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ORIGINAL RESEARCH

A Prospective Randomized Controlled Trial Assessing the Impact of Preoperative Combined with Postoperative Progressive Resistance Training on Muscle Strength, Gait, Balance and Function in Patients Undergoing Total Hip Arthroplasty

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Purpose: The aim of this study is to investigate the effects of a preoperative combined with postoperative moderate-intensity progressive resistance training (PRT) of the operative side in patients with hip osteoarthritis (HOA) who are undergoing total hip arthroplasty (THA). The study seeks to evaluate the impact of this combined intervention on muscle strength, gait, balance, and hip joint function in a controlled, measurable, and objective manner. Additionally, the study aims to compare the outcomes of this combined intervention with those of preoperative or postoperative muscle strength training conducted in isolation.

Methods: A total of 90 patients with HOA scheduled for unilateral primary THA were randomly assigned to three groups: Pre group (preoperative PRT), Post group (postoperative PRT), and Pre& Post group (preoperative combined with postoperative PRT) focusing on hip flexion, extension, adduction, and abduction of operated side. Muscle strength, gait parameters, balance, and hip function were assessed at specific time points during a 12-month follow-up period.

Results: All three groups showed significant improvements in muscle strength, with the Pre& Post group demonstrating the most pronounced and sustained gains. Gait velocity and cadence were significantly improved in the Pre& Post group at 1-month and 3-month postoperative follow-ups compared to the other groups. Similarly, the Pre& Post group exhibited superior balance performance at 3-month and 12-month postoperative follow-ups. The Harris Hip Score also showed better outcomes in the Pre& Post group at all follow-up intervals.

Conclusion: Preoperative combined with postoperative moderate-intensity PRT in HOA patients undergoing THA led to superior improvements in muscle strength, gait, balance, and hip joint function compared to preoperative or postoperative PRT alone. This intervention shows significant promise in optimizing postoperative rehabilitation and enhancing patient outcomes following THA.

Keywords: exercise therapy, muscle strength, progressive resistance training, total hip arthroplasty, gait variability

Introduction

Hip osteoarthritis (HOA) is a prevalent degenerative condition affecting the hip joint, leading to hip pain, deformity, and functional limitations, ultimately impacting the quality of life in patients.[1] The affected limb often experiences muscle atrophy, neuromuscular dysfunction, and pain, resulting in decreased muscle strength compared to the unaffected limb and healthy individuals of similar age.[2] Gait analysis reveals reduced hip range of motion (ROM), decreased walking speed, and diminished hip flexion and abduction moments during the midstance phase and maximal hip extension.[3] Despite the significant pain relief provided by total hip arthroplasty (THA), several studies have reported persistent

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deficiencies in muscle strength, muscle endurance, gait, and standing balance on the operated side compared to the unaffected side and healthy individuals, even during a 2–3 years follow-up period after THA.[4,5]

Previous studies have demonstrated that hip muscle strength training can benefit patients by improving gait, balance, and function to a certain extent.[6,7] The majority of current research on lower limb or hip muscle strength training in patients undergoing THA has primarily focused on post-operative interventions. There is limited research evaluating the potential benefits of preoperative combined with postoperative muscle strength training for THA patients. A study conducted by Gilbey et al aimed to design exercise programs for THA patients both before and after the surgery, incorporating various components such as aerobic exercise, muscle strength training, and hydrotherapy.[8] The research findings indicated that these exercise programs had a significant positive effect on alleviating postoperative pain and enhancing hip strength, walking ability, and overall satisfaction in patients. However, it is important to note that these exercise programs were not quantitatively standardized, leading to considerable variations in the volume and intensity of exercises for individual patients. Additionally, the use of outdated instruments for muscle strength testing, like the Kinetech hip and knee machine, might have affected the accuracy of the results. Similarly, in Wang et al's study, non-quantitative clinic and home exercise programs were designed for both preoperative and postoperative stages of THA patients.[9] However, this study did not directly assess changes in postoperative muscle strength. Instead, it evaluated certain parameters such as gait speed and stride length through manual measurements in tests like the Twenty-Five Meter Walk Test and Six-Minute Walk Test, without the use of professional gait analysis instruments. The research findings revealed that, at 6 months postoperatively, patients demonstrated an improvement in stride length and walking speed. On the other hand, Holsgaard-Larsen's randomized controlled trial (RCT) stands out as one of the few studies investigating the effects of preoperative PRT in patients undergoing THA.[10] The results showed that preoperative PRT did not exhibit a significant impact on functional improvement one year after surgery, but it did seem to accelerate the recovery process at three months postoperatively. However, it should be noted that this study did not include quantitative muscle strength training in the postoperative period for the patients. Postoperative balance in THA patients is a crucial area of focus as it significantly influences gait and overall function.[11] However, the studies mentioned earlier, which investigated combined preoperative and postoperative PRT for muscle strength, did not assess balance. In summary, there is currently limited literature on combined preoperative and postoperative PRT muscle strength training in THA patients. Additionally, some studies use outdated evaluation equipment and rely on manual measurements. Furthermore, the current research on preoperative and postoperative muscle strength training primarily involves weight-bearing or non-weight-bearing hip muscle exercises, conducted under the guidance of rehabilitation therapists in rehabilitation centers or at home. These exercises lack standardization and are not performed on specialized instruments following established protocols, making it challenging to quantitatively design, implement, and monitor the training intensity and range. Consequently, this situation may lead to significant biases and substantial errors in the intervention outcomes among the enrolled patients, ultimately weakening the strength of the research results.

The study aims to investigate the impact of a 10-week preoperative combined with postoperative moderate-intensity progressive resistance training (PRT) program on patients with hip osteoarthritis (HOA) undergoing total hip arthroplasty (THA). Our focus is on assessing the effects of this combined intervention on muscle strength (hip maximal isokinetic torque normalized for body mass, surgical limb advantage ratio), gait (velocity, cadence), balance (duration of stance, distance and area traveled by the peak pressure point on the foot), and hip joint function (HHS scores). Specifically, we compare the outcomes of the combined intervention with those of isolated preoperative or postoperative muscle strength training. The hypothesis suggests that the combined intervention will yield superior improvements in muscle strength, gait, balance, and hip joint function compared to isolated training. This study provides valuable insights into the efficacy of a holistic rehabilitation approach for enhancing outcomes in THA patients with HOA.

Methods

Trial Design

This study was designed as a standard 3-arm, parallel, randomized, controlled trial. The trial was registered in the Chinese Clinical Trial Registry under the registration number ChiCTR-2300072553. Ethical approval for all procedures was obtained from the ethics committee of Sichuan Provincial Orthopedic Hospital (Approval No. KY202001501). Prior to participation, written informed consent was obtained from all the participants, ensuring their voluntary participation and understanding of the study objectives. Throughout the trial, the research team adhered to the guidelines and recommendations provided by the Consolidated Standards for Reporting of Trials (CONSORT),[12] ensuring rigorous and transparent reporting of the study procedures and results. By following these standards, the study aimed to maintain high-quality research practices and foster the credibility and reliability of the findings.

