FLEX CEUs

Total Knee Arthroplasty Rehabilitation Considerations

Effect of the knee position during wound closure after total knee arthroplasty on early knee function recovery

Abstract

Objective: This study investigated the effect of the knee position during wound closure on early knee function recovery after total knee arthroplasty (TKA).

Methods: This study included 80 primary total knee arthroplasties due to osteoarthritis. The patients were randomized according to the type of wound closure: extension group for full extension and flexion group for 90° flexion. The incision of articular capsule was marked for precise wound alignment. In the flexion group, the knee was kept in high flexion for 1 to 2 min after wound closure. The two groups were treated with the same postoperative rehabilitation exercises. The range of motion (ROM), visual analogue scale (VAS) score of anterior knee pain, Knee Society Score (KSS) and postoperative complications were assessed at 6 weeks, 3 months and 6 months, postoperatively.

Results: At 6 weeks and 3 months postoperatively, the ROM in flexion group was 98.95 ± 10.33° and 110.05 ± 4.93° respectively, with 87.62 ± 8.92° and 95.62 ± 6.51° in extension group, respectively; The VAS score of anterior knee pain in flexion group was 2.02 ± 1.38 and 2.21 ± 0.87, respectively, with 2.57 ± 1.07 and 2.87 ± 0.83 in extension group, respectively. The ROM and VAS pain score of the two groups were significantly different at these two time points, with no significant difference at 6 months postoperatively. The two groups were not significantly different in KSS, and no apparent complication was observed at three time points.

Conclusion: Marking the articular capsule incision, wound closure in flexion and high flexion after wound closure can effectively decrease anterior knee pain after TKA and promote the early recovery of ROM.

Keywords: Anterior knee pain, Range of motion, Wound closure, Total knee arthroplasty

Introduction

Total knee arthroplasty (TKA) has been considered a successful surgical method in the treatment of knee osteoarthritis. TKA can effectively remove pain associated with joint activities and can recover the range of motion (ROM), which is closely related to the degree of satisfaction in patients [1]. Previous studies reported that the incidence of anterior knee pain after primary TKA is from 10% to 15% [2-4]. The reason remains unclear. Nevertheless, this phenomenon may be associated with patient factors, degree of patellar cartilage damage, prosthesis design, patellar resurfacing, surgical technique and treatment of soft tissue around patella [5,6]. A simple soft-tissue tension in the anterior knee after TKA can cause knee pain and loss of ROM [7]. Surgical technique significantly influences joint function recovery after TKA. Research mainly focuses on flexion and extension gap balance, rotational alignment and medial and lateral collateral ligament balance. The traditional knee wound closure in extension may lead to soft-tissue misalignment and relative shortening of the knee extension device, resulting in higher soft-tissue tension of the anterior knee in flexion. This condition may lead to anterior knee pain and may limit postoperative ROM recovery [8]. The effect of wound closure in knee flexion on ROM has been reported differently. Emerson et al. [9] indicated that wound closure in flexion contributes to ROM recovery, but Masri et al. [10] suggested otherwise. In the reported cases of wound closure, the angle of flexion did not exceed 60° and has no comprehensive treatment on soft tissue. In wound closure in extension, failure to mark the preoperative soft tissue may lead to in situ closure without complete anatomy and increased local tension of the soft tissue in knee flexion. In this study, we marked the capsular incision during the arthrotomy, sutured the wound in 90° flexion and kept the knee over-flexed for soft-tissue tension rebalance of the sutured area during wound closure. This study aims to investigate the effects of these measures on anterior knee pain and early knee function recovery.

Materials and methods

General data

A total of 80 patients (18 males and 62 females; 57 years old to 83 years old; average age, 68.26 ± 9.08 years; body mass index, 25.96 ± 3.65 kg/m; 80 knees) from January 2009 to August 2010 were enrolled in this study. All patients had been treated with primary TKA for osteoarthritis. The exclusion criteria were as follows: knee surgery history (femur or tibia osteotomy, knee extension device surgery and arthroscopic surgery), patella fracture history, knee valgus (>15°, requiring lateral retinacular release) or fixed-flexion deformity, knee infection history and neuromuscular disorders affecting knee motion. Stata 7.0 statistical software was used to randomly divide all patients into the extension group and flexion group, with 40 patients in each group. Age, gender, body mass index, ROM, visual analogue scale (VAS) pain score of anterior knee and Knee Society Score (KSS, American Society of Knee Surgery) were not significantly different between the two groups (Table 1). Thus, extension group and flexion group were comparable.

After the completion of evaluation according to the enrolment and exclusion criteria, an informed consent was signed by the patients. Randomisation was performed prior to surgery to determine the patients to be assigned in each group. Surgery was performed by the physicians who did not participate in the preoperative grouping and postoperative evaluation. Postoperative evaluation was conducted by the physicians who were unaware of the grouping. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Fudan University. Written informed consent was obtained from all participants.

Surgical method

All patients were administered with general anaesthesia and subjected to TKA through parapatellar medial approach by the same doctor. The skin, patellar tendon and upper and lower patella poles with articular capsule incision were marked for precise soft-tissue alignment in closure. An equivalent osteotomy was conducted on the femur and tibia, and the posterior knee osteophyte was removed. The tibia posterior slope was 3°, and Smith-Nephew Genesis II prosthesis was implanted. After osteophyte removal, the patella was shaped using an electric pendulum saw without patellar resurfacing. Prior to skin incision, a tourniquet was placed in flexion and was released after bone cement hardening. During surgery, cocktail analgesic injection [11] was injected into the articular capsule, suprapatellar bursa and infrapatellar fat pad. In the extension group, the wound closure was performed in full extension (Figure 1A). In the flexion group, during flexion the articular capsule was incised and marked by a stitch, which facilitated the accurate joint of soft tissue during suture. In the 90° flexion, the articular capsule, soft tissue and skin were enclosed. The knee was kept in high flexion for 1–2 min after wound closure to balance the uneven tension of soft tissue in the suture site (Figure 1B). All patients did not undergo patellar replacement. However, the osteophyte in all patellas was removed and subsequently underwent patellar articular surface formation via a pendulum saw. All patients went through primary TKA, and patients with excessive deformity were excluded. Lateral retinacular release was not conducted to ensure the comparability of this study. After 24 hrs, the negative pressure drainage was removed, and the patients could perform full weight-bearing walk.

Postoperative treatment

After the surgery, the thigh of the patient was elevated to 60° (45° knee flexion) using a bracket. After 24 hrs, the negative pressure drainage was removed. The two groups were treated with the same postoperative rehabilitation exercises. At 2 days postoperatively, quadriceps

Table 1 General data in two groups (mean ± SD)

Group	Age (years)	Gender	Body mass index (kg/m^2)	Anterior knee VAS pain score	ROM (°)	KSS	
						Knee	Function
Extension group (40)	67.87 ± 6.47	9/31	24.94 ± 4.64	7.97 ± 1.37	84.23 ± 3.68	46.02 ± 3.20	48.75 ± 2.03
Flexion group (40)	68.34 ± 7.09	7/33	25.00 ± 3.88	8.02 ± 1.08	82.11 ± 4.25	46.15 ± 2.78	47.37 ± 1.60
t	0.92	1.526	−0.07	0.63	1.69	0.07	−0.36
P	0.34	0.58	0.93	0.55	0.75	0.96	0.73

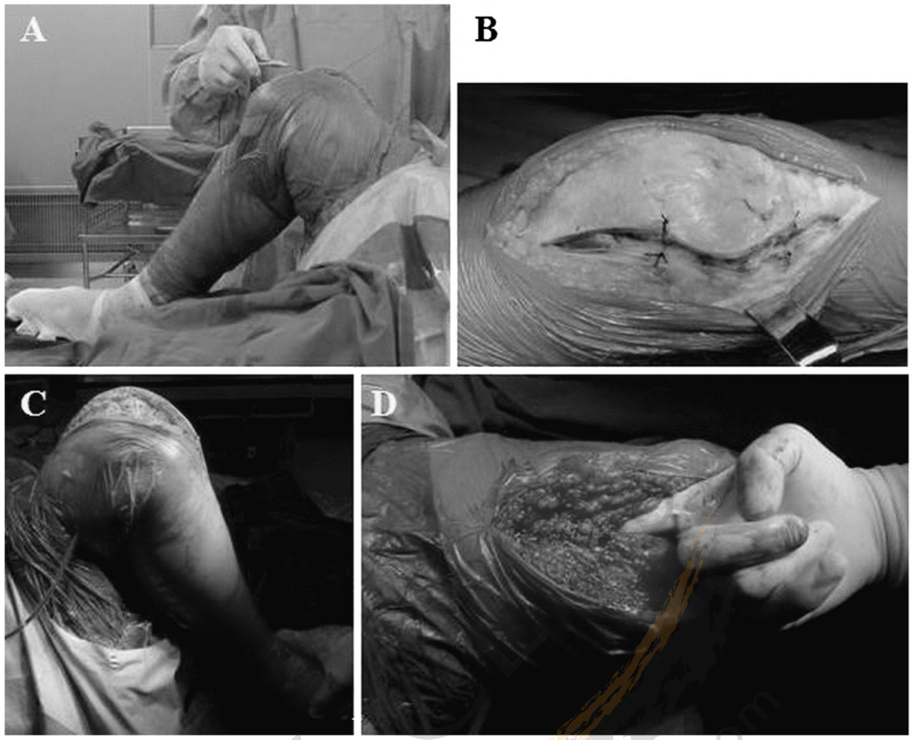

Figure 1 Intra-operative technical treatment in the flexion group. (A) Knee wound closure in 90° flexion during the TKA. **(B)** Suture mark on incision of articular capsule. **(C)** High knee flexion after wound closure. **(D)** Checking the interspace between quadriceps tendon and suprapatellar bursa after tendon closure in flexion.

contraction training was conducted with full weight-bearing walk under the help of a walking aid, which prevents falls. After 2 weeks, the knee was flexed at 90°, and the patient independently walked with weight-bearing. Corresponding corrections had been made. In the original study design, the follow-up time was 1 year. However, the two groups were not significantly different after six postoperative months.

Efficacy observation

Efficacy of the surgery was observed using the blind method. At 6 weeks, 3 months and 6 months postoperatively, the ROM, VAS pain score of the anterior knee and KSS were assessed, as well as the knee extension lag and other complications.

Statistical analysis

Data were expressed as mean ± standard deviation. Statistical analysis was performed using SPSS 11.5 statistical software (SPSS Inc., Chicago, IL, USA). Moreover, *t*-test and chi-square test were used to analyse the measurement data and enumeration data, respectively. $P < 0.05$ was considered statistically significant.

Results

ROM

At 6 weeks and 3 months postoperatively, the ROM in the flexion group was 98.95 ± 10.33° and 110.05 ± 4.93°, whereas 87.62 ± 8.92° and 95.62 ± 6.51° in the extension group, respectively. The recovery of ROM in the flexion group was significantly higher and faster than that in the extension group ($P < 0.05$). This finding indicated that the closure in flexion was beneficial to postoperative early ROM recovery. ROM was not significantly different between the two groups at 6 months postoperatively ($P > 0.05$; Table 2).

VAS pain score of the anterior knee and KSS

The VAS pain score of the anterior knee with 90° knee flexion in the flexion group was 2.02 ± 1.38 and

Table 2 Postoperative ROM in two groups (°)

Group	6th week	3rd month	6th month
Extension group (40)	87.62 ± 8.92	95.62 ± 6.51	110.87 ± 5.03
Flexion group (40)	98.95 ± 10.33	110.05 ± 4.93	115.05 ± 3.24
t	2.47	3.29	−0.06
P	0.03	0.04	0.72

Table 3 Postoperative anterior knee VAS pain score in two groups

Group	6th week	3rd month	6th month
Extension group (40)	2.57 ± 1.07	2.87 ± 0.83	1.12 ± 0.68
Flexion group (40)	2.02 ± 1.38	2.21 ± 0.87	1.15 ± 0.73
t	−2.52	−2.69	−0.49
P	0.02	0.03	0.64

2.21 ± 0.87 at 6 weeks and 3 months postoperatively, whereas 2.57 ± 1.07 and 2.87 ± 0.83 in the extension group, respectively. A significant difference was observed between the two groups ($P < 0.05$), indicating that the closure in flexion can decrease postoperative anterior knee pain. However, no significant difference was observed between the two groups at 6 months postoperatively ($P > 0.05$; Table 3). Moreover, KSS was not significantly different between the flexion group and the extension group at 6 weeks, 3 months and 6 months postoperatively ($P > 0.05$; Table 4). This finding indicated that the location of wound closure has no effect on the postoperative joint function.

Postoperative complications

Knee extension lag was not observed in the two groups after surgery. An apparent complication of wound disunion, patella fracture and infection that required second surgery was not detected in the extension group and the flexion group.

Discussion

Anterior knee pain after TKA is currently a major problem. Although most scholars consider anterior knee pain to be related to the pathogenic factor on patellofemoral joint, a clear consensus on the cause and treatment of anterior knee pain has not been achieved [12]. Previous studies reported that anterior knee pain is associated with different factors, including patient factors (pain threshold, preoperative activity and obesity), degree of patellar cartilage damage and wear, prosthesis factors (anatomy and non-anatomical design, rotating and stationary platform), surgery technique (extremely high joint line, patella thickness and height, patellar resurfacing and soft tissue treatment), postoperative pain management and rehabilitation exercises [2,13]. In this study, preoperative ROM, VAS pain score of the anterior knee, KSS and other indexes are not significantly different between the two groups. All patients were treated with Smith-Nephew Genesis II prosthesis with patella forming but not with resurfacing or lateral retinacular release. The postoperative pain management and rehabilitation exercises in the two groups are the same, excluding the interference factors. After TKA, the effects of wound closure in flexion and extension on anterior knee pain are investigated.

High patellofemoral compartment pressure and pain with lateral retinaculum are the main factors for the anterior knee pain of patellofemoral osteoarthritis [14]. King et al. [7] suggested that anterior knee skin and soft tissue tension cause postoperative anterior knee pain and affect ROM recovery. Knee wound closure in extension can lead to relative shortening of the knee extension device and wound constraint. With the increase of knee flexion degree, the patellofemoral compartment pressure is elevated with pull and tearing of wound-wrinkled tissue, which then results in anterior knee discomfort. However, the knee wound closure in flexion can prevent this risk. The results of this study show that the VAS pain score of the anterior knee in flexion group is significantly lower than that in extension group at 6 weeks and 3 months postoperatively. The dominating nerve located in the lateral retinaculum can cause anterior knee pain. Thus, all patients in this study are not treated with lateral retinacular release. Therefore, the effect of lateral retinaculum on anterior knee pain can be prevented effectively.

