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High-intensity preoperative training improves physical and functional recovery in the early post-operative periods after total knee arthroplasty: a randomized controlled trial

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Abstract
Purpose The benefits of preoperative training programmes compared with alternative treatment are unclear. The purpose of this study was to evaluate the effectiveness of a high-intensity preoperative resistance training programme in patients waiting for total knee arthroplasty (TKA).
Methods Forty-four subjects (7 men, 37 women) scheduled for unilateral TKA for osteoarthritis (OA) during 2014 participated in this randomized controlled trial. Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Physical Functioning Scale of the Short Form-36 questionnaire (SF-36), a 10-cm visual analogue scale (VAS), isometric knee flexion, isometric knee extension, isometric hip abduction, active knee range of motion and functional tasks (Timed Up and Go test and Stair ascent–descent test) were assessed at 8 weeks before surgery (T1), after 8 weeks of training (T2), 1 month after TKA (T3) and finally 3 months after TKA (T4). The intervention group completed an 8-week training programme 3 days per week prior to surgery.
Results Isometric knee flexion, isometric hip abduction, VAS, WOMAC, ROM extension and flexion and all the functional assessments were greater for the intervention group at T2, T3 and T4, whereas isometric knee extension was greater for this group at T2 and T4 compared with control.
Conclusion The present study supports the use of preoperative training in end-stage OA patients to improve early postoperative outcomes. High-intensity strength training during the preoperative period reduces pain and improves lower limb muscle strength, ROM and functional task performance before surgery, resulting in a reduced length of stay at the hospital and a faster physical and functional recovery after TKA. The present training programme can be used by specialists to speed up recovery after TKA.
Level of evidence I

Keywords Prehabilitation · Osteoarthritis · Ageing · Resistance training · Knee · Strength training

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Introduction

As osteoarthritis (OA) is the most common joint disease worldwide, the individual and societal consequences in terms of musculoskeletal pain, disability and socioeconomic costs are substantial [2, 12]. Patients having knee OA suffer from pain and function impairments that hamper participation in daily activities [15] and participation in work [23]. At the end stage of the disease, the knee replacement surgery is the most common and effective treatment to reduce pain and improve functionality [7]. However, high prevalence of persistent mild and infrequent pain after total knee arthroplasty (TKR) has been reported, and 15 % suffers from severe pain at 3–4 years post-surgery [47]. During the first years after TKA, patients have greater functional impairments than age-matched subjects [29, 36]. Strength and muscle activation reductions of up to 60 and 17 %, respectively, were found immediately after TKA [39]. Together with the age-related loss of muscle mass, the risk of disability increases [44]. In fact, preoperative quadriceps strength has been found to be a strong predictor of functional performance one year [21] and 2 years [48] after TKA. In this regard, preoperative exercise training may be beneficial as exercise-based programmes previously have demonstrated efficacy in reducing pain [11] and increasing functional performance among OA patients [37]. A recent systematic review [35] found a reduced length of stay at hospitals (LOS) among those who participated in a preoperative programme, which is associated with functional recovery [9] and a major contributor to additional healthcare costs [45]. However, the benefits of preoperative training programmes are unclear [35]. For instance, the large body of the literature still fails in showing clear strength improvements after these programmes [17, 20, 30, 31, 40, 43]. Low training intensities and/or volumes used in the aforementioned studies may explain the contrasting results. A preoperative training period typically lasts between 4 and 8 weeks before surgery [17]. During this period of time, increases in muscle strength are allowed due to neural adaptations rather than hypertrophy [10]. A greater volume and intensity in order to induce a proper neural drive to the muscle fibres are needed [5], especially when the goal is to promote the greatest possible muscle strength gains during a few weeks only.

Regaining muscle strength is a major goal for orthopaedic surgeons and rehabilitation specialists [33], and due to the controversial findings regarding the positive effects of preoperative strength training programmes in the early postoperative periods, additional well-designed studies are needed. Hence, our purpose was to evaluate the effectiveness of a high-intensity preoperative resistance training programme in patients awaiting TKA, which provides a novel aspect compared with previous studies. It was hypothesized that the preoperative training programme would lead to greater improvements in strength, range of motion (ROM), pain and functional measures before TKA and would reduce LOS in comparison with controls. In addition, it was hypothesized that the intervention programme would promote improvements both 1 and 3 months after TKA compared with controls.

