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Effects of an Enhanced Recovery After Surgery Program on Early Functional Recovery Following Total Hip Arthroplasty via the Direct Anterior Approach: A Randomized Controlled Trial

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Abstract

Background

The effectiveness of enhanced recovery after surgery (ERAS) programs following total hip arthroplasty (THA) via the direct anterior approach (DAA) remains unclear. This study aimed to (1) examine within-group improvements in muscle strength, balance, gait, and functional outcomes postoperatively, (2) compare recovery outcomes between regular care (RC) and ERAS groups over the first three months.

Methods

In this randomized controlled trial, patients aged 40–75 years undergoing unilateral DAA THA were assigned to RC or ERAS groups. Outcomes were assessed preoperatively and at 2, 4, 8, and 12 weeks postoperatively, including hip muscle strength, functional scores (HHS, HOOS, WOMAC), balance performance, and gait parameters. Data were analyzed using mixed-model ANOVA and independent t-tests.

Results

Thirty-three participants completed the study (RC: n = 18; ERAS: n = 15). Significant within-group improvements over time were observed in both groups across all outcomes ($p < 0.05$), particularly within the first four postoperative weeks. Between-group comparisons showed that the ERAS group demonstrated significantly greater hip flexor strength at postoperative week 2 ($p = 0.039$), higher functional scores (HHS: $p = 0.016$; HOOS: $p = 0.009$; WOMAC: $p = 0.012$), and improved gait parameters, including step length ($p = 0.007$) and walking velocity ($p = 0.008$). No serious postoperative complications were observed.

Conclusion

ERAS significantly enhanced early postoperative recovery following DAA THA and resulted in superior functional outcomes compared with conventional care, without increasing complication rates.

Trial registration

The study protocol was registered at ClinicalTrials.gov (No. NCT06356116) on February 16, 2024. This is retrospectively registered.

Introduction

According to data from the Taiwan National Health Insurance program, an average of 6,206 primary total hip replacements (THRs) were performed annually between 1996 and 2004, corresponding to an incidence of approximately 15 cases per 100,000 population per year (Lai et al., 2008). Furthermore, the annual incidence increased from 17.5 to 19.5 cases per 100,000 population between 1998 and 2009, representing an 11.4% rise (Kumar et al., 2015). According to the annual report of the American Joint Replacement Registry, the number of patients undergoing primary THR has also demonstrated an upward trend, with the annual rate increasing from 39.2 to 44.3 between 2022 and 2024 (Carender et al., 2025). The major indications for performing THR are avascular necrosis (AVN), which accounted for 46.9% of cases (79% male), and osteoarthritis (OA), which accounted for 41.6% of cases (43% male) (Lai et al., 2008). A 2023 review reported that approximately 61.3% of elderly individuals worldwide are affected by hip OA (Fan et al., 2023). Moreover, both the incidence and social burden of hip OA have shown an increasing trend over time (Fu et al., 2022), suggesting that the demand for THR will continue to rise in the future.

Total hip replacement (THR) provides substantial benefits, including pain relief, improved mobility, enhanced function, and better quality of life (Judd et al., 2014; Zimmerer et al., 2022). However, the extent of functional recovery is influenced in part by the surgical approach employed. The most commonly used approaches are the posterior approach (PA), direct lateral approach (DLA), and direct anterior approach (DAA), which differ in incision site and the degree of soft tissue involvement. Unlike PA and DLA, both of which require muscle detachment, the DAA preserves muscle integrity by avoiding muscle transection. Evidence suggests that patients undergoing THR via DAA experience superior outcomes compared with other approaches. Barrett et al. reported that DAA was associated with better pain relief and higher functional scores than PA at one year postoperatively (Barrett et al., 2013). Similarly, Zimmerer et al. demonstrated that DAA yielded more favorable pain and functional outcomes than DLA at six weeks postoperatively (Zimmerer et al., 2022). These findings suggest that DAA facilitates earlier recovery and aligns with the principles of enhanced recovery after surgery (ERAS).

With advances in surgical and anesthetic techniques, the concept of ERAS for total joint replacement has gained increasing attention. The benefits of ERAS for THR patients include preoperative optimization and a reduction in perioperative injury, pain, and stress, which collectively shorten hospital stays (Morrell et al., 2021) and decrease postoperative complications (Ripolles-Melchor et al., 2020). Several studies have compared the effects of ERAS protocols between the DAA and the PA for THR. Their findings indicate that patients undergoing PA had a 3.5-fold higher likelihood of staying in the hospital for more than one day compared with those undergoing DAA (Sibia et al., 2016). Furthermore, a greater proportion of patients who received THR via DAA achieved discharge goals within three days postoperatively compared with those who underwent PA (Malek et al., 2016). However, the DAA was showed a higher incidence of periprosthetic femoral fractures (Malek et al., 2016). In a recent study comparing outcomes of THR performed via DAA and the PA in patients with femoral fractures, the DAA group demonstrated shorter hospital stays, better pain control, less leg-length discrepancy, and earlier functional recovery within the first postoperative month (Wang et al., 2025). By six months after surgery, however, outcomes between the two approaches were comparable (Wang et al., 2025). So that, integrating ERAS protocols with DAA in THR can further enhance recovery efficiency and support earlier patient rehabilitation.

In Taiwan, most rehabilitation services remain outpatient-based, requiring patients to visit clinics or hospitals to receive face-to-face interventions from therapists. This mode of delivery can be disadvantageous and inconvenient for patients living in rural or remote areas. To address these issues, telemedicine has been introduced, utilizing internet and communication technologies to overcome geographical barriers. Previous systematic reviews and meta-analyses have indicated that telerehabilitation can achieve comparable outcomes to traditional face-to-face rehabilitation and may provide additional benefits in certain functional tasks, such as the Timed Up and Go test and the Harris Hip Score (Wu et al., 2023; Zhou et al., 2024). Furthermore, patient compliance and satisfaction with the quality of telerehabilitation interventions were significantly higher than those associated with traditional rehabilitation approaches (Nelson et al., 2020; Zhou et al., 2024).

