopulmonary capacity compared to the control group after accounting for the pre-treatment values ($p < 0.05$). In addition, the values in functional performance and quality of life measures showed significantly larger improvements in the VR-EX group ($p < 0.05$).

CONCLUSIONS: Children with repaired CDH may benefit more from VR-based exercises when combined with traditional physical therapy than from traditional physical therapy alone regarding their pulmonary functions, cardiopulmonary capacity, functional performance, and quality of life.

Key Words:
Cardiopulmonary capacity, Diaphragmatic hernia, Functional performance, Pulmonary functions, Quality of life, Virtual reality-based exercises.

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Introduction

Congenital diaphragmatic hernia (CDH) is a condition where the diaphragm is defective, causing the abdominal contents to protrude into the thoracic cavity and preventing the lungs from developing normally[1]. A high mortality rate for CDH was seen[2] as a result of pulmonary hypoplasia and associated malformations. Although the breakthroughs in medical and surgical interventions have improved the prognosis, survival rates still hover around 60-70%[3]. CDH survivors frequently present with pulmonary hypertension, impaired lung functions, and signs of obstructive airway disease, with decreased forced expiratory volume in 1 second (FEV_1), and decreased forced vital capacity (FVC)[4,5].

Later in life, in children with CDH, these pulmonary abnormalities may lead to a reduction in cardiopulmonary capacity. According to Gischler et al[6], children with CDH show a disruption at their maximum exercise tolerance. Also, Bojanić et al[7] reported that children with CDH continue to live with chronic lung issues and exhibit lower cardiorespiratory fitness than their healthy counterparts. Consequently, there is a chance that functional performance and physical ability will decline in these children due to decreased cardiopulmonary fitness and physical activity levels[8].

Children with CDH have significant disturbances in their quality of life (QoL) due to their poor health. According to Peetsold et al[9], CDH survivors had poorer overall health than their normal counterparts and also had below-average levels of physical and psychosocial functioning dimensions. The health-related QoL of children with CDH was also studied by Michel et al[10], who discovered that ratings of all QoL dimensions in CDH children were considerably lower than those of their normal peers, with the social domain receiving the lowest values.

Several treatment modalities are used to manage breathing and pulmonary problems in CDH survivors, like inspiratory muscle training[11], and traditional chest physical therapy[12]. One of the recent techniques used to optimize pulmonary function and exercise capacity is Virtual Reality (VR). VR-based exercises are a novel alternative style of therapy that is applied in many rehabilitation fields. The VR-based exercises have been shown[13,14] to be effective, motivating, enjoyable, and clinically valuable strategies for reducing respiratory distress symptoms, enhancing cardiopulmonary capacity, and increasing physical fitness in the rehabilitation of patients with chronic pulmonary disorders.

To the best of our knowledge, numerous studies have been conducted on the role of VR-based exercises for a variety of respiratory conditions, such as bronchial asthma and chronic obstructive pulmonary disorders, however, this study represents the first work to determine whether the combination of the VR-based exercises with chest physical therapy provide benefits over chest physiotherapy alone for enhancing pulmonary functions, cardiopulmonary capacity, functional performance, and health-related quality of life (HRQoL) in children with surgically repaired CDH after 12 weeks months.

Patients and Methods

Study Design

This was a randomized controlled clinical trial carried out between January 2021 and September 2021 at the Physiotherapy Outpatient Clinic, College of Applied Medical Science, Prince Sattam bin Abdulaziz University (PSAU). Ethical approval has been obtained from the Ethics Committee at the Physical Therapy Department (No.: RHPT/2021/0074). The study was registered at ClinicalTrials.gov (ID: NCT05612503). All procedures were in agreement with the ethical standards of the 1964 Declaration of Helsinki. Parents/guardians of the children were asked to sign a consent form before the start of the study.

Participants

This study included 52 children with surgically repaired CDH of both sexes. The participants were recruited from Maternity and Child Hospital and King Khalid Hospital, Al-Kharj, Saudi Arabia. The inclusion criteria were: age between 6 and 10 years, BMI between 20 and 24 kg/m^2, surgically-repaired CDH, respiratory distress symptoms, and follow-up care in the pediatric and physical therapy clinic. Children were excluded if they had atypical growth, neuromotor disorders, unable to understand the procedures or children with cardiac problems.