Materials and methods

All patients above 60 years old who were diagnosed with advanced idiopathic knee OA (according to the radiological criteria of the American College of Rheumatology Guidelines) and scheduled for unilateral total knee arthroplasty in a local hospital during 2014 were considered candidates for the present study and were asked to participate. Participants were excluded if pain was present in the contralateral limb (maximum pain, ≥4 of 10 during daily activities) [48], if they had undergone another hip or knee joint replacement in the previous year, if they had any medical condition in which exercise was contraindicated or if they had any disease that affected functional performance. All participants were informed about the purpose and content of the project and gave their written informed consent to participate in the study.

Of the 186 subjects screened (Fig. 1), 50 patients were included in the study and 136 were excluded because 57 did not meet the inclusion criteria and 79 declined to participate in the investigation (especially due to transportation difficulties for those living outside the city). For this study, participants were randomly allocated to either an intervention group or control by assigning random numbers with a computer. The researcher was blinded to the randomization, so the knowledge of the allocated interventions was prevented. Twenty-five patients were allocated to the intervention group, and 25 were allocated to the control group. Of these 50 patients, six subjects withdrew from the study due to different reasons, which included: (a) three participants had post-operative complications, (b) one did not want to continue in the study, (c) two patients decided not to have surgery after the intervention, and (d) one moved to another city. Finally, forty-four patients (7 men, 37 women) divided into two groups of 22 participated in this study (Table 1).

Surgical procedures

All patients underwent a TKA, which was implanted with cement (Vanguard, Biomet Inc, Warsaw, Indiana) with the same standardized preoperative protocol, surgical technique and performed by the same experienced orthopaedic surgeon. In all cases, the posterior cruciate ligament was retained, and the operations were performed with use of a tourniquet. After TKA surgery, all subjects received the same post-operative rehabilitation protocol at the hospital as a part of the usual care treatment. This programme was focused in restoring knee ROM, strength and normal gait. The strength exercises were specially focused on knee extensor strength, starting without external load and progressing by adding a maximum of 2 or 3 kg. Manual therapy, proprioceptive training and ice were also applied after the strength training. This rehabilitation programme was daily performed (from Monday to Friday) during one month, and each session lasted 1 h. The physiotherapist conducting this rehabilitation protocol was not involved in any assessment performed during the present study.

