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ORIGINAL ARTICLE

Enhanced recovery after surgery combined with quantitative rehabilitation training in early rehabilitation after total knee replacement: a randomized controlled trial

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ABSTRACT

BACKGROUND: The number of patients undergoing total knee replacement (TKR) is increasing yearly; however, there is still a relative lack of specific, individualized, and standardized protocols for functional exercise after TKR. Quantitative rehabilitation training was developed to improve the recovery of postoperative joint function, increase patient satisfaction, shorten the length of the hospital stay, improve the quality of life, and promote rapid patient recovery.
AIM: We aimed to compare the effectiveness of quantitative rehabilitation training based on the enhanced recovery after surgery (ERAS) concept with conventional rehabilitation training in the early rehabilitation of patients with TKR.
DESIGN: This was a single-centre, prospective, randomized controlled trial.
SETTING: Inpatient department.
POPULATION: Participants were patients who underwent unilateral total knee replacement.
METHODS: Based on the ERAS concept, a quantitative rehabilitation training program was developed for the quantitative group, and the control group underwent conventional rehabilitation training. Seventy-eight patients undergoing TKR were randomly divided into two blinded groups: the quantitative rehabilitation group and the conventional rehabilitation group. The analysis was performed according to per-protocol practice. The primary outcome metric was the Hospital for Special Surgery Knee Score (HSS Score), and secondary outcomes included patient satisfaction, Visual Analog Pain Score (VAS), time to get out of bed for the first time after surgery, 6-minute-walk test (6MWT), quality-of-life score (SF-36), and number of days in the hospital. The incidence of postoperative complications was also recorded.
RESULTS: There was no significant difference in HSS scores between the two groups before surgery (P=0.967), but the quantitative rehabilitation training group had significantly higher scores at two weeks (P=0.031), 3 months (P<0.01), and 12 months (P<0.01) after surgery than did the conventional rehabilitation training group, and both groups had higher HSS scores than before surgery. The quantitative training group had significantly higher VAS scores at 24 hours and three days postoperatively than the conventional training group (P<0.01), while there was no statistical significance at any other time points. The quantitative rehabilitation group had an earlier time to get out of bed for the first time after surgery (P<0.01), a longer 6MWT distance (P=0.028), and higher patient satisfaction and quality of life scores (SF-36) (P<0.01) that did the control group. The number of days in the hospital was lower in the quantitative training group than in the control group (P<0.001). There was no significant difference in the incidence of postoperative complications between the two groups.
CONCLUSIONS: Compared with conventional rehabilitation training, quantitative rehabilitation training based on the ERAS concept was found to be safe and effective and can accelerate the recovery of joint function after surgery, shorten hospitalization time, improve patient satisfaction, and promote rapid recovery.
CLINICAL REHABILITATION IMPACT: The quantitative rehabilitation training based on the ERAS concept provides a new program for rehabilitation exercises after total knee arthroplasty, which is safe and reliable, accelerates the recovery of joint function, and should be considered for clinical promotion.

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KEY WORDS: Enhanced recovery after surgery; Arthroplasty, replacement, knee; Randomized controlled trial.

Osteoarthritis of the knee (KOA) is one of the most common types of arthritis and has been a leading cause of disability for many years.[1, 2] Total knee replacement (TKR) is the most effective treatment of end-stage KOA. The annual TKR rate has recently increased from 5% to 17% worldwide.[3]

Rehabilitation, including physical therapy, pedal-based protocols, and continuous passive motion (CPM),[4-7] is often required after TKR, but the appropriate format remains highly controversial. Loss of lower extremity strength and function often occurs within one month after TKR,[8] so early exercise plays an important role in functional recovery. Although previous studies reported that rehabilitation for TKR was not correlated to the ultimate prognosis,[9-11] recent studies have found that progressive resistance training and functional strengthening exercises can improve knee function while ensuring safety.[12, 13] Therefore, adequate functional exercise can stimulate muscle growth, increase muscle strength, and improve recovery of joint function. However, to date, most rehabilitation programs have been limited to preoperative or postoperative periods,[14-16] and there is still a lack of specific, individualized, and standardized programs for functional exercise in the perioperative period of TKR. Quantitative rehabilitation is a step-by-step optimization of previous studies to develop progressive and phased training for patients throughout the perioperative period.[14, 15, 17, 18]

Since the concept of enhanced recovery after surgery (ERAS) was introduced in 2001,[19] it has gained wide acceptance and application in the perioperative surgical period. ERAS was implemented in general surgery with positive results and then gradually applied to joint surgery. Still, there are relatively few prospective studies comparing the clinical results of ERAS in TKR.[20]

Therefore, the purpose of this randomized controlled trial was to evaluate the impact of quantitative rehabilitation training based on the ERAS concept on the early recovery of patients after TKR. We hypothesized that quantitative rehabilitation training based on the ERAS concept would be superior to conventional rehabilitation training in early postoperative recovery in patients undergoing TKR.