Participants

Between February 2021 and March 2022, participants were recruited through various means, including poster advertisements and other promotional materials prominently displayed in the outpatient clinic of a specialized orthopedic surgeon specializing in joint replacement. These promotional materials aimed to inform potential candidates about the study and encourage their participation. All eligible participants had been diagnosed with either unilateral or bilateral HOA and were scheduled to undergo unilateral primary THA with the same orthopedic surgeon (Y.S.), with the surgery planned at least 3 weeks after their enrollment in the study. Prospective candidates were informed about the study during their initial consultation with the surgeon.

The inclusion criteria encompassed the following: (1) having a primary diagnosis of unilateral or bilateral HOA; (2) for patients with bilateral HOA, the non-operative side had no symptoms at the time of admission; (3) providing informed consent and demonstrating the willingness to comply with the study procedures during follow-up. On the other hand, the exclusion criteria were as follows: (1) having scheduled additional, unrelated surgery within 3 months of their THA; (2) having undergone surgery in the 3 months before recruitment; (3) having contraindications for muscle strength exercise; (4) having severe lower limb vascular disease, severe dysfunction of major visceral organs, and significant limb movement or sensory impairment due to severe spinal diseases, which could potentially interfere with the conduct of the trial.

The postoperative follow-up period for the study was 12 months. The flow of participants through the study, including enrollment, allocation, and follow-up, is presented in Figure 1, offering a visual representation of the participant flow.

Randomization

After obtaining baseline measurements, participants were randomly assigned to one of three groups: Pre group, Post group, or Pre& Post group. The randomization process employed block randomization with a block size of 10, and it was conducted by an independent research assistant not directly involved in the study. Specifically, the research assistant used a computer-generated random sequence, and the allocation concealment was maintained throughout the process. To ensure the blinding of the surgeon and outcome assessors (Y.S. and G.C.), stringent measures were implemented. The treatment allocation information was kept confidential and revealed only to an independent third party responsible for the randomization process. This third party had no direct involvement in the study and did not interact with the participants, surgeon, or outcome assessors. Blinding was rigorously maintained during the study to prevent bias in the evaluation of results. The surgeon and outcome assessors were unaware of the assigned treatment groups throughout the trial. However, due to the nature of the intervention, blinding of patients and the physical therapist (D.D.Y), who conducted the training and measurements, was deemed impractical. Despite the lack of blinding in these aspects, steps were taken to minimize potential bias by strictly adhering to standardized procedures and protocols.

Interventions

The unilateral PRT for muscle strength and the muscle, gait, and balance tests for all three groups of patients were conducted at the Sports Medicine Center of Sichuan Provincial Orthopedic Hospital. The Pre group received hip muscle strength training on the operated side using the ISOMED2000 dynamometer (D. & R. Ferstl GmbH, Hemau, Germany), focusing on hip flexion, extension, adduction, and abduction. The training commenced during the preoperative period, with a frequency of three sessions per week for a duration of two weeks. The Post group initiated hip muscle strength training on the operated side with the same frequency and intensity as the Pre group, starting from the 14th day after the surgery and continuing for eight weeks. The Pre& post group commenced their training two weeks before the operation and resumed it from the 14th day after the surgery, following the same training content, frequency, and intensity as the

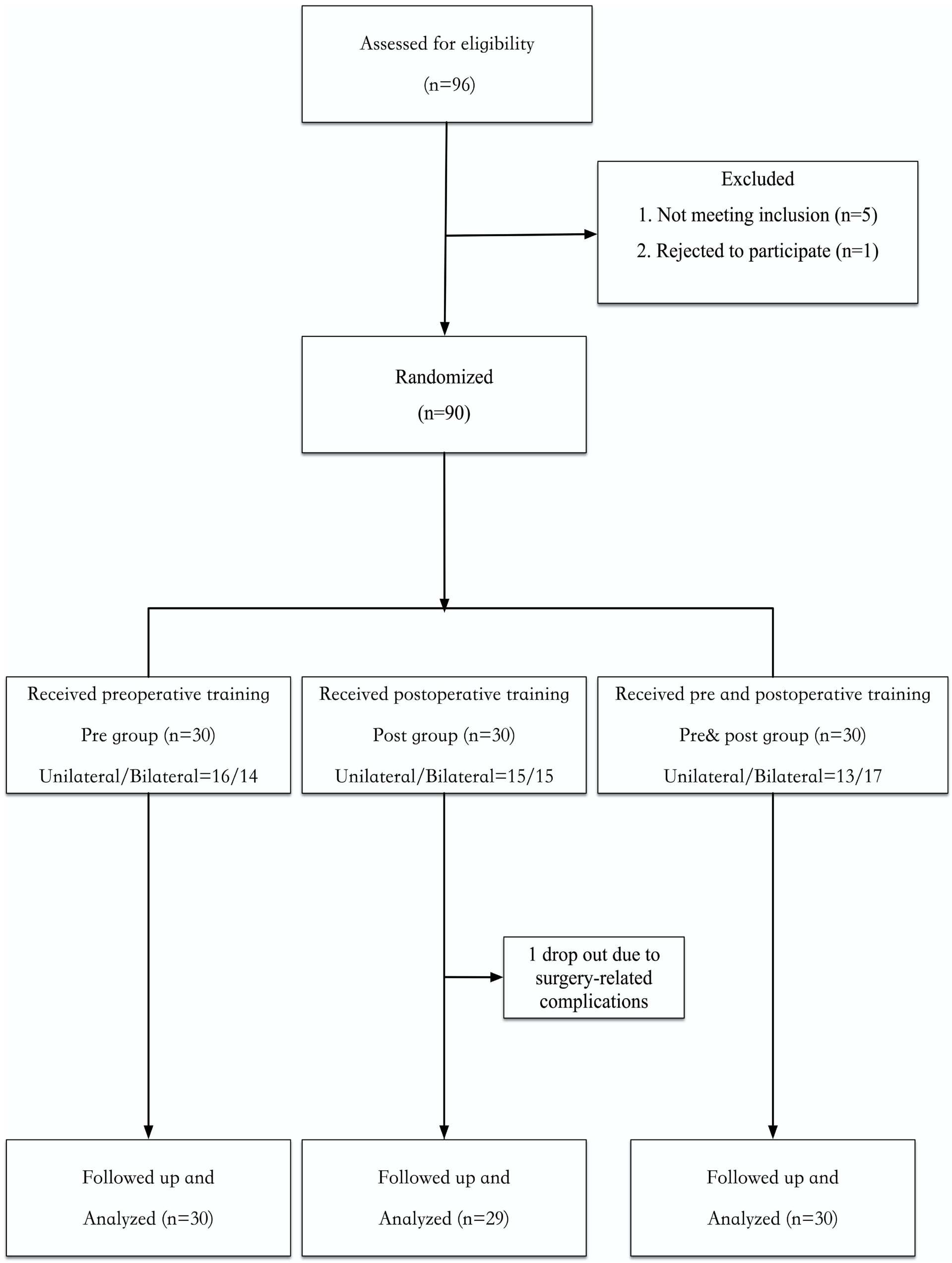

Figure 1 Flow diagram of patients' selection and exclusion.

previous two groups, and the training lasted for eight weeks. The total duration of the training for the Pre& Post group was 10 weeks.