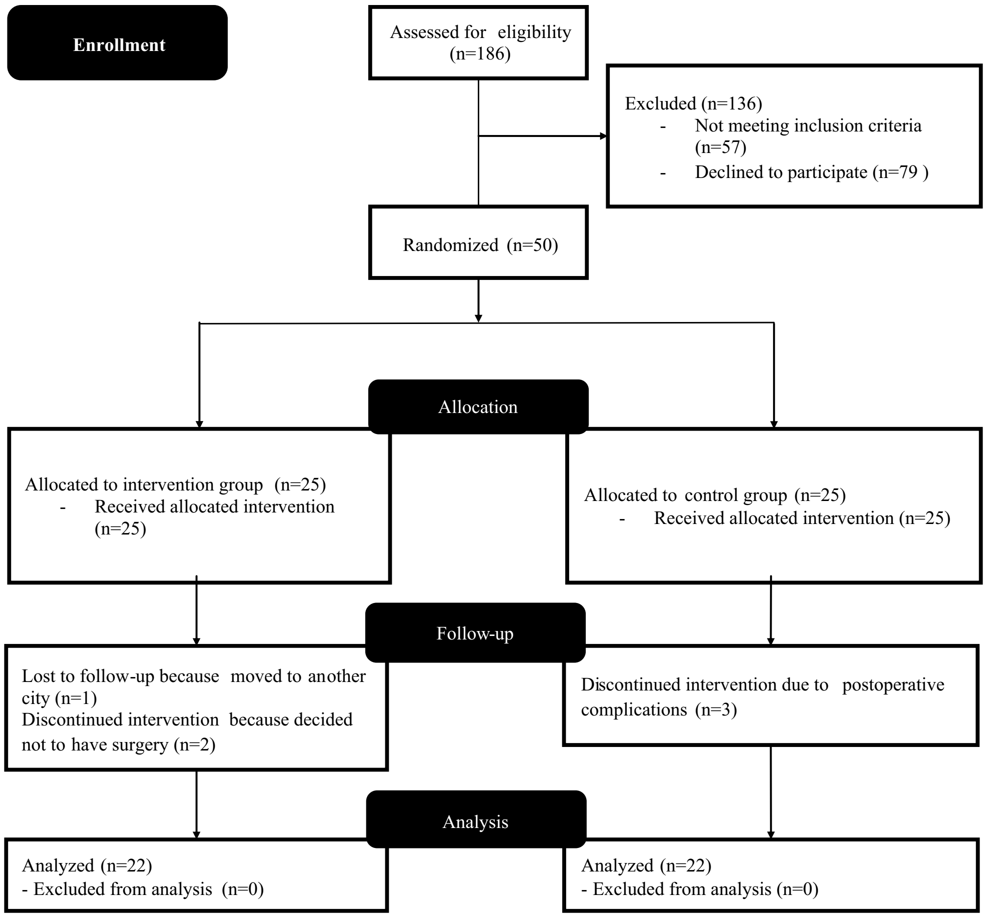

Fig. 1 Flow diagram of the progress through the phases of the study

Table 1 Demographic characteristics presented as mean (range) ± SD

	Control group	Intervention group	*p* value
Age (years)	66.7 (61–72) ± 3.1	66.8 (60–75) ± 4.8	(n.s.)
Weight (kg)	80.9 (66–102) ± 9.9	82.1 (65.6–101.5) ± 11.8	(n.s.)
Height (m)	1.6 (1.5–1.8) ± 0.1	1.6 (1.5–1.8) ± 0.1	(n.s.)
BMI (kg/m^2)	31 (27–39) ± 3.8	32 (28–45) ± 4.2	(n.s.)

Intervention

The intervention group completed a training programme prior to surgery for 3 days per week for 8 weeks. The exercise programme was especially designed to increase lower limb muscle strength. Sessions were performed at the same time of the day (i.e. during the morning) and were separated by at least 48 h. Each training session took place under the supervision of an experienced physical therapist.

The training session started with a 15-min warm-up consisting of dynamic joint movements performed without ballistic movements and dynamic body weight exercises including 2 sets of 20 repetitions of step-ups and calf raises at a platform and finally 10 min of light-intensity hand or leg ergometry cycling (depending on the perceived pain). A single warm-up set was also performed before each resistance training exercise by using a light resistance for 10 repetitions. The main programme comprised 5 sets of 10 repetitions for each exercise, with 60-s rest between sets. The exercises were performed in the following order: seated leg press, knee extension, leg curl and hip abduction. Intensity was based on participant's ability to execute 10 repetition maximum (10 RM). After completing the strengthening exercises, participants performed 4 sets of 30 s of double leg stance and 4 sets of 15 s of single leg stance on the same unstable device (Bosu® Balance Trainer), starting with the non-affected leg. Each training session was concluded with a 5-min cool-down of light static stretching of hip abductors, flexors and extensors of the knee and ankle plantar flexors.

Measures

Participants were scheduled for 1 familiarization session and 4 test days. During the familiarization sessions, the test procedure was explained and practised 1–3 times until the subject felt confident and the researcher was satisfied that proper form was achieved.

The order of the 4 data assessment tests was as follows: baseline (T1) was performed 8 weeks before surgery. After 8 weeks of training and prior to the surgery, the second testing was effected (T2). The third testing (T3) was performed 1 month after TKA, and the final testing (T4) was executed 3 months after TKA.

Each of these testing sessions consisted in completing the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), the Physical Functioning Scale of the Short Form-36 questionnaire (SF-36), a 10-cm visual analogue scale (VAS), isometric strength (knee flexion, knee extension and hip abduction), active knee ROM (flexion and extension) and functional tasks (Timed Up and Go test and Stair ascent–descent test). All measurements were performed by the same physical therapist at the university who was not involved in the training supervision to avoid possible risk of bias.