Allocation, Randomization, and Blinding

Fifty-two eligible participants were randomly assigned by an independent researcher into two groups of equal size after the baseline assessment: the VR-based exercises in addition to tra-

ditional physical therapy (VR-EX group, n = 26) and the traditional chest physical therapy alone (control group, n=26). To assign each participant to the VR-EX or control group, a simple randomization procedure was performed, where sealed, opaque envelopes bearing codes for several research groups were drawn.

Power Analysis and Sample Size

The G-power program (version 3.1.9.2, Dusseldorf, Germany) was used for a preliminary power analysis to determine the optimal sample size. Based on estimates of peak VO_2 means (M1 = 39.5 mL/kg/min and M2 = 35.2 mL/kg/min) and common standard deviation (SD = 4.26 mL/kg/min), gathered from a pilot study, a group sample of 22 children (i.e., a total sample of 44 children) was needed to achieve 90.87% power to reject the null hypothesis of equal means with a significance level of 0.05 using an independent *t*-test. The sample size was expanded to 52 children (26 per group) to adjust for the potential dropouts.

Primary Outcome Measures

Pulmonary function

A pulmonary function test was conducted for all participants using a spirometry analyzer (Autospiro-507; Minato Medical Science; Osaka, Japan), to measure forced vital capacity (FVC), Forced expiratory volume in 1 second (FEV_1), and the FEV_1/FVC ratio. First, each child was in a standing position and asked to inspire and expire normally many times with their lips closed firmly on the mouthpiece, and a soft caliper on the nose. Then the child was asked to inspire slowly and deeply and, after that, expire strongly. Data were collected from three trials and the highest value was recorded, which accords with the American Thoracic Society/European Respiratory Society (AST/ERS) recommendations for pulmonary function report[15].

Cardiopulmonary capacity

The cardiopulmonary capacity was assessed using the Bruce treadmill test under the same conditions. A demonstration session was given to all participants and their caregivers to familiarize themselves with the test procedures. The treadmill speed and incline were both set to the children's preferences to start the test. Based on the children's capabilities, the speed was increased until it reached the maximum brisk walking. After that, the inclination was steadily raised by 1% every minute while maintaining the same speed. A portable gas analyzer (Cosmed K4b^2, COSMED Srl, Rome, Italy) was used to continually collect and analyze expired gases breath by breath. Heart rate and oxygen saturation were continuously monitored throughout the test using a heart rate monitor and pulse oximetry, respectively. Children were verbally encouraged to continue till the point of fatigue. When participants indicated fatigue and were unable to continue despite verbal encouragement the test was terminated. For the purpose of this study, the maximal oxygen uptake (VO_2max) and the ratio of minute ventilation (VE) to carbon dioxide production (VCO_2) were recorded[16,17].

Secondary Outcome Measures

Functional performance assessment

Functional performance was assessed using the 6-min walk test (6-MWT). Which is considered as a valid and reliable tool for healthy children[18] and children with chronic respiratory disease as it is a submaximal test[19]. First, the children and their guardians were briefed about the procedures of the test and directed to avoid hopping, jumping and running. Also, they were aware of the starting and endpoints. Then the child was asked to walk as afar as possible through a 50-meter straight corridor over six minutes, while the examiner carefully monitored each child with a stopwatch. The distance in meters covered by each child was recorded[20].

Quality of life assessment

Quality of life (QoL) was evaluated using self-report Pediatric Quality of Life Inventory (PedsQL), which is a valid tool used to assess children and adolescents with chronic conditions[21,22]. PedsQL is a multidimensional measure of HRQoL in children and adolescents, and it includes 23 items distributed among 4 domains [physical (8 items), emotional (5 items), social (5 items), and school functions (3 items)]. It provides child self-report and parents' reports with a 5-points scale (0 means never, and 4 means almost always).

Interventions

Traditional chest physical therapy program

Each child in both groups performed the following respiratory exercises: resistance-based diaphragm strengthening exercises, breathing exercises to increase costal or chest breathing,

and breathing exercises to relax the breathing muscles, chest percussion while the child is in a side-lying or prone position to promote oxygenation, also aerobic exercises in the form of group walking exercises or exercises on a stationary bicycle for 15 minutes[23,24]. Patients in both groups received inspiratory muscle training.