The above findings indicate a growing demand for THR, with DAA emerging as the preferred approach due to its superior early postoperative recovery profile. When combined with ERAS and telerehabilitation strategies, patient outcomes may be further optimized, providing more comprehensive postoperative care and functional recovery.

Therefore, this study aims to provide evidence of following purposes. First, to examine within-group improvements in muscular strength, balance ability, gait, and function after DAA-THR, comparing conventional care and ERAS program. Second, to compare between-group recovery outcomes (conventional care vs. ERAS rehabilitation) over the first three months postoperatively. And finally, to record postoperative complication rates in all participants. The hypotheses of our study are (1) Patients undergoing accelerated rehabilitation will show greater improvements in early postoperative muscular strength, balance ability, gait, and function compared with those receiving regular care; (2) Among patients undergoing DAA-THR, those assigned to accelerated rehabilitation will achieve superior recovery outcomes within the first three months postoperatively compared with those receiving conventional care.

Methods

Study Design

This study was a single-center and single-blind randomized controlled trial. After providing informed consent, participants completed baseline demographic information and were randomly allocated to either the conventional care group or the ERAS group. Outcome assessments included balance ability (center of mass, sway area, and sway velocity), gait parameters, muscle strength (hip abductor and hip flexor muscles), and functional questionnaires. Assessments were conducted at five time points: one day before surgery (baseline, T1), postoperative week 2 (T2), postoperative week 4 (T3), postoperative week 8 (T4), and postoperative week 12 (T5).

Participants

The inclusion criteria were as follows: (1) age between 40 and 75 years; (2) diagnosis of avascular necrosis of the femoral head or osteoarthritis requiring unilateral total hip arthroplasty; and (3) surgery performed using the direct anterior approach. Exclusion criteria included: (1) inability to walk independently for more than 10 meters prior to the onset of the current condition; (2) presence of diseases affecting gait function; (3) history of other lower extremity surgeries within the past year (excluding contralateral total hip arthroplasty or decompression surgery); (4) receipt of nerve block procedures. All participants were screened for eligibility by a physiotherapist according to these criteria.

Between September 2022 and July 2024, a total of 35 individuals aged 40–75 years were screened at China Medical University Hospital. Of these, 33 participants consented to participate in the study. Of these, all participants provided written informed consent and were enrolled in the study. They were randomly allocated to the regular care group (n = 18) or the ERAS group (n = 15). All participants were diagnosed by orthopedic surgeons. Eligibility screening was conducted using structured questionnaires based on the predefined inclusion and exclusion criteria.(Fig. 1)

Interventions

Both groups received identical regular hospital care from one day prior to surgery until discharge on postoperative day two by the same physiotherapist. Conventional care protocols were based on Clinical Orthopedic Rehabilitation (Giangarra & Manske, 2017) and included preoperative education via instructional videos and handouts on assistive device use. On the first postoperative day, bedside physical therapy was provided, including ankle pumping exercises, isometric quadriceps contractions, assisted hip range-of-motion exercises, and bedside standing. These exercises were repeated on postoperative two days. Stair-climbing training was provided only if required for home mobility. These interventions constituted the full treatment for the regular care group.

In addition to regular care, the ERAS group received preoperative goal-setting discussions with a physical therapist and practiced postoperative rehabilitation exercises in advance. Ambulation with a walker began on the day of surgery after recovery from anesthesia. Rehabilitation began immediately after surgery, with two sessions conducted daily. Morning sessions included assisted hip range-of-motion exercises and five minutes of bedside ambulation, while afternoon sessions involved stair climbing and ten repetitions of mini-squat sit-to-stand exercises. On the second day, participants practiced climbing one to two floors of stairs and received a personalized one-month home exercise booklet based on preoperative rehabilitation goals.

After discharge, telerehabilitation was conducted via LINE video calls two to three times per week for up to one month postoperatively. Each session lasted 20–30 minutes and was conducted under the supervision of a family member or therapist.

Outcomes

Muscle Strength

Hip abductor and hip flexor muscle strength were assessed using a handheld dynamometer (MicroFET 2, Hoogan Health Industries, USA). For hip abductor testing, participants lay supine with feet shoulder-width apart. The dynamometer was placed on the lateral aspect of the knee and stabilized by the examiner. Participants were instructed to abduct the leg slowly with the knee extended until maximal force or pain occurred.

For hip flexor strength testing, participants lay supine with the tested hip slightly flexed and the knee flexed to 90°, with the foot flat on the bed. The dynamometer was positioned at the distal thigh between the medial and lateral femoral condyles and stabilized by the examiner. Participants were instructed to lift the knee toward the chest until maximal force or pain occurred. Each muscle group was tested three times per limb, and the peak force was recorded. The average of these peak forces was used for analysis.

Functional Questionnaires

Functional outcomes were assessed using the Chinese versions of the Harris hip score (HHS), the hip disability and osteoarthritis outcome score (HOOS), and Chinese version of the Western Ontario and McMaster Universities osteoarthritis index (WOMAC). The HHS evaluates pain, function, and range of motion, with a total score of 100 points; higher scores indicate better function. The HOOS is a self-administered questionnaire assessing symptoms and functional limitations across five domains: symptoms and stiffness (5 items), pain (10 items), activities of daily living (17 items), sports and recreation (4 items), and quality of life (4 items). Each item is scored from 0 to 4, with higher scores indicating better function. The WOMAC assesses pain (5 items), stiffness (2 items), and physical function (17 items). Scores range from 0 to 4, with lower scores indicating better function.