Stair-climbing test

Subjects were asked to ascend and to descend a flight of 4 stairs once (each step was 50 cm wide, 15 cm high and 25 cm deep) as quickly but safely as possible. Patients were asked to stand at the bottom of the first step, go up the stairs, turn around on the top step and come all the way down until both feet were on the floor. Patients were instructed to use the handrails if they needed while ascending or descending the stairs [40]. Total time taken to complete this task was measured in seconds with a stopwatch that was stopped when the patient reached the start line after ascent and descent the stairs. The test was performed 2 times with a 30-second rest period [40], and the average time to complete the task was recorded [48]. The stair-climbing test has shown to be highly reliable, with a test–retest reliability coefficient of 0.93 [28] and interrater reliability with an intraclass correlation coefficient (ICC) of 0.94 [3].

Timed Up and Go

The Timed Up and Go test (TUG) is a simple-to-perform test to assess mobility, lower extremity function and fall risk without requiring any specific equipment [25]. The TUG measures the time that a person takes to rise from a standard arm chair (not using their arms to stand up), walk to a line on the floor 3 m away, turn around, walk back to the chair and sit down again [13].

Subjects were permitted to use walking aids if necessary, and the time was measured in seconds with a chronometer. Shorter times indicate better performance [13]. High intratester and intertester reliability has been found in elderly populations with ICCs ranging from 0.92 to 0.99 [14, 25, 34].

Isometric strength with dynamometer

For measuring the isometric strength, a portable handheld dynamometer was used (Nicholas Manual Muscle Tester, Lafayette Instruments, Indiana, USA). For measuring the maximal isometric knee flexion and extension strength, patients were seated at the edge of the plinth, with their thighs in contact with the examination table and with the hip drawing a constant angle (90°), not leaning their trunk backward. They were instructed to produce as much force as possible against the dynamometer, held by the examiner. One practice trial was given before the assessment. For measuring the isometric knee extension strength, the dynamometer was positioned perpendicular to the tibia, proximal to the ankle, and fixated by a belt to the plinth. For measuring the isometric knee flexion strength, the dynamometer was placed on the posterior aspect of the lower leg, anchored by a belt to the handlebar of a glass suction cup on the wall. For measuring the isometric hip abduction strength, the patient was placed supine, with one leg extended over the examination table and the other leg flexed. The dynamometer was fixed with a belt towards the wall and held by the examiner, and the patient was instructed to exert an abduction maximal contraction with the flexed leg. All patients performed three isometric maximal voluntary contractions for each muscle group, and the mean maximal strength of the three repetitions was used for the further analysis. The handheld dynamometer demonstrated good inter- and intrarater reliability values for knee flexors (ICC range 0.76–0.94) and excellent for the knee extensors (ICC range 0.92–0.97) in patients awaiting TKA in both the affected and unaffected knees [16]. In addition, the handheld dynamometer yielded excellent reliability during the isometric abduction strength test, with an ICC of 0.95 [4].

Active knee range of motion

A digital goniometer was used (Digital absolute Axis goniometer, Baseline evaluation instruments, White Plains, USA) for the measurement of active knee range of motion. In accordance with previous recommendations [22], the subject was placed supine for the measurement of the active knee flexion and extension ROM, with extended knees and the hip in neutral position and with the upper thigh exposed so that the greater trochanter could be visualized. The patient was asked to maximally flex the knee for the assessment of the flexion ROM and maximally extend the knee for the extension ROM evaluation, with a towel roll under the ankle in that case to allow the knee to extend as much as possible. The goniometer was positioned with its centre fulcrum over the lateral epicondyle of the femur, the proximal arm was aligned with the lateral midline of the femur, using the greater trochanter for reference, and the distal arm was aligned with the lateral midline of the fibula, using the lateral malleolus and fibular head for reference. Measurements were made three times, taking the average value to analyse data. Assessment of the knee ROM in patients with knee OA showed high reliability values, with a coefficient of 0.96 for flexion and 0.81 for extension [8].

All procedures described in this section were approved by the Institution's Review Board of the Clinical Hospital of Valencia (approval number: F-CE-GEva-15) and comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

Statistical analysis

In a previous study, the baseline WOMAC scores had a standard deviation of 11 [17]. If the true difference in the intervention and control group means is at least 10, a sample size of 20 patients in each group is adequate to reject the null hypothesis with statistical power of 80 % and at a significance level of $p < 0.05$.