Muscle strength training: Muscle strength training sessions begin with a standardized warm-up exercise, which involves 5–10 minutes of stationary cycling at an intensity of 1.5 W/kg and a pedal rate of 40–50 rpm. After the warm-up, there is a resting period of approximately 5 minutes. The patient then lies supine on the ISOMED 2000 dynamometer. To stabilize the upper body, pelvis, and contralateral (untrained) ankle joint during hip joint muscle training on one side, padded straps are used. These straps also keep the contralateral lower limb stable and immobile. Additionally, the patient holds handles on both sides of the instrument with both hands to provide further stability during muscle training. The middle and lower part of the patient's thigh on the training side is secured with the hip adapter, allowing the thigh to move together with the adapter during hip motion. The hip joint adapter's connection rod is adjustable and has a load resistance at the terminal end, providing constant resistance for hip muscle isometric resistance training on the operated side. Following the guidelines of the American Geriatrics Society,[13] the resistance for moderate-intensity isometric muscle training is set to achieve a resistance equivalent to 1 repetition maximum (RM) during one flexion repetition. In this study, the resistance load for moderate-intensity isometric muscle training is set at 50% of 1 RM. Each training set comprises 8–10 repetitions of flexion exercises, and there are 6–8 sets per training session, with a 2-minute rest interval between sets.

Outcomes

Muscle strength and gait assessments were conducted at specific time points for the patients: pre-2 weeks, pre-1 day, post-1 month, post-3 months, post-6 months, and post-12 months. Additionally, balance testing and hip function scores were performed at pre-2 weeks, post-3 months, and post-12 months.

Primary Outcome Measure: Isokinetic Strength Assessment

Before the muscle strength testing, patients performed routine elastic band stretching and hip joint movements as their warm-up exercises, without using any specific instruments. The starting position of the adapter was set at a horizontal 0°, representing one complete flexion-extension cycle of 0°-120°-0°. The testing angular velocity was set at a slow 60°/s. Connected to a stress sensor on the hip joint adapter, the computer generated the patient's torque-time curve. From this curve, hip maximal isokinetic torque normalized for body mass) (HMIT-NBM) of flexion, extension, adduction, and abduction, normalized to body weight, were collected to calculate the Surgical Limb Advantage Ratio (SLAR). SLAR is defined as the difference between HMIT-NBM on the surgical side and the HMIT-NBM on the non-surgical side, divided by the HMIT-NBM on the surgical side. Patients underwent five tests following this procedure, and the physician recorded the data for mechanical variables obtained from the five test repetitions. These values were used to calculate the average values, as shown in the Figure 2a and b.

Secondary Outcome Measure

Gait analysis: Each participant underwent a calibration process by standing on one foot for 10 seconds on each tile of the walkway gait assessment platform (Tekscan Inc., MA, USA) without wearing shoes, to calibrate the sensor tiles individually. Subsequently, the participants were instructed to walk at their preferred speed on the walkway, completing three full gait cycles. The walkway captured various gait parameters and provided measurements for comfortable gait velocity (cm/sec) and cadence (steps/min) (see Figure 2c).

Eyes-Closed Single-Leg Standing Balance Test: Proper set-up and calibration of the Tekscan instrument should be performed. The patient should remove their shoes and socks to ensure optimal contact with the instrument's sensors. The patient should stand on a flat surface with their hands on hips posture. Upon hearing instructions from the researcher, the patient should initiate the single-leg stance with their eyes closed. The test is considered to be completed when the patient exhibits obvious signs of imbalance, such as swaying, foot movement, or reliance on the toes or heels for support. Throughout the patient's single-leg stance with closed eyes, the Tekscan instrument will continuously record the pressure distribution and changes on the plantar surface of the foot in real-time. The data will be transmitted to a computer, allowing for the measurement of plantar peak pressure point change such as duration of stance (in seconds), distance (in centimeters) and area (in square centimeters) traveled by the peak pressure point on the foot (see Figure 2d).

Harris Hip Score (HHS): The HHS is a commonly employed clinical assessment tool for evaluating the functional status and pain levels of patients with hip conditions, particularly following hip surgery. Created by William H. Harris in 1969,[14] it encompasses questions that address different facets of hip function and pain. The total score ranges from 0 to 100, with higher scores signifying better hip function and lower levels of pain. The HHS was collected through face-to-face questionnaire surveys at specific follow-up time points.

Sample Size

The sample size calculation for this study was based on data from a pilot study involving 20 patients with unilateral HOA. In the pilot study, the mean hip abduction maximal isokinetic torque on the affected side was found to be 0.66 Nm/Kg with

Figure 2 The enrolled patients underwent muscle strength training and testing, as well as gait and balance assessments. (**a-c**) Follow-up patients are undergoing Isokinetic Strength Assessment and Gait analysis. (**d**) Follow-up patients are undergoing Eyes-Closed Single-Leg Standing Balance Test.

a standard deviation of 0.16 Nm/Kg. To detect a 30% increase in muscle strength after PRT with a significance level (alpha) of 0.05 and a power of 0.80, a minimum sample size of 24 patients per group would be required. However, to ensure sufficient statistical power and account for any potential dropouts or other factors, the decision was made to include thirty patients per group, resulting in a total of 90 randomized patients (N=90) in the study. The power analysis was conducted to determine the study's appropriateness in detecting a significant effect. The chosen sample size of 90 patients was deemed sufficient to achieve the desired power of 0.80, ensuring the study's reliability in detecting meaningful changes in muscle strength (primary outcome measure) resulting from the proposed intervention.

Statistical methods

The statistical analyses were conducted using SPSS 26.0 software for Mac (SPSS Inc., Chicago, IL, USA) on personal computers. Continuous variables were reported as means ± standard deviation. Between-group comparisons of normally distributed data were analyzed using *t*-tests. Within-group comparisons at different time points were assessed using repeated measures analysis of variance (ANOVA). If the data did not follow a normal distribution or exhibited heterogeneity of variance, Wilcoxon rank-sum tests were used as an alternative. Categorical variables were analyzed using Chi-squared tests or Fisher's exact tests. A significance level of less than 0.05 ($P<0.05$) was considered statistically significant.

Results

The recruitment for this study took place from February 2021 to March 2022. The follow-up period started in March 2021 and is expected to continue until April 2023. During this time, regular follow-ups will be conducted with all enrolled patients to collect relevant data, including muscle strength, gait, balance and function assessments. One participant withdrew from the study due to surgery-related complications, but the remaining participants completed all interventions and follow-up assessments. Table 1 presents the baseline characteristics of the three groups of patients. There were no significant differences observed among the three groups regarding sex distribution, age, body mass index (BMI), or the proportion of patients with unilateral or bilateral HOA.