Materials and methods

Trial design and participants

This double-blind, randomized controlled trial was conducted in one hospital from April 2019 to May 2020. The clinical ethics committee of the authors' hospital approved the study (2019-086-01) and registered it on ClinicalTrials.gov (ChiCTR1900023136). The study design and implementation followed the Consolidated Standards of Reporting Trials (CONSORT) Statement guidelines. The diagnosis of KOA was based on the criteria of the American College of Rheumatology. The inclusion criteria were as follows: 1) age >65 years; 2) diagnosis of end-stage KOA and no hip or ankle disease; 3) first unilateral total knee arthroplasty; and 4) the patient voluntarily participated and signed an informed consent form. The exclusion criteria were as follows: 1) patients who had undergone major surgery within the past month; 2) patients with cognitive or mental disorders that prevent rehabilitation training; and 3) patients with poor muscle strength of the muscles around the knee joint before surgery.

Data availability statement

The data associated with the paper are not publicly available but are available from the corresponding author on reasonable request.

Randomization and blinding

Eligible patients were given information about the study for at least one day to decide whether to participate. Random sequences were created by SAS 9.1 statistical software (SAS Institute) and placed in opaque sealed envelopes. The enrolled patients were randomly assigned to the quantitative and conventional rehabilitation training groups in a 1:1 ratio, with block sizes of 4 and 6. Different personnel completed the random assignment sequence, patient registration, and outcome assessment. The surgeons, outcome assessors, and data analysts were unaware of the grouping and implementation during the study. Patients were also unaware of the groupings and the training performed in each group. The rehabilitation therapist only

performed rehabilitation for the patient and did not interfere by providing advice or analysis.

Interventions

The quantitative rehabilitation training program was carried out throughout the perioperative period. Preoperative muscle strength training and postoperative functional exercise were divided into three phases, each with a gradual transition process. The first phase was muscle strength training with passive rehabilitation training. The second phase shifted from passive rehabilitation training to active rehabilitation training. The third stage was the transition from non-weight-bearing to weight-bearing training, with a gradual increase in standing and walking. The rehabilitation therapist explained and assessed the patient to ensure the rehabilitation plan was followed accurately. The therapist explained or demonstrated in detail the content, method, and duration of rehabilitation training and recorded the amount of daily training on an assessment form. Any adverse reactions were reported to the physician, who then provided treatment or adjusted the rehabilitation program. The conventional rehabilitation training group was given only conventional exercises, such as CPM, according to the traditional method. The same rehabilitation therapist explained the techniques of functional training to the patient but did not specify the frequency and intensity of each training modality, and did not interfere with the completion of the training.

Surgical procedure

All operations were performed under general anesthesia by surgeons with at least 5 years of TKR experience. The procedure was performed in a standard fashion with an anterior longitudinal midline approach for medial parapatellar arthroplasty. Femoral and tibial prostheses were fixed with bone cement. A tourniquet was used during the procedure, and the average time was 45 minutes.

Outcome measurements

Study results were predetermined at the time of clinical enrollment and prior to trial initiation.

Knee function score

The Hospital for Special Surgery (HSS)[21] scoring system was used to collect HSS knee scores from both groups before surgery and two weeks, three months, and 12 months after surgery to evaluate the functional recovery of the knee joint. The score includes pain (30 points), function (22 points), mobility (18 points), muscle strength (10 points), flexion deformity (10 points), and stability (10 points). The maximum score is 100 points, and the higher the score, the better the recovery of joint function.

VAS

VAS scores were used preoperatively and 24 hours, three days, two weeks, three months, and 12 months postoperatively. The VAS uses a 10-cm line to assess the patient's pain by informing the patient that 0 means "no pain" and 10 means "severe pain" and asking the patient to draw a line crossing the 10-cm line at a level that best reflected their pain level.