All statistical analyses were performed using the SAS statistical software for Windows (SAS Institute, Cary, NC). The change in isometric strength, ROM, VAS, WOMAC, SF-36, TUG and stair-climbing test was evaluated using a repeated measures linear mixed models with *group*, *time* and *group by time* as independent variables. LOS was evaluated using unpaired t test. Participant was entered as random effect. Analyses were adjusted for age, gender, BMI and the baseline value of the outcome measure. All statistical analyses were performed in accordance with the intention-to-treat principle, i.e. using the mixed procedure which inherently accounts for missing values. An alpha level of 0.05 was accepted as statistically significant. Outcomes are reported as between-group least mean square differences and 95 % confidence intervals.

Results

There was no significant difference in baseline data between both groups. Between-group interactions over time were found in all the tested variables (Tables 2, 3). Isometric knee flexion and hip abduction values were greater for the intervention group at T2, T3 and T4, whereas isometric knee extension was greater at T2 and T4. Lower pain scores in the VAS and WOMAC pain dimensions were found in the intervention group during all the assessments. ROM extension and flexion were greater in the intervention group at T2, T3 and T4. Likewise, the intervention group showed greater WOMAC stiffness scores at all these time points. All the functional assessments (Physical Functioning Scale of the SF-36, TUG, Stair test and WOMAC functional) showed greater values in favour of the intervention group at T2, T3 and T4. In regard of the LOS, the intervention group showed a reduced stay compared with the control group (4.5 ± 0.9 vs 6.4 ± 1.1; $p < 0.001$). Nonsignificant (n.s) between-group differences were found in the weight after the intervention ($p = 0.537$).

Discussion

The main finding of our study was that high-intensity preoperative training improved strength, ROM and functional measures as well as reduced pain and LOS in the early postoperative periods compared with control.

The intervention group showed greater knee extension strength values at T2 and T4, while knee flexion and hip abduction were greater at T2 and during all post-surgery assessments. Previous literature failed to report a positive effect of preoperative programmes in maximal strength variables after TKA [17, 20, 30, 31, 40, 43]. It has been reported that subjects can recover to preoperative strength levels at 2 [31] or 3 months [17, 46] after TKA. In our study, the intervention group regained their baseline knee extension strength 3 months after TKA, whereas only 1 month was needed to regain preoperative knee flexion and hip abduction strength. These results seem plausible because the extensor musculature is especially affected during the TKA surgery.

Pain is considered as one of the main symptoms in OA patients [15] and is a predictor of mortality during a 10 year post-surgery period [18]. While previous preoperative studies did not find between-group differences in pain reductions [6, 20, 31, 43, 46], we did find a greater progressive pain reduction from T2 to T4 in the intervention group. Since pain is a key determinant of isometric knee extension and flexion strength in knee OA [32], the improvements that we found in these variables among the intervention group could explain the lower pain scores after the training programme. Besides the general TKA effectiveness in reducing pain [7], high-intensity preoperative training leads to further reductions. Thorstensson et al. [42] found that patients with OA were afraid that exercise would cause further harm to their knee joints. That study further showed that those who had never exercised believed that it might harm the osteoarthritic joint. This may suggest that