Balance and fall risk assessment

Balance testing was conducted using the Biodex Balance System (Biodex Medical Inc., USA). Participants stood on firm and foam surfaces with eyes open and closed for 30 seconds each. Foot placement was standardized and recorded during the first trial. Participants were instructed to stand still with arms at their sides and avoid touching external supports. The system automatically calculated the sway index.

Fall risk testing was also performed using this system, with participants standing on a firm surface with eyes open and closed for 45 seconds. The system calculated displacement velocity (mm/s) and sway velocity index (SVI), which were converted into standardized Z-scores.

Gait function

Gait function was performed using the portable RehaGait system (Hasomed RehaGait, Germany). Sensors were placed bilaterally on the lateral thighs, lateral shank, dorsal side of the feet, and sacrum. After attaching the sensors, participants walked along a 10-meter straight path at a self-selected pace, stopped at a marked point, turned upon instruction, and walked back to the starting point. Two trials were recorded. Gait-related parameters, including step length, walking speed, cadence, and hip joint kinematics, were recorded.

Complications

Postoperative complications were assessed at postoperative week 12 through patient interviews and medical record review.

Statistical Analysis

Statistical analyses were conducted using SPSS version 22 (SPSS Inc., USA). Categorical variables (gender, affected side, diagnosis) were analyzed using chi-square tests. Continuous variables (age, height, weight) were analyzed using independent t-tests to compare baseline characteristics. Intervention effects at different time points (T1 - T5) were analyzed using independent t-tests for between-group comparisons and paired t-tests for within-group bilateral comparisons. Mixed-model ANOVA was used to evaluate time effects, group effects, and time-by-group interactions. Bonferroni post hoc tests were applied when significant time effects were detected.

Sample size estimation was performed using G*Power 3.1.9.7 based on postoperative week two data, with a two-tailed test, power of 0.95, and alpha level of 0.05. The minimum required sample sizes per group were 10 for HHS, 11 for affected-side hip flexor strength, 9 for WOMAC total score, and 10 for HOOS total score. In this study, a minimum of 15 participants were enrolled, which was considered sufficient to achieve adequate statistical power.

Results

Participant

A total of 35 patients scheduled to undergo total hip arthroplasty were recruited for this study. Two patients withdrew due to inability to comply with the study procedures. Consequently, 33 participants met the inclusion criteria and consented to participate. Baseline characteristics of the participants are presented in Table 1. Among these, only the stiffness and exercise subscales of the HOOS and the stiffness of the WOMAC were significantly higher in the ERAS group.

In the regular care (RC) group, 18 participants completed the baseline assessment (T1), 11 completed the second assessment (T2), 15 completed the third assessment (T3), 12 completed the fourth assessment (T4), and 14 completed the final assessment (T5). In the ERAS group, 15 participants completed the

first assessment (T1), 14 completed the second assessment (T2), and all 15 participants completed the subsequent assessments (T3–T5). The flow chart throughout the study is illustrated in Fig. 1.

Table 1
Basic information of participants

Gender	RC group (n = 18)	ERAS group (n = 15)	p-value
Female	11	7	0.407 [1]
Male	7	8	
Age (year)	58.78 ± 11.66	51.07 ± 12.02	0.072
Height (cm)	163.44 ± 10.05	163.07 ± 8.32	0.908
Weight (kg)	68.11 ± 13.82	64.20 ± 12.42	0.403
Affected side			
Left	9	5	0.335 [1]
Right	9	10	
Diagnosis			
Avascular necrosis	12	11	0.678 [1]
Osteoarthrosis	6	4	
HHS	69.80 ± 13.95	75.00 ± 9.07	0.236
HOOS			
Symptoms	9.00 ± 2.75	10.33 ± 2.41	0.169
Stiffness	6.60 ± 0.74	7.47 ± 0.74	0.003*
Pain	29.07 ± 4.43	30.07 ± 5.76	0.598
Function	54.00 ± 9.36	59.53 ± 5.66	0.060
Exercise	8.67 ± 2.99	11.33 ± 2.87	0.019*
Quality of life	7.80 ± 2.46	7.47 ± 2.56	0.719
Total	115.20 ± 18.87	126.07 ± 15.52	
WOMAC			
Pain	7.07 ± 2.91	6.60 ± 4.15	0.724
Stiffness	1.40 ± 0.74	0.53 ± 0.74	0.003*
Function	13.47 ± 8.81	8.40 ± 5.54	0.070
Total	21.93 ± 10.89	15.53 ± 8.47	0.083
*: $p < 0.05$			
[1]: Chi-square test			

Muscle Strength

Muscle strength results are presented in Table 2. Significant time effects were observed for hip abductor ($p = 0.013$) and hip flexor strength ($p = 0.001$) on the affected side. A significant group effect was found only for affected-side hip flexor strength ($p = 0.003$). Between-group comparisons showed greater strength in the ERAS group than in the RC group for affected-side hip abductors at postoperative week 8 ($p = 0.008$) and hip flexors at postoperative weeks 2 ($p = 0.039$) and 8 ($p = 0.036$). Within-group comparisons demonstrated greater strength on the unaffected side for hip abductors in the ERAS group at postoperative week 2 ($p = 0.047$). For hip flexors, both groups showed greater unaffected-side strength preoperatively and at postoperative week 2 (ERAS: $p = 0.013$, $p = 0.026$; RC: $p = 0.018$, $p < 0.001$).

Table 2
Changes in bilateral muscle strength at different time points in both groups.