Isokinetic Strength Capacity

For isokinetic strength capacity, the baseline comparisons among the three groups were similar. We observed similar trends in the changes of flexor and abductor HMIT-NBM. Through preoperative PRT, both the Pre group and the Pre& Post group showed improvements in flexor and abductor HMIT-NBM at Pre-1 day compared to Pre-2 weeks, and both groups had higher HMIT-NBM values than the Post group. At post-1 month, all three groups showed a decrease in flexor and abductor HMIT-NBM compared to pre-1 day. Both the Pre group and the Post group had lower values than their baseline or decreased to the same level as the baseline at Pre-2 weeks, while the Pre& Post group had higher values than their baseline. Subsequently, HMIT-NBM gradually increased, and at post-3 months, both the Post group and the Pre& Post group had higher HMIT-NBM than pre-1 day, while the Pre group remained lower than or to the same level as Pre-1 day. At post-3 months and 6 months, the Pre& Post group showed a faster improvement in HMIT-NBM. At post-12 months, all three groups significantly improved from baseline values. There was no difference between the Pre group and the Post group, but the Pre& Post group had higher values than the two aforementioned groups (see Figure 3, Table 2). The trend of flexors and adductors HMIT-NBM are also presented in Figure 3. The results comparing different time points within each group are presented in Table 2.

When the SLAR is a positive value, it indicates that the HMIT-NBM of the surgical limb is superior to that of the non-surgical limb. Following surgical intervention and perioperative muscle strength exercises, at the post-3 months follow-up, the SLAR for hip flexion, extension, abduction, and adduction significantly increased compared to the baseline measurements taken at pre-2 weeks in all three groups of patients. The changes in flexion, extension, and

Table 1 Demographic Data of the Subjects

Parameter	Pre Group	Post Group	Pre& Post Group	P_{12} value	P_{13} value	P_{23} value
Age (years)	63.1±7.9	61.2±6.8	63.3±7.5	0.798	0.094	1.023
BMI (kg/m2)	23.5±3.7	24.2±2.8	24.6±3.0	1.189	1.790	0.794
Duration of HOA(year)	7.4±1.5	7.2±2.2	7.5±1.7	0.381	0.146	0.471
Gender (male/female)	17/13	16/14	16/14	P=0.956*		
Unilateral/Bilateral HOA	16/14	15/15	13/17	P=0.733*		

Notes: P_{12} represents P value of Pre group vs Post group; P_{13} represents P value of Pre group vs Pre& Post group; P_{23} represents P value of group Post group vs Pre& Post group; *Denotes the use of the Pearson chi-square test.
Abbreviation: BMI, body mass index.

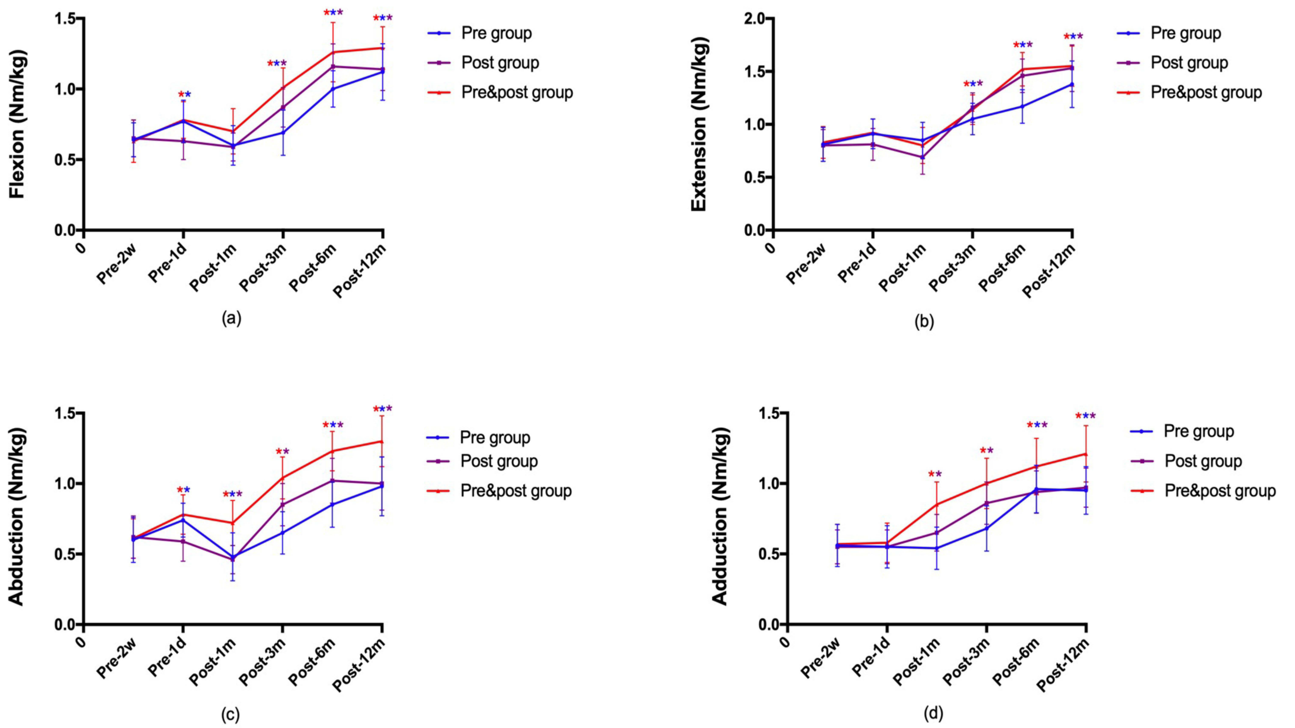

Figure 3 (**a-d**) represent the changing trend of hip maximal isometric torque normalized for body mass(HMIT-NBM) in three groups of patients at different time points. (**a**) represents flexion HMIT-NBM; (**b**) represents extension HMIT-NBM; (**c**) represents abduction HMIT-NBM; (**d**) represents adduction HMIT-NBM. An asterisk (*) indicates a significant difference compared to the baseline value (pre-2w) within the group. For example, the Blue asterisk (*) denotes a significant difference at this time point compared to the pre-2w baseline value in the pre group.

abduction SLAR at the post-12 months follow-up were depicted in Figure 4 on the line chart. Notably, the Pre& Post group exhibited the most remarkable improvement, suggesting that the surgical limb's HMIT-NBM on the operated side was stronger compared to the non-operated side, with greater advantages. However, even at the post-12 months follow-up, the Pre group still showed weaker hip extension and abduction HMIT-NBM on the operated side compared to the non-operated side (Table 3).