The factors affecting ROM recovery after TKA mainly include patient selection, prosthesis design, surgical technique, postoperative rehabilitation, pain management and wound healing [15,16]. Correct wound treatment can reduce tissue adhesion and promote ROM increase [16]. Improper wound treatment or infection may affect postoperative knee function recovery [17]. The tension of the wound soft tissue may increase in knee flexion for wound closure in extension, which results in risks of cracking and wound infection. However, wound closure in flexion can effectively promote ROM recovery after TKA [9]. The results in this study showed that ROM and ROM recovery in the flexion group are significantly higher and faster than those in the extension group, respectively, at

Table 4 Postoperative KSS in two groups

Group	6th week		3rd month		6th month	
	Knee score	Function score	Knee score	Function score	Knee score	Function score
Extension group (40)	48.76 ± 7.88	56.33 ± 6.29	89.23 ± 5.75	82.92 ± 9.57	90.56 ± 6.88	88.67 ± 7.85
Flexion group (40)	49.11 ± 10.39	58.96 ± 8.69	90.34 ± 5.85	85.63 ± 7.26	91.19 ± 6.31	92.46 ± 7.34
t	0.07	2.48	−0.77	0.64	2.11	715.5
P	0.92	0.81	0.43	0.57	0.37	0.67

6 weeks and 3 months postoperatively. Masri et al. [10] assumed that wound closure in flexion is not beneficial for ROM recovery; however, the flexion angle in their study is only 60°, which is inadequate. In the current study, the flexion angle is 90°. Therefore, wound closure with flexion angle higher than 60° is effective. In situ alignment of soft tissue at incision is important for postoperative comfort and ROM, particularly for the precise alignment of articular capsule with quadriceps tendon. In this study, the incision of the articular capsule is marked using a suture (Figure 1B), which can tighten the sutured wound tissue in knee flexion and contribute to the precise alignment of wound. After wound closure, the knee is elevated in high flexion. Therefore, a high-tension pull on the soft-tissue wound with high tension results in the rebalancing of tension of sutured area and in the reduction of discomfort in flexion (Figure 1C). The ROM in the two groups is not significantly different at 6 months postoperatively. This finding indicates that wound closure in flexion is beneficial for early ROM recovery. Many factors affect function recovery after TKA. Wound closure is a soft-tissue treatment technique that should be used with other methods to promote knee function after TKA to obtain high ROM.

The effect of wound closure in flexion on knee extension lag is controversial. Previous research found that knee wound closure in extension can cause tissue accumulation, resulting in the relative shortening of the knee extension device. By contrast, wound closure in flexion does not harm the knee extension device and therefore does not cause knee extension lag [5]. In this study, knee extension lag is not observed in the two groups. However, preoperative quadriceps weakness is a reverse indication of wound closure in flexion [9]. Wound closure in flexion is beneficial to reduce intraoperative bleeding but may cause scratches on the surface of the femoral prosthesis. Thus, intraoperative protection is necessary. In flexion, the quadriceps tendon has close contact with soft tissues in the suprapatellar bursa. For wound closure in flexion, the quadriceps tendon may be sutured with the suprapatellar bursa tissue. The interspace between the quadriceps tendon and suprapatellar bursa should be checked, and the adhesion should be separated (Figure 1D). Otherwise, postoperative anterior knee pain in knee flexion will occur, which then affects ROM.

Many factors affect knee function recovery after TKA [18]. Wound closure is a treatment on soft tissue and has no decisive effect on postoperative knee function recovery. To increase postoperative knee flexion, wound closure can be used together with other methods that promote ROM recovery. Wound closure is a supplement to other technologies. In conclusion, marking the articular capsule incision, wound closure in flexion and high flexion after wound closure can effectively decrease anterior knee pain after TKA and promote the early recovery of ROM. We propose that wound closure can reduce anterior knee pain after TKA and can promote early recovery of ROM.

Conclusions

The knee position during wound closure after TKA is not only critical but also very important for postoperative knee function recovery. Marking the articular capsule incision, wound closure in flexion and high flexion after wound closure can effectively decrease anterior knee pain after TKA and promote the early recovery of ROM. There is a significant difference between the two groups only in the early postoperative period, with no obvious difference upon follow-up of more than 6 months.

The effect of continuous passive motion and sling exercise training on clinical and functional outcomes following total knee arthroplasty: a randomized active-controlled clinical study

Abstract

Background: The parallel-group randomized active-controlled clinical study was conducted to compare the effectiveness of two in-hospital range of motion (ROM) exercise programs following total knee arthroplasty (TKA). Continuous passive motion (CPM) is frequently used to increase ROM and improve postoperative recovery despite little conclusive scientific evidence. In contrast, a new active sling-based ROM therapy requires the activation of the knee joint muscles and dynamic joint stabilization. It was hypothesized that higher demands on muscle strength and muscle coordination during sling exercise training (ST) might be advantageous for early recovery following TKA.

Methods: A total of 125 patients undergoing primary TKA were assessed for eligibility. Thirty-eight patients were randomly assigned to receive ST or CPM (control intervention) during hospital stay. Patients were assessed before TKA for baseline measurement (pretest), 1 day before discharge (posttest) and 3 months after TKA (follow-up). The passive knee flexion range of motion (pFL) was the primary outcome measure. Secondary outcome measures included active knee flexion range of motion, active and passive knee extension ROM, static postural control, physical activity, pain, length of hospital stay as well as clinical, functional and quality-of-life outcomes (SF-36, HSS and WOMAC scores). Data were analyzed according to the intention-to-treat principle. Differences between the groups were tested for significance by the unpaired Student's *t* test or an analysis of covariance (ANCOVA) adjusted for baseline, weight, sex, age, pain and physical activity.

Results: A between-group difference could be determined at posttest. The pFL was significantly higher by 6.0° (95% CI 0.9 to 11.2°; $P = 0.022$) in the ST group. No difference between groups in pFL was documented at follow-up. Furthermore, no significant differences could be observed for any secondary outcome measure at posttest and follow-up.

Conclusions: ST seems to have a clinically relevant beneficial short-term effect on pFL compared to CPM. The results support the implementation of ST in rehabilitation programs following TKA.

Level of evidence: Therapy, level 2b

Keywords: Continuous passive motion (CPM), Postoperative physical therapy, Range of motion, Rehabilitation, Total knee arthroplasty (TKA)

Background

The major objectives of rehabilitation after total knee arthroplasty (TKA) are the early regain of range of motion (ROM) and mobilization of the patient. Continuous passive motion (CPM) has been frequently used as part of the postoperative care regime following TKA with the aim to increase knee joint mobility and improve postoperative recovery despite little conclusive scientific evidence [1-4]. Conflicting research findings have generated an ongoing debate on its usage. The evidence for the effects on pain [5,6], function [5,7], length of hospital stay [8,9], swelling [6,10] and quadriceps strength [5,11] is inconclusive. The Cochrane Review of Harvey et al. reported evidence for small short-term effects of CPM on active and passive knee flexion ROM (aFL, pFL) of 2° and 3° [1]. The ROM is a primary indicator of a successful TKA [12] and is directly related to function [13]. Adequate knee flexion up to 90-120° is required for activities of daily living such as sit to stand transfers and climbing stairs [13]. Consequently, most research on the effectiveness of CPM focuses on ROM as the primary outcome variable [5,7,14-18]. The attainment of at least 0-90° ROM is the goal upon hospital discharge and a more functional range of 0-120° should be attained upon completion of postoperative physiotherapy. Nevertheless, Harvey et al. suggested that the beneficial effects of CPM on ROM are too small to be practically relevant. Clinically meaningful differences between standard physiotherapy and standard physiotherapy combined with CPM are reported to be at least 5° [1].

As the greatest loss of function occurs in the first month following TKA [19], it is surprising that the ROM therapy during hospital stay is still carried out passively. A passive mobilization of the knee joint with CPM does not encourage the patients to actively participate in their rehabilitation. Research on the effectiveness of active ROM exercises added to standard physiotherapy during the short in-hospital period is lacking so far. Only two studies have investigated an adjunctive active motion therapy by comparing it to patients treated with physiotherapy plus CPM and to patients treated only with physiotherapy [17,20]. Group differences were not reported, indicating that an adjunctive active ROM therapy has no benefit for patients' recovery. However, it should be taken into account that knee joint mobilization exercises using passive or active motion machines are guided movements and are therefore less functional.

The present randomized clinical study was conducted to compare a new active sling-based in-hospital ROM exercise program with the standard-of-care therapy (CPM) following TKA. Sling exercises are self-induced and non-guided movements with unstable support which require the activation of muscles and dynamic knee joint stabilization. It was assumed that higher demands on muscle strength and muscle coordination during ST might be advantageous for early recovery following TKA

Whether an early postoperative application of ST could be beneficial for postoperative ROM, pain, physical activity, static postural control, length of hospital stay as well as clinical, functional and quality-of-life outcomes compared to CPM therapy was analyzed.

Methods

The two arm parallel-group superiority randomized active-controlled clinical study was conducted from January 2011 to April 2012 and approved by the Ethical Review Commitee of the University Medicine Rostock (A 2009 25).

Eligible participants were patients undergoing primary TKA for osteoarthritis aged 50 to 80 years with a body mass index (BMI) less than 40. Patients with contralateral TKA or total hip arthroplasty were included when the surgery was performed more than one year before the current TKA. Exclusion criteria were as follows: musculoskeletal and neurological disorders that limit physical function, any planned further joint surgery within 12 months and substantial pain or functional limitation which made the patients unable to perform the study procedures. Prior to participation, written informed consent was obtained from all participants. Afterwards, eligible patients were randomly assigned to one of two treatment groups using blocked randomization by a computer-generated table of random numbers, a block size of ten and an allocation ratio of 1:1. Participants were sequentially allocated to the treatments in the order in which they were recruited. Intervention assignment was ascertained using sealed, opaque envelopes with consecutive numbering after the enrolled patients completed all baseline measurements. The investigator who opened the envelopes and carried out the implementation of assignments was not involved in the generation and allocation concealment. Outcome investigators and participants were blinded to the treatment at baseline measurements. Afterwards, participants and physiotherapists were aware of the group allocation due to the nature of the intervention.

All patients underwent a standard surgical procedure by inserting the same implant (Multigen Plus, Lima-Lto, San Daniele, Italy) with an identical surgical approach. Postoperatively they received continuous peridural analgesia or femoral nerve block. Additionally, a 3-step analgesia was performed to provide optimal pain relief with (1) indomethacin (25 mg), (2) metamizol and (3) paracetamol. The Multigen Plus implant is a non-constrained surface replacement consisting of symmetrical, cruciate-retaining, cemented metallic femoral and tibial components and fixed-bearing ultra-high molecular weight polyethylene liners. All patients underwent full-weight-bearing with two crutches beginning on the second postoperative day.

Interventions

Eligible patients were either allocated to (a) the CPM group, which received physiotherapy and CPM application (control intervention; standard-of-care therapy) or (b) the ST group, which received physiotherapy and performed sling exercises. All patients participated in a standardized in-hospital physiotherapy which was carried out by physical therapists twice a day for 30 minutes each, starting on the first postoperative day. Physiotherapy consisted of active and passive ROM exercises, active isometric contractions of the quadriceps and exercises to improve activities of daily living like transfer from bed to chair, transition from sitting to standing, walking and climbing stairs. Exercise intensity was gradually increased according to pain and tolerance. Furthermore, patients received two 30 minutes CPM or ST applications each day from the second postoperative day until 1 day prior to discharge. The patients were shown the CPM or the ST exercises by a physiotherapist.

The CPM protocol was started with 0° to the maximum tolerated flexion at the highest, adjustable speed. ROM was increased daily depending on tolerance. The CPM machines used were Kinetec® Optima™ S3 and S4 (AbilityOne Kinetec S.A., Tournes, France) with maximal possible flexion angles of 115° and 120°. Participants were instructed not to resist or actively support the motion of the device.

The participants in the ST group performed active knee flexions and extensions in a sling while lying in a supine position. The sling exercise intervention is shown in Figure 1. The patient's leg was placed in a standard tubular bandage that was suspended from a cross brace fixed to the bed. The ST protocol was started with 0° to maximum tolerated flexion at a movement speed comparable to those used in the CPM protocol. Exercise progression was achieved by asking the patients to gradually increase the range of motion as tolerated.

Patients were discharged when sufficiently mobile (i.e., at least 90° knee flexion and no need of personal care) and medically stable. After discharge, all patients participated in daily physical therapy for 3 weeks in a rehabilitation hospital.

Outcomes

Participants were assessed before TKA for baseline measurement (pretest), 1 day before discharge (posttest) and 3 months after TKA (follow-up). The pFL was the primary outcome measure. Secondary outcome measures included aFL as well as active and passive knee extension ROM (aEX, pEX), static postural control, physical activity, pain and length of hospital stay. Furthermore, clinical, functional and quality-of-life outcomes were evaluated (i.e., SF-36, HSS and WOMAC scores). Any outcomes were determined by the same investigator. Table 1 shows the methods and parameters.

Range of motion (ROM)

Active and passive ROM (aFL, pFL, aEX and pEX) were measured using a standard handheld goniometer with the patient in a supine position [21]. The goniometer was placed over the joint space with one arm in line with the fibular head and lateral malleolus and the other aligned with the greater trochanter. The knee was flexed maximally and the angle was measured in degrees. Knee extension was measured in the same position as for flexion. The knee was moved to maximal extension and the angle was measured. Jakobsen et al. (2010) showed substantial inter-tester and intra-tester reliability of the knee joint ROM measurement in patients with TKA [22].