Patient satisfaction

On the day of the patient's discharge and at three months and one year after surgery, patients were asked to rate their satisfaction according to four options: very satisfied, satisfied, neither satisfied nor unsatisfied, or unsatisfied. Surveys were completed according to the patient's actual condition.

Six-Minute-Walk Test

The patient walked for 6 minutes at a speed as fast as possible. The patient walked back and forth along a 50-meter corridor, and the distance traveled was measured. If needed, patients used a cane or stick to perform the test.

Other measurements

A 36-item short form survey was used to assess the quality-of-life status of patients at 12 months after TKR. It included both physical health and mental health, with higher scores indicating better health. The incidence of postoperative complications was recorded, and the changes of inflammatory markers in both groups were also evaluated after surgery.

Sample size calculations

Sample size calculations were based on data from previous studies,[21] and we expected a difference of 85±4.1 between groups in the conventional rehabilitation group at 12 months. At α=0.05, the difference in HSS scores between the quantitative rehabilitation training group and the conventional rehabilitation training group at 12 months postoperatively was tested at approximately 5.2. Allowing 20% of patients to miss follow-up evaluations, we ultimately determined that at least 38 participants in each group would provide 80% of the power.

Statistical analysis

We used SPSS software (version 24.0; IBM) for all statistical analyses. Continuous data were tested for normal distribution using the Shapiro-Wilk Test. Data that conformed to a normal distribution are expressed as mean and standard deviation, and those that did not are expressed as median and interquartile range. Data for categorical variables are expressed as frequencies and proportions. Continuous variables were analyzed using Student's *t*-test and associated 95% confidence intervals and the Mann-Whitney U Test. Preoperative and postoperative changes were analyzed using paired *t*-tests. The Chi-squared or Fisher's Exact Test was used to compare categorical variables. Multiple comparisons were performed using repeated measures Analysis of Variance and P values with Bonferroni correction.

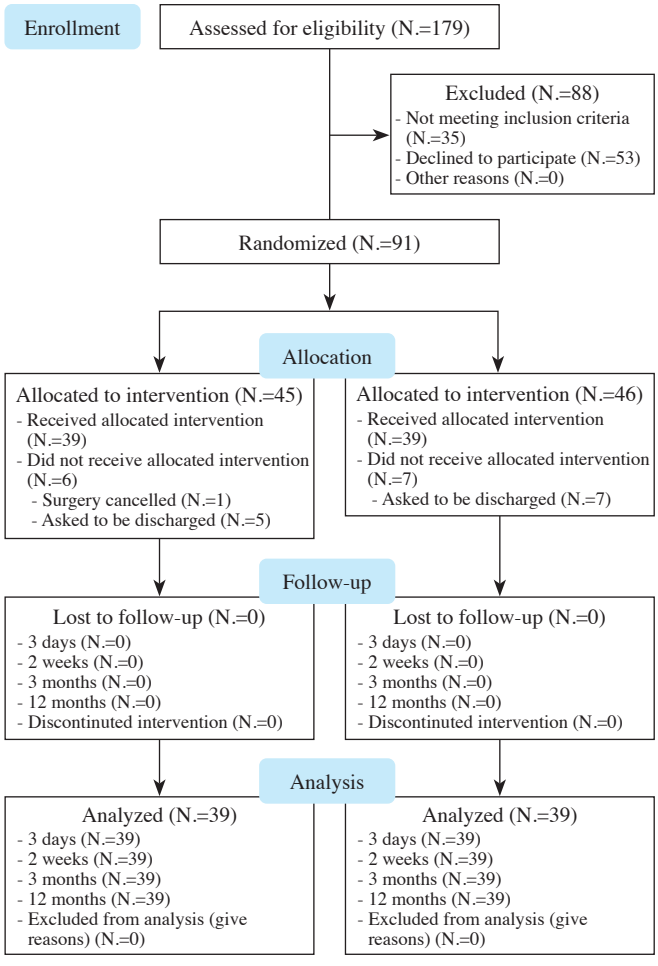

Figure 1.—CONSORT inclusion flowchart.