Table 2 Scores for all physical measures

Variable	Testing time	Mean (95 % CI)		*p* value for group by time interaction	Between-group difference (95 % CI)
		Control group	Intervention group		
ROM flexion (°)	Baseline	104.2 (100.7 to 107.7)	104.0 (100.5 to 107.4)	.0055	0.2 (−4.4 to 4.9)
	Before surgery	102.8 (99.3 to 106.3)	114.4 (110.9 to 117.8)		−11.6 (−16.3 to −7.0)[a]
	1 month after surgery	82.3 (78.8 to 85.8)	88.8 (85.4 to 92.3)		−6.5 (−11.2 to −1.9)[a]
	3 months after surgery	96.4 (92.9 to 99.9)	101.2 (97.8 to 104.7)		−4.8 (−9.5 to −0.2)[a]
ROM extension (°)	Baseline	14.0 (13.0 to 15.0)	14.4 (13.4 to 15.5)	<.0001	−0.4 (−1.7 to 0.9)
	Before surgery	14.9 (13.9 to 16.0)	6.6 (5.6 to 7.6)		8.3 (7.0 to 9.6)[a]
	1 month after surgery	16.9 (15.9 to 17.9)	11.1 (10.1 to 12.2)		5.8 (4.5 to 7.0)[a]
	3 months after surgery	13.9 (12.8 to 14.9)	8.2 (7.2 to 9.3)		5.6 (4.3 to 6.9)[a]
Timed Up and Go (s)	Baseline	8.5 (8.1 to 8.8)	8.6 (8.3 to 9.0)	<.0001	−0.1 (−0.6 to 0.3)
	Before surgery	9.0 (8.7 to 9.4)	6.7 (6.4 to 7.1)		2.3 (1.8 to 2.7)[a]
	1 month after surgery	9.4 (9.0 to 9.7)	7.3 (6.9 to 7.6)		2.1 (1.7 to 2.6)[a]
	3 months after surgery	8.7 (8.3 to 9.1)	7.0 (6.7 to 7.3)		1.7 (1.3 to 2.1)[a]
Stair test (s)	Baseline	11.2 (10.5 to 11.8)	11.0 (10.4 to 11.7)	<.0001	0.1 (−0.7 to 0.9)
	Before surgery	11.4 (10.8 to 12.1)	7.2 (6.6 to 7.9)		4.2 (3.4 to 5.0)[a]
	1 month after surgery	12.7 (12.1 to 13.4)	9.1 (8.4 to 9.7)		3.6 (2.8 to 4.5)[a]
	3 months after surgery	12.1 (11.5 to 12.8)	7.9 (7.2 to 8.5)		4.2 (3.4 to 5.1)[a]
Isometric knee flexion (kg)	Baseline	9.1 (8.5 to 9.7)	9.2 (8.7 to 9.8)	<.0001	−0.1 (−0.8 to 0.5)
	Before surgery	8.2 (7.6 to 8.8)	17.6 (17.1 to 18.2)		−9.4 (−10.1 to −8.7)[a]
	1 month after surgery	3.9 (3.3 to 4.4)	8.7 (8.1 to 9.3)		−4.8 (−5.5 to −4.1)[a]
	3 months after surgery	4.4 (3.8 to 5.0)	9.4 (8.8 to 9.9)		−5.0 (−5.7 to −4.3)[a]
Isometric knee extension (kg)	Baseline	23.5 (20.3 to 26.7)	23.5 (20.4 to 26.6)	<.0001	0.0 (−3.6 to 3.7)
	Before surgery	22.0 (18.8 to 25.2)	37.8 (34.7 to 40.9)		−15.8 (−19.5 to −12.2)[a]
	1 month after surgery	7.7 (4.5 to 10.9)	8.9 (5.8 to 12.0)		−1.2 (−4.9 to 2.5)
	3 months after surgery	14.3 (11.1 to 17.5)	22.8 (19.7 to 25.9)		−8.5 (−12.1 to −4.8)[a]
Isometric hip abduction (kg)	Baseline	7.2 (6.8 to 7.6)	7.3 (6.9 to 7.7)	<.0001	−0.1 (−0.6 to 0.5)
	Before surgery	7.1 (6.7 to 7.5)	13.4 (13.0 to 13.8)		−6.3 (−6.9 to −5.8)[a]
	1 month after surgery	4.8 (4.3 to 5.2)	7.7 (7.3 to 8.1)		−2.9 (−3.5 to −2.4)[a]
	3 months after surgery	5.0 (4.5 to 5.4)	7.8 (7.4 to 8.2)		−2.8 (−3.4 to −2.3)[a]

[a] Denotes significant between-group difference

preoperative training could reduce this fear and help to find strategies to cope with the pain as well as maintain exercise levels after surgery as a part of a new lifestyle.