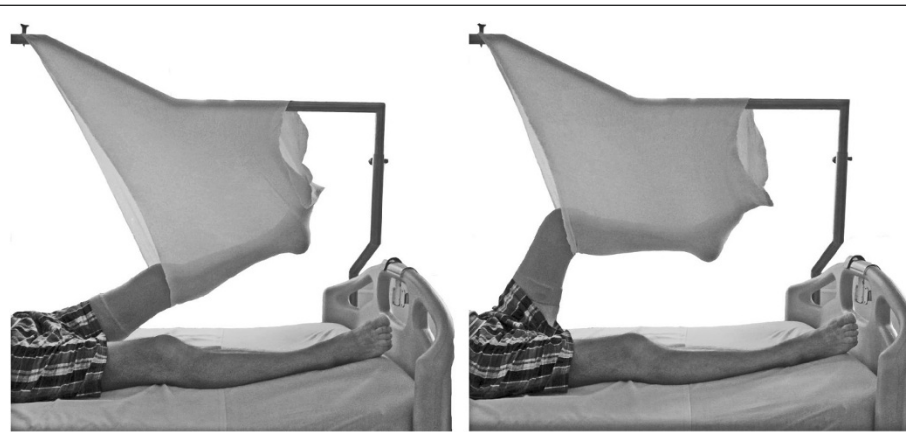

Figure 1 Sling exercise training.

Table 1 Primary and secondary outcomes

Variable	Method
Primary outcome	
pFL	Goniometry
Secondary outcomes	
aFL	Goniometry
aEX	Goniometry
pEX	Goniometry
Physical activity	Activity monitor
Static postural control	Force plate
Length of hospital stay	
Pain	Visual analogue scale
Clinical, functional and quality-of-life outcomes	HSS, SF-36 and WOMAC scores

Abbreviations: pFL, maximal passive knee flexion; aFL, maximal active knee flexion; aEx, maximal active knee extension; pEx, maximal passive knee extension; HSS score, Hospital for Special Surgery Score; SF-36, Short Form Health Survey; WOMAC score, Western Ontario and McMaster Osteoarthritis Score.

Pain

Pain was evaluated using a 10 cm visual analog scale (VAS). Patients were asked to mark their degree of knee pain on a continuous horizontal line whereby the very left end indicated no pain (score 0) and the very right end (score 10) indicated unbearable pain. Studies have shown that the VAS is more reliable than the questionnaires in patients with TKA [23].

Physical activity

Physical activity was determined with an accelerometer-based mobility monitoring device (activPAL™, PAL Technologies Ltd., Glasgow, UK) [24]. The activity monitor was attached to the thigh anteriorly in the middle between the knee and the hip. Physical activity was monitored during hospital stay over a period of 5 days (fourth to eighth day) and 3 months postoperatively for 7 days. During hospital stay the sensor was applied to the thigh of the un-operated leg to preclude measurement errors due to intervention-related joint mobilization. At the follow-up the sensor was fixed to the right thigh. Participants were instructed to wear the device permanently except when performing water activities (e. g., taking a shower, swimming). The absolute time spent lying/sitting, standing and stepping as well as the number of steps and sit to stand transitions were measured. Data were obtained with a sampling frequency of 10 Hz and analyzed with the activPAL™ interface program.

Static postural control

The participants executed postural tasks in upright bipedal stance on a force plate (GKS 1000®, IMM Holding GmbH, Mittweida, Germany) in static condition. The force plate measured the trajectory of the center of pressure (CoP) in medio-lateral (m-l) and anterior-posterior (a-p) direction. Participants were asked to stand as stable as possible, in slight knee flexion and with hands akimbo. The position of feet was marked for repeated testing. Two conditions of vision were tested: (1) eyes open, (2) eyes closed. In the eyes-open condition, the participants were instructed to fixate a black point (Ø 10 cm) located 1.20 m away from the platform at eye level. In the eyes-closed condition, they were instructed to close their eyes and maintain the gaze straight ahead. In order to become familiar with the procedure the participants completed three pre-trials. Thereafter, three test trials each of 15 seconds duration were performed. Before the recording of measurement was started, patients had to stabilize stance for 10 seconds. A rest period of 1 minute was allowed between the trials. Data were obtained with a sampling frequency of 40 Hz and analyzed with the GKS-MED Software (IMM Holding GmbH, Mittweida, Germany) und Excel 2007 (Microsoft Inc., Seattle, USA). The velocity and sway of the CoP displacement in m-l and a-p direction ($velocity_{m-l}$, $velocity_{a-p}$, $sway_{m-l}$, $sway_{a-p}$) and the area of the CoP displacement were evaluated. The mean value of the three test trials was used for further analyses.

Clinical, functional and quality-of-life outcomes

Health-related status, function and quality of life were evaluated using the 36-item Short Form Health Survey (SF-36) [25], Hospital for Special Surgery Knee Score (HSS) [26], and Western Ontario and McMaster University Osteoarthritis Index (WOMAC) [27]. The scores are generally acknowledged to have good reliability and validity [25,27,28]. Each scale ranges from 0 (poorest status) to 100 points (best status). The SF-36 consists of 36 items assigned to 8 subscales: physical functioning, physical role, bodily pain, general health, vitality, social functioning, emotional role and mental health. Two summary scores (mental and physical health) and one total score were calculated as the mean of the 8 subscales. The WOMAC score is a disease-specific, self- administered, health status measure using 3 subscales with a total of 24 items: pain (5 items), function (17 items) and stiffness (2 items). Each question was answered using a 5-point Likert scale. The HSS score is subdivided into six categories: pain, function, range of motion, muscle strength, flexion deformity and instability.

Statistical analysis

There are no preliminary studies on the comparison of both interventions. Based on the review of Harvey et al. (2010) and with the aim of showing clinically relevant differences, we hypothesized a difference in ROM between ST and CPM therapy of 5° [1]. Sample size calculation in-dicated that a total of 52 patients would be required to detect a large effect (Cohen's $f = 0.40$) with a two-sided significance of 0.05 and a power of 0.80. In considering an anticipated dropout rate of 10%, a total of 58 patients were needed for the trial. A 14-month recruitment period was assumed to enroll this number of participants.

Data analysis included all randomized patients according to their original treatment allocation (intention-to-treat analysis) [29]. Data were checked for normal distribution using the Shapiro-Wilk *W* Test. Non-normally distributed data were log-transformed before analysis. Multiple imputation (5 imputed data sets) was used to account for missing data using the Markov Chain Monte Carlo (MCMC) method [30]. Differences between the groups were tested for significance by the unpaired Student's *t* test ($P \leq 0.050$) or an analysis of covariance (ANCOVA) adjusted for baseline [31], weight, sex, age, pain and physical activity (alpha-adjustment for conducting two ANCOVA's $P \leq 0.050/2 = 0.025$). All data were analyzed using the SPSS statistical package (version 20.0, SPSS Inc., Chicago, IL, USA). Sample size, power and Cohen's effect size were calculated with the statistical software package G*Power (version 3.1.4.) [32]. The effect size *f* was interpreted using the classification of Cohen (1988): $f = 0.10$ small effect, $f = 0.25$ medium effect, $f = 0.40$ large effect [33].

Data of the pretest are presented as mean and standard deviation in the tables. Pooled multiple imputation data of each primary and secondary outcome are reported as covariate-adjusted means and standard deviation together with the effect size (mean difference) and its precision (95% confidence intervals, 95% CI) in the figures and tables.

Results

Thirty-eight participants were recruited from 125 available patients within the 14 month recruitment period. The recruitment of patients was stopped when the scheduled date of closure was reached. The minimum sample size (N = 58) required was not achieved. Recruitment numbers, reasons for not being eligible or enrolled as well as

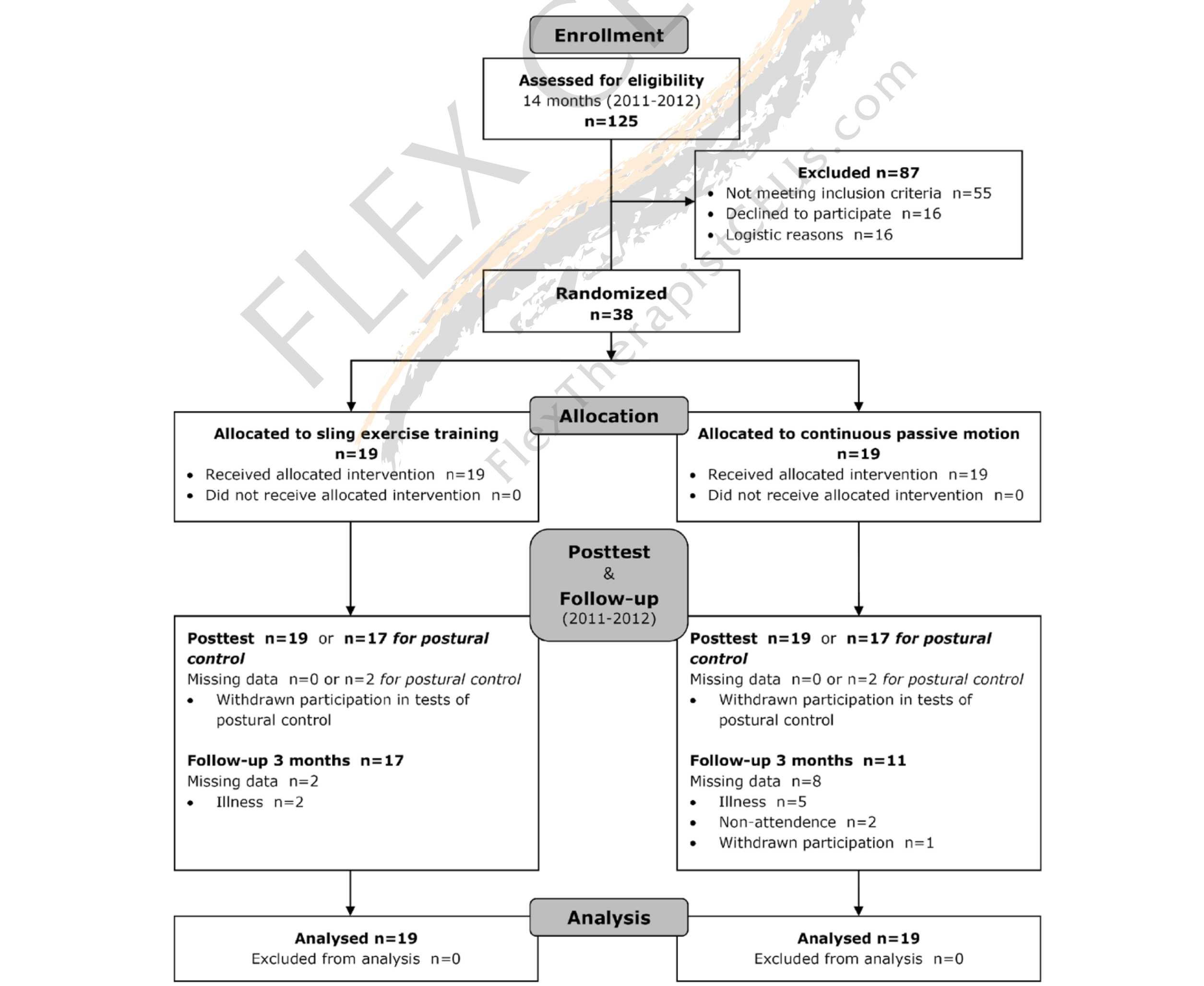

Figure 2 CONSORT flow diagram to show the flow of participants through the trial [34].

Table 2 Baseline demographic and clinical subject characteristics

Variable	ST (n = 19)	CPM (n = 19)
Age, yrs	68.8 (8.0)	67.1 (8.8)
Sex, men	12.0 (63.2%)	10.0 (52.6%)
Weight, kg	88.9 (13.3)	93.6 (15.9)
Height, m	1.69 (0.1)	1.68 (0.1)
BMI	31.1 (4.2)	33.3 (5.1)
Affected side, right	8.0 (42.1%)	7.0 (36.8%)
Hypertension	13.0 (68.4%)	14.0 (73.7%)
Cardiac problems	6.0 (31.6%)	5.0 (26.3%)
Pulmonary problems	1.0 (5.3%)	0.0 (0%)
Diabetes	2.0 (10.5%)	5.0 (26.3%)
Cancer	1.0 (5.3%)	0.0 (0%)
TKA contralateral side	5.0 (26.3%)	6.0 (31.6%)
THA contralateral side	2.0 (10.5%)	0.0 (0%)
THA ispilateral side	3.0 (15.8%)	1.0 (5.3%)

Abbreviations: ST, sling exercise training group; CPM, continuous passive motion group; BMI, body mass index; TKA, total knee arthroplasty; THA, total hip arthroplasty.
Values are presented as mean (standard deviation) or numbers (%).

allocation, missing data and reasons for missing data are reported in the CONSORT flow diagram (Figure 2). The patients' demographic and clinical characteristics are displayed in Table 2. All patients received an allocated intervention and were analyzed for outcome measures. Both groups did not differ significantly in the number of physiotherapy, CPM and ST interventions and in the time to posttest and follow-up (Table 3). No incidents of adverse effects or harm during the study could be observed.

Primary outcome

A between-group difference could be determined at posttest. The pFL was significantly higher by 6.0° ($F = 5{,}80$; $P = 0.022$; $\eta_p^2 = 0.162$; $f = 0.440$) in the ST group. No difference in pFL was documented at follow-up (Table 4; Figure 3).

Secondary outcomes

No significant differences between the groups could be observed for any secondary outcome measure at posttest and follow-up (Tables 4, 5, 6). However, a statistical tendency toward an increase in aFL by 4.4° ($F = 3.53$; $P = 0.070$; $\eta_p^2 = 0.105$; $f = 0.343$; Power = 0.533) could be documented for the ST group (Table 4; Figure 3). Furthermore, the velocity$_{a\text{-}p}$ for the eyes closed condition tended to be higher by 4.5 mm·s-1 ($F = 4.66$; $P = 0.040$; $\eta_p^2 = 0.143$; $f = 0.480$; Power = 0.683) and the HSS score demonstrated a trend toward lower muscle strength by −0.9 ($F = 4.20$; $P = 0.049$; $\eta_p^2 = 0.116$; $f = 0.362$; Power = 0.582) in the ST group at posttest (Tables 4, 6).

Discussion

The objective of the present randomized clinical study was to compare the effectiveness of a new sling-based ROM therapy with the traditional CPM application as an adjunct to daily physiotherapy following TKA. The knee joint mobilization in the sling requires the activation of muscles. Furthermore, the unstable support during the performance of ROM exercises might contribute to higher demands on muscle strength and muscle coordination. Therefore, it was assumed that an ST might be advantageous for early recovery following TKA.

There is evidence that ST has a significant positive, short-term effect on pFL of 6°. A medium-term benefit of these positive effects on knee flexion ROM could not be confirmed because no differences between groups were determined at the 3-month follow-up. Furthermore, there were no significant beneficial effects of ST on the secondary outcomes (aFL, aEX, pEX, pain, physical activity, static postural control, length of hospital stay and health-related status, function or quality of life).