TABLE I.—*Patient demographics and preoperative characteristics.*

Characteristic	QRT (N.=39)	RRT (N.=39)	P value
Age*(yr)	74.6±6.0	76.0±6.3	P=0.313†
Sex#			P=0.215‡
Male	13 (33.3)	9 (23.1)	
Female	26 (66.7)	30 (76.9)	
BMI*(kg/m²)	30.0±2.1	30.8±2.7	P=0.189†
ASA classification#			P=0.720‡
I	6 (15.4)	8 (20.5)	
II	27 (69.2)	26 (66.7)	
III	6 (15.4)	5 (12.8)	
Laterality#			P=0.651‡
Right	18 (46.2)	20 (51.3)	
Left	21 (53.8)	19 (48.7)	

*The values are given as the mean and the standard deviation; #data are presented as the number (percentage) of patients; †Student's *t*-test; ‡Pearson χ^2.

Results

Patient demographics

A total of 179 patients who underwent TKR between April 1, 2019, and May 1, 2020, underwent screening, and 78 patients who completed follow-up and were analyzed were divided into quantitative and conventional rehabilitation training groups (Figure 1). There was no significant difference in the preoperative baseline characteristics between the two groups of patients (Table I). All patients completed the 12-month postoperative follow-up, and the patients did not experience any adverse effects during the rehabilitation period.

Knee function and VAS pain score

The HSS knee score, the primary measure, was higher in both groups postoperatively than preoperatively (Figure 2A). After multiple corrected comparisons, the HSS scores at two weeks, three months, and 12 months postoperatively were higher in the quantitative rehabilitation training group than in the conventional rehabilitation training group (P=0.031, P<0.001, P<0.001, respectively) (Table II, Figure 2B). Compared with the conventional rehabilitation group, the quantitative rehabilitation group had significantly higher VAS scores at 24 hours and 3 days postoperatively (P<0.001) (Table II, Figure 3B), but there was no significant difference in the scores between the two groups at two weeks, three months, and 12 months postoperatively. The VAS scores gradually decreased after surgery in both groups (Figure 3A).

Patient satisfaction and 6-Minute-Walk Test

The satisfaction rate of the quantitative rehabilitation training group was significantly higher than that of the

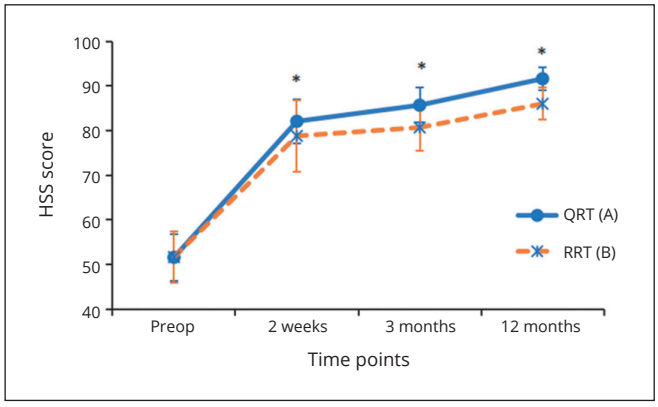

Figure 2.—A) Changes in HSS scores of patients in the quantitative rehabilitation training (QRT) and routine rehabilitation training (RRT) groups before and after surgery. The error bars indicate the standard deviation of the mean. Preop: Preoperative (day of admission); B) HSS scores of patients in the quantitative rehabilitation training (QRT) and routine rehabilitation training (RRT) groups preoperatively and postoperatively. The top and bottom of the boxes indicate the 25th and 75th percentiles, and the horizontal line is the median. The whiskers indicate the minimum and maximum values, and the circles represent outliers. *P value <0.05.

TABLE II.—*Changes in HSS and VAS scores by time.*

Outcome	QRT (N.=39)	RRT (N.=39)	Difference (95% CI)	P value
HSS Score*				
Pre	50.6±4.1	49.6±4.6	-0.05 (-2.54-2.44)	P=0.967†
Two weeks	82.1±4.9	78.8±7.9	3.28 (0.30-6.26)	P=0.031†
Three months	85.7±3.9	80.7±5.2	5.00 (2.94-7.05)	P<0.001†
One year	90.1±3.3	86.0±3.6	5.62 (4.20-7.03)	P<0.001†
Pre to 2 weeks&	30.5±6.9	27.1±8.7		
P value††	P<0.001	P<0.001		
Pre to one year&	40.0±6.1	34.4±7.0		
P value††	P<0.001	P<0.001		
VAS Score*				
Pre	8.6±1.0	8.1±1.0	0.31 (-0.15-0.77)	P=0.18†
Twenty-four hours	6.1±1.4	4.6±1.5	1.46 (0.80-2.12)	P<0.001†
Three days	4.3±1.3	3.3±1.3	1.00 (0.41-1.59)	P<0.001†
Two weeks	2.6±1.0	2.2±0.8	0.39 (0.04-0.80)	P=0.07†
Three months	1.5±0.9	1.2±0.8	0.33 (-0.04-0.71)	P=0.08†
One year	1.0±0.7	1.1±0.6	0.77 (-0.30-0.45)	P=0.687†
Pre to 24 hours&	1.5±1.8	2.6±1.7		
P value††	P<0.001	P<0.001		
Pre to 12 months&	6.5±1.4	6.2±1.3		
P value††	P<0.001	P<0.001		