Table 2 Comparison of HMIT-NBM at Specific Time Points Among 3 Groups

HMIT-NBM (Nm/Kg)	Pre Group	Post Group	Pre& Post Group	P_{12} value	P_{13} value	P_{23} value
Flexion						
Pre-2 weeks	0.64 ± 0.12	0.65 ± 0.13	0.63 ± 0.15	0.831	0.688	0.514
Pre-1 day	0.77 ± 0.15	0.63 ± 0.13	0.78 ± 0.13	0.002	0.965	0.002
Post-1 month	0.6 ± 0.14	0.59 ± 0.10	0.70 ± 0.16	0.671	0.014	0.019
Post-3 months	0.69± 0.16	0.87 ± 0.14	1.01 ± 0.14	0.066	0.001	0.001
Post-6 months	1.0 ± 0.13	1.16 ± 0.16	1.26 ± 0.21	0.036	0.001	0.007
Post-12 months	1.12 ± 0.20	1.14 ± 0.15	1.29 ± 0.15	1.000	0.814	0.033
Extension						
Pre-2 weeks	0.81 ± 0.16	0.80 ± 0.15	0.83 ± 0.15	0.989	0.964	0.733
Pre-1 day	0.91 ± 0.14	0.81 ± 0.15	0.92 ± 0.13	0.233	0.950	0.197
Post-1 month	0.85 ± 0.17	0.69 ± 0.16	0.80 ± 0.17	0.089	0.151	0.557
Post-3 months	1.05 ± 0.15	1.16 ± 0.14	1.14 ± 0.14	0.176	0.680	0.776
Post-6 months	1.17 ± 0.16	1.46 ± 0.16	1.52 ± 0.16	0.003	0.001	0.001
Post-12 months	1.38 ± 0.22	1.53 ± 0.22	1.55 ± 0.19	0.027	0.005	0.004

(*Continued*)

Table 2 (Continued).

HMIT-NBM (Nm/Kg)	Pre Group	Post Group	Pre& Post Group	P_{12} value	P_{13} value	P_{23} value
Abduction						
Pre-2 weeks	0.60 ± 0.16	0.62 ± 0.15	0.61 ± 0.14	0.897	0.942	0.942
Pre-1 day	0.74 ± 0.12	0.59 ± 0.14	0.78 ± 0.14	0.030	0.726	0.012
Post-1 month	0.48 ± 0.17	0.46 ± 0.10	0.72 ± 0.16	0.822	0.018	0.011
Post-3 months	0.65 ± 0.15	0.85 ± 0.15	1.04 ± 0.15	0.005	0.001	0.068
Post-6 months	0.85 ± 0.16	1.02 ± 0.16	1.23 ± 0.14	0.157	0.001	0.002
Post-12 months	0.98 ± 0.21	1.00 ± 0.19	1.30 ± 0.18	0.860	0.007	0.017
Adduction						
Pre-2 weeks	0.56 ± 0.15	0.55 ± 0.12	0.57 ± 0.14	0.444	0.416	0.464
Pre-1 day	0.55 ± 0.15	0.55 ± 0.12	0.58 ± 0.14	0.992	0.817	0.703
Post-1 month	0.54 ± 0.15	0.65 ± 0.13	0.85 ± 0.16	0.175	0.001	0.007
Post-3 months	0.68 ± 0.16	0.86 ± 0.15	1.00 ± 0.18	0.007	0.001	0.006
Post-6 months	0.96 ± 0.17	0.94 ± 0.15	1.12 ± 0.20	0.294	0.003	0.003
Post-12 months	0.95 ± 0.17	0.97 ± 0.14	1.21 ± 0.20	0.470	0.002	0.001

Notes: P_{12} represents P value of Pre group vs Post group; P_{13} represents P value of Pre group vs Pre& Post group; P_{23} represents P value of group Post group vs Pre& Post group.
Abbreviation: HMIT-NBM, hip maximal isokinetic torque normalized for body mass.

Gait Parameters

The Pre& Post group demonstrated a more significant improvement in gait velocity at the 1-month postoperative follow-up, with statistically significant differences compared to both the Pre group and the Post group. This difference was also observed during the 3-month postoperative follow-up. By the 3-month follow-up, the gait velocity in the Pre& Post group

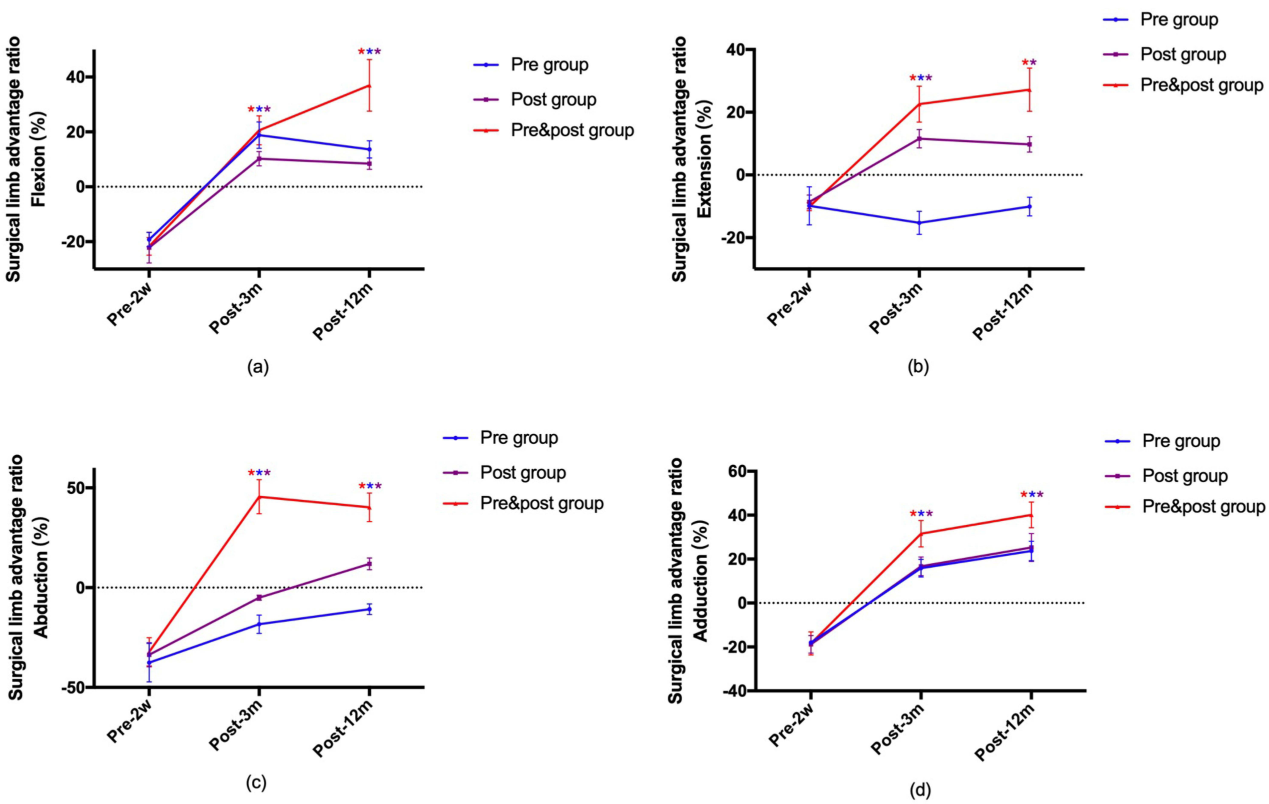

Figure 4 The changing trend of Surgical Limb Advantage Ratio (SLAR) in three groups of patients at different time points. (**a**) represents flexion SLAR; (**b**) represents extension SLAR; (**c**) represents abduction SLAR; (**d**) represents adduction SLAR. An asterisk (*) indicates a significant difference compared to the baseline value (pre-2w) within the group. For example, the Blue asterisk (*) denotes a significant difference at this time point compared to the pre-2w baseline value in the pre group.