Muscle strength (kg)	RC group					ERAS group					Between group p-value				
Postoperative week	0 (n = 15)	2 (n = 9)	4 (n = 12)	8 (n = 12)	12 (n = 13)	0 (n = 15)	2 (n = 14)	4 (n = 15)	8 (n = 14)	12 (n = 12)	0	2	4	8	12
US abd.	11.17 ± 3.49	9.40 ± 3.27	9.98 ± 3.23	11.33 ± 3.20	12.2 ± 3.36	11.23 ± 3.59	10.89 ± 3.25	12.26 ± 3.76	12.11 ± 3.79	11.26 ± 3.11	0.959	0.269	0.085	0.579	0.4
AS abd. †, ▯, ▯, ▯	9.46 ± 3.28	7.31 ± 2.74	9.58 ± 3.98	9.36 ± 1.81	11.55 ± 4.19	10.18 ± 4.67	8.58 ± 2.42	11.34 ± 4.26	12.57 ± 3.73	11.81 ± 3.42	0.611	0.241	0.251	0.008*	0.8
Within group p-value	0.139	0.119	0.762	0.076	0.643	0.492	0.047*	0.535	0.740	0.650					
US flex.	11.3 ± 4.14	9.34 ± 2.26	10.73 ± 4.81	9.89 ± 2.69	11.56 ± 4.74	11.23 ± 3.20	10.46 ± 3.12	11.60 ± 4.10	11.99 ± 4.01	12.14 ± 3.96	0.927	0.331	0.606	0.131	0.7
AS flex. †, ‡, ▯, ▯, ▯, ▯, ▯	6.85 ± 5.24	4.61 ± 2.02	8.27 ± 3.62	8.04 ± 2.21	9.97 ± 4.85	7.83 ± 3.76	7.32 ± 3.64	9.27 ± 2.75	10.67 ± 3.25	10.27 ± 4.07	0.563	0.039*	0.406	0.036*	0.2
Within group p-value	0.018*	< 0.001*	0.137	0.110	0.424	0.013*	0.026*	0.078	0.330	0.213					

RC: regular care, ERAS: enhanced recovery after surgery, US: Unaffected side, AS: Affected side, abd.: abductor, flex.: flexor

*: Significant difference ($p < 0.05$), †:Times effect, ‡:Group effect, ▯: Significant difference between baseline (T1) and postoperative 8 week (T4), ▯: Significant difference between baseline (T1) and postoperative 12 week (T5), ▯: Significant difference between postoperative 2 week (T2) and postoperative 4 week (T3 ▯: Significant difference between postoperative 2 week (T1) and postoperative 8 week (T4), ▯: Significant difference between postoperative 2 week (T2) and postoperative 12 week (T5)

Functional Questionnaires

For HHS, significant effects were observed for time ($p < 0.001$) and group ($p < 0.001$). Post-hoc analysis showed significant improvements at postoperative weeks 4 (T3), 8 (T4), and 12 (T5) compared with preoperative (T1) and postoperative week 2 (T2) assessments. Between-group comparisons demonstrated significantly higher HHS scores in the ERAS group than in the RC group at postoperative weeks 2 (T2) ($p = 0.016$), 4 (T3) ($p = 0.004$), and 8 (T4) ($p = 0.038$) (Fig. 3).

For HOOS, significant time effects were observed for the total score and some subdomains, including symptoms, pain, function, and exercise (all $p < 0.001$). Significant group effects were observed for pain ($p = 0.018$), function ($p < 0.001$), sports activity domain ($p < 0.001$), and total score ($p < 0.001$). Significant group-by-time interactions were identified for stiffness ($p = 0.019$) and exercise ($p = 0.032$). Between-group comparisons showed that the ERAS group had significantly better pain (RC: 34.64 ± 3.53, ERAS: 37.36 ± 1.82, $p = 0.035$), function (RC: 49.45 ± 9.00, ERAS: 57.14 ± 5.35, $p = 0.014$), exercise domain (RC: 8.27 ± 2.33, ERAS: 10.36 ± 2.53, $p = 0.045$), and total scores ($p = 0.009$) at postoperative week 2. At postoperative weeks 4 and 8, the ERAS group also demonstrated significantly better function, exercise, and total scores than the RC group (Fig. 2).

For WOMAC, significant time and group effects were found for pain ($p < 0.001$, $p = 0.046$), function ($p < 0.001$, $p < 0.001$), and total score ($p < 0.001$, $p < 0.001$). A significant group-by-time interaction was observed for stiffness ($p = 0.005$). Between-group comparisons revealed significantly better function (T2 RC: 18.45 ± 8.79, ERAS: 10.93 ± 5.46, $p = 0.015$; T3 RC: 8.73 ± 6.43, ERAS: 3.07 ± 3.03, $p = 0.006$; T4 RC: 4.58 ± 5.25, ERAS: 1.13 ± 2.29, $p = 0.030$) and total scores (T2 $p = 0.012$; T3 $p = 0.012$; T4 $p = 0.045$) in the ERAS group at postoperative weeks 2, 4, and 8 compared with the RC group (Fig. 3).

Balance and fall risk assessment

For the balance test (Table 3), a significant time effect was observed only for standing on a foam surface with eyes closed ($p = 0.012$), while no significant differences were found for other conditions. Between-group comparisons showed that the ERAS group demonstrated better balance than the RC group when standing on foam with eyes open ($p = 0.035$) and eyes closed ($p = 0.015$) at postoperative week 2.