Virtual reality-based exercises (VR-EX)[13]

Following a session of traditional physical therapy, the children in the study group rested for 30 minutes and then joined in a 30-minute VR exercise session using Nintendo Wii systems. As game interfaces, the Nintendo Wii systems employ haptic sensor-based controllers and a balance board. The therapist generates the child's "avatar", which is used to represent the patient in the games. In the real world, the movements of the controllers (remote controller and Wii Balance Board) correspond to the movement of the "avatar" in the games. In order to correctly perform the activity, the patient looks at and replicates the "avatar" movements, receiving visual and auditory feedback. Sessions were carried out in a separate room on an individual basis. The therapist randomly chose three distinct types of activity from the system for all patients.

1) At the beginning of the session, 5 minutes of "Yoga" activity were performed. Yoga consisted of deep breathing in a standing position on the balance board while maintaining body balance using feedback from a screen.
2) "Jogging Plus" consisted of 10 minutes of running on a spot while the pulse and respiratory rate were continuously monitored. During running, heart rate should not exceed 80% of the maximum predicted, and oxygen saturation (SaO_2) should not fall below 85%.
3) "Twisting and squatting": consisted of 10 minutes of trunk twisting and arms and legs squatting while being monitored as in "Jogging Plus".

Statistical Analysis

SPSS version 26 (IBM Corp., Armonk, NY, USA) was utilized to complete all statistical analyses. The normality of data distribution was assessed through the Kolmogorov-Smirnov test. The baseline group comparison (for demographic, anthropometric, and clinical characteristics) was performed using an independent *t*-test and Chi-square test for the numerical and categorical data, respectively. The post-treatment variations between the two groups concerning dependent variables (pulmonary functions, cardiopulmonary fitness, functional performance, and quality of life) were computed using the analysis of covariance (ANCOVA) test, with controlling for the pre-treatment scores. The effect size (ES) was determined using the partial eta-squared equation whenever the ANCOVA test revealed a significant between-group difference. The significance level for all statistical tests was established at $p < 0.05$.

Results

The CONSORT flowchart for the recruitment, randomization, and retention of the study participants is shown in Figure 1. Out of 79 prospective eligible children, 52 satisfied the inclusion criteria and were randomly assigned to either the VR-EX group or the control group (26 participants for each group). Due to a change in domicile or schedule conflicts, five participants – two from the VR-EX group and three from the control group – were unable to complete the study. However, in accordance with the intention-to-treat principle, their data were substituted and included in the statistical analyses.

The baseline characteristics of the VR-EX and control groups are demonstrated in Table I. Both groups were similar regarding the demographic (age and gender), anthropometric (body mass index weight, and height) and clinical (type of CDH, surgical repair, initial hospital and ICU stays, mechanical ventilation duration, and ventilator-free days) characteristics at the baseline ($p > 0.05$). The pre-treatment group comparisons for the dependent variables are shown in Table II. No significant difference was detected between both groups for the measures of pulmonary function (FEV_1, FVC, and FEV_1/FVC), cardiopulmonary fitness (peak VO_2 and lowest VE/VCO_2) and quality of life (total, physical, or psychosocial PedsQL scores) ($p > 0.05$).

The post-treatment differences among the study groups are shown in Table III. The ANCOA analyses detected a significant between-group difference favoring the VR-EX group regarding all measures of pulmonary functions [FEV_1 ($F_{(1.49)} = 12.05$, $p = 0.001$, ES = 0.19), FVC ($F_{(1.49)} = 16.31$, $p = 0.0002$, ES = 0.25), and FEV_1/FVC ($F_{(1.49)} = 9.46$, $p = 0.003$, ES = 0.16)] after controlling for the pre-treatment values of each measure. Also, the analyses identified a significant between-group difference for the cardiopulmonary fitness [Peak VO_2 ($F_{(1.49)} = 28.42$, $p < 0.001$, ES =