Table 3 Comparison of SLAR at Specific Time Points Among 3 Groups

SLAR (%)	Pre Group	Post Group	Pre& Post Group	P_{12} value	P_{13} value	P_{23} value
Flexion						
Pre-2 weeks	−19.23% ± 2.61%	−22.14% ± 5.65%	−21.73% ± 3.25%	0.420	0.586	0.772
Post-3 months	18.80% ± 4.80%	10.20% ± 2.60%	20.56% ± 5.24%	0.001	0.166	0.001
Post-12 months	13.64% ± 3.16%	8.40% ± 2.12%	36.99% ± 9.42%	0.001	0.001	0.001
Extension						
Pre-2 weeks	−9.83% ± 6.06%	−8.63% ± 2.20%	−10.12% ± 1.31%	0.685	0.305	0.162
Post-3 months	−15.28% ± 3.70%	11.56% ± 2.94%	22.60% ± 5.73%	0.001	0.001	0.002
Post-12 months	−10.07% ± 2.98%	9.73% ± 2.46%	27.19% ± 6.86%	0.001	0.001	0.037
Abduction						
Pre-2 weeks	−37.60% ± 9.60%	−33.65% ± 6.03%	−32.17% ± 7.07%	0.691	0.546	0.775
Post-3 months	−18.29% ± 4.64%	−5.08% ± 1.31%	45.60% ± 8.52%	0.001	0.001	0.001
Post-12 months	−10.84% ± 2.69%	11.96% ± 3.01%	40.21% ± 7.16%	0.001	0.001	0.001
Adduction						
Pre-2 weeks	−17.98% ± 0.67%	−18.80% ± 4.02%	−18.35% ± 5.28%	0.280	0.708	0.648
Post-3 months	15.84% ± 4.02%	16.71% ± 4.23%	31.55% ±6.02%	0.431	0.001	0.001
Post-12 months	23.74% ± 4.47%	25.32% ± 6.39%	40.16% ± 5.88%	0.271	0.001	0.001

Notes: P_{12} represents P value of Pre group vs Post group; P_{13} represents P value of Pre group vs Pre& Post group; P_{23} represents P value of group Post group vs Pre& Post group.
Abbreviation: SLAR: Surgical limb advantage ratio.

had reached the same level as at the 1-year postoperative follow-up (P >0.05). At the 6-month postoperative follow-up, the gait velocity in the Pre group and the Post group caught up and improved to the same level as the Pre& Post group. At the 1-year postoperative follow-up, there was no significant difference in gait velocity among the three groups. The trend of cadence was similar to that of gait velocity. The Pre& Post group exhibited a faster improvement in cadence compared to the other two groups, but at the 1-year postoperative follow-up, there was no significant difference in cadence among the three groups (Figure 5, Table 4).

Balance Parameters

At 3 months postoperatively, the duration of stance (in seconds), distance (in centimeters), and area (in square centimeters) of the plantar peak pressure point change during single-leg stance on the surgical limb showed significant improvement in all three groups compared to their respective baseline values from the preoperative 2 weeks. These improvements were statistically significant. At the 3-month postoperative follow-up, when comparing between groups, the Pre& Post group demonstrated significantly better performance in duration and area during single-leg stance compared to both the Pre group and the Post group. By the 12-month postoperative follow-up, the balance indicators further improved in all three groups of patients. The Pre& Post group still exhibited significantly better performance in duration and area during single-leg stance on the surgical limb compared to both the Pre group and the Post group (Figure 5, Table 5).

Harris Hip Score

At 3 months postoperatively, HHS in all three groups showed significant improvement compared to their respective baseline values from the preoperative 2 weeks. The differences were statistically significant. When comparing between groups, the Pre& Post group exhibited superior HHS compared to both the Pre group and the Post group. By the 12-month postoperative follow-up, the HHS further improved in all groups. The Pre& Post group still demonstrated superior HHS compared to both the Pre group and the Post group at this time point (Figure 5, Table 5).

Harms

(1) Hip Periarticular Pain: Five patients (5.62%) reported experiencing hip periarticular pain after exercise. This pain could be attributed to overexertion of the hip periarticular muscles during the muscle training process. The research team closely monitored and documented these instances of pain and took appropriate measures to address the issue.