For the fall risk test (Table 3), under the eyes-open condition, a significant group effect was observed only for the sway velocity index ($p = 0.048$). Under the eyes-closed condition, significant time effects were found for velocity ($p = 0.015$), sway index ($p = 0.013$), and Z-score ($p = 0.038$). Post-hoc analysis indicated that velocity during eyes closed standing improved significantly at postoperative week 12 compared with preoperative values. Between-group comparisons further showed that velocity and sway velocity index during eyes open standing were significantly better in the ERAS group than in the RC group at postoperative week 4.

Table 3
Balance and fall risk test results at different time points in both groups.

Postoperative week	RC group					ERAS group					p-value				
	0 (n = 15)	2 (n = 9)	4 (n = 12)	8 (n = 12)	45 (n = 13)	0 (n = 15)	2 (n = 14)	4 (n = 15)	8 (n = 14)	12 (n = 12)	0	2	4	8	12
Balance test															
EO_firm	1.23 ± 0.83	1.56 ± 1.07	1.33 ± 0.73	1.49 ± 1.51	1.30 ± 0.75	1.01 ± 0.47	1.18 ± 0.53	1.11 ± 0.45	1.24 ± 0.40	1.19 ± 0.71	0.401	0.258	0.323	0.598	0.6
EC_firm	1.65 ± 0.81	2.11 ± 1.48	1.80 ± 1.17	1.70 ± 0.86	1.64 ± 0.96	1.70 ± 0.78	1.57 ± 0.79	1.64 ± 0.67	1.67 ± 0.75	1.58 ± 0.90	0.885	0.245	0.653	0.908	0.8
EO_foam	2.23 ± 0.75	3.17 ± 1.51	2.36 ± 1.30	2.38 ± 0.95	2.42 ± 1.25	2.19 ± 0.72	2.02 ± 0.66	2.07 ± 0.80	2.09 ± 0.69	2.17 ± 0.43	0.895	0.035*	0.468	0.359	0.4
EC_foam †	5.76 ± 1.35	7.35 ± 2.12	6.07 ± 2.46	5.56 ± 2.08	5.63 ± 1.83	5.24 ± 1.08	5.49 ± 1.42	5.26 ± 1.32	4.97 ± 1.62	4.99 ± 1.28	0.289	0.015*	0.269	0.417	0.2
Fall risk test															
EO_V (mm/sec)	10.12 ± 4.89	8.11 ± 2.87	8.03 ± 3.57	6.83 ± 3.98	6.50 ± 2.04	7.46 ± 3.03	7.22 ± 2.80	5.80 ± 1.49	6.37 ± 2.49	6.00 ± 2.07	0.100	0.444	0.038*	0.670	0.5
EO_S ‡	13.85 ± 2.95	12.81 ± 2.21	12.56 ± 2.76	11.43 ± 2.77	11.20 ± 2.39	10.92 ± 3.43	11.77 ± 2.21	10.66 ± 1.83	11.12 ± 2.51	10.70 ± 2.22	0.032*	0.256	0.035*	0.758	0.5
EO_Z	1.85 ± 1.28	1.47 ± 1.00	1.48 ± 1.22	0.94 ± 1.00	1.02 ± 1.07	1.61 ± 1.40	1.43 ± 0.94	0.91 ± 0.75	1.08 ± 1.15	0.94 ± 1.05	0.666	0.923	0.131	0.752	0.8
EC_V (mm/sec) †, d	13.44 ± 6.77	11.92 ± 8.25	9.57 ± 4.34	8.43 ± 3.47	8.10 ± 3.17	10.65 ± 5.95	9.87 ± 4.18	7.73 ± 2.97	8.34 ± 3.61	8.64 ± 3.86	0.275	0.427	0.186	0.945	0.6
EC_S †	15.31 ± 3.95	14.70 ± 3.55	13.53 ± 2.95	12.75 ± 3.18	12.39 ± 2.65	13.84 ± 3.39	13.66 ± 2.53	12.15 ± 2.49	12.51 ± 2.82	12.74 ± 2.56	0.319	0.398	0.175	0.843	0.7
EC_Z †	1.35 ± 1.57	1.20 ± 1.21	0.85 ± 0.93	0.54 ± 0.95	0.60 ± 1.02	1.43 ± 1.53	1.25 ± 1.07	0.65 ± 0.96	0.79 ± 1.13	0.90 ± 1.11	0.899	0.911	0.554	0.548	0.4

EO: Eyes open, EC: Eyes closed, V: Velocity, S: Sway velocity Index, Z: Z-score

*: Significant difference (p < 0.05), †:Times effect, ‡:Group effect, □: significant difference between baseline (T1) and postoperative 12 week (T5)

Gait Analysis

Gait analysis results are shown in Fig. 3. Significant time effects were observed for stride length ($p < 0.001$), walking velocity ($p < 0.001$), cadence ($p < 0.001$), hip flexion and total range of motion (ROM) of the unaffected side during walking (both $p < 0.001$). Gait symmetry also showed a significant time effect ($p < 0.001$). Significant group effects were observed only for hip total ROM ($p = 0.026$) of the unaffected side during walking.

Post-hoc analysis showed significant improvements in hip total ROM of the unaffected side at postoperative week 2 compared with preoperative values. At postoperative week 4, significant improvements were observed in stride length, walking velocity, cadence, and hip total ROM of the affected side. At postoperative week 12, further improvements were noted in stride length, walking velocity, cadence, hip total ROM of the affected side, and gait symmetry.

Between-group comparisons showed that the ERAS group demonstrated significantly greater stride length ($p = 0.007$), and walking velocity ($p = 0.008$) at postoperative week 2 (T2) compared with the RC group. At postoperative week 8 (T4). Within-group comparisons showed greater hip total ROM of the unaffected side compared with the affected side across multiple time points, particularly in the ERAS group.