Table 3 Number of interventions during hospital stay and time to posttest and follow-up

Variable	ST (n = 19)	CPM (n = 19)	Mean difference (95% CI)	P
CPM or ST, n	14.2 (2.2)	14.6 (1.8)	−0.46 (−1.8, 0.89)	0.597
Standard physiotherapy, n	8.1 (1.0)	8.4 (0.7)	−0.32 (0.29, −0.90)	0.281
Gait training, n	6.4 (1.3)	6.6 (1.0)	−0.26 (−1.00, 0.47)	0.472
Start day of walking corridor[‡]	4.0 (1.2)	4.3 (1.2)	−0.31 (−1.10, 0.49)	0.437
Start day of climbing stairs[‡]	7.5 (1.6)	7.5 (1.6)	<0.01 (−0.99, 0.99)	0.997
Postest, d	9.6 (1.3)	9.5 (0.6)	0.06 (−0.67, 0.78)	0.870
Follow-up, d	95.5 (9.7)	90.7 (8.7)	4.77 (−2.89, 12.44)	0.212

Abbreviations: ST, sling exercise training group; CPM, continuous passive motion group.
[‡]ANCOVA: adjusted for sex, weight, age, pain and physical activity.
Values are presented as means (standard deviation).

Table 4 Outcome measures of knee joint range of motion and static postural control with open and closed eyes

Variable	Pretest		Posttest‡			Follow-up‡		
	ST (n = 19)	CPM (n = 19)	ST (n = 19)	CPM (n = 19)	Mean difference (95% CI)	ST (n = 19)	CPM (n = 19)	Mean difference (95% CI)
Range of motion								
Active flexion, °	108.4 (15.1)	103.0 (21.7)	91.8 (6.9)	87.4 (6.9)	4.4 (−0.4, 9.1)†	101.4 (9.6)	103.3 (9.6)	−1.9 (−8.5, 4.7)
Passive flexion, °	111.6 (13.7)	106.1 (20.2)	95.3 (7.4)	89.2 (7.4)	6.0 (0.9, 11.2)*	104.1 (8.6)	107.1 (8.6)	−3.0 (−8.9, 2.9)
Active extension, °	4.5 (5.2)	3.4 (6.7)	1.6 (3.2)	1.7 (3.2)	−0.1 (−2.3, 2.1)	3.8 (5.4)	2.0 (5.4)	1.8 (−1.9, 5.4)
Passive extension, °	3.6 (4.0)	3.4 (5.5)	0.7 (1.6)	<0.1 (1.6)	0.7 (−0.4, 1.8)	2.8 (4.1)	0.8 (4.1)	2.0 (−0.8, 3.8)
Postural control – eyes open								
Area, cm^2	1.50 (0.52)	1.47 (0.92)	1.63 (0.83)	1.62 (0.83)	0.01 (−0.54, 0.56)	1.42 (0.62)	1.44 (0.62)	−0.03 (−0.43, 0.38)
$Sway_{m-l}$, mm	5.33 (2.46)	4.84 (1.77)	6.61 (2.73)	7.29 (2.73)	−0.68 (−2.50, 1.14)	6.25 (2.18)	6.12 (2.18)	0.13 (−1.30, 1.56)
$Sway_{a-p}$, mm	5.66 (2.22)	4.99 (1.64)	8.77 (4.11)	7.86 (4.11)	0.92 (−1.82, 3.66)	7.29 (2.95)	6.17 (2.95)	1.12 (−0.83, 3.07)
$Velocity_{m-l}$, $mm \cdot s^{-1}$	11.32 (2.66)	11.55 (4.78)	17.87 (7.59)	18.03 (7.59)	−0.17 (−5.19, 4.86)	15.70 (8.59)	18.32 (8.59)	−2.62 (−8.26, 3.02)
$Velocity_{a-p}$, $mm \cdot s^{-1}$	12.53 (3.09)	11.89 (3.40)	24.39 (8.72)	22.39 (8.72)	2.00 (−3.80, 7.79)	19.64 (8.00)	20.13 (8.00)	−0.48 (−5.74, 4.77)
Postural control – eyes closed								
Area. cm^2	3.24 (2.11)	4.16 (3.39)	3.83 (1.41)	3.23 (1.41)	0.59 (−0.35, 1.53)	3.19 (2.09)	3.68 (2.09)	−0.49 (−1.87, 0.89)
$Sway_{m-l}$, mm	6.30 (2.08)	6.90 (2.28)	6.84 (2.55)	7.13 (2.55)	−0.29 (−1.98, 1.40)	6.36 (2.01)	6.03 (2.01)	0.32 (−1.00, 1.64)
$Sway_{a-p}$, mm	7.33 (2.65)	8.29 (4.76)	9.12 (3.98)	7.54 (3.98)	1.58 (−1.05, 4.22)	7.99 (2.31)	7.33 (2.31)	0.66 (−0.86, 2.18)
$Velocity_{m-l}$, $mm \cdot s^{-1}$	16.54 (5.48)	19.10 (11.70)	18.61 (5.59)	17.37 (5.59)	1.23 (−2.47, 4.94)	16.95 (7.25)	17.20 (7.25)	−0.25 (−5.04, 4.54)
$Velocity_{a-p}$, $mm \cdot s^{-1}$	19.34 (5.58)	21.63 (14.36)	25.71 (6.44)	21.21 (6.44)	4.50 (0.23, 8.77)†	20.44 (6.66)	19.41 (6.66)	1.03(−3.36, 5.42)

Abbreviations: ST, sling exercise training group; CPM, continuous passive motion group; m-l, medio-lateral; a-p, anterior-posterior.
*denotes a significant difference ($P \leq 0.025$); †denotes a statistical tendency ($P \leq 0.100$). ‡ANCOVA: values of the posttest were adjusted for baseline, sex, weight, age, pain and physical activity; values of the follow-up-measurement were adjusted for baseline, sex, weight, age and physical activity.
Values of the pretest are presented as mean (standard deviation). Values of the posttest and follow-up-measurement are presented as estimated marginal means (standard deviation).

A recent review on the effectiveness of adjunctive CPM therapy compared to physiotherapy alone reported short-term effects on aFL and pFL by 3° and 2°, respectively [1]. The authors suggested that these effects on ROM are too small to be clinically relevant. Taking into account the fact that the application of CPM is associated with high costs for the rental or acquisition of the device and additional technical and personnel efforts to set up and operate the machine, it was suggested that an additional ROM of more than 5° is required to justify its use [1]. Following this recommendation, we hypothesized a clinically relevant mean difference in ROM of 5° between ST and CPM therapy. Our present data demonstrate a between-group difference in pFL of 6°, which is above the hypothesized and clinically relevant difference. This result leads to the assumption that the application of an adjunctive ST therapy in the early postoperative phase could be recommended as a part of the rehabilitation program following TKA. Nevertheless, the clinical relevance remains uncertain as the confidence interval

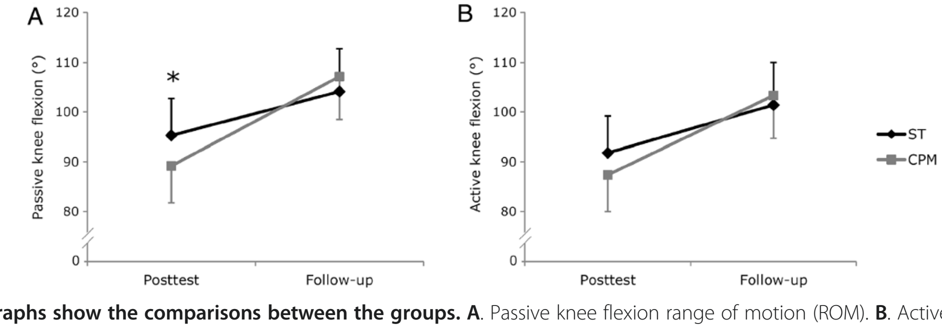

Figure 3 The Graphs show the comparisons between the groups. A. Passive knee flexion range of motion (ROM). **B**. Active knee flexion ROM. The dark grey line represents the sling exercise training group (ST) and the light grey line the continuous passive motion group (CPM). Data are presented as estimated marginal means and standard deviation (ANCOVA: posttest adjusted for baseline, sex, weight, age, pain and physical activity; follow-up adjusted for baseline, sex, weight, age and physical activity. * denotes a significant difference ($P \leq 0.025$).

Table 5 Outcome measures for pain and physical activity

Parameter	Pretest		Posttest‡			Follow-up‡		
	ST (n = 19)	CPM (n = 19)	ST (n = 19)	CPM (n = 19)	Mean difference (95% CI)	ST (n = 19)	CPM (n = 19)	Mean difference (95% CI)
Pain	n/a	n/a	1.22 (1.73)	1.78 (1.73)	−0.56 (−1.73, 0.60)	n/a	n/a	n/a
Length of hospital stay, d			9.99 (0.31)	10.52 (0.32)	−0.53 (−1.47, 0.41)			
Physical activity								
Lying/sitting, h	n/a	n/a	112.0 (3.4)	111.5 (3.4)	0.5 (−1.8, 2.8)	134.4 (9.1)	132.3 (9.1)	2.2 (−4.0, 8.2)
Standing, h	n/a	n/a	7.1 (2.7)	6.1 (2.7)	1.0 (−0.8, 2.8)	25.3 (6.0)	25.5 (6.0)	−0.2 (−4.2, 3.8)
Stepping, h	n/a	n/a	1.4 (0.80)	1.3 (0.80)	0.1 (−0.5, 0.6)	9.5 (3.6)	9.4 (3.6)	0.1 (−2.3, 2.6)
Sit to stand transition, n	n/a	n/a	156.4 (56.3)	129.2 (56.3)	27.2 (−10.9, 65.2)	330.5 (102.4)	320.8 (102.4)	9.7 (−59.0, 78.4)
Step count, n	n/a	n/a	4685 (3087)	4151 (3087)	534 (−1555, 2624)	42037 (14412)	36203 (14412)	5834 (−3836, 15504)

Abbreviations: ST, sling exercise training group; CPM, continuous passive motion group; n/a, not available.
‡ANCOVA: pain was adjusted for sex, weight, age and physical activity; length of hospital stay was adjusted for sex, weight, age, pain and physical activity; the posttest-values of physical activity were adjusted for sex, weight, age and the follow-up-values were adjusted for sex, weight and age.
Values are presented as estimated marginal means (standard deviation).

was fairly wide and some methodological limitations have to be considered.

Study limitations

Our study was limited by the small sample size. The target number of participants was not achieved by the scheduled day of closure due to an unexpectedly low number of patients that met the inclusion criteria. It was not possible to extend the study to achieve adequate enrollment, as the date of termination of financial support of the project had been reached. The high proportion of ineligibility reduces the generalizability of the findings. A post-hoc power

Table 6 Outcome measures of clinical, functional and quality-of-life outcomes

Variable	Pretest		Posttest‡			Follow-up‡		
	ST (n = 19)	CPM (n = 19)	ST (n = 19)	CPM (n = 19)	Mean difference (95% CI)	ST (n = 19)	CPM (n = 19)	Mean difference (95% CI)
HSS score, %								
Pain	10.8 (6.9)	14.5 (7.4)	24.3 (6.4)	22.3 (6.4)	1.9 (−2.5, 6.4)	23.1 (6.1)	20.9 (6.1)	2.2 (−2.0, 6.4)
Function	13.7 (4.1)	15.1 (4.2)	9.7 (3.4)	10.0 (3.4)	−0.3 (−2.6, 2.0)	16.7 (3.1)	17.7 (3.1)	−1.1 (−3.2, 1.1)
Strength	10.0 (0.0)	9.9 (0.5)	8.9 (1.3)	9.7 (1.3)	−0.9 (−1.7, 0.0)†	10.0 (0.0)	10.0 (0.0)	-
Instability	9.6 (1.2)	9.6 (1.2)	10.0 (0.0)	10.0 (0.0)	-	10.0 (0.0)	10.0 (0.0)	-
FlexDeform	9.1 (1.9)	8.7 (2.3)	10.0 (0.0)	10.0 (0.0)	-	10.0 (0.0)	10.0 (0.0)	-
ROM	13.9 (1.6)	13.1 (2.4)	12.3 (1.0)	11.5 (1.0)	0.8 (0.2, 1.5)*	12.7 (1.8)	12.9 (1.8)	−0.2 (−1.4, 1.1)
Total	66.3 (11.8)	69.9 (11.8)	71.6 (9.7)	70.8 (9.7)	0.8 (−5.8, 7.4)	81.6 (10.2)	79.2 (10.2)	2.4 (−4.5, 9.4)
SF-36 score, %								
Physical health	32.9 (16.2)	30.3 (13.5)	40.0 (14.0)	37.6 (14.0)	2.5 (−6.9, 11.9)	52.5 (19.7)	52.6 (19.7)	0.1 (−13.3, 13.2)
Mental health	66.3 (19.8)	57.8 (20.5)	68.1 (18.1)	66.2 (18.1)	1.6 (−10.6, 13.9)	72.7 (18.2)	69.4 (18.2)	3.2 (−9.0, 15.6)
Total	49.9 (15.1)	44.0 (15.4)	50.9 (14.3)	52.3 (14.3)	−1.4 (−11.1, 8.3)	63.5 (16.3)	61.3 (16.3)	2.2 (−8.8, 13.2)
WOMAC score, %								
Pain	8.9 (3.3)	9.5 (3.9)	15.2 (3.7)	14.9 (3.7)	0.3 (−2.2, 2.8)	15.2 (3.6)	14.7 (3.6)	0.42 (−2.03, 2.87)
Stiffness	4.6 (2.0)	4.0 (1.9)	6.0 (1.5)	6.4 (1.5)	−0.4 (−1.4, 0.6)	5.5 (1.6)	5.1 (1.6)	0.31 (−0.75, 1.37)
FD	32.3 (9.2)	34.7 (8.7)	44.9 (12.9)	43.7 (12.9)	1.2 (−7.5, 9.9)	49.4 (8.3)	47.2 (8.3)	2.22 (−3.40, 7.83)
Total	47.9 (13.6)	46.8 (18.2)	69.6 (18.1)	67.3 (18.1)	2.3 (−9.8, 14.4)	73.2 (12.5)	67.7 (12.5)	5.51 (−2.83, 13.86)

Abbreviations: ST, sling exercise training group; CPM, continuous passive motion group; HSS score, Hospital for Special Surgery Knee Score; FlexDeform, flexion deformity; ROM, range of motion; SF-36, Short Form Health Survey; WOMAC score, Western Ontario and McMaster University Osteoarthritis Score; FD, functional difficulty.
*denotes a significant difference ($P \leq 0.025$); †denotes a statistical tendency ($P \leq 0.100$). ‡ANCOVA: adjusted for baseline, sex, weight and age.
Values of the pretest are presented as mean (standard deviation). Values of the posttest and follow-up-measurement are presented as estimated marginal means (standard deviation).

analysis was conducted for all secondary outcomes that did not reach statistical significance in order to rule in or rule out inadequate power as a threat to the internal validity of the findings [35]. The post-hoc power coefficients were low (power < 0.80). Thus, the study was underpowered for many outcome variables and a lack of power, possibly due to small sample size, is an alternative explanation of the statistically non-significant findings. It could be assumed that, if the study had been adequately powered we could have seen a greater number of statistically significant differences.