*The values are given as the mean and the standard deviation; ††paired *t*-test; †Student's *t*-test; &difference between the values obtained preoperatively and postoperatively.

conventional rehabilitation group at discharge, three months, and 12 months after surgery (P<0.001). The quantitative rehabilitation group had the highest satisfaction rate (94.87%) at discharge compared with the conventional rehabilitation group (Figure 4, Table III) and walked longer distances in the 6-Minute Walk Test (Figure 5, Table IV).

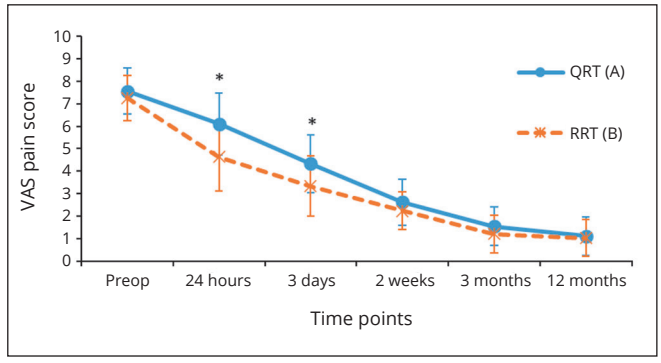

Figure 3.—A) Changes in mean VAS pain scores in patients in the quantitative rehabilitation training (QRT) and routine rehabilitation training (RRT) groups before and after surgery; B) pre- and postoperative VAS pain scores of patients in the quantitative rehabilitation training (QRT) and routine rehabilitation training (RRT) groups.

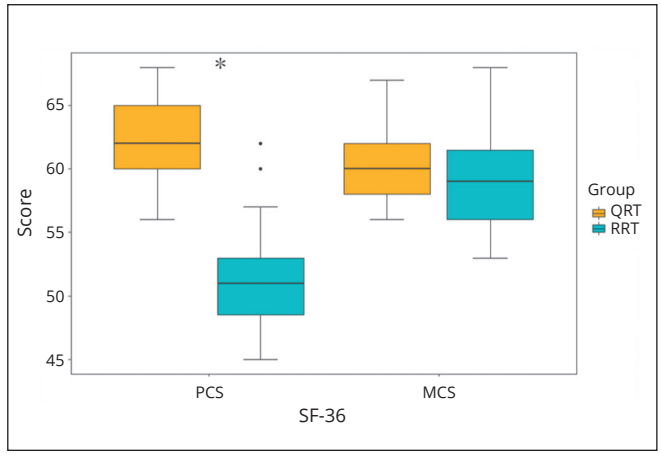

Figure 4.—SF-36 scores of patients in the quantitative rehabilitation training (QRT) and routine rehabilitation training (RRT) groups at 1 year postoperatively. The SF-36 is divided into two parts: physical component summary (PCS) and mental component summary (MCS).

Quality of life and time to get out of bed for the first time

The physical component summary at 12 months postoperatively was significantly higher in the quantitative rehabilitation group than in the conventional rehabilitation group (P<0.001). In contrast, the mental component summary showed no significant difference between the two groups (P=0.114). The quantitative rehabilitation group time to get out of bed for the first time after surgery earlier (P<0.001) (Figure 4, Table IV).