Complications

Paresthesia (tingling, numbness, burning sensation, or pain) was the only complication observed. It occurred in 11 patients (61%) in the RC group and six patients (40%) in the ERAS group, representing 17 participants (52%) overall. No other complications or adverse events were reported.

Discussion

The present study demonstrated significant improvements in hip muscle strength following total hip arthroplasty using the DAA (Table 2). Affected-side hip abductor strength significantly increased at postoperative weeks 4, 8, and 12 compared with week 2, and even exceeded preoperative levels. At postoperative week 8, affected-side hip abductor strength was significantly greater in the ERAS group than in the RC group. In contrast, no significant differences between the affected and unaffected sides were observed in the RC group throughout the study period, whereas a transient difference was observed in the ERAS group at postoperative week 2, which may be attributed to early postoperative pain and wound recovery.

For hip flexor strength on the affected side, both groups showed significant improvements at postoperative weeks 8 and 12 compared with preoperative values and postoperative week 2. Notably, hip flexor strength on the unaffected side in the ERAS group recovered to preoperative levels as early as postoperative week 2, whereas significant improvement in the RC group was not observed until postoperative week 4. These findings suggest that the ERAS program may facilitate earlier recovery of hip flexor strength. The ERAS protocol emphasizes sagittal-plane activities, such as high-knee angle walking and partial squats, which may enhance muscle activation and accelerate strength recovery. Compared with Nelson et al., the improvements in hip muscle strength observed in this study were greater than those reported, who found minimal changes in hip abductor and flexor strength up to six months postoperatively (Nelson et al., 2020). The relatively younger age of participants in the present study may partially explain these differences.

Functional outcomes assessed using HHS, HOOS, and WOMAC showed significant improvements over time in both groups (Fig. 2). For the HHS, both groups demonstrated significant improvement from postoperative week 2. However, the ERAS group showed significantly higher scores than the RC group between weeks 2 and 8. The ERAS group reached the minimal clinically important difference (MCID; 15.9–18.0) (Singh et al., 2016) by postoperative week 4, whereas the RC group reached MCID at week 8, indicating faster functional recovery in the ERAS group. HOOS results also showed significant improvements across all domains after surgery. The ERAS group demonstrated significantly better functional, sports, and total scores between postoperative weeks 2 and 8. Compared with previous studies (Barrett et al., 2013), functional recovery in the present study appeared faster, likely due to the increased intervention dosage associated with the structured rehabilitation program. In addition, the ERAS group approached near-maximal scores by postoperative week 4. Both groups demonstrated clinically meaningful improvement (MCID: 6–9 points (Lyman et al., 2018)) as early as postoperative week 2. For WOMAC scores, both groups showed significant improvements in pain at postoperative week 2, whereas improvements in function and total score became significant at week 4. Although neither group reached the reported MCID threshold (25 point)(Quintana et al., 2005), the ERAS group showed faster functional improvement and approached minimal symptom levels earlier than the RC group. Overall, functional outcomes in this study improved more rapidly than in many previous reports, possibly due to the younger study population and the enhanced postoperative rehabilitation program.

Balance testing showed significant improvements over time, particularly in the sway index under the eyes-closed foam condition (Table 3). The ERAS group demonstrated significantly better balance performance than the RC group when standing on foam at postoperative week 2. Despite these improvements, sway index values remained higher than normative data from the norm of Biodex Balance System across most testing conditions, suggesting that the rehabilitation program may not have been sufficiently intensive to fully restore balance function. These findings indicate that surgical treatment alone may not substantially improve balance, while structured rehabilitation may contribute to partial recovery.

Gait analysis revealed progressive improvements in gait parameters following surgery (Fig. 3). Step length, walking velocity, and cadence improved significantly by postoperative week 8, whereas hip flexion ROM on the unaffected side improved as early as postoperative week 2. Gait symmetry improved more gradually and became significant at postoperative week 12. The ERAS group demonstrated greater step length and walking velocity at postoperative week 2 compared with the RC group, indicating faster early functional recovery. Compared with previous studies, cadence values in both groups at postoperative weeks 4 and 12 in the present study were comparable to those reported at 3 months and 2 years postoperatively, respectively (Mayr et al., 2009). Furthermore, walking velocity showed a faster recovery trajectory than that reported in previous studies (Mayr et al., 2009; Thaler et al., 2018). According to Carse et al., the minimal clinically important difference (MCID) for walking speed after surgery is 0.21 m/s (Carse et al., 2021). In the present study, the RC group reached the MCID at postoperative week 8 compared with preoperative values, whereas the ERAS group approached the MCID at postoperative week 12. Although the RC group appeared to achieve earlier recovery based on MCID. The baseline walking velocity differed between groups by 0.07 m/s, and no significant between-group differences were observed from postoperative week 4 onward. Notably, walking velocity in the ERAS group remained comparable to preoperative levels as early as postoperative week 2, whereas the RC group exhibited a greater initial decrease at postoperative week 2, followed by an early increase. Furthermore, from postoperative week 8 onward, walking velocity in the ERAS group was consistently higher than in the RC group. These findings suggest that although the RC group reached the MCID earlier, the ERAS group demonstrated a more stable and sustained recovery pattern.

The only complication observed in this study was paresthesia associated with lateral femoral cutaneous nerve irritation. The incidence was higher in the RC group (61%) than in the ERAS group (40%). These findings are consistent with previous reports indicating that sensory disturbances following the direct anterior approach are relatively common but typically transient (Bhargava et al., 2010). No serious complications or adverse events were observed during the study period.

Several limitations should be acknowledged. First, the relatively small sample size (n = 33) may limit the generalizability of the findings. Although the sample size exceeded the minimum requirement based on the power analysis, caution is still warranted when interpreting the results. Second, baseline differences in some questionnaire subscales may have influenced postoperative comparisons. Third, postoperative rehabilitation outside the study protocol could not be fully controlled, which may have introduced potential bias.