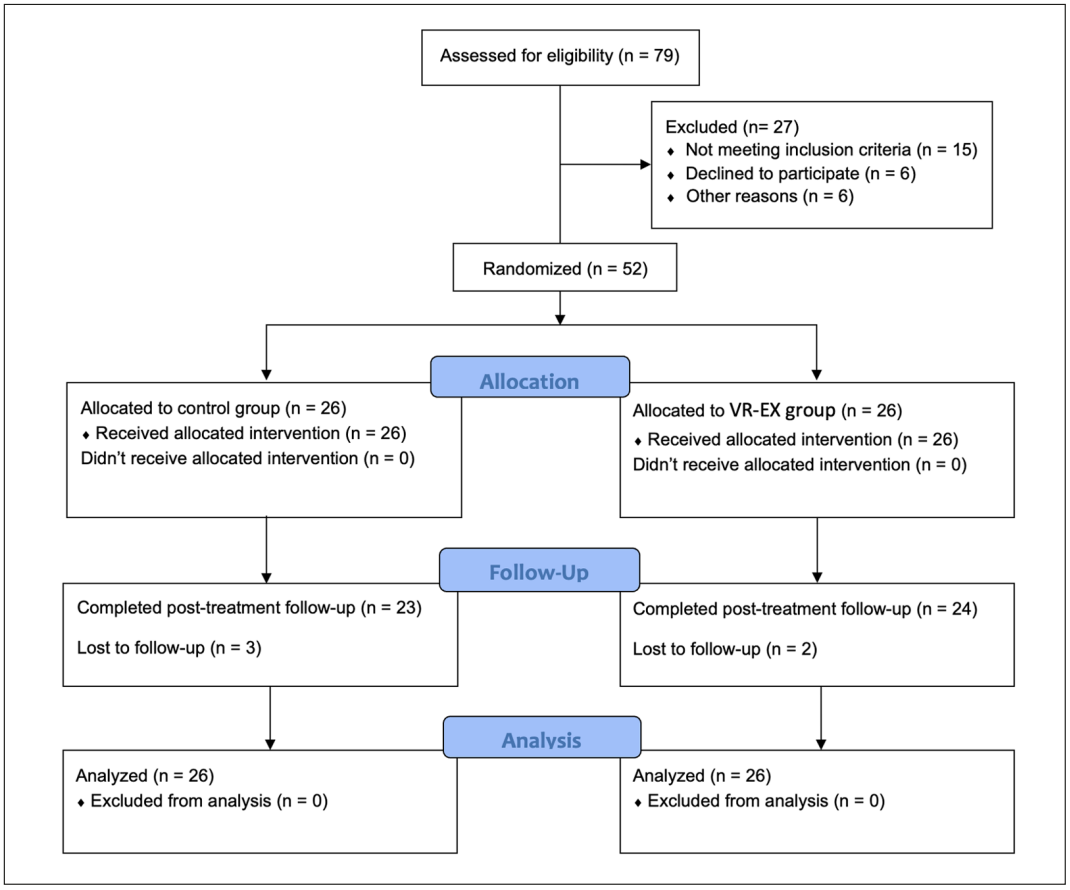

Figure 1. Participants' CONSORT flowchart.

0.37); lowest VE/VCO_2 ($F_{(1.49)} = 5.67$, $p = 0.021$, ES = 0.11)], where the VR-EX group achieved a higher level of fitness compared to the control group.

In terms of functional performance, there was also a considerable post-treatment difference between the study groups according to the 6-MWT ($F_{(1.49)} = 23.97$, $p < 0.001$, ES = 0.33) after controlling for

Table I. Demographic and clinical characteristics of children in the VR-EX and control groups.

Participants' characteristics	VR-EX group (n = 26)	Control group (n = 26)	Sig.
Age, years	8.10 ± 1.16	7.62 ± 1.29	0.18†
Gender (M/F), n	15 (57.7)/11 (42.3)	18 (69.2)/8 (30.8)	0.57‡
Height, m	1.25 ± 0.08	1.23 ± 0.06	0.45†
Weight, kg	32.81 ± 5.01	33.15 ± 3.84	0.78†
BMI, kg/m^2	20.95 ± 1.99	21.76 ± 1.74	0.13†
Type of CDH (RT/LT sided), n (%)	21 (80.8)/5 (19.2)	23 (88.5)/3 (11.5)	0.70‡
Surgical repair (primary/patch), n (%)	22 (84.6)/4 (15.4)	19 (73.1)/7 (26.9)	0.49‡
Duration of ICU stay, days	25.69 ± 6.92	26.35 ± 5.68	0.71†
Mechanical ventilation days	15.54 ± 3.44	16.27 ± 5.16	0.55†
Ventilator-free days	12.46 ± 3.44	11.73 ± 5.16	0.55†
Initial hospital stay, days	36.23 ± 8.79	33.35 ± 5.92	0.17†

VR-EX: virtual reality-based exercise, M/F: male/female, BMI: body mass index, CDH: congenital diaphragmatic hernia, RT/LT: right/left, ICU: intensive care unit. Ventilator-free and mechanical ventilation data represent days through the first 28 days of life. Sig: significance level at $p < 0.05$, †Unpaired *t*-test, ‡Chi-square test.