TABLE III.—*Patient satisfaction at various time points after discharge from hospital.*

Satisfaction level	QRT (N.=39)	RRT (N.=39)	P value
Discharge#			P<0.001§§
Very satisfied	27	4	
Satisfied	10	20	
Neither satisfied nor dissatisfied	2	15	
Dissatisfied	0	1	
Satisfaction rate	94.87%	61.54%	
Three months#			P<0.001§§
Very satisfied	27	6	
Satisfied	9	13	
Neither satisfied nor dissatisfied	3	19	
Dissatisfied	0	1	
Satisfaction rate	92.31%	43.59%	
Twelve months#			P<0.001‡
Very satisfied	12	3	
Satisfied	21	11	
Neither satisfied nor dissatisfied	6	25	
Dissatisfied	0	0	
Satisfaction rate	84.62%	35.90%	

§§Fisher's Exact Test; ‡Pearson χ^2; #data are presented as the number (percentage) of patients.

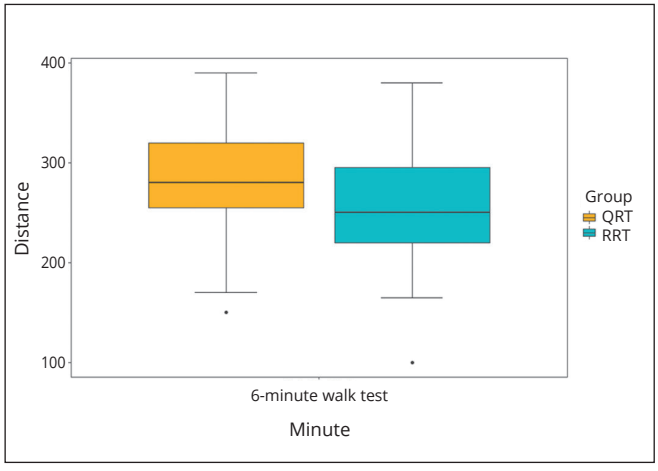

Figure 5.—Six-minute-walk test (6MWT) for patients in the quantitative rehabilitation training (QRT) and routine rehabilitation training (RRT) groups during hospitalization. The distance is in meters.

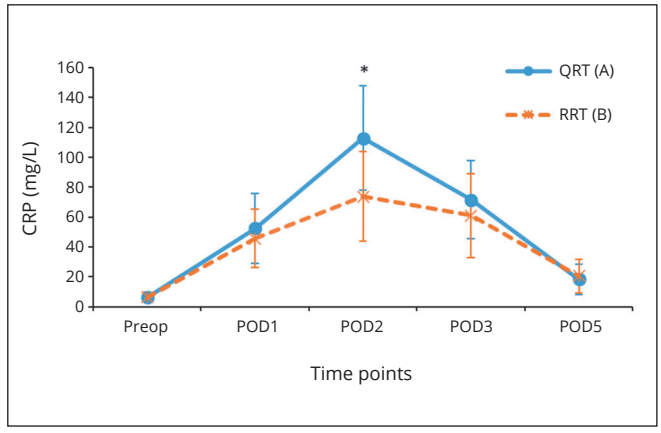

Figure 6.—Mean serum concentrations of C-reactive protein (CRP) inflammatory markers (A) and interleukin-6 (IL-6) (B) in the perioperative period. Preo: Preoperative (morning of surgery).
POD: postoperative day.

Inflammatory markers

All patients' postoperative IL-6 and C-reactive protein (CRP) levels were elevated (Figure 6A, B). IL-6 levels peaked on postoperative day 1 in both groups. At all postoperative time points, the quantitative rehabilitation group IL-6 levels were significantly higher than those of the conventional rehabilitation group. Still, there was a significant difference only on postoperative days 1 and 2 (P=0.006, P=0.005, P=0.151, P=0.506). CRP levels peaked on postoperative day 2. At all postoperative time points, the quantitative rehabilitation group's CRP levels were significantly higher than those of the conventional rehabilitation group, but there was a significant difference only on postoperative day 2 (P=0.164, P<0.001, P=0.093, P=0.356) (Table V).

Hospitalization time and complications

The hospitalization time of the quantitative rehabilitation group was less than that of the conventional rehabilitation group (P<0.001). The incidence of postoperative compli-

TABLE IV.—*Physical component summary at 12 months postoperatively.*

Outcome	QRT (N.=39)	RRT (N.=39)	Difference (95% CI)	P value
First time of standing after surgery (days)	2 (1, 2)	3 (2, 5)		P<0.001§
Hospitalization days (days)	9.7±2.2	12.5±4.5	-4.90 (-6.64- -3.157)	P<0.001†
6MWT(meter)	263.1±53.1	263.4±52.3	28.59 (3.23-53.95)	P=0.028†
SF-36				
PCS	60.3±3.1	50.3±3.6	10.82 (9.28-12.36)	P<0.001†
MCS	61.2±2.7	60.3±4.3	1.23 (0.30-2.77)	P=0.231†

*The values are given as the mean and the standard deviation; §Mann-Whitney U Test;†Student's *t*-test.