A second limitation was the 26% dropout rate at the 3-month follow-up. However, none of the patients withdrew from the study for a reason related to the study treatment. Missing values will result in a reduction of the number of cases for analysis which reduces precision and possibly introduces bias. The missing-data problem was handled by imputing missing values using multiple imputation [29,30].

A further limitation was the inability to blind the patients and practitioners, which was impossible due to the nature of the intervention. Although it would be appropriate, it was not possible to run a 3-arm trial including an arm with no additional intervention because CPM combined with usual physiotherapy is the standard treatment following TKA in the Department of Orthopedics at the University Medicine Rostock. Thus, it was not considered appropriate to exclude the CPM therapy.

Despite these limitations, a statistically significant and clinically relevant positive result relating to the ST therapy could be presented.

Conclusions

This study was the first randomized controlled trial to systematically assess the effectiveness of a new active sling-based in-hospital ROM exercise program with the standard-of-care therapy (CPM) following TKA. Findings in the literature indicate that an adjunctive passive ROM therapy using CPM only slightly contributes to an initial regain of ROM. The present data suggest that more complex tasks using active sling-based exercises could have a further beneficial short-term effect on knee flexion ROM compared to conventional CPM therapy. A clinically relevant difference between groups was found in pFL. The ST is easy to carry out during hospital stay and is less expensive than CPM therapy. Since the cost-effectiveness could be increased while even improving the quality of clinical results, the application of an ST therapy in the post-operative phase can be recommended as part of the early post-operative rehabilitation management. Against the background of some methodological limitations, the results of the present study should be interpreted with caution and could be strengthened after a replication study is carried out on a larger sample set.

Rehabilitation and Physical Therapy before and after Total Knee Arthroplasty: A Literature Review and Unanswered Questions

Abstract

This review focuses on the validity and the effectiveness of rehabilitation techniques and physical therapies before and after total knee arthroplasty (TKA). The intent is to drive surgeons and rehabilitation specialists in the choice of the strategies for the treatment after TKA. The Data sources were MEDLINE, PubMed, CINAHL, EMBASE, and PsychINFO databases using the selected key words. Three authors independently selected studies for review using as criteria English, adults, any clinical population, and intervention for. Among several published studies of rehabilitation after TKA, only a few were based on scientific evidence. Moreover, many studies were heterogeneous and included different outcomes and evaluations. There is consensus that a complete and specific rehabilitation post-operative programme is effective in reducing the length of hospitalisation and the incidence of early complications. However, it is not clear what “complete and specific rehabilitation” may mean: the real efficacy of every specific treatment (continuous passive motion, cryotherapy, magneto therapy, neuro muscular electrical stimulation, whole body vibration, hydrotherapy, pre-operative physiotherapy) is still questionable, and often related to the experience of the authors. In conclusion, patients undergoing physiotherapy obtain a better and faster outcome achievement than non-treated patients; however, evidence-based treatments, protocols and clinical trials are recommended.

Keywords: Total knee arthroplasty; Rehabilitation; Physical therapy; Knee arthritis

Introduction

Arthritis of the knee is very common and has high social impact [1] because it reduces the mobility of the joint, causes pain, and limits the ability of the patient to walk, work and carry out daily and sport activities [2]. When pain and functional disability are no longer sustainable, the definitive treatment is total knee arthroplasty (TKA), which allows excellent recovery and complete return to normal activities [3-9].

The number of TKAs performed is increasing annually and the length of hospital stay is decreasing [10]. Patients have increased expectations for a fast and complete recovery. Nevertheless, TKA may result in severe post-operative pain, muscular weakness, articular reduction and disability in general, which may last for a considerable time. Since range of movement (ROM) and pain perception in the early post-operative phase seem to be important prognostic factors for the patient’s future satisfaction and mental status, effective analgesia and appropriate rehabilitation are required [11,12].

For these reasons, there is strong support for a specific programme of pre- and post-operative rehabilitation. Nevertheless, most studies of the role of rehabilitation and physiotherapy around TKA do not have specific standardised protocols; therefore, controversies remain regarding the choice and the effectiveness of the different techniques. Consequently, the purpose of this literature review is to focus on physical therapy and rehabilitation techniques before and after total knee replacement, and to evaluate their efficacy.

Physiotherapy and Rehabilitation

Physiotherapeutic intervention: Relevant clinical studies

A randomised blinded study compared for two years 120 patients divided into groups, one of which received outpatient physiotherapy and the other did not [13]. Both groups began physiotherapy and home exercise regimes immediately after discharge: the outpatient physiotherapy group performed slightly better, although the difference was not clinically significant.

Another study investigated whether a standard protocol of outpatient physiotherapy could improve the knee ROM after primary TKA [14]. One hundred and fifty patients were recruited and randomised into two groups: one group received the outpatient physiotherapy and the other did not. All patients resumed full weight bearing and mobilisation as soon as possible after surgery. At three months, the outpatient physiotherapy group showed a better ROM compared to the other group while, at one year, there were no differences in the two groups in terms of ROM, walking distance and ability. According to these results, the physiotherapy was associated with a faster return to a functional range of motion but did not provide clinical benefits at one year.

A sequential cohort study compared the effectiveness and the time efficiency of physiotherapy rehabilitation provided through home protocols with those provided in exercise groups (class-based exercise) [15]. The outcome measures were assessed by WOMAC, SF-36, the timed up and go test, knee ROM, a six minutes' walk test, and a patient evaluation questionnaire: no differences were detected between the two groups in any of the outcomes. However, it was noted that class-based rehabilitation allowed more frequent access to physiotherapy and reduced the physiotherapist's work.

A pilot randomised clinical trial [16] showed the importance of balance training after TKA. The exercises proposed were based on the protocol published by Fitzgerald [17] (involving agility and perturbation techniques). The authors demonstrated the potential benefits related to walking speed, single leg stance, stiffness and pain intensity.

None of these studies discusses the protocols of rehabilitation, but their common goal was to suggest whether physiotherapy is useful or not. The following paragraphs will discuss evidence-based studies of the specific rehabilitative techniques.

Neuro muscular electrical stimulation

Neuro muscular electrical stimulation (NMES) is defined as the application of an electrical current to the neuro muscular junction and to the surrounding muscle fibres to cause a muscle contraction [18]. It causes the muscle contraction by applying a transcutaneous current to terminal branches of the motor neuron [19], and it can increase the muscle strength by increasing the load on the muscle, using an electrically induced contraction with a training effect. According to the literature, all evaluations of the effects of NMES to improve strength in the quadriceps muscle after TKA must analyse all the parameters of electrical stimulation [20]. Neuro muscular electrical stimulation may be applied both before and after surgery.

To our knowledge, the first study that used NMES as a pre-rehabilitation modality was published in 2010: patients treated with NMES increased pre-operative quadriceps femoris muscle strength by 28% and had a faster functional recovery following TKA [21].

A Cochrane review published in 2010 was unable to assess the effectiveness of NMES in increasing quadriceps strength pre- and post-TKA. A meta-analysis could not be carried out because the imprecision of the results of studies analysed, published before 2008, led to a high risk of bias [22].

A randomised controlled trial (RCT), assessed the efficacy of a strengthening rehabilitation programme associated with NMES [23]. It compared two groups of 100 patients in whom the treatment began four to six weeks after surgery and lasted six weeks. There were no differences in outcomes between the two groups. A prospective, longitudinal RCT also evaluated the efficacy of NMES, which was applied to the quadriceps muscle twice a day at the maximum tolerable intensity for 15 contractions, while the treatment started 48 hours after TKA surgery complemented by standard rehabilitation [24]. At 3.5 weeks after surgery, significant improvements were found in quadriceps and hamstring muscle strengths, functional tests, and knee extension ROM. Fifty-two weeks after surgery, the differences between the two groups were reduced but still present.

Whole body vibration

Whole body vibration (WBV) can be used to improve muscular strength: it is a type of exercise used to rehabilitate patients with low extremity weakness to increase muscular strength at the same level as standard strength training [25]. A RCT showed an increase in knee extensor strength, and improvements in countermovement jumping in older women, and in the sit to stand test, and in postural control in the elderly [26].

Only one clinical trial concerning the role of WBV after TKA has been identified [27]. In this study, all subjects received physical therapy care including a warm up, pain relief, oedema management, ROM treatment and a strength training programme. While the WBV group carried out strengthening exercises on a WBV platform, the other did progressive resisted exercises. No increased pain was reported in the WBV group during or after vibrations. There was a significant increase in knee extensor strength and an improvement in mobility in both groups. However, no significant differences between groups regarding strength, muscle activation or mobility were seen, and the influence of WBV after TKA still remains unclear.

Continuous passive motion

Continuous passive motion (CPM), first introduced in the 1960s [28], is a way of providing regular movement to the knee using an external motorised device that passively moves the joint through an established arc of motion [29].

A study considered 178 papers that compared the physiotherapeutic treatment alone versus the physiotherapy plus CPM [30]. Continuous passive motion associated with rehabilitation was found to reach the goal of 90° knee flexion more quickly, and a statistically significant higher active knee flexion at two weeks after surgery. However, the results were not confirmed one year after surgery and CPM did not have a statistically significant effect on knee extension.

It has been suggested that CPM should be applied immediately after surgery in the recovery room, setting an initial value of 40° of flexion that could be increased in the following days, according to patient tolerance [31,32]. Other authors have proposed applying the CPM immediately at high flexion degrees for one or two days. They found a quick and significant gain in the degree of flexion; however, that gain was not confirmed in the long-term, patients reported severe pain and major bleeding was observed after surgery [33].

A RCT [34], studied 34 patients divided into two groups: the first group received CPM from the first day after surgery (1st day CPM-group), while the other started treatment with CPM immediately in the recovery room (immediate CPM-group). They concluded that the immediate CPM-group, at the first visit after TKA, had a higher active and passive knee flexion. At the outpatient visit three months after surgery, the knee flexion second was similar in the two groups.

Another RCT investigated the effectiveness of prolonged CPM use at home as an adjunct to standardised physiotherapy [35]. The CPM group achieved 5° more in ROM than the physiotherapy-only group. Another prospective RCT examined whether the incorporation of regular passive ROM exercise (PROM), in a post-operative rehabilitation protocol after TKA, was effective or not in 50 patients undergoing bilateral TKA. The authors concluded that there were no significant differences between the two groups in terms of pain level and maximum flexion [36].

However, a recent RCT observed that CPM, compared to active exercises alone, had no additional effect on knee ROM, pain or walking ability at one week or three months after TKA [37]. Similarly, another recent randomised study demonstrated that there was no statistical difference in flexion and oedema in the CPM group versus the no-

CPM group [38]. Another study aimed to compare mean knee flexion in patients on continuous passive motion and those without it after total knee arthroplasty (76 patients, 38 in each group: standardised physiotherapy from 1st postoperative day and physiotherapy and one hour of continuous passive motion twice a day from 1st postoperative day until discharge): again the conclusion was that continuous passive motion had no influence on knee range of motion after total knee arthroplasty at the time of discharge [39]. A systematic review, published by Cochrane, provided high quality evidence to indicate that CPM had small, short-term effects on active knee flexion ROM and passive knee flexion ROM [22]. However, there was no evidence to support the presence of CPM effects on active or passive knee extension. In addition, the medium and long-term effects of CPM on all ROM measures were unclear; although the data suggested a small long-term effect of CPM on active knee flexion ROM. Low-quality evidence was reported concerning the relationship between CPM and reductions in length of hospital stay, as well as between CPM and the need for manipulation under anaesthesia. Finally, there was inconclusive evidence of the short, medium and long-term effects of CPM on pain, function, swelling or quadriceps strength.

Hydrotherapy

Patients treated with hydrotherapy (HT) for six months after discharge from a rehabilitation unit after TKA showed better subjective functional outcome, compared to the non-HT land-kinesis group: the study showed reduced pain, stiffness and function impairment with HT [40].

A randomized single blind controlled trial, conducted in 2009, compared land-based versus pool-based exercise in people awaiting joint replacement surgery (land-based group, 40 patients: 23 total knee and 17 total hip arthroplasty; pool-based group 42 patients: 24 total knee and 18 total hip arthroplasty) [41]. One group underwent a six-week program comprising education, twice-weekly land-based exercise classes; the other group were given pool-based exercises and an occupational therapy home assessment. Both interventions were effective in reducing pain and improving function; there were no post-intervention differences between the groups. However, the pool-based exercise group appeared to experience less pain immediately after the exercises; whereas the facilities required for a land-based exercise program were more readily available, and cheaper.

A multi center RCT, to evaluate whether the timing of aquatic therapy affected clinical outcomes after TKA, showed that all the primary outcomes (as assessed by the WOMAC scale) were better in the early aquatic therapy group [42]. Hydrotherapy positively influenced mood and socialisation, and promoted social relationships such as friendship and feelings of well-being.

A RCT showed that aquatic resistance training after knee replacement, from day four after surgery, gave increased mobility, increased knee extensor and flexor power and tightened muscle strength in the affected leg [43].

Finally, a study evaluated the effect of inpatient aquatic physiotherapy (comprising an aquatic physiotherapy session or non-specific water exercise) in addition to the usual land physiotherapy from day four after TKA. The recovery of strength, function and gait speed, measured on day 14, was all better in the specific aquatic exercise group. The same outcomes measured at days 90 and 180 did not present statistically significant differences. However, the non-specific water exercise group remained weaker than the aquatic physiotherapy group. The conclusion was that hydrotherapy gave beneficial effects on the recovery of hip muscle strength early after surgery without adverse effects [44].