Table II. Primary and secondary outcomes in the VR-EX and control group at entry.

	VR-EX group (n = 26)	Control group (n = 26)	Sig.
Pulmonary Function			
FEV1, %	76.62 ± 8.71	77.81 ± 5.29	0.55
FVC, %	86.34 ± 3.74	85.35 ± 2.65	0.27
FEV1/FVC	84.23 ± 5.54	83.92 ± 5.41	0.84
Cardiopulmonary fitness			
Peak VO_2, mL/Kg/min	35.66 ± 4.60	34.85 ± 3.47	0.47
VE/peak VCO_2	28.93 ± 3.53	29.67 ± 2.83	0.41
Functional performance			
6-MWT, m	437.46 ± 56.24	452.19 ± 65.40	0.39
Quality of life			
Total score	78.78 ± 4.60	76.80 ± 4.14	0.11
Physical score	76.42 ± 6.96	74.25 ± 3.40	0.16
Psychosocial score	81.14 ± 5.67	79.35 ± 6.35	0.29

VR-EX: virtual reality-based exercise, FEV1: forced expiratory volume in one second, FVC: forced vital capacity, peak VO_2: peak oxygen uptake; VE/peak VCO_2: minute ventilation/carbon dioxide output slope, 6-MWT: 6-minute walk test. Sig: significance level at $p < 0.05$.

the pre-treatment scores, where the VR-EX group walked a longer distance compared to the control group. For the quality of life, there was a significant between-group difference in the total PedsQL score ($F_{(1.49)} = 19.68$, $p < 0.001$, ES = 0.28), physical health score ($F_{(1.49)} = 5.33$, $p = 0.025$, ES = 0.10), and the psychosocial health score ($F_{(1.49)} = 19.81$, $p < 0.001$, ES = 0.29), and all were in favor of the VR-EX group.

Discussion

The present study has been designed to investigate the effect of 12 weeks of using VR-based exercises on pulmonary functions, exercise capacity, functional performance, and QoL in children with surgically-repaired CDH. The results of this study showed that the combination of VR-EX with conventional chest physiotherapy had a significant effect in improving pulmonary function (FVC, FEV_1, and the FEV_1/FVC ratio), cardiopulmonary capacity (peak VO_2 and lowest VE/VCO_2 slope), functional performance (the distance in meters within the 6-MWT), and health-related QoL.

There were improvements in pulmonary function, exercise capacity, functional performance and health-related quality of life in both the control and study groups but with major improve-

Table III. Post-treatment differences in dependent variables between the VR-EX and control group, after controlling for the pre-treatment values.

	VR-EX group (n = 26)	Control group (n = 26)	Sig.	ES
Pulmonary Functions				
FEV1, %	85.46 ± 11.57	79.77 ± 9.10	0.001*	0.19
FVC, %	93.27 ± 4.41	87.73 ± 4.94	0.0002*	0.25
FEV1/FVC	90.73 ± 5.76	86.46 ± 5.03	0.003*	0.16
Cardiopulmonary fitness				
Peak VO_2	41.63 ± 4.69	37.10 ± 3.66	< 0.001*	0.37
Lowest VE/VCO_2	25.12 ± 4.24	27.77 ± 3.24	0.021*	0.11
Functional performance				
6-MWT, m	510.77 ± 62.44	464.27 ± 58.29	< 0.001*	0.33
Quality of life				
Total score	86.64 ± 5.19	80.89 ± 5.81	< 0.001*	0.28
Physical score	85.22 ± 6.05	79.84 ± 7.94	0.025*	0.10
Psychosocial score	88.06 ± 8.29	81.94 ± 6.93	< 0.001*	0.29

VR-EX: virtual reality-based exercise, FEV1: forced expiratory volume in one second, FVC: forced vital capacity, peak VO_2: peak oxygen uptake; VE/VCO_2: minute ventilation/carbon dioxide output slope, 6-MWT: 6-minute walk test. Sig: significance level, ES: effect size, *Significant at $p < 0.05$.