TABLE V.—*Changes in inflammatory markers at various postoperative time points.*

Octcome	QRT (N.=39)	RRT (N.=39)	P value
IL-6 (pg/mL) *			
Pre	4.3±1.8	5.1±1.2	P=0.333†
Postoperative day 1	121.2±40.2	93.6±45.9	P=0.006†
Postoperative day 2	98.2±39.2	75.9±27.6	P=0.005†
Postoperative day 3	47.1±23.2	40.3±22.1	P=0.231†
Postoperative day 5	16.5±7.6	15.4±7.3	P=0.401†
CRP (mg/L)*			
Pre	5.2±3.1	6.7±3.5	P=0.732†
Postoperative day 1	52.4±21.4	42.3±17.6	P=0.164†
Postoperative day 2	112.8±35.0	73.8±30.0	P<0.001†
Postoperative day 3	70.2±23.1	59.1±27.0	P=0.073†
Postoperative day 5	19.2±10.1	21.6±12.6	P=0.453†

*The values are given as the mean and the standard deviation.†Student's *t*-test. CRP: C-reactive protein; IL-6: interleukin-6.

TABLE VI.—*Incidence of postoperative complications.*

	QRT (N.=39)	RRT (N.=39)	P value
Complications (N., %)	6 (15.4%)	8 (21.1%)	P=0.519‡
Wound infection	3	4	
DVT	2	3	
Prosthesis loosening	0	0	
Stiff knee	1	1	

DVT: deep venous thrombosis; ‡Pearson χ^2.

cations in the two groups was 15.4% and 21.1%, respectively, but there was no significant difference (P=0.519) (Table IV, VI).

Discussion

In this randomized controlled trial, we found that the postoperative HSS scores were higher and increased gradually with time in the quantitative training group. The degree of knee function recovery was better compared to the conventional training group. In addition, compared with the conventional rehabilitation group, patients in the quantitative rehabilitation training group had high satisfaction during follow-up, short hospital stays, and improved quality of life one year after surgery, but there were no significant differences in mental health.

TKR is traumatic, with varying degrees of preoperative functional deficits, postoperative pain, muscle weakness, and limited joint movement.[22-24] Knee function recovery is an important outcome after TKR and an important determinant of early functional outcome.[25] However, perioperative rehabilitation exercises for TKR still have a relative lack of specific, individualized, and standardized protocols, and their appropriate form remains much debated. Quantitative rehabilitation training has been progressively optimized by combining the results of previous studies and developing progressive phases of training for patients based on the ERAS concept throughout the entire perioperative period.[14, 15, 17]

In this study, the quantitative rehabilitation group had higher HSS scores at one year compared to the conventional rehabilitation group, and the scores increased gradually with time. This indicates that the quantitative rehabilitation program had a positive effect on the recovery of the patient's postoperative knee function. If further loss of muscle strength is to be avoided, starting high-intensity training early in the postoperative period should be an effective therapy to prevent muscle strength loss, which is thought to be more effective than restoring muscle strength.[14, 26] Regarding rehabilitation programs and postoperative muscle strength recovery, our results are consistent with those of Bade *et al.*,[15] who found that early high-intensity rehabilitation programs produced greater quadricep strength and joint mobility than low-intensity programs in patients after TKR. The difference between their results and ours is that their rehabilitation program was only based on increasing strength training but did not make gradual transitions to the rehabilitation program, which can potentially increase the patient's postoperative pain. The hospitalization period of TKR patients is an important period for postoperative functional rehabilitation, not only to reduce complications but also to develop good functional exercise habits. Sochart DH[27] suggested that active exercise was more effective than passive exercise in eliminating blood stagnation and accelerating recovery of joint function. It is worth noting that active functional exercise is generally carried out gradually on the basis of passive activities. In this study, the quantitative rehabilitation training was based on ERAS with progressive transitional training for the patients. Regarding knee function recovery, the quantitative rehabilitation group had better function than the conventional training group, and the difference between the groups became more pronounced with time. In deference to the Sochart DH scholars, passive rehabilitation has not been effectively linked to active rehabilitation exercises in previous studies. In another study, Stevens *et al.* also suggested that progressive postoperative lower extremity strength training could lead to substantial recovery of quadricep strength and consequent improvement in knee function.[28]