Cryotherapy

Two literature reviews concerning the effects of cryotherapy have been published. The first found small, but statistically significant benefits concerning blood loss and early knee flexion. In addition, a marginal gain in pain reduction on day two post-operatively was identified, although no statistically significant benefit was found regarding post-operative narcotic consumption. A simultaneous application of cold and compression resulted in more reduction of the swelling compared to cryotherapy alone [45]. Six of the studies examined by the second review showed significantly lower pain scores when a cold compression was applied. Also, three studies showed an increase in the ROM in the cold compression group; and most of the studies noted a decrease in swelling and in blood loss with the cold compression [46].

Low frequency, low intensity magnetic fields

Very few studies have addressed the application of magnetic fields after TKA. A two-part clinical trial indicated, in the first part, that magnetic fields did not influence the parameters evaluated and did not give danger for the stability of the prosthesis [47]. The second part comprised a clinical trial that could not demonstrate improved rehabilitation using magnetic fields after total knee replacement [48].

A RCT studying patients undergoing TKA and stimulated with pulsed electromagnetic fields (PEMFs), showed a statistically significant level of pain reduction in the treated group at one and six months follow-up [49]. In addition, the SF-36 pain evaluation instrument showed a significant improvement in the treated group only; and also a significantly better result in the treated group regarding knee swelling. Finally, one month after surgery, the treated group showed a statistically significant improvement in function and knee score, but at two and six months no significant difference between the groups was observed. The entire group of patients in the treated group reported walking without limitation or walking aids. The advantages deriving from early control of joint inflammation can certainly justify the use of PEMF therapy in the first two months post-operatively and should be considered as an effective completion of the surgical procedure. Another controlled trial demonstrated a good effect of PEMF therapy in the first months after surgery [50], demonstrating that PEMF has an agonist effect on A22 adenosine receptors; this explains the anti-inflammatory effects. These two RCTs were conducted in a similar way and reached similar results.

The role of prehabilitation before total knee arthroplasty: education and treatment Post-operative functional ability following TKA surgery has been strongly associated with pre-operative functional ability [51]. Moreover, pre-operative quadriceps strength has been found to be a predictor of post-operative functional ability up to a year following surgery [52]. The concept of preparing the body for a stressful event, such as surgery, has been named “prehabilitation” [53]. Its efficacy is still under debate: the effects of pre-operative physical therapy and general cardiovascular conditioning exercises on the post-operative functional recovery have been compared with those of no pre-operative therapy [54]. Three patient groups were created, each one characterised by different pre- and post-operative protocols; the results showed that, if all groups showed tolerance on their exercise protocols, none showed significant benefits compared with the others.

A Cochrane systematic review assessed the effect of pre-operative education on outcomes in hip and knee replacement [55]. Only one study demonstrated a positive effect of pre-operative rehabilitation on the length of hospital stay; however, there was no effect on disability [56]. Another review assessed some RCTs, and concluded that there were no effects of pre-operative physical therapy on post-operative impairment and disability after TKA [57]. A systematic review was published concerning pre-operative rehabilitation for patients' undergoing TKA or Total Hip Arthroplasty, with the aim of constructing French clinical guidelines: the main finding was that analysis of the studies was difficult because of the heterogeneous interventions. Four types of outcomes had been suggested to assess the evidence of pre-operative rehabilitation: impairment, disability, medical-economic implications, and post-operative complications [58].

A two-group study evaluated the efficacy of pre-operative physical therapy for patients undergoing TKA: one group performed physical therapy before surgery and the control group did not. The therapy produced modest gains in isokinetic flexion strength but no difference in extension strength [59]. A Cochrane review suggested a benefit of pre-operative rehabilitation comprising at least physiotherapy with education and also suggested a multidisciplinary approach for the most fragile patients [22]. A singular case-report of a female patient who underwent two separate TKA surgeries (and had a four-week prehabilitation program for the left knee, but not for the right) compared pre- and post-operative functional ability: the comparison between the two knees showed that prehabilitation was effective in facilitating rehabilitation after TKA surgery and had positive effects on strength and some functional tasks. The authors strongly suggested the implementation of prehabilitation 6-12 weeks before TKA [60]. A RCT compared the leg strength and performance of functional tasks among subjects scheduled for TKA with osteoarthritis and pain that was non-responsive to medicine. These patients were randomized into two groups assigned either to the usual care or to exercises. Again, the results suggested the efficacy of prehabilitation in increasing surgical leg strength, decreasing leg strength asymmetry, and increasing the ability to perform functional tasks before TKA [61].

Nevertheless, concerns still exist: there is a systematic review on how TKA preoperative rehabilitation affects quality of life, pain, and physical outcomes after surgery. The conclusion was unfavourable for preoperative rehabilitation, which is conflicting with the conclusion drawn by the previous authors [62].

Discussion

There is a wide clinical consensus by physicians, as well as patients' expectations, about the role of rehabilitation after TKA. Many studies suggest or support specific rehabilitative treatments [63]. Most of these studies have important clinical relevance because they are based on large patients series, on case-control groups, on well-functioning practical experiences and on world-wide accepted treatments. Nevertheless, close analysis of the literature reveals a certain deficiency in terms of evidence-based protocols, well defined studies and the use of scientific approaches in general, as well as suggested by a recently published revision about TKA and rehabilitation [63].

Many different kinds of physical therapies and strategies have been proposed and studied. Differences in terms of rapidity of recovery and better knee function have been found between patients undergoing post-operative rehabilitation and non-treated patients in the short and medium term. Moreover, even when the two groups, comprising treated and non-treated patients, reached the same outcome after a certain period of time, the treated patients showed a great advantage in terms of cost and general health. Consequently, rehabilitation after TKA is recommended for a faster recovery.

Unfortunately, it is difficult to find evidence of the effectiveness of rehabilitation programmes before and after TKA because of the lack of randomisation and the low number of subjects included in the studies [63]. Moreover, in many cases, the types of exercises and interventions are not clear, or are too heterogeneous for effective comparison. All these factors cause the exclusion of many clinical trials in systematic reviews or meta-analyses. We, however, are taking this opportunity to comment on such studies in this present review. In addition, although many studies may not be able to detect differences in outcomes in patients who performed, or did not perform, the particular rehabilitation, it should be remembered that "no-difference studies make a big difference" [64].

Physiotherapy

Patients undergoing standard physiotherapy, including exercises for balance, gait training initially with devices, muscular strength training and ROM recovery, obtain a better and faster outcome than non-treated patients. It is recommended to begin knee mobilisation as soon as possible to avoid stiffness and the complications of prolonged bed-rest (for example: deep venous thrombosis, pulmonary oedema, and skin lesions). Another advantage of early post-operative rehabilitation is the possibility of avoiding the development of a stiff knee. Stiff TKA is a problem that must be avoided with intensive rehabilitation and possibly with prehabilitation, since the most important factor to be considered in stiff TKA is the pre-surgery ROM. Nevertheless, to our knowledge, there are no high quality studies investigating the optimal timing and procedure to treat stiffness after TKA [13-17].

Neuro muscular electric stimulation

Studies suggest that-in subjects with knee osteoarthritis and/or TKA - NMES increases quadriceps strength and improves functional performance and therefore may be effective as an exercise therapy. Furthermore, NMES may also reduce the extent of post-operative muscle atrophy [18-24].

Whole body vibration

The influence of WBV after TKA remains unclear: in many studies the improvements in knee strength and function was similar in treated and non-treated patients. In the very few studies that have been found on the use of magnetic fields after total knee replacement the authors could not demonstrate a significant improvement in outcome measures through their application [25-27].

Continuous passive motion

Despite being probably the most studied among the physical treatments, there is not a definitive judgement about CPM. The use of CPM in the classic way after TKA can have a beneficial effect on knee flexion, post-surgery pain, knee oedema and hospitalisation, but it has no effect on extension recovery, wound healing or reduction of thromboembolic risk. Continuous passive motion can be considered as an adjuvant device to increase results in the short-term, but the effects of CPM on ROM are too small to justify its use, even if there is some evidence that CPM may reduce the need for subsequent manipulation under anaesthesia [28-39].

Hydrotherapy

The positive effects of hydrotherapy on mood can be a great help in the management of subclinical surgery-correlated depression. The problems connected with hydrotherapy are cost and organisation. Hydrotherapy seems to be a better treatment than land-kinesis, because pain, stiffness and function impairment emerged as significantly lower and it had a positive influence on social behaviour and mood [40-44].

Cryotherapy

Cryotherapy after TKA has uncertain clinical benefits; however, it was associated with better patient compliance. Clinical evidence seems to suggest that cold and compression together are more effective than ice alone. In conclusion, no particular clinical benefits have been demonstrated by using cryotherapy after TKA [45-46].

Pre-operative rehabilitation

Concerning pre-operative rehabilitation, the literature generally recognises some benefits of pre-operative treatment when based at least on physiotherapy with education; while a multidisciplinary approach is usually suggested for the most fragile patients. Occupational therapy and patient education could also improve patient compliance with further treatments. The efficacy of pre-operative rehabilitation programmes has been clearly related to increased strength of the affected leg, decreased leg strength asymmetry and increased ability in performing functional tasks before TKA. Similarly-and most interestingly-encouraging results have been shown after prehabilitation, in terms of achieving a better quality of life, a faster ROM recovery and shorter time of hospitalisation: also it can improve muscle tropism, which is a positive predictor for post-operative functional recovery [50-61]. Neuro muscular electrical stimulation was found to be useful in prehabilitation to expedite a return to normal activities in patients undergoing TKA for knee osteoarthritis.

Nevertheless, concerns still exist and studies had a conclusion unfavourable for preoperative rehabilitation [62].

Conclusion

Most of the analysed studies did not show statistically significant results regarding the effectiveness of rehabilitation and physical therapies before and after TKA. The lack of well-designed randomised trials, the heterogeneous interventions, and the imprecision of the results make analysis of the literature difficult. Future well-designed RCTs to assess the effectiveness of balance exercises are recommended: larger sample size groups, programmes with more specific task oriented exercises and the analysis of the influence of the non-affected leg on rehabilitation results. Future studies are needed to elaborate better rehabilitation and physical therapy programmes, with the ultimate aim of improving patients' recovery and quality of life in the first period after TKA.

Clinical Message

Most of the current studies did not show significant differences in groups who had, or did not have, physiotherapy after approximately one year after TKA, when most of the patients had recovered well, even without physiotherapy. However, there is no doubt about the benefits of rehabilitation in the short and medium term after surgery. The key point concerns patient satisfaction and patient perception in the first months after surgery. A rapid recovery has an immense effect on patients' activities and mood: they can resume their normal life and activities faster, and will be safer and happier. In this way, patients can avoid depression, anxiety, immobility and longer illness in general. They can return to their ADL and habits without caregiver assistance, resulting in higher patient satisfaction and reduced economic impact on the healthcare services.

Hip Abductor Strengthening Exercises Following Total Knee Replacement- A Need or Luxury

Abstract

Total knee replacement (TKR) is a well renowned surgical procedure for those presenting with intractable joint pain and impaired physical function following end stage knee osteoarthritis (OA). It is well established that any exercise performed and supervised will improve pain and physical function in people with knee OA. Proximal muscle contribution especially the hip abductors are important in providing frontal plane stability, the stabilization of trunk and hip during walking, maintaining the femoropelvic alignment, femoral head stability and transferring the forces from the lower limbs to the pelvis and considered as important for enhanced functional performance. Recent studies have proven that proximal muscle weakness especially hip abductors play a vital role in knee joint function and a significant reduction in hip abductor strength observed in knee OA. Hip abductor strengthening exercises given post TKR could possibly enhance physical function and pain, might share a contribution similar to quadriceps strength in improving functional performance. Hip abductor strengthening exercises could be a key component in rehabilitation following TKR for enhanced physical function. This review attempts to report the evidence supporting the involvement of the hip abductor strength and its influence on pain and physical functional in post total knee replacement.

Keywords: Total knee replacement; Exercises; Hip abductor

Introduction

Total knee replacement (TKR) is a well renowned surgical procedure for those presenting with intractable joint pain and impaired physical function following end stage knee osteoarthritis (OA) [1,2]. Early rehabilitation aiming pain reduction, improved physical function and patient satisfaction were the main goals following TKR [3,4]. TKR provides a substantial pain relief; enhanced health related quality of life for 90% of patients with a varied physical function [5]. Preoperative factors like increase in age >80 years, higher BMI >40, emotional wellbeing and quadriceps strength were positively associated with higher likelihood of poor functional performance following TKR [6].

Amongst, the poor predictor's quadriceps strength is an imperative factor for improved knee functional performance [7]. Recent studies assessed the strengthening of quadriceps post TKR and found strength increments at 6 months and 1 year following surgery [8-10]. However, Bade et al. [11] in his study documented that patients who underwent unilateral TKR had persistent impairment in functional outcome when compared to healthy adults and recommended the need of a more intensive rehabilitation [11]. Later, the same authors found that a high intensity rehabilitation program shown better Improvement in functional performance measures when compared to low intensity rehabilitation program me with age matched and sex matched controls [4].

Despite the improvements observed, a contemporary systematic review recognized that there are small and mixed changes in physical activity at 6 months and at 1 year; it was considerably lower when compared with healthy adults [12]. Declined functional tasks of 15% reduced walking speed, 50% more time taken to complete stair climbing tasks and 20% less distance covered during the six minute walk test were reported following TKR when compared to their healthy age matched controls [11,13].

Therefore, it is skeptical whether exercises steering quadriceps strengthening alone will improve physical function after TKR. It is implausible that quadriceps strengthening alone could contribute to physical function following OA of the knee; contribution of proximal muscle weakness could possibly lead to altered physical function [14]. Recent studies have proven that proximal muscle weakness especially hip abductors play a vital role in knee joint function and a significant reduction in hip abductor strength observed in knee OA [15,16]. The hip abductors are well renowned for the stabilization of trunk and hip during walking, maintaining the femoropelvic alignment, and transferring the forces from the lower limbs to the pelvis [17,18]. Weakness of the hip abductor can lead to contralateral pelvic drop, this in turn will shifting the center of mass with increased load medially to the medial tibiofemoral joint [19].

Thus, an increased medial joint loading could progress to development of knee OA and increase strength of hip abductors might have a disease modifying effect by reducing the medial joint loading [20]. However, eight weeks of home program of hip abductor exercises not reduced the knee joint loading but shown an improvement in functional performance [21] Arnold et al. in a recent systematic review concluded that significant hip strength deficits observed in knee OA patients and recommended that hip strength assessments may assist with targeted rehabilitation [22].