In line with the other results, preoperative training positively affected the active knee flexion and extension ROM. These findings seem logical since active ROM is specially influenced by muscle strength [27]. In line with this, in the study conducted by Matassi et al. [19] the treatment group reached 90° of knee flexion at a mean of 5.8 days (±2.1) after the operation, whereas the control group had 6.9 days (±1.9). In contrast, Rodgers et al. [30] found that extension and flexion ROM differences between groups did not differ over time. As ROM measurements were performed to the maximal possible joint angle, which is limited by pain and strength in these patients, it seems that the improvements in these variables led to the observed ROM improvements. Additionally, the greater gains in muscle strength provided by the training programme may have provided a positive transference to ROM values, allowing between-group differences across time. Supporting these results, we also found greater improvements for the WOMAC stiffness dimension in the intervention group although no benefits were reported in previous investigations [17, 20, 31]. As knee extensor strength is more impaired than knee flexor strength after TKA, the ROM extension results presented additional difficulty to improve.

The ability to ascend and descend stairs and the ability to walk are activities of daily living and predictors of mobility and functional capacity [25, 38]. Until now, no improvements in stair climbing or TUG have been demonstrated after a period with preoperative training [17, 20, 31, 40, 43]. In contrast, we found a progressive and greater performance in both functional tasks among the intervention group. The positive association between knee extension strength and walking or stair-climbing ability after TKA

Table 3 Scores for all the questionnaires

Variable	Testing time	Mean (95 %CI)		*p* value for group by time interaction	Between-group difference (95 % CI)
		Control group	Intervention group		
10-cm visual analogue scale	Baseline	5.9 (5.5 to 6.2)	6.1 (5.7 to 6.4)	<.0001	−0.2 (−0.6 to 0.2)
	Before surgery	6.0 (5.6 to 6.3)	4.0 (3.7 to 4.3)		2.0 (1.6 to 2.4)[a]
	1 month after surgery	4.2 (3.9 to 4.5)	2.5 (2.2 to 2.8)		1.7 (1.3 to 2.1)[a]
	3 months after surgery	2.9 (2.5 to 3.2)	1.4 (1.1 to 1.7)		1.5 (1.1 to 1.9)[a]
WOMAC	Baseline	53.2 (51.7 to 54.7)	54.0 (52.5 to 55.4)	<.0001	−0.8 (−2.7 to 1.1)
	Before surgery	58.6 (57.1 to 60.1)	40.0 (38.6 to 41.4)		18.6 (16.7 to 20.5)[a]
	1 month after surgery	42.4 (40.9 to 43.8)	28.4 (27.0 to 29.8)		14.0 (12.1 to 15.9)[a]
	3 months after surgery	30.7 (29.2 to 32.2)	25.0 (23.5 to 26.4)		5.8 (3.9 to 7.6)[a]
WOMAC pain	Baseline	10.6 (10.2 to 11.0)	10.5 (10.1 to 10.9)	<.0001	0.1 (−0.4 to 0.6)
	Before surgery	10.3 (9.9 to 10.7)	6.8 (6.4 to 7.2)		3.5 (2.9 to 4.0)[a]
	1 month after surgery	5.1 (4.7 to 5.5)	4.0 (3.6 to 4.4)		1.1 (0.6 to 1.6)[a]
	3 months after surgery	3.8 (3.4 to 4.2)	2.9 (2.5 to 3.3)		0.9 (0.4 to 1.5)[a]
WOMAC stiffness	Baseline	4.1 (3.8 to 4.3)	4.0 (3.8 to 4.3)	<.0001	0.0 (−0.3 to 0.4)
	Before surgery	4.7 (4.5 to 5.0)	3.5 (3.2 to 3.7)		1.3 (0.9 to 1.6)[a]
	1 month after surgery	4.2 (3.9 to 4.4)	2.8 (2.6 to 3.1)		1.4 (1.0 to 1.7)[a]
	3 months after surgery	3.2 (2.9 to 3.4)	2.2 (2.0 to 2.5)		0.9 (0.6 to 1.3)[a]
WOMAC functional	Baseline	36.7 (35.7 to 37.7)	37.2 (36.2 to 38.1)	<.0001	−0.5 (−1.7 to 0.8)
	Before surgery	40.3 (39.3 to 41.3)	29.0 (28.0 to 29.9)		11.3 (10.1 to 12.6)[a]
	1 month after surgery	31.6 (30.6 to 32.5)	20.5 (19.6 to 21.5)		11.0 (9.8 to 12.3)[a]
	3 months after surgery	22.7 (21.7 to 23.7)	18.8 (17.8 to 19.7)		3.9 (2.7 to 5.2)[a]
SF-36 (Physical Functioning Scale)	Baseline	42.5 (41.4 to 43.6)	42.5 (41.4 to 43.5)	<.0001	0.0 (−1.4 to 1.4)
	Before surgery	40.2 (39.1 to 41.3)	49.0 (47.9 to 50.1)		−8.8 (−10.2 to −7.4)[a]
	1 month after surgery	46.9 (45.8 to 48.0)	51.4 (50.3 to 52.4)		−4.4 (−5.8 to −3.0)[a]
	3 months after surgery	53.0 (51.9 to 54.1)	55.7 (54.6 to 56.8)		−2.7 (−4.1 to −1.3)[a]