The average number of hospital days of the quantitative rehabilitation group in this study was 12 days, which

was lower than that of the conventional rehabilitation group; however, the satisfaction rate of the quantitative rehabilitation group was higher than that of the conventional rehabilitation group during the one-year follow-up period. This indicates that quantitative rehabilitation training based on the ERAS concept can significantly reduce the number of hospital days and improve patient satisfaction rates after surgery. The reasons for this are twofold. First, the repeated functional training instruction before and after surgery reinforces the importance of rehabilitation training in patients' minds, thus achieving better results. Second, in our contact with patients, we found that the frequency of communication with patients and their families had a positive relationship with patient recovery and hospital satisfaction. Communication on multiple occasions promoted rapport between the doctor and the patient, which led to increased compliance and ultimately resulted in shorter hospital stays and increased satisfaction.

Furthermore, the quantitative rehabilitation group had a longer distance for the 6-minute walk test and an earlier time to get out of bed for the first time after surgery. However, in the Stevens-Lapsley *et al.* study, no differences were found between the two groups in the 6-minute walk test when comparing high-intensity rehabilitation to low-intensity rehabilitation programs.[13] The reason for this analysis may be that the time reported in their study was 12 weeks postoperatively, whereas we measured this during the patient's hospitalization. The 6-minute walk test itself did not require patients to have greater lower extremity support strength, and the recovery of muscle strength over time was sufficient to balance out the differences between the two groups.

We found that patient CRP and IL-6 levels began to decrease on postoperative days 1 and 2 gradually, but there was a statistical difference only on postoperative day 2. VAS scores were statistically different only at 24 hours and 3 days postoperatively. This indicates that rehabilitation in both groups did not cause significant additional pain or inflammatory responses in the patients. The main reason why patients are reluctant to exercise early is pain. Therefore, attention should be paid to the multimodal analgesia of early postoperative functional exercise to achieve effective pain relief. There are reports in the literature that patients in the clinic often refuse to exercise due to postoperative muscle weakness, wound adhesions, and other problems that cause pain when performing rehabilitation.[29-31] In consideration of this, this study conducted rehabilitation training under the concept of ERAS and paid attention to the management of the TKR perioperative period.[19, 32] Warm-up activities such as straight leg raising and knee extension exercises were also included to adapt the knee to small flexion activities before the next stage of rehabilitation, reducing the occurrence of pain.

Developing a scientifically effective and easily implemented functional training program is a prerequisite for effective functional training after TKR.[33, 34] Studies have shown that postoperative functional training should follow the principles of early implementation, scientifically based and systematically applied. The functional training program was developed based on the training program of previous studies, through communication with several rehabilitation physicians, and combined with the ERAS program to develop a quantitative rehabilitation training schedule.

Limitations of the study

This study does have some limitations. First, the present study was not sufficiently comprehensive to examine the indicators of functional recovery of the patient's knee. In the next study, more indicators will be included to assess the functional recovery of the patient after surgery fully. Second, this study was a single-center study and was not universal, and we will next conduct a multicenter population-based study to validate our findings. Third, our results apply to patients with severe osteoarthritis who have received their first TKR. It is unclear whether the same results can be obtained in patients with other preoperative diagnoses (such as rheumatoid arthritis and traumatic arthritis) or in patients who have undergone bilateral knee replacement.

Conclusions

Compared with conventional rehabilitation training, ERAS-based quantitative rehabilitation training is safe and effective. It can accelerate the recovery of knee function after surgery, shorten hospitalization time, improve patient satisfaction, and promote rapid patient recovery.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions

Songsong Jiao formulated the idea and the study design; Zhencheng Feng, Jian Huang, and Tianming Dai conducted research, provided research materials, where responsible for the clinical evaluation of the subjects, and organized data; Songsong Jiao was involved in writing the manuscript; Qingqi Meng carried out the data analysis and interpretation; Qingqi Meng and Ruijia Liu revised the final draft; all authors confirmed the final manuscript and were responsible

for the content of the manuscript. Songsong Jiao and Zhencheng Feng contributed equally to this work and should be considered co-first authors. All authors are responsible for the content and similarity index of the manuscript. All authors read and approved the final version of the manuscript.

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