Piva et al. [23] revealed that hip abductor strength was an independent correlate of functional performance measures for participants who underwent TKR [23]. In a study by Alnahdi et al., the physical function following unilateral TKR was associated with hip abductor strength and revealed that it contributes to the improvement in performance-based test and not in the self-reported functional measure [24]. Hip abductor strength could possibly share a contribution similar to quadriceps strength in improving functional performance. In view of the above findings, we postulated that hip abductor strengthening exercises are likely to be the catalyst for the improvement in the physical function following TKR.

As a corollary, the hip abductor strengthening exercises established a favorable path for targeted rehabilitation to enhance physical function for those who undergo TKR. We believe studies should use hip abductor strengthening exercises as an adjunct with quadriceps strengthening exercise following TKR for the enhanced performance based functional measure. Future trials should investigate whether hip abductor exercise provide enhanced self-reported and performance based functional outcome measure when added to the quadriceps exercise with proven efficacy or when applied over a longer period to consider it as clinically important or relevant. We recommend future trials to lay focus on the effect of hip abductor strength in pain and self-reported; performance based functional performance in further investigation.

Conclusion

The authors believe that hip abductor strengthening post-total knee replacement is an important predictor of the expected functional outcome. Future studies designing an effective rehabilitation protocol can implement hip abductor strengthening and consider, as essential concept following TKR. Hip abductor strengthening exercises could be a key component in rehabilitation following TKR for enhanced physical function.

Circuit training enhances function in patients undergoing total knee arthroplasty: a retrospective cohort study

Abstract

Background: The number of patients receiving total knee arthroplasty (TKA) has been rising every year due to the aging population and the obesity epidemic. Post-operative rehabilitation is important for the outcome of TKA.

Methods: A series of 34 patients who underwent primary unilateral TKA was retrospectively collected and divided into either exercise group (*n* = 16) and control group (*n* = 18). The exercise group underwent a 24-week course of circuit training beginning 3 months after total knee arthroplasty (TKA). The effect of circuit training on TKA patients in terms of motion analysis, muscle strength testing, Knee injury and Osteoarthritis Outcomes Score (KOOS) questionnaire and patient-reported outcome measurement Short-Form Health Survey (SF-36) at the pre-operation, pre-exercise, mid-exercise, and post-exercise.

Results: Motion analysis revealed the stride length, step velocity, and excursion of active knee range of motion significantly improved in the exercise group when compared to those in the control group. KOOS questionnaire showed a greater improvement in pain, ADL, and total scores in the exercise group. The SF-36 questionnaire revealed a significant improvement in general health, bodily pain, social function, and physical components score in the exercise group.

Conclusions: The post-operative circuit training intervention can facilitate recovery of knee function and decrease the degree of pain in the TKA and might be considered a useful adjunct rehabilitative modality. The ultimate influence of circuit training on TKA needs further a prospective randomized clinical trial study and long-term investigation.

Trial registration: NCT02928562

Keywords: Circuit training, Total knee arthroplasty, Motion analysis, KOOS, SF-36

Background

Total knee arthroplasty (TKA) is a well-accepted procedure for the treatment of advanced osteoarthritis of the knee joint [1], with good long-term survivorship of the implants and satisfactory surgical outcome [2]. The number of patients receiving TKA has been rising every year due to the aging population and the obesity epidemic [3–5]. Enhancing the recovery process after TKAs is an important issue. Physical exercise was suggested to enhance muscular strength, muscular endurance, cardiovascular fitness, flexibility, agility, balance, and coordination in the healthy aged population [6]. Physical exercise could further increase the range of motion and quadriceps strength in TKA patients [7]. However, these effects of post-operative exercise were usually limited by a short hospital stay, impaired exercise adherence, and in compliance to exercise regimens [8–10].

A more balanced exercise approach is therefore recommended for TKA patients [11]. Circuit training comprised of different exercise principles, including stretching exercise, aerobic training, and resistant training. Multiple stations for training different muscle groups, stretching exercise, and aerobic exercise was employed to progress towards cardiovascular fitness and muscle strength [12]. We had previously reported its positive effect on body composition improvement in overweight women [9]. Meanwhile, good exercise adherences were also observed with concomitant increases in the mental domain of functional score, since the incidence of female osteoarthritis (OA) is twice that of men [13] and the number undergoing TKA in the female is about twice in men between 2001 and 2010 [14]. The retrospective study focused on the female and assessed the feasibility and effect of post-operative circuit training intervention on TKA. The circuit training intervention would carry out at 3 months after the operation for 6 months. The assessments of this intervention were measured using motion analysis and muscle strength testing, KOOS questionnaire, and patient-reported outcome measurement Short-Form Health Survey (SF-36). The goal was to demonstrate the effect, if any, that circuit training intervention might have on post-operative knee functional recovery and daily activities.

Methods

Participants

The aim was to demonstrate the effect, if any, that circuit training intervention might have on post-operative knee functional recovery and daily activities in female TKA.

The inclusion criteria of the study included end-stage OA and female. Patients with diabetes, neuromusculoskeletal disorders, severe chronic medical disease, history of fracture of a lower limb, artificial limb, and being otherwise unsuitable for exercise training were excluded.

From October 2013 to August 2015, a consecutive cohort of 34 patients underwent TKA (16 in the exercise group and 18 in the control group) at Chang Gung Memorial Hospital Chiayi branch was included in the current study.

The participants in the exercise group practiced a 24-week circuit training intervention while the control group followed the routine post-operative rehabilitation protocol, including quadriceps training and range of motion exercise during the same time period.

Intervention

The circuit training program included stretching, aerobic training, and resistance training. The order of practice was performed in the following pattern: stretching/aerobic training/resistance training/aerobic training/resistance training/stretching. Each exercise was performed for 10 min, with a 30 s rest period between each exercise, and the program was carried out three times a week for 24 weeks. Aerobic training consisted of riding an exercise bike with the intensity of 60–80% target heart rate, and the resistance training was performed on hydraulic resistance equipment (AGOSS, Taipei, Taiwan) set at an intensity of 60–80% one repetition maximum. Six exercise machines were randomly chosen from ten exercise machines which included six types of equipment for the upper limbs and four for the lower limbs. The program was hospital-based and supervised by one exercise therapist at the Sports Medicine Center of Chang Gung Memorial Hospital Chiayi branch.

Objectives

The aim of the study was to assess the feasibility and effect of post-operative circuit training intervention on TKA women. The effect of this intervention was measured using motion analysis, muscle strength testing, Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaire and Short-Form Health Survey (SF-36) measurement patient-reported outcome. The goal was to demonstrate the effect, if any, that circuit training intervention might have on post-operative knee functional recovery and daily activities.

Outcomes

All measurements in both the exercise group and control group were performed at the following time points, i.e., before TKA operation (pre-operation), before exercise (pre-exercise), at 12 weeks after the beginning of the circuit training program (mid-exercise), and after completion of the circuit training (post-exercise).

Gait analysis

Gait analysis was performed by a three-dimensional, eight-camera motion capture system (VICON, Oxford Metrics, London, England) synchronized with two force platforms (OR6, AMTI, Watertown, Massachusetts) to record ground reaction force. Marker data were sampled at 100 Hz. Force platform data were sampled at 1000 Hz. Data collection starts with standing calibration to identify joint centers and create a segment impeded coordinate system. After calibration, subjects practiced walking until reaching a constant self-selected speed. The collected trials fell within 5% of the practiced speed with clear contact of only one foot on each force plate. Five walking trials were collected for each subject. While kinematics and kinetics of the segments are calculated, the whole body is modeled as a segment-linkage system consisting of the head, trunk, pelvis, bilateral upper arms, forearms, hands, thighs, shanks, and feet. Reflective markers attached on the segments were used to establish coordinate systems representing each segment. Data were processed utilizing the Nexus motion analysis system (VICON; Oxford Metrics Ltd. Ver.1.6.5), which was integrated with data recording software.

Muscle strength

Lower extremity muscle strength (including extension and flexion of the hip and knee, dorsi, and plantar flexion of the ankle) was measured using the HUMAC NORM system (CSMi, Stoughton, MA) with the concentric/eccentric contraction mode at an angular velocity of 60° per second. All measurements were evaluated with the participant in a sitting position. Isokinetic tests were performed five times for each participant, and each test was separated by a rest period of 3 min. The participants received verbal encouragement during the exertion of peak torque. The muscle strength was presented as a peak torque which was normalized to body weight [15].

KOOS assessment

Clinical knee scoring using the Chinese version KOOS scale was performed in the outpatient self-explanatory assessment [16]. The KOOS is a 42-item self-administered knee-specific questionnaire assessing pain (9 items), symptoms (7 items), activities of daily living (ADL, 17 items), function, sports and recreational activities (sports/rec, 5 items), and knee-related quality of life (QOL, 4 items) in five separate subscales. All items are scored 0 to 4; for each subscale, the scores are transformed to a 0 to 100 scales (0 representing extreme knee problems and 100 representing no knee problems) [17].

Quality of life

Quality of life was assessed using the Short-Form Health Survey (SF-36, Taiwan version [18]). The SF-36 questionnaire is a multi-purpose and short-form health survey, which is commonly used to evaluate patients' quality of life in clinical practice. A total of eight domains were evaluated in this questionnaire including physical functioning (PF), role limitation due to physical problems (RP), bodily pain (BP), general health (GH), vitality (VT), social functioning (SF), role limitation due to emotional problem (RE), and mental health (MH). Additionally, the eight health domains can be used to provide physical component summary (PCS) and mental component summary (MCS) scores.

Statistical analysis

All data analysis was done using the Statistical Package for the Social Sciences, Windows version 17.0 (SPSS, Chicago, IL, USA). All continuous data are presented as the mean ± standard deviation. Generalized estimating equations (GEEs) [19] were used for determining the differences between the exercise and control groups across the time period. A p value of < 0.05 was considered statistically significant.

Results

The demographic data, including age, height, and weight was similar in the exercise and control groups (Table 1). The mean age was 72 and 70 years old for the exercise and control groups, respectively.

In gait analysis, it was noted both exercise and control group were shown similar in gait parameters at pre-operation and pre-exercise evaluation. Three months after beginning exercise interventions, the stride length for exercise and control group were 101.6 ± 3.4 and 85.0 ± 5.5 cm, respectively ($p = 0.01$). Similarly, step length and step velocity were greater in the exercise group than those in control group. ($p < 0.05$) (Table 2). Meanwhile, the excursion of knee range of motion was 48.6 ± 1.2 and 44.5 ± 1.6 degree for exercise and control group, respectively ($p < 0.05$). The differences in stride length and excursion of knee range of motion (ROM) lasted till the post-exercise evaluation (Table 2). When comparison was performed within the individual group in temporal fashion, it was shown that stride length, stride velocity, step length, and step velocity increased in mid-excise assessment in the exercise group, while no such difference was noted in control group. The control group demonstrated increases in these parameters at post-exercise assessment ($p < 0.05$). Circuit training improved gait pattern at an earlier time point compared with the control group.

In isokinetic muscle strength assessment, it was shown that the maximal knee extensor torque for the exercise group was 24.4 ± 5.2, 31.4 ± 3.3, 44.0 ± 4.8, and 51.0 ± 5.9 N-m/Kg for pre-operation, pre-exercise, mid-exercise, and post-exercise, respectively ($p < 0.05$). Similar increases were demonstrated in the control group for knee extensor (Table 3). Indeed, it was shown that maximal muscle strength in hip extensor, hip flexor, knee extensor and knee flexor, ankle plantar flexor, and dorsiflexor all increased after TKA surgery in a temporal fashion for both exercise and control group ($p < 0.05$). Meanwhile, it was shown that there were no differences between the exercise and control group at all time point (Table 3). Meanwhile, we measured the muscular strength of lower extremity since previous studies have shown that knee extensor strength is closely correlated to functional performance, especially after TKA [20, 21].

Table 1 Demography of participants

	Exercise group (n = 16)	Control group (n = 18)
Age (years)	72.1 ± 6.7	69.6 ± 8.2
Height (cm)	152.6 ± 5.6	154.3 ± 6.4
Weight (kg)	63.7 ± 6.0	63.2 ± 11.9
BMI (kg/m^2)	27.5 ± 3.3	26.5 ± 4.0

Data presented as mean ± SD

Table 2 Comparison of gait kinematics between two groups of the TKA patients

	Pre-operation			Pre-exercise			Mid-exercise			Post-exercise		
	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*
Stride time (sec)	1.2 ± 0.1	1.2 ± 0.1	.709	1.2 ± 0.1	1.2 ± 0.1	.716	1.1 ± 0.1	1.1 ± 0.1	.988	1.1 ± 0.1**,***	1.1 ± 0.1**	.270
Stride length (cm)	85.6 ± 5.7	82.0 ± 5.8	.663	92.0 ± 5.0	81.5 ± 4.9	.136	101.6 ± 3.4**,***	85.0 ± 5.5	.010*	100.0 ± 4.3**,***	85.1 ± 5.2	.027*
Stride velocity (cm/s)	72.6 ± 6.0	70.4 ± 6.7	.808	78.2 ± 5.9	69.8 ± 5.5	.295	90.4 ± 4.8**,***	76.1 ± 5.8	.060	91.0 ± 5.8**,***[b]	80.5 ± 5.7**,***	.198
Step time (sec)	0.6 ± 0.1	0.6 ± 0.1	.633	0.6 ± 0.1	0.6 ± 0.1	.938	0.6 ± 0.1**,***	0.6 ± 0.1	.959	0.6 ± 0.1**,***	0.5 ± 0.1**,***	.383
Step length (cm)	42.6 ± 2.9	39.3 ± 3.0	.436	45.7 ± 2.6	40.5 ± 2.7	.158	50.9 ± 1.9**,***	42.6 ± 2.8	.013*	50.8 ± 2.3**,***	44.8 ± 2.9**,***	.102
Step velocity (cm/s)	69.6 ± 5.8	68.9 ± 7.0	.937	78.0 ± 5.4	71.1 ± 6.1	.400	92.2 ± 5.1**,***	77.0 ± 5.7	.046*	93.5 ± 5.8**,***	80.5 ± 6.6**,***	.136
Excursion of active knee ROM (°)	34.9 ± 2.8	35.7 ± 2.7	.836	44.0 ± 1.9**,***	40.2 ± 1.5	.112	48.6 ± 1.2**,***	44.5 ± 1.6**,***	.045*	51.0 ± 1.4**,***	44.8 ± 2.6**,***	.037*