Conclusion

The enhanced recovery after surgery program significantly improved postoperative recovery following total hip arthroplasty using the direct anterior approach. Patients in the ERAS group demonstrated faster recovery in hip muscle strength, functional outcomes, balance performance, and gait parameters compared with the RC group. These findings suggest that structured accelerated rehabilitation may enhance early functional recovery and may be particularly beneficial for patients who require home-based rehabilitation programs.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of China medical university Hospital (Protocol Number: CMU111-S-31/CMUH111-REC3-029). All participants provided written informed consent before they were enrolled in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Table legends

Table 1. Baseline characteristics of participants

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Author Contribution

Chih-Hung Hung, Horng-Chaung Hsu and Hsiu-Chen Lin conceived and designed the study.Chia-Ming Chang and Teng-Wei Huang performed the literature search and data extraction.Teng-Wei Huang and Hsiu-Chen Lin analyzed and interpreted the data.Chia-Ming Chang drafted the manuscript.All authors critically revised the manuscript, approved the final version, and agree to be accountable for all aspects of the work.

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Not applicable.

Data Availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Figures

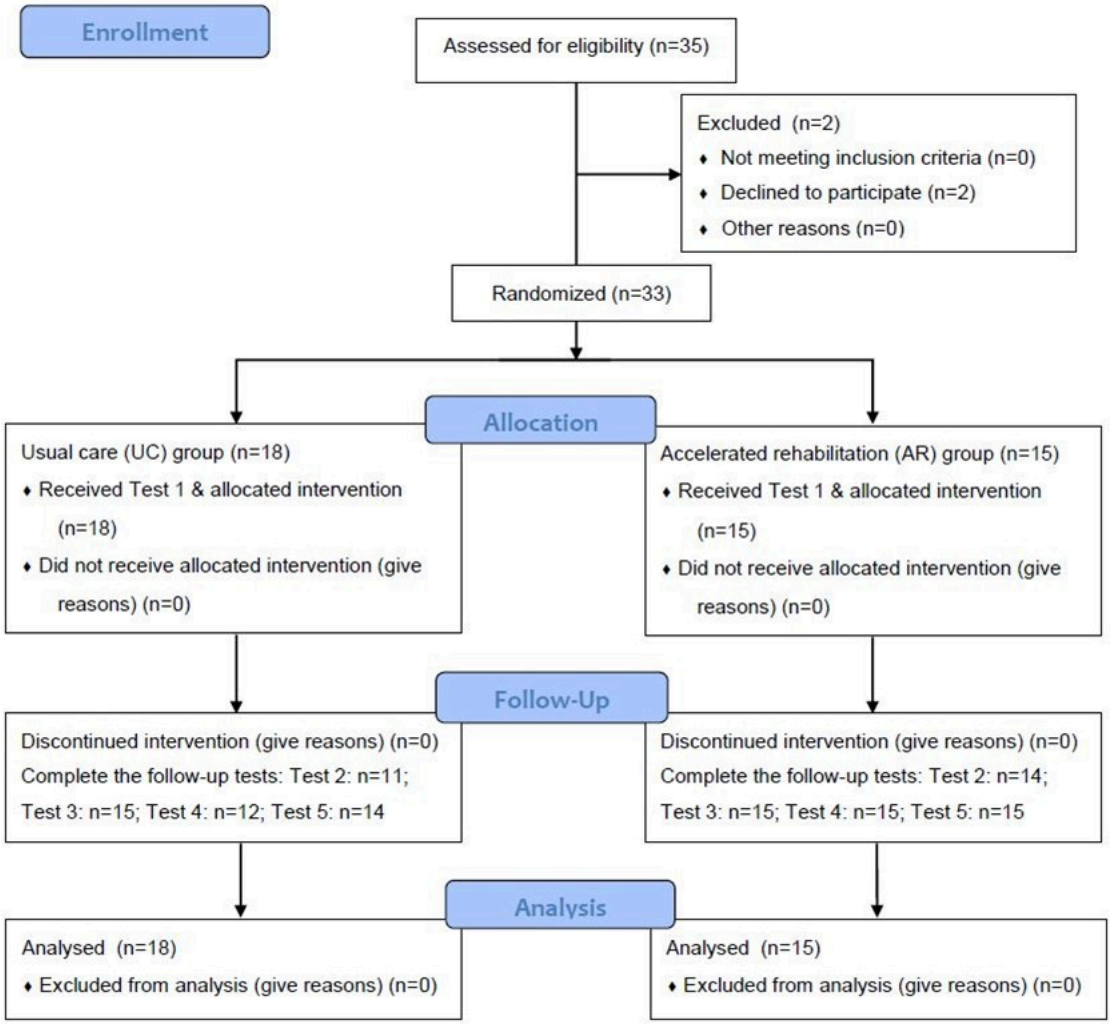


Figure 1

Study flowchart.