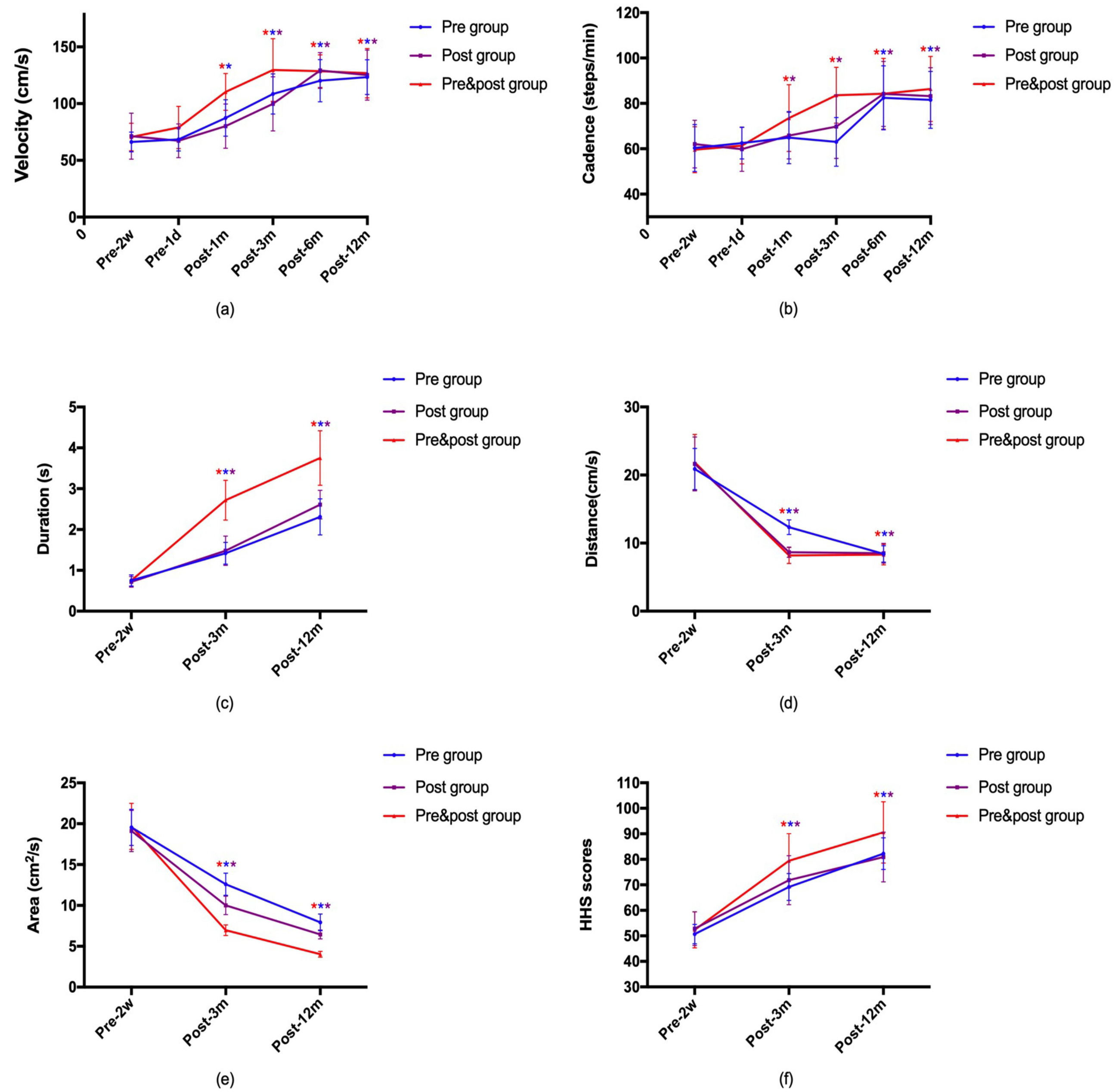

Figure 5 The changing trends of gait, balance indicators, and HHS scores in three groups of patients at different time points. (**a**) represents velocity; (**b**) represents cadence; (**c**) represents duration; (**d**) represents distance; (**e**) represents area; (**f**) represents HHS scores. An asterisk (*) indicates a significant difference compared to the baseline value (pre-2w) within the group. For example, the Blue asterisk (*) denotes a significant difference at this time point compared to the pre-2w baseline value in the pre group.

(2) Dizziness and Discomfort: Three patients (3.37%) reported feeling dizziness and discomfort during the exercise sessions. These sensations may have been temporary and related to physiological responses during the training. In response, the training plan for these patients was temporarily suspended for the day, allowing them to rest and recover. They resumed the training plan the following day after ensuring their well-being. For patients experiencing hip periarticular pain, short-term administration of enteric-coated sodium diclofenac tablets was provided to alleviate their discomfort and promote recovery. These adverse events were managed and addressed promptly to ensure the safety and well-being of all participants throughout the study.

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Table 4 Comparison of Gait Parameters at Specific Time Points Among 3 Groups

Gait Parameters	Pre Group	Post Group	Pre& Post Group	P_{12} value	P_{13} value	P_{23} value
Velocity (cm/s)						
Pre-2 weeks	66.25 ± 8.75	71.30 ± 20.27	70.58 ± 12.16	0.227	0.112	0.868
Pre-1 day	68.50 ± 10.24	67.32 ± 14.95	79.01 ± 18.62	0.722	0.012	0.011
Post-1 month	87.32 ± 16.11	80.12 ± 19.62	110.25 ± 16.32	0.129	0.001	0.001
Post-3 months	108.55 ± 17.66	99.80 ± 23.93	129.63 ± 27.60	0.116	0.001	0.001
Post-6 months	120.27 ± 18.70	129.15 ± 15.80	128.69 ± 14.47	0.051	0.052	0.127
Post-12 months	123.35 ± 15.35	125.10 ± 22.09	126.75 ± 21.86	0.713	0.494	0.770
Cadence (steps/min)						
Pre-2 weeks	60.35 ± 10.37	62.03 ± 10.54	59.58 ± 10.16	0.537	0.774	0.379
Pre-1 day	62.50 ± 7.01	59.83 ± 9.76	61.39 ± 8.06	0.216	0.559	0.497
Post-1 month	64.92 ± 11.50	65.80 ± 10.30	73.55 ± 14.73	0.750	0.017	0.026
Post-3 months	63.02 ± 10.72	69.78 ± 14.03	83.61 ± 12.36	0.045	0.001	0.001
Post-6 months	82.46 ± 14.12	84.20 ± 14.37	84.24 ± 15.63	0.639	0.639	0.991
Post-12 months	81.55 ± 12.53	83.18 ± 12.52	86.35 ± 14.32	0.594	0.175	0.366

Notes: P_{12} represents P value of Pre group vs Post group; P_{13} represents P value of Pre group vs Pre& Post group; P_{23} represents P value of group Post group vs Pre& Post group.

Table 5 Comparison of Balance Parameters and HHS Scores at Specific Time Points Among 3 Groups

Parameter	Pre Group	Post Group	Pre& Post Group	P_{12} value	P_{13} value	P_{23} value
Duration (s)						
Pre-2 weeks	0.75 ± 0.14	0.72 ± 0.13	0.75 ± 0.14	0.547	0.993	0.465
Post-3 months	1.42 ± 0.27	1.48 ± 0.36	2.72 ± 0.49	0.178	0.001	0.001
Post-12 months	2.31 ± 0.44	2.61 ± 0.35	3.75 ± 0.67	0.001	0.001	0.001
Distance (cm/s)						
Pre-2 weeks	20.89 ± 3.02	21.63 ± 3.95	21.87 ± 4.12	0.28	0.104	0.772
Post-3 months	12.34 ± 1.07	8.66 ± 0.74	8.19 ± 1.17	0.001	0.001	0.446
Post-12 months	8.40 ± 1.21	8.51 ± 1.46	8.32 ± 1.50	0.467	0.805	0.602
Area (cm2/s)						
Pre-2 weeks	19.56 ± 2.21	19.12 ± 2.52	19.67 ± 2.81	0.452	0.077	0.097
Post-3 months	12.6 ± 1.36	10.02 ± 1.13	6.97 ± 0.64	0.001	0.001	0.001
Post-12 months	7.92 ± 1.03	6.45 ± 0.55	4.03 ± 0.36	0.001	0.001	0.001
HHS scores						
Pre-2 weeks	50.73 ± 3.86	52.82 ± 6.60	52.35 ± 7.09	0.209	0.411	0.858
Post-3 months	69.17 ± 5.25	71.82 ± 9.60	79.46 ± 10.64	0.185	0.001	0.001
Post-12 months	82.25 ± 6.24	80.90 ± 9.71	90.58 ± 12.02	0.338	0.001	0.001

Notes: P_{12} represents P value of Pre group vs Post group; P_{13} represents P value of Pre group vs Pre& Post group; P_{23} represents P value of group Post group vs Pre& Post group.