Data presented as mean ± SD
A significant difference ($p < 0.05$) between two groups is calculated by GEEs
*$p < .05$, difference between groups; **$p < .05$, difference with pre-operation; ***$p < .05$, difference with pre-exercise

Table 3 Comparison of muscle strength between the two groups of the TKA patient

	Pre-operation			Pre-exercise			Mid-exercise			Post-exercise		
(Nm/kg)	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*
HE	40.9 ± 5.5	44.2 ± 10.3	.733	56.0 ± 5.2**	58.1 ± 5.0	.774	66.9 ± 7.2**	74.1 ± 9.4**	.543	80.4 ± 10.4**,***	84.0 ± 7.0**,***	.773
HF	14.6 ± 2.5	16.7 ± 3.5	.615	17.8 ± 2.4	23.1 ± 2.2**	.109	26.0 ± 3.0**,***	27.2 ± 3.6**	.807	26.2 ± 3.6**,***	33.3 ± 2.6**,***	.114
KE	24.4 ± 5.2	32.5 ± 7.2	.363	31.4 ± 3.3	38.2 ± 6.4	.345	44.0 ± 4.8**,***	56.2 ± 8.4**,***	.207	51.0 ± 5.9**,***	61.5 ± 6.6**,***	.236
KF	26.1 ± 3.5	23.2 ± 4.3	.608	34.2 ± 2.4**	39.1 ± 5.9**	.444	48.6 ± 4.0**,***	52.0 ± 8.3**,***	.705	49.8 ± 3.7**,***	55.3 ± 5.6**,***	.413
PF	20.0 ± 2.6	20.8 ± 4.7	.888	24.6 ± 3.0	23.6 ± 3.1	.805	34.6 ± 4.0**,***	34.0 ± 6.6	.939	32.7 ± 2.9**,***	41.7 ± 5.4**,***	.145
DF	2.5 ± 0.6	3.3 ± 1.1	.568	3.7 ± 0.7**,***b	4.3 ± 1.5	.718	5.3 ± 0.8**,***	7.8 ± 1.8**,***	.204	6.6 ± 1.2**	7.6 ± 1.8**,***	.309

Data presented as mean ± SD
A significant difference ($p < 0.05$) between two groups is calculated by GEEs
HE hip extension, *HF* hip flexion, *KE* knee extension, *KF* knee flexion, *PF* plantarflexion, *DF* dorsiflexion
*p < .05, difference between groups; **p < .05, difference with pre-operation; ***p < .05, difference with pre-exercise

In post-exercise KOOS assessment, KOOS total score was 78.7 ± 3.2 and 66.4 ± 4.1 for exercise and control group, respectively ($p = 0.018$). In the subcategorical assessment, these differences were observed in pain and ADL ($p < 0.05$) (Table 4). When comparison of KOOS was performed within the individual group, the temporal improvement was observed in symptoms, pain, ADL, QOL, and total score for both exercise and control group ($p < 0.05$) (Table 4). Interestingly, the sports subcategory was shown significantly improved from 17.1 ± 5.4 at pre-operative assessment to 48.3 ± 7.8 at post-exercise assessment in the exercise group ($p < 0.05$), while no such difference was shown in the control group.

In the SF-36 questionnaire which included physical and mental domains, it was shown a significant increase in the domains of GH, SF, and PCS at the mid-exercise point in the exercise group compared to the control group ($p < 0.05$) (Table 5). The circuit training efficiently improved the GH, SF, and PCS at the earlier time point. At the post-exercise assessment, only SF and BP were shown a significant increase in the exercise group compared with the control group (Table 5). When comparison was performed within the individual group in temporal fashion, it was shown that exercise improved all mental domains in mid-exercise assessment, and these improvements lasted to the post-exercise assessment, while no such improvement was observed in the control group. In the physical domain, it seemed both groups were shown improvement.

Discussion

The most significant findings in the present study were that 24-week circuit training resulted in a decrease of pain and an increase of ADL and SF, along with an increase in stride length and excursion of knee ROM in gait analysis [8, 22, 23]. Second, the increases in all muscle strength were demonstrated in a temporal fashion in both exercise and control group [24]. Circuit training seemed not further increase the maximal muscle strength. Third, earlier recoveries in gait parameters, KOOS, and SF-36 at mid-exercise assessment for exercise group were well demonstrated. Although circuit training did not result in a further increase in maximal isokinetic muscle strength, it was postulated to enhance the muscle coordination which facilitated the performance of walking and daily function [25]. The improvement in pain after circuit training both in the KOOS and SF-36 further provided an important basis that knee can undergo unlimited swing and hence to increase the stride length [23].

In gait analysis, stride length and excursion of knee ROM in the exercise group were shown significant increases as compared to control group at the mid-exercise assessment, and these differences lasted to the post-exercise assessment (Table 2). It is well demonstrated that faster restoration of gait patterns in exercise group as compared to the control group. None of the subjects enrolled in the exercise group reported discomfort or injury, and none needed further management. This indicates that our circuit training intervention is safe for TKA patients and feasible to perform following the TKA surgery.

The function of quadriceps strength relied on maximal muscular strength and muscular coordination in TKA patients, which could be improved by post-operative progressive strengthening protocol [24, 26–29]. Quadriceps weakness is a hallmark characteristic of knee osteoarthritis [24, 27, 30, 31]. Post-operatively, quadriceps strength was not comparable to their age-matched counterparts in the mid- or long-term follow-up [29]. Muscle strength recovery in those aging patients underwent TKA followed a temporary pattern [24]. The current study displayed a simultaneous trend in pain and muscle function recovery. Actually, as the pain improved 3 months after TKA, the patient was able to load their knees and hence improve the lower extremity muscle force. As the pain improved more, it was shown that lower leg muscle strength has a corresponding further increase. We have previously demonstrated the progress of both cardiovascular fitness and muscle strength by circuit training and 12-week circuit training in healthy middle-aged women (aged 45–75) [12]. However, the circuit training in the current study did not result in a further increase in the maximal isokinetic muscle strength. Two possibilities existed. First, the intensity of resistant training in the current study could be inadequate and would not result in a further increase as compared to the daily activities [23]. Second, the maximal strength has plateaued. Further study was warranted to delineate the mechanism underlying the findings in the current study. On the other hand, the muscle coordination and performance were improved by circuit training as shown in gait parameters. This finding paralleled literature that modified gait efficacy scale was improved by exercise [23]. In this laboratory study, it was further shown a 15% increase in stride length, accompanied by 10% increase in excursion of knee ROM during walking. These results provided a solid basis to explain the positive effect of exercise on gait function. It was possible that the decrease in pain and a more coordinated muscle function improved the gait function.

Decreased exercise adherence usually endangered the effect of exercise intervention [10, 32]. The motives for exercise participation among patients with knee OA was suggested mainly as positive outcome expectation [10]. Other factors such as social interaction and enjoyment of exercise have been described as important facilitators

Table 4 Comparison of KOOS subscales between two groups of the TKA patients

	Pre-operation			Pre-exercise			Mid-exercise			Post-exercise		
	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*
Symptom	45.9 ± 5.3	49.4 ± 4.8	.628	61.6 ± 3.1**	67.4 ± 3.8**	.240	72.9 ± 3.2**,***	71.0 ± 3.6**	.700	82.7 ± 3.2**,***	72.4 ± 4.5**	.059
Pain	46.8 ± 9.1	47.3 ± 6.4	.964	71.6 ± 4.5**	70.5 ± 4.8**	.866	76.3 ± 4.2**	77.8 ± 5.0**	.813	84.0 ± 2.5**,***	73.8 ± 4.5**	.048*
ADL	48.8 ± 7.5	48.5 ± 5.7	.980	72.6 ± 5.1**	70.8 ± 4.8**	.792	77.1 ± 4.2**	73.5 ± 5.0**	.570	84.5 ± 2.7**,***	71.2 ± 5.1**	.020*
Sport	17.1 ± 5.4	28.6 ± 6.7	.182	51.3 ± 8.6**	38.8 ± 6.1	.240	38.7 ± 4.9**	34.8 ± 5.9	.607	48.3 ± 7.8**	33.7 ± 5.4	.123
QOL	38.1 ± 6.0	40.2 ± 4.0	.775	53.9 ± 5.1**	48.3 ± 3.6	.367	63.5 ± 4.6**	61.7 ± 4.2**,***	.778	67.6 ± 4.3**,***	60.7 ± 4.7**,***	.277
Total score	43.3 ± 6.3	44.7 ± 4.9	.856	66.2 ± 4.1**	64.2 ± 3.9**	.715	70.4 ± 3.0**	68.3 ± 4.4**	.698	78.7 ± 3.2**,***	66.4 ± 4.1**	.018*

Data presented as mean ± SD

A significant difference ($p < 0.05$) between two groups is calculated by GEEs

*$p < .05$, difference between groups; **$p < .05$, difference with pre-operation; ***$p < .05$, difference with pre-exercise

Table 5 Comparison of perceived health (SF-36) between two groups of the TKA patients

	Pre-operation			Pre-exercise			Mid-exercise			Post-exercise		
	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*	Exercise	Control	*p*
PF	40.0 ± 4.8	35.2 ± 4.9	.487	49.1 ± 6.7	42.1 ± 6.3	.444	58.9 ± 4.5**	45.8 ± 5.5	.065	54.4 ± 6.5**	45.4 ± 6.6	.330
RP	31.7 ± 10.4	19.0 ± 9.2	.362	31.4 ± 10.4	50.2 ± 10.5**	.203	76.3 ± 9.**,***	48.0 ± 11.5**	.058	58.4 ± 12.9	51.4 ± 12.9**	.702
BP	36.0 ± 4.5	34.0 ± 4.6	.761	52.1 ± 5.0**	54.2 ± 5.0**	.763	64.1 ± 3.2**,***	57.7 ± 4.5**	.244	76.8 ± 3.7**,***	65.4 ± 4.1**	.038*
GH	49.9 ± 6.8	44.3 ± 5.3	.519	53.0 ± 5.3	50.5 ± 4.3	.715	62.5 ± 4.9***	46.1 ± 5.3	.022*	56.8 ± 5.8	49.3 ± 5.4	.340
VT	60.2 ± 4.5	55.5 ± 4.9	.477	65.5 ± 3.6	58.8 ± 4.4	.237	63.9 ± 3.9	63.9 ± 4.0	.986	71.2 ± 4.5**	64.1 ± 3.7	.220
SF	65.1 ± 7.4	61.4 ± 7.1	.715	66.5 ± 5.3	63.9 ± 4.6	.709	80.6 ± 3.6**,***	65.3 ± 4.7	.010*	82.8 ± 3.7**,***	68.6 ± 3.8	.008*
RE	43.8 ± 10.9	43.1 ± 10.7	.964	46.6 ± 11.2	65.5 ± 9.6	.138	75.5 ± 9.2**,***	62.7 ± 10.3	.352	76.1 ± 10.9**,***	64.3 ± 11.9	.465
MH	57.5 ± 4.3	56.2 ± 3.9	.823	64.9 ± 2.7	62.1 ± 2.9	.489	65.4 ± 3.6	65.5 ± 3.6	.995	68.5 ± 3.9**	63.0 ± 4.3	.343
PCS	35.5 ± 1.7	32.6 ± 1.7	.230	38.6 ± 2.1**	38.2 ± 1.4**	.874	45.6 ± 1.5**,***	38.5 ± 2.2**	.008*	43.9 ± 2.5**	40.4 ± 2.3**	.309
MCS	45.3 ± 2.4	44.8 ± 2.7	.900	46.9 ± 2.0	48.0 ± 1.8	.675	49.3 ± 2.1	48.4 ± 2.3	.766	51.8 ± 2.2**	48.6 ± 2.3	.318

Data presented as mean ± SD
A significant difference ($p < 0.05$) between two groups is calculated by GEEs
*$p < .05$, difference between groups; **$p < .05$, difference with pre-operation; ***$p < .05$, difference with pre-exercise

of exercise behavior [22, 32]. The present study demonstrated the improvement in social function which could result in exercise adherence to 80%, which was comparable in OA patient without TKA [10, 22]. Our results supported that a more balanced exercise program in patients with TKA to achieve a better exercise adherence and consequent improvement in gait and function [11]. Furthermore, the present study provided a quantitative data regarding the exercise prescription with efficacy and efficiency, which could be practiced for months. These results could be the basis for developing home exercise regimens.

Several limitations in this study must be acknowledged. First, the small sample size (34 patients) in this study resulted in under power to show a statistical difference between two groups in head-to-head comparisons. However, comparisons in repeated measure provided a better statistical power. Comparisons of repeated measurements in the same patient demonstrated the effect of exercise in a time sequence. Second, the study is limited to the Asian experience of knee arthroplasty. Third, this was a short-term study; thus, we were unable to assess the effect post-operative circuit training in long-term functional outcomes. The resistance training, though might be submaximal, in combination with aerobic exercise and stretching exercise help faster recovery in gait, functional score, and social function. Fourth, this study is a retrospective study. The results of circuit training on TKAs should be further proved by a prospective randomized clinical trial design. Fifth, there was a heterogeneous effect among the patients in the exercise. The previous investigation has shown that the carrier with polymorphism of monocarboxylate transporter 1 gene (A1470T) exhibits a worse lactate transport and influences the performance with high-intensity circuit training [33]. The genetic variance may be responsible for the heterogeneity of circuit training effect on the individual patients. The further study focused on the genetic test before training intervention was suggested.

Conclusions

Our post-operative circuit training intervention is safe and effective in improving and hastening the functional recovery after TKA surgery, even without enhancement of lower limb muscle strength. This circuit training intervention might be incorporated into the standard post-operative rehabilitation protocol for TKA patients. The ultimate influence of circuit training on TKA needs further long-term investigation.

Abbreviations

ADL: Activities of daily living; BP: Bodily pain; GEE: Generalized estimating equations; GH: General health; KOOS: Knee injury and Osteoarthritis Outcome Score; MCS: Mental component summary; MH: Mental health; OA: Osteoarthritis; PCS: Physical component summary; PF: Physical functioning; RE: Role Limitation due to emotional problem; ROM: Range of motion; RP: Role Limitation due to physical problems; SF: Social functioning; SF-36: Short-Form Health Survey; VT: Vitality