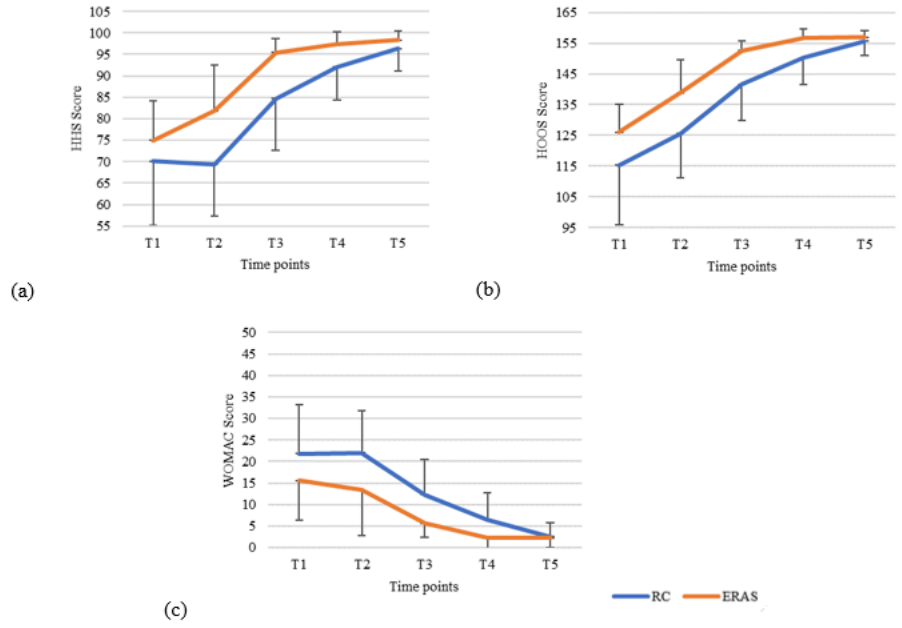


Figure 2. Functional scales (a) HHS total score; (b) HOOS total score; (c) WOMAC total score

Figure 2

Total score of functional questionnaires across time points: (a) HHS; (b) HOOS; (c) WOMAC.

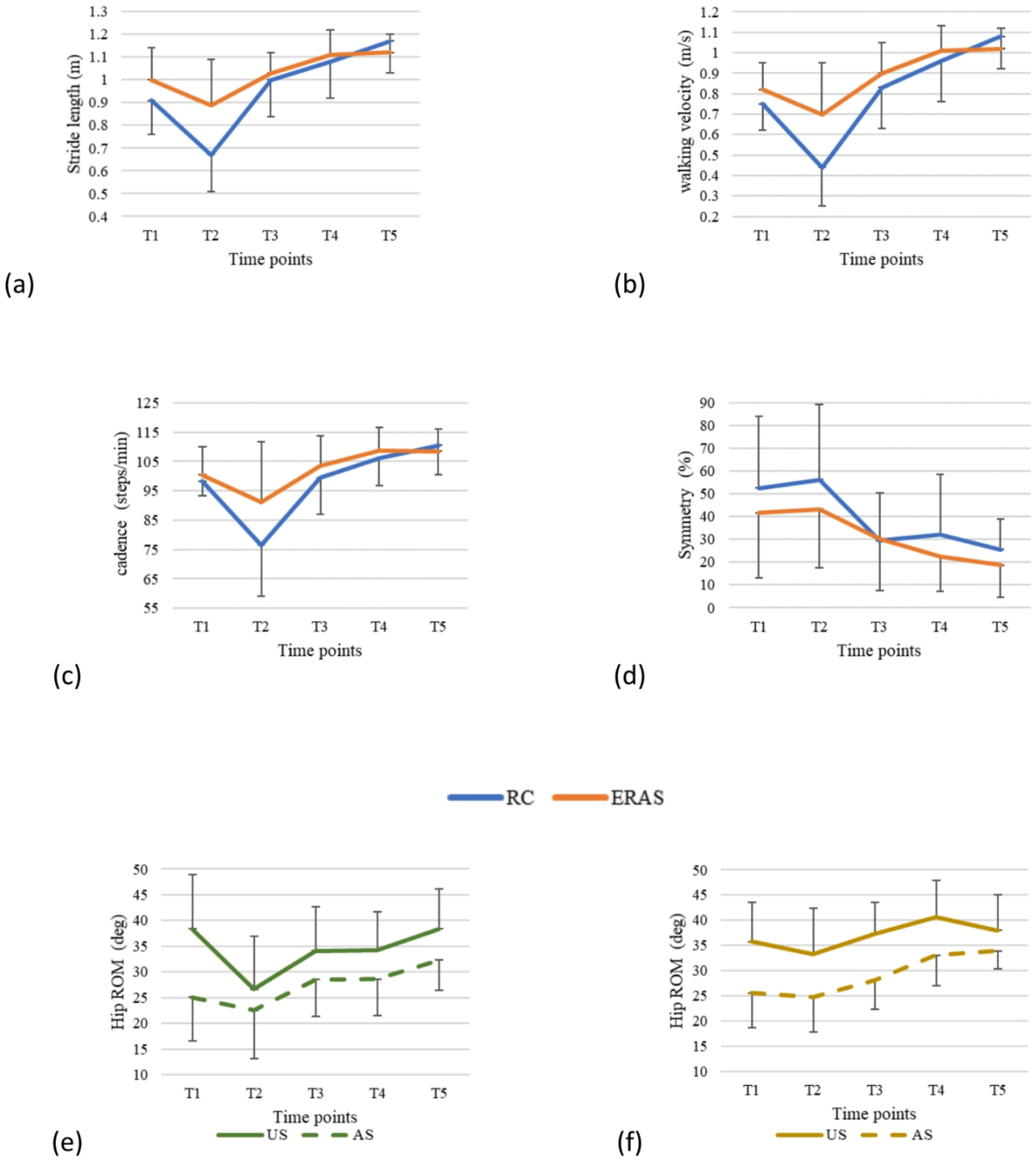


Figure 3

Gait parameters at different time points in both groups. (a) Stride length; (b) walking velocity; (c) cadence; (d) symmetry of bilateral hip joint range of motion (ROM) during walking; (e) hip joint range of motion during walking in the RC group; (f) hip joint range of motion during walking in the ERAS group. (US: Unaffected side, AS: Affected side)

Supplementary Files

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- Tables20260331.docx