Discussion

In our study, we opted for ISOMED-based moderate-intensity PRT and subsequent measurements. This approach offers several advantages over traditional training methods such as hydrotherapy, aerobic training, treadmill training, home-resistance training, and intermittent walking training.[6,7,15] ISOMED-based PRT provides clear objectives and quantifiable indicators, allowing for better control of the training process and more precise assessment of its effects. To evaluate muscle strength, we utilized an isokinetic test, which offers a more accurate and objective assessment of muscle strength compared to other methods. Our research demonstrated significant improvements in postoperative muscle strength across all three patient groups. These findings align with previous literature published.[2,10] Our muscle strength training regimen adhered to the guidelines provided by the American Geriatrics Society,[13] focusing on moderate-intensity isotonic strength training. While ISOMED-based training led to notable improvements in muscle strength for our patients, our research results do not yet provide an optimal protocol in terms of intensity and frequency for PRT muscle training in ISOMED-based THA postoperative patients.

Previous studies have consistently highlighted that although hip function tends to improve after THA, the hip muscles on the operated side often experience atrophy and weakened strength, which can persist for an extended period, sometimes up to two years or more after the surgery.[4,16,17] However, our study's results paint a more optimistic picture, demonstrating that targeted muscle training can effectively reverse this trend. We observed that the hip muscle strength in all three groups surpassed their baseline levels by approximately three months postoperatively. The improvement was remarkable, with a relative increase ranging from 162.50% to 201.58% compared to baseline at the 12-month follow-up. Additionally, the SLAR data provided valuable insights into the relative strength of hip muscles on the surgical and non-surgical limbs. At the 12-month follow-up, the majority of hip muscles on the surgical limb were notably stronger than those on the non-surgical limb, except for hip extension and abduction strength in the Pre group. Literature reports suggest that muscle strength reduction in patients with end-stage hip diseases, including HOA, is associated with various factors such as muscle atrophy, pain, anxiety, aberrant joint mechanics, and muscle activation deficit.[2,16,17] Muscle activation deficit refers to the muscles' incapacity to effectively activate and generate the required torque for joint movement, resulting in decreased joint mobility.[18] Electromyography studies have confirmed the presence of muscle activation deficit after THA, although the underlying pathophysiology remains intricate and not yet fully understood.[18,19] This deficit is common both before and after THA, leading to an emphasis in the literature on early postoperative rehabilitation interventions to enhance patients' muscle activation ability.[18–20] In our study, the THA surgery played a crucial role in alleviating hip pain, correcting aberrant joint mechanics, and establishing a foundation for muscle recovery. Muscle training can help improve muscle atrophy and muscle self-activation. We found that the Pre& Post group showed faster recovery compared to the other two groups, with higher absolute muscle strength at one year. This notable improvement in muscle strength can be attributed to the preoperative PRT improving muscle activation deficit and reducing anxiety that may arise during postoperative exercises, thereby promoting and consolidating the effects. This finding further confirms the positive significance of preoperative combined with postoperative PRT training in enhancing hip muscle strength on the surgical limb.

Maintaining adequate muscle strength is crucial for promoting balance and gait stability, especially in patients undergoing THA.[19,21] Strong muscles provide the necessary support and control during movement, which helps in maintaining balance and preventing falls. Preoperative muscle atrophy and pain, as well as postoperative changes in muscle strength, can significantly impact gait and balance. Moreover, THA surgery itself may lead to damage to joint proprioceptors, and abnormal proprioceptive signals can affect both sensation and motor control, further influencing gait and balance.[22,23] Numerous studies have established a positive correlation between muscle strength, gait and balance outcomes after THA.[19,21] PRT, when implemented following THA, has been shown to be effective in enhancing muscle strength and improving gait and balance. Building on this existing evidence, our study provides further confirmation that a combined approach of preoperative and postoperative PRT yields better and faster improvements in gait and balance compared to preoperative or postoperative PRT alone. The Pre& Post group, benefiting from the comprehensive training program, experienced rapid and robust improvements in muscle strength, gait, and balance. This group demonstrated superior hip joint function at both the 3-month and 12-month follow-ups compared to the other groups. These findings underscore the importance of implementing a well-designed, integrated rehabilitation protocol that includes both preoperative and postoperative PRT to optimize gait, balance, and overall hip joint function in patients undergoing THA.

This study offers a valuable moderate-intensity PRT muscle training program for postoperative THA patients, presenting a more quantifiable and predictable approach compared to traditional strength training methods. The emphasis on pre-operative combined with postoperative PRT training highlights its positive significance in enhancing muscle strength, gait, balance, and overall hip joint function in patients undergoing THA. As a result, this PRT training program holds promising clinical application prospects and can serve as a vital component of postoperative rehabilitation plans for THA patients.

Despite the significant findings that demonstrate the effectiveness of preoperative combined with postoperative PRT training in improving various outcomes for HOA patients after THA, our study has inherent limitations that warrant careful consideration. Firstly, the homogeneity of our study subjects, all derived from the same hospital and within a specific age range and disease category, raises concerns about the generalizability of our findings to a broader patient population. While this homogeneity allowed for a focused examination of the chosen cohort, it may limit the external validity of our results. Future research endeavors should aim to include a more diverse and representative sample, encompassing various demographics and clinical settings. Additionally, we acknowledge that our intervention measures, although efficacious in a controlled laboratory setting, necessitate further exploration regarding their feasibility and long-term effects in real-world clinical practice. The observed positive outcomes within the study's timeframe prompt the consideration of prolonged follow-up periods and real-world scenarios to better understand the sustainability and practicality of the proposed interventions. This aspect is crucial for translating research findings into applicable and beneficial clinical practices. Furthermore, variations in the intervention protocol and treatment implementation may have influenced our study results. While we strived for consistency, the dynamic nature of clinical settings introduces variability that should be acknowledged. Future research could focus on refining and standardizing intervention protocols to minimize these variations and enhance the reproducibility of results across diverse clinical environments. In light of these limitations, we emphasize caution when extrapolating our research findings to a broader patient population and diverse clinical settings. A nuanced understanding of the study's constraints is essential for both researchers and clinicians in contextualizing and applying our results. Looking ahead, future research endeavors could address these limitations by incorporating a more diverse participant pool, extending follow-up durations, and refining intervention protocols. Such efforts will contribute to the evolution of evidence-based practices and improve the translation of research findings into meaningful advancements in clinical care.

Conclusion

Preoperative combined with postoperative moderate-intensity PRT in HOA patients undergoing THA led to superior improvements in muscle strength, gait, balance, and hip joint function compared to preoperative or postoperative PRT alone. This intervention shows significant promise in optimizing postoperative rehabilitation and enhancing patient outcomes following THA.

Data Sharing Statement

Original data supporting the results of this study are available from the corresponding author upon request if needed.

Ethics Approval and Consent to Participate

The trial was registered in the Chinese Clinical Trial Registry under the registration number ChiCTR-2300072553. The research plan was approved by the Ethics Committee of the Sichuan Provincial Orthopedic Hospital (Approval No. KY202001501) and was carried out in accordance with the Helsinki Declaration. Written informed consent was obtained from all subjects involved in the study.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

All authors declare that there is no conflicts of interest in this work.

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