ments in the study group. These improvements may be attributed to many factors, such as the proper selection of exercise programs with consideration of child preference and the physical abilities of the participants. Other factors may be children's interest, enjoyment, and motivation during exercises, as children are more likely to adhere to the physiotherapist's recommendations if exercise is included in a game. The usage of VR technology includes biofeedback which encourages the child's participation in the game and improves motor performance. Also, it includes a graded level of exertion, the ability to monitor the duration and intensity of exercises, providing feedback on errors, and supervision of the performed exercises[25].

To date, there have been no prior studies that have examined the impact of VR-based exercises on pulmonary functions, cardiopulmonary capacity, functional performance, and QoL in children with surgically corrected CDH, although there has been research that has examined the impact of comparable cases. Rutkowski et al[26] found that utilization of immersive VR for 2 weeks in patients with the chronic obstructive pulmonary disease led to significant improvement in cardiopulmonary function and exercise capacity. Also, in a study by Wardini et al[27] about using virtual training in patients with chronic obstructive pulmonary disease (COPD), it showed that there were significant changes in heart rate, oxygen saturation, dyspnea and respiratory parameters.

Huss et al[28] assessed the impact of video games on treating asthmatic children aged 7-12 years. This study found significant changes in pulmonary functions (specifically, FEV_1, FVC and FEV_1/FVC). Albores et al[29] evaluated the effect of VR games for three months, five days per week, on moderate to severe COPD patients, and they found significant improvement in exercise capacity and health-related QoL.

One important aspect of VR is the interactivity of children and their interests in choosing the exercise game. The results of our study showed that there was an improvement in health-related QoL. Our result came in agreement with Jung et al[30] who concluded that the usage of VR exercises had a positive impact on patients' physical and psychological well-being as all patients were more enjoyable and social than before. Also, Schneiderman-Walker et al[31] found that there were improvements in self-reported attitude in children with cystic fibrosis, and video games could be used as a home program for these children. According to Tennant et al[32], there were improvement in emotional well-being in children with cancer following the usage of immersive VR.

Despite the favorable findings of the present investigation, there are significant limitations. The findings of this study are restricted to a specific age group. So, caution should be applied as these findings might not be applicable to other age groups. An additional limitation is that the current study cannot confirm the long-term effect of VR-based exercises, Therefore, future studies need to consider the follow-up effect after the end of treatment.

Conclusions

Our findings suggest that 12 weeks of VR-based exercises, when combined with conventional physical therapy, has the potential to improve pulmonary functions, cardiopulmonary capacity, functional performance, and quality of life more favorably than conventional physical therapy alone in children with surgically repaired congenital diaphragmatic hernia.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Ethics Approval

The present study was approved by the Ethics Committee at physical therapy department, collage of applied medical science, Prince Sattam bin Abdulaziz University (No: RHPT/2021/0074), and it was performed according to the principles of the Declaration of Helsinki. The study was registered at ClinicalTrials.gov (ID: NCT05612503).

Informed Consent

All participants signed a written informed consent before the examination. Instructions, objectives, and steps of the procedure were explained to each participant.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' Contribution

Conception and design: Alshimaa R. Azab, Ragab K. Elnaggar, Maged A. Basha, FatmaAlzahraa H. Kamel. Analysis and interpretation of data: Walid K. Abdelbasset, Mshari Alghadier, Ahmed S. Ahmed, Ashwag S. Alsharidah, Enas N. Morgan, Mostafa A. Hassan. Drafting the article: Alshimaa R. Azab, Ragab K. Elnaggar, Maged A. Basha, FatmaAlzahraa H. Kamel. Supervision: Alshimaa R. Azab, Walid K. Abdelbasset, Mshari Alghadier, Ahmed S. Ahmed, Ashwag S. Alsharidah, Enas N. Morgan, Mostafa A. Hassan. Validation and final approval of the version of the article to be published: Alshimaa R. Azab, Ragab K. Elnaggar, Walid K. Abdelbasset, Mshari Alghadier, Ahmed S. Ahmed, Ashwag S. Alsharidah, Enas N. Morgan, Maged A. Basha, Mostafa A. Hassan, FatmaAlzahraa H. Kamel.

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