[a] Denotes significant between-group difference

has been well demonstrated in cross-sectional data either 1 year [21] or 2 years [48] after surgery. The WOMAC functional scores and the Physical Functioning Scale of the SF-36 improved over time in both groups. This could be expected due to the benefits of the surgery per se. However, greater benefits were shown in favour of the intervention group. It is also worth mentioning that the improved self-rated functionality among the control group measured by questionnaires was not reflected in greater functional tasks performance over time. The increased functional ability showed after training may reduce the patients' need of social and health care.

The LOS is a major contributor to additional health-care costs after TKA [45]. Our data show a reduction in the LOS by 1.95 days for those undergoing preoperative training. Likewise, Matassi et al. [19] showed a significant reduction in the length of stay by 0.8 days after preoperative training mainly focused on lower extremity muscle strength and flexibility. A poorer functional capacity measured by the use of aids in the preoperative period [26] is a predictor of greater LOS after TKA. Our results show that proper preoperative training improving muscular strength and functional health before surgery leads to a faster functional regaining after TKA, resulting in a reduced LOS and possibly reducing healthcare costs.

A major strength of our study compared with previous literature is the use of a higher training intensity and volume during training sessions (number of sets per muscle group and total time of training). Proper training intensity and volume are important to achieve optimal gains in muscle strength [1] and could be the main reason why previous research on preoperative training did not augment treatment success. While multiple sets are more effective than one or two sets [24], the majority of studies performed 2 [20, 31] or 1–4 sets for each muscle group [40, 43]. Moreover, the intensity of the exercises was not reported in some cases [31], and in other studies [40, 43], the intensity was designed to be moderately fatiguing depending on different elastic bands colours instead of a perception of a maximal number of repetitions (i.e. RM) or a percentage of a maximum load (i.e. % 1RM). In addition, in the study conducted by Van Leeuwen et al. [17], the control group received a treatment including exercise which may explain the absence of between-group difference.

In the present study, patients performed dynamic training. Because neurological adaptations have a training-specific component [10], a possible limitation of our study is that dynamic muscle strength rather than isometric assessment could have provided further differences (for example in knee extension strength). Thus, the true effect of the intervention may have been underestimated. However, the isometric assessments were adequate to note strength improvements and have been widely used in other studies. In addition, consumption of medication was not measured and could have provided valuable information about possible training effects in medication reductions and their effect on pain self-reported questionnaires. Despite that the intervention was effective, it is likely that education about self-management, exercise and coping strategies together with the training programme could have provided even better outcome scores [41, 42]. It is possible that patients have found new strategies to cope with everyday life activities with increased independency as a consequence of the training programme. Finally, it should be taken into account that the present results may not be extended above 3 months after TKA. However, the present training programme can be used by specialists to speed up recovery early after TKA, which together with a proper post-operative training should lead to even further benefits. Overall, the present study provides important clinical benefits in terms of improvements of several physical characteristics known to be important for daily functioning.

Conclusions

The present study supports the use of preoperative training in end-stage OA patients to improve early postoperative outcomes. High-intensity strength training during the preoperative period reduces pain and improves lower limb muscle strength, ROM and functional task performance before surgery, resulting in a reduced LOS and a faster physical and functional recovery after TKA.

Compliance with ethical standards

Conflict of interest The authors did not receive financial support for this study, and there are no known conflicts of interest associated with this publication that could have influenced its outcome.

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